Delay discounting and probability discounting as related to cigarette smoking status in adults

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Abstract

This study examined relations between adult smokers and non-smokers and the devaluation of monetary rewards as a function of delay (delay discounting, DD) or probability (probability discounting, PD). The extent to which individuals discount value, either as a function of a reward being delayed or probabilistic, has been taken to reflect individual differences in impulsivity. Those who discount most are considered most impulsive. Previous research has shown that adult smokers discount the value of delayed rewards more than adult non-smokers. However, in the one published study that examined probability discounting in adult smokers and non-smokers, the smokers did not discount the value of probabilistic rewards more than the non-smoker controls. From this past research, it was hypothesized that measures of delay discounting would differentiate between smokers and non-smokers but that probability discounting would not. Participants were 54 (25 female) adult smokers (n = 25) and non-smokers (n = 29). The smokers all reported smoking at least 20 cigarettes per day, and the non-smokers reported having never smoked. The results indicated that the smokers discounted significantly more than the non-smokers by both delay and probability. Unlike past findings, these results suggest that both delay and probability discounting are related to adult cigarette smoking; however, it also was determined that DD was a significantly stronger predictor of smoking than PD.

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1. Introduction

People will typically discount the value of rewards when the rewards are coupled with a long delay or low probability of occurrence (e.g. Rachlin, 2000). For example, virtually everyone would prefer a larger amount of money over a smaller amount. However, most would at some point shift their preference to the smaller amount of money (thus receiving less total money) if a delay to the larger amount were added and gradually increased. This shift to a smaller amount of money would represent a decrease in subjective value for the larger amount of money as a function of it being delayed. An individual whose preference shifts to smaller rewards due to relatively short delays would be considered more “impulsive” than another individual who shifts preference only after longer delays (e.g. Bickel et al., 1999; Green et al., 1994). In addition to delay discounting (DD), the same generalized predisposition towards discounting has been demonstrated in...
a number of human studies with probabilistic rewards (e.g. Mitchell, 1999; Richards et al., 1999). The current paper is an examination of the relation between both delay and probability discounting (PD) as they relate to cigarette smoking status in adults.

1.1. Delay and probability discounting

Delay discounting as described above is the extent to which an individual discounts the value of a reward (e.g. money, food, weight loss, etc.) as a function of having to wait for it. Procedures for assessing delay discounting in humans, most of which present participants with hypothetical choice options that require them to imagine receiving differing monetary amounts after certain delays, involve determining indifference points between larger reinforcers delivered after different delays and smaller more immediate reinforcers. An indifference point is the point at which two reinforcers (i.e. a large reinforcer delivered after a delay and a smaller more immediate reinforcer) are of equal subjective value for an individual.

Indifference points obtained across a series of different delay lengths can be used to plot discount curves. The curve represents the rate of reinforcer discounting that occurs as a function of increasing the delay to its delivery. Discount curves for delayed reinforcers have been characterized most accurately in humans, rats, and pigeons by Mazur’s (1987) hyperbolic function

\[ V = \frac{A}{1 + kD}, \]

(1)

where \( V \) represents the value of the delayed reinforcer, and \( A \) and \( D \) are the amount of reinforcer and length of delay to its delivery, respectively and \( k \) is a free parameter that indicates the steepness of the discount curve. Higher \( k \) values indicate more rapid discounting, which has been defined to represent greater impulsivity (e.g. Evenden, 1999; Logue, 1988; Monterosso and Ainslie, 1999; Richards et al., 1999). Higher \( k \) values reflect a preference for more immediate smaller reinforcers at the expense of larger but delayed reinforcers.

Similarly, the outcome measure in probability discounting is the extent to which an individual discounts a larger reinforcer as a function of a decreasing probability of its delivery. Indifference points and discount curves can be derived from PD procedures just as they are for DD procedures. The pattern of discounting as a function of probability is best characterized by a hyperbolic model (Rachlin et al., 1991). The hyperbolic discount functions for probability discounting are calculated as follows

\[ V = \frac{A}{(1 + hO)}, \quad O = \left(\frac{1}{p}\right) - 1, \]

(2)

where \( p \) and \( O \) are inversely related. The \( p \) represents the probability of receiving the reinforcer, the \( O \) stands for odds against receiving the reinforcer, and the \( h \) represents the rate of discounting as a function of decreasing probability of receiving the larger reinforcer. Higher \( h \) values represent a more rapid rate of discounting and thus greater impulsivity. The \( h \) value of Eq. (2) is analogous to the \( k \) value of Eq. (1).

Measures of DD and PD are typically correlated with one another (e.g. Mitchell, 1999; Richards et al., 1999); however, correlations between these discounting measures and well recognized self-report personality questionnaires with impulsivity scales are typically low or non-existent (e.g. Crean et al., 2000; Mitchell, 1999). However, relations have been found between excessive alcohol consumption (Vuchinich and Simpson, 1998), opioid dependence (Madden et al., 1997; Petry and Casarella, 1999), and the clinical diagnoses of substance abuse and dependence, borderline personality disorder, and bipolar disorder (Allen et al., 1998; Crean et al., 2000) and higher rates of DD. Similarly, research with adult smokers has shown that those who smoke cigarettes clearly discount money by delay more on average than those who have never smoked or those who have quit smoking (e.g. Bickel et al., 1999). Such findings point to the “real-life” validity of DD as a measure of impulsivity. However, even with the typically observed correlations between DD and PD, the relation between PD and cigarette smoking in adults is less clear, with PD not differentiating between adult smokers and non-smokers in the one published study examining PD and smoking status (Mitchell, 1999). In another study with adolescent participants, PD differentiated between those adolescents who had recently tried smoking versus those who had never tried smoking, with those who had tried smoking being significantly more impulsive. In the same participants, DD did not differentiate between the groups (Reynolds et al., submitted for publication).
1.2. General hypotheses

Given the lack of correspondence between adult and adolescent findings regarding PD and cigarette smoking, and also the lack of corroborating research in the literature examining PD and cigarette smoking in adults, the present study sought to further examine the relation between PD and smoking in adults. Measures of both DD and PD were compared between adult smokers and non-smokers. It was hypothesized that DD would differentiate between these two groups, as it has in other studies with this population (e.g. Bickel et al., 1999; Mitchell, 1999). However, given the lack of observed relation between PD and smoking in adults (Mitchell, 1999), it was hypothesized that PD would not differentiate between smokers and non-smokers, which would be consistent with the earlier finding with adults.

2. Method

2.1. Participants

The participants were 54 (25 females) adults between 19 and 21 years of age ($M = 20.04; S.D. = 0.78$). Twenty-five of the participants (10 females) were regular smokers who reported smoking at least 20 cigarettes a day. The remaining 29 participants (15 females) were non-smokers who reported having never smoked. To biochemically validate the self-reported smoking status, a breath sample was taken to measure level of carbon monoxide (CO). Regular smokers were required to have a score $\geq 9$ to participate (Bedfont Instruments, Micro III, UK). The average CO reading for the regular smoker group was 15.96 (S.D. = 7.53) and was 1.55 (S.D. = 1.12) for the non-smokers.

Participants were recruited from West Virginia University and the surrounding community through advertisements placed in the university newspaper requesting participants who were smoking 20 or more cigarettes a day or who had not smoked at all. Potential participants phoned the laboratory and were screened for participation requirements. Participants were asked if they were currently taking any medications and/or if they had ever been diagnosed with any psychiatric conditions. All participants reported “no” to both questions.

2.2. Procedure

Total participation time for each participant was approximately 2h. Participants in the present study also completed other laboratory tasks related to other research; however, the order of the different tasks completed during participation was counterbalanced in an effort to reduce the influence of any possible carryover effects. Total participation time for the procedure detailed in this paper (computerized measure of DD and PD, CO recording, and three paper and pencil measures of personality) was approximately 45 min.

By appointment, participants reported to the Health Effects Laboratory Division building of the National Institute for Occupational Safety and Health located in Morgantown, WV. The research lab was equipped with eight desktop computers arranged along two opposing walls of a 6.1 m x 5.18 m room. Each computer was on a computer table with 2.13 m high partitions between the different computer work stations so that participants next to each other could not see one another. While using the computers, participants were required to wear headphones, which were intended to reduce auditory distraction. Participation took place with either one or two participants in the lab at one time. When there were two participants in the lab, they were seated on opposite sides of the room and received instructions independently.

Participants first completed informed consent forms, then they gave a breath sample for CO assessment. After the breath sample, participants completed three personality questionnaires (see Section 2.4). Participants then completed the DD/PD task after receiving the following instructions:

You will have the opportunity to choose between different amounts of money available after different delays or with different chances. The task consists of about 80 questions, such as the following: (a) Which would you prefer: $10 in 30 days or $2 now, or (b) Which would you prefer: $5 for sure or $10 with a 25% chance? At the end of the session, one of the choices you made will be selected at random and you will receive whatever you chose in response to that question. If on that trial you selected an immediate amount of money, you will receive the money in cash at the end of the session. If you selected delayed money, the money will be placed
in an envelope with your name and mailing address on it, and it will be sent to you when the time has elapsed. If you selected a probabilistic amount, you will draw a token from a bag containing two colors of tokens in the proportion that reflects the probability. For example, if the trial you selected was $10 with a 25% chance, you will draw one token from a bag containing 1 blue token representing “get $10” and 3 red tokens representing “get $0.” You will receive the amount of money indicated by the color of the token immediately in cash.

All of the questions for DD and PD were presented during a single session. The DD and PD questions were intermixed with one another in a random order determined by the computer program.

Following completion of all lab tasks, one of the participants’ responses to the computerized task for DD/PD was selected at random with a random number generator available via the Internet (http://randomizer.org/). As described in the instructions, participants received either immediate or delayed money ranging in amount from $0 to $10 for completing the DD/PD assessment task. Participants received a total payment amount between $20 and $30 dollars for the completion of all tasks—$0 to $10 dollars of which was determined by payment for the DD/PD task.

2.3. Discounting variables

2.3.1. Delay discounting choice task

A computerized procedure developed for the purpose of studying choice behavior was used for assessing DD (see Richards et al., 1999 for a detailed description of the task). The task was used to determine indifference points for five different delay intervals: 1, 2, 30, 180, and 365 days. The program presented a series of questions that asked the participant to decide between $10 to be received after one of the different delay periods or a smaller amount of money (e.g. $2) that could be received immediately. The smaller amount of immediate money was adjusted up or down by the program depending on participant responses to previous questions. Adjustments in amount of immediate money were made in a manner as to narrow the range of values on successive choice trials until an indifference point was arrived at for each of the delay intervals. The indifference points for all five delay periods were used to calculate delay discount curves (i.e. Eq. (1)).

2.3.2. Probability discounting choice task

The same computerized procedure as used for assessing DD was used to assess PD (see Richards et al., 1999). Indifference points were determined for five different probability values: 1.0, 0.9, 0.75, 0.5, and 0.25. Questions for establishing PD required participants to choose between a specified probability of receiving $10 (e.g. 25% chance) or a smaller amount to be received for sure. The smaller amount of certain money was adjusted up and down in amount by the program until an indifference point was arrived at for each of the probabilities—as described above for DD. Indifference point values were used to calculate probability discounting curves (i.e. Eq. (2)).

2.4. Personality questionnaires

2.4.1. Sensation-seeking scale (SSS, from Zuckerman, 1971)

This 63-item questionnaire requires participants to respond either “true” or “false” to the accuracy of different statements as they pertain to the participant. Scores from this questionnaire characterize four different dimensions of sensation-seeking: boredom susceptibility, disinhibition, experience seeking, and thrill and adventure seeking. All of these scales are considered dimensions of impulsivity.

2.4.2. I7 (from Eysenck et al., 1985)

This 54-item questionnaire requires participants to respond either “yes” or “no” to questions about their own behavioral tendencies. The I7 yields three different dimensions: impulsivity, venturesomeness, and empathy. The impulsivity and venturesomeness are both considered different dimensions of impulsivity.

2.4.3. Big Five (from Goldberg, 1990)

This 100-item adjective questionnaire requires participants to mark on an eight-point scale how accurately (from “extremely inaccurate” to “extremely accurate”) an adjective describes them. The Big Five is considered a broad measure of personality intended to characterize the five most basic dimensions of human personality. The five dimensions of the Big
Five are: surgency, agreeableness, conscientiousness, emotional stability, and intellect. The Big Five was included in the present study for the purpose of conducting analyses with personality dimensions beyond the more narrowly defined measures of impulsivity characterized by the other two personality questionnaires.

2.5. Analyses

There were two steps leading to analyses for both DD and PD. In the first step, a non-linear curve-fitting program (Origin 7.5, 2002) was used to determine each participant’s best-fit values of \( k \) and \( h \) from Eqs. (1) and (2), respectively. The second step was to perform a log transformation of the \( k \) and \( h \) values. Log transformed \( k \) and \( h \) values were the different test values for subsequent analyses. A log transformation was required for these data due to their being non-normal (e.g., Mitchell, 1999; Richards et al., 1999). The resulting distribution of scores was normal.

To examine possible gender differences and smoking group differences in DD and PD, a between-subjects two-way analysis of variance (ANOVA) was performed for DD comparisons, and a separate between-subjects two-way ANOVA was performed for PD comparisons. For these analyses, smoking group category was one grouping variable, and gender was a second grouping variable. Partial eta squares (\( \eta^2 \)) were used to determine effect size. Pearson’s correlation coefficients were calculated to test for relations between \( k \) and \( h \) values, age and \( k \) and \( h \) values, the questionnaire scores and \( k \) and \( h \) values, and individual participant CO recordings and \( k \) and \( h \) values. Finally, logistical regressions were performed to explore the predictive power of DD and PD independently and in relation to one another.

3. Results

Figs. 1 and 2 are graphs made from the median indifference point values for DD and PD functions, respectively. Median values were used for Figs. 1 and 2 because the data are necessarily skewed due to limits on potential variability imposed by the nature of the choice options during the task (Myerson and Green, 1995). The \( R^2 \) values for the different discount functions for DD (0.82 for non-smokers and 0.75 for smokers) and PD (0.99 for both) represent the variance accounted for by Eqs. (1) and (2). These data were characterized well by the hyperbolic model. The between-subjects two-way ANOVA with logged \( k \) values showed no significant gender by smoking status interaction, nor was there a significant effect for gender. However, there was a significant main effect for smoking status, \( F(1, 42) = 6.26, P = 0.02 \). The median \( k \) value for the smoking group was 0.066 and for the non-smoking group was 0.015. The effect size for smoking group status on logged \( k \) values was 0.138 (\( \eta^2 \)). The between-subjects two-way ANOVA with logged \( h \) values also showed no significant gender by smoking status interaction or main effect for gender. There was a significant main effect for smoking group status, \( F(1, 47) = 6.37, P = 0.02 \). The median \( h \) value for the smoking group was 1.91 and 1.47 for the non-smoking group. The effect size for smoking group status on \( h \) values was 0.126 (\( \eta^2 \)).

Logged \( k \) and \( h \) values were not significantly correlated, \( r(41) = 0.23, P = 0.07 \) (one-tail test). There were no significant correlations between logged \( k \) or \( h \) values and age or any of the questionnaire variables. However, there was a significant positive correlation between CO level and logged \( k \) values, \( r(41) = 0.39, P < 0.01 \). There was no significant correlation between CO level and logged \( h \) values.

Logistical regressions were performed to determine to what extent DD and PD accounted for variance in smoking group status independently, and also to determine if each was still predictive when the predictive power of the other was controlled for. See Table 1 for the logistical regression table. Both DD and PD

Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Odds ratio (9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Univariate logistical regressions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log ( k )</td>
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<td>6.49*</td>
</tr>
<tr>
<td>Log ( h )</td>
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<td>3.21*</td>
</tr>
<tr>
<td>Multivariate logistical regression</td>
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</tr>
<tr>
<td>Log ( k )</td>
<td></td>
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</tr>
<tr>
<td>Log ( h )</td>
<td></td>
<td>4.07*</td>
</tr>
</tbody>
</table>

DD data from five participants were excluded because the data could not adequately fit to Eq. (1).

* \( P < 0.05 \).
predicted smoking group status when considered individually. However, when considered together in a multivariate logistical regression, PD was not a significant predictor of smoking group status after adjusting for the predictive power of DD. Conversely, DD was still a significant predictor of smoking group status even after adjusting for the predictive power of PD. These data indicate that both DD and PD were predictors of smoking group status, but also that DD represents a more powerful predictor than PD.

4. Discussion

Results of the present study are consistent with past research that has shown DD differentiates between smokers and non-smokers (e.g., Bickel et al., 1999). Also PD differentiated between smokers and non-smokers, which is a new finding. Surprisingly, DD and PD were not significantly correlated with each other or with any of the questionnaire measures of personality. However, past research with these questionnaire measures of personality have shown only modest correlations with DD/PD measures (Richards et al., 1999), and in other instances no correlation with the I or the SSS (Crean et al., 2000; Mitchell, 1999). There were no observed gender or age differences in DD or PD. Again, past research findings have been inconsistent on gender differences in DD, with some studies reporting gender differences (e.g., Kirby and Marakovic, 1996) and others reporting no gender differences (e.g., Logue and Anderson, 2001). With respect to finding no age differences, it is likely that the age variability in the present study was not sufficient to detect age differences. One study has shown age differences in DD (Green et al., 1994), however the age differences for that study were comparatively extreme.

Figs. 1 and 2, suggest that smoking group status had a much larger effect on DD than PD. However, the actual effect sizes did not differ as much between the two procedures as might appear from Figs. 1 and 2 (see Section 3). The similarity in effect sizes between these
two procedures is likely due to $h$ values being considerably less variable than $k$ values (see Section 3). In using effect size as a standard of comparison between these two procedures in this instance, the effect of smoking group status was similar for both DD and PD, though the effect on PD was still somewhat smaller.

The current association between PD and smoking status is inconsistent with the one other study in the literature that included this comparison (Mitchell, 1999). The procedures for assessing DD and PD between the two studies were very similar. However, the present study did differ from the earlier study in two ways. First, the current study required a minimum of 20 cigarettes a day, whereas Mitchell required a minimum of 15 cigarettes a day. It is possible that the 20 cigarettes a day constituted a stronger smoking-group manipulation, which could have been a contributing factor to the difference between the studies. The positive correlation between CO recordings and $k$ values support the notion that heavier smoking may represent a stronger smoking status manipulation. However, one possible limitation of the current study is that the recruitment advertisements stated that the smoker participants were required to smoke at least 20 cigarettes per day. Some prospective participants may have inflated their daily cigarette intake number during screening to be included in the study. The same problem may also exist with the participants of the non-smoker group underestimating their cigarette intake to get into the study.

Second, the current study had 25 participants in the smoking group and 29 participants in the non-smoking group, whereas the earlier study had 20 participants in each group (Mitchell, 1999). Though these group differences between studies are not large, the current study still may have had more power to detect a PD effect.

The finding that DD and PD were not significantly correlated in the present study (though the relation approached significance) is inconsistent with a
number of studies that used very similar versions of the measurement task (e.g. Crean et al., 2000; Mitchell, 1999; Reynolds et al., submitted for publication; Richards et al., 1999). The correlations in these studies, however, ranged from 0.40 (Mitchell) to 0.75 (Richards et al., 1999), which represents substantial between-study variability in DD/PD correlations. The relation between DD and PD may be susceptible to the effects of uncertain and/or unmeasured sample characteristics. For example, there may be age-related differences in perception of delay and probability that could lead to discordance between the measures. For example, the highest correlation cited above (Richards et al., 1999) was with a sample of participants ranging in ages from 21 to 35 years old, whereas the current sample ranged between 19 and 21 years of age. These types of sample differences as they relate to the relation between DD and PD represent empirical questions for future research.

Finally, findings from the current study have implications for a better understanding of the relation between DD and PD as they relate to smoking status. As described above, past research would suggest that DD is related to smoking group status and that PD is not; however, the findings of the present study suggest that this difference is a matter of degree rather than an absolute difference. The logistical regression analyses (see Section 3), suggests that both DD and PD predict smoking status. However, it is also evident that DD is a better predictor of smoking status than PD, and that PD does not contribute a significant amount of predictive power above and beyond DD.

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References


