Original Investigation

Temporal and Probability Discounting by Cigarette Smokers Following Acute Smoking Abstinence

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Abstract

Introduction: Given the lack of consensus regarding changes in temporal and probability discounting as a function of smoking abstinence in cigarette smokers, the present study comprehensively examined possible changes in these processes following a period of acute smoking abstinence consistent with elevated withdrawal symptoms and craving.

Methods: Computerized temporal and probability discounting assessments were collected from cigarette smokers following normal smoking and 24-hr smoking abstinence, with the order of normal smoking and abstinence sessions counterbalanced across participants. Other conditions included commodity (money and cigarettes), sign (gains and losses), and magnitude ($50 and $1,000).

Results: Twenty four-hour smoking abstinence resulted in a reduction in expired carbon monoxide to near-zero levels and increases in withdrawal and craving. Examination of discounting parameters as a function of smoking abstinence revealed a general pattern of increase in the temporal discounting of monetary gains and losses following abstinence but not in the temporal discounting of cigarettes nor probability discounting of money or cigarettes. Pearson correlations also revealed an expected pattern of significant relationships.

Conclusions: The present study is a comprehensive examination of temporal and probability discounting following smoking abstinence and reveals a generalized change in intertemporal decision making for monetary rewards.

Introduction

Though cigarette smokers are largely aware of the health consequences of smoking (Cummings et al., 2004; Schoenbaum, 1997) and often express a desire to quit, many continue to smoke. Though estimates vary, most reports indicate that more than 70% of current smokers want to quit, but only a very small minority stop smoking. Given the public knowledge about the health consequences of cigarette smoking, individuals who continue to smoke are failing to delay the immediate gratification of smoking (rush of smoking and removal of withdrawal) for the delayed gratification of not smoking (improved health and quality of life). And one possible explanation for why smokers have difficulty delaying gratification is intolerance to delay (Allen, Moeller, Rhoades, & Cherek, 1998) as measured by temporal discounting.

Temporal discounting refers to the decrease in the subjective value of an outcome as delay to the outcome increases; a sum of money delayed by 1 year is subjectively less valuable than the same sum of money available immediately. Temporal discounting has received much recent attention in the area of addiction because drug use and abuse is a classic manifestation of a behavioral pattern that overweighs present outcomes in comparison to delayed ones. And research has confirmed that cigarette smokers (Baker, Johnson, & Bickel, 2003; Bickel, Odum, & Madden, 1999; Mitchell, 1999, 2004; Odum, Madden, & Bickel, 2002; Ohmura, Takahashi, & Kitamura, 2005; Reynolds, Richards, Horn, & Karraker, 2004) and users of other drugs discount delayed rewards more than controls (see Reynolds, 2006; Yi, Mitchell, & Bickel, 2009 for reviews). Importantly, this relative preference for immediacy of outcomes does not appear to be restricted to the drug of choice but applies for other rewards (e.g., money rewards) even when relevant variables (e.g., age, income) are methodologically or statistically controlled. This important distinction suggests that a higher rate of temporal discounting is indicative of a generalized deficit in intertemporal decision making, where present outcomes are globally preferred to delayed outcomes independent of the reward domain (i.e., other than the drug of dependence).

Elevated temporal discounting is particularly problematic because it is associated with higher probabilities of smoking relapse in both laboratory (Dallery & Raiff, 2007; Mueller et al., 2009) and clinical settings (Krishnan-Sarin et al., 2007; MacKillop & Kahler, 2009; Yoon et al., 2007) as well as a failure

to maintain other health-related behaviors (Daugherty & Braise, 2010; Weller, Cook, Avsar, & Cox, 2008).

Temporal Discounting During Smoking Abstinence

Withdrawal and craving following periods of smoking abstinence result in a variety of executive function deficits including working memory (Hirshman, Rhodes, Zinser, & Merritt, 2004; Merritt et al., 2010). While temporal discounting is correlated with working memory (Bickel, Yi, Landes, Hill, & Baxter, 2011; Shamosh et al., 2008) and is a possible surrogate measure of executive functioning (Bickel & Yi, 2008; Olson et al., 2009), few studies have examined temporal discounting during smoking abstinence; we are aware of only two studies that have examined temporal discounting of rewards by smokers during a period of smoking abstinence. In one study, temporal discounting of $10 gains by nicotine-dependent individuals under acute abstinence was examined in a within-subjects procedure (Mitchell, 2004). Discounting rates were determined for smokers under normal smoking patterns (satiated) and following 24-hr smoking and nicotine abstinence. Interestingly, Mitchell (2004) observed no difference in smokers under satiation and abstinence conditions in the discounting of money rewards (single commodity, where choice were between delayed and immediate money) but an increase in cross-commodity discounting (immediate cigarettes vs. delayed money) as a result of smoking abstinence, suggesting a nongeneralized increase in the relative valuation of the abstinent commodity/drug available immediately (namely, cigarettes). In contrast, Field, Santarcangelo, Sumnall, Goudie, and Cole (2006) found that smokers increased their rate of temporal discounting of money rewards following at least 13-hr smoking abstinence compared with normal smoking, suggesting a generalized increase in the valuation of other commodities available immediately (namely, money). Some methodological differences between these studies are noteworthy and provide context for the contrasting results. Namely, Mitchell obtained complete datasets from 11 smokers for $10 money rewards, with the longest delay being 25 years. In contrast, Field et al. obtained complete datasets from 30 participants for £500 money rewards, with the longest delay being 1 year. No previous studies have examined temporal discounting of losses during smoking abstinence—surprising since discounting of negative outcomes may best model the negative reinforcement that occurs when abstinent smokers smoke to avoid or remove withdrawal symptoms.

Probability Discounting

The value of outcomes also decreases as a function of the probability of occurrence: $10 with a .5 probability is worth less than $10 with certainty for most people. Some researchers have proposed that probabilistic events occur with a relative frequency over a series of repeated opportunities and as such, that temporal and probability discounting are conceptually related and possibly a function of the same or very similar underlying process (Green & Myerson, 1996; Prelec & Loewenstein, 1991; Rachlin, Raineri, & Cross, 1991; Stevenson, 1986). Support for this hypothesis has been mixed. The research supporting this hypothesis reveals (a) that the mathematical model that describes temporal discounting also describes probability discounting (Rachlin et al., 1991), (b) rates of temporal and probability discounting are positively correlated (Myerson, Green, Hansen,

Holt, & Estle, 2003; Richards, Zhang, Mitchell, & de Wit, 1999), and (c) that temporal discounting differences observed between smokers and nonsmokers are similarly observed with probability discounting (Mitchell, 2004; Reynolds et al., 2004; Yi, Chase, & Bickel, 2007). The research that does not support the common process hypothesis is based primarily on the different effects of magnitude observed across the types of discounting; temporal discounting decreases and probability discounting increases as the magnitude of the outcome increases (Christensen, Parker, Silbergeld, & Hursh, 1998; Myerson et al., 2003; see an excellent review in Green & Myerson, 2004). To date, this divergence of effects of magnitude has only been observed in normal individuals, and we are not aware of any research that has examined this in drug-dependent individuals. And while Mitchell (2004) previously found no difference in the probability discounting of smokers as a function of smoking abstinence, extrapolating the conflicting results obtained in temporal discounting by smokers in the same study, a replication of this effect appears pertinent. No studies have previously examined probability discounting of losses by smokers during smoking abstinence.

Present Study

Given the importance of generalized changes in intertemporal decision making during smoking abstinence and the current uncertainty on whether possible changes during smoking abstinence are generalized to nondrug rewards, the current study examined temporal and probability discounting of gains and losses during acute smoking abstinence. Furthermore, given the extensive number of discounting assessments collected as part of this study, the present study explored (a) possible relationships between comparable conditions following normal smoking and following acute abstinence and (b) possible relationships between parametric conditions within assessments collected following normal smoking and abstinence (e.g., $50 money gains and $50 cigarette gains, $1,000 money gains and $1,000 money losses).

Method

Participants

Twenty-eight cigarette smokers (eight female) completed all assessments. All participants met at least two of the following three smoking criteria: (a) *DSM-IV* criteria for nicotine dependence, (b) a score of 5 or higher on the Fagerström Tolerance Questionnaire (FTQ; Fagerström & Schneider, 1989), and (c) self-report of smoking 20 or more cigarettes per day for a minimum of 1 year. Smoking status was verified with an expired carbon monoxide (CO) level of at least 12 parts per million (ppm) of expired air (using an EC 50 Micro CO monitor, Bedfont Scientific Ltd, Rochester, UK) during the preliminary session. Participants were at least 18 years old, did not meet dependence criteria for any substance other than nicotine, and did not have any significant medical (e.g., emphysema) or psychiatric (e.g., psychosis) conditions. On average, participants were 40.0 ($SD = 10.0$) years of age, smoked 21.45 ($SD = 9.59$) cigarettes daily, met 4.45 ($SD = 1.12$) *DSM* criteria for nicotine dependence, scored 6.40 ($SD = 1.35$) on the FTQ, exhibited a baseline CO breath sample of 19.40 ($SD = 7.06$) ppm, earned $12,105 ($SD = 12,828$) annual income, and completed 12.81 ($SD = 1.47$) years of education.

Assessments

Temporal Discounting: Hypothetical Monetary Gains and Losses

A personal computer was employed to conduct the discounting procedure. To obtain measures of temporal discounting of hypothetical money gains, a computer program similar to that of Estle, Green, Myerson, & Holt (2006) was employed. Indifference points were obtained for $50 and $1,000 hypothetical gains at each of the following delays: 1 day, 1 week, 1 month, 6 months, 1 year, 5 years, and 10 years. For each trial, two outcomes were presented on the screen. One outcome, listed in a command box on the left side of the screen, was a money gain occurring immediately (the adjusting amount). The phrase in this command box was "Receive $___ right away," where the amount varied according to the program algorithm. The other outcome, listed in a command box on the right side of the screen, was a larger amount of money gain occurring after a specified delay (the standard amount). The phrase in this command box was "Receive $___ after waiting ___," where the amount and delay depended on the specific condition.

The computerized discounting procedure adjusted the outcome available in the left command box (adjusting amount) to determine a single indifference point at each delay. In the first trial, the participant choice between the standard ($50 or $1,000) and an adjusting alternative that was half of the standard amount ($25 or $500). If the participant chose the adjusting alternative, the adjusting amount decreased by half of the value of the adjusting amount; if the participant chose the standard alternative, the adjusting amount increased by half of the value of the adjusting amount. Every successive choice then increased or decreased the adjusting amount by 50% of the previous trial's adjustment. For instance, if a participant chose a $500 immediate gain over a $1,000 1-month delayed gain, the adjusting immediate amount decreased to $250 for the second trial. If a participant chose a $1,000 1-month delayed gain over a $250 immediate gain in the second trial, the adjusting amount increased to $375. The adjusting amount was altered in this manner over six trials at each delay to determine an indifference point.

Measures of hypothetical money losses were obtained using nearly identical procedures with two exceptions; in all other respects, gains and losses were identical, and the same magnitudes and delays were used. First, the word "receive" was replaced with the word "lose" in the command boxes. Second, the algorithm of the discounting procedure adjusted in the opposite direction as that for gains. For instance, if a participant chose a $500 immediate loss over $1,000 1-month delayed loss, the adjusting immediate amount increased to $750 for the second trial. If a participant chose a $1,000 1-month delayed loss over a $750 immediate loss in the second trial, the adjusting amount decreased to $625. The adjusting amount was altered in this manner over six trials at each delay to determine an indifference point.

Temporal Discounting: Hypothetical Cigarette Gains and Losses

Previous research has found that cigarettes are temporally discounted more than comparable money amounts by cigarette smokers. The discounting procedures for cigarettes (employed by Baker et al., 2003) attempted to replicate this finding and to determine the effect of acute withdrawal on discounting of cigarettes. In the discounting of hypothetical cigarette gains and losses conditions, participants chose between gains (or losses) of packs of cigarettes immediately and following a delay. Prior to the procedure, each participant indicated the number of packs of cigarettes equivalent to the two magnitude outcomes ($50 and $1,000). The numbers of packs of cigarettes constituted that participant's standard delayed amounts. "Packs of cigarettes" replaced the money amounts in the command boxes. In all other respects, the procedure and algorithm was identical to that used with hypothetical money.

Probability Discounting: Hypothetical Money Gains and Losses

A procedure similar to that for temporal discounting of hypothetical money gains and losses was used to obtain measures of probability discounting of hypothetical money, with the only difference being that the standard amount was probabilistic instead of delayed. Indifference points were obtained for $50 and $1,000 hypothetical money gains and losses at each of the following percent chances: 95%, 75%, 50%, 25%, 10%, 5%, and 1%. The phrase in the adjusting amount command box was "Receive (or lose) $___ with certainty," while the phrase in the standard amount command box was "Receive (or lose) $___ with a ___% chance."

Probability Discounting: Hypothetical Cigarette Gains and Losses

A procedure similar to that for temporal discounting of hypothetical cigarette gains and losses was used to obtain measures of probability discounting of hypothetical cigarettes, with the only difference being that the standard amount was probabilistic instead of delayed. The employed probabilities of winning were identical to those in the probability discounting of hypothetical money conditions.

Temporal and Probability Discounting: Real Money Gains

In the temporal discounting of real money procedure, indifference points were obtained for $50 real money gains at the following delays: 1day, 1 week, 1 month, and 6 months. The procedure during the experimental session was similar to that for hypothetical gains, but at the end of the session, one of the trials was selected at random, and the participant received the outcome s/he picked for that trial. For instance, if the selected trial offered a choice between $50 in 1 month and $25 immediately, a participant who picked the immediate amount received $25 at the end of the session; one who picked the delayed amount received $50 after 1 month. Differences in the range of delays and available magnitudes with the hypothetical gains conditions are due to practical reasons.

In the probability discounting procedure of real money gains condition, indifference points were obtained for $50 real money gains at the following percentages: 95%, 75%, 50%, and 25%. One of the trials was selected at random at the conclusion of the session, and the participant received the outcome s/he picked for that trial. For instance, if the selected trial offered a choice between receiving $50 with 75% chance and $25 with certainty, a participant who picked the certain amount received $25 at the end of the session. A participant who picked the probabilistic amount blindly picked a marble from a bag of marbles with a 75% chance of a "win" (receiving $50). The number of probabilities is fewer than that for hypothetical money gains in

order to maintain continuity with the temporal discounting of real money gains condition.

Procedures

Participants completed one preliminary and two experimental sessions. During the preliminary session, participants provided expired CO measures to confirm smoking status and completed comprehensive screening procedures. Participants then completed questionnaires unrelated to this study and not reported here, before being scheduled for the first experimental session. Participants attended one session after smoking normally and one session after abstaining from cigarettes for 24 hr.

Twenty-four hours prior to experimental sessions, all participants were contacted to remind them of their scheduled session. At that time, they were told either to continue smoking as usual until the next day's session (normal smoking condition) or to smoke one cigarette immediately and abstain from smoking and other tobacco products thereafter (abstinent). The instruction to smoke one cigarette immediately was to standardize the number of hours since the last cigarette. The literature indicates that 24 hr of abstinence is appropriate for initiating nicotine withdrawal (Henningfield, Cohen, & Pickworth, 1993). Using a semi-random procedure, half of the participants were assigned to the normal smoking condition and the other half in the abstinence condition for session 1. These assignments were reversed for session 2. Sessions 1 and 2 were separated by approximately 1 week.

Upon arrival for experimental sessions, all participants were queried on the number of cigarettes smoked in the last 24 hr. Expired CO measures were collected to confirm the self-report. Participants in the normal smoking condition were required to self-report smoking in their usual manner, verified by a CO measure that was at least 75% of the CO measure obtained in the preliminary session. Participants in the abstinence condition were required to self-report 24-hr tobacco abstinence, confirmed by a CO measure of 4 ppm or less (24-hr cigarette abstinence should result in the near absence of expired CO; Leitch, Harkawat, Askew, Masel, & Hendrick, 2005). Participants in the abstinence condition that did not fulfill all criteria for abstinence were rescheduled for another day. Measures from the Questionnaire on Smoking Urges (QSU; Tiffany & Drobes, 1991) and the Minnesota Nicotine Withdrawal Scale (MNWS)-Revised (Hughes & Hatsukami, 1986) were collected first and followed by the battery of discounting procedures.

Timing of Procedures
The order of temporal and probability discounting procedures and money/cigarette procedures was counterbalanced. The sign and magnitude conditions for hypothetical outcomes were counterbalanced within each set of procedures. For half of all participants, real money conditions occurred prior to the hypothetical conditions. Real money conditions occurred following hypothetical conditions for the remaining participants.

Statistical Method

Though the hyperbolic model (Mazur, 1987) has been favored as a model of discounting behavior (e.g., Kirby, 1997; Kirby & Markovic, 1995), we use the exponential power model because recent evidence suggests it is empirically justified (Yi, Landes, & Bickel, 2009), while continuing to account for preference

reversals observed in intertemporal choice (see Green & Myerson, 2004). Furthermore, the model's assumptions are theoretically justified in the constant sensitivity model of Ebert & Prelec (2007), the β–δ systems model of McClure, Erickson, Laibson, Loewenstein, & Cohen (2007) and McClure, Laibson, Loewenstein, & Cohen (2004), and as a specific case of Killeen's (2009) Additive Utility Model.

$$\frac{v_d}{A} = e^{-k\sqrt{d}} \tag{1}$$

In the exponential power equation, v_d is the discounted value of an outcome, A is the undiscounted amount, d is delay, and k is the discounting parameter (rate). This parameter (k) provides a measure of the degree to which the value of a reward is discounted when it is delayed, with higher values of k indicating greater discounting.

Rachlin, Logue, Gibbon, & Frankel (1986) and Rachlin et al. (1991) argue that discounting due to probability follows the same mathematical function as discounting due to delay. Equation 2 is a variation of the temporal discounting model of Equation 1,

$$\frac{v_d}{A} = e^{-h\sqrt{\theta}} \tag{2}$$

where, v_d is the discounted value of an outcome, A is the undiscounted amount, θ is odds against [computed as (1−probability)/ probability], and h is the discounting parameter. As the free parameter (h) increases, so does the preference for smaller, certain rewards over larger probabilistic outcomes. The free parameter (h) provides a measure of the tendency to prefer smaller, certain rewards to larger, probabilistic outcomes. High h values indicate greater reduction in subjective value resulting from uncertainty (more discounting); low h values indicate little reduction in subjective value (less discounting); and a value of zero indicates no discounting.

Distributions of temporal and probability discounting rates tend to be positively skewed. Further, discounting rates from different individuals tend to have heterogeneous variances. Therefore, all parameter estimates were analyzed according to the method proposed by Landes et al. (2010; also see Yi et al., 2009). Briefly, noting that $k = \exp[\ln(k)]$ and $h = \exp[\ln(h)]$, Equations 1 and 2 were parameterized in terms of $\ln(k)$ and $\ln(h)$, respectively. The estimates of the log discount rates and their *SE*s were obtained using least squares nonlinear regression, and a heterogeneity variance weight akin to 1/[variance of all estimates + (*SE* of estimate)²] was constructed. Evaluating the goodness-of-fit of the exponential power model to each discounting dataset, we computed R^2 values by squaring the correlation of the observed and predicted value (Neter, Kutner, Nachtsheim, & Wasserman, 1996). Johnson & Bickel (2008) make a compelling case to avoid use of R^2 calculated as $1 - SS_{error}/SS_{total}$ in nonlinear regression because it cannot be interpreted as a proportion of variance accounted for as in linear modeling, and tends to be positively correlated with discount rate (while both variations are comparable in linear regression, they are not in nonlinear regression).

We analyzed the log discount rates within an analysis of variance (ANOVA) context. Discount rates of hypothetical and real outcomes were analyzed separately. Among discounting of hypothetical outcomes, we analyzed delayed gains, delayed losses, probabilistic gains, and probabilistic losses separately (i.e., four

ANOVAs). The factors in these four ANOVAs were physiologic state (normal [NOR] and abstinent [ABS]), commodity (cigarettes and money), magnitude ($50 and $1,000), and all two- and three-way interactions. We report the results from these four ANOVAs by factor rather than by ANOVA so that patterns across the four analyses will be more evident. For discounting of real outcomes, an ANOVA accounting for discounting type (delayed and probabilistic), physiologic state, and their interaction was used. In all of the ANOVAs, we used a general (a.k.a., unstructured) covariance structure to account for the correlations of discounting rates coming from the same individual and estimated error degrees of freedom with the Kenward–Roger method. These analyses were conducted in the MIXED procedure of SAS v. 9.2. We did not adjust p values for multiple comparisons, leaving this to the reader who may apply the post-hoc adjustment or false discovery rate of his or her choice (Bailar & Mosteller, 1988). Our significance level was .05.

We examined effects of session order (NOR-ABS vs. ABS-NOR) on our inferences by including this factor, along with all interactions with it, in the ANOVAs described above. Our inferences on the primary three factors were little changed when including the order factor in all the ANOVAs, save that for probabilistic (hypothetical) gains. In the latter, the main effects for commodity and magnitude, respectively, went from marginally to not significant and from clearly significant to marginally so when employing the ANOVA that excluded the order factor to including the order factor. Though commodity and magnitude effects were attenuated when including the order factor, the direction of their effects was not reversed. We present results for the ANOVAs which exclude the order factor and note those results that were affected when including the order factor in the ANOVA.

We also consider area under the curve (AUC; Myerson, Green, & Warusawitharana, 2001) as a model-free measure of discounting to substantiate the results for discounting as described by the exponential power model. Most instances of contrast between analysis of AUC and the primary analyses suggest a minor loss of sensitivity, with statistically significant differences using model-based parameters becoming marginally nonsignificant using AUC. They are noted below.

Results

Smokers self-reported abstinence from smoking prior to the ABS session and normal smoking prior to the NOR session. This was confirmed with significantly lower CO measures in ABS ($M = 3.07$) compared with NOR [$M = 22.07$; $t(27) = 11.78$, $p < .0001$]. Nicotine withdrawal, as measured by the MNWS, was higher during ABS ($M = 26.14$) compared with NOR [$M = 13.04$; $t(27) = 4.96$, $p < .0001$]. Craving, as measured by the QSU, was higher during ABS ($M_{Factor1} = 77.46$ and $M_{Factor 2} = 43.50$) compared with NOR [$M_{Factor1} = 62.04$ and $M_{Factor 2} = 31.68$; $t_{Factor1}(27) = 4.16$, $p = .0003$ and $t_{Factor 2}(27) = 5.18$, $p < .0001$]. Median R^2 for the exponential power model of discounting were .903 (delay hypothetical gains), .845 (delayed hypothetical losses), .895 (probabilistic hypothetical gains), .888 (probabilistic hypothetical losses), and .860 (real gains). Means and R^2 or for each condition are given in the Supplementary Appendix.

Comparison of Discounting Parameters

Significant two-way interactions were observed in the temporal discounting of gains and losses ANOVAs, necessitating comprehensive follow-up analyses. No interactions were observed in the ANOVAS for probability discounting of gains and of losses, but similar follow-up tests were conducted so that comprehensive results of each ANOVA could be disclosed (Supplementary Appendix). Below, we list the results of the analyses that can address each set of comparisons.

Effects of Magnitude

Previous temporal discounting research indicates an omnipresent magnitude effect, where small-magnitude gains are discounted more than large-magnitude gains. This was confirmed with a significant difference ($p = .0152$) observed across hypothetical money and cigarette gains. Simple effects tests indicated that this magnitude effect was observed in the domain of money gains ($p = .0051$) but not cigarette gains ($p = .2677$). Likewise, a statistically significant magnitude effect was observed in the temporal discounting of hypothetical losses ($p = .0013$), and simple effects tests indicated a magnitude effect for money losses ($p < .0001$) but not cigarette losses ($p = .1364$). Congruent effects were generally observed using AUC with the following exceptions: The effect of magnitude in the temporal discounting of gains failed to reach statistical significance ($p = .29$), specifically for money gains ($p = .77$). The effect of magnitude also failed to reach significance for losses ($p = .10$).

Limited research on probability discounting of gains indicates the possibility of a reverse magnitude effect, where large magnitude outcomes are discounted more than small magnitude outcomes. This was observed for hypothetical gains ($p = .002$) overall and separately for money ($p = .0064$) and cigarettes ($p = .0475$); including the effect of order, this effect remained statistically significant for money ($p = .016$) but not for cigarettes ($p = .747$). No effect of magnitude was observed in the probability discounting of losses ($p = .2491$). Congruent effects were generally observed using AUC with the following exceptions: The effect of magnitude did not reach statistical significance for cigarette gains ($p = .28$) while reaching significance for probability discounting of losses ($p = .02$).

Effects of Commodity

Previous temporal discounting research typically indicates a commodity effect, where cigarette gains are discounted more than money gains. Across magnitude and state conditions, a commodity effect was observed in the temporal discounting of hypothetical gains ($p = .0008$) and was observed for $50 ($p = .0112$) and $1,000 magnitudes ($p = .0002$) separately (e.g., there was no magnitude–commodity interaction). No main effect of commodity was observed in the temporal discounting of hypothetical losses ($p = .0558$), but simple effects tests revealed a commodity effect at $1,000 ($p = .0304$) but not at $50 ($p = .4593$). Congruent effects were observed using AUC with the following exceptions: The effect of commodity failed to reach statistical significance in the $50 gains ($p = .08$) while reaching significance for losses overall ($p = .003$) and specifically for $50 losses ($p = .008$ for both).

No main effect of commodity was observed in the probability discounting of gains ($p = .0874$); including the effect of order,
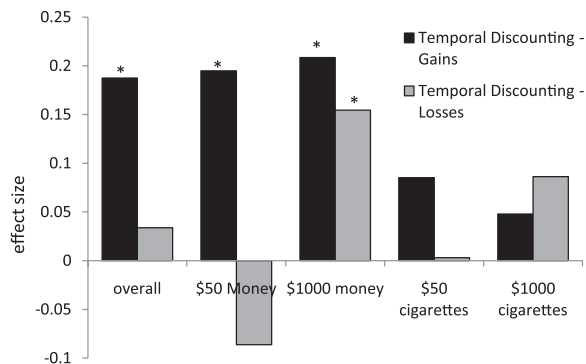
Figure 1. Effects sizes from comparison of temporal discounting parameters (natural logarithm-transformed) obtained in abstinent [ABS] versus normal [NOR] smoking conditions. Effects in the predicted direction, greater discounting in ABS than NOR, are indicated by positive values. Statistical significance at $p < .05$ is indicated by *.

there remained no statistically significant commodity effect ($p = .3308$). Simple effects tests revealed greater discounting of cigarettes at $50 ($p = .0226$) but nonsignificant difference at $1,000 ($p = .3985$). No main effect of commodity was observed in the probability discounting of losses ($p = .4930$) nor in the results of any simple effects tests ($p > .13$). Congruent effects were observed using AUC with the exception that the effect of commodity failed to reach statistical significance in the $50 gains ($p = .25$) condition.

Effects of Abstinence

The predicted increase in temporal discounting of hypothetical gains was confirmed with higher overall discount rates in the ABS condition compared with NOR (Figure 1; $p = .0065$). Simple effects tests indicated that the elevated temporal discounting of gains occurred in the domain of money ($p = .0006$) but not cigarette gains ($p = .2279$) and was consistently observed across money magnitudes ($p < .005$). No difference was observed in the temporal discounting of real $50 gains ($p = .2683$). Though

no main effect was observed between ABS and NOR in the temporal discounting of hypothetical losses ($p = .6198$), simple effects tests revealed greater temporal discounting in ABS compared with NOR for $1,000 money ($p = .0245$) but not $50 money ($p = .2072$). Congruent effects were observed using AUC with the following exceptions: The effect of abstinence failed to reach statistical significance in the $50 hypothetical money gains ($p = .08$) and $1,000 hypothetical money losses ($p = .11$) conditions. And no significant main effects or simple effects were observed between ABS and NOR in any of the probability discounting conditions ($p > .10$).

Finally, discounting (temporal and probability) of real $50 money gains revealed nonsignificant effects of smoking abstinence overall ($p = .32$) with no significant difference on either type of discounting separately (both $p > .26$). Mean differences, however, were in the predicted direction. Congruent effects were observed with AUC.

Relationship Between and Across Discounting Assessments

Table 1 shows Pearson correlation coefficients of parametric temporal discounting conditions (commodity, sign) within the NOR and ABS conditions. Given the number of correlations, we note patterns of correlations across conditions rather than individual coefficients. A pattern of highly significant and positive correlations were observed between money and cigarette gains, with correlation coefficients ranging from +.90 to +.92 from the NOR condition and +.78 to +.88 from the ABS condition. Correlations of money and cigarette losses were all positive, but generally nonsignificant from the NOR session, ranging from +.10 to +.47. In contrast, they were generally significant from the ABS session ranging from +.29 to +.82. Though mostly positive, no theoretically attributable pattern was apparent in the significance of correlations between the money gains and losses conditions from the NOR and ABS sessions. No significant correlations were observed across cigarette gains and losses conditions from either NOR or ABS sessions.

Table 1. Pearson Correlations of Temporal Discount Rates and Probability Discount Rates Between Commodity (Money, Cigarettes) and Sign (Gain, Losses) Conditions Within NOR and ABS Sessions

		NOR				ABS			
		Money gains		Cigarette losses		Money gains		Cigarette losses	
		$50	$1,000	$50	$1,000	$50	$1,000	$50	$1,000
Temporal discounting									
Money losses	$50	+.02	−.01	+.17	+.11	+.41*	+.48*	+.65**	+.29
	$1,000	+.49**	+.45*	+.47*	+.10	+.33	+.37	+.82**	+.51**
Cigarette gains	$50	+.91**	+.92**	−.37	−.02	+.83**	+.78**	+.09	+.32
	$1,000	+.90**	+.91**	−.34	+.00	+.83**	+.88**	−.06	+.15
Probability discounting									
Money losses	$50	−.62**	−.58**	+.79**	+.49*	+.05	+.01	+.84**	+.81**
	$1,000	−.68**	−.51*	+.49*	+.69*	−.16	−.15	+.16	+.15
Cigarette gains	$50	+.92**	+.74**	−.63**	−.45*	+.80**	+.69**	−.02	+.14
	$1,000	+.91**	+.80**	−.77**	−.69**	+.79**	+.70**	−.05	+.11

Note. ABS = abstinent; NOR = normal.

*$p < .05$. **$p < .01$.

Table 1 also shows Pearson correlation coefficients of parametric probability discounting conditions (commodity and sign) within the NOR and ABS conditions. Like temporal discounting, a pattern of highly significant and positive correlations were observed between money and cigarette gains, with correlation coefficients ranging from +.74 to +.92 from the NOR condition and +.69 to +.80 from the ABS condition. In contrast to temporal discounting, correlations between the money gains and losses conditions from the NOR session were all negative and statistically significant, while correlations from the ABS session were mixed (positive and negative) and nonsignificant. Correlations of money and cigarette losses were all positive and significant in the NOR session (correlation coefficients of +.49 to +.79), but generally mixed from the ABS session, ranging from +.15 to +.84. Likewise, correlations between cigarette gains and losses were negative and significant from the NOR session, while mixed and nonsignificant from the ABS session. A general and noteworthy pattern that differentiates the NOR and ABS sessions is that correlations between commodities and between signs tended to be significant in the NOR session compared with the ABS session.

Table 2 shows Pearson correlation coefficients of comparable temporal discounting conditions between the NOR and ABS sessions. All correlations between money gains conditions across NOR and ABS were positive and highly significant ($p < .01$). Similarly, all correlations between cigarette gains conditions across NOR and ABS were positive and highly significant ($p < .01$). In contrast, nonsignificant correlations were generally observed between money losses conditions and cigarette losses conditions ($p > .05$). Finally, positive and statistically significant correlations were observed between real and hypothetical $50 gains conditions from the NOR session ($r = +.84$, $p < .01$) and the ABS session ($r = +.89$, $p < .01$).

Table 2 also shows Pearson correlation coefficients of comparable probability discounting conditions between the NOR and ABS sessions. Like temporal discounting, all correlations between money gains conditions across NOR and ABS were positive and highly significant ($p < .01$) as were all correlations between cigarette gains conditions across NOR and ABS. Correlations between NOR and ABS money losses were generally

nonsignificant similar to correlations between cigarette losses. Finally, positive and statistically significant correlations were observed between real and hypothetical $50 gains conditions from the NOR session ($r = +.67$, $p < .01$) and the ABS session ($r = +.43$, $p < .05$).

Discussion

The present study is a comprehensive examination of possible changes in temporal and probability discounting by smokers due to smoking abstinence (and related withdrawal/craving). These conditions allow for a unique exploration of how delay and probability (risk) affect the present subjective value of positive and negative outcomes. First, the study replicated the previously established magnitude effect, where small amount outcomes are temporally discounted more than large amount outcomes; the reverse magnitude effect, where small amount outcomes are probabilistically discounted less than large amount outcomes; and the commodity effect, where the drug of dependence (or perhaps generally less fungible commodities) is discounted more than money (or generally more fungible commodities).

Related to smoking abstinence, we observed an interesting pattern of differences in discounting parameters between normal smoking and acute abstinence. Noteworthy is that smokers temporally discounted money gains more following smoking abstinence than normal smoking. This supports the previously obtained result in cigarette smokers by Field et al. (2006) and is in contrast to Mitchell (2004). Though the reasons for this are not known, we speculate that procedural factors noted previously play a prominent role. Specifically, the present study is more similar to the Field et al. study on various factors including delays to outcomes and statistical power (based on sample size). A particularly likely candidate is the very small magnitude reward in Mitchell; the established magnitude effect suggests that a ceiling effect may have inhibited or concealed possible increases in discounting following abstinence. An increase in temporal discounting of money gains following acute drug abstinence has been previously observed in another drug-dependent population (opioid-dependent participants who were

Table 2. Pearson Correlations of Temporal Discount Rates and Probability Discount Rates Between Corresponding Conditions of NOR and ABS Sessions

	ABS							
	Money gains		Money losses		Cigarette gains		Cigarette losses	
	$50	$1,000	$50	$1,000	$50	$1,000	$50	$1,000
Temporal discounting								
NOR								
$50	+.91**	+.86**	−.26	+.27	+.80**	+.88**	+.08	+.23
$1,000	+.90**	+.89**	+.39*	+.24	+.83**	+.93**	−.16	+.06
Probability discounting								
NOR								
$50	+.75**	+.72**	+.26	−.10	+.95**	+.80**	+.29	−.03
$1,000	+.76**	+.69**	+.03	+.51*	+.74**	+.56*	+.31	+.12

Note. ABS = abstinent; NOR = normal.

*$p < .05$. **$p < .01$.

acutely abstinent from opioids in Giordano et al. (2002) using large-magnitude gains similar to Field et al. and the present study. Noteworthy is that the increase in discounting occurred not for drug outcomes but for a commodity other than the drug of choice in both the present study and Giordano et al. This suggests a generalized change in intertemporal decision making and has significant implications since elevated levels of temporal discounting of money are associated with various health-related behaviors (Daugherty & Braise, 2010; Odum, Madden, Badger, & Bickel, 2000; Weller et al., 2008).

The present study also included temporal discounting of losses conditions not explored in previous studies of smoking abstinence. Based on the rationale that negative reinforcement occurs when cigarette smokers consume tobacco in order to maintain a preferred level of nicotine intake (Ashton, Stepney, & Thompson, 1979; Russell, 1974) and avoid withdrawal symptoms (Eissenberg, 2004), and given the importance of withdrawal in failure to maintain smoking abstinence (Allen, Bade, & Center, 2008; Orleans & Slade, 1993), we believed that temporal discounting of losses mapped onto the preference for large delayed negative outcomes (long-term negative consequences from smoking) over smaller immediate negative outcomes (experience of withdrawal due to abstinence). Though no overall difference was observed as a function of acute smoking abstinence and associated withdrawal (compared with temporal discounting of gains), a significant increase in temporal discounting was observed as a function of smoking abstinence in the $1,000 money loss condition. This is largely consistent with the results of the temporal discounting of gains, where changes in discounting were observed with money but not cigarette outcomes, but somewhat inconsistent in that no significant difference was observed in the $50 money condition. Indeed, these results suggest either that temporal discounting of money losses is influenced by smoking abstinence but that $50 losses was inadequate to influence choice or that the observed significant difference is specious and that temporal discounting of losses does not correctly model nicotine withdrawal. Our interpretation, given the overall pattern of mean differences, is that the former is more likely to be true; this will require future study and replication.

Nonsignificant changes in the temporal discounting of cigarette outcomes (gains or losses) as a function of acute smoking abstinence is inconsistent with the notion that smoking abstinence engenders a generalized change in intertemporal choice. However, we propose a possible explanation for the absence of a statistical difference: namely, the commodity effect. As noted previously, we observed a high rate of temporal discounting of cigarette gains compared with money gains (also previously observed with cigarettes; Baker et al., 2003 and other drugs of abuse; and Madden, Petry, Badger, & Bickel, 1997). One interpretation of the commodity effect for a drug of abuse is that the immediacy of the drug is highly preferred. An alternative and equally likely interpretation is that the delayed drug is highly dispreferred; smokers' frequent desire and expectation to quit in the future is likely to make delayed cigarettes functionally worthless. Given the binary choice procedure of the present study, strong dispreference for delayed cigarettes could be manifest in a ceiling effect for discount rates of cigarettes, even if the valuation of immediate cigarettes were to be enhanced due to smoking abstinence. A cross-commodity discounting procedure,

where choices are between immediate cigarettes and delayed money (and vice versa), would have been able to address the nature of this commodity effect. Unfortunately, no such condition was included in the present study, and future research should explore this possibility. A previous finding that supports this interpretation occurred in Mitchell (2004), where elevated preference for immediate cigarettes was found as a function of smoking abstinence when the alternative was delayed money, probabilistic money, or physical effort.

The literature on nicotine withdrawal, executive function, and temporal discounting suggests a mechanism that may account for changes in intertemporal decision making due to smoking abstinence. Performance deficits in working memory and related executive functions due to smoking abstinence are well-established (i.e., see al'Absi, Amunrud, & Wittmers, 2002; Blake & Smith, 1997; Snyder & Henningfield, 1989), and poor performance in working memory tasks are associated with elevated temporal discounting (Bickel et al., 2011; Shamosh et al., 2008), while taxed working memory increases temporal discounting (Hinson, Jameson, & Whitney, 2003) and working memory training decreases temporal discounting (Bickel et al., 2011). With evidence that brain regions associated with executive function are also associated with relative preference for delayed rewards (McClure et al., 2004, 2007), we have hypothesized that rate of temporal discounting is a summary measure of relative executive and limbic brain function (Bickel et al., 2007). Given the correlational nature of these insights, it is unclear if smoking abstinence directly affects intertemporal decision making or is mediated by effects on executive function and working memory. However, the body of evidence convincingly establishes the relationship between smoking abstinence/acute withdrawal, executive function, and intertemporal decision making.

The present study also comprehensively examined possible changes in probability discounting due to smoking abstinence, finding no changes. This is somewhat inconsistent with results from temporal discounting, and adds to some literature contradicting the conceptualization that temporal and probability discounting are common processes, given dissimilar effects of magnitude (e.g., Green & Myerson, 2004) as well as commodity and smoking abstinence from the present study. This null effect of abstinence is significant in that it suggests that smokers' decision making regarding probabilistic outcomes is not influenced by smoking abstinence, withdrawal, or craving.

This result supports the growing consensus that probability discounting is not a measure of real-life risk taking or risk preference as typically conceptualized in drug-dependent and other risk-engaging individuals nor of drug-dependent individuals experiencing drug withdrawal; elevated risk taking in probability discounting would be reflected in less discounting (greater preference for the larger probabilistic outcome). To date, less discounting has not been observed in populations typically thought as risk preferring (Holt, Green, & Myerson, 2003; Madden, Petry, & Johnson, 2009; Reynolds et al., 2004; Yi et al., 2007), frequently finding the reverse.

Finally, the present study also comprehensively examined the relationships between the battery of discounting assessments. Not surprisingly, significant and positive patterns of correlations were observed between magnitude conditions (within

commodity/sign conditions differ only in the amount of the delayed outcome). Some informative patterns of correlations include:

1. Positive and significant patterns of correlations across commodity (money and cigarette) gains in both temporal and probability discounting procedures. This suggests a common or related discounting mechanism for temporal (and probability) discounting of rewards, independent of the specific nature of the reward.
2. Positive and significant patterns of correlations across commodity (money and cigarette) losses, primarily in temporal discounting. Like the pattern observed with discounting of rewards, this pattern suggests a common or related discounting mechanism for temporal discounting of losses, independent of the specific nature of the negative outcome.
3. Positive and significant patterns of correlations between temporal (and probability) discounting of money (and cigarette) gains across the smoking conditions but not in any losses conditions between smoking conditions. This suggests that an individual's rate of discounting relative to others remains consistent (ranking remains approximately the same) for gains but not for losses. In other words, the increase in temporal discounting of money gains as a function of smoking abstinence appears to result from a generalized upward shift for all smokers rather than differential effects on different smokers.
4. Generally nonsignificant or inconsistent patterns of results across discounting of losses conditions, including money (and cigarette) losses between NOR and ABS smoking conditions, between cigarette gains and losses following smoking abstinence and between cigarette gains and losses following normal smoking. We have conducted extensive exploratory analysis to examine this pattern of nonsignificant correlations and have not been able to detect any statistical reason (e.g., increased error variance and unsystematic or overly systematic data). Thus, we are left to tentatively conclude that discounting of losses does not typically reveal a systematic pattern of preference across conditions.

One principal weakness of the present study is that the temporal discounting of real money condition did not confirm NOR/ABS differences observed in the comparable procedure for hypothetical money. Previous temporal discounting research has typically found consistent results with real and hypothetical money outcomes (e.g., comparing smokers and nonsmokers in Baker et al., 2003). Nonetheless, there are potentially substantive differences between the parameters for the real and hypothetical money conditions (specifically the employed delays) that may account for this inconsistent result. Also a possibility is that the small magnitude outcomes are more susceptible to error variability and consistent with the relatively less conclusive results in the temporal discounting of hypothetical $50 condition compared with $1,000.

The present study contributes to the current understanding of decision making by smokers during an acute period of smoking abstinence, indicating an increase in intertemporal decision making associated with executive function deficits, smoking relapse, and other behaviors associated with poor health and elevated risk. However, this period of smoking abstinence does not appear to influence decisions involving money or cigarette

outcomes with explicit probabilities. Finally, the present study further illuminates the relationship between temporal and probability discounting as well as various parameters of these forms of discounting.

Supplementary Material

A Supplementary appendix can be found online at http://www.ntr.oxfordjournals.org

Declaration of Interests

The authors have no competing interests.

References

al'Absi, M., Amunrud, T., & Wittmers, L. (2002). Psychophysical effects of nicotine abstinence and behavioral challenges in habitual smokers. *Pharmacology, Biochemistry, and Behavior*, *72*, 707–716. doi:10.1016/S0091-3057(02)00739-6. Retrieved from http://dx.doi.org/10.1016/S0091-3057%2802%2900739-6

Allen, S., Bade, T. H., & Center, B. (2008). Craving, withdrawal, and smoking urges on days immediately prior to smoking relapse. *Nicotine & Tobacco Research*, *10*, 35–45. doi:10.1080/14622200701705076

Allen, T., Moeller, G., Rhoades, H., & Cherek, D. (1998). Impulsivity and history of drug dependence. *Drug and Alcohol Dependence*, *50*, 137–150. doi:10.1016/S0376-8716(98)00023-4. Retrieved from http://dx.doi.org/10.1016/S0376-8716%2898%2900023-4

Ashton, H., Stepney, R., & Thompson, J. (1979). Self-titration by cigarette smokers. *British Medical Journal*, *2*, 357–360. doi:10.1136/bmj.2.6186.357

Bailar, J., & Mosteller, F. (1988). Guidelines for statistical reporting in articles for medical journals. *Annals of Internal Medicine*, *108*, 266–273. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3341656

Baker, F., Johnson, M., & Bickel, W. (2003). Delay discounting differs between current and never-smokers across commodities, sign, and magnitudes. *Journal of Abnormal Psychology*, *112*, 382–392. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12943017

Bickel, W., Miller, M., Yi, R., Kowal, B., Lindquist, D., & Pitcock, J. (2007). Behavioral- and neuro-economics of drug addiction: Competing neural systems and temporal discounting processes. *Drug and Alcohol Dependence*, *90S*, S85–S91. doi:10.1016/j.drugalcdep.2006.09.016. Retrieved from http://dx.crossref.org/10.1016%2Fj.drugalcdep.2006.09.016

Bickel, W., Odum, A., & Madden, G. (1999). Impulsivity and cigarette smoking: Delay discounting in current, never-, and ex-smokers. *Psychopharmacology*, *14*, 447–454. doi:10.1007/PL00005490

Bickel, W., Yi, R., Landes, R., Hill, P., & Baxter, C. (2011). Remember the future: Working memory training decreases temporal discounting among stimulant addicts. *Biological Psychiatry*, *69*, 260–265. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20965498

Bickel, W. K., & Yi, R. (2008). Temporal discounting as a measure of executive function: Insights from the competing neuro-behavioral decision system hypothesis of addiction. In D. Houser, & K. McCabe (Eds.), *Neuroeconomics: Vol. 20. Advances in health economics and health services research* (pp. 289–309), Bingley, UK: Emerald Publishing. doi:10.1016/S0731-2199(08)20012-9

Blake, J., & Smith, A. (1997). Effects of smoking and smoking deprivation on the articulatory loop of working memory. *Human Psychopharmacology*, *12*, 259–264. doi:10.1002/(SICI)1099-1077(199705/06)

Christensen, J., Parker, S., Silbergeld, A., & Hursh, S. (1998). Tradeoffs in choice between risk and delay depend on monetary amounts. *Journal of the Experimental Analysis of Behavior*, *69*, 123–139. doi:10.1901/jeab.1998.69-123

Cummings, K. M., Hyland, A., Giovino, G. A., Hastrup, J., Bauer, J., & Bansal, M. A. (2004). Are smokers adequately informed about the health risks of smoking and medicinal nicotine? *Nicotine & Tobacco Research*, *6*, S333–S340. doi:10.1080/1462200412331320734

Dallery, J., & Raiff, B. (2007). Delay discounting predicts cigarette smoking in a laboratory model of abstinence reinforcement. *Psychopharmacology*, *190*, 485–496. doi:10.1007/s00213-006-0627-5

Daugherty, J., & Braise, G. (2010). Taking time to be healthy: Predicting health behaviors with delay discounting and time perspective. *Personality and Individual Differences*, *48*, 202–207. doi:10.1016/j.paid.2009.10.007. Retrieved from http://dx.doi.org/10.1016/j.paid.2009.10.007

Ebert, J. E. J., & Prelec, D. (2007). The fragility of time: Time-insensitivity and valuation of the near and far future. *Management Science*, *53*, 1423–1438. doi:10.1287/mnsc.1060.0671

Eissenberg, T. (2004). Measuring the emergence of tobacco dependence: The contribution of negative reinforcement models. *Addiction*, *99*, 5–29. doi:10.1111/j.1360-0443.2004.00735.x

Estle, S., Green, L., Myerson, J., & Holt, D. (2006). Differential effects of amount on temporal and probability discounting of gains and losses. *Memory & Cognition*, *34*, 914–928. doi:10.3758/BF03193437

Fagerström, K.-O., & Schneider, N. (1989). Measuring nicotine dependence: A review of the Fagerstrom Tolerance Questionnaire. *Journal of Behavioral Medicine*, *12*, 159–182. doi:10.1007/BF00846549

Field, M., Santarcangelo, M., Sumnall, H., Goudie, A., & Cole, J. (2006). Delay discounting and the behavioural economics of cigarette purchases in smokers: The effects of nicotine deprivation. *Psychopharmacology*, *186*, 255–263. doi:10.1007/s00213-006-0385-4

Giordano, L., Bickel, W., Loewenstein, G., Jacob, E., Marsch, L., & Badger, G. (2002). Mild opioid deprivation increases the degree that opioid-dependent outpatients discount delayed heroin and money. *Psychopharmacology*, *163*, 174–182. doi:10.1007/s00213-002-1159-2

Green, L., & Myerson, J. (1996). Exponential versus hyperbolic discounting of delayed outcomes: Risk and waiting time. *American Zoologist*, *36*, 496–505. doi:10.1093/icb/36.4.496

Green, L., & Myerson, J. (2004). A discounting framework for choice with delayed and probabilistic rewards. *Psychological Bulletin*, *130*, 769–792. doi:10.1037/0033-2909.130.5.769. Retrieved from http://dx.crossref.org/10.1037%2F0033-2909.130.5.769

Henningfield, J., Cohen, C., & Pickworth, W. (1993). Psychopharmacology of nicotine. In C. Orleans, & J. Slade (Eds.), *Nicotine addiction: Principles and management* (pp. 24–45), New York: Oxford University Press.

Hinson, J., Jameson, T., & Whitney, P. (2003). Impulsive decision making and working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*, 298–306. doi:10.1037/0278-7393.29.2.298

Hirshman, E., Rhodes, D. K., Zinser, M., & Merritt, P. (2004). The effect of tobacco abstinence on recognition memory, digit span recall, and attentional vigilance. *Experimental and Clinical Psychopharmacology*, *12*, 76–83. doi:10.1037/1064-1297.12.1.76. Retrieved from http://psycnet.apa.org/doi/10.1037/1064-1297.12.1.76

Holt, D. D., Green, L., & Myerson, J. (2003). Is discounting impulsive? Evidence from temporal and probability discounting in gambling and non-gambling college students. *Behavioural Processes*, *64*, 355–367. doi:10.1016/S0376-6357(03)00141-4. Retrieved from http://dx.doi.org/10.1016/S0376-6357%2803%2900141-4

Hughes, S., & Hatsukami, D. (1986). Signs and symptoms of tobacco withdrawal. *Archives of General Psychiatry*, *43*, 289–294. Retrieved from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=3954551

Johnson, M. W., & Bickel, W. K. (2008). An algorithm for identifying nonsystematic data in delay discounting research. *Experimental and Clinical Psychopharmacology*, *16*, 264–274. doi:10.1037/1064-1297.16.3.264. An. Retrieved from http://dx.doi.org/10.1037/1064-1297.16.3.264.An

Killeen, P. (2009). An additive-utility model of delay discounting. *Psychological Review*, 116, 602–619. doi:10.1037/a0016414. Retrieved from http://dx.doi.org/10.1037/a0016414

Kirby, K. (1997). Bidding on the future: Evidence against the normative discounting of delayed rewards. *Journal of Experimental Psychology: General*, 126, 54–70. doi:10.1037/0096-3445.126.1.54

Kirby, K., & Markovic, N. (1995). Modeling myopic decisions: Evidence for hyperbolic delay-discounting within subjects and amounts. *Organizational Behavior and Human Decision Processes*, 64, 22–30. doi:10.1006/obhd.1995.1086. Retrieved from http://dx.doi.org/10.1006/obhd.1995.1086

Krishnan-Sarin, S., Reynolds, B., Duhig, A., Smith, A., Liss, T., McFetridge, A., et al. (2007). Behavioral impulsivity predicts treatment outcome in a smoking cessation program for adolescent smokers. *Drug and Alcohol Dependence*, 88, 79–82. doi:10.1016/j.drugalcdep.2006.09.006. Retrieved from http://dx.doi.org/10.1016/j.drugalcdep.2006.09.006

Landes, R. D., Pitcock, J. A., Yi, R., & Bickel, W. K. (2010). Analytical methods to detect within-individual changes in discounting. *Experimental and Clinical Psychopharmacology*, 18, 175–183. doi:10.1037/a0018901

Leitch, D., Harkawat, R., Askew, J., Masel, P., & Hendrick, D. (2005). Relation of expired carbon monoxide to smoking history, lapsed time, TLCO measurement, and passive smoking. *Respiratory Medicine*, 99, 32–38. doi:10.1016/j.rmed.2004.03.027. Retrieved from http://dx.doi.org/10.1016/j.rmed.2004.03.027

MacKillop, J., & Kahler, C. (2009). Delayed reward discounting predicts treatment response for heavy drinkers receiving smoking cessation treatment. *Drug and Alcohol Dependence*, 104, 197–203. doi:10.1016/j.drugalcdep.2009.04.020. Retrieved from http://dx.doi.org/10.1016/j.drugalcdep.2009.04.020

Madden, G., Petry, N., Badger, G., & Bickel, W. (1997). Impulsive and self-control choices in opioid-dependent patients and non-drug-using control participants: Drug and monetary rewards. *Experimental and Clinical Psychopharmacology*, 5, 256–262. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9260073

Madden, G., Petry, N., & Johnson, P. S. (2009). Pathological gamblers discounting probabilistic rewards less steeply that matched controls. *Experimental and Clinical Psychopharmacology*, 17, 283–290. doi:10.1037/a0016806

Mazur, J. (1987). An adjusting procedure for studying delayed reinforcement. In J. Nevin, & H. Rachlin (Eds.), *Quantitative analysis of behavior: Vol. 5. The effect of delay and of intervening events on reinforcement value* (pp. 55–73), Hillsdale, NJ: Erlbaum.

McClure, S. M., Erickson, K. M., Laibson, D. I., Loewenstein, G., & Cohen, J. (2007). Time discounting for primary rewards. *Journal of Neuroscience*, 27, 5796–5804. doi:10.1523/JNEUROSCI.4246-06.2007

McClure, S. M., Laibson, D., Loewenstein, G., & Cohen, J. (2004). Separate neural systems value immediate and delayed monetary rewards. *Science*, 306, 503–507. doi:10.1126/science.1100907

Merritt, P. S., Cobb, A. R., Moissinac, L., & Hirshman, E. (2010). Evidence that episodic memory impairment during tobacco abstinence is independent of attentional mechanisms. *Journal of General Psychology*, 137, 331–342. doi:10.1080/00221309.2010.499395

Mitchell, S. (1999). Measures of impulsivity in cigarette smokers and nonsmokers. *Psychopharmacology*, 146, 455–464. doi:10.1007/PL00005491

Mitchell, S. (2004). Effects of short-term nicotine deprivation on decision-making: Delay, uncertainty, and effort discounting. *Nicotine & Tobacco Research*, 6, 819–828. doi:10.1080/14622200412331296002

Mueller, E., Landes, R., Kowal, B., Yi, R., Stitzer, M., Burnett, C., et al. (2009). Delay of smoking gratification as a laboratory model of relapse: Effects of incentives for not smoking, and relationship with measures of executive function. *Behavioral Pharmacology*, 20, 461–473. doi:10.1097/FBP.0b013e3283305ec7

Myerson, J., Green, L., Hansen, J., Holt, D., & Estle, S. J. (2003). Discounting delayed and probabilistic rewards: Processes and traits. *Journal of Economic Psychology*, 24, 619–635. doi:10.1016/S0167-4870(03)00005-9

Myerson, J., Green, L., & Warusawitharana, M. (2001). Area under the curve as a measure of discounting. *Journal of the Experimental Analysis of Behavior*, 76, 235–243. doi:10.1901/jeab.2001.76-235

Neter, J., Kutner, M. H., Nachtsheim, C. J., & Wasserman, W. (1996). *Applied linear statistical models* (4th ed). New York: McGraw Hill. ISBN: 0-256-11736-5.

Odum, A., Madden, G., Badger, G., & Bickel, W. (2000). Needle sharing in opioid-dependent outpatients: Psychological processes and underlying risk. *Drug and Alcohol Dependence*, 60, 259–266. doi:10.1016/S0376-8716(00)00111-3. Retrieved from http://dx.doi.org/10.1016/S0376-8716%2800%2900111-3

Odum, A., Madden, G., & Bickel, W. (2002). Discounting delayed health gains and losses by current, never-, and ex-smokers of cigarettes. *Nicotine & Tobacco Research*, 4, 295–303. doi:10.1080/14622200210141257

Ohmura, Y., Takahashi, T., & Kitamura, N. (2005). Discounting delayed and probabilistic monetary gains and losses by smokers of cigarettes. *Psychopharmacology*, 182, 508–515. doi:10.1007/s00213-005-0110-8

Olson, E. A., Collins, P. F., Hooper, C. J., Muetzel, R., Lim, K. O., & Luciana, M. (2009). White matter integrity predicts delay discounting behavior in 9- to 23-year-olds: A diffusion tensor imaging study. *Journal of Cognitive Neuroscience*, 21, 1406–1421. doi:10.1162/jocn.2009.21107. Retrieved from http://www.mitpressjournals.org/doi/abs/10.1162/jocn.2009.21107?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%3dncbi.nlm.nih.gov

Orleans, C., & Slade, J. (1993). *Nicotine addiction: Principles and management*. New York: Oxford University Press.

Discounting by abstinent smokers

Prelec, D., & Loewenstein, G. (1991). Decision making over time and under uncertainty: A common approach. *Management Science*, *37*, 770–786. doi:10.1287/mnsc.37.7.770

Rachlin, H., Logue, A., Gibbon, J., & Frankel, M. (1986). Cognition and behavior in studies of choice. *Psychological Review*, *93*, 33–45. doi:10.1037/0033-295X.93.1.33. Retrieved from http://dx.doi.org/10.1037/0033-295X.93.1.33

Rachlin, H., Raineri, A., & Cross, D. (1991). Subjective delay and probability. *Journal of the Experimental Analysis of Behavior*, *55*, 233–244. doi:10.1901/jeab.1991.55-233

Reynolds, B. (2006). A review of delay-discounting research humans: Relations to drug use and gambling. *Behavioural Pharmacology*, *17*, 651–667. doi:10.1097/FBP.0b013e3280115f99

Reynolds, B., Richards, J., Horn, K., & Karraker, K. (2004). Delay and probability discounting as related to cigarette smoking status in adults. *Behavioural Processes*, *65*, 35–42. doi:10.1016/S0376-6357(03)00109-8. Retrieved from http://dx.doi.org/10.1016/S0376-6357%2803%2900109-8

Richards, J., Zhang, L., Mitchell, S., & de Wit, H. (1999). Delay or probability discounting in a model of impulsive behavior: Effect of alcohol. *Journal of the Experimental Analysis of Behavior*, *71*, 121–143. doi:10.1901/jeab.1999.71-121

Russell, M. (1974). Realistic goals for smoking and health. *Lancet*, *1*, 254–258. doi:10.1016/S0140-6736(74)92558-6

Schoenbaum, M. (1997). Do smokers understand the mortality effects of smoking? Evidence from the Health and Retirement Survey. *American Journal of Public Health*, *87*, 755–759.

Shamosh, N. A., DeYoung, C. G., Green, A. E., Reis, D. L., Johnson, M. R., Conway, A. R., et al. (2008). Individual differences in delay discounting: Relation to intelligence, working memory, and anterior prefrontal cortex. *Psychological Science*, *19*, 904–911. doi:10.1111/j.1467-9280.2008.02175.x

Snyder, F., & Henningfield, J. (1989). Effects of nicotine administration following 12 h of tobacco deprivation: Assessment on computerized performance tasks. *Psychopharmacology*, *97*, 17–22. doi:10.1007/BF00443406

Stevenson, M. (1986). A discounting model for decisions with delayed positive and negative outcomes. *Journal of Experimental Psychology: General*, *115*, 131–154. doi:10.1037/0096-3445.115.2.131. Retrieved from http://dx.doi.org/10.1037/0096-3445.115.2.131

Tiffany, S., & Drobes, D. (1991). The development and initial validation of a questionnaire on smoking urges. *British Journal of Addiction*, *86*, 1467–1476. doi:10.1111/j.1360-0443.1991.tb01732.x

Weller, R., Cook, E., III, Avsar, K., & Cox, J. (2008). Obese women show greater delay discounting than healthy-weight women. *Appetite*, *51*, 563–569. doi:10.1016/j.appet.2008.04.010. Retrieved from http://dx.doi.org/10.1016/j.appet.2008.04.010

Yi, R., Chase, W., & Bickel, W. (2007). Probability discounting among smokers and non-smokers: Molecular analysis discerns group differences. *Behavioural Pharmacology*, *18*, 633–639. doi:10.1097/FBP.0b013e3282effbd3

Yi, R., Landes, R., & Bickel, W. (2009). Novel models of intertemporal valuation: Future and past outcomes. *Journal of Neuroscience, Psychology, and Economics*, *2*, 102–111. doi:10.1037/a0017571

Yi, R., Mitchell, S., & Bickel, W. (2009). Delay discounting and substance abuse. In W. Bickel, & T. Critchfield (Eds.), *Impulsivity: The behavioral and neurological science of discounting* (pp. 191–211), Washington, DC: American Psychological Association. doi:10.1037/12069-007

Yoon, J., Higgins, S., Heil, S., Sugarbaker, R., Thomas, C., & Badger, G. (2007). Delay discounting predicts postpartum relapse to cigarette smoking among pregnant women. *Experimental and Clinical Psychopharmacology*, *15*, 176–186. doi: 10.1037/1064-1297.15.2.176