Published in final edited form as:

Pers Individ Dif. 2007 November ; 43(7): 1886–1897.

Adolescents' performance on delay and probability discounting tasks: contributions of age, intelligence, executive functioning, and self-reported externalizing behavior

Elizabeth A. Olson^{*}, Catalina J. Hooper, Paul Collins, and Monica Luciana

Department of Psychology and Institute of Child Development, University of Minnesota, Twin Cities Campus, Minneapolis, MN, US

Abstract

Healthy adolescents, ages 9–23, completed delay and probability discounting tasks and measures of verbal and nonverbal intelligence, executive functioning, and self-reported internalizing and externalizing behavior. Delay but not probability discounting decreased with age. Delay discounting was also associated with verbal intelligence and Go-NoGo and Iowa Gambling Task performance. Probability discounting was associated only with externalizing behavior. Findings conform to an accumulation of evidence that while delay and probability discounting may have some overlapping components, they also reflect some fundamentally different processes in this age group.

Keywords

delay discounting; probability discounting; adolescence; development; executive functioning; externalizing

Introduction

Adolescents are overrepresented in most categories of reckless behavior (Arnett, 1992), including reckless driving, unsafe sex, and substance use. Their general lack of consideration of future consequences as well as underestimation of negative consequences has led some to describe adolescents as impulsive. Impulsivity can be defined as the inability to consider future events, or the preference for small immediate rewards over larger delayed rewards (Ainslie, 1975). Studying how adolescents evaluate rewards in different temporal and probabilistic contexts may illuminate why their behavior often differs from adults'.

Generally, humans prefer large to small, immediate to delayed, and guaranteed to uncertain rewards. However, as the delay preceding delivery of a larger reward increases, or the likelihood of receiving a larger reward decreases, the reward's subjective value decreases. This decline results in a tendency to choose small immediate/certain rewards instead of larger delayed/uncertain rewards. Declines in subjective value attributable to the time of reward delivery are termed *delay discounting*. Declines that relate to the reward's uncertainty are termed *probability discounting*. Discounting tasks require participants to choose between

^{*} Corresponding author. Address: Department of Psychology, N218 Elliott Hall, 75 East River Road, Minneapolis, MN 55455, Phone: 612-624-4054, Fax: 612-626-2079, E-mail: olso3663@umn.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

smaller immediate/certain rewards versus larger delayed/uncertain rewards, allowing the effects of manipulating delays and probabilities to be quantified (Madden et al., 2004; Mazur, 1987; Richards, Zhang, Mitchell, & de Wit, 1999).

Developmental trends in delay discounting are evident. Delay discounting decreases with maturation in 6–17 year-olds (Scheres et al., 2006). Green, Fry, and Myerson (1994) found that children discount delayed rewards more steeply than college-aged adults, who discount more steeply than older adults. Green, Myerson, Lichtman, Rosen, and Fry (1996) found similar discounting rates in 30- to 70-year-olds. Overall these patterns suggest that discounting rates asymptote in early adulthood. Probability discounting has been less extensively studied. Sheres et al. (2006) reported no changes in probability discounting rates between ages 6 and 17.

It has been suggested that the two types of discounting may be similar because they both entail risk; while probability discounting explicitly involves risk, delay discounting may involve risk because there is increasing likelihood that something will happen to prevent the receipt of the reward at greater delays (Green & Myerson, 1996; Myerson, Green, Hanson, Holt, & Estle, 2003). Alternatively, Rachlin, Logue, Gibbon, and Frankel (1986) argue that delay and probability discounting are similar because probabilistic rewards are conceptualized as repeated gambles, with lower probabilities implying a longer wait until the reward is received. Finally, it has been hypothesized that a general trait of impulsivity may underlie both delay and probability discounting. Specifically, impulsive individuals are expected to discount improbable rewards *less* than non-impulsive individuals, consistent with increased risk-taking, and to discount future rewards *more* than non-impulsive individuals, consistent with disregard for future outcomes (Green & Myerson, 2004). This latter model would predict that delay and probability discounting would be inversely correlated. However, the two discounting tasks are either positively correlated (Holt, Green, & Myerson, 2003; Richards et al., 1999) or uncorrelated (Ohmura, Takahashi, & Kitamura, 2005) in adults. This is more consistent with theories suggesting that delay and probability discounting are similar because delay discounting may be conceptualized in terms of probability of reward, or probability discounting may be conceptualized in terms of delay to reward delivery. However, manipulating a given variable does not always similarly impact both tasks. Experiments in adults and non-human animals indicate that increasing the delayed reward's magnitude has opposite effects on delay and probability discounting: smaller delayed rewards are discounted more steeply than larger rewards, while smaller probabilistic rewards are discounted less steeply than larger rewards, suggesting that separate processes may underlie delay and probability discounting (Green & Myerson, 2004; Green, Myerson, & Ostaszewski, 1999; Holt et al., 2003).

Relations with impulsivity have been examined using personality measures. In adults, findings for delay discounting are inconsistent, with some reports of associations with self-reported impulsivity/disinhibition (de Wit, Flory, Acheson, McCloskey, & Manuck, 2007; Madden, Petry, Badger, & Bickel, 1997; Richards et al., 1999) but also negative findings (Dom, D'Haene, Hulstijn, & Sabbe, 2006; Reynolds, Ortengren, Richards, & de Wit, 2006a). Positive correlations between probability discounting and extroversion/disinhibition (Richards et al., 1999) have been observed. These associations have not been studied in developmental samples.

Altered discounting behavior has been observed in psychopathological conditions. Delay discounting rates are elevated in adolescent smokers (Audrain-McGovern et al., 2004), adolescents with ADHD (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001), adult gamblers (Dixon, Marley, & Jacobs, 2003), adult alcoholics (Dom et al., 2006), and adult opiate addicts (Madden et al., 1997). Holt et al. (2003) found that college-aged gamblers discounted probabilistic rewards less steeply than non-gamblers, with no group difference in delay discounting. These findings may reflect the hypothesized impulsivity/discounting association. Alternatively, relations between discounting and other executive functions may mediate these

associations. For instance, response control might be better in individuals who forgo immediate gains (but see Reynolds et al., 2006a).

Recently, de Wit et al. (2007) reported that intelligence inversely correlates with delay discounting in adults. Most studies of discounting have not controlled for intelligence, so the ramifications of this finding are unclear. It is also unknown whether IQ effects vary over the course of typical development.

Thus, although the developmental literature has demonstrated continuing maturation of delay discounting, probability discounting has been examined less thoroughly. Examining trends in both types of discounting in a developmental sample may illuminate the extent to which they reflect a single underlying process. The effects of intelligence, executive functioning, and self-reported impulsivity on the two forms of discounting also remain to be delineated in relation to adolescent development given the pronounced changes in motivational systems that are occurring during this time (Chambers, Taylor, & Potenza, 2003). Accordingly, the current study was designed to examine the relative contributions of age, executive functioning, IQ, and self-reported impulsivity to delay and probability discounting in adolescents.

Method

Participants ages 9 to 23 years were recruited. Individuals under age 18 were recruited from a parent volunteer database. Individuals in the target age range were identified, telephoned, and invited to participate in a study of adolescent brain development. The second recruitment method was to mail postcards to University staff members inviting children's participation. Individuals ages 18 and up were recruited through posted advertisements at the University. Inclusion criteria included being 9 to 23-years-old, being a native English speaker, having normal or corrected-to-normal vision and hearing, and having no history of neurological or psychological illness, mental retardation, or learning difficulties. Participants also completed a neuroimaging study. All were right-handed without contraindications to MRI testing. These criteria were assessed through parent and child interviews using the Kiddie-SADS-Present and Lifetime Version (K-SADS-PL: Kaufman et al., 1997) and an in-house health questionnaire. Intelligence was measured by the four subtests of the Wechsler Abbreviated Scale of Intelligence (WASI: The Psychological Corporation, 1999). Participants and parents provided informed consent or assent according to local IRB requirements.

Table 1 summarizes demographic data. Participants under versus over age 18 were demographically compared given the use of different recruitment strategies. The groups were comparable in gender, ethnicity, paternal education, annual family income, and IQs. Mothers of younger participants reported higher years of education than those of older participants (see Table 1). This difference, while significant, is unlikely to be meaningful. Both groups of mothers completed several years of college, on average, and there were no significant differences in paternal education or family income. Expectedly, the groups differed in age.

Participants completed a three-hour screening session on one day and were tested on another day. Testing included a structural magnetic resonance imaging scan (not discussed here) and a neurocognitive battery. Measures discussed here include the Delay/Probability Discounting Task, a Go-NoGo task, and the Iowa Gambling Task. All tasks were programmed in E-prime and administered in the same order to all participants. Age-appropriate self-report forms from the Achenbach System of Empirically Based Assessment (ASEBA: Achenbach & Rescorla, 2001) were administered.

Delay/Probability Discounting Task (Richards et al., 1999)

On each trial, participants chose between an immediate amount of money or \$10 available after a delay (i.e., “Would you rather have \$2 now or \$10 in 30 days?”). On probability trials, the choice was between a certain amount of money or \$10 available with a given probability. The immediate/certain amount was determined by a random adjusting-amount procedure (Richards et al., 1999) involving random selection within a fixed interval that depends on previous choices. Task instructions appeared onscreen and were read aloud. Afterwards, the computer ‘randomly’ selected one trial and the participant received a cash payment based on that trial. (Although participants were told that all trials had an equal chance of being selected, selections were constrained without their knowledge to choices involving immediate payoffs for pragmatic reasons). Although it has been demonstrated that adults discount real and hypothetical rewards to similar degrees (Madden et al., 2004), provision of a real reward appeared to increase participants’ attention and task enjoyment.

Discounting was assessed at six delays (1, 2, 10, 30, 180, and 365 days later) and five probabilities (25, 50, 75, 90, and 95% chance of winning). Participants ages 11 through 23 completed both tasks; 9 and 10 year-olds completed the delay task only, because the overall protocol was too lengthy for them to complete in a reasonable timecourse.

Go-NoGo Task (Braver, Barch, Gray, Molfese, & Snyder 2001; Hooper, Luciana, Conklin, & Yarger, 2004)

Stimulus letters (20% X’s) were presented consecutively onscreen for 250 ms. The interstimulus interval was 1000 ms. Participants responded to non-Xs, which were frequent (80% occurrence), eliciting a bias to respond. Responding had to be inhibited to X’s. Outcome measures included hit rate (that is, correct responses to non-X’s) and false alarm rate (that is, errors of commission in which a response was made to an X). A second target detection trial block required responses only to Xs (20% frequency); because performance on this block showed very little variability, with high accuracy overall, it was excluded from further analysis. Task performance reflects behavioral inhibition, that is, the ability to withhold a prepotent motor response (Braver et al., 2001).

Iowa Gambling Task (Bechara, Damasio, Damasio, & Anderson, 1994)

Participants selected from four decks of cards varying in rewards and punishments. Decks 1 and 2 yielded \$0.25 for each selection; over 20 selections, a net loss of \$1.25 was incurred. Decks 3 and 4 yielded \$0.10 or \$0.15 for each selection; over 20 selections, a net gain of \$1.25 was incurred. Thus, Decks 3 and 4 are advantageous (‘good’), yielding smaller immediate rewards and long-term gains. Decks 1 and 2 are disadvantageous (‘bad’), yielding larger immediate rewards and long-term losses. Deck 1/3 and 2/4 differ in punishment frequency: Decks 1 and 3 yield frequent (50%) small losses and Decks 2 and 4 yield infrequent (10%) large losses. Participants received feedback with each trial; those with positive net earnings were paid that amount. Task performance reflects decision-making based on implicit contingencies in the context of personally relevant motivational influences on behavior; the extent to which individuals prefer the high immediate reward decks may reflect risk-taking or impulsivity (Bechara et al., 1994; Bechara, Tranel, & Damasio, 2000).

ASEBA

Participants ages 17 and under completed the Youth Self-Report; those ages 18 and up completed the Adult Self-Report (Achenbach & Rescorla, 2001). The ASR and YSR include eight subscales assessing symptoms of DSM-IV psychopathology and an “other problems” scale. Internalizing is computed by summing scores on the Anxious/Depressed, Withdrawn/

Depressed, and Somatic Complaints subscales. Externalizing is computed by summing scores on the Rule-Breaking and Aggressive Behavior subscales.

Data were analyzed using SPSS for Windows, version 12.0.0 (SPSS Inc., Chicago, IL). Data were inspected for normality prior to using parametric statistics. Alpha levels of .05 were employed. Correlations identified variables associated with discounting behavior; significant associations were then examined using hierarchical regressions to assess whether correlates independently contributed to discounting.

Discounting analysis—The adjusting-amount procedure (Richards et al., 1999) results in the establishment of one indifference point for each delay/probability interval. Indifference points reflect the subjective value of the delayed or probabilistic amount at a given delay. Indifference points were established within participants at each interval and plotted against time (delay) or odds against (probability). Following Myerson, Green, and Warusawitharana (2001), the areas under these discounting curves (AUC) were calculated by summing the resulting trapezoids. The AUC method of quantifying discounting behavior is frequently used (e.g. Dixon et al., 2003; Du, Green, & Myerson, 2002; Ohmura et al., 2005)) and provides a straightforward measure of discounting that is not linked to any theoretical framework (Myerson et al., 2001).

Validity of Discounting Data—Participants may produce inconsistent or erratic discounting behavior due to inattention and/or poor motivation. Indifference points should decrease as the time until or odds against reward delivery increases. Otherwise, discounting behavior is absent. Erratic performers are typically excluded (Dixon et al., 2005; Reynolds, Richards, & de Wit, 2006b; Reynolds & Schiffbauer, 2004).

Consistent discounting behavior was defined as having at least two decreases in subjective value (indifference point) and not more than one increase in subjective value as time or odds against increased (Dixon et al., 2005; Dixon et al., 2003). Since the subjective value at the first point (time=0 or odds against=0) is assumed to be \$10, a value lower than \$10 at the first point assessed (time=1 day or odds against= .0526) was counted as a decrease.

Of 111 participants completing the DD task, 91 showed consistent discounting. Of 92 participants completing the PD task, 82 showed consistent discounting. Compared to consistent delay discounters, inconsistent delay discounters had significantly lower Verbal IQ's, $F(1,109)=9.206, p<.01$, and Full Scale IQ's, $F(1,108)=6.998, p<.01$. Otherwise, inconsistent and consistent discounters were comparable in age, gender, ethnicity, maternal/paternal education, family income, IQ, self-reported internalizing, externalizing, and total behavior problems, and AUC's. Inconsistent discounters were excluded from further analyses. One individual was excluded due to adoption of the wrong response set on the Go-NoGo task. Final analyses were conducted on cases with complete data on the remaining measures ($n=80$ for DD; $n=74$ for PD).

Results

Delay and Probability Discounting Associations

Sixty-two participants had consistent discounting behavior on both tasks. Delay and probability discounting AUC's were positively but not significantly correlated ($r=.238, p>.05$); the correlation was higher in adults (18+ years: $r=.325, p=.065$) versus 11 to 17-year-olds ($r=-.002, p=.992$).

Age and Gender Relations

For DD, the AUC increased with age (see Table 3). Older adolescents discounted delayed rewards less steeply than younger adolescents. Age and probability AUC were uncorrelated. Gender was unrelated to discounting.

Cognitive Correlates

Variables examined included WASI-derived IQ scores; hit rate and false alarm rate on the Go-NoGo task; the overall number of choices from ‘good’ decks minus choices from ‘bad’ decks on the Iowa Gambling Task (IGT), and IGT choices from frequent relative to infrequent punishment decks.

Delay AUC was significantly correlated with verbal IQ, with Go-NoGo false alarm rate, and with IGT good minus bad choices (Table 3). Better performers on these measures discounted delayed rewards less steeply than poorer performers. There were no significant correlations between probability AUC and cognitive measures.

Self-Reported Behavioral Correlates

The ASEBA’s raw internalizing, externalizing, and total problem scores were converted into z-scores. Delay AUCs were unrelated to these variables. The Externalizing z-score was positively correlated with probability AUC (Table 3). Adolescents with higher levels of externalizing discounted probabilistic rewards less steeply than those with lower levels. Internalizing was not associated with discounting.

Regression Models

Hierarchical linear regressions assessed whether the multiple delay discounting behavior correlates contributed independently to the prediction of discounting behavior (Table 4). First, age, verbal IQ, and Go-NoGo and IGT task performance were entered in successive blocks to examine their ability to predict delay AUC. Age accounted for a significant proportion of the variance, indicating that older adolescents discounted less. Adding verbal IQ significantly improved the model fit, such that individuals with higher verbal IQ’s discounted less. Adding IGT and Go-NoGo performance did not improve the model fit. In a separate analysis (not shown), age, verbal IQ, and the age-verbal IQ interaction term were entered in successive blocks in order to assess whether the interaction contributed to performance. The interaction was not significant.

Discussion

We examined adolescent performance on delay and probability discounting tasks in relation to intelligence, executive functioning, and self-reported internalizing and externalizing behavior. The three main findings of the study relate to the relationship between delay and probability discounting, developmental trends in performance, and cognitive and behavioral correlates of discounting in healthy adolescents. Overall, our findings indicate that delay and probability discounting do not reflect a single underlying process but rather tap different facets of impulsive behavior.

Developmental changes were seen only for delay discounting. Delayed monetary rewards lost subjective value more slowly for older versus younger adolescents, consistent with others’ reports (Green et al., 1994; Scheres et al., 2006). Our findings concur with Scheres et al. (2006) with respect to probability discounting, which did not change with age. A possible explanation for the age-related changes in delay but not probability discounting is that children may acquire more subjective experience of longer delays as they age; thus, older children may have a better sense than younger children for what it feels like to wait a year. A related

explanation is that a given delay may be perceived as ‘longer’ for younger children because it constitutes a greater fraction of their lifetimes. By definition, maturation involves increasing experience with temporal periods, but it does not necessarily involve increasing experience with odds or probabilities, which may account for age-related changes in delay but not probability discounting.

Delay discounting rates decreased with verbal IQ and executive functioning ability. The finding that probability discounting was associated with externalizing but not other executive function measures suggests that the process of making decisions about *uncertain* rewards relies on different mechanisms than the process of making decisions about *future* rewards. Thus, although delay discounting can be conceptualized as involving assessment of probabilistic risk (Myerson et al., 2003), and although probability discounting can be conceptualized as involving a series of gambles over time (Rachlin et al., 1986), it is clear that there are separate, non-overlapping factors that contribute to performance on delay and probability discounting tasks, with delay discounting having stronger relationships with intelligence and executive functioning and probability discounting relating more strongly to social disinhibition.

Although the ASEBA does not directly measure impulsivity, its externalizing scale includes rule-breaking behavior (e.g. drug and alcohol use, stealing, lying, etc.) and aggressive behavior (e.g. arguing, threatening others, etc.). The association between externalizing and probability discounting in this adolescent sample has particular implications for financial management and risk behavior. Less-inhibited adolescents were less averse to taking risky bets but equally likely to wait for delayed rewards. This pattern is striking given that it was observed across the normal range of disinhibition/impulsivity (i.e., in a healthy sample).

The observed association between verbal IQ and delay discounting is interesting given de Wit et al.’s (2007) recent report that IQ is associated with delay discounting in adults. The current study represents the first examination of this association in a developmental sample and suggests that the association is independent of age. Why and how IQ contributes to delay discounting is unclear. de Wit et al. identified the association, but did not report which IQ components contributed to the relationship. Our findings suggest that the association is driven solely by verbal aspects of intelligence. Verbal IQ scores are associated with family income and parental education (Wechsler, 1999), so socioeconomic status is one potential mediator of this relationship. However, we did not find associations with income or parental education. Delay discounting involves making judgments about personal preferences in the future; perhaps some participants adopt a verbally-mediated strategy when forecasting their preferences, somehow yielding greater tolerance for delays. Further research is needed to explore these hypotheses.

Like all studies, this one is not without limitations. First, our ability to make inferences about developmental trajectories is limited by our cross-sectional design. Second, we administered the tasks in our battery in the same order to all participants to allow for a standardized administration. This strategy precludes us from examining how task order might have impacted performance. Third, the ability to assess relationships between cognitive factors, behavioral factors, and demographic factors may be limited by nature of our sample, which is predominantly Caucasian, of relatively high socioeconomic status, and of above-average intelligence. These associations between delay discounting, age, intelligence, and executive functioning should be examined in groups with average or low-average intelligence to determine their generalizability. Fourth, a potential explanation for why age did not relate to probability discounting is that younger participants did not understand the task. However, younger adolescents were not more likely to behave erratically and produced valid task data. Thus, this explanation is unlikely to explain our findings.

Our findings agree with a growing body of evidence that while delay and probability discounting may share some features, they reflect at least partially different processes. We suggest that intelligence should be routinely assessed in studies of discounting. An important future step would be to examine the relative contributions of individual difference factors, cognitive functioning, and maturation of brain systems during adolescence to the development of delay and probability discounting behavior.

Acknowledgements

This study was supported by a grant from the National Institute on Drug Abuse awarded to Monica Luciana (grant # 5R01DA017843-03; project title, "Adolescent Brain Development and Effects of Drug Abuse"), and by a National Science Foundation Graduate Research Fellowship awarded to Elizabeth Olson.

We thank Ann Schissel, Kristin Sullwold, and Dustin Wahlstrom for assistance with data collection and the parents and adolescents who volunteered their time to participate in the study.

References

- Achenbach, TM.; Rescorla, LA. Manual for the ASEBA School-Age Forms & Profiles. Burlington, VT: University of Vermont, Research Center for Children, Youth, & Families; 2001.
- Ainslie G. Specious reward: a behavioral theory of impulsiveness and impulse control. *Psychological Bulletin* 1975;82:463–496. [PubMed: 1099599]
- Arnett J. Reckless behavior in adolescence: a developmental perspective. *Developmental Review* 1992;12:339–373.
- Audrain-McGovern J, Rodriguez D, Tercyak KP, Epstein LH, Goldman P, Wileyto EP. Applying a behavioral economic framework to understanding adolescent smoking. *Psychology of Addictive Behaviors* 2004;18(1):64–73. [PubMed: 15008687]
- Barkley RA, Edwards G, Laneri M, Fletcher K, Metevia L. Executive functioning, temporal discounting, and sense of time in adolescents with attention deficit hyperactivity disorder (ADHD) and oppositional defiant disorder (ODD). *Journal of Abnormal Child Psychology* 2001;29(6):541–556. [PubMed: 11761287]
- Bechara A, Damasio AR, Damasio H, Anderson SW. Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition* 1994;50:7–15. [PubMed: 8039375]
- Bechara A, Tranel D, Damasio H. Characterization of the decision-making deficit of patients with ventromedial prefrontal cortex lesions. *Brain* 2000;123:2189–2202. [PubMed: 11050020]
- Braver TS, Barch DM, Gray JR, Molfese DL, Snyder A. Anterior cingulate cortex and response conflict: effects of frequency, inhibition and errors. *Cerebral Cortex* 2001;11(9):825–836. [PubMed: 11532888]
- Chambers RA, Taylor JR, Potenza MN. Developmental neurocircuitry of motivation in adolescence: a critical period of addiction vulnerability. *American Journal of Psychiatry* 2003;160:1041–1052. [PubMed: 12777258]
- de Wit H, Flory JD, Acheson A, McCloskey M, Manuck SB. IQ and nonplanning impulsivity are independently associated with delay discounting in middle-aged adults. *Personality & Individual Differences* 2007;42:111–121.
- Dixon MR, Jacobs EA, Sanders S, Guercio JM, Soldner J, Parker-Singler S, et al. Impulsivity, self-control, and delay discounting in persons with acquired brain injury. *Behavioral Intervention* 2005;20:101–120.
- Dixon MR, Marley J, Jacobs EA. Delay discounting by pathological gamblers. *Journal of Applied Behavior Analysis* 2003;36(4):449–458. [PubMed: 14768665]
- Dom G, D'Haene P, Hulstijn W, Sabbe B. Impulsivity in abstinent early- and late-onset alcoholics: differences in self-report measures and a discounting task. *Addiction* 2006;101(1):50–59. [PubMed: 16393191]
- Du W, Green L, Myerson J. Cross-cultural comparisons of discounting delayed and probabilistic rewards. *The Psychological Record* 2002;52:479–492.
- Green L, Fry AF, Myerson J. Discounting of delayed rewards: a life-span comparison. *Psychological Science* 1994;5(1):33–36.

- Green L, Myerson J. Exponential versus hyperbolic discounting of delayed outcomes: risk and waiting time. *American Zoologist* 1996;36:496–505.
- Green L, Myerson J. A discounting framework for choice with delayed and probabilistic rewards. *Psychological Bulletin* 2004;130(5):769–792. [PubMed: 15367080]
- Green L, Myerson J, Lichtman D, Rosen S, Fry A. Temporal discounting in choice between delayed rewards: the role of age and income. *Psychology and Aging* 1996;11(1):79–84. [PubMed: 8726373]
- Green L, Myerson J, Ostaszewski P. Amount of reward has opposite effects on the discounting of delayed and probabilistic outcomes. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 1999;25(2):418–427.
- Holt DD, Green L, Myerson J. Is discounting impulsive?. Evidence from temporal and probability discounting in gambling and non-gambling college students. *Behavioural Processes* 2003;64(3):355–367. [PubMed: 14580704]
- Hooper CJ, Luciana M, Conklin HM, Yarger RS. Adolescents' performance on the Iowa Gambling Task: implications for the development of decision making and ventromedial prefrontal cortex. *Developmental Psychology* 2004;40(6):1148–1158. [PubMed: 15535763]
- Kaufman J, Birmaher B, Brent D, Rao U, Flynn C, Moreci P, et al. Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime Version (K-SADS-PL): initial reliability and validity data. *Journal of the American Academy of Child and Adolescent Psychiatry* 1997;36(7):980–988. [PubMed: 9204677]
- Madden GJ, Petry NM, Badger GJ, Bickel WK. Impulsive and self-control choices in opioid-dependent patients and non-drug-using control participants: drug and monetary rewards. *Experimental and Clinical Psychopharmacology* 1997;5(3):256–262. [PubMed: 9260073]
- Madden GJ, Raiff BR, Lagorio CH, Begotka AM, Mueller AM, Hehli DJ, et al. Delay discounting of potentially real and hypothetical rewards: II. Between- and within-subject comparisons. *Experimental and Clinical Psychopharmacology* 2004;12(4):251–261. [PubMed: 15571442]
- Mazur, JE. An adjusting procedure for studying delayed reinforcement. In: Commons, ML.; Mazur, JE.; Nevin, JA.; Rachline, H., editors. *Quantitative analysis of behavior: The effects of delay and of intervening events on reinforcement value*. 5. Hillsdale, NJ: Erlbaum; 1987. p. 55-73.
- Myerson J, Green L, Hanson JS, Holt DD, Estle SJ. Discounting delayed and probabilistic rewards: processes and traits. *Journal of Economic Psychology* 2003;24:619–635.
- Myerson J, Green L, Warusawitharana M. Area under the curve as a measure of discounting. *Journal of the Experimental Analysis of Behavior* 2001;76(2):235–243. [PubMed: 11599641]
- Ohmura Y, Takahashi T, Kitamura N. Discounting delayed and probabilistic monetary gains and losses by smokers of cigarettes. *Psychopharmacology* 2005;182(4):508–515. [PubMed: 16167142]
- Rachlin H, Logue AW, Gibbon J, Frankel M. Cognition and behavior in studies of choice. *Psychological Review* 1986;93:35–45.
- Reynolds B, Ortengren A, Richards JB, de Wit H. Dimensions of impulsive behavior: personality and behavioral measures. *Personality & Individual Differences* 2006a;40:305–315.
- Reynolds B, Richards JB, de Wit H. Acute-alcohol effects on the Experiential Discounting Task (EDT) and a question-based measure of delay discounting. *Pharmacology, Biochemistry, and Behavior* 2006b;83(2):194–202.
- Reynolds B, Schiffbauer R. Measuring state changes in human delay discounting: an experiential discounting task. *Behavioural Processes* 2004;67(3):343–356. [PubMed: 15518985]
- Richards JB, Zhang L, Mitchell SH, de Wit H. Delay or probability discounting in a model of impulsive behavior: effect of alcohol. *Journal of the Experimental Analysis of Behavior* 1999;71(2):121–143. [PubMed: 10220927]
- Scheres A, Dijkstra M, Ainslie E, Balkan J, Reynolds B, Sonuga-Barke E, et al. Temporal and probabilistic discounting of rewards in children and adolescents: effects of age and ADHD symptoms. *Neuropsychologia* 2006;44(11):2092–2103. [PubMed: 16303152]
- The Psychological Corporation. Wechsler Abbreviated Scale of Intelligence (WASI) manual. San Antonio, Texas: The Psychological Corporation; 1999.

Table 1

Demographics

Characteristic	Total Sample	Age 9–17	Age 18–23	Group Difference
<i>N</i>	92	52	40	
% female	52.2	48.1	57.5	$\chi^2 = .805, ns$
% Caucasian	86.8	90.4	82.1	$\chi^2 = 1.352, ns$
Age (years)	16.49 (4.08)	13.50 (2.58)	20.37 (1.69)	$F(1,90)=213.12, p<.001$
Mother's Education (years)	15.38 (2.54)	15.96 (1.77)	14.57 (3.18)	$F(1,86)=6.90, p<.05$
Father's Education (years)	15.57 (3.12)	15.88 (2.98)	15.14 (3.30)	$F(1,84)=1.18, ns$
Income	87,756 (67,013)	92,600 (76,633)	79,107 (45,032)	$F(1,76)=0.73, ns$
WASI Verbal IQ	115.08 (10.44)	114.56 (11.92)	115.75 (8.23)	$F(1,90)=0.29, ns$
WASI Performance IQ	112.23 (11.88)	112.44 (13.87)	111.95 (8.83)	$F(1,90)=0.04, ns$
WASI Full Scale IQ	115.46 (10.85)	115.29 (12.44)	115.67 (8.50)	$F(1,90)=0.03, ns$

Values represent percentages or means (and standard deviations). Degrees of freedom vary because some participants omitted responses.

Table 2**Participant Breakdown**

Total participants at start:	111
Completed the delay discounting task:	111
Inconsistent delay discounters:	20
Missing data on other measures:	11
Consistent delay discounters with complete data:	80
1. Consistent delay discounting <i>and</i> probability discounting:	62
2. Consistent delay discounting only:	18
Completed the probability discounting task ¹ :	92
Inconsistent probability discounters:	10
Missing data on other measures:	8
Consistent probability discounters with complete data:	74
3. Consistent probability discounting only:	12
Total final sample (1+2+3)	92

¹ Excludes 19 participants: 9 to 10-year-olds and one 17-year-old

Table 3

Age, Behavior & Cognition Pearson Correlations

Variable	Delay AUC	Probability AUC
N	80	74
Age	.369**	.146
VIQ	.300**	-.187
PIQ	.049	-.119
FIQ	.209	-.162
IGT: good-bad	.254*	-.016
IGT: frequent-infrequent	-.187	.026
Go-NoGo: hit rate ¹	.059	.010
Go-NoGo: false alarm rate ¹	-.348**	-.092
Internalizing	-.143	-.005
Externalizing	.084	.272*
Total problems	-.044	.147

*
 $p < .05$ **
 $p < .01$ ¹
Transformed variables

Table 4
Hierarchical Regression Analysis: Variables Predicting Delay AUC

Step and Variable	B	SE B	β
Step 1			
Age	.024	.007	.369**
Step 2			
Age	.027	.006	.414**
Verbal IQ	.010	.003	.352**
Step 3			
Age	.019	.009	.284*
Verbal IQ	.010	.003	.339**
Go-NoGo false alarm rate	-.231	.200	-.149
IGT good-bad choices	.026	.030	.093

Note: $R^2 = .136$ for Step 1 ($p < .01$), $\Delta R^2 = .122$ for Step 2 ($p < .01$), $\Delta R^2 = .017$ for Step 3 (ns).

*
 $p < .05$

**
 $p < .01$