Published in final edited form as:

Psychol Addict Behav. 2014 September ; 28(3): 761–768. doi:10.1037/a0036726.

Clarifying the Relationship between Impulsive Delay Discounting and Nicotine Dependence

Michael Amlung^{1,2} and James MacKillop^{1,3,*}

¹Department of Psychology, University of Georgia, Athens, GA

²Department of Psychological Sciences, University of Missouri, Columbia, MO

³Department of Behavioral and Social Sciences, Brown University, Providence, RI

Abstract

Impulsive delayed reward discounting (DRD) has been linked to nicotine dependence, but with some inconsistency. This may be related to the considerable variability in the literature with regard to the DRD assessments used, particularly in the case of reward magnitudes assessed. In addition, previous studies have often not considered concurrent substance use when examining the relationship between DRD and nicotine dependence. The current study sought to further clarify the relationship between DRD and nicotine dependence by characterizing DRD across diverse reward magnitudes and incorporating other substance use. Daily smokers ($N = 933$) were assessed for DRD preferences across nine reward magnitudes (delayed reward range: \$2.50–\$850), comorbid substance use, and relevant demographic variables (age, education, income). A significant large effect size magnitude effect was found for DRD, reflecting steeper discounting for smaller delayed rewards, but significant correlations across magnitudes also suggested similar relative levels of discounting. Principal components analysis (PCA) was used to generate a single latent index of discounting across all magnitudes that accounted for 67% of the total variance. In both correlation and regression analyses, steeper composite DRD was significantly associated with nicotine dependence severity. This relationship remained statistically significant after incorporating demographic variables and alcohol and illicit drug use. These findings provide evidence of a specific link between impulsive DRD and nicotine dependence, and reveal that this association is robust across a broad range of monetary rewards. The study also demonstrates the utility of using PCA to generate latent indices of delay discounting across multiple magnitudes of delayed reward.

Keywords

Nicotine dependence; behavioral economics; delay discounting; magnitude effects

*Correspondence concerning this article should be addressed to James MacKillop, Ph.D., Department of Psychology, University of Georgia, Athens, GA 30602; Phone: (706) 542-3033; Fax: (706) 542-3275; jmackill@uga.edu.

The authors affirm that they have no conflicts of interest in conducting this research.

Introduction

Cigarette smoking continues to be the largest preventable cause of morbidity and mortality in the United States and the developed world (Centers for Disease Control and Prevention, 2008; Mokdad, Marks, Stroup, & Grerberding, 2004; World Health Organization, 2011). Understanding the factors that contribute to smoking is a major focus of diverse disciplines, including behavioral economics, which integrates principles from psychology and economics to study healthy and unhealthy decision-making. A behavioral economic approach has characterized how individuals exhibiting a variety of addictive behaviors overvalue addictive commodities relative to alternate reinforcers, how the value of cigarettes and other drugs fluctuates in response to a variety of internal and external factors, and how individual differences in impulsive decision-making contribute to substance misuse (for a review, see MacKillop, Amlung, Murphy, Acker, & Ray, 2011). In the latter case, the primary behavioral economic measure of impulsivity is delayed reward discounting (DRD) which reflects the extent to which individuals prefer smaller-immediate rewards over larger-delayed rewards that are discounted based on their temporal delay (Madden & Bickel, 2009).

In the context of nicotine dependence, impulsive DRD in smokers has been found in a number of cross-sectional studies (e.g., Baker, Johnson, & Bickel, 2003; Bickel, Odum, & Madden, 1999; S. H. Mitchell, 1999; Reynolds, Richards, Horn, & Karraker, 2004). Furthermore, a recent meta-analysis found a medium effect size difference between smoking groups and control groups across studies ($d = 0.57$) (MacKillop, Amlung, Few, et al., 2011). However, there have also been a number of studies that have not found significant differences (e.g., Ohmura, Takahashi, & Kitamura, 2005; Reynolds, Karraker, Horn, & Richards, 2003). One source of this inconsistency may be substantial methodological heterogeneity across studies. In particular, there is substantial variability in the reward magnitudes used in delay discounting tasks, ranging from \$10 to >\$1000 in past studies (MacKillop, Amlung, Few, et al., 2011). Reward amount is a particularly important task parameter considering the well-documented magnitude effects in DRD, with discounting rate decreasing as reward magnitudes increase (Green, Myerson, & McFadden, 1997; Kirby & Marakovic, 1996). Differences in reward magnitude and, in turn, the resulting discounting functions could contribute to the mixed findings. The findings of one study (Heyman & Gibb, 2006) suggest that differences between smokers and non-smokers may depend on the magnitude of the rewards being considered. Specifically, Heyman and Gibb (2006) used two discounting tasks, one for large rewards (\$1000) and one for more modest rewards (\$10-\$29) and only found significant group differences on the small reward version. In contrast to these results, other studies have found no differences across different reward magnitudes (e.g., Baker et al., 2003; Johnson, Bickel, & Baker, 2007).

A second methodological issue is that most studies focus on a single addictive behavior but do not fully incorporate other substance use. This is a significant issue because nicotine dependence is highly comorbid with both alcohol and illicit drug dependence (Dani & Harris, 2005; Degenhardt & Hall, 2001). A number of more general factors, such as age and education, have also been linked to discounting and nicotine dependence, but have been inconsistently accounted for in previous studies. These characteristics could have significant

confounding effects, as the elevated discounting putatively associated with nicotine dependence could actually be attributable to other factors. Certainly, some studies have fully incorporated these variables. For example, Sweitzer et al. (2008) found that current smokers exhibited significantly steeper DRD in relation to both ex-smokers and never smokers, even after controlling for years of education and comorbid drug and alcohol abuse based on DSM-IV criteria. However, a number of other studies have reported significant differences in terms of substance use and demographics, but have not incorporated those characteristics in the analyses (Baker et al., 2003; S. H. Mitchell, 1999). The variation in DRD task reward magnitudes and role of collateral factors may be contributing to ambiguity in the specific relationship between impulsive DRD and nicotine dependence.

The current study sought to address these methodological limitations to clarify the relationship between impulsive DRD and nicotine dependence. First, we assessed DRD at nine widely-ranging delayed reward magnitudes (\$2.50–\$850) and used a factor analytic approach to generate a latent DRD index across these magnitudes. Consolidating intertemporal choice preferences across reward sizes was intended to capture the common decision-making profile independent of magnitude-specific influences. Second, we directly examined the extent to which magnitude effects were associated with nicotine dependence. Third, in addition to assessing severity of nicotine dependence, we also assessed alcohol use, illicit drug use, and relevant demographic variables. This permitted comprehensive assessment of DRD across magnitudes and also the incorporation of multiple types of addictive behaviors and more general demographic factors.

Method

Participants

These data were collected as part of a larger project to inform tobacco tax policy using behavioral economics (MacKillop et al., 2012). A sample of 933 daily smokers was enrolled from two sites: Athens, GA (94%) and Aiken, SC (6%). Eligibility criteria were: i) 18+ years-old; ii) 5+ cigarettes/day; iii) 8th grade education. Overall sample characteristics are provided in Table 1 and site-specific characteristics and comparisons between sites are provided in Supplementary Materials (Table S1).

Assessments

Participants completed a DRD assessment that was based on the Monetary Choice Questionnaire (MCQ) (Kirby, Petry, & Bickel, 1999). The MCQ is a validated measure of DRD that is comprised of 27 choices between smaller-immediate and larger-delayed rewards that are preconfigured to provide estimates of discounting rates (i.e., k). The standard MCQ assesses DRD preferences across three reward magnitudes (see below). To achieve a more comprehensive assessment of DRD across a larger range of reward amounts, we also administered two alternate versions of the MCQ in which monetary values were increased or decreased by one order of magnitude above and below the standard MCQ values. Therefore, participants completed three unique MCQ assessments that provided estimates of k at nine different average delayed reward magnitudes: \$3, \$5.50, \$8, \$30, \$55, \$80, \$300, \$550, and \$800. The first three reflect the standard measure decreased by an

order of magnitude, henceforth referred to as the MCS-S and the last three reflect the standard measure increased by an order of magnitude, henceforth referred to as the MCQ-L. The full set of discounting items is provided in Supplementary Materials (Table S2).

Participants also completed a comprehensive demographics assessment. Severity of nicotine dependence was assessed via the Fagerström Test for Nicotine Dependence (FTND; Heatherton, Kozlowski, Frecker, & Fagerstrom, 1991), a validated self-report assessment of cigarette consumption and nicotine dependence severity. Alcohol use and misuse was assessed via the Alcohol Use Disorders Identification Test (AUDIT; Saunders, Aasland, Babor, de la Fuente, & Grant, 1993), which yielded two subscales corresponding to quantity/frequency of alcohol consumption (AUDIT-QF) and hazardous alcohol use (AUDIT-HZD) (Maisto, Conigliaro, McNeil, Kraemer, & Kelley, 2000). Illicit substance use frequency over the past 3 months was assessed via self-report for each of the following substances: marijuana, stimulants (cocaine or methamphetamine), and opiates (heroin, opium, or prescription painkillers). Frequency was categorized as never, occasional (monthly), regular (weekly or greater). All measures were counterbalanced in the questionnaire packet and the three MCQ versions were separated from each other to minimize carryover effects.

Procedure

Prior to enrollment participants completed a phone screening to verify eligibility. Participants initially underwent informed consent and then received instructions with regard to the assessment. Then, participants completed paper-pencil assessments during a 90-minute group sessions in a conference room with adequate space and privacy (~10 participants per session). Participants were compensated either \$30 or, for some university students (3% of sample), research credit. All procedures were approved by the appropriate Institutional Review Boards.

Data Analysis

All variables were initially screened for missing data, outliers ($z_s > 3.29$), and distribution abnormalities (Tabachnick & Fidell, 2001). Hyperbolic discounting functions (k) were estimated for each of the nine MCQ reward magnitudes using the established approach (Kirby et al., 1999). We examined the pattern of DRD choices within each magnitude for each participant in order to identify the k parameter that most closely corresponded to their choices. Specifically, an index of consistency was calculated for each possible k value which reflected the proportion of individual choices that were consistent with that value. The k with the highest consistency was selected or, if two or more k values were equally consistent, the geometric mean of these values was used.

Magnitude effects on the MCQ assessments were examined using a one-way nine-level within-subjects analysis of variance (ANOVA) with planned pairwise comparisons between each of the nine magnitudes. We also investigated whether magnitude effects were related to dependence severity. To do so, we calculated the correlation between each participant's nine k values and the corresponding reward magnitude values. This approach is preferable over using difference scores between magnitudes since the correlation takes into account all nine magnitudes when generating a single index of the magnitude effect per participant. Negative

correlation coefficients reflected the well-established magnitude effect (i.e., smaller k values—reflecting decreased impulsivity—with increased magnitudes), and the size of the coefficient indicated the strength of the magnitude effect. These coefficients were used for subsequent continuous analyses.

The factor analytic approach used principal components analysis (PCA; oblique, direct oblimin rotation) for data reduction to generate a single latent factor of discounting from the nine k values. Pearson's correlations (r) were used to examine the relations among nicotine dependence (FTND) and DRD, demographic variables, alcohol use/misuse (AUDIT-QF, AUDIT-HZD), and drug use. Simultaneous multiple regression was then used to determine the closest associates of nicotine dependence. To maximize power, only those variables that were statistically significantly correlated with FTND at $p < .05$ were included in the regression analyses.

Results

Preliminary Analyses

No outlying values were detected for any variables. Missing or incomplete data were as follows: sex ($n = 4$), education ($n = 4$), income ($n = 6$), cigarettes/day ($n = 4$), marijuana use ($n = 15$), stimulant use ($n = 7$), opiate use ($n = 11$), and were excluded on a pairwise basis (i.e., sample size was maximized for a given analysis). The distributions of the k values obtained from the MCQ assessments were positively skewed, so these variables were square root transformed prior to analysis. These transformations improved the distributions, resulting in non-significant levels of skewness ($zs < 2.5$, $ps > .01$). DRD performance did not significantly differ between the two data collection sites.

Individual k values for each of the nine magnitudes are presented in Table 2 and discounting functions for each magnitude are depicted in Figure S1 in Supplementary Materials. Correlations among the individual k values ranged from .34 to .89 ($ps < .001$), indicating that discounting at different magnitudes was generally overlapping but at varying effect sizes (Table 3). In general, the more similar the two magnitudes were, the higher the correlation. The repeated measures ANOVA examining differences across the nine MCQ magnitudes revealed a significant main effect of magnitude, $F(8, 7456) = 537.85$, $p < .001$, $\eta_p^2 = .37$. Pairwise comparisons indicated that all of the magnitudes significantly differed from each other ($ps < .001$), with the exception of the choices for an average of \$8 and \$30 ($p = .83$). Of note, these two magnitudes were at the boundary between the small and standard MCQ versions (i.e., the largest magnitude rewards on the MCQ-S and the smallest rewards on the standard MCQ). The magnitude effect was also evident in terms of the correlations between each participant's k values and reward amounts (M correlation = $-.55$, $SD = 0.33$).

Primary Analyses

The PCA generated a single latent discounting factor that accounted for 68.67% of variance in MCQ scores, hereafter referred to as MCQ_{Factor}. Scree plot discontinuity did not suggest additional factors: first Eigenvalue = 6.18, second Eigenvalue = 1.20. Factor loadings for

each of the individual MCQ, MCQ-L, and MCQ-S k values were all high (range = .70–.88; see Table 3). Continuous associations among variables are presented in Table 4. The primary relation of interest was the association between higher nicotine dependence severity (FTND) and greater DRD. The composite MCQ_{Factor} score was significantly correlated with FTND scores ($r = .24, p < .0001$). Of note, individual MCQ indices also exhibited significant associations with FTND, but at variable levels of effect size (M correlation = .18, range = .10–.24, $ps < .05$). FTND scores were also significantly correlated with the magnitude effects index ($r = .16, p < .001$), such that individuals with higher dependence severity showed less robust magnitude effects (i.e., higher FTND scores were associated with less negative correlation coefficients between magnitude and k). Significant associations were found between MCQ_{Factor} scores and participant demographics (sex, age, education, and income), both AUDIT subscales, and marijuana use. Significant correlations were also observed between FTND scores and several demographic variables (age, education, and income), AUDIT-QF and HZD subscales, and stimulant use.

Multiple regression was then used to examine simultaneous relationships between discounting and the other variables in relation to nicotine dependence (Table 5). The predictor variables entered into this regression were those that were significantly associated with FTND scores at $p < .05$ in the correlation analyses, including: age, education, income, AUDIT-QF, AUDIT-HZD, stimulant use, the MCQ magnitude effect index, and the MCQ_{Factor}. The overall model was significant, $R^2 = .29, F(8, 915) = 45.46, p < .001$. Each of the demographic variables along with both AUDIT indices were significant predictors of nicotine dependence severity ($ps < .01$). Stimulant use also predicted FTND score, but only at trend level ($p = .08$). The magnitude effect index was not a significant predictor of FTND score ($p = .86$). After accounting for all other variables, MCQ_{Factor} remained a significant predictor of FTND scores ($\beta = .08, p < .05, 95\% \text{ CI: } 0.03, 0.34$).

Discussion

The goal of this study was to clarify the relationship between impulsive DRD and nicotine dependence by addressing a number of methodological issues in the existing literature. Specifically, we characterized DRD across a wide variety of delayed reward magnitudes and concurrently examined several pertinent collateral variables, including both substance use and demographic variables. Using a latent index of DRD that substantially captured discounting across nine different magnitudes of monetary rewards, we found that higher MCQ_{Factor} scores, reflecting more impulsive DRD, were significantly positively associated with level of nicotine dependence. Furthermore, this single discounting factor was found to be specifically associated with nicotine dependence severity, even after accounting for comorbid substance use and age, education, and income. These findings converge with and extend the findings from previous studies in this area, providing relatively strong evidence for a specific relationship between impulsive discounting and nicotine dependence.

Several additional findings from this study are also notable. First, both the differences and similarities in discounting preferences across reward values merit discussion. As anticipated, a robust magnitude effect was present for DRD, which is consistent with prior studies (e.g., Green et al., 1997; Kirby & Marakovic, 1996), and confirms that decision-making for

smaller rewards is generally more impulsive. Nonetheless, the latent index of discounting derived from diverse reward amounts that ranged across three orders of magnitude captured more than two-thirds of the variability in DRD. This suggests that while individuals' rates of impulsive discounting decrease as a function of the monetary amounts being considered, the overall tendency to prefer immediate vs. delayed outcomes remains relatively consistent. In other words, although there were clear *absolute* differences in discounting functions across reward magnitudes, *relative* preferences corresponded across magnitudes. This is also reflected by the significant correlations across discounting indices, where, even at the smallest relationship, there was a medium magnitude correlation between discounting for the smallest and largest amounts.

The present findings also suggest that in addition to the well-documented global magnitude effects on DRD, within-magnitude context effects may also exist. Specifically, we found that magnitude effects were not as robust at the boundaries between MCQ versions. There was not a significant difference between the highest magnitude on the MCQ-S (\$8) and the lowest magnitude on the MCQ (\$30). The effect size of the difference between highest magnitude on the MCQ (\$80) and the lowest on the MCQ-L (\$300) was similarly modest. This suggests that individuals are not only sensitive to overall changes in magnitude, but they are also particularly sensitive to variation in reward magnitude in the context of a single set of items. Future studies are needed to further investigate the impact of item magnitude context on DRD magnitude effects.

Also of relevance, we directly examined whether the magnitude effect itself was related to nicotine dependence. Although a significant correlation was present, suggesting that greater dependence severity was associated with a smaller magnitude effect, it was of small magnitude and was not a significant predictor of dependence when combined with the other variables. These results provide fairly clear evidence that the overall steepness of the discounting function, not how it changes across magnitudes, is the most relevant to nicotine dependence. These results converge with prior studies that have found that magnitude effects and smoking severity are largely independent (e.g., Baker et al., 2003; Johnson et al., 2007).

These results also clarify which collateral variables are associated with DRD in smokers. One such variable, age, has been found to be inversely related to discounting in healthy participants (Green, Fry, & Myerson, 1994; Green, Myerson, Lichtman, Rosen, & Fry, 1996; Olson, Hooper, Collins, & Luciana, 2007) and smokers (Yoon et al., 2007). However, a different study of smokers found steeper DRD in adult smokers compared to adolescent smokers (Reynolds, 2004). Methodological differences between these studies, particularly in the case of reward magnitude (\$1000 vs. \$10 delayed reward) and age, may have contributed to these inconsistent findings. Here, we found that a single index of discounting that encompasses a range of reward amounts akin of each of these studies was positively associated with age in smokers, which is consistent with the study by Reynolds (2004). Although it is speculation, impulsive DRD has been consistently associated with smoking cessation treatment failure (Krishnan-Sarin et al., 2007; MacKillop & Kahler, 2009; Sheffer et al., 2012), which could play a role in these findings. More specifically, the younger smokers in this study may reflect a group comprised of individuals of more variable

discounting preferences for whom a proportion will ultimately successfully quit. In contrast, the older smokers may reflect individuals with more uniformly high levels of impulsive DRD who have not been able to successfully quit. This is conjecture, but is worth exploring further in future studies.

In a similar fashion, our data also speak to the relationship between DRD and other demographic variables in smokers. For example, MacKillop & Kahler (2009) found that higher income was significantly correlated with decreased DRD on the MCQ (average magnitude = \$.55). Here, we replicate this association using a more extensive DRD assessment across magnitudes. Our results also replicate the negative association between DRD and level of education reported in previous smoking studies (Jaroni, Wright, Lerman, & Epstein, 2004; Yoon et al., 2007). The present data also further characterize the relationship between DRD and other addictive behaviors among smokers. Impulsive DRD was positively associated with both alcohol use and misuse, though the absolute magnitude of these associations was modest. These findings are generally consistent with previous studies (e.g., Field, Christiansen, Cole, & Goudie, 2007; MacKillop et al., 2010; J. M. Mitchell, Fields, D'Esposito, & Boettiger, 2005; Vuchinich & Simpson, 1998). However, DRD was not significantly associated with stimulant or opiate use, which is inconsistent with several previous studies focusing on those behaviors (e.g., Coffey, Gudleski, Saladin, & Brady, 2003; Kirby et al., 1999; Madden, Bickel, & Jacobs, 1999; Monterosso et al., 2007). This is surprising, although those studies were not in samples of exclusively smokers and did not systematically examine nicotine dependence also, making comparisons difficult. Also surprising was that increased frequency of marijuana use was associated with less impulsive DRD in this sample, which has not been observed previously. However, a recent study of DRD in marijuana-dependent individuals and controls found no significant differences (Johnson et al., 2010), which suggests the relationship between marijuana use and DRD may be different from the general patterns in the literature. Given the relatively large number of correlations examined, it is also possible this association arose by chance. As relatively few studies have been conducted on DRD and marijuana use, future studies will be needed to address these possibilities.

Importantly, these findings should be viewed in the context of several methodological considerations. It is worth noting that the assessments of illicit drug use were somewhat coarse, pertaining only to measures of drug use frequency. However, a substantial portion of the sample used marijuana on at least an occasional basis and approximately half of the sample also frequently used stimulants and opiates, suggesting that the results were not simply an artifact of low rates of use. Nonetheless, we were unable to account for clinical severity associated with illicit drug use or the quantity of drug use, both of which should be addressed in future research. With regard to generalizability, a consideration is that the sample was majority male, white, and of relatively low income and education level. Also notable is that all the DRD outcomes were hypothetical and it is not known whether participants' preferences for immediate versus delayed outcomes may have been different had actual money been at stake. This is addressed to an extent by previous studies that have found a close correspondence between DRD assessments for actual and hypothetical monetary rewards (Bickel, Pitcock, Yi, & Angtuaco, 2009; Johnson & Bickel, 2002; Madden, Begotka, Raiff, & Kastern, 2003). Based on this, we would predict that using a task

using actual outcomes would yield qualitatively similar findings, but this is an empirical question.

As a final point, the current study offers a potentially important methodological contribution. This is the first study, to our knowledge, that has used PCA to generate a latent DRD index across different reward magnitudes. The PCA-based index captured the majority of variance across magnitudes and the individual indices exhibited robust factor loadings, from .70–.88. Further, the magnitude of the relationship between nicotine dependence and the latent index was generally larger than the relationships when the MCQ indices were examined individually. The only exception was the small magnitude on the MCQ-L, which had the same effect size relationship with dependence. This suggests that using a factor analytic approach did not dilute the relationship between dependence and DRD, but actually brought it into somewhat sharper relief. These results illustrate several advantages of using PCA to derive a single index of DRD across magnitudes. First, a single index limits the number discounting metrics in statistical analyses, reducing Type I error rate. Second, this approach creates a variable that is largely independent of reward amounts. This is potentially important in light of variability in the size of the observed associations between dependence and the individual DRD indices assessed here. Finally, it is possible that a PCA-derived index provides a more reliable estimate of DRD preferences because of its cross-magnitude nature, although this is an empirical question for future research. Taken together, the findings of the current study suggest that a PCA-based approach offers substantial benefits at relatively modest costs.

In sum, the current study sought to clarify the relationship between impulsive DRD and nicotine dependence by examining discounting preferences across a number of reward magnitudes and incorporating a number of potential confounding variables. Using a latent composite of DRD, impulsive discounting was indeed significantly associated with nicotine dependence and this association remained when considered in integrative models. These findings provide further evidence for a specific relationship between impulsivity and nicotine dependence, identify important collateral factors that should be considered in understanding the relationship, and suggest the utility of a factor analytic approach in creating a representative latent index of discounting.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This project was partially supported by grants from the Substance Abuse Policy Research Program of the Robert Wood Johnson Foundation (JM) and the National Institutes of Health (NIH) (K23 AA016936; JM). Dr. Amlung is currently supported by a postdoctoral fellowship awarded from the NIH to the University of Missouri (T32 AA013526). The sponsors played no role in study design, data collection, data analysis, interpretation, or manuscript preparation. The authors are grateful to James Murphy, PhD; Maureen Carrigan, PhD; Lauren R. Few, PhD; John Acker, MS; Cara Murphy, MS; Monika Stojek, MS; Lauren M. Wier, MPH for contributions to the parent project.

References

- Baker F, Johnson MW, Bickel WK. Delay discounting in current and never-before cigarette smokers: similarities and differences across commodity, sign, and magnitude. *J Abnorm Psychol.* 2003; 112(3):382–392.10.1037/0021-843X.112.3.382 [PubMed: 12943017]
- Bickel WK, Odum AL, Madden GJ. Impulsivity and cigarette smoking: delay discounting in current, never, and ex-smokers. *Psychopharmacology (Berl).* 1999; 146(4):447–454.10.1007/PL00005490 [PubMed: 10550495]
- 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(27):8839–8846.10.1523/JNEUROSCI.5319-08.2009 [PubMed: 19587291]
- Centers for Disease Control and Prevention. Smoking attributable mortality, years of potential life lost, and productivity losses--United states, 2000–2004. *Morbidity and Mortality Weekly Report.* 2008; 57(45):1226–1228. [PubMed: 19008791]
- Coffey SF, Gudleski GD, Saladin ME, Brady KT. Impulsivity and rapid discounting of delayed hypothetical rewards in cocaine-dependent individuals. *Exp Clin Psychopharmacol.* 2003; 11(1): 18–25.10.1037/1064-1297.11.1.18 [PubMed: 12622340]
- Dani JA, Harris RA. Nicotine addiction and comorbidity with alcohol abuse and mental illness. *Nat Neurosci.* 2005; 8(11):1465–1470.10.1038/nn1580 [PubMed: 16251989]
- Degenhardt L, Hall W. The relationship between tobacco use, substance-use disorders and mental health: results from the National Survey of Mental Health and Well-being. *Nicotine Tob Res.* 2001; 3(3):225–234.10.1080/14622200110050457 [PubMed: 11506766]
- Field M, Christiansen P, Cole J, Goudie A. Delay discounting and the alcohol Stroop in heavy drinking adolescents. *Addiction.* 2007; 102(4):579–586.10.1111/j.1360-0443.2007.01743.x [PubMed: 17309540]
- Green L, Fry AF, Myerson J. Discounting of delayed rewards: A life-span comparison. *Psychological Science.* 1994; 5(1):33–36.10.1111/j.1467-9280.1994.tb00610.x
- Green L, Myerson J, Lichtman D, Rosen S, Fry A. Temporal discounting in choice between delayed rewards: the role of age and income. *Psychol Aging.* 1996; 11(1):79–84.10.1037/0882-7974.11.1.79 [PubMed: 8726373]
- Green L, Myerson J, McFadden E. Rate of temporal discounting decreases with amount of reward. *Memory and Cognition.* 1997; 25:715–723.10.3758/BF03211314 [PubMed: 9337589]
- Heatherton TF, Kozlowski LT, Frecker RC, Fagerstrom KO. The Fagerstrom Test for Nicotine Dependence: A revision of the Fagerstrom Tolerance Questionnaire. *British Journal of Addiction.* 1991; 86:1119–1127.10.1111/j.1360-0443.1991.tb01879.x [PubMed: 1932883]
- Heyman GM, Gibb SP. Delay discounting in college cigarette chippers. *Behav Pharmacol.* 2006; 17(8):669–679.10.1097/FBP.0b013e3280116cfe [PubMed: 17110793]
- Jaroni JL, Wright SM, Lerman C, Epstein LH. Relationship between education and delay discounting in smokers. *Addict Behav.* 2004; 29(6):1171–1175.10.1016/j.addbeh.2004.03.014 [PubMed: 15236819]
- Johnson MW, Bickel WK. Within-subject comparison of real and hypothetical money rewards in delay discounting. *J Exp Anal Behav.* 2002; 77(2):129–146.10.1901/jeab.2002.77-129 [PubMed: 11936247]
- Johnson MW, Bickel WK, Baker F. Moderate drug use and delay discounting: a comparison of heavy, light, and never smokers. *Exp Clin Psychopharmacol.* 2007; 15(2):187–194.10.1037/1064-1297.15.2.187 [PubMed: 17469942]
- Johnson MW, Bickel WK, Baker F, Moore BA, Badger GJ, Budney AJ. Delay discounting in current and former marijuana-dependent individuals. *Exp Clin Psychopharmacol.* 2010; 18(1):99–107.10.1037/a0018333 [PubMed: 20158299]
- Kirby KN, Marakovic NN. Delay-discounting probabilistic rewards: Rates decrease as amounts increase. *Psychonomic Bulletin & Review.* 1996; 9(1):100–104.10.3758/BF03210748 [PubMed: 24214810]

- Kirby KN, Petry NM, Bickel WK. Heroin addicts have higher discount rates for delayed rewards than non-drug-using controls. *J Exp Psychol Gen.* 1999; 128(1):78–87.10.1037/0096-3445.128.1.78 [PubMed: 10100392]
- Krishnan-Sarin S, Reynolds B, Duhig AM, Smith A, Liss T, McFetridge A, Potenza MN. Behavioral impulsivity predicts treatment outcome in a smoking cessation program for adolescent smokers. *Drug Alcohol Depend.* 2007; 88(1):79–82.10.1016/j.drugalcdep.2006.09.006 [PubMed: 17049754]
- MacKillop, J.; Amlung, M.; Murphy, CM.; Acker, J.; Ray, LA. A behavioral economic approach to health behavior. In: DiClemente, R.; Salazar, LF.; Crosby, RA., editors. *Theory and Practice for a New Public Health.* Sudbury, MA: Jones and Bartlett Publishers; 2011. p. 131-162.
- MacKillop J, Amlung MT, Few LR, Ray LA, Sweet LH, Munafo MR. Delayed reward discounting and addictive behavior: a meta-analysis. *Psychopharmacology (Berl).* 2011; 216(3):305–321.10.1007/s00213-011-2229-0 [PubMed: 21373791]
- MacKillop J, Few LR, Murphy JG, Wier LM, Acker J, Murphy C, Chaloupka F. High-resolution behavioral economic analysis of cigarette demand to inform tax policy. *Addiction.* 2012; 107(12):2191–2200.10.1111/j.1360-0443.2012.03991.x [PubMed: 22845784]
- MacKillop J, Kahler CW. Delayed reward discounting predicts treatment response for heavy drinkers receiving smoking cessation treatment. *Drug Alcohol Depend.* 2009; 104(3):197–203.10.1016/j.drugalcdep.2009.04.020 [PubMed: 19570621]
- MacKillop J, Miranda R Jr, Monti PM, Ray LA, Murphy JG, Rohsenow DJ, Gwaltney CJ. Alcohol demand, delayed reward discounting, and craving in relation to drinking and alcohol use disorders. *Journal of Abnormal Psychology.* 2010; 119(1):106–114.10.1037/a0017513 [PubMed: 20141247]
- Madden GJ, Begotka AM, Raiff BR, Kastern LL. Delay discounting of real and hypothetical rewards. *Exp Clin Psychopharmacol.* 2003; 11(2):139–145.10.1037/1064-1297.11.2.139 [PubMed: 12755458]
- Madden, GJ.; Bickel, WK., editors. *Impulsivity: The Behavioral and Neurological Science of Discounting.* Washington, D.C: American Psychological Association; 2009.
- Madden GJ, Bickel WK, Jacobs EA. Discounting of delayed rewards in opioid-dependent outpatients: exponential or hyperbolic discounting functions? *Exp Clin Psychopharmacol.* 1999; 7(3):284–293.10.1037/1064-1297.7.3.284 [PubMed: 10472517]
- Maisto SA, Conigliaro J, McNeil M, Kraemer K, Kelley ME. An empirical investigation of the factor structure of the AUDIT. *Psychol Assess.* 2000; 12(3):346–353.10.1037/1040-3590.12.3.346 [PubMed: 11021159]
- Mitchell JM, Fields HL, D'Esposito M, Boettiger CA. Impulsive responding in alcoholics. *Alcohol Clin Exp Res.* 2005; 29(12):2158–2169.10.1097/01.alc.0000191755.63639.4a [PubMed: 16385186]
- Mitchell SH. Measures of impulsivity in cigarette smokers and non-smokers. *Psychopharmacology (Berl).* 1999; 146(4):455–464. 91460455.213 [pii]. [PubMed: 10550496]
- Mokdad AH, Marks JS, Stroup DF, Gerberding JL. Actual causes of death in the United States. *Journal of the American Medical Association.* 2004; 291(10):1238–1245.10.1001/jama.1993.03510180077038 [PubMed: 15010446]
- Monterosso JR, Ainslie G, Xu J, Cordova X, Domier CP, London ED. Frontoparietal cortical activity of methamphetamine-dependent and comparison subjects performing a delay discounting task. *Hum Brain Mapp.* 2007; 28(5):383–393.10.1002/hbm.20281 [PubMed: 16944492]
- Ohmura Y, Takahashi T, Kitamura N. Discounting delayed and probabilistic monetary gains and losses by smokers of cigarettes. *Psychopharmacology (Berl).* 2005; 182(4):508–515.10.1007/s00213-005-0110-8 [PubMed: 16167142]
- Olson EA, Hooper CJ, Collins P, Luciana M. Adolescents' performance on delay and probability discounting tasks: contributions of age, intelligence, executive functioning, and self-reported externalizing behavior. *Pers Individ Dif.* 2007; 43(7):1886–1897.10.1016/j.paid.2007.06.016 [PubMed: 18978926]
- Reynolds B. Do high rates of cigarette consumption increase delay discounting? A cross-sectional comparison of adolescent smokers and young-adult smokers and nonsmokers. *Behav Processes.* 2004; 67(3):545–549.10.1016/j.beproc.2004.08.006 [PubMed: 15519004]

- 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(3):333–344.10.1016/S0376-6357(03)00168-2 [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(1):35–42.10.1016/S0376-6357(03)00109-8 [PubMed: 14744545]
- Saunders JB, Aasland OG, Babor TF, de la Fuente JR, Grant M. Development of the Alcohol Use Disorders Identification Test (AUDIT): WHO collaborative project on early detection of persons with harmful alcohol consumption. II. *Addiction*. 1993; 88:791–804.10.1111/j.1360-0443.1993.tb02093.x [PubMed: 8329970]
- Sheffer C, Mackillop J, McGeary J, Landes R, Carter L, Yi R, Bickel W. Delay discounting, locus of control, and cognitive impulsiveness independently predict tobacco dependence treatment outcomes in a highly dependent, lower socioeconomic group of smokers. *Am J Addict*. 2012; 21(3):221–232.10.1111/j.1521-0391.2012.00224.x [PubMed: 22494224]
- Sweitzer MM, Donny EC, Dierker LC, Flory JD, Manuck SB. Delay discounting and smoking: association with the Fagerstrom Test for Nicotine Dependence but not cigarettes smoked per day. *Nicotine Tob Res*. 2008; 10(10):1571–1575.10.1080/14622200802323274 [PubMed: 18946776]
- Tabachnick, BG.; Fidell, LS. *Using Multivariate Statistics*. 4. Needham Heights, MA: Allyn & Bacon; 2001.
- Vuchinich RE, Simpson CA. Hyperbolic temporal discounting in social drinkers and problem drinkers. *Exp Clin Psychopharmacol*. 1998; 6(3):292–305.10.1037/1064-1297.6.3.292 [PubMed: 9725113]
- World Health Organization. *World Health Organization report on the global tobacco epidemic 2011: Warning about the dangers of tobacco*. Washington, DC: 2011.
- Yoon JH, Higgins ST, Heil SH, Sugarbaker RJ, Thomas CS, Badger GJ. Delay discounting predicts postpartum relapse to cigarette smoking among pregnant women. *Exp Clin Psychopharmacol*. 2007; 15(2):176–186.10.1037/1064-1297.15.2.186 [PubMed: 17469941]

Table 1

Participant Characteristics

	Mean (SD)/%
N	933
Sex	61% Male; 39% Female
Age	31.61 (12.70)
Race	White: 66%; African American: 26%; Asian: 3%; Mixed Race: 3%; American Indian/Alaskan Native: .4%; Pacific Islander: .1%; Other: 1%;
Hispanic Ethnicity	2.4%
Income	<\$15k: 52%; \$15–30k: 21%; \$30–45k: 7%; \$45–60k: 3%; \$60–75k: 4%; \$75–90k: 3%; \$90–105k: 2%; \$105–120k: 3%; >\$120,000: 5%
Education (years)	12.74 (2.23)
Cigarettes/Day	16.25 (11.07)
FTND	4.16 (2.44)
AUDIT-QF	4.99 (3.37)
AUDIT-HZD	4.36 (5.47)
Marijuana Use	Regular: 42%; Occasional: 45%; None: 13%
Stimulant Use	Regular: 9%; Occasional: 37%; None: 54%
Opiate Use	Regular: 15%; Occasional: 32%; None: 53%

Note: SD: standard deviation; AUDIT-QF: Quantity/frequency subscale of Alcohol Use Disorders Identification Test; AUDIT-HZD: Hazardous use subscale of the Alcohol Use Disorders Identification Test; FTND – Fagerström Test of Nicotine Dependence; For drug use variables, regular use reflects weekly or greater use, occasional use reflects monthly use.

Table 2

Delay Discounting across MCQ Versions and Reward Magnitudes

		Small Magnitude	Medium Magnitude	Large Magnitude
MCQ-S	Reward Range	\$2.50–3.50	\$5–\$6	\$7.50–\$8.50
	Mean (<i>SE</i>) <i>k</i>	0.144 (0.003)	0.117 (0.003)	0.100 (0.003)
MCQ	Reward Range	\$25–35	\$50–60	\$75–85
	Mean (<i>SE</i>) <i>k</i>	0.097 (0.003)	0.078 (0.003)	0.061 (0.003)
MCQ-L	Reward Range	\$250–350	\$500–600	\$750–850
	Mean (<i>SE</i>) <i>k</i>	0.056 (0.003)	0.047 (0.003)	0.040 (0.003)

Note: *N* = 933; MCQ = multiple choice questionnaire standard version; MCQ-S = multiple choice questionnaire small version; MCQ-L = multiple choice questionnaire large version; *SE* = standard error of the mean

Table 3
Factor Loadings on the MCQ_{Factor} Latent Index Scores and Correlations among the Individual MCQ k Values.

	FL	2	3	4	5	6	7	8	9	10
MCQ _{Factor}	—									
2. MCQ-S (\$3)	.70	—								
3. MCQ-S (\$5.50)	.82	.83	—							
4. MCQ-S (\$8)	.84	.74	.84	—						
5. MCQ (\$30)	.83	.56	.63	.62	—					
6. MCQ (\$55)	.88	.54	.64	.64	.81	—				
7. MCQ (\$80)	.87	.47	.59	.59	.75	.83	—			
8. MCQ-L (\$300)	.85	.44	.57	.60	.65	.69	.69	—		
9. MCQ-L (\$550)	.85	.42	.54	.60	.61	.68	.71	.86	—	
10. MCQ-L (\$800)	.81	.34	.50	.56	.55	.65	.72	.81	.89	—

Note: $N = 933$; All correlations significant at $p < .001$; MCQ_{Factor} = Delay discounting factor score from principal components analysis; FL = Factor loading; MCQ = multiple choice questionnaire standard version; MCQ-S = multiple choice questionnaire small version; MCQ-L = multiple choice questionnaire large version; Monetary values in parentheses correspond to mean reward magnitudes for each version.

Table 4

Correlations between Nicotine Dependence and Delay Discounting, Demographic Variables, and Alcohol and Drug Use

	1	2	3	4	5	6	7	8	9	10	11	12
1. FTND	—											
2. MCQ _{Factor}	.24***	—										
3. MCQ _{Magnitude}	.16***	.44***	—									
4. Sex	-.06	-.10**	-.02	—								
5. Age	.45***	.27***	.17***	-.02	—							
6. Education	-.27***	-.22***	-.22***	.01	-.17***	—						
7. Income	-.32***	-.17***	-.11**	.03	-.33***	.16***	—					
8. AUDIT-QF	-.15***	.07*	-.05	-.16***	-.23***	.10**	.16***	—				
9. AUDIT-HZD	.09**	.10*	.10**	-.10**	.02	-.03	-.05	.53***	—			
10. Marijuana Use	-.05	-.11**	-.07*	-.05	-.20***	.06	.07*	.20***	.07*	—		
11. Stimulant Use	.13***	-.02	-.02	-.09**	.19***	.03	-.07*	.08*	.15***	.30***	—	
12. Opiate Use	.02	-.06	.05	-.04	-.05	.04	.03	.16***	.17***	.32***	.45***	—

Note: $n = 933$ (FTND, MCQ_{Factor}, MCQ_{Magnitude}, Age, AUDIT-QF, and AUDIT-HZD); $n = 929$ (Education); $n = 927$ (Income); $n = 924$ (Sex); $n = 922$ (Opiate Use); $n = 918$ (Marijuana Use). Missing data were excluded on a pairwise basis for each correlation. FTND = Fagerström Test of Nicotine Dependence; MCQ_{Factor} = Delay discounting factor score from principal components analysis; MCQ_{Magnitude} = Magnitude effect index reflecting correlation between individual k values and corresponding reward amounts by participant; Sex: 1 = Male, 2 = Female; AUDIT = Alcohol Use Disorders Identification Test; QF = quantity-frequency subscale; HZD = hazardous use subscale;

* $p < .05$;

** $p < .01$;

*** $p < .001$.

Table 5

Simultaneous Linear Regression Investigating Demographic Variables, Alcohol and Drug use, and Delay Discounting as Predictors of Nicotine Dependence Severity (FTND)

Variable	<i>B</i>	<i>SE</i>	95% CI	β
Age	0.06	0.01	0.05, 0.07	.32***
Education	-0.19	0.03	-0.25, -0.13	-.17***
Income	-0.16	0.03	-0.23, -0.10	-.15***
AUDIT-QF	-0.07	0.03	-0.12, -0.02	-.10**
ADUIT-HZD	0.05	0.02	0.02, 0.08	.12**
Stimulant Use	0.18	0.11	-0.03, 0.40	.05 [†]
MCQ _{Magnitude}	-0.04	0.23	-0.50, 0.42	-.01
MCQ _{Factor}	0.18	0.08	0.03, 0.34	.08*

Note: $n = 916$. MCQ_{Factor} = Delay discounting factor score from principal components analysis; MCQ_{Magnitude} = Magnitude effect index reflecting correlation between individual k values and corresponding reward amounts by participant; B = Unstandardized regression coefficients; SE = Standard Errors; β = Standardized regression coefficients; CI = Confidence interval.

[†] $p = .08$;

* $p < .05$;

** $p < .01$;

*** $p < .001$.