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Delay Discounting and Preference Reversals by Cigarette Smokers

Richard Yi, **Alexis K. Matusiewicz**, and **Antonio Tyson**
University of Maryland

Abstract

Quit attempts made by smokers that result in relapse to smoking are conceptualized in behavioral economics as preference reversals, in which preference for a larger-later outcome switches to preference for a smaller-sooner outcome. Though preference reversals are predicted by models of delay discounting, we are aware of no human research that has explicitly established that rate of delay discounting is associated with preference reversals. The present study attempted to establish this connection. Assessments of delay discounting of hypothetical money rewards at two magnitudes ($50, $1000) were examined from forty-five smokers, as well as a novel preference reversal task designed to determine when a preference reversal would occur for the same amounts of hypothetical money. Results from the preference reversal task were used to classify participants as predicted high, moderate, and low discounters, and rates of delay discounting were compared between these classifications at each magnitude. Statistically significant differences were observed between predicted high and low discounters in both magnitude conditions, and between predicted high and moderate discounters in the $1000 magnitude condition. Correlations between delay discounting and preference reversal amongst moderate discounters, though in the predicted direction, did not reach statistical significance. The overall pattern of results are consistent with the indication that rate of delay discounting is associated with the timing of preference reversals.

Keywords

preference reversals; delay discounting; cigarette smoking; relapse model

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Despite smokers' awareness of the health consequences (DHHS, 1989), cigarette smoking remains the leading cause of preventable morbidity and mortality in the U.S. (CDC, 2014). Reasons for continued or relapse to smoking frequently include avoidance of immediate consequences such as craving (Killen et al., 1991), withdrawal (West et al., 1989), stress (Cohen & Lichtenstein, 1990), and negative affect (Shiffman et al., 1996). This relative bias for immediacy, in lieu of the delayed benefits of not smoking (e.g., health), can be

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Corresponding Author: Richard Yi, 2103 Cole Activities Center, Department of Psychology, University Maryland, College Park, MD 20742, ryi1@umd.edu, phone: (301) 405-7724, fax: (301) 405-3223.

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conceptualized as steep delay discounting - an exaggerated loss of the value of future outcomes.

The research examining cigarette smoking and delay discounting bear out the relation, with cigarette smokers exhibiting steeper delay discounting compared to nonsmokers and those who have successfully quit (Bickel, Odum, & Madden, 1999; Secades-Villa et al., 2014; see reviews in MacKillop et al., 2011; Reynolds, 2006; Yi, Mitchell, & Bickel, 2009). Though the connection between pre-treatment delay discounting and treatment outcomes is equivocal for non-tobacco drugs of abuse, showing both significant (Passetti et al., 2011; Stanger et al., 2012; Washio et al., 2011) and non-significant relations (DeWilde et al., 2013; Passetti et al., 2008; Heinz et al. 2013; Peters et al., 2013; see review in Stevens et al., 2014), a developing literature indicates that steep delay discounting is associated with relapse to smoking in a human laboratory model (Dallery & Raiff, 2007; Mueller et al., 2009) as well as in real-world clinical settings (MacKillop et al., 2009; Sheffer et al., 2012; 2014; Yoon et al., 2007).

While greater likelihood of relapse to smoking by individuals with greater bias for immediate rewards is intuitive, the hyperbolic model (as well as other non-normative models[1]) of delay discounting explicitly predicts reversals of preference that are thought to model failures of self-control such as relapse.

Figure 1 illustrates how hyperbolic discounting predicts preference reversal. Assuming that a delayed smaller-sooner (SS) reward has an objective value as indicated by the length of the vertical line marked SS, that a more-delayed larger-later (LL) reward has an objective value as indicated by the length of the vertical line marked LL (shown here with both shown as a percentage of the LL), and the delay *between* the SS and LL remains constant, the panels represent four hypothetical individuals with different delay discount rates: very high (i.e., steep) to very low (i.e., shallow), going left-to-right. Moving from right-to-left within each panel as time passes, preference is for the smaller-sooner (SS) or larger-later (LL) alternative with the higher discounted value (y-axis) at any given point in time. When both SS and LL are very distal (before time *A*), the very high discounter (far left panel) exhibits a switch in preference very early, resulting in behavior that appears to always prefer SS. As time passes (between times *A* and *B*), the moderate-high discounter (center left panel) now prefers the SS. As more time passes (between times *B* and *C*), the moderate-low discounter (center right panel) prefers the SS. It is important to note that preference reversals in these examples occur simply due to the passage of time, as the objective values of the SS and LL, and the duration of the delay between them (the additional delay associated with waiting for the LL) remain constant. Finally, the very low-discounter (far right panel) consistently prefers LL.

Despite the significance of relapse as a defining characteristic of addiction, very little research has directly explored the presumptive relationship between delay discounting and preference reversals. Though a number of human and non-human animal studies have illustrated that preference reversals do occur (Ainslie & Herrnstein, 1981; Green & Estle,

[1]Exponential discounting combined with the magnitude effect can also explain preference reversals (Green & Myerson, 2003; Noor, 2011).

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2003; Green, Fisher, Perlow, & Sherman, 1981; Holt, Green, Myerson, & Estle, 2008; Kirby & Herrnstein, 1995; Luhmann, 2013; Millar & Navarick, 1984), no explicit connection to rate of delay discounting has been made. For example, while Green, Fristoe, and Myerson (1994) demonstrated that preference reversals occur in a predictable manner as a function of both delay to the sooner reward and delay between sooner and later rewards, no attempt was made to examine the relation between preference reversals and delay discounting. Thus, while non-normative models of delay discounting predict preference reversals, and the literature indicates that preference reversals occur, we are aware of no research that is able to speak to the direct relation between delay discount rate and timing of preference reversals. The purpose of the present study was to address this gap in the literature by examining the relation between delay discounting and preference reversals for hypothetical money in a sample of cigarette smokers.

METHOD

Participants

Forty-seven (47) adult, non-treatment-seeking smokers from the Washington, D.C. metropolitan area met two or more of the following smoking criteria: 1. currently smoking ≥10 cigarettes per day for ≥1 year (*M* [*SD*] cigarettes/day= 18.7 [7.84]); 2. score 5 ≥ on the Fagerstrom Tolerance Questionnaire (FTQ; Fagerstrom & Schneider, 1989; *M* [*SD*] = 7.25 [1.82]); 3. DSM-IV-TR diagnostic criteria for nicotine dependence. Due to technical problems, three participants had missing data on relevant variables and were excluded from analyses, yielding a final sample of 44. Individuals with major medical illnesses, psychiatric disorders, or dependence other than nicotine were excluded. Smoking status was verified by an expired carbon monoxide ≥ 8 parts per million.

Materials

Delay Discounting Task—Delay discounting was assessed using a computerized binary choice procedure, where participants indicated preference between two amounts of hypothetical money by using the mouse to click on the preferred alternative. The *smaller-sooner* (SS) alternative was an amount of money that was available immediately, and adjusted trial-to-trial in the task. The larger-later (LL) alternative was an amount of money that was available following a delay, and remained fixed trial-to-trial within a magnitude condition. The LL amount was $50 or $1000, depending on the magnitude condition. The delays for the LL alternatives were: 1 day, 1 week, 1 month, 6 months, 1 year, 5 years, and 25 years.

Using the algorithm of Du, Green, and Myerson (2002; see also Holt, Green, & Myerson, 2003), the SS was titrated across 6 trials to determine an indifference point for each unique magnitude/delay pairing of the LL. On the first of six trials within each magnitude/delay pairing, the SS was 50% of the LL. If the LL was selected, the SS was increased on the subsequent trial to 75% of the LL; if the SS was selected, the SS was decreased to 25% of the LL. Over the remaining trials within each magnitude/delay pairing, the SS was increased or decreased in this manner, by half of the previous adjustment (e.g., 12.5% increase/

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decrease for trial 3). The indifference point (i.e., the present subjective value of the delayed LL amount) was calculated as the resulting SS following the sixth trial.

Preference Reversal Task—Preference reversals were assessed using four variations of a novel computerized choice procedure partially informed by established procedures to assess delay discounting (Du et al., 2002) and preference reversals (Green et al., 1994; Holt et al., 2008), with the purpose of allowing a higher degree of temporal specificity than previous studies of preference reversal. In each trial of the choice procedure, two hypothetical money rewards (SS and LL) were presented where the SS was delayed (by a *front-end delay*) and the LL was more-delayed (by the same *front-end delay* plus *back-end delay*). The four variations of the preference reversal task incorporated each combination of a magnitude condition of the LL from the delay discounting task ($50, $1000) and a back-end delay condition (7 days, 30 days). To wit, the preference reversal conditions were: (1) LL = $50 with back-end delay = 7 days, (2) LL = $50 with back-end delay = 30 days, (3) LL = $1000 with back-end delay = 7 days, (4) LL = $1000 with back-end delay = 30 days.

In order to determine the appropriate SS value for each preference reversal task condition, the SS values at which a significant majority of participants were expected to exhibit a preference reversal were calculated using archival hyperbolic discount rates from a similar population, within each combination of LL magnitude and back-end delay. Based on these calculations, the SS was set at 95% of the LL at back-end delay = 7 days (i.e., $47.50 and $950 for $50 and $1000 magnitude conditions, respectively) and 65% of the LL at back-end delay = 30 days (i.e., $32.50 and $650 for $50 and $1000 magnitude conditions, respectively).

A two-step algorithm was applied in order to determine the front-end delay (i.e., preference reversal point) at which participants exhibit a preference reversal. Algorithm step 1 sought to identify an initial temporal window in which a preference reversal occurred by working backwards in time (i.e., left-to-right in each panel of Figure 1). On the first trial, the SS amount was 95% or 65% of the LL amount (depending on the back-end delay condition) with front-end delay = 0; the LL amount was $50 or $1000 (magnitude condition), delayed by 7 or 30 days (back-end delay condition). This first trial was similar to a now-versus-later trial of a conventional delay discounting task. If the participant indicated preference for the LL alternative on this first trial, the program was terminated and the participant was scored as *Larger-Later in First Trial* for that combination of magnitude and back-end delay conditions, indicating no preference reversal was possible given study parameters (i.e., the far right panel of Figure 1). For participants that indicated preference for the SS alternative in this initial trial, the front-delay was increased by 4-month (when back-end delay = 7 days) or 8-year (when back-end delay = 30 days) increments until the participant switched preference toward the LL alternative. For example, in the $50, 7-day back-end delay condition, the second trial was a choice between $47.50 delayed by 4 months (SS) and $50 delayed by 4 months plus 7 days (LL). If no switch to preference for the LL was observed across 5 trials of increasing front-end delay while back-end delay remained constant, the program was terminated and the participant was scored as *Smaller-Sooner for All Trials* for that combination of magnitude and back-end delay conditions, indicating no preference reversal was observed given study parameters (i.e., the far left panel of Figure 1).

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For those participants who did exhibit a switch in preference from the SS to LL alternatives during algorithm step 1, the switch point defined the initial preference reversal window as between the longest front-end delay where SS was preferred and the shortest front-end delay where LL was preferred. Within these lower and upper boundaries, algorithm step 2 sought to more-focally define the preference reversal point. For the first of six trials in this second step, the two alternatives were: (1) the SS alternative with a front-end delay halfway between the lower and upper boundaries, and (2) the LL alternative with the same front-end delay plus back-end delay (7 or 30 days, depending on the condition). If the LL was selected, the front-end delay for both SS and LL was increased on the subsequent trial by 25% of the preference reversal window. If the SS was selected, the front-end delay for both SS and LL was decreased on the subsequent trial by 25% of the preference reversal window. Over the remaining trials, the front-end delay for both SS and LL was increased or decreased in this manner, by half of the previous adjustment (e.g., 12.5% increase/decrease for trial 3). An example series of trials is shown in Figure 2.

Procedure

As part of an IRB-approved 2-hour session, the computerized delay discounting task for both magnitude conditions were completed prior to the computerized preference reversal tasks. In the delay discounting tasks, the magnitude condition order was counterbalanced between-subjects, and the delay order was fixed (increasing). In the preference reversal tasks, the order of conditions was counterbalanced across participants. A questionnaire battery completed following these assessments are not reported here, and participants were financially compensated for participation.

RESULTS

Using individual indifferent points at each delay in each magnitude condition, delay discount rate (*k*) was estimated separately for each participant using nonlinear regression based on the hyperbolic decay function (Mazur, 1987): $V_d = \frac{V}{1+kd}$, where V_d is the discounted value (i.e., the indifference point) of a reward at delay d, and V is the undiscounted value of a reward (i.e., the magnitude of the LL). High values of discount rate k indicate steep discounting, where the subjective value of the LL quickly loses value as a function of delay. In instances where delay discounting data for only one reward magnitude condition was available (8 participants, due to technical problems), participant data were considered only for the available magnitude condition. Discount rate from two participants were outliers in the $1000 condition (>3 standard deviations from the mean; Ratcliff, 1993), and excluded from analyses.

The model provided a good fit to individual data, with low root mean squared error (RMSE; $\underline{M}_{\$50}$=.141 and $\underline{M}_{\$1000}$=.123; RMSE is a more appropriate measure of fit with nonlinear regression than R^2; Johnson & Bickel, 2008). For demonstration purposes, the model is fit to median indifference points in Figure 3 at each magnitude. Natural-logarithm transformations

[2]Determined by examining the distribution of indifference points from the $50, 1-week delay condition.

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of discount rate *k* (ln-*k*) were conducted in order to normalize the distribution and allow for parametric analyses.

Age, sex, and income were not significantly associated with any of the variables of interest, and are not considered further. A paired t-test compared delay discount rate (ln-*k*) between $50 (M=−4.40) and $1000 (M=−5.61) reward outcomes (t[33]=2.57, p=.015). These means were consistent with previous work using identical methods and magnitude conditions with smokers (e.g., Yi & Landes, 2012), and replicated the established magnitude effect in which high-magnitude amounts are discounted less steeply than low-magnitude amounts (Kirby, 1997; see review in Madden & Johnson, 2010).

The relation between delay discounting and preference reversals was first explored by determining if rates of delay discounting differed in the predicted manner among individuals who were classified within each magnitude as high-discounters (left panel of Figure 1), as moderate-discounters (two center panels), or as low-discounters (right panel). Classification was based on the pattern of responding in the preference reversal tasks within each magnitude condition, resulting in a separate classification for each participant in the $50 and $1000 magnitude conditions. A participant was classified within a magnitude condition as a (a) predicted low-discounter if s/he preferred the LL on the first trial for both preference reversal tasks (7-day and 30-day back-end delay conditions), (b) predicted high-discounter if s/he preferred the SS on all trials for both preference reversal tasks, and (c) predicted moderate-discounter in all other instances (e.g., exhibited a preference reversal on both preference reversal tasks within a magnitude condition; preferred the LL on the first trial in one preference reversal task and preferred SS on all trials in the other preference reversal task).

The frequency of each classification (Table 1) indicates an appropriate degree of coherence. Consistent with the magnitude effect (increasing discounting with decreasing magnitude), the percentage of low-discounting classifications was higher in the $1000 than $50 magnitude conditions, while the percentage of high-discounting classifications was higher in the $50 than $1000 magnitude conditions.

Following classification based on preference reversal tasks, ANOVA and chi-square analyses were conducted to explore possible group differences in sociodemographic or smoking characteristics, and no significant differences were observed (all ps > .09). Rate of delay discounting for the three groups (predicted high, moderate, low discounters) were then compared at each reward magnitude ($50, $1000).

Analyses of Variance were conducted (Figure 4), with rate of delay discounting for the corresponding magnitude ($50, $1000) as the dependent variable. A significant overall difference was observed in the $50 magnitude condition ($F$[2, 38]=3.92, p =.03), with Tukey's post-hoc comparisons indicating that predicted low discounters had significantly lower observed discount rates than predicted high discounters (p=.023); no significant differences were observed in the other pairwise comparisons. A significant overall difference was also observed in the $1000 magnitude condition (F[2,39]=7.38, p<.01), with Tukey's post-hoc analyses indicating that predicted high discounters had significantly higher

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discount rates than predicted low discounters (p<.01) and predicted moderate discounters (p<.01).

For the purpose of a correlational analysis of delay discounting and preference reversals, moderate discounters were subclassified as low-moderate (LL on the first trial in one task and preference reversal on the other task), mid-moderate (LL on the first trial in one task and SS on all trials in the other task; preference reversal on both tasks), and high-moderate (SS on all trials in one task and preference reversal on the other task). Spearman correlations conducted with this ordinal preference reversal subclassification and rate of delay discounting revealed non-significant correlations (r_s=+.26, p=.28 and r_s=+.34, p=.25 in the \$50 and \$1000 magnitude conditions) in the predicted direction.

DISCUSSION

The reversal of preference from larger-later to smaller-sooner outcomes as a function of the passage of time models an initial decision to quit smoking followed by relapse. Such preference reversals are predicted by hyperbolic and other non-exponential models of delay discounting, and studies of intertemporal choice have frequently assumed this relation without formally determining that the relation exists. We believe that the present study is the first to explicitly examine whether rate of delay discounting is associated with preference reversals in a human sample. We examined this population because smokers have elevated delay discounting and may be particularly vulnerable to preference reversals.

Based on the pattern of responding in the preference reversal task, participants were predicted to fall into one of the following categories: high, moderate, and low discounters. Consistent with prediction, the predicted high discounters exhibited significantly higher rates of delay discounting than predicted low discounters in both (\$50 and \$1000) magnitude conditions. A significantly higher rate of delay discounting was also observed in predicted high discounters relative to predicted moderate discounters in the \$1000 magnitude condition. Though some pairwise comparisons were not statistically significant, the *pattern* across predicted high, moderate, and low discounters was identical in the two magnitude conditions. A more-precise examination of this relation between delay discounting and preference reversal via correlational analysis revealed predicted relations that did not reach statistical significance, and in this respect, the present preference reversal task failed to provide the high degree of temporal resolution we had hoped for during task-development. Nonetheless, we believe this consistent overall pattern of results in support of the delay discounting and preference reversal relation is compelling.

The lack of statistically significant findings in some of the analyses highlights insufficient statistical power as the primary limitation of the present research. Given the clear pattern of results when comparing predicted high, moderate, and low discounters, it appears likely that nonsignificant contrasts were due to the small sample. One obvious solution would be to increase sample size in future research. Based on the most conservative (i.e., smallest) effect size obtained in the present research when making binary contrasts comparing predicted discounter classifications (η_p^2=.02), a sample size of 144 in each classification would have been necessary for .80 power when conducting a two-tailed (p = .05) test to detect statistically significant differences in all pairwise contrasts. This is assuming that there is a true difference between participants classified as low- and moderate-discounters using the present study paradigm, which may or may not be the case.

Modification of the preference reversal task (e.g., larger SS or longer back-end delay conditions; different titrating algorithm) could also have resulted in a higher number of observed preference reversals, which would have enhanced the correlational analysis of delay discounting and preference reversal. Using the present paradigm, we observed few preference reversals (46% and 32% in $50 and $1000 magnitude conditions) which was likely insufficient to adequately power such an analysis. Previous studies (Green et al., 1994; Holt et al., 2008) have used a variety of inter-reward delays (i.e., back-end delay of the present study) in a preference reversal task, and a similar procedure could have been used to personalize the back-end delay such that preference for the SS on the first preference reversal trial was guaranteed (i.e., preference reversal was possible). We elected not to implement such a personalized task because back-end delays that allow for preference reversals at the individual level (which are theoretically influenced by delay discount rate) would have then been confounded with the timing of preference reversals (also theoretically influenced by delay discount rate). Given that we elected to make SS and back-end delay constant across all participants, a closer examination of the data indicates that SS = $49.79 would have been appropriate to obtain 90% of participants choosing SS in the first trial (thereby allowing the possibility of a preference reversal in the $50, 7-day back-end delay condition[2]).

Despite the failure to reach conventional thresholds for statistical significance in some analyses, we wish to note the high degree of coherence in the classification distribution (Table 1) that is consistent with theory and as such, not likely due to chance. For example, the observation that a higher percentage of participants were classified as low-discounters in the $1000 magnitude conditions (compared to the $50 magnitude conditions), and a higher percentage of participants were classified as high-discounters in the $50 magnitude conditions (compared to the $1000 magnitude conditions), is consistent with the well-established magnitude effect (Kirby, 1997) that was replicated in the present study.

A minor limitation related to an insufficient portion of the sample exhibiting a preference reversal is that the present study is unable to differentiate between various models of delay discounting that also predict preference reversals. We examined data from the present study using an alternative single-parameter delay discounting model (exponential-power; Yi, Landes, & Bickel, 2009), and no differences were observed in the pattern of results when compared to results with the hyperbolic model. This is partially due to the fact that indices from different models of delay discounting are highly correlated, so that scoring of delay discounting using an alternative to Mazur's (1987) hyperbolic model do not typically change the results. While alternative indices of delay discounting might have made a small difference when examining the possible continuum of the delay discounting and preference reversal relation, the insufficient power for that analysis in the present study made model-comparison unfeasible.

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Another minor limitation of the present research is that the outcomes for both delay discounting and preference reversal tasks were hypothetical money. This is partially addressed by previous research using real money outcomes that have exhibited elevated delay discounting by smokers (e.g., Bickel, Odum, & Madden, 1999; Mitchell, 1999), and recent evidence indicating that delay discounting metrics for outcomes that are hypothetical and real are statistically equivalent (Matusiewicz et al., 2013).

Despite these limitations, we believe the present results provide basic support for the conceit that rate of delay discounting can predict preference reversals. To the extent that preference reversals model smoking relapse, assessment of smoking-related delay discounting (e.g., discounting of cigarettes, withdrawal symptoms) in future research may provide additional insight into when a smoker who has or will quit is vulnerable to relapse. Establishment of the predictive utility of delay discounting on smoking relapse could inform the appropriate temporal targeting of interventions to help prevent relapse and maintain quit attempts.

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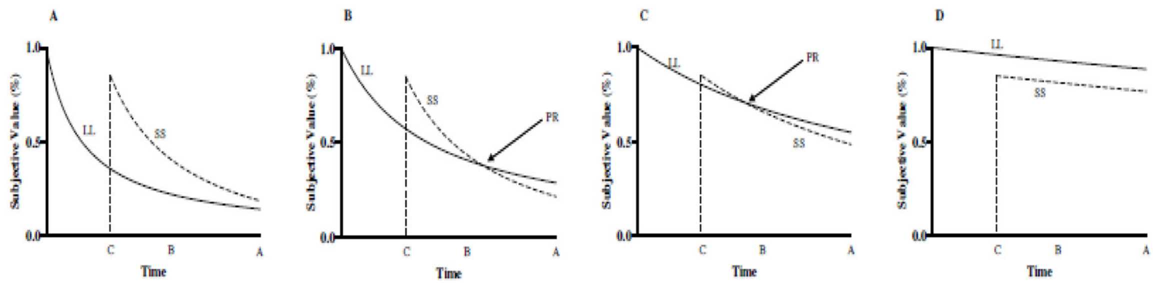

Figure 1.

The x-axis represents time, starting at the right and going left as time passes. SS ("smaller, sooner") represents a small reward that is available relatively sooner, and LL ("larger, later") represents a larger reward that is available relatively later. The y-axis indicates subjective value. The far left panel depicts a very high discounter, such that the intersection of discounted utility functions occurs at some point prior to point *A* and is not visible in this depiction. The middle-left panel depicts a moderate-high discounter, such that the intersection of discounted utility functions occurs relatively early, between points *A* and *B*. The middle-right panel depicts a moderate-low discounter, such that the intersection of discounted utility functions occurs relatively late, between points *B* and *C*. The far right panel depicts a very low discounter, such that the LL always has higher discounted utility (i.e., exhibits no preference reversal).

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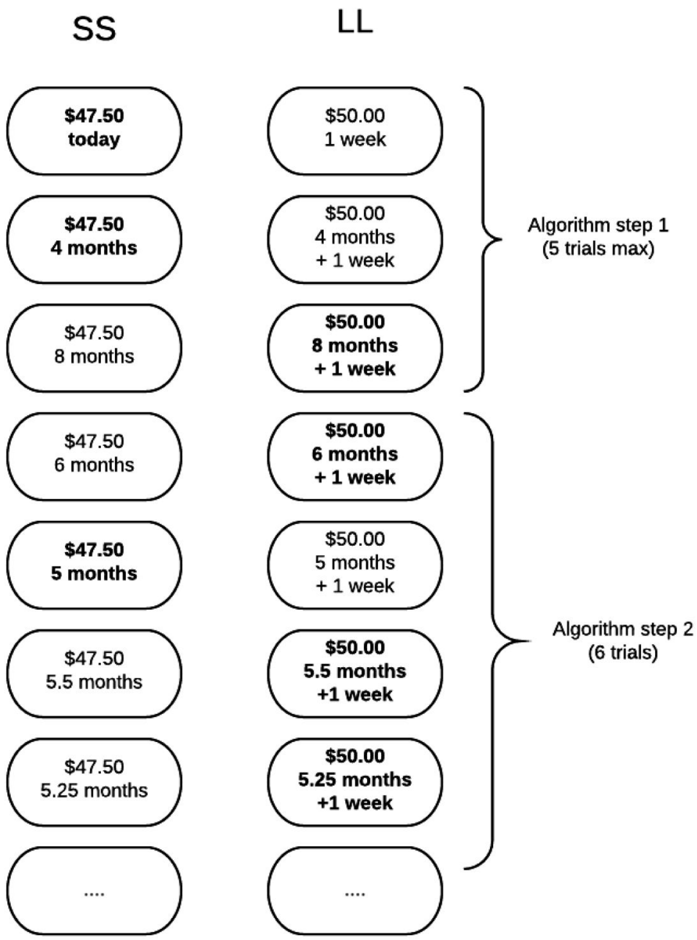

Figure 2.

Diagram of hypothetical sequence of trials in the preference reversal task for a participant who exhibits a preference reversal in the $50, 7 day back-end delay condition. The left and right columns represent the smaller-sooner and larger-later alternatives, respectively. Each row represents a single trial, and the bolded alternative represents the selected alternative in the hypothetical sequence.

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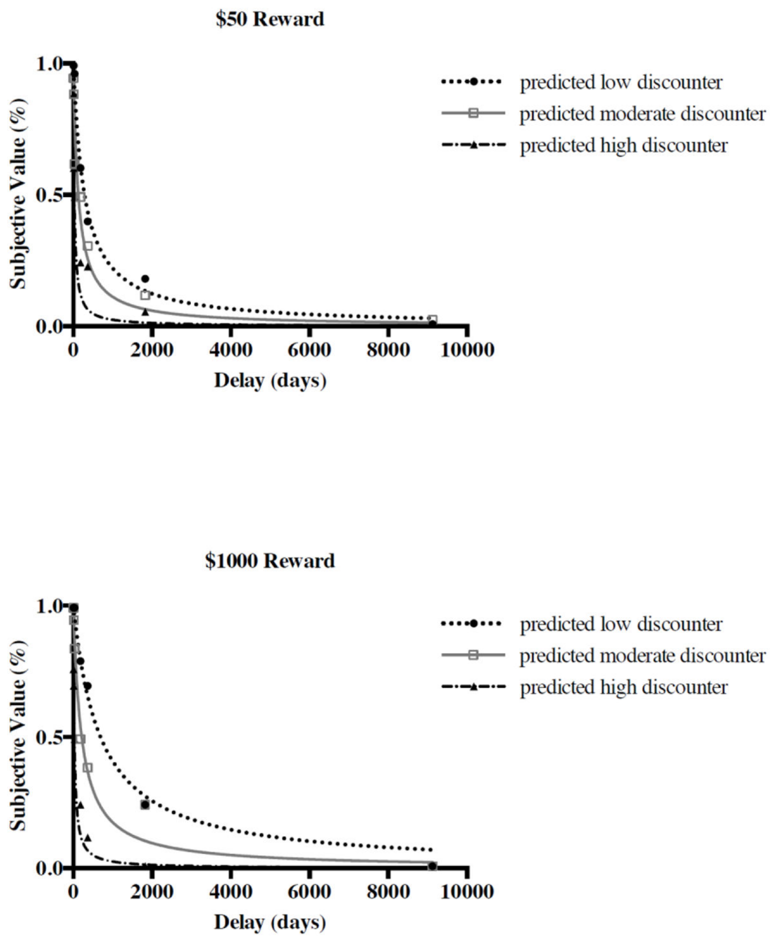

Figure 3.

Mazur's (1987) hyperbolic decay function fit to median indifference points as a function of delay, represented as a proportion of the delayed amount in the $50 (top panel) and $1000 (bottom panel) magnitude conditions. Classifications (predicted low, moderate, high discounter) were determined by the pattern of responding in the preference reversal tasks.

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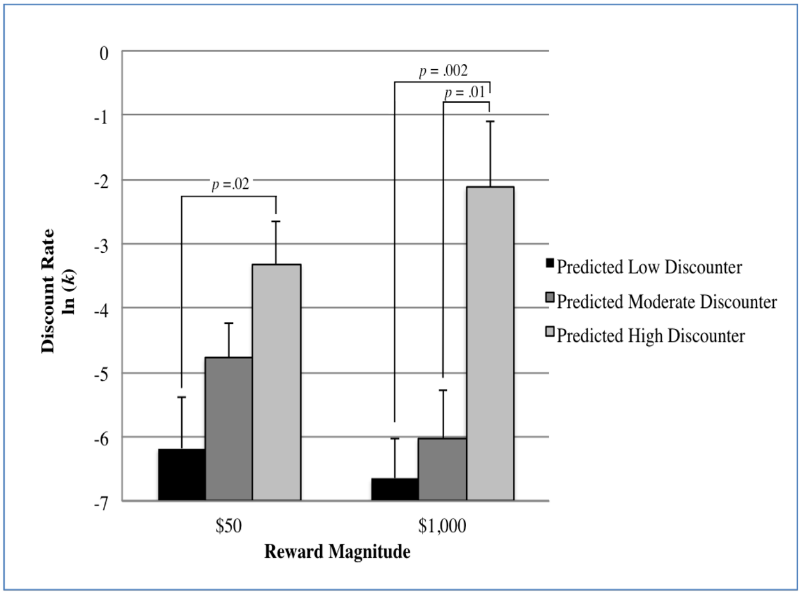

Figure 4.

Mean rate of delay discounting is shown as a function of classification (predicted low, moderate, high discounter) within each magnitude condition. All means are in the predicted direction, with statistically significant differences between predicted low-/high-discounters in the $50 condition, and between predicted low-/high- and moderate-/high-discounters in the $1000 condition.

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Table 1

Percent and number of participants in each classification resulting from the preference reversal task, as a function of reward magnitude.

Reward Magnitude	Predicted High-Discounters	Predicted Moderate-Discounters	Predicted Low-Discounters
$50	34% (15)	46% (20)	21% (9)
$1000	18% (8)	32% (14)	50% (22)