HHS Public Access
Author manuscript
Exp Clin Psychopharmacol. Author manuscript; available in PMC 2020 February 01.

Published in final edited form as:
Exp Clin Psychopharmacol. 2019 February ; 27(1): 19–28. doi:10.1037/pha0000224.

Past and future preference reversals are predicted by delay discounting in smokers and non-smokers

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Abstract

Delay discounting, the devaluation of delayed reinforcers, is one defining behavioral economic characteristic of cigarette smokers. Attempts at abstinence by smokers that result in relapse are conceptualized in this framework as preference reversals. Despite preference reversals being predicted by delay discounting models, little research has investigated the association between discount rate and preference reversals. The present study extended this research by examining the relation between discounting and preference reversals. Because previous research indicates that cigarette smokers discount at higher rates than controls and that past and future discounting are symmetrical, the present study assessed the relation between these two processes when hypothetical money was distanced in the past and future, respectively. These assessments of delay discounting and preference reversals were adapted from Yi et al. (2016) and examined in 68 smokers and 68 non-smokers using the crowdsourcing program, Amazon Mechanical Turk. Smokers discounted both past and future hypothetical money more steeply than demographically-matched controls. Smokers switched preference from the smaller-sooner (SS) to the larger-later (LL) outcome more slowly than non-smokers, consistent with smokers steeper delay discounting. For each group, significant positive correlations between past and future discount rates and past and future preference reversals was obtained. The overall pattern of results illustrate symmetry between past and future discounting and preference reversals, respectively and that discount rate is positively associated with the timing of preference reversals. Importantly, the results confirm that

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Conflict of Interest: W. K. Bickel is a principal of HealthSim, LLC and Notifius, LLC; a scientific advisory board member of Sober Grid, Inc. and DxRx, Inc.; and a consultant for ProPhase, LLC and Teva Branded Pharmaceutical Products R&D, Inc.

Contributors Statement: All authors have contributed a significant and important role to the manuscript and each author approved of the manuscript before submission.

cigarette smokers discount more and reverse preference from a SS to a LL reward later than controls.

Keywords

Cigarette smoking; delay discounting; addiction; preference reversal; behavioral economics

1. Introduction

Smoking is the leading preventable cause of morbidity and mortality in the United States (CDC, 2014). Each year smoking contributes to approximately 443,000 deaths, more than the deaths attributable to alcohol, illicit-drug use, homicide, AIDS, and suicide combined (Mokdad et al. 2005). Although the mechanisms that underlie initiation, maintenance, and relapse of cigarette smoking and tobacco dependence are complex, and determined by multiple factors, much evidence suggests a strong, possibly causal role for the rate at which events (e.g., reinforcers) are devalued – a phenomenon known as delay discounting (Bickel et al. 2014; Stein et al. 2016). For example, cigarette smokers discount delayed commodities including money, food, and health at higher rates than demographically-matched controls and those who have successfully quit (Bickel, Odum, and Madden 1999; Odum and Baumann 2007; Odum, Madden, and Bickel 2002; Secades-Villa et al. 2014; Stein et al. 2016; see reviews MacKillop et al. 2011; Yi, Mitchell, and Bickel 2010). The elevated discount rate for cigarette smokers is associated with higher indices of smoking addiction severity (Sweitzer et al. 2008; Ohmura, Takahashi, and Kitamura 2005) and a greater number of cigarettes smoked per day (Ikeda et al. 2016; Reynolds 2004; Reynolds et al. 2004), in addition to predicting the induction of smoking in adolescence (Audrain-McGovern et al. 2009). Moreover, elevated discount rates are associated with relapse to smoking in both a human laboratory model and in real-world clinical settings (Dallery and Raiff 2007; Mueller et al. 2009; C. Sheffer et al. 2012; 2014; Yoon et al. 2007).

The extant results presented above are consistent with delay discounting functioning as a behavioral marker of the addiction process (Bickel et al. 2014, 2016) and suggest that smokers who more greatly value smaller, immediate reinforcers (e.g., effects of cigarette smoking on the nervous system) at the expense of larger, delayed reinforcers (e.g., better health associated with smoking abstinence) are more likely to relapse. Rapid devaluation of delayed reinforcement associated with smoking abstinence may also serve to increase the relative value of the immediate, reinforcing effects of smoking. In this view, attempts at abstinence by cigarette smokers that later result in relapse are conceptualized as preference reversals, which, in the case of relapse is a switch in preference from a larger-later (LL) reward (e.g., health) to a smaller-sooner (SS) reward (e.g., nicotine). Conversely, attempting to quit smoking is a preference reversal from a SS reward (e.g., nicotine) to a LL reward (e.g., health). Interestingly, preference reversals are predicted by and are a pivotal component of many delay discounting models (Ainslie 1974; Ainslie and Herrnstein 1981; Logue 1988; Rachlin and Green 1972; Yi, Matusiewicz, and Tyson 2016).

Figure 1, adapted from Yi et al. (2016), illustrates how discount rate (*k*) and preference reversals are related and how the rate of future devaluation predicts significant shifts (or lack thereof) in decision-making through epochs of time. Figure 1 shows time-points of preference reversals for 4 hypothetical individuals with different rates of discounting. Moving from left to right panels, very steep to very shallow discounting predicts both whether, when, and the time over which preference reversals occur. Figure 1 also illustrates how preference reversals and delay discounting are related and how increases in discount rates (ranging from very steep to very shallow) predict increases in the length of the delay preceding the two options that results in preference for the LLR over the SSR. The perspective provided by Figure 1 may also be related to relapse, in so far as discounting and preference reversals are predictive of such behavior. If so, the SS reward could be viewed as relapsing to the drug, a quick high, but with poor future health and the LL reward viewed as continued abstinence, no high, but better future health. Moreover, if this relation is robust, it would suggest that increases in discounting increase the chance of relapse through the mechanism of preference reversals and hyperbolic discounting.

Only Yi et al. (2016) to our knowledge, has directly explored the underlying relation between delay discounting and preference reversals (but see Green, Fristoe, and Myerson 1994; Holt et al. 2008 for research on preference reversals). In that study, Yi et al. (2016) sought to establish the relation between the rate of discounting and preference reversals by assessing delay discounting of hypothetical monetary rewards at two magnitudes ($50, $1000) in smokers. Additionally, a novel preference reversal task designed to determine the point in time a preference reversal would occur for the same amount of hypothetical money in the discounting task was used. To analyze the data, the authors used the results of the preference reversal task to classify participants as predicted steep, moderate, and shallow discounters. The obtained rates of discounting were then compared between the predicted classifications at each reward magnitude. Although Yi et al. (2016) observed statistically significant differences between the predicted high and low discounters at both magnitudes, and between predicted high and moderate discounters in the $1000 condition, correlations between delay discounting and preference reversals amongst the predicted moderate discounters did not reach significance. The authors suggested that because a large proportion of participants did not exhibit a preference reversal, either by constantly preferring the SS reward (i.e., predicted high discounting) or LL reward (i.e., predicted low discounting), the degree of temporal specificity in the algorithm to determine points of preference reversal was not high enough. Thus, the present study slightly modified the preference reversal procedure introduced by Yi et al. (2016) to incorporate a higher degree of temporal resolution, allowing a full-range analysis of the correlation between discount rate and preference reversals.

While discounting research, and the presumed relationship with preference reversals, typically focuses on the future, a sizeable body of evidence indicates that similar neurobehavioral processes govern retrospection and prospection (Buckner and Carroll 2007). Indeed, past and future delay discounting gradients have been shown to be symmetric, past and future discount rates decrease as reinforcer magnitude increases (i.e., magnitude effect), and past and future rewards are discounted at a higher rate than losses (i.e., sign effect). The strong parallelisms between discounting of past and future outcomes (e.g., Bickel et al. 2008; Yi, Gatchalian, and Bickel 2006) among control participants and cigarette smokers, and the presumed relation between delay discounting and preference reversals, suggest that past and future preference reversals may too be governed by the same processes and should differ between smokers and controls (e.g., Quisenberry et al. 2016). The present study then has three hypotheses. First, smokers should discount past and future outcomes more steeply than controls. Second, both smokers and controls should discount the past and future symmetrically, thus providing more evidence that discounting is related to temporal horizon more so than impulsivity. Third, past and future discounting should be related to past and future preference reversals, with smokers reversing preference from a SSR to a LLR at longer delays than controls due to the former's steeper discounting. Identifying symmetry in principles operating within a physical system (e.g., Randall, 2005) is important and advantageous because not only may they require fewer observations, but symmetrical discounting and preference reversal processes afford internal harmony and consistency in behavioral economics and neuroscience. Moreover, such symmetry among past and future discounting and preference reversals suggests applications derived from these processes may extend to a larger scale (Marr, 2006).

2. Methodology

2.1 Participants

Using Amazon Mechanical Turk (mTurk), we sought to target and recruit 70 participants who were non-smokers and 70 participants who were current cigarette smokers. Two Human Intelligence Tasks (HITs) were posted to mTurk; one implicitly directed at *non-smokers* and one implicitly directed at *smokers*. A HIT is one or more small assessment(s) posted on Amazon mTurk for human workers to complete; essentially a crowdsourcing internet marketplace where workers can explore and have the potential to be paid contingent upon meeting eligibility criteria, accepting the HIT, and completing the assessment(s) contained within the HIT. Screening questions were used to determine the eligibility to participate and the classification of non-smoker or smoker (see below).

2.1.1 Screening and eligibility questions prior to HIT—Before participants were allowed access to the HIT, a series of eligibility questions were required to be completed. The eligibility questions determined first if participants qualified to be in the study in any capacity (i.e., allowed overall), then whether the participant would be classified as a non-smoker or smoker.

First, all participants were required to meet the following eligibility in order to be able to be classified as a non-smoker or smoker and then complete the HIT. The eligibility to complete the HIT was restricted to individuals who resided in the United States; whose mTurk completion percentage was greater than 90%; were over the age of 18; reported not currently using illicit drugs; and were not, nor had ever been, employed by Virginia Tech or the Virginia Tech Carilion Research Institute. If a participant met these eligibility criteria, they were then asked additional questions to determine if they were to be classified as a non-smoker, smoker, or ineligible before being allowed to complete the HIT. When completing this screener, including the previous eligibility criteria and the additional questions described next, participants were not explicitly told that non-smokers or smokers were being targeted or that non-illicit drug users were being targeted. Instead, the pattern of answers to the screening questions determined whether someone would either be classified as a non-smoker, smoker, or ineligible to complete the HIT.

In order to be allowed to complete the HIT and then be classified as a non-smoker, participants had to first had to meet the eligibility criteria listed above, including not currently using illicit drugs, followed by reporting not now or ever smoking cigarettes (i.e., not a current or ex-smoker). If participants reported not currently using illicit drugs and not now or ever smoking cigarettes, they were allowed to complete the HIT and were classified as a non-smoker. Participants were also asked to complete the Alcohol Use Disorders Identification Test (AUDIT), the scores of which are described below.

In order to be allowed to complete the HIT and be classified as a smoker, participants again first had to meet the eligibility criteria listed above, including not currently using illicit drug, followed by self-reporting that they are currently a daily-cigarette smoker and that they smoke 10 or more cigarettes per day. Thus, participants were allowed to complete the HIT and were classified as a smoker if they reported not using illicit drugs and were a daily smoker of 10 or more cigarettes. These participants were also asked to complete the AUDIT, in addition to the Fagerstrom Test for Cigarette Dependence (FTCD), described next.

2.1.1 Demographic characteristics and addiction severity—No statistically significant differences were observed between smokers and non-smokers on demographic variables that may affect delay discounting (gender, age, income, education, and employment); therefore, combined demographics are discussed next. Fifty-seven percent of participants were female ($N = 136$). The mean age was 31.74 +- 7.36 (SD). Income was highly skewed (skew = 5.32) with a median of $50,400 per year and interquartile range ($34,000-$76,000). The average number of years of school completed was 15.18 +- 2.66 (SD). For employment, frequencies (percentages) for the six possible employment statuses were as follows: 60 (45.45%) Full-time, 25 (18.93%) Part-time, 12 (9.09%) Unemployed, 4 (3.03%) Retired, 29 (21.97%) Students, and 2 (1.51%) Other. The scores on the AUDIT were not significantly different between non-smokers (12.42 [SD = 3.51]) and smokers (10.79 [SD = 2.66]), although mean AUDIT scores were higher than the accepted cut-off point, median AUDIT scores were closer to the accepted cut-off. Further, there was not a significant relation between AUDIT scores and past and future delay discounting or past and future preference reversals. The average scores on the FTCD for smokers was 5.88 (SD = 1.92). See table 1 for more detail.

2.2 Procedures

All procedures in this study were reviewed and approved by the Virginia Tech Institutional Review Board. After meeting the respective eligibility criteria for each group listed above, participants completed four assessments, the order of which was randomly determined: 1) future monetary delay discounting; 2) future monetary preference reversal; 3) past monetary delay discounting; 4) past monetary preference reversal. Note that after meeting the respective eligibility criteria for each group, the progression of the procedures and assessments were identical for smokers and non-smokers. The average time to completion of all procedures in the HITs was 20 minutes. Participants were paid $1.00 for completing the HIT and an additional $3.00 if the data were systematic and usable. All but 4 participants (2 non-smokers and 2 smokers) earned both the $1.00 for HIT completion and the $3.00 for systematic data. The 4 participants that did not earn the $3.00 for systematic data failed the attention-check added into the delay discounting and preference reversal assessments.

2.3 Materials

2.3.1 Delay Discounting Assessments—Past and future delay discounting were assessed using the validated computerized, 5-trial adjusting delay task described in Koffarnus and Bickel (2014). This method quickly and accurately determines a participant's discount rate by directly measuring the Effective Delay 50% (ED50) value, the simple inverse of discount rate and the temporal distance at which the subjective value of the LL alternative decays to 50% of its objective value (Yoon & Higgins, 2008). In order to determine these values, a series of choice questions between $1,000 temporally distant in the past or future (LL; e.g., delay) and $500 available immediately (SS) were presented. The amount of money assigned to the SS and LL alternatives remained stagnant while the temporal distance to the LL alternative was titrated to determine the ED50 value. Over the course of the 5 adjusting-delay trials, the titration of temporal distances to the LL alternative were determined by the participant's pattern of choices. This procedure yields 32 possible temporal adjusted distances to the LL alternative. The first trial consisted of a choice between $1,000 distanced by 3 weeks (i.e., 3 weeks in the past or future) and $500 available immediately. If a participant selected the SS alternative on this first trial, the temporal distance adjusted closer to 0 in a stepwise fashion; if a participant selected the LL alternative, the temporal distance adjusted farther from 0 in a stepwise fashion. Over the course of the next four trials, this titration continues and results in 1 of 32 potential ED50 values nearly evenly spaced on a logarithmic scale between 1 hour and 25 years. The past and future delay discounting assessments were identical in all ways (e.g., monetary amounts, temporal distance to reward) except the direction in which the psychotemporal distances to the larger reward were posed (i.e., in the past or the future).

2.3.2 Preference Reversal Assessments—Past and future preference reversals were assessed using a modified version of a computerized choice procedure used in Yi et al. (2016), with the purpose of allowing a high degree of temporal specificity and larger range of time points. The past and future preference reversal assessments were identical in all ways (e.g., monetary amounts, temporal distance to reward) except the direction in which the psychotemporal distances to SS and LL rewards were posed (i.e., in the past or the future).

Figure 2 demonstrates that during each choice trial, two hypothetical monetary rewards (SS & LL) were presented where the SS reward was temporally distant by a changing delay and the LL reward was more distal by the same, common delay *plus* a constant difference interval between the SS and LL outcome deliveries. In addition, the LL reward was equal to $1000, so as to be identical with the delay discounting assessments, and the constant difference interval between the delivery of the SS and LL rewards was equal to 7 days in the past or future. In order to determine the appropriate SS monetary reward amount for this task, the SS value at which a significant majority of participants exhibited a preference reversal was calculated using pilot discount rates from a similar population. Based on the pilot data (*N* = 109), the SS reward was set at 97.5% of the LL reward at a constant difference interval between the two outcome deliveries = 7 days; i.e., $975 for the $1000 LL reward.

The time point of a preference reversal was determined through application of a two-step, titration algorithm. The first step of the algorithm was used to identify an initial temporal 'zone' in which preference reversals are likely to occur, while the second step was used to more precisely identify the temporal location of indifference points or the temporal location where switches in preference between the LL and SS are equally likely and reversals of preference most probable. On the first trial the SS reward = $975 and the LL reward = $1000; the common delay preceding both options = 0 and the constant, difference interval between the SS and LL outcome deliveries = 7 days. The difference interval was set equal to 7 days based on Yi et al. (2016) reporting elevated sensitivity of behavior to a shorter, seven-day difference interval compared to a longer, 30 day difference interval. Indeed, the hyperbolic nature of delay discounting suggests that preference reversals from the SS to the LL outcome should be more sensitive when the SS is higher and the common difference interval shorter.

If a participant indicated preference for the LL alternative during the first trial, step 1 of the algorithm was complete; the initial temporal window in which a preference reversal could potentially occur was set to 3 days (i.e., approximately halfway between 0 and 7 days for the common delay) for the second step of the algorithm (explained in detail below). If participants specified preference for the SS alternative during this initial trial, the common delay preceding both choices was increased by 4-month increments until the participant switched to the LL alternative. For example, the second trial would be a choice between $975 temporally distanced by 4 months (SS) and $1000 temporally distanced by 4 months plus the constant, difference interval of 7 days (LL); the SS and LL alternatives could be distanced in the past or future, depending on assessment. All participants who chose the SS alternative on the first trial switched preference from the SS to the LL alternative at or before the 6th of 7 possible trials (i.e., common delay = 20 months).

Within these lower and upper boundaries determined during step 1, the algorithm in step 2 sought to more focally determine the amount of time, in the past or future, necessary for preference to switch from the SS to LL alternative. Functionally, this means that step 2 of the algorithm sought to find the common delay preceding both options (measured from delivery of the SS reward) that yielded indifference in preference between the SS and LL alternatives, similar to that described in the delay discounting procedure above.

During the first of eight possible trials in algorithm step 2, the SS and LL alternatives were (1) the SS alternative with a delay to both options halfway between the lower and upper bounds, defined above, and (2) the LL alternative with the same preceding delay plus the constant difference interval between the SS and LL deliveries of 7 days. If the SS alternative was selected on the first trial of step 2, the common delay preceding both the SS and LL alternatives was increased by 50% of the initial preference reversal window on the subsequent trial. If the LL alternative was selected, the common delay for both alternatives was decreased on the subsequent trial by 50% of the initial preference reversal window. Over the course of the remaining trials, the common delay preceding each alternative was titrated in this manner, i.e., by half of the previous adjustment (e.g., 12.5% decrease/increase of initial window for the fourth trial). The progression of the two-step algorithm can be seen in Fig. 2. Step two of the titration procedure continued until participants demonstrated two reversals in preference (i.e., SS to LL to SS) or until 8 trials occurred, whichever came first.

2.4 Statistical Analysis

2.4.1 Past and Future Delay Discounting—The following equation was fitted to participants indifference points for past and future delay discounting (Mazur 1987):

$$V = \frac{A}{1 + kD} \quad \text{Eq. 1}$$

where A is the objective amount or magnitude of reward, d is the delay to reward in days, k is the discount rate, and V is the subjective value of the delayed commodity. Larger values of k indicate rapid or steep discounting. Past and future discount rates were calculated for individual subjects in each group by obtaining the inverse of obtained ED50 values, which is equivalent to the value of k in Eq. 1 when fitted to a singular point. Values of k were log normal-transformed for all data analyses to combat the positive skewness typical in delay discounting data (i.e., ln[k]). With this transformation, higher values of ln[k] (i.e., more positive) still indicate steeper rates of discounting and lower values of ln[k] (i.e., more negative) still indicate shallower rates of discounting.

2.4.2 Past and Future Preference Reversals—As described above, the primary dependent variable in the past and future preference reversal assessments was the number of days both SS and LL alternatives needed to be distanced in the past or future for preference reversals from the SS to the LL outcome to occur; that is, the time points of indifference determined by step-two of the algorithm.

2.5 Statistical Approach

All statistical analyses were conducted in Microsoft Excel or GraphPad Prism 7.0. Because no statistically significant differences were found between smokers and non-smokers in demographic variables that may affect delay discounting (gender, age, income, education, and employment), all possible comparisons and combinations of relations between past and future discount rates and past and future preference reversal time-points between non-smokers and smokers were conducted with two-way mixed analysis of variance (ANOVA), with smoking status as a between-subjects variable and temporal frame (past or future) as a repeated measure. In addition, Pearson correlations were also conducted to examine all possible bivariate relationships. Statistical tests were considered significant at $p < 0.05$.

3. Results

3.1 Comparison of Smokers and Non-Smokers

Delay Discounting—The first test was used to determine, at a more global level, whether past and future discount rates (ln[*k*]) were symmetrical and if differences were observed between smokers and non-smokers (Fig. 3).

A two-way mixed ANOVA revealed no main effect of temporal frame on values of ln[*k*] (F [1, 134] = 2.49, $p = 0.12$) nor a significant interaction between temporal frame and smoking status on values of ln [*k*] (F[1, 134] = 0.05, $p = 0.83$), confirming symmetry between past and future discount rates for both smokers and non-smokers. The test did, however, reveal a significant main effect of smoking status (F[1, 134] = 17.22, $p < 0.001$) on values of ln *k*, indicating that cigarette smokers discounted past and future $1000 monetary outcomes at a higher rate than non-smoking controls (see Fig. 3).

Preference Reversals—The second test was used to determine whether the number of days both SS and LL alternatives needed to be distanced in the past and future for preference reversals from the SS to the LL outcome to occur (i.e., common delay preceding options) were symmetrical and if differences were observed in these time-points between smokers and non-smokers. Note that 28% of all participants across both groups (38/136) did not exhibit a preference reversal; that is, 38 participants chose the LL reinforcer on the first trial of the preference reversal procedure and were given a preference reversal value of 0, with 24/68 non-smokers and 14/68 smokers not exhibiting a preference reversal, respectively. However, of those 38 participants their average past ln[*k*] was −6.14 and their average future ln[*k*] was −6.21, thus suggesting that the potential reason a preference reversal did not occur for those individuals was due to extremely shallow rates of discounting and very high value placed on delayed rewards.

A two-way mixed ANOVA revealed no main effect of temporal frame on time-points of SS-LL preference reversals (F[1, 134] = 0.19, $p = 0.66$) nor a significant interaction between temporal frame and smoking status on time-points of SS-LL preference reversals (F[1, 134] = 0.10, $p = 0.75$), confirming symmetry between past and future SS-LL preference reversals for both smokers and non-smokers. Similar to the results of the delay discounting assessments, this ANOVA revealed a significant main effect of smoking status (F[1, 134] = 13.17, $p < 0.01$) on time-points of SS-LL preference reversals, indicating that significantly more days were required for smokers (compared to controls) for both alternatives to be distanced in the past or future in order for preference reversals from SS to LL to occur (see Fig. 4).

3.2 Within-Subject Relations

The final analyses used correlational methods to determine past and future symmetry and relations, both within and across the delay discounting and preference reversal assessments for non-smokers and smokers, respectively. Table 1 lists the correlations discussed below.

Non-Smokers—The final test of past and future symmetry involved the examination of a within-subject relationship between obtained past and future discount rates with obtained time-points of past and future SS-LL preference reversals. For non-smokers, significant positive correlations were observed between past and future ln k values ($r(68) = 0.61$, $p < 0.001$) and time-points of past and future SS-LL preference reversals ($r(68) = 0.80$, $p < 0.001$), respectively. Importantly, significant positive correlations were also observed between past discount rates and past SS-LL preference reversals ($r(68) = 0.56$, $p < 0.001$) as well as future discount rates and future SS-LL preference reversals ($r(68) = 0.53$, $p < 0.001$). This indicates that for non-smokers, not only are past and future discount rates and preference reversals both symmetrical in time (see section 3.1 above), but past and future discount rates are correlated with past and future preference reversals, respectively (see Table 1 for details).

Smokers—For smokers, significant positive correlations were also observed between past and future values of ln [k] ($r(68) = 0.66$, $p < 0.001$) as well as time-points of past and future SS-LL preference reversals ($r(68) = 0.67$, $p < 0.001$). Importantly, positive correlations were also observed between past discount rates and past SS-LL preference reversals ($r(68) = 0.42$, $p < 0.001$) and future discount rates and future SS-LL preference reversals ($r(68) = 0.50$, $p < 0.001$). As demonstrated with non-smokers, in smokers, not only are past and future discount rates and SS-LL preference reversals both symmetrical in time, but past and future discount rates are correlated with past and future SS-LL preference reversals (see Table 1 for details).

Finally, the relationships between average number of cigarettes smoked per day and past and future discount rates and time-points of SS-LL preference reversals, respectively, were also explored. A significant positive correlation was observed between number of cigarettes smoked per day and future time-points of SS-LL preference reversals, $r(68) = 0.27$, $p = 0.024$, suggesting that elevations in the average number of cigarettes smoked per day is related to persistent preference for smaller, more immediate outcomes over larger, more distal outcomes. Although not significant, positive correlations were observed between daily number of cigarettes smoked and future discount rates ($r = 0.17$, $p = 0.17$) in addition to SS-LL past preference reversals ($r = 0.20$, $p = 0.10$). The correlation between number of cigarettes smoked and past discounting was very low and near zero ($r = 0.04$, $p = 0.73$).

Note that the correlations between past and future discounting and past and future preference reversals were not significantly different between non-smokers and smokers; that is, the relationship between past and future delay discounting and past and future preference reversals were not appreciably different between these two groups. Confirming the lack of difference in these correlations, a Z-test comparing the correlation between past and future discounting for non-smokers ($r = 0.61$) and smokers ($r = 0.66$) revealed no difference ($Z = -0.48$, $p = 0.63$); nor was there a difference between past and future preference reversal correlations observed for non-smokers ($r = 0.80$) and smokers ($r = 0.66$) ($Z = 1.74$, $p = 0.09$). The lack of difference in the relationships between the past and future frames of these measures can also be observed in the large overlap of the 95% confidence intervals for the correlations between past and future discounting and past and future preference reversals for non-smokers and smokers, respectively. Specifically, the 95% confidence interval for the correlation between past and future discounting in non-smokers was 0.44 - 0.74 which overlaps with the 95% confidence interval for the same correlation in smokers, 0.50 - 0.78.

Similarly, the 95% confidence interval for the correlation between past and future preference reversals in non-smokers was 0.70 - 0.87, which overlaps with the 95% confidence interval obtained for the smokers, which was (0.50 - 0.78). These results indicate that there was no interaction or moderation effect of the relation between the past and future frames of these measures that may disrupt a proper interpretation.

4. DISCUSSION

The present study replicates and extends the results of Yi et al. (2016) by explicitly examining whether time-points of preference reversals are correlated with rates of discounting. Moreover, the present study sought to determine the temporal symmetry and associative strength of this relation by measuring both past and future discount rates and past and future preference reversals. As previous studies have definitively illustrated that cigarette smokers discount past and future outcomes more steeply than non-smoking controls, but that past and future discounting are symmetrical in both populations, the differentiation between these two populations in time-points of past and future preference reversals was also explored.

An attempt at abstinence from cigarettes that is followed by relapse can functionally be conceptualized as a reversal in preference for a larger, more delayed outcome (e.g., health) over a smaller, more immediate outcome (e.g., tobacco/nicotine high). Non-exponential models of delay discounting, such as the oft used inverse linear relation known as hyperbolic (Killeen, 2001a; Killeen, 2011; Mazur, 1987; Eq. 1), predicts these preference reversals; as a result, the majority of research regarding delay discounting has implicitly assumed a relationship between preference reversals and discounting without any direct evidence that such a relation exists. The present work confirmed the relation between delay discounting and preference reversals while extending the literature concerning differences between cigarette smokers and controls in these measures.

Consistent with previous work, cigarette smokers discounted past and future outcomes more rapidly than controls. Extending this work, the common delay preceding both alternatives that was required to shift preference from the SS to the LL was greater for cigarette smokers than controls. A more precise investigation of this relation between discount rate and preference reversal via correlational analyses indicated that discount rate was positively related to time-points of SS-LL preference reversal within each group. In this respect, the results suggest that the preference reversal procedure used here provided a greater temporal resolution within the two-step algorithm. That is, using the 7-day constant difference interval between the two outcome deliveries and accompanying SS value equal to $1000, 7 days delayed, and the 8 step-algorithm likely increased the probability with which a preference reversal was observed (although Yi et al., 2016 did not report the actual value). Thus, the present study revealed a pattern of results consistent with the purported relation between delay discounting and preference reversals.

Despite the strengths of the present study, several considerations deserve note. First, while the present study improved the titration algorithm for determining time-points of preference reversal, several participants (28% of participants across groups; 38/136 participants) preferred the LL reward exclusively and therefore did not exhibit a preference reversal. Although those 38 participants had lower than average past and future discount rates, suggesting that preference reversals did not occur because the LLR was valued very high no matter the relative delays to the SSR, future studies should attempt to increase the degree of temporal resolution in the preference reversal task by modifying the procedure by, for example, changing the titrating algorithm so that preference reversals are more likely to occur. In the present procedure the titrating algorithm and constant difference intervals were uniform for all participants and perhaps more nuanced results would be obtained if titrating was personalized for individual participants (e.g., Green et al., 1994; Holt et al., 2008). Moreover, the present procedure changed the common delay preceding both alternatives while keeping the difference interval between the time at which the SS and LL constant; thus, the procedure heavily manipulated the absolute delay, but the relative delays between the options was changed only to a small degree. Additionally, the present procedure used relatively high magnitudes of money (i.e., $1000) because higher magnitudes typically demonstrate greater sensitivity to differences among drug-dependent individuals, however, smaller magnitudes similar to that spent on cigarettes may have been more informative. Future research should manipulate both the common delay preceding the two options and the difference interval between the delivery of the two outcomes to better understand if and how the absolute delay to the two options, the relative delays between the two options, and/or some combination of the two control decision-making and points of preference reversal. Finally, the outcomes for both the delay discounting and preference reversals tasks were hypothetical money. Although previous research has illustrated that smokers exhibit elevated discount rates for real monetary outcomes (Baker, Johnson, and Bickel 2003; Mitchell 1999), and that delay discounting metrics for hypothetical and real outcomes are statistically similar (Matusiewicz et al., 2013), future research should extend the preference reversal tasks to non-monetary (e.g., drug) rewards. (Johnson & Bickel, 2011).

Another interesting pattern that was observed and deserves further attention was the relation between average number of cigarettes smoked per day and time-points of future preference reversals. Previous research has demonstrated that severity of nicotine dependence (Sweitzer et al. 2008) and number of cigarettes smoked per day (Ikeda et al. 2016; Ohmura, Takahashi, and Kitamura 2005; Reynolds 2004; Reynolds et al. 2004) are positively correlated with future delay discounting for monetary rewards. Although the correlation between number of cigarettes smoked per day was not significantly positively correlated with future discounting rate ($r = 0.17$, $p = 0.17$), past and future discounting rates were predictive of past and future preference reversals in the current study. Determining the extent to which smoking dependency modulates past and future delay discounting and preference reversals may help inform probability of relapse and designing future interventions. To the extent that preference reversals model attempts at abstinence from cigarette smoking, future studies might assess cross-commodity discounting for money, cigarettes and/or health (Friedel et al. 2014; Johnson, Herrmann, and Johnson 2015; MacKillop et al. 2012) to more precisely determine when, if, and the likelihood someone will quit smoking, remain abstinent, or relapse.

As suggested by Bickel et al. (2012; see also Bickel and Marsch 2001) if delay discounting is related to preference reversals, then altering delay discounting via certain interventions (e.g., episodic future thinking; Snider et al., 2016) should alter preference reversals. Further, to the extent that preference reversals for hypothetical money model relapse, then altering delay discounting rate should also alter relapse rates. Establishing the ability for delay discounting and preference reversals to predict periods of abstinence and relapse would aid the development of interventions to prolong and maintain attempts at quitting using techniques to increase the relative value of the LLR reward (or decrease the relative value of the SSR) over large temporal epochs.

Acknowledgments

Funding: This work was supported by the Virginia Tech Carilion Research Institute and by NIH Grant No. R01 DA034755-01A1S1, 2013.

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Public Significance Statement

The present study confirms previous research indicating that the influence and value of events decrease symmetrically as they retreat into the past and future and that cigarette smokers devalue events in the past and the future more steeply than matched-controls. The present study is the first to demonstrate that the rate of devaluation is positively associated with changes in preference, which has implications for relapse and smoking cessation interventions.

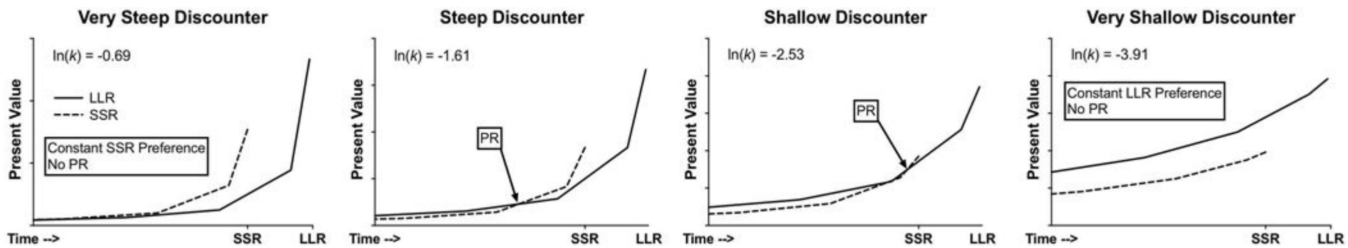

Figure 1.
In the leftmost panel of Fig. 1, a smaller-sooner (SS) reinforcer has an objective value indicated by the height of the vertical, dashed line given by the SSR label on X-axis; likewise, a larger-later (LL) reinforcer has a (larger) objective value given by the LLR label on the x-axis, indicated by the height of the vertical, solid line. Subjective value of each alternative is shown on the y-axis. The delay discounting models mentioned above predict that as discount rate increases so does the point at which preference reverses from the LL to the SS alternative; constant preference for the SS outcome emerges as the limit of this reversal time-point approaches infinity. When the SS and LL options and outcomes are both distal from the observer’s current point in time by a common delay preceding both choice options and outcomes, represented by difference between the beginning of the x-axis to the time of SSR, the very steep discounter (far-left panel) never reverses preference from the SS to the LL outcome. In the far-right panel, the very shallow discounter displays constant preference for the LL over the SS outcome at all common, additional delays preceding the two choice options; this means that as discount rate approaches zero, preference for the LL alternative approaches constancy.

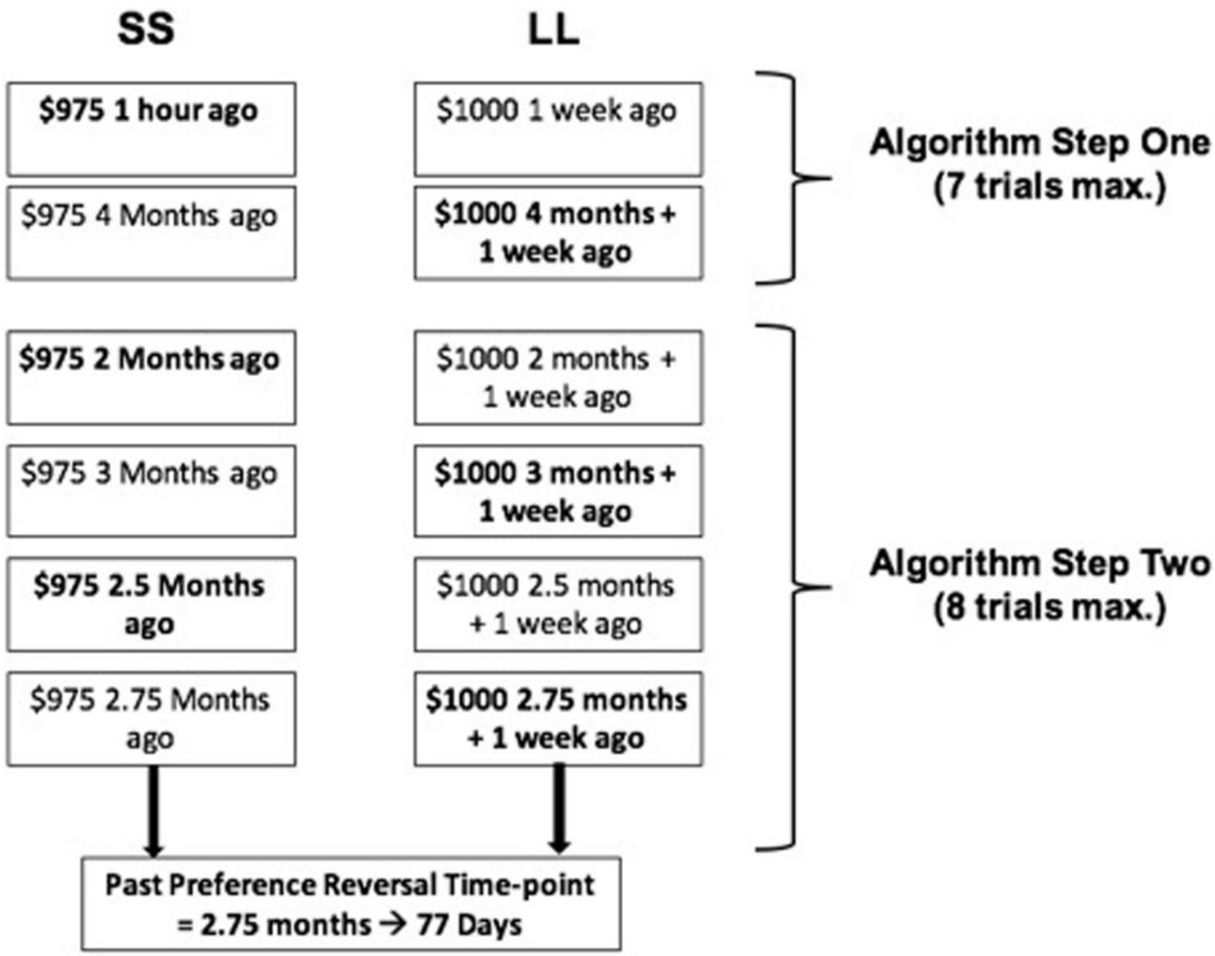

Figure 2.

Schematic of a hypothetical sequence of trials in a past preference reversal assessment; the left and right columns represent the SS and LL alternatives, respectively. Each row represents a single trial, and the bolded alternative represents the preference outcome within the hypothetical sequence. The delay commonly preceding each option changes with each trial within both steps of the algorithm. Here the constant difference interval the SS and LL outcome deliveries was 1 week (7 days), as it was in the study. See section 2.3.2 for additional details.

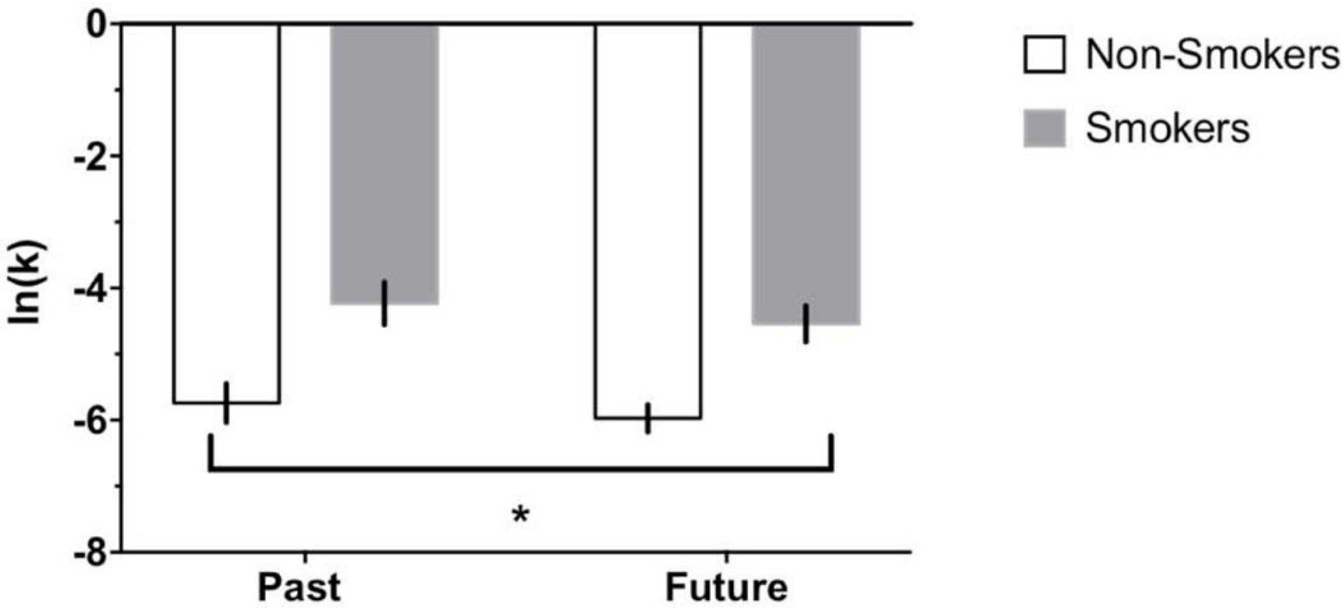

Figure 3.

Obtained discount rates from Eq. 1 (i.e. ln[k]) for past and future assessments in non-smokers and smokers. The asterisk ($p < 0.01$) represents significantly higher past and future discount rates for smokers than non-smokers and that symmetry between past and future ln[k] values held within each group. Vertical bars represent +/−1 SEM.

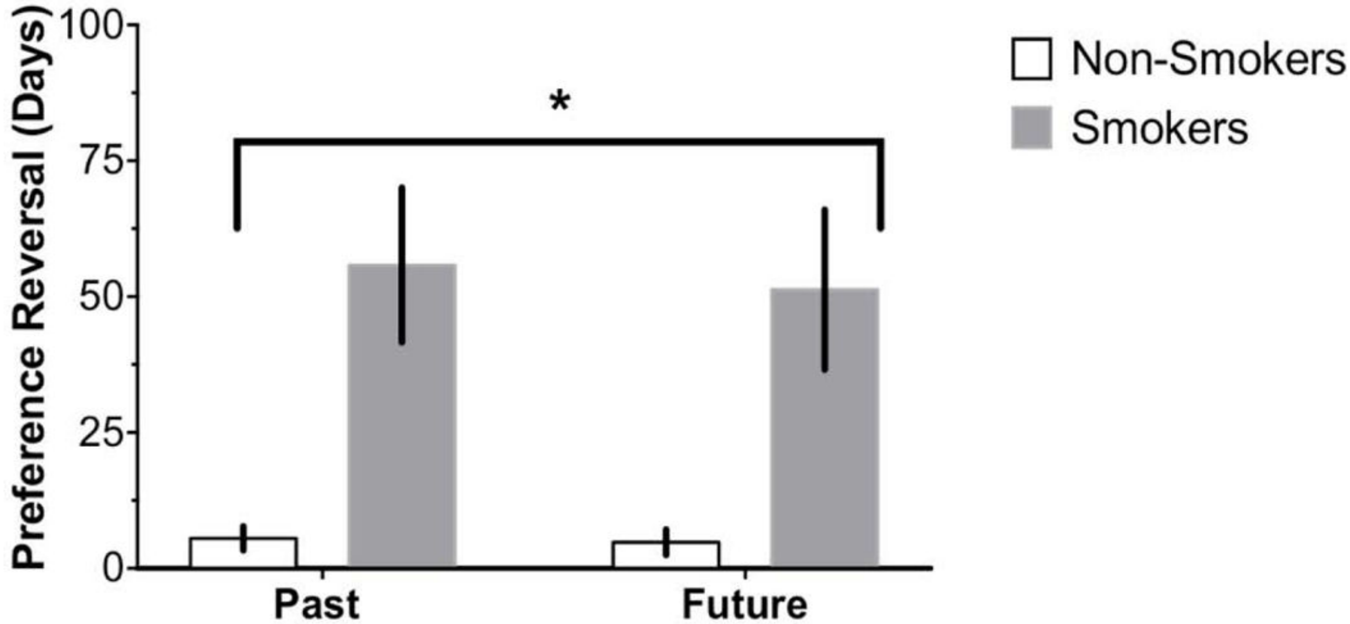

Figure 4.

Obtained time-points of past and future preference reversals for non-smokers and smokers. The asterisk ($p < 0.01$) represents a significantly higher number of days both alternatives needed to be commonly distanced in the past and future for smokers (compared to non-smokers) to exhibit a SS-LL preference reversal. The figure also illustrates symmetry between time-points of past and future preference reversals within each group, as past and future time-points of reversal were not different within smokers or non-smokers. Vertical bars represent +/−1 SEM.

Table 1

Results of the correlational analyses within and across past and future discounting rates (i.e., ln[*k*]) and time-points of past and future preference reversals (i.e., common delay preceding both alternatives required for preference to switch from the SS to LL reward) for non-smokers and smokers, respectively. See section 3.2 for details.

	Non-Smokers			Smokers		
	Past Discounting	**Future Discounting**	**Past Preference Reversal**	**Past Discounting**	**Future Discounting**	**Past Preference Reversal**
Future Discounting	r=0.61,p< 0.01	-	-	r= 0.66, p < 0.01	-	-
Past Preference Reversal	r= 0.56, p < 0.01	-	-	r= 0.42, p < 0.01	-	-
Future Preference Reversal	–	r = 0.53, p < 0.01	r= 0.80, p <0.01	–	r = 0.50, p < 0.01	r= 0.67, p < 0.01