Published in final edited form as:
Psychopharmacology (Berl). 2012 January ; 219(2): 549–562. doi:10.1007/s00213-011-2521-z.

Differences in delay discounting between smokers and nonsmokers remain when both rewards are delayed

Suzanne H. Mitchell[1,2] and **Vanessa B. Wilson**[1]

[1]Department of Behavioral Neuroscience, Oregon Health & Science University

[2]Department of Psychiatry, Oregon Health & Science University

Abstract

Rationale—When offered a choice between a small monetary reward available immediately (SmallNow) versus a larger reward available after a delay (LargeLater), smokers select the SmallNow alternative more than nonsmokers. That is, smokers discount the value of the LargeLater reward more than nonsmokers.

Objectives—To investigate whether this group difference was due to smokers overweighing the value of rewards available immediately compared with nonsmokers, we examined whether the group difference was also seen when both alternatives were delayed, i.e., when choosing between a SmallSoon reward and a LargeLater reward.

Methods—In Experiment 1, smokers and nonsmokers completed a task including SmallNow versus LargeLater choices and SmallSoon versus LargeLater choices. In Experiment 2, smokers and nonsmokers completed the same task but with hypothetical choices.

Results—Analyses using hyperbolic and double exponential (β-δ) models replicate prior findings that smokers discount the LargeLater reward more than nonsmokers when the smaller reward is available immediately. The smoker-nonsmoker difference was also seen when the smaller reward was slightly delayed, though this effect was primarily driven by heightened discounting in male smokers. However, for potentially real rewards only, this smoker-nonsmoker difference was significantly reduced when the smaller reward was delayed.

Conclusions—The smoker-nonsmoker difference in discounting is not confined to situations involving immediate rewards. Differences associated with potentially real vs. hypothetical rewards and gender underscore the complexity of the smoking-delay discounting relationship.

Keywords

delay discounting; smokers; nonsmokers; gender differences

There have been numerous behavioral studies examining delay discounting in smokers, and virtually all have reported steeper discounting in smokers compared with nonsmokers (e.g., Baker et al. 2003; Bickel et al. 1999; Mitchell 1999; Odum et al. 2002; Ohmura et al. 2005; Reynolds, 2006; Reynolds et al. 2004; but also see Reynolds et al. 2003, who did not find such a relationship in adolescents). Recent data suggest that steeper discount functions are

Corresponding author information: Suzanne H Mitchell, Ph.D. Dept. of Behavioral Neuroscience, L470, Oregon Health & Science University, 3181 SW Sam Jackson Park Road, Portland OR 97239, Tel (503) 494-1650, Fax (503) 494-6877, mitchesu@ohsu.edu.

The authors report no conflicts of interest and did not receive funds from a commercial sponsor.

SHM was primarily responsible for study design, and shared responsibility for data interpretation and manuscript writing with VBW. VBW conducted the experimental procedures and performed the data analyses.

associated with higher smoking rates (Epstein et al. 2003; Heyman & Gibb 2006; Ohmura et al. 2005 but also see Johnson et al. 2007) and earlier ages of smoking initiation (Kollins, 2003). Short-term nicotine deprivation also is associated with increased discounting (Field et al. 2006, but also see Mitchell 2004), though ex-smokers have discount functions that are similar to those of never smokers (Bickel et al. 1999; Odum et al. 2002). Additionally, higher discounting rates are associated with shorter times to relapse in smokers attempting to abstain (Yoon et al. 2007; also Dallery & Raiff 2007 for related findings in smokers not intending to quit). Collectively these data imply that the neurobehavioral processes involved in the choice between rewards available now and those available later differ between smokers and nonsmokers in a way that is intimately related to the processes involved in nicotine addiction. Data relating delay discounting to the abuse of other substances is not as extensive as for cigarette smoking, but also suggests that the neurobehavioral processes associated with these types of decision are related to processes involved in other forms of substance abuse (see Yi et al. 2010 for review).

The majority of studies examining delay discounting, including those unrelated to substance abuse, have compared choices between small rewards available immediately and larger rewards available later (SmallNow versus LargeLater). Few studies have examined choices between a smaller, delayed reward and a larger, more delayed reward and none of these have provided drug use information for participants. Green et al. (2005) reported that discount functions are well described by a hyperbolic function when both rewards are delayed. However, in their study, the gradient of the discounting function was steeper when one of the rewards was available immediately than when both alternatives were delayed (but also see Kable and Glimcher 2010, who did not observe any differences in gradient).

Two studies by McClure et al. (2004, 2007) used functional magnetic imaging techniques to examine the neuroanatomical structures activated when healthy volunteers chose between rewards when one or both of them were delayed. Figner et al. (2010) also examined these decisions following transcranial magnetic stimulation. Unfortunately, behavioral data were not presented in sufficient detail in any of these three articles to permit the discount functions to be compared. However, McClure et al. did show that trials including an immediate alternative were associated with activation of different brain regions (ventral striatum, nucleus accumbens, medial orbitofrontal cortex, medial prefrontal cortex, posterior cingulate cortex) compared with trials in which both alternatives were delayed. Further, these authors presented data suggesting that choice of the SmallNow alternative occurred when the relative activation of the areas associated with the presentation of an immediate alternative outweighed the activation associated with the presentation of delayed alternatives.

Such a finding opens the possibility that differences between drug dependent and nondependent individuals are rooted in differences in the neural processing of the choice alternatives. Thus, the heightened discounting in smokers compared with nonsmokers might reflect disproportional overweighting of the immediate alternative or underweighting of the delayed alternative. If the former is the case, one would predict that the smoker-nonsmoker difference would be observed when one of the alternatives was immediate, and there would be reduced or no discounting differences if both alternatives were delayed. If the latter is the case, one would predict that discounting differences would be seen in all task variants. The current study compared smokers and nonsmokers on a delay discounting task including SmallNow-LargerLater and SmallSoon-LargerLater questions to examine these hypotheses in the context of potentially real rewards (experiment 1) and hypothetical rewards (experiment 2). Notice it is also possible that the smoker-nonsmoker differences are driven by some combination of smokers overweighting immediacy and underweighting rewards

associated with a delay, or vice versa for nonsmokers, but teasing apart these subtleties are beyond the abilities of the current study.

EXPERIMENT 1: DISCOUNTING OF POTENTIALLY REAL REWARDS

Method

Participants—Twenty regular smokers and 20 nonsmokers participated (see Table 1 for demographic characteristics). Regular smokers reported that they smoked an average of at least 15 cigarettes each day for at least the past year while nonsmokers reported that they had smoked fewer than 20 cigarettes in their lifetime.

Participants were recruited from the university and surrounding community via posters, online message boards and word-of-mouth referrals. Participants were initially screened over the phone to ensure that they were a regular smoker or nonsmoker, were age 18 or older, had a high school diploma or equivalent, were not pregnant, were not taking any prescription drugs (except birth control), and were fluent English speakers. Potential participants were invited to the lab to complete a screening session that included a brief health questionnaire, assessment of psychiatric and physical disorders (SCL-90R: Derogatis 1994; health questionnaire), and assessment of use of alcohol (Michigan Alcoholism Screening Test: Selzer 1971), nicotine (Nicotine Tolerance Questionnaire: Heatherton et al. 1991) and other drugs (health questionnaire). Participants also completed a smoking history questionnaire, a general demographics questionnaire, an income questionnaire, and an intellectual ability measure (Shipley Institute of Living Scale [SILS]; Zachary 1991). Exclusion criteria were (1) a history of substance use disorder except nicotine dependence (DSM-IV criteria: American Psychiatric Association, 2000), (2) current physical or psychiatric problems, and (3) a history of serious psychiatric disorder (DSM-IV, Axis 1 disorders). Participants provided a breath sample to verify their smoker status (regular smokers ≥ 10 ppm carbon monoxide and nonsmokers ≤ 5 ppm: BreathCo, Vitalograph, Lenexa, KS). Participants were required to abstain from alcohol and drug use for 12 hours prior to all appointments, except that smokers were asked to smoke as normal and all participants were permitted to consume caffeinated beverages during this period. Potential participants verified alcohol abstinence with a breath sample (breath alcohol level [BAL] <0.003 g/dl: Alco-Sensor III, Intoximeters Inc., St. Louis, MO) and illicit drug abstinence with a urine sample (tested for cocaine, amphetamines, opiates, and methamphetamines: DrugCheck dip test, Abatek Medical, Dover, NH). Females were also screened with test strips for pregnancy (Early-Pregnancy-Tests.com, Bellingham, WA).

The local Institutional Review Board approved the study and participants were treated according to the “Ethical Principles of Psychologists and Code of Conduct” (American Psychological Association, 2002). At the conclusion of the study, participants were debriefed and were compensated $10 for time and travel expenses, which was in addition to money obtained from the discounting task.

Procedure—Eligible participants completed three personality questionnaires to provide trait measures of impulsivity and the delay discounting task (described below) immediately following completion of the in- person screening. Tasks were completed in the order in which they are described below.

Personality questionnaires

Barratt Impulsiveness Scale, version 11 (BIS: Patton et al. 1995): This 30-item questionnaire asked participants how frequently specific statements applied to them: rarely/ never, occasionally, often, almost always/always. Responses are used to generate scores for

three second-order factors: Attentional impulsiveness, Motor impulsiveness, and Non-planning impulsiveness.

Sensation-Seeking Scale, Form V (SSS: Zuckerman et al. 1978): This 40-item questionnaire asked participants to choose which of two statements best applied to them. Scores on this questionnaire create four dimensions of sensation-seeking: boredom susceptibility, disinhibition, experience seeking, and thrill and adventure seeking.

Tridimensional Personality Questionnaire (TPQ: Cloninger 1987): This is a 100-item true-false questionnaire, including a novelty seeking scale with four subscales.

Delay Discounting Task: This computer task presented a series of 210 questions one at a time. For each question, participants indicated which of two alternatives they preferred: the smaller, sooner money (SS) or the larger, later money (LL). The SS was an amount of money ($0.00, $2.50, $5.00, $7.50, $10.00, $12.50, $15.00, $17.50, $20.00, $22.50, $25.00, $27.50, $30.00, $32.50, $35.00, $37.50, $40.00, $42.50, $45.00, $47.50, or $50.00) available after 0 weeks (immediate) or after 12 weeks. The LL amount of money was $50.00 available 2, 4, 8, 14 or 22 weeks after the SS alternative (inter-reward interval). During the task, SS and LL alternatives were selected at random, without replacement, to form the question. Thus, questions were presented in a random order. Participants indicated whether they preferred the SS or LL using the computer mouse (see Appendix for task instructions).

At the end of the experiment, one question was selected at random. The participant received which ever alternative they had chosen for that question (SS or LL). If a delayed alternative had been chosen, participants were contacted two weeks before the waiting period had elapsed and given the choice between having a check for the amount due mailed to them or returning to the laboratory on the due date to pick up their payment. If an immediate alternative had been chosen, participants received the money before they left the laboratory.

Dependent variables: The main dependent variable was the amount of money at which each participant was indifferent between the money available after the shorter delay and the more delayed alternative for each inter-reward interval (2, 4, 8, 14, and 22 weeks), i.e., the indifference point. The indifference point may be viewed as indexing the subjective value of the delayed alternative. This point was operationally defined as being midway between the smallest value of the smaller, sooner alternative accepted and the largest value that was rejected (see Mitchell, 1999 for additional details). Indifference point data for all participants were deemed systematic based on the Johnson and Bickel (2008) criterion 1, which classifies data as non-systematic if an indifference point is greater than the indifference point associated with the adjacent (i.e., shorter) delay by more than 20% of the larger-later reward ($10).

To assess the rate at which the more delayed outcome was discounted we fitted a hyperbolic equation to each participant's indifference points (Mazur, 1987) using the Solver subroutine in Microsoft Excel2007. Points obtained when the sooner reward was available immediately and after 12 weeks were fit to the equation separately:

$$V = \frac{M}{1 + kX} \quad \text{Equ 1}$$

Where V represents the subjective value of the delayed alternative, as indexed by the indifference point. M represents the objective value of the more delayed item ($50). X represents the length of time between the delivery of the earlier and later money (inter-

reward interval). The free parameter, *k*, represents the gradient of the discounting function. For all tasks, larger values indicate lower indifference points and a greater preference for the earlier reward alternative. Because *k* values were not normally distributed, all statistical analyses were carried out on natural log-transformed *k* values, which markedly reduced skewness.

A MatLab routine was also used to obtain maximum likelihood estimates of *k* for the two tasks by fitting the hyperbolic model to data indicating the preferred alternative for each choice question (as opposed to the indifference points as described above). While we would expect these techniques to result in the same *k*-parameter values if data are relatively clean (i.e. there is a single point of switching from the delayed to the immediate option), as far as we are aware, this has not been examined previously. Preliminary data analyses indicated that the *k*-values for the hyperbolic model obtained using this MatLab routine (fit to all 210 choices) did not differ from those obtained fitting to the 10 indifference points. Specifically, correlations between the two methods were highly significant ($\ln(k)_{\text{Smallnow:}}$ $r = 0.998$, $p = 0.000$, $n = 40$; $\ln(k)_{\text{SmallSoon}}$: $r = 0.996$, $p = 0.000$, $n = 40$). Extremely high levels of concordance between the two estimates of *k* were also obtained for Experiment 2 (hypothetical rewards) ($\ln(k)_{\text{Smallnow:}}$ $r = 0.995$, $p = 0.000$, $n = 32$; $\ln(k)_{\text{SmallSoon}}$: $r = 0.994$, $p = 0.000$, $n = 32$).

Primary analyses were carried out using Analysis of Variance techniques (ANOVA). For within subject factors of ANOVAs, Huynh–Feldt corrections were made when there were violations of sphericity and these corrected degrees of freedom are shown in the text. Pearson's product moment correlations were used to assess whether the discounting parameters correlated with personality questionnaires, cigarette use measures and with each other. To explore whether the current study was more concordant with data from Green et al. (2005) who found steeper discounting functions when one reward was delayed or Kable and Glimcher (2010) who found no such difference, we examined whether the *k*-values derived from Equation 1 differed significantly between the SmallNow and the SmallSoon conditions (all of these analyses were carried out on the *k* values fit using the indifference points).

We also examined whether smokers and nonsmokers differed using the "double exponential" β-δ model proposed by McClure et al. (2004, 2007):

$$V(t)=\omega\sum_{\tau=0}^{\infty}\beta^{\tau}u(c_{t+\tau})+(1-\omega)\sum_{\tau=0}^{\infty}\delta^{\tau}u(c_{t+\tau}) \quad \text{Equ 2}$$

(where $\beta < \delta$). Parameters were fit to the model using a MatLab routine that obtained the best fitting values using maximum likelihood estimation. In this model, $V(t)$ is the aggregate of two weighted systems: one less patient (β^{τ}) and one more patient (δ^{τ}). Thus, a value of 1 for either β or δ would suggest that the system did not discount at all. Parameters were then compared using between-groups t-tests.

Results

Demographics and Personality Questionnaires—Table 1 summarizes the participant characteristics. As expected, Groups differed significantly on all smoking-related measures. While groups were not explicitly matched on demographic characteristics, exclusion criteria were such that the resulting groups were not expected to differ substantially. Groups were not significantly different in terms of their age, income, or SILS scores (two-tailed independent sample t-tests or Mann-Whitney U test; all *p*s > 0.05). Also, participants in both groups reported similar levels of current drug use and no participants reported using any drugs, other than nicotine, alcohol, caffeine, and marijuana, within the

preceding 30 days. Tests for group differences in lifetime drug use indicated that significantly more smokers than nonsmokers had used hallucinogens and marijuana (Fisher's exact test, $p = 0.04$ and $\chi^2[1] = 20.42$, $p < 0.001$).

Smokers scored significantly higher than nonsmokers on several of the personality questionnaires (The Motor impulsiveness and Non-planning impulsiveness subscales of the BIS, the Experience seeking subscale of the SSS, and the Novelty Seeking subscale of the TPQ; Table 2). However, none of the personality measures were correlated with either $\ln(k)_{\text{Smallnow}}$ or $\ln(k)_{\text{SmallSoon}}$. Further, for smokers, neither of these discounting parameters was significantly correlated with any of the measures of smoking behavior (BCO, Fagerström score, Amount smoked, Years smoking at current level, Age started; All ps > 0.05), possibly because of the restricted range of smoking characteristics in participants.

Delay Discounting—Smokers discounted delayed rewards systematically in both the SmallNow and the SmallSoon tasks (Figure 1). Indifference points decreased systematically as the inter-reward interval increased (Smokers: SmallNow Task: $F[1.90, 36.13] = 14.04$, $p = 0.000$, SmallSoon Task: $F[1.88, 35.72] = 23.63$, $p = 0.000$) and this relationship was well described by a hyperbolic function for both tasks. Comparing actual choices made to those predicted by the hyperbolic model indicated the prediction of choice behavior was high for both tasks (mean percent [SD] correctly predicted choices: SmallNow Task: 92.24[4.97], SmallSoon Task: 91.57[4.49]) and median R^2 values for the function fit to the SmallNow and SmallSoon indifference data were 0.92 and 0.87 respectively. Indifference points for nonsmokers also decreased systematically as the inter-reward interval increased (SmallNow Task: $F[3.21, 60.98] = 5.036$, $p = 0.003$, SmallSoon Task: $F[1.81, 34.30] = 11.98$, $p = 0.000$; note that while the median indifference points do not appear to decrease systematically in the SmallNow Task depicted in Figure 1, there was a significant linear trend in the mean indifference points for this task, $p = 0.01$). Prediction of choice behavior using the hyperbolic function was also good for the nonsmokers (Mean[SD]: SmallNow Task: 92.76[5.40], SmallSoon Task: 94.67[4.62]). However, median R^2 values were smaller for the nonsmokers than the smokers (SmallNow Task: $R^2 = 0.02$; SmallSoon Task: $R^2 = 0.66$). The smaller R^2 values observed in nonsmokers are not unexpected since R^2 values tend to be positively correlated with degree of discounting, and nonsmokers exhibited very low levels of discounting in the current study, (SmallNow Task R^2-k correlation: $r^2 = 0.40$, $p = 0.000$, SmallSoon Task R^2-k correlation: $r^2 = 0.49$, $p = 0.000$).

The effects of smoking status, time to the small reward, and gender on the natural log transformed discounting rate, $\ln(k)$, were examined with a three-way ANOVA (Group [smoker, nonsmoker] x Delay to small reward [0, 12 weeks] x Gender [male, female]). While the three-way interaction was not significant, all three main effects were significant (Group: $F[1, 36] = 24.57$, $p = 0.000$; Delay: $F[1, 36] = 34.474$, $p = 0.000$; Gender: $F[1, 36] = 5.52$, $p = 0.024$). Thus, smokers discounted delayed rewards more steeply than nonsmokers, discounting was steeper for questions including an immediate alternative than ones in which both rewards were delayed, and males discounted delayed rewards more steeply than female. Interestingly, the interaction between time to the smaller reward and smoking status was significant ($F[1, 36] = 9.07$, $p = .005$, See Figure 2a). Follow up analyses of simple effects indicated that, while the data replicate previous findings showing that smokers discount the delayed reward more than nonsmokers, this group difference was seen to a significantly lesser degree for the SmallSoon versus LargeLater choices ($t[38] = -3.35$, $p = 0.001$). Finally, there was also a significant interaction between gender and smoking status ($F[1, 36] = 5.02$, $p = 0.031$, see Figure 2b). Follow up analyses indicated that, for smokers only, males discounted the delayed reward more than females (Smokers: SmallNow: $t[18] = 2.97$, $p = 0.008$, SmallSoon: $t[18] = 2.55$, $p = 0.020$; Nonsmokers: SmallNow: $t[18] = -0.21$, $p = 0.835$, SmallSoon: $t[18] = 0.42$, $p = 0.683$).

To examine how well the discounting parameter *k* estimated by the SmallNow fit could predict the observed indifference points for the SmallSoon discounting curve, each individual's *k* values were inserted into Equ 1 for each participant. These predicted points were compared to the observed points using an ANOVA with inter-reward interval (IRI: 2, 4, 8, 14, or 22 weeks) and set (predicted, observed) as within-subject factors and gender and smoking status as between-subject factors (see Figure 3). None of the 3- or 4-way interactions were significant, however several of the 2-way interactions were. A significant interaction between set and smoking status ($F[1, 36] = 11.927$, $p = 0.001$) indicated that, for smokers, the predicted values were significantly lower than the observed values of the SmallSoon curve, but this was not the case for nonsmokers. Of less interest, the interaction between IRI and smoking status was also significant ($F[1.59, 57.05] = 4.77$, $p = 0.018$), reflecting nonsmokers' shallower observed and predicted discounting curves.

Preliminary ANOVAs to examine gender effects on β and δ revealed no main effect of gender nor interactions, so simple comparisons of smoker and nonsmoker groups are reported. T-tests examining the effects of smoking status on β and δ revealed that only δ was related to smoking status. Specifically, δ was significantly higher in nonsmokers than smokers (Mean[SD]: Smokers: 0.927[0.114]; Nonsmokers: 0.988[.017]; $t[19.867] = 2.365$, $p = 0.028$), while β did not differ (Mean[SD]: Smokers: 0.275[0.306]; Nonsmokers: 0.283[.395]; $t[38] = 0.064$, $p = 0.949$). In addition, a paired *t*-test indicated that the hyperbolic model and β-δ both performed well in prediction of choice behavior (Mean percent [SD] correctly predicted choices: Hyperbolic: 92.81[4.22]; β-δ: 93.33[4.32]; $t[39] = 1.066$, $p = 0.293$).

EXPERIMENT 2: DISCOUNTING OF HYPOTHETICAL REWARDS

Method

Participants—Sixteen regular smokers and 16 nonsmokers participated (see Table 3 for demographic characteristics). As in Experiment 1, regular smokers reported that they smoked an average of at least 15 cigarettes each day for at least the past year while nonsmokers reported that they had smoked fewer than 20 cigarettes in their lifetime. Recruitment and screening methods were identical to those used in Experiment 1.

As in Experiment 1, the local Institutional Review Board approved the study and participants were treated according to the "Ethical Principles of Psychologists and Code of Conduct" (American Psychological Association, 2002). At the conclusion of the study, participants were debriefed and were compensated $10 for time and travel expenses.

Procedure—Eligible participants completed the same three personality questionnaires and delay discounting task as in Experiment 1. However, all choices made in the delay discounting task were hypothetical and the task instructions were modified to reflect this (see Appendix). Participants were compensated an additional $50, paid at the end of the study, for completing the protocol. Thus, comparable amounts were earned by participants in the two studies.

The data analysis pathway was essentially the same as that for Experiment 1. Indifference points were calculated for each of the delays/inter-reward intervals. The hyperbolic model was fit to each participant's indifference points to determine the discounting gradients. Analyses were performed on natural log-transformed *k* values. The hyperbolic and β- δ models were fit to the choice data using MatLab routines.

Results

Demographics and Personality Questionnaires—Table 3 summarizes the participant characteristics. Characteristics were highly similar to those of participants in Experiment 1 (though none of the same individuals participated in both studies). As required by the experimental protocol, groups differed significantly on smoking-related measures. Groups did not differ significantly in age, income, or SILS scores (two-tailed independent sample t-tests or Mann-Whitney U test; all ps > 0.05). Participants in both groups reported similar levels of current drug use and no participants reported using any drugs, other than nicotine, alcohol, caffeine, and marijuana, within the preceding 30 days. Tests for group differences in lifetime drug use indicated that significantly more smokers had used stimulants and marijuana ($\chi^2[1] = 6.79$, $p < 0.009$ and $\chi^2[1] = 8.53$, $p < 0.003$).

Smokers scored significantly higher than nonsmokers on the same subscales of the personality questionnaires as in Experiment 1 (see Table 4). Again, none of the personality measures were correlated with the discounting parameters for either the SmallNow or SmallSoon tasks, and neither of the discounting parameters were significantly correlated with any of the measures of smoking behavior (BCO, Fagerström score, Amount smoked, Years smoking at current level, Age started; all ps > 0.05).

Delay Discounting—As in Experiment 1, smokers discounted delayed rewards systematically in both the SmallNow and the SmallSoon tasks (Figure 4). Indifference points decreased systematically as the inter-reward interval increased (Smokers: SmallNow Task: $F[3.07, 46.09] = 18.90$, $p = 0.000$, SmallSoon Task: $F[2.56, 38.35] = 28.77$, $p = 0.000$) and this relationship was well described by a hyperbolic function for both tasks (mean percent [SD] correctly predicted choices: SmallNow Task: 89.52[5.66], SmallSoon Task: 90.245[6.48]; median R^2 values: 0.81 and 0.78 for the SmallNow and SmallSoon tasks respectively). Indifference points for nonsmokers also decreased systematically as the inter-reward interval increased (SmallNow Task: $F[2.54, 38.10] = 11.818$, $p = 0.000$, SmallSoon Task: $F[2.12, 1.81] = 8.63$, $p = 0.001$). Accuracy of choice prediction was also high for nonsmokers (SmallNow Task: 91.90[4.64], SmallSoon Task: 93.81[3.44]). As in Experiment 1, median R^2 values were smaller for the nonsmokers than the smokers (SmallNow Task: $R^2 = 0.44$; SmallSoon Task: $R^2 = 0.47$).

The effects of smoking status, time to the small reward, and gender on discounting rate, k, were examined with a three-way ANOVA (Group [smoker, nonsmoker] x Delay to small reward [0, 12 weeks] x Gender [male, female]). As in Experiment 1, while the three-way interaction was not significant, the main effects of group and delay were significant (Group: $F[1, 28] = 10.81$, $p = 0.003$; Delay: $F[1, 28] = 24.15$, $p = 0.000$). That is, smokers discounted more steeply than nonsmokers, and discounting was steeper when questions included an immediate alternative. Unlike Experiment 1, there was no main effect of Gender ($F[1, 28] = 0.87$, $p = 0.359$), nor interactions with gender, and the interaction between time to the smaller reward and smoking status was not significant ($F[1, 28] = 0.24$, $p = 0.625$, see Figure 5a) indicating that the smoker-nonsmoker difference was expressed similarly for questions with an immediate alternative and for questions where both rewards were delayed.

As in Experiment 1, we compared the indifference points for the SmallSoon discounting curve to those predicted using the discounting parameter k estimated by the SmallNow fit (see Figure 6). As in Experiment 1, the interaction between IRI and smoking status was significant ($F[1.89, 52.84] = 6.16$, $p = 0.005$), reflecting nonsmokers' shallower observed and predicted discounting curves. However, unlike Experiment 1, where only smokers exhibited lower observed than predicted indifference points, there was no significant interaction between smoker status and set in this study. That is, both smokers and nonsmokers exhibited similar degrees of less steep discounting in the SmallSoon curve than

predicted. Further, for both smokers and nonsmokers, the interaction between IRI (2, 4, 8, 14, 22 weeks) and set (predicted, observed) was significant ($F[2.77, 77.66] = 5.88$, $p = 0.002$) and post-hoc Tukey tests (with smokers and non-smokers collapsed) indicated that the predicted points were significantly lower than the observed points at all levels of IRI (p's < 0.05), however the difference decreased as the IRI increased.

As in Experiment 1, δ was significantly higher in nonsmokers than smokers (Mean[SD]: Smokers: 0.966[0.030]; Nonsmokers: 0.988[.014]; $t[30] = 2.730$, $p = 0.011$), while β did not differ (Mean[SD]: Smokers: 0.314[0.325]; Nonsmokers: 0.432 [.394]; $t[30] = 0.923$, $p = 0.363$). In addition, a paired t-test indicated that, while the hyperbolic model and β-δ both performed well in prediction of choice behavior, the β-δ performed slightly better (Mean percent [SD] correctly predicted choices: Hyperbolic: 91.37[4.83]; β-δ: 92.01[4.59]; $t[31] = 2.748$, $p = 0.010$).

Discussion

Our study replicated prior data showing that smokers discounted delayed rewards to a greater degree than nonsmokers (e.g., Bickel et al. 1999; Mitchell 1999). However, our study extends these findings by demonstrating in two independent studies that the heightened discounting of delayed rewards by smokers compared with nonsmokers is not confined to situations in which one reward is available immediately. This finding has important theoretical ramifications as it indicates that the difference in discounting between the groups is not solely driven by a difference in response to immediate rewards.

While discounting was observed when both rewards were delayed, the extent to which smokers and nonsmokers discounted the delayed rewards was not accounted for entirely by the inter-reward interval. This was demonstrated by data showing that, although the inter-reward intervals were the same, discounting was less than when one reward was immediate than when both rewards were delayed for smokers and nonsmokers (Figures 1 and 4). It was also shown by our inability to predict the indifference points for individuals when both rewards were delayed from the discount function obtained when one reward was immediate (Figures 3 and 6). This finding, that the effects of delay on the subjective value of rewards is more profound when one reward is immediate, is consistent with results reported by Green et al. (2005), but not with those reported by Kable and Glimcher (2010).

While these results are concordant with Green et al., the reason for the discrepancy with Kable & Glimcher's results is not immediately apparent, although there are numerous procedural and analytic differences that may be responsible. As pointed out by Green et al. (2005) decreased discounting when both rewards are delayed, relative to when one is immediate, implies that participants may be making decisions using one of two techniques: (1) by converting each alternative to its present value then selecting the item with the highest value ("*present-value comparison hypothesis*") or (2) by factoring in the delay to the SmallSoon reward using some type of weighting function ("*common-aspect attenuation hypothesis*"). Testing these hypotheses requires the estimation of the discounting rate for both the smaller delayed reward and the larger delayed reward. However, the current study design (which included a varying smaller, sooner reward) does not allow the estimation of the discounting rate for the smaller delayed reward. Green et al. were able to avoid this problem by using very large amounts of money (this relies on the assumption that the relationship between magnitude and discounting rate diminishes at very large amounts). Based on their results they determined that the most likely hypothesis to explain discounting behavior when choices are between two delayed rewards was the common-aspect attenuation hypothesis.

Note that if we assume that the larger, more delayed reward is discounted at the same rate as the smaller, less delayed reward, the following model may also be fit:

$$\frac{V}{1+k(d_s)}=\frac{M}{1+k(d_s+X)} \quad \text{Equ 3}$$

Where d_s is the delay to the smaller, sooner reward. This model reduces to Equ 1 when only one reward is delayed. When this model was fit to the data obtained when both rewards are delayed, it did not alter the pattern of results, however a large number of subjects exhibited data that would not converge to this model [potentially real task: 10/40 (9 smokers), hypothetical task: 5/32 (5 smokers)] and convergence appeared related to the steepness of the discounting function. For the remaining subjects the *k*-values derived using this model were very similar to those obtained using the alternative model ($R^2 \geq 0.94$ for each experiment).

The analyses associated with predicting the SmallSoon task indifference points revealed an interesting difference between Experiments 1 and 2. When rewards were hypothetical (Experiment 2), smokers and nonsmokers did not differ in the degree to which the indifference points were underestimated by the SmallNow discounting parameter fits. In contrast, when rewards were potentially real, only smokers' indifference points were underestimated. Nonsmokers' indifference points did not differ from those predicted based on discounting on the SmallNow task. Additionally, a between-groups analysis on the discounting parameters did not reveal an overall difference between the potentially real and hypothetical rewards. Previous studies examining whether discount curves differ systematically when rewards are real or hypothetical have not indicated that there is an effect of reward type (e.g., Bickel et al. 2009; Johnson and Bickel, 2002; Madden et al. 2003, 2004; but also see Scheres et al. 2010). However these studies did not examine tasks in which both rewards were delayed and so it is possible the concordance in decision making between real and hypothetical rewards is confined to scenarios when decisions are simpler because one dimension includes a zero value. Building from ideas about different strategies that might be employed when both rewards are delayed (Green et al. 2005), it may be that smokers used a similar strategy, in which the shorter delay contributes to the value of the SmallSoon alternative, when rewards were potentially real and when they were hypothetical. In contrast, nonsmokers appeared to consider the length of the short delay and the difference between delays when rewards were hypothetical and to focus solely on the difference between delays when rewards were potentially real, that is, their decision strategy varied according to reward type. While speculative, it may be that the reduced cognitive flexibility in smokers observed in this study reflects a reduced level of cognitive flexibility in heavy smokers (Nesic et al. 2011); however, data relating smoking to cognitive flexibility is complex and interactions with the presence of other psychopathologies and genotype are often reported (e.g., Lawton-Craddock et al. 2003; Mooney et al. 2011; Zhang et al. 2010). An alternative explanation is that nicotine enhances the value of hypothetical rewards in the same way that it enhances the value of conditioned reinforcers in animal paradigms (e.g., Chaudhri et al. 2006; Donny et al. 2003), thereby causing the hypothetical rewards to be treated similarly to potentially real rewards. Both of these explanations can be examined in future studies.

The two tasks were also associated with a different profile of gender effects. In Experiment 1, potentially real rewards were associated with steeper discounting in males than females, and discounting in male smokers being substantially higher than that of female smokers, who resembled nonsmokers of each gender (Figure 2). No such effect was seen in Experiment 2. It is possible that this difference may be attributable to differences in smoking

profiles or recreational drug use between males and females in the two experiments. However, males and females did not differ in amount smoked or Fagerström scores in either of the two experiments (females did begin smoking at a significantly younger age than males in the potentially real condition only). Future studies considering additional measures of smoking behavior may be needed. Additionally, two-way ANOVAs (Experiment x Gender) separated by smoking status revealed no main effects or interactions on any of the continuous demographic variables, except that there was a main effect of Gender on the amount of alcohol consumed for each group. Similarly, logistic regression analyses with experiment and gender entered as predictors showed no significant effects, except that for never-smokers only, lifetime marijuana use was greater in the Experiment 2 than Experiment 1. Gender differences in delay discounting have been reported previously in some studies (e.g., Jones et al. 2009; Mitchell 2003; Petry et al. 2002; Reynolds et al. 2007) but not in other studies (e.g., Epstein et al. 2003). Often gender effects are not examined, and future research delineating the conditions under which gender differences are seen would be useful. The real versus hypothetical nature of the tasks would not appear to be an explanatory variable in these differences reported in the existing literature. However, in light of these differences between the two samples described above, it is not possible to determine the exact source of the effect and future research is required on this issue.

A novel feature of the current study was the examination of β and δ values. Recently, there has been interest in conceptualizing delay discounting as the functional outcome of the action of two processes: β reflecting an impulsive component focused on the immediate or earliest reward available and δ reflecting the action of more self-controlled executive processes (e.g., Bickel et al. 2010; Laibson 1997; McClure et al. 2004, 2007). One might predict that smokers would exhibit larger β values than nonsmokers, as smokers are often viewed as more impulsive; a view that can be seen in even the most cursory glance at published research article titles. Further, the majority of studies using personality questionnaires designed to assess impulsivity and closely related constructs report that smokers are more impulsive (e.g., Mitchell 1999; Reynolds et al. 2007; and data from each experiment in the current study). However, β values did not differ between smokers and nonsmokers in either experiment (indicating that smokers do not overweight immediate outcomes exclusively), rather smokers exhibited lower δ values. This would suggest that smokers are characterized by lower executive functioning, as it related to decision making, than nonsmokers (Dinn et al. 2004 provide some evidence supporting this contention). The current study did not provide evidence addressing this issue but our ability to do so may have been limited by the education requirements of the recruitment procedures (participants had to have at least graduated from high school). Such executive function deficits would be in general accord with a recent study by Warren Bickel's group in which stimulant users received training in working memory tasks (a prototypical executive function) and their subsequent levels of delay discounting became more shallow (Bickel et al. 2011). However, it is unclear what precisely constitutes the executive functions that contribute to the δ process, as this was initially defined in terms of brain areas activated when participants were faced with choices between a SmallSoon and a LargeLater reward compared with any other activities in the scanner (ventrolateral prefrontal cortex [PFC], dorsolateral PFC, right lateral OFC, and posterior parietal cortex; McClure et al. 2004, 2007). Additional research is needed to replicate the smoker-nonsmoker difference observed here and to delineate precisely what processes are associated with differences in δ or β. It is also intriguing that the hyperbolic and the β-δ models performed similarly well for potentially real rewards, with a slight advantage for the β-δ model for hypothetical rewards. This finding calls out for replication and extension to other populations of substance users.

Acknowledgments

This research was supported by R01 DA015543 (SHM) and R03 DA024195 (SHM).

The authors would like to thank Dr Sam McClure for providing the MatLab script used to derive the β and δ values for the double exponential model, Dr Rick Bevins for helpful discussion about the effects of nicotine and Stacy Legg for assistance conducting the experimental visits.

References

American Psychiatric Association. Diagnostic and statistical manual of mental disorder. 4. Washington, D.C: Author; 2000. Revised

American Psychological Association. Ethical principles of psychologists and code of conduct. Washington, D.C: Author; 2002.

Baker F, Johnson MW, Bickel WK. Delay discounting in current and never-before cigarette smokers: Similarities and differences across commodity, sign, and magnitude. J of Abnorm Psychol. 2003; 112:382–392. [PubMed: 12943017]

Bickel WK, Odum AL, Madden GJ. Impulsivity and cigarette smoking: Delay discounting in current, never, and ex-smokers. Psychopharmacol. 1999; 146:447–454.

Bickel WK, Pitcock JA, Yi R, Angtuaco EJ. Congruence of BOLD response across intertemporal choice conditions: Fictive and real money gains and losses. J Neurosci. 2009; 29:8839–8846. [PubMed: 19587291]

Bickel WK, Yi R, Mueller ET, Jones BA, Christensen DR. The behavioral economics of drug dependence: Towards the consilience of economics and behavioral neuroscience. Curr Top Behav Neurosci. 2010; 3:319–41. [PubMed: 21161759]

Bickel WK, Yi R, Landes RD, Hill PF, Baxter C. Remember the future: Working memory training decreases delay discounting among stimulant addicts. Biol Psychiatry. 2011; 69:260–5. [PubMed: 20965498]

Chaudhri N, Caggiula AR, Donny EC, Booth S, Gharib M, Craven L, et al. Operant responding for conditioned and unconditioned reinforcers in rats is differentially enhanced by the primary reinforcing and reinforcement-enhancing effects of nicotine. Psychopharmacol. 2006; 189:27–36.

Cloninger CR. A systematic method for clinical description and classification of personality variants. A proposal. Arch Gen Psychiatry. 1987; 44:573–588. [PubMed: 3579504]

Dallery J, Raiff BR. Delay discounting predicts cigarette smoking in a laboratory model of abstinence reinforcement. Psychopharmacol. 2007; 190:485–96.

Derogatis, LR. SCL-90-R: Administration, scoring, and procedures manual. 3. Minneapolis, MN: National Computer Systems Inc; 1994.

Dinn WM, Aycicegi A, Harris CL. Cigarette smoking in a student sample: Neurocognitive and clinical correlates. Addictive Behav. 2004; 29:107–126.

Donny EC, Chaudhri N, Caggiula AR, Evans-Martin FF, Booth S, Gharib MA, et al. Operant responding for a visual reinforcer in rats is enhanced by noncontingent nicotine: Implications for nicotine self-administration and reinforcement. Psychopharmacol. 2003; 169:68–76.

Epstein LH, Richards JB, Saad FG, Paluch RA, Roemmich JN, Lerman C. Comparison between two measures of delay discounting in smokers. Exp Clin Psychopharmacol. 2003; 11:131–138. [PubMed: 12755457]

Field M, Santarcangelo M, Sumnall H, Goudie A, Cole J. Delay discounting and the behavioural economics of cigarette purchases in smokers: The effects of nicotine deprivation. Psychopharmacol (Berl). 2006; 186:255–263.

Figner B, Knoch D, Johnson EJ, Krosch AR, Lisanby SH, Fehr E, et al. Lateral prefrontal cortex and self-control in intertemporal choice. Nat Neurosci. 2010; 13:538–539. [PubMed: 20348919]

Green L, Myerson J, Macaux EW. Temporal discounting when the choice is between two delayed rewards. J Exp Psychol Learn Mem Cogn. 2005; 31:1121–1133. [PubMed: 16248754]

Heatherton TF, Kozlowski LT, Frecker RC, Fagerström KO. The Fagerström Test for Nicotine Dependence: A revision of the Fagerström Tolerance Questionnaire. Br J Addict. 1991; 86:1119–1127. [PubMed: 1932883]

Heyman GM, Gibb S. Delay discounting in college cigarette chippers. Behav Pharmacol. 2006; 17:660–679.

Johnson MW, Bickel WK. Within-subject comparison of real and hypothetical money rewards in delay discounting. J Exp Anal of Behav. 2002; 77:129–146. [PubMed: 11936247]

Johnson MW, Bickel WK. An algorithm for identifying nonsystematic data in delay discounting research. Exp Clinical Psychopharmacol. 2008; 16:264–274.

Johnson MW, Bickel WK, Baker F. Moderate drug use and delay discounting: A comparison of heavy, light, and never smokers. Exp Clinical Psychopharmacol. 2007; 15:187–194.

Jones BA, Landes RD, Yi R, Bickel WK. Temporal horizon: Modulation by smoking status and gender. Drug Alcohol Depend. 2009; 104(Suppl 1):S87–93. [PubMed: 19446407]

Kable JW, Glimcher PW. The neural correlates of subjective value during intertemporal choice. Nature Neurosci. 2007; 10:1625–1633. [PubMed: 17982449]

Kollins SH. Delay discounting is associated with substance use in college students. Addict Behav. 2003; 28:1167–1173. [PubMed: 12834659]

Laibson D. Golden Eggs and Hyperbolic Discounting. Q J Econ. 1997; 112:443–477.

Lawton-Craddock A, Nixon SJ, Tivis R. Cognitive efficiency in stimulant abusers with and without alcohol dependence. Alcohol Clin Exp Res. 2003; 27:457–46. [PubMed: 12658111]

Madden GJ, Begotka AM, Raiff BR, Kastern LL. Delay discounting of real and hypothetical rewards. Exp Clin Psychopharm. 2003; 11:139–145.

Madden GJ, Raiff BR, Lagorio CH, Begotka AM, Mueller AM, Hehli DJ, et al. Delay discounting of potentially real and hypothetical rewards: II. Between- and within-subject comparisons. Exp Clin Psychopharm. 2004; 12:251–261.

Mazur, JE. An adjusting procedure for studying delayed reinforcement. In: Commons, ML.; Mazur, JE.; Nevin, JA.; Rachlin, H., editors. The effect of delay and of intervening event on reinforcement value. Quantitative analyses of behavior. Vol. 5. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc; 1987. p. 55-73.

McClure EB, Ericson KM, Laibson DI, Loewenstein G, Cohen JD. Time discounting for primary rewards. J Neurosci. 2007; 27:5796–5804. [PubMed: 17522323]

McClure SM, Laibson DI, Loewenstein G, Cohen JD. Separate neural systems value immediate and delayed monetary rewards. Science. 2004; 306:503–507. [PubMed: 15486304]

Mitchell SH. Measures of impulsivity in cigarette smokers and non-smokers. Psychopharmacol. 1999; 146:455–464.

Mitchell, SH. Discounting the value of commodities according to different types of cost. In: Heather, N.; Vuchinich, RE., editors. Choice, Behavioral Economics and Addiction: Theory, Evidence and Applications. Elsevier; New York: 2003. p. 339-357.

Mitchell SH. Effects of short-term nicotine deprivation on decision-making: Delay, uncertainty and effort discounting. Nicotine Tob Res. 2004; 6:819–828. [PubMed: 15700917]

Mooney ME, Odlaug BL, Kim SW, Grant JE. Cigarette smoking status in pathological gamblers: Association with impulsivity and cognitive flexibility. Drug Alcohol Depend. 2011 Feb 4. [Epub ahead of print].

Nesic J, Rusted J, Duka T, Jackson A. Degree of dependence influences the effect of smoking on cognitive flexibility. Pharmacol Biochem Behav. 2011; 98:376–84. [PubMed: 21281663]

Odum AL, Madden GJ, Bickel WK. Discounting of delayed health gains and losses by current, never- and ex-smokers of cigarettes. Nicotine Tob Res. 2002; 4:295–303. [PubMed: 12215238]

Ohmura Y, Takahashi T, Kitamura N. Discounting delayed and probabilistic monetary gains and losses by smokers of cigarettes. Psychopharmacol. 2005; 182:508–515.

Patton JH, Stanford MS, Barratt ES. Factor structure of the Barratt impulsiveness scale. J Clin Psychol. 1995; 51:768–774. [PubMed: 8778124]

Petry NM, Kirby KN, Kranzler HR. Effects of gender and family history of alcohol dependence on a behavioral task of impulsivity in healthy subjects. J Stud Alcohol. 2002; 63:83–90. [PubMed: 11925063]

Reynolds B. A review of delay-discounting research with humans: Relations to drug use and gambling. Behav Pharmacol. 2006; 17:651–667. [PubMed: 17110792]

Reynolds B, Karraker K, Horn K, Richards JB. Delay and probability discounting as related to different stages of adolescent smoking and non-smoking. Behav Processes. 2003; 64:333–344. [PubMed: 14580702]

Reynolds B, Richards JB, Horn K, Karraker K. Delay discounting and probability discounting as related to cigarette smoking status in adults. Behav Processes. 2004; 65:35–42. [PubMed: 14744545]

Reynolds B, Patak M, Shroff P, Penfold RB, Melanko, Duhig AM. Laboratory and self-report assessments of impulsive behavior in adolescent daily smokers and nonsmokers. Exp Clin Psychopharm. 2007; 15:264–271.

Scheres A, Sumiya M, Thoeny AL. Studying the relation between temporal reward discounting tasks used in populations with ADHD: A factor analysis. Int J Method Psych. 2010; 19:167–176.

Selzer ML. The Michigan alcoholism screening test: The quest for a new diagnostic instrument. Am J Psychiatry. 1971; 127:89–94.

Yi, R.; Mitchell, SH.; Bickel, WK. Delay discounting and substance abuse. In: Madden, GJ.; Bickel, WK., editors. Impulsivity: The Behavioral and Neurological Science of Discounting. American Psychological Association; Washington, DC: 2010. p. 191-212.

Yoon JH, Higgins ST, Heil SH, Sugarbaker RJ, Thomas CS, Badger GJ. Delay discounting predicts postpartum relapse to cigarette smoking among pregnant women. Exp Clinical Psychopharmacol. 2007; 15:176–186.

Zachary, RA. Shipley institute of living scale: Revised manual. Western Psychological Services; Los Angeles: 1991.

Zhang H, Kranzler HR, Poling J, Gelernter J. Variation in the nicotinic acetylcholine receptor gene cluster CHRNA5-CHRNA3-CHRNB4 and its interaction with recent tobacco use influence cognitive flexibility. Neuropsychopharmacol. 2010; 35:2211–24.

Zuckerman M, Eysenck SBG, Eysenck HJ. Sensation seeking in England and America: Cross-cultural, age and sex comparisons. J Consult Clin Psychol. 1978; 46:139–149. [PubMed: 627648]

Appendix – Instructions received by participants

Experiment 1

This task has 210 questions. For each question, you can choose between 2 options by clicking on it using the computer mouse. You can change your selection as often as you like and there is no right or wrong answer - we are interested in your personal preferences. Once you have finally decided which option you prefer you can register your preference and go on to the next question by clicking on the ‘next question’ box.

You will make choices between two amounts of money. One or both of the amounts of money will be available after a delay.

Remember, at the end of the task, one of the questions that you answered will be chosen at random. You should answer all of the questions on the task honestly, because you will actually receive whatever you chose on that question. If you chose ‘money now’ you will receive that amount of money at the end of the task and if you chose ‘money later’ you will actually have to wait before receiving the money.

Please try the demonstration below. When you are ready to begin the task, click on the ‘begin task’ box.

Experiment 2

This task has 210 questions. For each question, you can choose between 2 options by clicking on it using the computer mouse. You can change your selection as often as you like and there is no right or wrong answer - we are interested in your personal preferences. Once

you have finally decided which option you prefer you can register your preference and go on to the next question by clicking on the ‘next question’ box.

You will make choices between two amounts of money. One or both of the amounts of money will be available after a delay. Imagine that the choices you are making are real - that if you choose ‘money now’ you would receive that amount of money at the end of the task and that if you choose ‘money later’ that you would actually have to wait before receiving the money.

Please try the demonstration below. When you are ready to begin the task, click on the ‘begin task’ box.

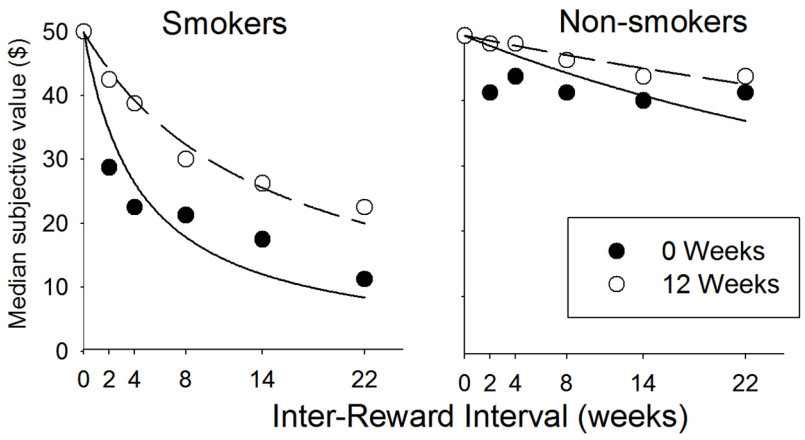

Fig. 1.

Median indifference points for the smokers and nonsmokers on the delay discounting task with real rewards (Experiment 1). Lines represent the hyperbolic functions fitted to these data points for each group (smokers: SmallNow: $k = 0.23$ and SmallSoon: $k = 0.07$; nonsmokers: SmallNow: $k = 0.02$ and SmallSoon: $k = 0.01$). Tests for differences in indifference points at each IRI were significant at all delays for smokers and all but the longest IRI for nonsmokers (Wilcoxon Signed Rank Tests $p \leq 0.05$)

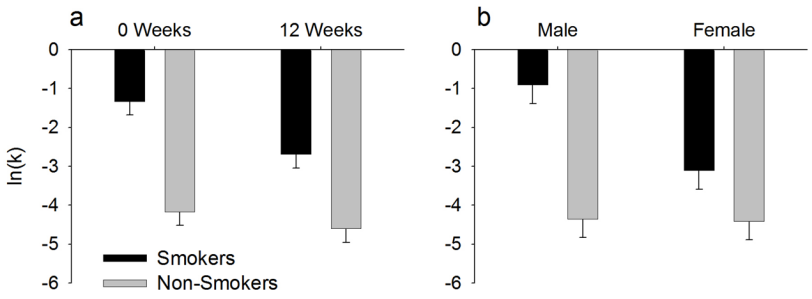

Fig. 2.

a. Average ln(*k*) split by time to the smaller reward and smoking status. b. Average ln(*k*) split by gender and smoking status

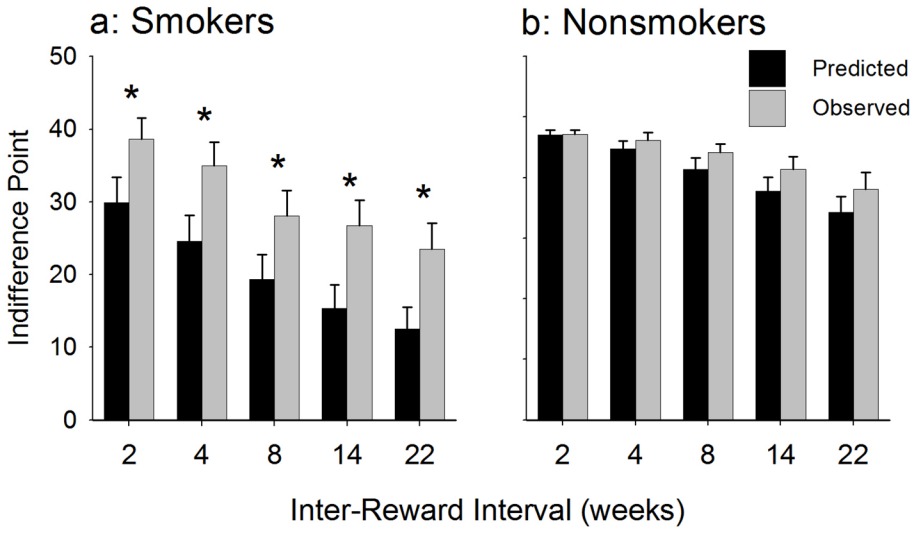

Fig. 3.

Average observed indifference points from SmallSoon task compared to the points predicted using the discounting parameter *k* estimated by the SmallNow fit for smokers (a) and nonsmokers (b). * $p \leq 0.05$ using a paired *t*-test for differences between observed and predicted points with Bonferroni correction for multiple comparisons

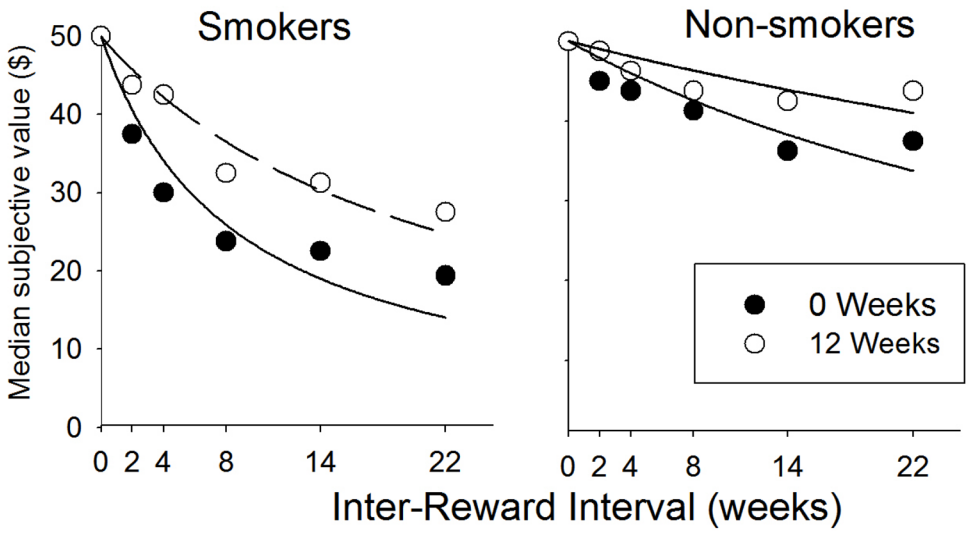

Fig. 4.

Median indifference points for the smokers and nonsmokers on the delay discounting task with hypothetical rewards (Experiment 2). Lines represent the hyperbolic functions fitted to these data points for each group (smokers: SmallNow: $k = 0.12$ and SmallSoon: $k = 0.05$; nonsmokers: SmallNow: $k = 0.02$ and SmallSoon: $k = 0.01$). Tests for differences in indifference points at each IRI showed significant differences at all delays for smokers and all but 8 and 22 week IRIs for nonsmokers (Wilcoxon Signed Rank Tests $p \leq 0.05$)

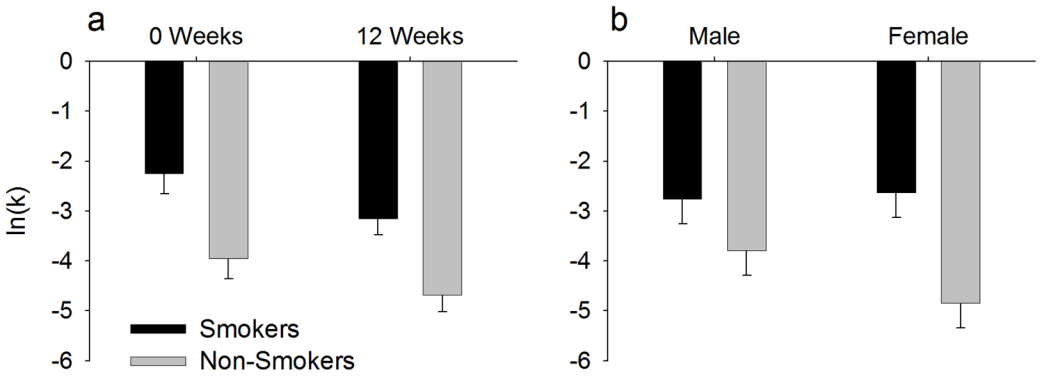

Fig. 5.

a. Average ln(*k*) split by time to the smaller reward and smoking status (SS = Delay to the sooner reward). b. Average ln(*k*) split by gender and smoking status

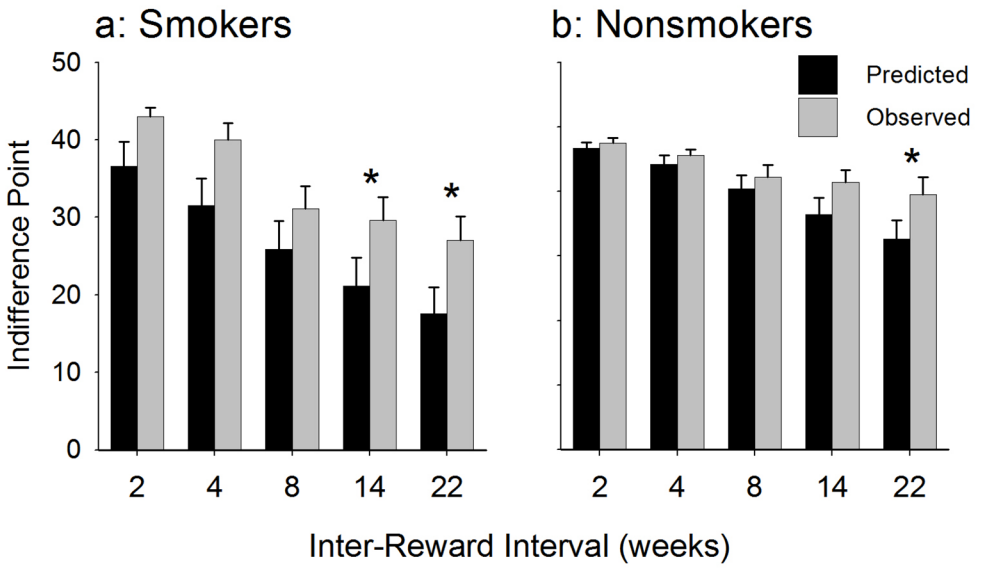

Fig. 6.

Average observed indifference points from SmallSoon task compared to the points predicted using the discounting parameter estimated by the SmallNow fit for smokers (a) and nonsmokers (b). * $p \leq 0.05$ using a paired *t*-test for differences between observed and predicted points with Bonferroni correction for multiple comparisons

Table 1

Experiment 1 (real rewards): Means (and Standard Deviations) of the Demographic Characteristics of Participants

	Regular Smoker				Never Smoker				
Participant Characteristics	**Male**		**Female**		**Male**		**Female**		***p*-value[d]**
N	10		10		10		10		
Age (years) (SD)	34.40	(10.67)	28.80	(6.49)	35.00	(8.97)	29.30	(5.74)	0.839
Shipley Institute of Living Scale									
Vocabulary - Raw Score	32.15	(4.47)	29.75	(3.58)	33.75	(4.47)	31.28	(5.25)	0.283
Abstraction - Raw Score	32.40	(6.38)	30.20	(4.57)	33.40	(3.13)	34.00	(6.25)	0.151
Cigarettes/day	17.75	(2.49)	19.70	(2.54)	0 (0.00)		0 (0.00)		0.000
Fagerström score	4.60	(1.78)	4.80	(1.87)	N/A		N/A		N/A
Age started smoking[a]	15.00	(3.16)	12.5	(2.01)	N/A		N/A		N/A
Years smoking at current level	13.43	(10.16)	9.95	(7.12)	N/A		N/A		N/A
Breath Carbon Monoxide (ppm)	18.90	(6.19)	21.60	(5.25)	2.30	(0.67)	2.10	(0.74)	0.000
Mean recreational (nonprescription) drug use in last 30 days[b]									
Alcohol drinks/week	6.29	(6.89)	2.27	(1.69)	2.31	(3.15)	1.94	(0.83)	0.204
Marijuana joints/week	2.33	(1.53)	3.00	(N/A)	N/A	(N/A)	N/A	(N/A)	N/A
Lifetime recreational drug use (Percent who reported lifetime use)									
Stimulants	40.00%		10.00%		10.00%		0.00%		0.182
Sedatives/tranqilizers	30.00%		10.00%		0.00%		0.00%		0.106
Hallucinogens	50.00%		20.00%		10.00%		0.00%		0.044
Opiates	20.00%		0.00%		0.00%		0.00%		0.487
Marijuana	70.00%		80.00%		10.00%		0.00%		0.000
Other[c]	30.00%		0.00%		0.00%		0.00%		0.231

Notes.

[a] Males and females within each group did not differ significantly on any measures except female smokers started smoking at a younger age than males ($p = .049$)

[b] For those participants that report any use in the last 30 days. Tests for group differences in amount used with non-users included also indicated no significant differences in the amount of drug used ($ps > 0.05$).

[c] Other included inhalants such as nitrous oxide, glue, whippets, and poppers.

[d] Tests for differences between smokers and never smokers. Two-tailed independent sample t-tests for continuous variables, χ^2 tests for lifetime marijuana use, Fisher's Exact Test for all others.

Table 2

Experiment 1 (real rewards): Means (and Standard Deviations) for smokers and nonsmokers on the personality measures

Questionnaire	Smokers		Non-Smokers		*t*-value	*p*-value[a]
BIS (2nd order factors)						
Attentional impulsiveness	13.95	(2.41)	13.70	(2.81)	−0.30	0.765
Motor impulsiveness	23.05	(3.87)	20.00	(3.46)	−2.63	0.012
Non-planning impulsiveness	22.80	(4.96)	19.80	(3.57)	−2.19	0.034
SSS						
Boredom susceptibility	2.45	(1.79)	2.10	(2.10)	−0.57	0.574
Disinhibition	4.55	(2.31)	3.45	(2.31)	−1.51	0.140
Experience seeking	6.80	(1.61)	4.90	(2.29)	−3.03	0.004
Thrill & adventure seeking	7.35	(2.50)	6.20	(3.47)	−1.20	0.237
TPQ						
Novelty seeking	16.45	(3.36)	13.25	(4.54)	−2.53	0.016
Harm avoidance	9.35	(4.17)	8.05	(5.99)	−0.80	0.431
Reward dependence	19.30	(4.39)	19.95	(4.87)	0.44	0.660

[a]Two-tailed independent sample *t*-tests (*df* =38)

Table 3

Experiment 2 (hypothetical rewards): Means (and Standard Deviations) of the Demographic Characteristics of Participants

	Regular Smoker				Never Smoker				
Participant Characteristics	**Male**		**Female**		**Male**		**Female**		***p*-value[d]**
N	8		8		8		8		
Age (years) (SD)	27.50	(5.88)	30.00	(12.01)	28.38	(7.63)	25.88	(6.81)	0.581
Shipley Institute of Living Scale									
Vocabulary - Raw Score	32.38	(2.62)	32.13	(3.04)	34.03	(3.07)	30.75	(6.80)	0.926
Abstraction - Raw Score	34.00	(4.00)	33.75	(4.20)	35.25	(3.01)	35.50	(5.42)	0.310
Cigarettes/day	18.44	(2.97)	20.13	(4.49)	0 (0.00)		0 (0.00)		0.000
Fagerström score	4.50	(1.77)	5.50	(2.00)	N/A		N/A		N/A
Age started smoking	15.88	(2.10)	16.13	(6.47)	N/A		N/A		N/A
Years smoking at current level	5.68	(5.89)	8.79	(9.28)	N/A		N/A		N/A
Breath Carbon Monoxide (ppm)	22.38	(6.30)	26.00	(12.84)	2.00	(0.93)	1.88	(0.64)	0.000
Mean recreational (nonprescription) drug use in last 30 days[a]									
Alcohol drinks/week[b]	13.58	(7.03)	3.43	(3.21)	7.53	(7.73)	1.38	(0.97)	0.190
Marijuana joints/week	1.50	(0.71)	N/A	(N/A)	0.05	(N/A)	N/A	(N/A)	N/A
Lifetime recreational drug use (Percent who reported lifetime use)									
Stimulants	62.50%		50.00%		25.00%		0.00%		0.009
Sedatives/tranqilizers	0.00%		0.00%		25.00%		12.50%		0.226
Hallucinogens	25.00%		37.50%		25.00%		12.50%		0.685
Opiates	0.00%		25.00%		12.50%		0.00%		1.000
Marijuana	87.50%		87.50%		37.50%		37.50%		0.003
Other[c]	12.50%		0.00%		12.50%		12.50%		0.106

Notes.

[a]For those participants that report any use in the last 30 days. Tests for group differences in amount used with non-users included also indicated no significant differences in the amount of drug used (ps > 0.05).

[b]Males and females within each group did not differ significantly on any measures except that male smokers drank significantly more alcohol than females ($p = 0.005$)

[c]Other included inhalants such as nitrous oxide, glue, whippets, and poppers.

[d]Tests for differences between smokers and never smokers. Two-tailed independent sample t-tests for continuous variables, χ^2 tests for lifetime marijuana use, Fisher's Exact Test for all others.

Table 4

Experiment 2 (hypothetical rewards): Means (and Standard Deviations) for smokers and nonsmokers on the personality measures

Questionnaire	Smokers	Non-Smokers	*t*-value	*p*-value[a]
BIS (2nd order factors)				
Attentional impulsiveness	16.25 (4.11)	13.75 (2.52)	−2.08	0.047
Motor impulsiveness	25.25 (4.81)	21.06 (2. 89)	−2.99	0.006
Non-planning impulsiveness	26.19 (4.64)	22.56 (5.05)	−2.12	0.043
SSS				
Boredom susceptibility	3.63 (1.63)	3.06 (1.61)	−0.98	0.334
Disinhibition	5.69 (1.96)	4.00 (3.06)	−1.86	0.074
Experience seeking	7.88 (1.63)	6.44 (2.28)	−2.05	0.049
Thrill & adventure seeking	5.88 (2.85)	6.56 (2.97)	0.67	0.509
TPQ				
Novelty seeking	19.25 (5.35)	14.94 (3.64)	−2.66	0.012
Harm avoidance	10.13 (5.35)	10.50 (6.42)	0.18	0.859
Reward dependence	17.75 (4.52)	18.50 (4.63)	0.46	0.647

[a]Two-tailed independent sample *t*-tests (*df* =30)