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Delay discounting: Trait variable?

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Abstract

Delay discounting refers to the tendency for outcomes that are remote in time to have less value than more immediate outcomes. Steep discounting of delayed outcomes is associated with a variety of social maladies. The degree of sensitivity to delayed outcomes may be a stable and pervasive individual characteristic. In analyses of archival data, the present study found positive correlations between the degree of delay discounting for one outcome (as measured by the Area Under the Curve), and the degree of discounting for other outcomes. Along with additional evidence reviewed, these data suggest that delay discounting may be considered a personality trait. Recent research in epigenetics, neuroscience, and behavior suggests delay discounting may prove to be a beneficial target for therapeutic attempts to produce global reductions in impulsivity related to delay discounting.

Keywords

delay discounting; impulsivity; humans; personality; trait

1. Introduction

Impulsivity is a multifaceted concept that includes relative insensitivity to delayed outcomes (see e.g., de Wit, 2008). Delay discounting refers to the decrease in the present value of an outcome when its receipt is delayed (Mazur, 1987). Across a variety of species and outcome types, the form of the function relating delay to value is hyperbolic: small delays to the receipt of the outcome have a proportionally greater impact on value than do longer delays (e.g., Rachlin et al., 1991; Richards et al., 1997). Steep hyperbolic discounting of value by delay can lead to one form of impulsivity: choice of a smaller sooner outcome over a larger later outcome (Logue, 1988).

Delay discounting is of growing interest because of its relation to a number of socially important problems. For example, cigarette smokers show greater discounting of delayed monetary outcomes than do matched non-smokers (e.g., Bickel et al., 1999). Furthermore, steep discounting is predictive of the initiation of regular smoking in adolescents (e.g., Audrain-McGovern et al., 2009). Cigarette smokers with shallower discount functions are also more likely to achieve abstinence from cigarettes (e.g., MacKillop and Kahler, 2009).

Substantial evidence indicates that delay discounting is sensitive to both state and trait influences (see Odum and Baumann, 2010, for review). A state variable influences behavior over a relatively short time frame, whereas a trait variable is a relatively stable pre-existing characteristic an individual brings to a situation. State variables shown to affect the degree of discounting include the type of outcome (e.g., Madden et al., 1997; Odum and Rainaud,

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2003), the magnitude of an outcome (e.g., Green et al., 1997), and the context in which a choice is made (e.g., Dixon et al., 2006).

A number of trait variables have been shown to affect the degree to which an outcome is discounted as well. For example, steeper discounting is associated with more fatalism (Johnson et al., 2010), less agreeableness (Miller et al., 2008) and less empathy (Kirby et al., 1999) as measured by personality scales. Similarly, certain psychiatric conditions, such as disinhibitory behavior problems and antisocial personality disorders (e.g., Bobova et al., 2009; Crean et al., 2000; Petry, 2002), as well as pathological gambling and drug abuse, are associated with elevated levels of delay discounting (see Petry and Madden, 2010; Yi et al., 2010 for review). It is interesting, however, that self-report measures of impulsivity have weak and often inconsistent relations to the degree of delay discounting across studies (e.g., Bobova et al., 2009; Janis and Nock, 2009; Perales et al., 2009; Smith and Hantula, 2008; see de Wit et al., 2007 for review). These inconsistencies may be due to the fact that these self-report scales measure multiple facets of impulsivity, including the tendency to act without thinking and the inability to withhold a pre-potent response, rather than aspects more specifically related to sensitivity to delayed outcomes.

1.1. Delay discounting as a trait

Although delay discounting is clearly related to some personality and individual characteristics, there has been little formal consideration of whether delay discounting itself might be considered a trait (see de Wit, 2008; Kirby, 2009; Reimers et al., 2009). A reasonably common definition of a personality trait is ‘a relatively enduring pattern of thoughts, feelings, and behaviors that reflects the tendency to respond in certain ways under certain circumstances’ (Roberts, 2009). What evidence is there that the degree of discounting in which a person engages might be an overt component of such a trait?

1.1.1. Relative endurance—First, consider the initial portion of the definition of a personality trait: that delay discounting is relatively enduring. This question may be answered in part by data concerning test-retest reliability. Test-retest reliability may be measured with the same form of the test on two occasions, or with one form of the test on one occasion and an alternate form of the test on another occasion.

Same form test-retest reliability is good for delay discounting as measured by a variety of techniques and over test-retest intervals ranging from weeks to a year. For example, Simpson and Vuchinich (2000) found evidence for strong test-retest reliability (r = .91) with a test-retest interval of 1 week using a choice task in which the delayed amount was a $1,000 and the outcomes were not actually delivered to the undergraduate participants (called a hypothetical money choice task). Test-retest reliability remains good up to intervals of one year (r = .71; Kirby, 2009). Several other studies have yielded similar conclusions regarding test-retest reliability of the degree of delay discounting using intermediate test-retest intervals and different monetary amounts, populations, and versions of the delay-discounting task (Baker et al., 2003; Beck and Triplett, 2009; Black and Rosen, 2011; Ohmura et al., 2006; Takahashi et al., 2007). Further investigation is warranted to determine whether discounting is stable over longer time frames.

Alternate form test-retest reliability is also good for delay discounting as assessed by a number of different versions of the task. For example, Johnson and Bickel (2002) found a robust relation (r = .83) between the degree of discounting on the hypothetical money choice task and a ‘real rewards’ version of the task in which one randomly selected outcome is delivered. Smith and Hantula (2008) reported good overall correspondence between different methods of task administration (paper and pencil vs. computer based) and task types (binary choice vs. fill in the blank; r = .75). Robles et al. (2009) obtained a moderate

relation between the degree of discounting as determined by different sequences of presentation of the choices between the immediate and delayed outcomes (ascending vs. descending outcome amounts; $\rho = .44$). The degree of delay discounting was strongly correlated between versions of the task that used fixed versus titrating amount sequences of presentation of the choices between the immediate and delayed outcomes ($r = .81$; Rodzon et al., 2011). Other studies have also reported good correlations between the degree of discounting obtained using alternate methods (e.g., Epstein et al., 2003; Kowal et al., 2007). Thus, there is evidence that delay discounting is reasonably stable over modest time frames and with different assessment techniques, providing at least a tentative positive answer to the first criterion for a trait given above, that it be 'relatively enduring'.

1.1.2. Response consistency—What evidence is there for the second part of the definition of a trait, that it 'reflects the tendency to respond in certain ways under certain circumstances'? (This requirement does not mean that people must behave identically in all situations, but that their behavior be 'meaningfully consistent'; Roberts, 2009). There are multiple ways to answer this question. One possible direction, which I shall pursue in this paper, is to examine the consistency of delay discounting across different types of outcomes.

Prior research has extensively shown that money is discounted less steeply than other types of outcomes. For example, Madden et al. (1997) found that people with opioid dependence discounted money less than they did an amount of heroin that was equated for monetary value. The finding that people discount their drug of abuse more steeply than money has been widely replicated with a variety of drug classes, including alcohol, cocaine, marijuana, and nicotine (e.g., Bickel et al., 1999; Coffey et al., 2003; Johnson et al., 2010; Petry, 2001). Although initially researchers speculated that the differences in discounting for drugs and money could be related to addiction specifically, Odum and Rainaud (2003) found that people without problematic drinking also discount alcohol more steeply than money. Furthermore, a variety of commodities are discounted more steeply than money, including an assortment of food and non-alcoholic beverages (e.g., Estle et al., 2007; Odum & Baumann, 2007; Odum & Rainaud, 2003; Odum et al., 2006), as well as music, CDs, and DVDs (Charlton & Fantino, 2008).

Examining discounting of different commodities opens the possibility to examine the second part of the definition of a personality trait, the 'tendency to respond in certain ways in certain circumstances'. People who show relatively steep discounting of one outcome (e.g., money) should also show relatively steep discounting of another outcome (e.g., food) if they indeed behave similarly with respect to different outcomes. In the words of Green and Myerson (2010), "If impatience is a trait, [impatient] individuals would be expected to consistently discount delayed outcomes more than do other individuals, regardless of what the outcome is …"(p. 68). Only a few studies to date, however, have investigated this issue. Charlton and Fantino (2008) found moderate to strong correlations, all positive, between discounting among various forms of entertainment (books, CDs, DVDs), food, and money. Johnson et al. (2010) reported a strong positive correlation ($r = .72$) between the degree of discounting for hypothetical marijuana and money in current marijuana users. In the present paper, I determine the generality of these findings by analyzing a number of archival data sets to determine whether there is tendency for people, across a variety of populations and outcome types, to discount different commodities in a related manner.

2.0 Methods

2.1 Studies

The data sets were drawn from all prior studies that included discounting for more than one commodity that my colleagues and I have published. Table 1 summarizes the studies in

terms of characteristics and number of participants and outcomes types and amounts. These studies include college students, community members screened for psychological disorders, and people with drug abuse problems. The outcomes used were food, alcohol, cigarettes, and/or heroin. The outcomes values ranged from amounts worth $10 to $1,000.

2.2 Experimental technique

In general, these experiments examined how delays to an outcome affect its value. The amount of an immediate outcome was titrated to gauge its value against a constant delayed outcome. The amount of the immediate outcome was systematically decreased and/or increased (fixed procedure; e.g., Rachlin et al., 1991) or adjusted up and down based on the participant's choice (titrating procedure; e.g., Du et al., 2002). These procedures yield an indifference point, the point at which a person switches from preferring the smaller-sooner to the larger-later outcome (when the value of the two outcomes is about equal). Indifference point estimates are similar with the fixed and titrating procedures (Rodzon et al., 2011). Indifference points measure the present value of the delayed outcome and indicate how much the delayed option is worth now. These points were found at a variety of delays to determine a discount function, showing how delay affects the present value of an outcome.

In each study, participants answered questions about money, and in separate questions, one or more other outcomes that were equated in dollar value to the money. For example, participants in Odum and Rainaud (2003) stated their favorite alcoholic beverage and its cost, and then answered questions in terms of $100 worth of that beverage. If a participant named beer (costing $8.00 a six pack) as her favorite beverage, for instance, then she would answer questions with 12.5 six packs of beer as the delayed alternative. The same procedure was followed with the participants' favorite food. The methodology is described in detail in each original study. The consumable outcomes were equated in value to the money because the value of an outcome affects how steeply it is discounted (e.g., Green et al., 1997). If the outcomes were not equated in value when not delayed, any differences in the degree of discounting could plausibly be attributed to the value of the outcome rather than its type.

2.3 Measures and Analyses

For each participant in each study, the degree of discounting for each outcome type was assessed with the Area Under the Curve (AUC; Myerson et al., 2001). The AUC is a desirable measure for the type of analysis conducted here because it is atheoretical and therefore does not impose a particular model or assumptions on the data. Furthermore, AUC is more normally distributed than the derived discounting parameter *k* from the hyperbolic decay and related models (e.g., Mazur, 1987; Myerson and Green, 1995), and can therefore be evaluated with parametric statistics. To calculate AUC, delays and indifference points were first normalized. Then the area underneath the curve was computed by summing the results of the following equation for each delay and indifference point pair: $x_2 - x_1 [(y_1 + y_2)/2]$, where x_1 and x_2 are successive delays and y_1 and y_2 are the indifference points associated with those delays (see Myerson et al., 2001, for more detail). The AUC can range from 1 (no discounting) to 0 (maximum discounting). In studies testing money and one other outcome, paired *t* tests were conducted to determine whether the AUC differed between commodities. For studies examining discounting for money and two other outcomes, AUC values were first assessed with Repeated Measure ANOVAs, after which follow-up tests were conducted with paired *t* tests.

Area Under the Curve values for one outcome type were also correlated with values for the other outcome type (or in two cases shown in Table 1, with two other outcome types) by calculating a Pearson's correlation coefficient using GraphPad Prism®, separately for each study in Table 1. The correlation coefficient ranges from 1.0 (a strong positive relation)

through 0 (no relation) to −1.0 (a strong negative relation). Positive correlation coefficients would indicate a direct association between AUC values for one outcome and AUC values for another outcome, as would be expected if there were a tendency for people to discount different commodities similarly. In addition, the AUC values were averaged across participants in each study separately to yield average values for each outcome for each study. These values were then entered into a correlational analysis to examine the relation between AUC for money and other outcomes across studies.

3.0 Results

Figure 1 shows the mean AUC values across participants for studies that examined discounting of money and one other outcome. In all cases, consumable commodities had lower AUCs, showing they were discounted more steeply, than money. Cigarette smokers (top panel) discounted cigarettes more than money ($t_{22} = 3.21$, $p = 0.004$), and people with opioid dependence (2nd panel) discounted heroin more so than money ($t_{31} = 4.93$, $p < 0.0001$). College students discounted $100 worth of food (third panel; $t_{51} = 5.24$, $p < 0.0001$) as well as $10 worth of food (fourth panel; $t_{50} = 4.55$, $p < 0.0001$) more so than money.

Figure 2 shows scatterplots of the value of the AUC for one outcome as a function of the AUC for another outcome for individual participants for the studies shown in Figure 1. The correlation coefficients relating the AUC for money to the AUC for the other outcome were positive, showing a direct relation between the degree of discounting for one outcome and the other. For cigarette smokers, discounting of cigarettes was significantly and strongly correlated with discounting of money ($r = 0.54$; $p = 0.0076$; top panel). Similarly, for opioid-dependent outpatients, discounting of heroin was significantly and strongly correlated with discounting of money ($r = 0.56$; $p = 0.0009$; second panel). For college students, discounting of $100 worth of food and money was significantly and moderately correlated ($r = 0.39$; $p = 0.0045$; third panel). Finally, for college students, the degree of discounting for $10 worth of food and money was weakly correlated, with a p value that only approached conventional levels of significance ($r = 0.27$; $p = 0.055$; bottom panel).

Figure 3 shows the mean AUC values across participants for studies that examined discounting of money and two other outcomes. As in Figure 1, in all cases consumable commodities had lower AUCs than that for money, showing they were discounted more steeply. For community members discounting food, alcohol, and money (top panel), there was an overall effect of outcome type on AUC ($F_{2,59} = 7.05$; $p = 0.0025$). Follow up tests indicated that discounting for money differed significantly from that for food ($t_{19} = 2.86$; $p = 0.01$) and alcohol ($t_{19} = 2.88$; $p = 0.0096$). The AUC for the two consumable commodities, food and alcohol, however, were not different ($t_{19} = 0.27$; $p = 0.79$). For cigarette smokers discounting food, cigarettes, and money (lower panel), there was an overall effect of outcome type on AUC ($F_{2,38} = 8.49$; $p = 0.0009$). Follow up tests indicated that discounting for money differed significantly from that for food ($t_{19} = 2.23$; $p = 0.038$) and cigarettes ($t_{19} = 3.35$; $p = 0.003$). The AUC for the two consumable commodities, food and cigarettes, was also different ($t_{19} = 2.64$; $p = 0.016$).

Figure 4 shows scatterplots of the value of the AUC for one outcome as a function of the AUC for another outcome for individual participants for the studies shown in Figure 3. The correlation coefficients relating the AUC for money to the AUC for the other outcome were also positive for these studies, showing a direct relation between the degree of discounting for one outcome and the others. For community members, discounting of food was significantly and strongly correlated with discounting of money ($r = 0.63$; $p = 0.0029$; top left panel), as was discounting of alcohol and money ($r = 0.68$; $p = 0.0009$; middle left

panel). Discounting of food was also significantly and strongly correlated with discounting of alcohol ($r = 0.90$; $p < 0.0001$; bottom left panel). For cigarette smokers, discounting of food was significantly and strongly correlated with discounting of money ($r = 0.50$; $p = 0.026$; top right panel). Discounting of cigarettes was weakly and not significantly correlated with discounting of money ($r = 0.18$; $p = 0.45$; middle right panel). Discounting of food was significantly and strongly correlated with discounting of cigarettes ($r = 0.51$; $p = 0.022$; bottom right panel).

As can be seen in Figures 1 and 2, the archival studies listed in Table 1 generated different overall levels of discounting by delay due to differences in the type and amount of the commodities as well as the populations. To examine the overall relation across studies between AUC for money and consumable commodities, AUC was averaged across participants in each study for money and the other outcomes. This process yielded one AUC value for money and one AUC value for the other commodity or commodities in each study. Figure 5 shows that averaged across studies, the mean AUC values for other outcomes were lower, indicating steeper discounting by delay, than the AUC values for money. As the scatterplot in Figure 6 indicates, across studies the average AUC value for other outcomes was strongly and significantly correlated with the average AUC value for money ($r = 0.93$; $p = 0.0007$).

4.0. Discussion

This examination of archival data investigated AUC values, indicative of the steepness of discounting by delay, across different commodities. In all cases, the AUC values for consumable commodities were significantly lower than values for money, indicating money was discounted less steeply. This finding with AUC replicates conclusions conducted in some of the original studies using a different measure of discounting (the derived parameter k, from the hyperbolic model; Mazur, 1987) as well as the results of other studies in the literature (e.g., Estle et al., 2007; Madden et al., 1997).

The novel finding in the present analysis was that the degree of discounting for one commodity was in all cases positively related to the degree of discounting for another commodity across different participant populations and commodity characteristics. This finding shows that there is a direct relation between delay discounting for one commodity and delay discounting for another commodity. In other words, a person who is relatively impulsive in one situation may tend to be relatively impulsive in other situations. This finding replicates that from a limited number of smaller prior studies (Charlton & Fantino, 2008; Johnson et al., 2010). Thus, the data provide evidence that delay discounting may fit the second part of the definition of a personality trait, the ‘tendency to respond in certain ways in certain circumstances’.

Though promising, the present analysis has limitations. The original studies were not designed as correlational analyses and thus have a relatively small number of participants. In some cases, there are also few values along parts of the range of the AUC. Furthermore, although 10 of the 10 correlations computed were positive, the degree of the relation varied within and across experiments. The two smallest correlations (which were also not statistically significant) were found in the two studies with smaller amounts of money and commodity equivalents ($10). One possible reason for this finding could be that smaller amounts tend to be discounted more steeply (e.g., Green et al., 1997). Especially steeply discounted outcomes could restrict the range of the AUC, making the relations less robust. In the present analyses, however, the range of the AUC does not appear particularly restricted in the studies involving smaller amounts of the commodities compared to the range in studies involving larger amounts of commodities. It is not possible to determine

from the present data whether correlations between AUC values are indeed less reliable with smaller monetary equivalents, and if so, why.

Another limitation of the present analysis is that all of the data sets analyzed involved hypothetical outcomes. That is, the participants did not actually receive any of the consequences of the choices they were making. So far, research indicates there is good correspondence between the degree of discounting obtained using a variety of techniques for assessing this type of impulsivity (e.g., Johnson and Bickel, 2002; Lagorio and Madden, 2005; Madden et al., 2003; 2004). For example, Madden et al. (2004) found that college students discounted delayed monetary outcomes similarly when the choices were all hypothetical and when they would receive the outcome of one of their choices. Under some circumstances, however, results could differ with real and hypothetical outcomes (e.g., Paloyelis et al., 2010). Future research could examine whether the positive relations between discounting for money and other outcomes found in the present analysis are also present when people receive the outcomes for the choices they make.

The present analysis would also be strengthened by further research extending the number and context of the choices. For example, a greater number of types of outcomes could be used in assessing delay discounting. Testing could also be done in different settings, and with different techniques to evaluate the degree of discounting. The goal would be to see if the limited analyses presented here extend to a greater variety of item types and situations.

Despite these limitations, the degree of delay discounting does appear to have features like that of a personality trait: 1) it is relatively enduring (as described in the Introduction) and 2) as shown in the present analysis, it may reflect the general tendency to respond certain ways in certain circumstances. If delay discounting is a personality trait, however, it does not mean that a person's delay discounting is immutable (not subject to change). Two forms of evidence indicate that sensitivity to delayed consequences can change.

First, delay discounting changes with age, presumably as part of normal development across the lifespan that is common with many personality characteristics (see e.g., McAdams and Olson, 2010, for review). For example, Green et al. (1994) found that children (M = 12 years) discounted delayed money more steeply than young adults (M = 20 years), who discounted delayed money more steeply than older adults (M = 68 years). Decreasing delay discounting with increasing age has been found a number of times in people (e.g., Prencipe et al., 2011; Reimers et al., 2009; Steinberg et al., 2009; Whelan and McHugh, 2009) as well as in rats (Simon et al., 2010). Delay discounting appears to stabilize in early adulthood in humans (around age 30; Green et al., 1996). Thus, delay discounting declines across the lifespan (people become less impulsive), just as other personality characteristics moderate with maturity (see McAdams and Olson, 2010).

Second, delay discounting can be changed through environmental means, above and beyond what would be expected by developmental processes. Two types of interventions have been used to change sensitivity to delayed consequences. The first line of studies has not measured delay discounting per se, which requires determination of the function relating choice of a larger later reward to delay. Instead, these studies measured static self-control: the percentage of choice of a larger later reward at one particular delay. For example, Mazur and Logue (1978) increased pigeons' choice of a larger later amount of grain (the self-controlled option) over a smaller sooner amount of grain with a fading procedure. Initially, the delay to the two rewards was the same, producing a high level of choice for the larger reward. When the delay to the smaller reward was reduced gradually to zero, self-controlled choice remained high in the fading group compared to a control group that started with the

smaller award available immediately. The increase in self-control was maintained at a year's follow up (Logue and Mazur, 1981).

The basic fading procedure developed by Mazur and Logue (1978) has been used and modified to increase self-control in a variety of human populations, including children with Attention Deficit Hyperactivity Disorder (Neef et al., 2001; Schweitzer and Sulzer- Azaroff, 1988), children with autism (Dixon and Cummings, 2001), adolescents and adults with traumatic brain injury (Dixon and Falcomata, 2004; Dixon and Tibbetts, 2009), children and adolescents with mental retardation (Dixon et al., 1998; Fisher et al., 2000; Ragotzy et al., 1988), as well as adults with mental retardation and mental illness (Dixon and Holcomb, 2000). Thus, in some cases organisms can learn to choose a larger later reward through fading procedures. Further research is needed to determine the generality and durability of these types of effects.

A second, more recent type of research investigates changes in delay discounting *per se* through intervention. Less working memory capacity is associated with steep discounting by delay (Shamosh et al., 2008), and psychomotor stimulant addiction is associated with reduced working memory capacity as well as steep discounting (e.g., Canales, 2010; Coffey et al., 2003; Monterosso et al., 2007). Bickel and colleagues (2011) assessed the effects of neurocognitive rehabilitation on delay discounting in recovering stimulant addicts. Participants who were given training designed to improve working memory function showed decreases in the degree of discounting for money after therapy compared to participants who underwent a yoked control procedure. In other words, procedures to improve working memory reduced impulsivity as measured by delay discounting. In a related result, Black and Rosen (2011) showed that with recovering cocaine addicts, financial management training was associated with less delay discounting for money and greater abstinence rates compared to control participants. These highly promising findings suggest that delay discounting can be modified, and that these changes may have beneficial impacts on problematic impulsive behavior. Additional research is required to establish the extent and generality of these types of interventions.

Changes in delay sensitivity through developmental processes and intervention are consistent with modern conceptualizations of personality (see Krueger et al., 2008; McAdams and Olson, 2010; Roberts and Jackson, 2008). For example, Sociogenomic Personality Psychology (e.g., Roberts, 2009) maintains that personality is the result of interactions between experience and heredity: 'Children are born with a wide variety of temperamental starting values that are then presumably shaped by environmental experiences' (p. 141). In this model, the environment acts on states, defined as thoughts, feelings, and (other) behaviors. Traits are conceptualized as stable, enduring patterns of states. Trait development is influenced by the interaction of heredity and environment through epigenetic expression.

Epigenetics refers to functional modifications to DNA that do not involve alteration of the sequence composition of the genome (see e.g., Bagot and Meaney, 2010; Zhang and Meaney, 2010, for review). Instead, through a variety of mechanisms, epigenetic modifications regulate the operation of the genome. Some of these modifications can be observed transiently, and reflect current environmental circumstances, whereas others can be persistent and reflect sustained environmental influences on the phenotype. The genome may be viewed 'not as a static form of background information, but rather as a dynamic and indeed modifiable force, the operation of which is constantly regulated by environmental signals' (Bagot and Meaney, 2010; p. 752–753). This view is based on evidence that environmental events can produce rapid and sustained effects on genomic function and phenotype at any point in the life span (see Bagot and Meaney, 2010).

Sociogenomic Personality Psychology (Roberts and Jackson, 2008) includes as its bases the fact that personality traits are heritable (see e.g., Turkheimer, 2000) and have physiological correlates in brain structure and function (e.g., Canli, 2004; Wright et al., 2007). Delay discounting has been studied in this regard only relatively recently, but the evidence thus far is congruent with this conceptualization. For example, the degree of delay discounting differs across strains of rats and mice (e.g., Anderson and Woolverton, 2005; Madden et al., 2008; Oberlin and Grahame, 2009; Wilhelm and Mitchell, 2009). Furthermore, the steepness of delay discounting in people is associated with particular dopamine polymorphisms (Eisenberg et al., 2007), and a recent longitudinal twin study estimated the heritability of delay discounting at up to 50% (Anokhin et al., 2011). Finally, choice of immediate rewards is linked to activity in the parts of the limbic system associated with the midbrain dopamine system, whereas choice of delayed rewards is associated with relatively more fronto-parietal activity (McClure et al., 2004; see Winstanley, 2010, for review).

Thus, a number of factors about delay discounting are consistent with its conceptualization as a personality trait with an epigenetic basis. Delay discounting is relatively stable over time, while exhibiting developmental and experiential change (e.g., Romer et al., 2010). Delay discounting is correlated across different decision domains. Finally, delay discounting is associated with activity in particular brain regions, certain genetic makeups, and appears to be heritable (e.g., Reynolds et al., 2009).

These factors make delay discounting an important target for understanding personality development and change. Delay discounting is a desirable conceptual and methodological model because it has good cross-species generality and allows causal investigation of effects in non-human animals (see Anokhin, 2011). The Sociogenomic Model of Personality holds that because the genome is highly conserved across species, studies of temperament in non-human animals will be enlightening to the human condition (e.g., Roberts and Jackson, 2008). Indeed, new and increased interest focuses on personality in animals (e.g., Stamps and Groothuis, 2010), defined as consistent behavioral differences in animals that can be described as individual traits (see Briffa and Weiss, 2010). Delay discounting may thus be a particularly good model to study facets of personality from a general process perspective.

In conclusion, if delay discounting is a personality trait, then interventions that decrease delay discounting in one domain could logically produce global changes in behavior. Steep delay discounting is related to a variety of maladaptive tendencies, including drug abuse (e.g., Madden et al., 1997; Romer et al., 2010), obesity (e.g., Davis et al., 2010; Reimers et al., 2009), pathological gambling (e.g., Alessi and Petry, 2003), and other problems (Reimers et al., 2009). Necessarily limited interventions to increase self-control in one domain (e.g., with money) may provide beneficial reductions in impulsive behaviors in other domains that may not be as amenable to direct intervention.

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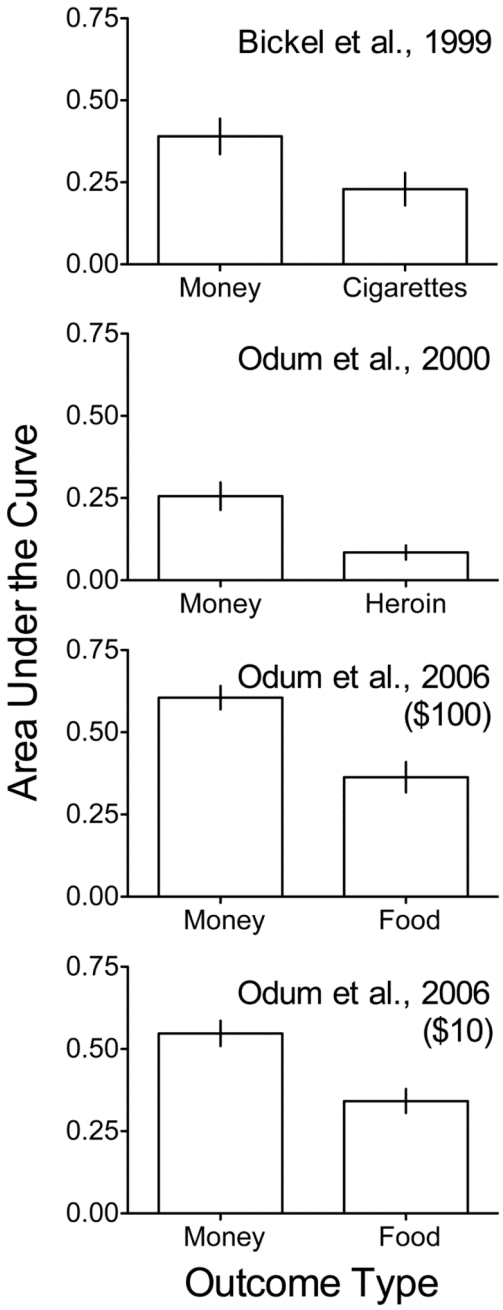

Figure 1.
Area Under the Curve (AUC) for money (left column) and consumable outcomes (right column) for four studies (rows). Error bars show one standard error above and below means.

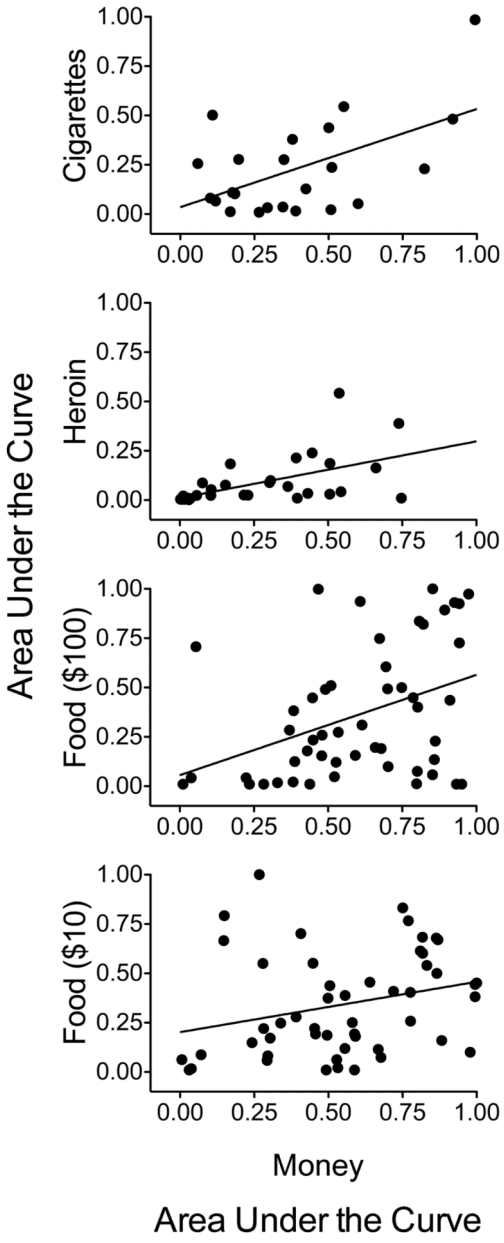

Figure 2.
Scatterplots relating Area Under the Curve (AUC) for one outcome to AUC for another outcome. The line through the data points was fitted with linear regression. The top panel shows data from Bickel et al. (1999), the second panel shows data from Odum et al. (2000), the third panel shows data from the $100 condition of Odum et al. (2006), and the bottom panel shows data from the $10 condition of Odum et al. (2006). See text for other details.

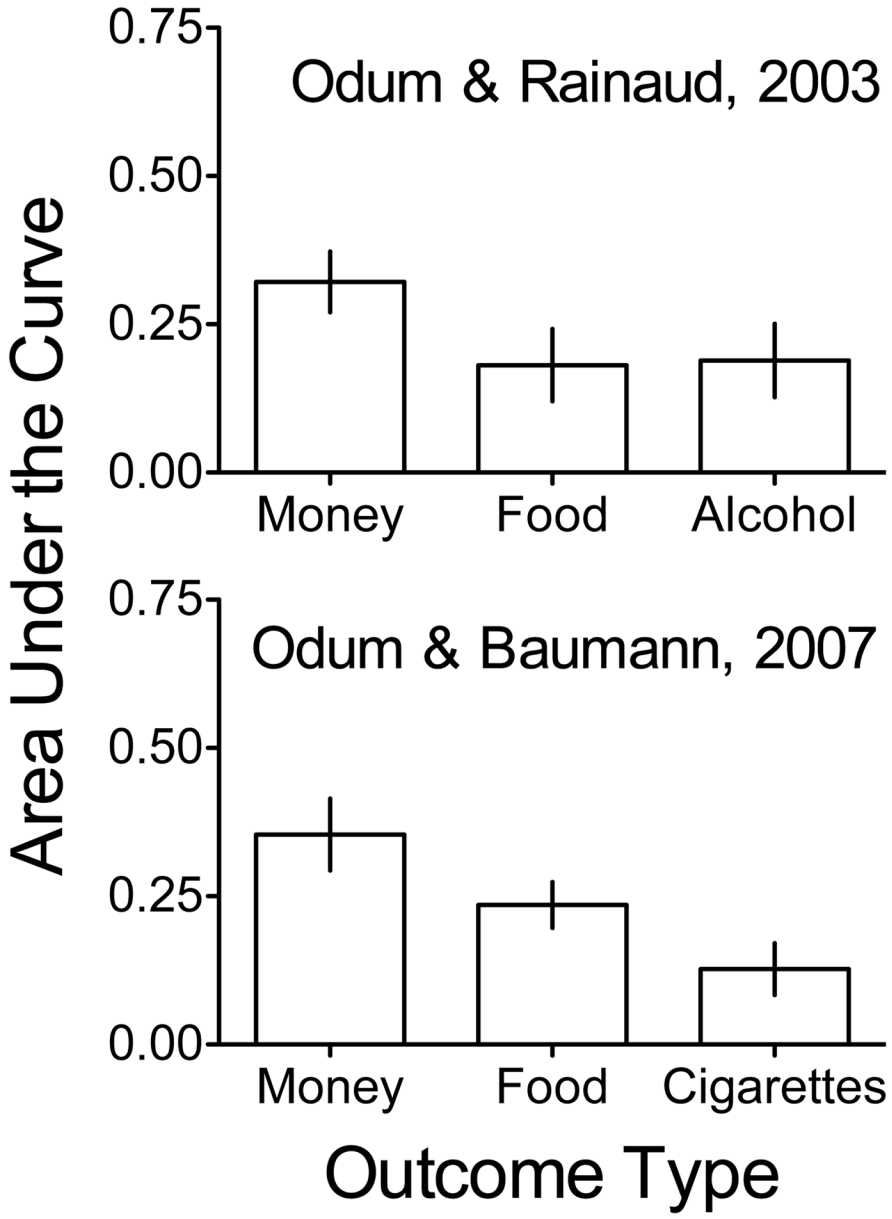

Figure 3.
Area Under the Curve (AUC) for money (left column) and two consumable outcomes (center and right columns) for two studies (rows). Other details as in Figure 1.

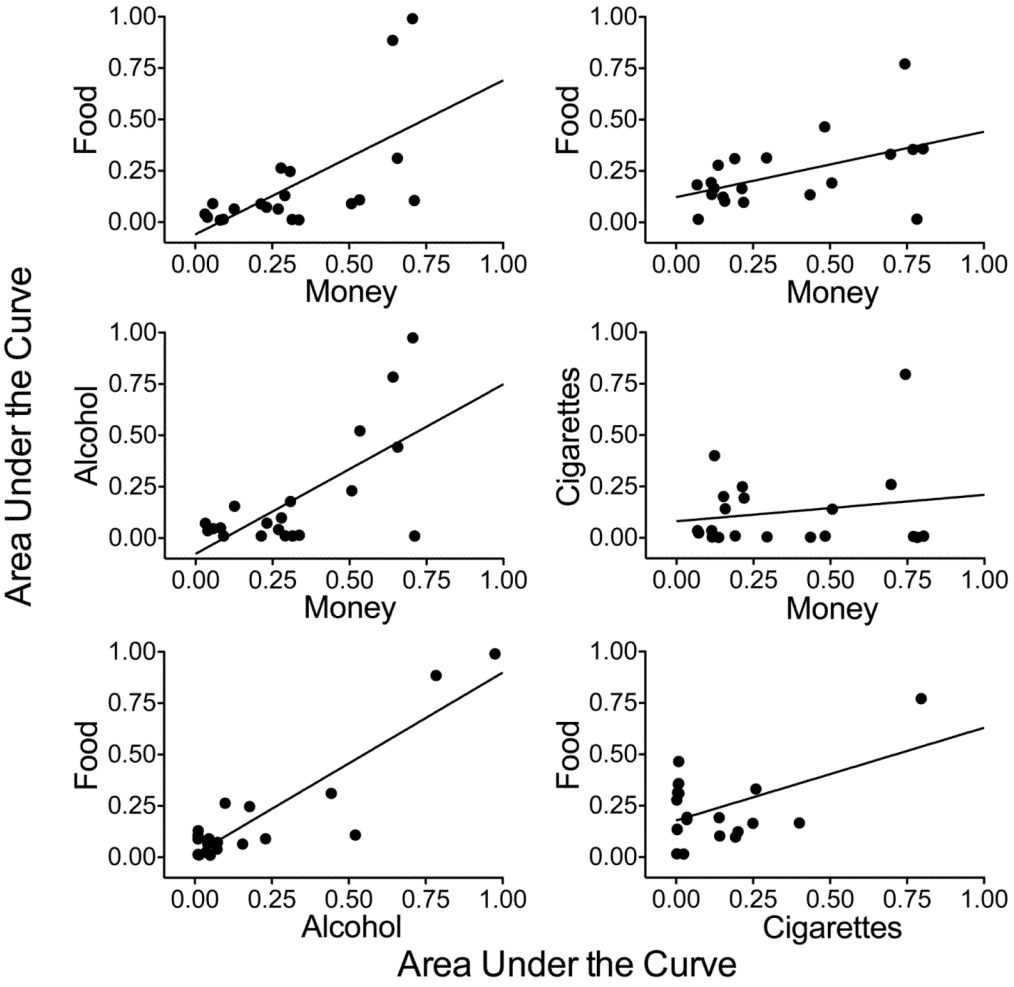

Figure 4.
Scatterplots relating Area Under the Curve (AUC) for one outcome to AUC for another outcome. The left column shows data from Odum and Rainaud (2003); the right column shows data from Odum and Baumann (2007). Other details as in Figure 2.

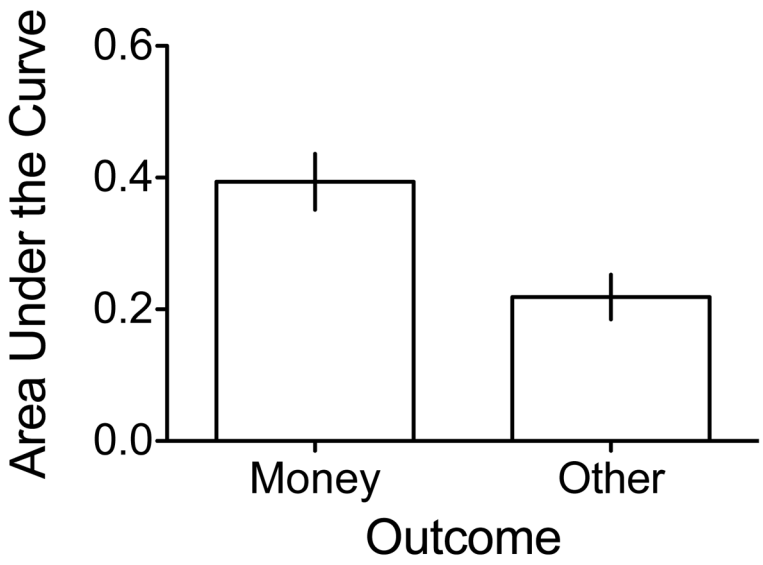

Figure 5.
Area Under the Curve (AUC) for money (left column) and other outcomes (right column) averaged across all studies included in the analyses. Other details as in Figure 1.

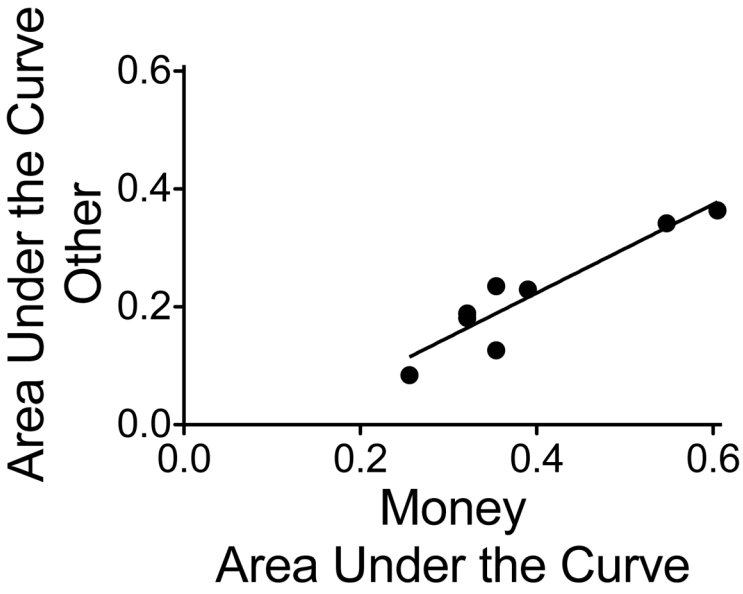

Figure 6.
Scatterplots relating Area Under the Curve (AUC) for one outcome to AUC for another outcome. Data are averaged across the studies presented in the prior figures. Other details as in Figure 2.

Table 1

Citation and characteristics of studies used in the analysis of Area Under the Curve.

Study	Population	N	Outcomes	Amount
Bickel, Odum, & Madden, 1999	Cigarette smokers	23	Money, cigarettes	$1,000
Odum, Madden, Badger, & Bickel, 2000	Opioid-dependent outpatients	22	Money, heroin	$1,000
Odum, Baumann, & Rimington, 2006	College students	51	Money, food	$100
	College students	51	Money, food	$10
Odum & Rainaud, 2003	Community members	20	Money, alcohol, food	$100
Odum & Baumann, 2007	Cigarette smokers	20	Money, cigarettes, food	$10