Published in final edited form as:

Behav Genet. 2014 March ; 44(2): 102–112. doi:10.1007/s10519-013-9638-2.

Preference on Cash-Choice Task Predicts Externalizing Outcomes in 17-Year-Olds

Jordan C. Sparks, Joshua D. Isen, and William G. Iacono

Department of Psychology, University of Minnesota

It is a well-established principle that rewards become subjectively more valuable as their availability becomes increasingly imminent. Delay-discounting refers to the tendency to prefer a smaller-sooner reward to a larger-later reward. This phenomenon has been observed across several different species and its exploration originated in the field of behavioral analysis with animal models (e.g., Baum & Rachlin 1969; Logan 1965; Rachlin & Green 1972). Historically, many studies have focused on how temporal reward preference changes when the amount of reward and time to delivery vary (Reynolds & Schiffbauer 2005). Of more recent interest is the finding that there are individual differences in this preference. For example, individuals who misuse substances value smaller-sooner rewards more than control subjects do (reviewed in MacKillop et al. 2011; Reynolds 2006). While studies that focus on only one specific subtype of addiction (e.g., cocaine use, nicotine use, gambling) have proliferated over the years (e.g., Bickel et al. 1999; Coffey et al. 2003; Mitchell et al. 2005; reviewed in MacKillop et al. 2011), recent research suggests that the tendency to prefer smaller-sooner rewards may reflect core processes underlying a general vulnerability for addiction and other externalizing behaviors. For example, Bobova et al. (2009) demonstrated that a preference for smaller-sooner rewards in adults is not *uniquely* associated with any one domain of externalizing.

Given these findings, delay-discounting tasks have emerged as potentially useful *laboratory* measures to index impulsivity, an important construct associated with a range of externalizing psychopathology (e.g., substance use disorders, attention-deficit/hyperactivity disorder) and antisocial behaviors. Historically, researchers have defined this construct in different ways, focusing on impulsivity as a personality trait, a psychiatric symptom, an experimentally measured laboratory task, and a biological process (reviewed in Evenden 1999). In practice, impulsivity researchers tend to use multiple indicators that vary in the extent to which they overlap; a recent principle components analysis of seven purported measures of impulsivity revealed a five factor solution (Meda et al. 2009). Emerging evidence suggests that delay-discounting may represent a distinct component of impulsivity, as it is not consistently well correlated with self-reports of personality traits and behavioral disinhibition laboratory tasks (Dom, D'haene, Hulstijn, & Sabbe 2006; Reynolds et al. 2007; Reynolds, Ortengren, Richards, & de Wit 2006; Reynolds, Penfold, & Patak 2008). Consistent with this finding, neuroimaging studies have identified unique neural systems

involved in delay-discounting, specifically, the interaction between the midbrain dopaminergic system and fronto-parietal regions (McClure et al. 2004).

Genetic Analyses of Delay-Discounting

Externalizing psychopathology has been linked to a latent factor that is highly heritable (Hicks et al. 2004; Young et al. 2000), but researchers are still exploring the genetic influences on specific processes and constructs that comprise the vulnerability for externalizing psychopathology. While it is generally accepted that delay-discounting tasks tap impulsivity, some researchers have more specifically suggested that they may serve as a useful *endophenotype* for *externalizing disorders* (Anokhin et al. 2011; Audrain-McGovern et al. 2009) in spite of the fact that there is a dearth of research on genetic influences on these tasks in humans (reviewed by Mitchell 2011). To our knowledge, there have been a handful of candidate gene studies of delay-discounting (e.g., Boettiger et al. 2007; Eisenberg et al. 2007; Paloyelis et al. 2010). Only one study examined the heritability of a delay-discounting task in humans; the results showed significant heritability of the task at ages 12 and 14 (30% and 51%, respectively) (Anokhin et al. 2011). It is critical to further investigate the genetic and environmental influences on delay-discounting. In particular, there is a need to understand the genetic and environmental sources of the covariation between delay-discounting and externalizing outcomes. Such findings will inform future research on the potential utility of delay-discounting tasks as endophenotypes for these outcomes, i.e., elucidate how the genetic influences on these tasks might underlie risk for externalizing psychopathology and related behaviors.

Reward Preference & Adolescence

Adolescence is a period in which individuals are at an increased vulnerability for risky behaviors, and as such, this age group represents a promising target for future research on the processes that link delay-discounting to the broader constructs of impulsivity and externalizing psychopathology. Many externalizing behaviors emerge in adolescence, and the immature nature of the prefrontal structures of the adolescent brain may render adolescents ill-equipped to exert control over impulsive drives that would lead them to select a smaller-sooner reward over a larger-later one (Casey et al. 2008; Steinberg 2008). Additionally, the finding that *genetic* influences on delay-discounting increase during early adolescence (Anokhin et al. 2011), along with studies demonstrating that a preference for immediate reward tends to decline as adolescents eventually mature (Olson et al. 2007; Steinberg et al. 2009), suggest that adolescence represents a sensitive period for investigating how individual differences in delay-discounting are shaped. This creates a need for nontrivial, ecologically valid tests of reward preference to be specifically geared towards adolescents.

Developing Laboratory Tasks for Adolescents

While there is a growing body of research on adolescents and delay-discounting, the vast majority of studies have focused on adult samples. As more research on the roots of impulsivity and externalizing behavior encompasses adolescent groups, the appropriateness of well-established “adult” decision-making tasks for use in adolescents is a relevant

concern. Indeed, researchers who have attempted to modify adult delay-discounting paradigms for use in adolescent populations have sometimes found discrepant results, raising questions about the sensitivity of adult decision-making tasks for adolescent use (Reynolds et al. 2003; Scheres et al. 2006).

From an economic perspective, there is also an incentive for researchers to identify delay-discounting tasks that are uncomplicated, straightforward, and expeditiously administered. While discounting tasks often vary in the type of reward studied, whether or not the reward is real or hypothetical, and the analytic strategy employed, a long-standing protocol is the “binary-choice” procedure in which individuals are presented with an extensive series of alternatives in which they must select a delayed or immediate reward (Mazur 1987). Their selections are used to calculate a “discounting curve” to identify the point at which they begin to undervalue future rewards as a function of time and value (Mazur 1987). There are some practical issues related to this protocol. Since it requires individuals to make a large number of choices, it is time-consuming and usually requires computer access. Some have argued that its ecological validity could be improved, since individuals typically focus on only one choice of interest and not an extensive series (Weatherly et al. (2011)).

Attempting to increase focus on adolescent delay-discounting, Wulfert et al. (2002) developed a “cash-choice” delay-discounting task in which adolescent participants were offered an immediate seven dollar reward or a ten dollar reward to be paid one week later. The authors were particularly interested in developing a task specifically designed for adolescents that was uncomplicated, ecologically valid, and easy to implement, as they did not want practical concerns in its administration to affect its potential utility. They found that students who selected the immediate choice were more likely to belong to a preselected group of “problem students” who had been disciplined by their school in the past year. They also found that failure to select the delay choice was positively correlated with substance use and negatively correlated with GPA and self-esteem. Further, Wulfert et al. (2002) found that parental socioeconomic status (SES) was not associated with cash-choice performance, although other decision-making tasks have been associated with measures of SES (e.g., Reimers et al. 2009). While the utility of other “one-shot” delay-discounting tasks has been previously assessed, to our knowledge, the cash-choice measure has only been analyzed in one other study. Anokhin et al. (2011) determined that the task was associated with a number of externalizing variables in 12 and 14 year olds. At both ages, subjects who chose the immediate reward endorsed more symptoms of conduct disorder and attention-deficit/hyperactivity disorder; at age 14, they endorsed more past-year substance use. Finally, adolescents from lower SES families were more likely to choose the immediate reward, as were younger adolescents compared to those who were older.

Current Study

The first aim of this study is to investigate the association between externalizing problems and performance on the cash-choice task (Wulfert et al. 2002), further demonstrating that this easily-administered, straightforward task is a useful index of externalizing in adolescents. In addition, we extend the literature by assessing task validity in *late* adolescence, a time when most forms of externalizing psychopathology (including substance

use) have emerged. Specifically, informed by the previous literature that many studies of delay-discounting do not address multiple types of externalizing behavior (MacKillop et al. 2011), we sought to expand upon the findings of Wulfert et al. (2002) and Anokhin et al. (2011) by including a wider range of variables, including clinical diagnoses that fall in the externalizing spectrum, substance use measures, and a global measure of externalizing liability. In addition, because our previous work has shown that sexual intercourse during adolescence is associated with externalizing, we also included measures of sexual behavior in our analyses (Hicks et al. 2011; McGue & Iacono 2005). Given the conflicting findings on the relationship between this particular task and socioeconomic status, we sought to clarify this association in our sample. Further, we sought to investigate the relationship between cash-choice and academic performance, extending the findings of Wulfert et al. (2002) for individuals aged 11 to 18. Finally, given the lack of attention to genetic contributions to delay-discounting tasks, we sought to estimate the heritability of cash-choice performance at age 17, which extends the findings obtained by Anokhin et al. (2011) for individuals aged 12 and 14. We further expanded upon their work by investigating the genetic and environmental sources of the covariation between cash-choice and externalizing.

We hypothesized that individuals who prefer the delayed reward will engage in fewer externalizing behaviors as compared to individuals who choose the immediate reward, and will have higher parental SES and higher academic performance. Furthermore, we assumed that genetic factors play a significant role in the variability of cash-choice, with common genetic factors largely accounting for the overlap between immediate reward preference and externalizing. As such, we were motivated by the hypothesis of Anokhin et al. (2011) that cash-choice is a promising endophenotype for externalizing.

Materials and Methods

Sample

The sample was drawn from participants in the Minnesota Twin Family Study (MTFS) Enrichment Study (ES). The MTFS is a longitudinal, population-based study of same-sex adolescent twins born in the state of Minnesota. The ES-sample consists of twins born between 1988 and 1994 located using birth records and public databases. The ES-recruitment strategy was designed to enrich the sample with twins at high risk for the development of substance use and childhood disruptive behavior disorders. Forty-eight percent of the sample was screened to include at least one twin offspring exhibiting elevated symptoms of attention-deficit/hyperactivity disorder or conduct disorder. Of the twin pairs initially targeted for inclusion in the study, 82% were successfully recruited, beginning at age 11. The final sample consists of 499 twin pairs ($n = 998$). Ninety-one percent of the twins are Caucasian, which is representative of children born in Minnesota during the ascertained birth years. The ES-sample returns for follow-up assessment every three years. We focused on the age 17 assessment (91% participation rate, $n = 913$). At the intake assessment, the age 17 participants and nonparticipants were similar in their levels of externalizing psychopathology. Of the individuals who participated at the age 17 assessment, approximately 13% completed a telephone interview rather than attending in-

person; the remaining 87% attended in-person and completed the cash-choice task ($n = 791$). For a detailed discussion of the recruitment procedures, see Keyes et al. (2009).

Zygosity was determined based on parental reports on a zygosity questionnaire, staff assessment of physical similarity, and an algorithm incorporating ponderal index, cephalic index, and fingerprint ridge count. If these three estimates yielded inconsistent results, zygosity was determined using a panel of highly polymorphic short tandem repeat markers. Sixty-one percent of the sample comprised MZ twins.

Cash-Choice Procedure

The cash-choice task was administered at the end of the age 17 follow-up session. Participants were asked individually (i.e., without their co-twin present) to choose between receiving seven dollars immediately or ten dollars in one week. Each individual filled out a short form indicating their choice. If the subjects chose the immediate reward, they were given seven dollars immediately. If they chose the delayed reward, they wrote their name and address on a provided envelope. Ten dollars were subsequently enclosed in this envelope and mailed to ensure arrival within seven days. Because ours was an ongoing longitudinal study focused on the investigation of individual differences, it was not our goal to evaluate how best to structure the dollar amounts used in the cash-choice task. Instead, we were guided by the existing literature in our use of the seven dollar versus ten dollar choice. The parameters of the cash-choice task were initially developed by Wulfert et al. (2002), who determined via pretesting that a ratio where the immediate reward was seventy percent of the delayed reward was most discriminative. Seven hundred and ninety-one individuals (392 males, 399 females) completed the cash-choice task.

Other Assessments

During day-long laboratory visits or telephone interviews, twins and their caregivers were interviewed separately by interviewers with a BA or MA in psychology who underwent extensive training. Following each assessment, the interviews were reviewed by individuals with advanced clinical training, supervised by a PhD clinical psychologist.

Substance use was assessed using a confidential computerized questionnaire regarding use for alcohol, tobacco, and other drugs and a modified version of the expanded Substance Abuse Module of the Composite International Diagnostic Interview (Robins et al. 1987). The SAM interview covers DSM-IV lifetime symptoms of alcohol, nicotine, and illicit drugs (including marijuana, cocaine, heroin, opiates, PCP, psychedelics, inhalants, gas, amphetamines, and barbiturates). For DSM-IV diagnoses, a symptom was considered present if either the primary caretaker or twin endorsed it as present. Because prior research has supported the construct validity of a “probable” diagnosis in our adolescent twin sample, individuals were considered cases of a particular disorder if they met a definite (all diagnostic criteria satisfied) or probable (all but one diagnostic criteria satisfied) diagnosis.

The Diagnostic Interview for Children and Adolescents – Revised (DICA-R), administered to cover the time elapsing since the last assessment (i.e., the age 14 follow-up), was used to assess symptoms of oppositional defiant disorder, conduct disorder, and attention-deficit/hyperactivity disorder via maternal report or twin self-report (Reich 2000; Welner et al.

1987). In all analyses of childhood disruptive disorders, individuals with possible diagnoses (i.e., all but two diagnostic criteria satisfied) were excluded to reduce the possibility that affected individuals were incorrectly categorized as being free of the disorder. (For the three childhood disruptive disorders, this resulted in one to ten percent of the sample being excluded.) ADHD is unique among these disorders in that it requires an onset before age seven. To avoid eliminating twins with ADHD symptoms onsetting after age seven, we ignored the onset requirement.

Academic achievement was assessed via a questionnaire completed by twins and their caretaker that examined their academic functioning. Sexual behavior was assessed via twin self-report; twins were asked if they had ever had sexual intercourse within the context of a casual relationship (i.e., with individuals with whom one does *not* have a committed romantic relationship). Socioeconomic status was assessed via a telephone intake interview with caregivers at intake. We estimated a latent SES factor based on the following four indicators: household income, highest parental occupational status, maternal educational attainment, and paternal educational attainment. Household income was an ordinal variable corresponding to ten income brackets: less than \$20,000, more than \$100,000, and eight intermediate deciles. Occupational status was coded via the Hollingshead coding system, a 7-point scale where categories range from “unskilled” to “major professional”. Educational attainment refers to total years of education.

Lastly, we obtained a comprehensive global measure of externalizing liability (EXT) by estimating latent scores in Mplus Version 6 (Muthén & Muthén 2010). Some of the participants in the current study were included in a larger project establishing an EXT latent factor, derived from 17 facet measures (tapping into nicotine use, alcohol use, alcohol dependence, illicit drug use, and behavioral disinhibition), that has excellent psychometric properties. For a detailed description of the various indicators used and the rationale for their selection, please see Hicks et al. (2011). Using these same 17 facet measures, we conducted a confirmatory factor analysis using all of the participants in the current study, deriving factor scores from the same higher-order factor structure described in Hicks et al. (2011). Given that the estimated EXT scores were positively associated with age, especially in males, we regressed EXT on sex, age, and the sex-by-age interaction. The residuals were subsequently rank-normalized using a Blom transformation. Scores ranged from -3.01 to 3.01 with a standard deviation of 1.00. The resulting EXT factor structure can be found in the supplemental materials, Figure 1S.

In sum, the outcome variables of interest included DSM-IV diagnoses at age 17 related to disinhibitory psychopathology: alcohol dependence, nicotine dependence, oppositional defiant disorder, conduct disorder, and attention-deficit/hyperactivity disorder. We also included a composite index of illicit drug dependence (i.e., possessing a dependence diagnosis for at least one illicit substance). Additional variables included the endorsement of whether individuals had ever used alcohol, ever used tobacco, ever used marijuana, and ever had casual sexual intercourse. We also included variables reflecting whether or not these behaviors had taken place in the last 12 months to relate them to the individual’s recent cash-choice selection. Twin self- and parent-reports of cumulative GPA (maximum possible GPA = 4.00) were averaged to provide a measure of academic functioning. Finally, we

included EXT factor scores based on a higher-order conceptualization of EXT that was designed to develop and refine an EXT latent trait for use in genetically informative investigations.

Statistical Analyses

Because observations from co-twins are not independent, using a standard regression procedure would incorrectly assume that there is more unique information in the data than actually exists. As a result, the estimated standard errors of the parameter estimates would likely be attenuated (Zeger & Liang 1992). Thus, we used an extension of the generalized linear model (GLM) that accommodates correlated data by using a robust “sandwich” estimator to provide estimates of the standard errors. GLM is appropriate when the outcome variable is not normally distributed, as is the case for diagnostic outcomes. Analyses were conducted using the “Survey” package (Version 3.28) in R (Lumley 2012; Lumley 2004). Hypothesis testing was based on Wald tests. Since the sample was screened to include individuals at risk for developing externalizing disorders, the probability of selection into the sample was not equal across all participants in the study. Thus, for the phenotypic analyses of externalizing and cash-choice, inverse probability weights were used to adjust for the difference between unscreened and screened participants so that the proportion of individuals who chose the immediate reward in the sample could be generalized to a representative population. The “Survey” package allowed us to account for nonrandom sampling. For more information about the weighting procedure, see Keys et al. (2009).

Univariate biometric analyses on cash-choice and the EXT factor were conducted via the structural equation model-fitting statistical packages OpenMx in R (Boker et al. 2011; Boker et al. 2012). Since cash-choice is categorical, we utilized liability threshold models to estimate variance components. That is, we assumed that the dichotomous cash-choice outcome is influenced by continuously distributed individual differences in temporal discounting. We assumed that the variance in a phenotype (e.g., cash-choice) is attributable to three latent factors: additive genetic effects (A), shared environmental effects (C), and non-shared environmental effects (E, which reflects experiences that are unique to the individual, as well as measurement error).

Since the sample included both male and female twins, we initially ran a general sex-limitation model, which assumes one set of parameters for males and another set of parameters for females. This model was compared to a constrained model that assumed equal genetic and environmental variance components for males and females. The latter model did not result in a significant reduction in fit; hence, variances were constrained to be equal for subsequent analyses. Four different models (ACE, AE, CE, and E models) were fitted to the data. The viability of these different hypotheses was based on 1) a Chi-squared goodness-of-fit test and 2) model parsimony. The Akaike Information Criterion (AIC; i.e., goodness-of-fit statistic minus twice the degrees of freedom) was used to select the best-fitting model; the lowest AIC indicates the most optimal balance of goodness-of-fit and parsimony (Akaike 1987).

A bivariate analysis of twin data was conducted to address whether genetic or environmental factors that influence cash-choice also influence the global EXT measure. We used

Cholesky decomposition to conduct the analysis in Mplus. Because cash-choice is categorical, it was necessary to implement the theta parameterization option in order to estimate specific non-shared environmental influences on cash-choice (see Prescott 2004). The first variable entered in the model was cash-choice, and the second variable was EXT. This particular ordering was based on the premise that the former is an endophenotype for externalizing outcomes, as suggested by Anokhin et al. (2011). According to this perspective, cash-choice performance should mediate much of the genetic influences on EXT.

Unlike the univariate biometric analyses, we did not use conventional maximum likelihood estimation. Rather, we employed a robust weighted least squares estimator for the bivariate analysis. We sequentially tested whether the means/thresholds and variances could be equated across co-twins, zygosity group, and sex. Next, we ran two additional submodels in which we constrained the A or C covariance parameters to equal zero. When determining the optimality of various submodels, we used the root mean square error of approximation (RMSEA) as a criterion for optimality as well as the results of chi-square goodness of fit testing. Since the difference in chi-square values (χ^2) of two models is not distributed as chi-square (given that cash-choice is non-normal), a robust chi-square difference test was performed using a mean and variance adjustment.

Results

In total, 185 out of 791 participants chose to receive the seven dollar immediate reward; the adjusted population estimate of the immediate preference was 21.3%. The population estimate of females preferring the immediate option was 18.0% while the male estimate was 24.6%. Sex was not a significant predictor of cash-choice preference (Wald $\chi^2 = 3.47$, $p = .06$). Parental SES was associated with cash-choice preference (Wald $\chi^2 = 8.40$, $p = .004$). With each one-unit increase in the standardized parental SES score, the odds of choosing the immediate preference decreased by 27%. The correlation between cash-choice and SES was quite modest (biserial $r = -.12$). Membership in the seven dollar group was associated with a .49 decrease in predicted GPA relative to the ten dollar group.

As seen in Table 1, a preference for the seven dollar immediate reward was associated with every diagnostic outcome of interest. Individuals who chose the immediate reward were also far more likely to have used alcohol, used tobacco, used marijuana, and had casual sexual intercourse in their lifetimes, and to have engaged in these behaviors in the last 12 months. Finally, membership in the seven dollar group was associated with a .64 increase in the Blom-transformed EXT factor score (Cohen's $d = .65$). All group differences remained significant after controlling for family SES.

Among these outcomes, the most extreme odds ratios were observed for drug dependence and nicotine dependence. Individuals who chose the immediate reward had over three and a half times the odds of receiving a diagnosis of drug dependence and almost five times the odds of receiving a diagnosis of nicotine dependence. Approximately fifty-percent of the individuals in these diagnostic groups chose the immediate reward (drug dependence = 47%,

nicotine dependence = 52%), over double the rate compared to individuals with few or no symptoms (drug dependence = 19%, nicotine dependence = 18%).

Biometric Analyses

Intraclass tetrachoric correlations for cash-choice were statistically significant for both MZ ($r = .50$, 95% CI = .29 – .67) and DZ ($r = .30$, 95% CI = .03 – .54) twin pairs. First, we fit an ACE model; the results are reported in Table 2. Importantly, when we included SES as a covariate, there was no evidence that SES interacted with the three variance components and no evidence that any individual component was affected by moderation. Subsequently, we fit an AE, CE, and E model. The best fitting AE model indicated that genetic and non-shared environmental effects, each accounting for equal proportions of variance, account for individual differences in cash-choice. However, the AIC value supporting the AE model was only slightly smaller than that for the CE and ACE models and dropping the A pathway did not lead to a significantly worse model fit ($p = .26$).

Univariate ACE estimates for the EXT factor are reported in Table 3. The twin correlations were statistically significant for both MZ ($r = .84$, 95% CI = .80 – .87) and DZ ($r = .53$, 95% CI = .43 – .62) twin pairs. The best-fitting etiological model for the externalizing factor was ACE. Genetic influences were moderate, and a significant shared environmental component was also evident. As discussed in Hicks et al. (2011), the significant shared environmental influences were likely attributable to the comprehensive range of dimensional facets used to obtain the factor.

We next proceeded with the bivariate genetic analysis of cash-choice and EXT. Compared to a fully saturated model in which all parameters were free, a bivariate model that constrained the EXT means/variances, cash-choice thresholds, and covariances to equality across co-twins and zygosity groups fit well; RMSEA = .038, $\chi^2(28) = 33.23$, $p = .23$. Similarly, further forcing the EXT variances and within-twin covariances (as well as the zygosity-specific cross-twin covariances) to be equal across sex led to a negligible loss of fit, $\chi^2(8) = 6.52$, $p = .59$. The cross-twin cross-trait correlations between cash-choice and the externalizing factor were comparable in MZ ($r = .36$) and DZ ($r = .37$) twins, suggesting that shared environmental factors account for the covariation. To identify non-shared environmental influences on cash-choice, we fixed the threshold value to the observed population z-score.¹

Rather than assuming that familial aggregation of cash-choice was wholly due to genetic sources (as the best-fitting univariate model supposes), we retained all three ACE components. The fit of the full bivariate ACE model was good, RMSEA = .031. Parameter estimates from this model are reported in Figure 1. Two sets of findings are noteworthy. First, there are significant additive genetic influences specific to EXT ($p = .04$), accounting for 19% of the variance in EXT (see the a_{22} path coefficient in Figure 1). Second, shared environmental contributions account for virtually all of the phenotypic association between cash-choice and EXT. We also accounted for the main effects of family SES, by regressing

¹The residual variance and mean/threshold of a dichotomous variable cannot both be freely estimated, given that the variance is dependent on the observed proportion of outcomes.

both cash-choice and EXT on SES. This reduced the phenotypic correlation from .38 to .32, but did not diminish the shared environmental contribution, which explained 100% of the association. In order to further examine the etiological contributions to the covariance, we fit two submodels to the data. The relative importance of shared environmental overlap was assessed by fixing the c_{21} path to zero (see Figure 1) and conducting a chi-square difference test suitable for a weighted least squares estimator. This led to a significant decrement in model fit, $\chi^2(1) = 6.23, p = .01, RMSEA = .047$. By contrast, constraining the a_{21} path to zero (while freeing the c_{21} path) resulted in a better-fitting model, $RMSEA = .022, \chi^2(1) = 0.00, p = .96$, thus confirming the importance of shared environment to the cash-choice externalizing association.

Discussion

The first aim of this study was to help validate the cash-choice task as a useful index of externalizing behavior in adolescents. The percentage of individuals preferring the immediate reward was less in our study compared to that reported by Anokhin et al. (2011) among younger adolescents (21.3% vs. 27.5%). As such, our findings are consistent with the observation that preference for the immediate reward decreases throughout adolescence.

Every externalizing outcome of interest was significantly associated with cash-choice. Since our sample was older than both of the samples used by Wulfert et al. (2002) and Anokhin et al. (2011), the present results provide evidence for the task's utility indexing a range of externalizing behaviors in late adolescence. Further, given our incorporation of additional behaviors (e.g., risky sexual behavior) and a global EXT factor, we can more confidently establish that immediate reward preference is associated with a range of externalizing outcomes. Finally, twin covariance was significant for both MZ and DZ twins, which supports the measure's reliability.

An additional aim was to extend the findings obtained by Wulfert et al. (2002) by examining the relationship between cash-choice and academic performance in an older group of adolescents. We confirmed that children who choose the immediate reward are more likely to have lower academic performance. Further, we sought to provide further clarity regarding the relationship between the cash-choice task and family SES. Wulfert et al. (2002) and Anokhin et al. (2011) reported conflicting findings, with the former failing to find an association with parental SES in their sample of urban 14–18 year olds, whereas the latter found that individuals who chose the immediate reward were more likely to come from lower SES households. Consistent with Anokhin et al. (2011), our findings suggest that children from low-SES families are more likely to choose the immediate reward. Future inquiries should seek to understand the mechanism underlying this association. Longitudinal investigations of the relationship between delay-discounting tasks and SES outcomes, as well as the biometric relationship between these tasks and SES, would be particularly revealing. (A joint biometric analysis is obviously not possible for the present sample, given that SES is obligatorily shared between co-twins.) A genetically mediated relationship would be consistent with an underlying “‘impulsive’ decision-making style”, as proposed by Anokhin et al. (2011), while an environmentally mediated relationship would be more consistent with an immediate reward preference as a response to impoverished

circumstances. Of note, we did not find any evidence that SES moderated the heritability or shared environmental influences on cash-choice, which we would expect to be the case if such a causal explanation existed (i.e., if immediate reward preference is a causally-linked response to impoverished circumstances, we would expect genetic factors to explain less of the variance in cash-choice among low-SES families). Future studies with greater power are needed to address these important questions.

Anokhin et al. (2011) conducted the first biometric analysis of a delay-discounting task in humans, and we sought to add to this body of literature, extending the findings in our group of 17-year-olds. In our AE model, the heritability estimate was .50, which is quite similar to the estimate obtained at age 14 (.51) by Anokhin et al. Our results also yielded some potentially interesting differences. First, while our tetrachoric correlation in MZ twins (.50) was somewhat comparable to the correlation found at age 14 in the Anokhin et al. (2011) study (.46 for MZ females, .82 for MZ males), our DZ correlation ($r = .30$) was higher than the coefficients reported by them, which ranged from $r = -.14$ to $r = .17$. The fact that Anokhin et al. incorporated opposite-sex DZ twin pairs does not appear to account for this difference, as the lowest DZ tetrachoric correlations were observed for same-sex pairs. A possible explanation could be that older adolescents are more aware of their socioeconomic circumstances (a shared environmental influence), and this awareness subsequently influences reward preference. However, given the limitations of comparing two different cross-sectional studies, we can only offer the barest speculation.

We conducted a bivariate analysis on the relationship between cash-choice and a global EXT factor as an initial step in understanding their shared etiological underpinnings. If the cash-choice task was a clear candidate for an EXT endophenotype at age 17, we would expect to observe a definitive link between EXT and cash-choice at the genetic level. However, this was not the case in our study. Cash-choice did not mediate the genetic influences on externalizing, as evidenced by the fact that the best fitting model did not include a path for shared genetic overlap coupled with the fact that unique genetic influences were identified for externalizing. Shared environmental factors were more important in explaining the covariation between cash-choice and externalizing. This is an especially interesting result given that the univariate biometric analyses revealed that genetic factors were most important in explaining the individual differences in the EXT factor. Since this is the first joint biometric analysis of a delay-discounting task and externalizing that we are aware of, future inquiries that attempt to elucidate the familial link between these constructs are encouraged.

One interesting issue beyond the scope of our study is how the cash-choice task relates to traditional measures of delay-discounting. As previously mentioned, many studies have utilized multi-trial hypothetical delay-discounting paradigms. As a “one-shot” delay-discounting measure, the cash-choice task does not provide any information about the slope of an individual’s discounting curve, which is a defining feature of most delay-discounting studies. Given the frequent use of multi-trial delay-discounting paradigms and some of the practical issues with their administration (e.g., they are time-intensive because participants must make decisions about many different contingencies), it would be valuable to ascertain the extent to which the cash-choice task correlates with traditional delay-discounting tasks.

This study has some limitations that are worth mentioning. First, the sample was largely composed of European Americans, so we are uncertain as to the generalizability of our results to other ethnic groups. Second, the power of our study was limited by the dichotomous nature of the cash-choice task. It can be quite difficult to distinguish twin models of discrete traits (Neale et al. 1994), and our results were no exception, as evidenced by the fact that the AE, CE, and ACE univariate models fit nearly equally well. Moreover, it is possible that a combination of non-additive genetic factors and shared environmental factors are involved – a phenomenon that cannot be addressed by the classic “twins reared together” design. Our version of the cash-choice task was the same as that used in prior research. As such, we do not know how our results might have varied had we used different dollar amounts for the immediate and delayed reward. Finally, the cash-choice measure was only available at one time point, and as such, we were unable to examine how the preference for immediate reward, as well as the structure of the etiological contributions to the covariation between cash-choice and externalizing, changes throughout adolescence.

In conclusion, future research on externalizing, its etiology, and its correlates will undoubtedly make use of adolescents because of their special vulnerability for impulsive behavior. Findings may have important implications for understanding externalizing and impulsivity in adult populations as well. Laboratory measures of delay-discounting, such as the cash-choice task, are a component of this research agenda, as they allow for greater control and consistency in measurement. Due to its high ecological validity and ease of implementation, the cash-choice task should be considered in future studies of externalizing and impulsivity in adolescents. It will be particularly appropriate for use in research programs with large, time-consuming batteries where impulsivity can be assessed by many converging modalities. However, given the results of the current study, we caution that it might not profitably serve as an endophenotype for externalizing psychopathology in late adolescence.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Data collection was supported by National Institute on Drug Abuse grant DA013240. Jordan Sparks was supported in part by a summer fellowship from Pearson Assessments. Joshua Isen was supported by National Institutes on Mental Health grant T32 MH017069.

References

- Akaike H. Factor analysis and AIC. *Psychometrika*. 1987; 52(3):317.
- Anokhin AP, Golosheykin S, Grant JD, Heath AC. Heritability of delay discounting in adolescence: A longitudinal twin study. *Behav Genet*. 2011; 41(2):175–183. [PubMed: 20700643]
- Audrain-McGovern J, Nigg JT, Perkins K. Phenotypes and endophenotypes: Foundations for genetic studies of nicotine use and dependence. *Natl Canc Inst Monogr No 22*. 2009; Chapter 8:337–386.
- Baum WM, Rachlin HC. Choice as time allocation. *J Exp Anal Behav*. 1969; 12(6):861–874. [PubMed: 16811415]
- Bickel WK, Odum AL, Madden GJ. Impulsivity and cigarette smoking: Delay discounting in current, never, and ex-smokers. *Psychopharmacology*. 1999; 146(4):447–454. [PubMed: 10550495]

- Bobova L, Finn PR, Rickert ME, Lucas J. Disinhibitory psychopathology and delay discounting in alcohol dependence: Personality and cognitive correlates. *Exp Clin Psychopharmacol*. 2009; 17(1): 51–61. [PubMed: 19186934]
- Boettiger CA, Mitchell JM, Tavares VC, Robertson M, Joslyn G, D'Esposito M, Fields HL. Immediate reward bias in humans: Fronto-parietal networks and a role for the catechol-O-methyltransferase 158(Val/Val) genotype. *J Neurosci*. 2007; 27(52):14383–14391. [PubMed: 18160646]
- Boker, SM.; Neale, MC.; Maes, HH.; Wilde, MJ.; Spiegel, M.; Brick, TR.; Brandmaier, A. OpenMx 1.2 user guide. 2012.
- Boker SM, Neale MC, Maes HH, Wilde MJ, Spiegel M, Brick TR, Fox J. OpenMx: An open source extended structural equation modeling framework. *Psychometrika*. 2011; 76(2):306–317. [PubMed: 23258944]
- Casey BJ, Jones RM, Hare TA. The adolescent brain. *Ann NY Acad Sci*. 2008; 1124(1):111–126. [PubMed: 18400927]
- Coffey SF, Gudleski GD, Saladin ME, Brady KT. Impulsivity and rapid discounting of delayed hypothetical rewards in cocaine-dependent individuals. *Exp Clin Psychopharm*. 2003; 11(1):18–25.
- 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]
- Eisenberg DT, Campbell B, Mackillop J, Lum JK, Wilson DS. Season of birth and dopamine receptor gene associations with impulsivity, sensation seeking and reproductive behaviors. *PloS One*. 2007; 2(11):e1216. [PubMed: 18030347]
- Evenden J. Impulsivity: A discussion of clinical and experimental findings. *J Psychopharmacol*. 1999; 13(2):180–192. [PubMed: 10475725]
- Hicks BM, Krueger RF, Iacono WG, McGue M, Patrick CJ. Family transmission and heritability of externalizing disorders: A twin-family study. *Arch Gen Psychiatry*. 2004; 61(9):922–928. [PubMed: 15351771]
- Hicks BM, Schalet BD, Malone SM, Iacono WG, McGue M. Psychometric and genetic architecture of substance use disorder and behavioral disinhibition measures for gene association studies. *Behav Genet*. 2011; 41(4):459–475. [PubMed: 21153693]
- Keyes MA, Malone SM, Elkins IJ, Legrand LN, McGue M, Iacono WG. The enrichment study of the Minnesota twin family study: Increasing the yield of twin families at high risk for externalizing psychopathology. *Twin Res Hum Genet*. 2009; 12(5):489–501. [PubMed: 19803776]
- Logan FA. Decision making by rats: Delay versus amount of reward. *J Comp Physiol Psychol*. 1965; 59:1–12. [PubMed: 14282403]
- Lumley, T. R package version 3.28–2. 2012. survey: analysis of complex survey samples.
- Lumley T. Analysis of complex survey samples. *J Stat Softw*. 2004; 9(1):1–19.
- MacKillop J, Amlung MT, Few LR, Ray LA, Sweet LH, Munafo MR. Delayed reward discounting and addictive behavior: A meta-analysis. *Psychopharmacology*. 2011; 216(3):305–321. [PubMed: 21373791]
- Mazur, JE. An adjusting procedure for studying delayed reinforcement. In: Commons, ML.; Mazur, JE.; Nevin, JA.; Rachlin, H., editors. *Quantitative Analyses of Behavior: The Effect of Delay and of Intervening Events on Reinforcement Value*. Erlbaum, NJ: Lawrence Erlbaum Associates; 1987. p. 55-73.
- McClure SM, Laibson DI, Loewenstein G, Cohen JD. Separate neural systems value immediate and delayed monetary rewards. *Science*. 2004; 306(5695):503–507. [PubMed: 15486304]
- McGue M, Iacono WG. The association of early adolescent problem behavior with adult psychopathology. *Am J Psychiat*. 2005; 162(6):1118–1124. [PubMed: 15930060]
- Meda SA, Stevens MC, Potenza MN, Pittman B, Gueorgieva R, Andrews MM, Thomas AD, Muska C, Hylton JL, Pearson GD. Investigating the behavioral and self-report constructs of impulsivity domains using principal component analysis. *Behav Pharmacol*. 2009; 20(5–6):390–399. [PubMed: 19724194]
- Mitchell JM, Fields HL, D'Esposito M, Boettiger CA. Impulsive responding in alcoholics. *Alcohol Clin Exp*. 2005; 29(12):2158–2169.

- Mitchell SH. The genetic basis of delay discounting and its genetic relationship to alcohol dependence. *Behav Process.* 2011; 87(1):10–17.
- Muthén, LK.; Muthén, B. *Mplus User's Guide*. 6. Los Angeles, CA: Muthén & Muthén; 1998–2010.
- Neale MC, Eaves LJ, Kendler KS. The power of the classical twin study to resolve variation in threshold traits. *Behav Genet.* 1994; 24(3):239–258. [PubMed: 7945154]
- 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. [PubMed: 18978926]
- Paloyelis Y, Asherson P, Mehta MA, Faraone SV, Kuntsi J. DAT1 and COMT effects on delay discounting and trait impulsivity in male adolescents with attention deficit/hyperactivity disorder and healthy controls. *Neuropsychopharmacol.* 2010; 35(12):2414–2426.
- Prescott CA. Using the Mplus computer program to estimate models for continuous and categorical data from twins. *Behav Genet.* 2004; 34(1):17–40. [PubMed: 14739694]
- Rachlin H, Green L. Commitment, choice and self-control. *J Exp Anal Behav.* 1972; 17(1):15–22. [PubMed: 16811561]
- Reich W. Diagnostic interview for children and adolescents (DICA). *J Am Acad Child Adolesc.* 2000; 39(1):59–66.
- Reimers S, Maylor EA, Stewart N, Chater N. Associations between a one-shot delay discounting measure and age, income, education and real-world impulsive behavior. *Pers Individ Dif.* 2009; 49(8):973.
- Reynolds B, Ortengren A, Richards JB, de Wit H. Dimensions of impulsive behavior: Personality and behavioral measures. *Pers Individ Dif.* 2006; 40(2):305–315.
- Reynolds B, Schiffbauer R. Delay of gratification and delay discounting: A unifying feedback model of delay-related impulsive behavior. *Psychol Rec.* 2005; 55(3):439–460.
- Reynolds B. A review of delay-discounting research with humans: Relations to drug use and gambling. *Behav Pharmacol.* 2006; 17(8):651–667. [PubMed: 17110792]
- Reynolds B, Karraker K, Horn K, Richards JB. Delay and probability discounting as related to different stages of adolescent smoking and non-smoking. *Behav Process.* 2003; 64(3):333–344.
- Reynolds B, Patak M, Shroff P, Penfold RB, Melanko S, Duhig AM. Laboratory and self-report assessments of impulsive behavior in adolescent daily smokers and nonsmokers. *Exp Clin Psychopharm.* 2007; 15(3):264–271.
- Reynolds B, Penfold RB, Patak M. Dimensions of impulsive behavior in adolescents: Laboratory behavioral assessments. *Exp Clin Psychopharm.* 2008; 16(2):124–131.
- Robins, LN.; Babor, TF.; Cottler, LB. *Composite international diagnostic interview: Expanded substance abuse module*. St. Louis: Authors; 1987.
- Scheres A, Dijkstra M, Ainslie E, Balkan J, Reynolds B, Sonuga-Barke E, Castellanos FX. Temporal and probabilistic discounting of rewards in children and adolescents: Effects of age and ADHD symptoms. *Neuropsychologia.* 2006; 44(11):2092–2103. [PubMed: 16303152]
- Steinberg L. A social neuroscience perspective on adolescent risk-taking. *Dev Rev.* 2008; 28(1):78–106. [PubMed: 18509515]
- Steinberg L, Graham S, O'Brien L, Woolard J, Cauffman E, Banich M. Age differences in future orientation and delay discounting. *Child Dev.* 2009; 80(1):28–44. [PubMed: 19236391]
- Weatherly JN, Derrene A, Terrell HK. Testing the reliability of delay discounting of ten commodities using the fill-in-the-blank method. *Psychol Rec.* 2011; 61(1):113.
- Welner Z, Reich W, Herjanic B, Jung KG, Amado H. Reliability, validity, and parent-child agreement studies of the diagnostic interview for children and adolescents (DICA). *J Am Acad Child Adolesc.* 1987; 26(5):649–653.
- Wulfert E, Block JA, Santa Ana E, Rodriguez ML, Colsman M. Delay of gratification: Impulsive choices and problem behaviors in early and late adolescence. *J Pers.* 2002; 70(4):533–552. [PubMed: 12095190]
- Young SE, Stallings MC, Corley RP, Krauter KS, Hewitt JK. Genetic and environmental influences on behavioral disinhibition. *Am J Med Genet.* 2000; 96(5):684–695. [PubMed: 11054778]

Zeger SL, Liang KY. An overview of methods for the analysis of longitudinal data. *Stat Med*. 1992; 11(14–15):1825–1839. [PubMed: 1480876]

Figure 1.

Standardized path coefficients from a bivariate Cholesky model. Genetic and environmental contributions to cash-choice influence the global externalizing (EXT) factor. Paths enclosed in parentheses are discussed in the text.

* $p < .05$

Table 1

Analysis of Cash-Choice as a Predictor of Externalizing Disorders & Behaviors in 17-year-old Twins

	No	Yes	Odds Ratio	χ^2 (df=1)
Ever Used Alcohol	0.14	0.28	2.41(1.70, 3.41)	17.08***
Used Alcohol in last 12 months	0.15	0.28	2.20(1.57, 3.08)	14.63***
Used Marijuana	0.16	0.36	3.04(2.09,4.44)	23.61***
Used Marijuana in last 12 months	0.19	0.34	2.20(1.47,3.28)	10.50**
Ever Used Tobacco	0.14	0.33	3.13(2.24,4.37)	31.23***
Used Tobacco in last 12 months	0.15	0.36	3.22(2.29,4.52)	31.79***
Alcohol Dependence DX	0.20	0.38	2.38(1.25,4.53)	4.92*
Nicotine Dependence DX	0.18	0.52	4.95(3.20,7.64)	36.51***
Drug Dependence DX	0.19	0.47	3.79(2.27,6.35)	18.14***
ADHD DX	0.18	0.33	2.32(1.57,3.43)	12.56***
Conduct Disorder DX	0.19	0.45	3.45 (2.13,5.59)	17.95***
ODD DX	0.18	0.33	2.19(1.46,3.29)	10.04**
Ever Had Casual Sexual Intercourse	0.19	0.34	2.24(1.53,3.28)	12.15***
Had Casual Sexual Intercourse in last 12 months	0.19	0.36	2.39(1.59,3.58)	12.43***
	\$10	\$7	B	χ^2 (df=1)
EXT Factor	-0.26	0.38	.64(0.47,0.80)	39.95***

Notes. Values in the “Yes” and “No” columns are the proportion of individuals in each group (e.g., yes – used alcohol or no – did not use alcohol) that chose the immediate reward. Values in the right-most columns reflect the Wald χ^2 statistic, the odds of a particular outcome for the \$7 group relative to the \$10 group, and the 95% confidence interval of the odds ratios. (For the global EXT, parameter estimates are provided. Values in the \$7 and \$10 columns are the means for each group.)

* p < 0.05;

** p < 0.01,

*** p < .001.

Table 2

Standardized Estimates of Genetic and Environmental Influence on Cash-Choice

Model	Hypothesis	Variance Components					df	AIC	p
		A	C	E	-2LL				
1	ACE	.37 (0, .66)	.12 (0, .54)	.51 (.34, .72)	833.63		787	-740.37	
2 vs. 1	AE	.50 (.31, .67)	-	.50 (.33, .69)	833.80		788	-742.20	0.69
3 vs. 1	CE	-	.41 (.24, .56)	.59 (.44, .76)	834.88		788	-741.12	0.26
4 vs. 1	E	-	-	1	856.20		789	-721.80	<.01

Note. The 95% confidence intervals of the variance component estimates are shown in parentheses.

Table 3
Standardized Estimates of Genetic and Environmental Influence on Global Externalizing Factor

Model	Hypothesis	Variance Components				df	AIC	p
		A	C	E	-2LL			
1	ACE	.61 (.44, .81)	.23 (.03, .40)	.16 (.13, .20)	2206.79	909	388.79	
2 vs. 1	AE	.84 (.81, .87)	-	.16 (.13, .19)	2211.73	910	391.73	.03
3 vs. 1	CE	-	.71 (.66, .75)	.29 (.25, .34)	2272.26	910	452.25	<.01
4 vs. 1	E	-	-	1	2583.26	911	761.26	<.01

Note. The 95% confidence intervals of the variance component estimates are shown in parentheses.