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A Longitudinal Analysis of Adolescent Decision-Making with the Iowa Gambling Task

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Abstract

Many researchers have used the standard Iowa Gambling Task (IGT) to assess decision-making in adolescence given increased risk-taking during this developmental period. Most studies are cross-sectional and do not observe behavioral trajectories over time, limiting interpretation. This longitudinal study investigated healthy adolescents' and young adults' IGT performance across a 10-year span. A total of 189 individuals (ages 9–23 at baseline) completed a baseline session and were followed at two-year intervals yielding five assessments. IGT deck contingencies were shuffled over time to reduce practice effects. IGT performance (good minus bad decisions) was measured at each assessment point and separated into three metrics: overall performance (all blocks), decision-making under ambiguity (blocks 1 and 2), and decision-making under risk (blocks 3, 4, and 5). Covariates included estimated intelligence and affective dispositions as measured by the Behavioral Inhibition and Activation System (BIS/BAS) Scales. A linear effect of age yielded the best fit when comparing linear and quadratic effects of age on overall IGT performance. Age and intelligence positively predicted overall performance, whereas affective approach tendencies (BAS) negatively predicted overall performance. Practice effects were observed and controlled for. Models of ambiguity and risk metrics yielded different patterns of significant predictors. Age predicted better performance and affective approach tendencies predicted worse performance for both metrics. Intelligence was a significant predictor for risk, but not ambiguity. This longitudinal study extends prior work by showing age-related improvements in reward-based decision-making and associating those improvements with cognitive and affective variables. Implications of the results for adolescent development are discussed.

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Keywords

Adolescence; decision-making; Iowa Gambling Task; reward processing; approach; avoidance

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Adolescence is a period of increased risk-taking (e.g., reckless driving, drug use, risky sex) relative to childhood and adulthood (Dahl, 2004; Steinberg. 2014). This increase, spurred by dopaminergic changes (Wahlstrom, Collins, White, & Luciana, 2010), may be influenced by adolescent-specific increases in incentive motivation, catalyzing behavior in anticipation of rewards (e.g., Luciana & Collins, 2012; Luciana, Wahlstrom, Porter, & Collins, 2012). The increased demand for regulation as a result of marked increases in incentive motivation and associated reward strivings can diminish the ability to engage in effective cognitive control (Luciana & Collins, 2012), leading to non-optimal decision-making strategies, particularly in emotionally-laden contexts. This cascade can lead to poor health outcomes and, in some cases, mortality (Mahalik et al., 2013). Prevention of these negative outcomes represents an obviously important public health goal (e.g., Patton et al., 2016; Steinberg, 2015). Understanding how incentive motivation and cognitive control impact developmental changes in decision-making is an important step in guiding prevention efforts (Albert & Steinberg, 2011) given that heightened risk-taking might otherwise extend into the mid-to-late twenties (i.e., emerging adulthood, Henin & Berman, 2016).

However, there are few longitudinal studies of adolescent decision-making, limiting progress in this area. In a recent meta-analysis of 25 relevant articles, only one was longitudinal (Defoe, Dubas, Figner, & van Aken, 2015). A reliance on cross-sectional studies in assessing age-related behavioral variance may yield interpretations of developmental trajectories that vary from what is observed longitudinally (Suddendorf, Oostenbroek, Nielsen, & Slaughter, 2013). To address this gap, the current study investigates the trajectory of motivated decision-making among early to late adolescents and adults (aged 9 to 23 at initial enrollment) across a ten-year span. Decision-making was assessed with the Iowa Gambling Task (IGT), one of the most frequently utilized measures (Bechara, Damasio, Damasio, & Anderson, 1994; Beitz, Salthouse, & Davis, 2014).

In the IGT, individuals select cards from one of four decks. Each selection confers a monetary gain or loss of varying magnitude. The decks also vary in the frequency through which gains and losses are experienced; two are advantageous, because in the long run, individuals benefit (i.e., gain money) from continued selections. Two decks are disadvantageous, because individuals lose money with continued selections. The nature of the deck contingencies is unknown to participants when they initiate the task. Trial-and-error learning is required to optimize task-based decisions.

A feature of studying decision-making with the IGT is its clinical neuroscientific relevance (Buelow & Suhr, 2009; Toplak, Sorge, Benoit, West, & Stanovich, 2010). Performance is notably poor with damage to the ventral medial prefrontal cortex (vmPFC: Bechara et al., 1994). Despite this damage, patients demonstrate intact levels of executive functioning, working memory, and sequential reasoning, but outside of the lab, they make decisions against their best interests, suggesting an inability to consider future consequences. Insensitivity to future consequences may characterize adolescent behavior and attitudes

(Steinberg et al., 2009), perhaps due to a still developing prefrontal cortex (e.g., Crone & van der Molen, 2004). Given studies that support the predictive utility of the IGT for real-world risk-taking (e.g., Johnson et al., 2008; Xiao, Koritzky, Johnson, & Bechara, 2013), the task is well suited to index adolescent decision-making.

The most consistent finding of cross-sectional IGT studies in adolescence is age-related improvement in advantageous decision-making (e.g. Cauffman et al., 2010; Crone & van der Molen, 2004; Hooper, Luciana, Conklin, & Yarger, 2004; Overman et al., 2004; Prencipe et al., 2011; Van Duijvenvoorde, Jansen, Bredman, & Huizenga, 2012; see Cassotti, Aïte, Osmont, Houdè, & Borst, 2014 for a brief review). Smith, Xiao, and Bechara (2012) report that the observed improvement in previous studies is mostly linear. However, they suggest that a quadratic trajectory may be masked by the typical analytic strategy of considering age as a categorical variable with differing ranges (i.e., defining age bands that cover a specific number of years). A quadratic, U-shaped trajectory with a vertex in adolescence may reflect underlying neural processes that impact motivation and cognition (e.g., Casey, Jones, & Hare, 2008; Luciana et al., 2012; Steinberg, 2010). Smith and colleagues (2012) observed this quadratic trajectory when modeling age in years as a continuous variable and observing IGT performance among 122 adolescents ages 8–17.

The observed quadratic trend was interpreted to reflect increased reward sensitivity in adolescence in the context of immature cognitive control, as cognitive control measures were found to increase linearly across adolescence. If adolescence is characterized by an imbalance of cognitive control and reward systems, with reward systems influencing adolescent decision-making more so than in children and adults, then the extent to which the IGT is sensitive to this imbalance should be reflected in a quadratic, U-shaped age-trajectory. Alternatively, IGT-based decision-making may be better construed as a form of hot executive function (EF), because performance requires cognitive control processes associated with vmPFC that operate in affective contexts (e.g., Kerr & Zelazo, 2004; Zelazo, 2015). The extent to which the IGT recruits cognitive control is an open question (e.g., Toplak et al., 2010). Within theories of adolescent development, a heuristic is that self-regulation measures that assess cognitive control generally show linear development across age, whereas reward sensitivity measures show quadratic trends (Duell et al., 2016; Steinberg et al., 2017). It may be that the IGT assesses both constructs. Observing the trajectory of IGT performance over time may provide insight into the relative influence of each process for performance. Furthermore, by also assessing other purported measures of reward sensitivity, specific contributions to task performance can be observed. Most studies utilizing the IGT to index adolescent development have not included measures of reward sensitivity.

The Behavioral Inhibition/Behavioral Activation System scales (BIS/BAS; Carver & White, 1994) are self-report measures that assess neurobehavioral dispositions towards approach and avoidance behaviors (Corr & McNaughton, 2012). The BIS reflects neural systems that are sensitive to punishment/loss and inhibits approach behaviors in situations where there are conflicts between risk and reward. The BAS reflects neural systems that promote behavior when rewards (or gains) are present or anticipated. Limited cross-sectional findings, focused on nonclinical undergraduate samples, have associated aspects of IGT performance with BIS/BAS tendencies, although findings are inconsistent and do not address age-related variation. For example, Franken and Muris (2005) reported a *positive* correlation between BAS Reward Responsiveness (RR) and overall IGT performance, whereas Suhr and Tsanadis (2007) reported a negative correlation between overall performance and BAS-RR, as well as the Fun-Seeking subscale. Individual differences in approach and avoidance tendencies were not assessed via self-report in a large cross-sectional study of modified IGT performance among a sample aged 10–30 (Cauffman et al., 2010). However, the IGT variant implemented capitalized on individual differences in approach and avoidance behaviors by asking individuals if they wanted to play or pass each deck. Adolescents demonstrated relatively greater approach behaviors (indicating “play” to good decks, peaking in a quadratic fashion), whereas adults demonstrated relatively greater avoidance behaviors (indicating “pass” to bad decks, increasing in a linear fashion). Thus, individual differences in approach and avoidance motivations, indexed in the current study by the BIS/BAS scales, may predict age-related variation in IGT-based decision-making.

These affective motivations may also change across adolescence, although there is relatively little research using the BIS/BAS scales to measure such trajectories (Gray, Hanna, Gillen, & Rushe, 2016; Pagliaccio et al., 2016). One longitudinal study observed age-related change in the BAS-RR subscale consistent with an adolescent-specific peak in incentive motivation (Urošević, Collins, Muetzel, Lim, & Luciana, 2012). Age in years was modeled as a continuous variable. An observed interaction between time point (i.e., baseline and two-year follow-up) and age was further explored using a group-based approach, contrasting early adolescents, middle-adolescents, and young adults across time. BAS-RR scores marginally increased in early adolescents, remained stable in late adolescents, and significantly decreased in adults. In contrast, Gray and colleagues (2016) did not find associations with age on the BAS-RR subscale in a sample of nearly 1000 individuals, ages 11 to 30, where age was treated categorically. There was an age-related increased for the BAS-Drive subscale. The BIS scale was not investigated. Modeling age as a continuous variable, Braams and colleagues (2015) assessed approximately 300 individuals aged 8–27 in a two time-point design and did not find evidence of age-related change (linear, quadratic, or cubic) on the BIS/BAS scales. The current study builds on this existing work by further following the sample reported previously (Urošević et al., 2012) from two to five time-points. Age in years is treated as a continuous variable to assess changes in approach and avoidance tendencies, which are independently measured.

While decision-making and affective dispositions are the primary foci of the current study, participant sex and cognitive ability are other variables that warrant investigation. Males engage in the majority of risk behaviors that adversely affect adolescent health (Mahalik et al., 2013) but have been shown to outperform females on the IGT in some (e.g., van den Bos, Homberg, & de Visser, 2013; Weller, Levin, & Bechara, 2010) but not all (e.g., Cauffman et al., 2010; Hooper et al., 2004) studies. In addition, general intelligence is usually controlled for in developmental IGT research (e.g., Cauffman et al., 2010; Crone & van der Molen, 2004; Hooper et al., 2004) and is statistically significant in some studies (e.g., Cauffman et al., 2010; Gansler, Jerram, Vannorsdall, & Schretlen, 2011b, Icenogle et al., 2016). Few studies have examined relations among IGT performance and both cognitive and affective variables.

It is recognized that healthy individuals perform the IGT differently across task phases. Performance tends to be poor early in the task trials with notable improvement thereafter (Crone et al., 2004; Hooper et al., 2004). It is possible that cognitive functions such as intelligence and cognitive control predict performance in later task trials, after participants have had an opportunity to learn deck contingencies. Research has generally suggested two task phases, whereby performance on later, but not earlier blocks is correlated with cognitive abilities (e.g., Brand, Recknor, Grabenhorst, & Bechara, 2007; Gansler, Jerram, Vannorsdall, & Schretlen, 2011a). These two phases correspond to decision-making under ambiguity (blocks 1 and 2) and decision-making under risk (blocks 3, 4, and 5). The current study therefore considers overall performance as well as these two task phases with repeated administrations of the IGT.

Longitudinal studies of decision-making that extend beyond two time points and utilize sophisticated longitudinal modeling techniques are rare. Several studies have investigated performance longitudinally in adult patients and healthy controls (Bechara et al., 1994; Bechara, Damasio & Damasio, 2000; Waters-Wood, Xiao, Denburg, Hernandez, & Bechara, 2012) and indicate performance improvements with repeated IGT attempts among controls. One study investigated genetic components by following twins assessed three times from early adolescence to age 18 (Tuvblad et al., 2013). Individuals made fewer disadvantageous decisions when they were 16–18 years old than when they were younger (i.e., previous two assessment points) specifically during blocks 2 and 3 of their third IGT attempt. Practice effects were not statistically examined, thus, the observed improvement may be due to maturation and/or experience with the task.

Accordingly, the primary goal of the current study is to investigate age-related changes in IGT performance with repeated measurements across adolescence and adulthood in relation to affective dispositions, with a particular focus on reward sensitivity. We hypothesize age-related improvements in advantageous decision-making, consistent with cross-sectional research. We predict that the trend of these improvements will be quadratic, that is, there will be an adolescent-specific *decrement* in performance followed by improvement, as demonstrated cross-sectionally by Smith and colleagues (2012). Furthermore, in accord with prior research (e.g., Luciana & Collins, 2012; Luciana et al., 2012) we predict that this adolescent-specific decrease in decision-making will be related to a quadratic, adolescent-specific *increases* in reward-sensitivity, as assessed by the BAS. Given previous research demonstrating the predictive value of general intelligence, avoidance related tendencies, and participant sex for decision-making, these variables will also be modeled. We do not expect participant sex to significantly predict performance. We expect intelligence to be positively correlated with advantageous decision-making performance. By modeling IGT performance over time with decision-making under ambiguity and decision-making under risk metrics, we hypothesize that intelligence will predict performance in the later blocks following the opportunity to consolidate deck contingencies (Brand et al., 2007; Gansler et al., 2011a). We expect that other covariates (e.g., BAS, age) may also be significant in this phase relative to earlier trials where decision-making may be more random (e.g., Smith et al., 2012).

Methods

Participants

The study incorporated a cohort sequential design. Participants ranged in age from 9 to 23 years at the baseline assessment. For minors, families were contacted through a community database maintained at the University of Minnesota's Institute of Child Development. When their child was born, parents indicated through postcard responses an interest in participating in University-sponsored research. Additionally, invitation postcards were distributed to nonacademic University employees who might be parents. Young adults (aged 18 and above) were recruited through campus flyers and mailings. A brief phone screening followed by an in-person clinical assessment (Kiddie-SADS-Present and Lifetime Version: Kaufman, Birmaher, Brent, Rao, & Ryan, 1996) determined study eligibility. Exclusions included histories of neurological or psychiatric disorders, preterm birth or other birth complications, current or past substance abuse, head injury with loss of consciousness, learning disabilities, psychoactive prescription drug use, non-native English speaking, and uncorrected vision or hearing. As this study also involved structural brain imaging (not presented here), those who were left-handed or had imaging contraindications were excluded. At baseline, 197 individuals were enrolled and 189 individuals (96%) yielded analyzable baseline IGT data. Participants were predominantly Caucasian with family incomes in the middle to upper-middle class range (Table 1). Adult participants and parents of minors provided informed consent at each assessment wave according to requirements of the University of Minnesota's Institutional Review Board (Protocol number: 0405M59982; Adolescent Brain Development and Effects of Drug Abuse). Minors (aged 17 and under) provided informed assent.

Procedures

Participants completed assessments approximately every two years after baseline for a maximum of five assessment points. The current study focuses on measures of age, participant sex, IGT performance, BIS/BAS measures, and estimated full-scale intelligence (see below).

Measures

Iowa Gambling Task (Bechara et al., 1994)—Participants completed a computerized variant of the standard IGT at each time-point using E-prime task presentation software (see Hooper et al., 2004). There were 100 total trials. Participants selected from one of four decks on each trial. There was no limit to how many times a participant could select from each deck, a feature that varies from the original IGT, which capped selections from each deck at 40 (Bechara et al. 1994). The E-prime button box was used to select buttons that corresponded to each deck. Deck A provided gains of $0.25, with a 50% chance of losses that varied from $0.35 to $0.90. Deck B provided the same gains ($0.25), however there was a 10% chance of losses that varied from $3.00 to $3.25. Deck C provided gains of $0.10 or $0.15 with a 50% chance of losses that varied from $0.05 to $0.20. Deck D provided the same gains ($0.10 or $0.15), however there was a 10% chance of losses that varied from $0.60 to $0.65. Decks A and B were disadvantageous as the expected net winnings after twenty selections was −$1.25. Conversely, Decks C and D were advantageous as the expected net winnings after twenty selections was $1.25. Decks A, B, C, and D with associated contingencies were spatially shuffled across assessments to reduce practice effects. Participants began with a "loan" of five dollars and were instructed to win as much money as possible. They were uninterrupted during task performance. Participants were paid their winnings in cash at the end of the day. Overall IGT performance was defined as the difference between numbers of advantageous ("good", Decks C and D) and disadvantageous ("bad", Decks A and B) selections across all 100 trials (Toplak et al., 2010). Additional metrics included decision-making under ambiguity, defined as the difference between good and bad selections across the first 40 trials (e.g., blocks 1 and 2), and decision-making under risk, defined as the difference between the selections across the last 60 trials (e.g., blocks 3, 4, and 5).

Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler 1999)—Participants completed WASI Matrix Reasoning and Vocabulary subtests at each wave. Raw scores were combined using standardized procedures to yield a two-scale intelligence estimate. Each subtest was administered by a trained psychometrist. The WASI-estimated two-subtest IQ score is strongly representative of WASI full-scale IQ ($r = .94$) and correlates highly with Wechsler Intelligence Scale for Children-III ($r = .81$) and Wechsler Adult Intelligence Scale-III ($r = .87$) full-scale IQs (Wechsler, 1999). The current study implemented standard age-corrected scores.

BIS/BAS Scales (Carver & White, 1994)—The BIS-BAS questionnaire is a 20-item self-report measure with two composite/total scales (BIS/BAS). The BIS assesses behavioral inhibition through 7 items. Recent work (Gray et al., 2016) indicates that the BIS can be further divided into two subscales, Fear and Anxiety. Fear consists of two items ("even if something bad is about to happen to me, I rarely experience fear or nervousness," "I have very few fears compared to my friends") and Anxiety consists of five items (e.g., "criticism or scolding hurts me quite a bit," "I worry about making mistakes"). The BAS is separated into three subscales, a 5-item Reward Responsiveness (RR) scale (e.g., "when good things happen to me it affects me strongly"), a 4-item Drive scale (e.g., "If I see a chance to get something I want I move on it right away") and a 4-item Fun Seeking scale (e.g., "I will often do things for no other reason other than that they might be fun"). Responses were made on a 4-point scale. The current study utilized models with BIS and BAS total scales as well as the five BIS and BAS subscales.

Statistical Approach

Overall IGT scores were normally distributed at each administration. While decision-making under ambiguity was normally distributed, decision-making under risk was left-skewed, particularly for the later administrations (4, 6, and 8 years after baseline). Ninety-five percent of covariates were also normally distributed, with the exception of two scales at certain time points. Mixed effects models (nlme package, R version 3.3.2; R Core Team, 2016) were used to model age-related changes in the three IGT metrics and covariates (Fitzmaurice, Laird, & Ware, 2011). One of the strengths of mixed effects models is the ability to handle missing data (Fitzmaurice, Laird, & Ware, 2011); these models use all available data to inform parameter estimates. Mixed effects modeling uses maximum-likelihood estimation to determine parameter values, and as long as data are missing completely at random or missing at random, the estimates are considered valid. This assumption was tested. Older age at baseline was negatively correlated with the total number of completed sessions ($r = -.42$, $p < .001$), as was the BAS composite scale ($r = -.24$, $p < .001$) and decision-making under risk ($r = -.17$, $p = .02$). However, when these three variables are entered into a linear regression predicting overall experience, baseline age was the only significant predictor, whereas BAS and the IGT risk metric were not. No other specific pattern of missing values was uncovered (e.g., participant sex, baseline intelligence, baseline BIS composite scale, baseline IGT overall performance and ambiguity metrics). These results are consistent with previous research findings from this study that sampled only two time-points (Urošević et al., 2012). Thus, data were considered missing at random (which is a less stringent assumption as opposed to the more restrictive assumption of missing completely at random (Heitjan & Basu, 1996)) since the probability of a missing response appears to depend on baseline age.

Furthermore, previous experience with the IGT was controlled for and grand mean centered, as the cohort-sequential design of the study results in individuals with anywhere from 1–5 attempts at a given age (e.g., 17-year-olds, 21-year-olds, etc.). Table 2 describes the number of participants who provided analyzable IGT data at each assessment wave. In all, 7 IGT administrations were dropped: 5 participants explicitly told staff they remembered the task and data from 2 participants were lost due to computer error.

Table 3 provides descriptive data for the three IGT metrics across assessments. Two main models were tested and compared to select an appropriate unadjusted model (i.e., model without covariates) describing whether the function of age-related changes in IGT performance was best described by a linear or nonlinear (quadratic) trend over time. Both unadjusted models contained a random effect of intercept to account for the within-subject performance correlation. A random effect of age was added to each main model to determine whether there was important variation among participants in the rate of change in addition to overall level. This resulted in four model types. The Bayesian Information Criterion (BIC) (Schwarz, 1978) and Akaike Information Criterion (AIC)(Akaike, 1974) values were used to compare model fit. In cases where there was disagreement between AIC and BIC, a likelihood ratio test was used to compare models with the same random effects. Age was grand-mean centered in all unadjusted models.

Age-related changes in time-varying covariates (intelligence, BIS, and BAS measures) were also assessed with mixed effects models. Descriptive data for each covariate are presented in Table 3. A similar model comparison procedure was used to assess the nature of age-related change for each covariate without additional covariates (i.e., models only contained age as a predictor). Because the effect of a time-varying covariate in the various models confounds within-subject changes and differences in initial levels of the covariate, the between-person and person-specific effects of these variables were estimated separately as described by Curran and Bauer (2011). Thus, for each time-varying covariate, there is a between-subjects variable that represents overall differences among the sample on a covariate, and a within-subjects variable that indicates change over time, independent of the overall differences. In accord with the study's hypotheses, BAS was expected to show a quadratic, age-related increase peaking in adolescence before declining into adulthood. All covariates were grand-mean centered.

Four models were tested to observe the effects of covariates on IGT performance: one model was the best-fitting unadjusted model (intercept and mean age). A second model added between and within-person covariates (e.g., intelligence, BIS, BAS), participant sex, and the experience variable to Model 1. Model 2 assessed whether the hypothesized covariates predicted IGT performance. For each individual, the experience variable was between-subjects and assessed how many times the individual had completed the IGT (i.e., from 1–5) over the course of the study. A third model added an interaction between age and experience to Model 2. Model 3 investigated whether the effect of IGT experience varied by age. A fourth model added interactions with between-subjects intelligence and age, between-subjects BIS/BAS and age, and participant sex and age to Model 3 to assess whether the effects of these covariates on performance varied by age. The best-fitting model was then selected and interpreted. One set of models compared covariates and BIS/BAS total scores, whereas another set compared covariates and the five BIS/BAS subscales. Thus, for each of the three IGT performance metrics, two sets of models were tested (one with BIS/BAS total scores and one with subscales).

Results

Covariate and IGT Performance Trajectories

Different models of age-related changes (null, linear, quadratic) in the covariates of interest using unadjusted models indicated that intelligence ($\hat{\beta} = .34$) and BIS total ($\hat{\beta} = .20$) displayed linear increases with age. Both BIS subscales, Anxiety ($\hat{\beta} = .15$) and Fear ($\hat{\beta} = .05$), also demonstrated linear increases with age. The BAS total score demonstrated significant age-related change, with significant linear ($\hat{\beta} = .11$) and quadratic ($\hat{\beta} = -.02$) effects. However, the trajectory did not clearly support an adolescent-specific peak. The quadratic trend appears to emerge due to the relatively lower average scores of older individuals (e.g., ages 26–29). When the BAS subscales were modeled, Fun-Seeking showed no age-related change. Drive and Reward Responsiveness (RR) demonstrated significant linear (Drive $\hat{\beta} = .09$; RR $\hat{\beta} = .03$) and quadratic (Drive $\hat{\beta} = -.008$; RR $\hat{\beta} = -.005$) age effects. Again, the trajectories for these two subscales did not support an adolescent specific peak despite the quadratic trends (see supplemental Figures plotting the time-varying covariates with age and model comparisons).

In predicting overall IGT performance (Figure 1), the best-fitting unadjusted model included a linear effect of age with a random effect of intercept (Table 4). Although evidence for a random effect of age was somewhat equivocal, evidence concerning the overall age trend was not: the posterior odds that the linear model was the true model, relative to the model with an additional quadratic component, were approximately 8 to 1. In predicting decision-making under ambiguity (Figure 2), the best-fitting unadjusted model included a linear effect of age with random effects of intercept and age (Table 4). For decision-making under risk (Figure 3), AIC and BIC did not converge on the same model for the fixed effect of age, as BIC was split between a quadratic and linear effect, and AIC favored a quadratic age term

(Table 4). However, the quadratic function did not reflect an adolescent specific decease. A likelihood ratio test indicated that a fixed quadratic effect should be added to the model. The variance associated with a random quadratic effect of age was near zero ($\sigma^2 = .04$, standard deviation = .19). Thus, an unadjusted model without random effects of age was interpreted, corresponding to the second-best model as indicated by the BIC. Please see the Supplemental Materials for correlations between the IGT metrics across assessment wave.

When comparing different adjusted models to the best-fitting unadjusted model for overall IGT performance, a model with covariates and no interactions fit the data best. There were no substantial differences in fixed effects when a random effect of age was added, thus the more parsimonious model was interpreted. A model with covariates and no interactions fit the data best for both decision-making under ambiguity and risk. This pattern held when the BIS/BAS subscales were modeled. Please see the Supplemental Materials for these model comparison results.

Predictors of IGT Performance Metrics

Overall performance—For overall performance, positive predictors included the linear effect of age and between-subjects intelligence, whereas between-subjects BAS was a negative predictor (high BAS associated with disadvantageous performance). There was a significant, positive effect of task experience (i.e., the number of completed sessions). Those with more experience made more advantageous choices. The significant between-subjects effects indicated that intelligence, as well as affective approach tendencies at study entry, predicted performance, as opposed to *changes* in these measures over time. Namely, higher levels of intelligence were associated with overall advantageous performance, whereas higher levels of behavioral activation were negatively associated with overall advantageous performance. For instance, a person scoring 1 standard deviation above the mean in estimated intelligence would score approximately 8 points higher on the IGT than a person scoring 1 standard deviation below the mean. Similarly, a person scoring 1 standard deviation above the mean in overall BAS would score approximately 9 points lower on the IGT than a person scoring 1 standard deviation below the mean. There were no significant effects of sex or affective avoidance tendencies for overall performance (Table 5). When BIS/BAS subscales rather than total scores were examined, the pattern of significant predictors (e.g., for age, intelligence, overall experience) generally remained the same. However, none of the BAS subscales were uniquely significant predictors. See Supplemental Materials for model comparisons and detailed results).

Decision-making under ambiguity (blocks 1 and 2)—Similar to findings for the total IGT score, a linear effect of age was a positive predictor of decision-making in the first two IGT blocks, whereas between-subjects BAS was a negative predictor. There was a significant, positive effect of task experience. Notably, intelligence was not a significant predictor of decision-making under ambiguity. A person scoring 1 standard deviation above the mean in overall BAS would score approximately 2 points lower on the first two blocks of the IGT than a person scoring 1 standard deviation below the mean. There were no significant effects of participant sex or affective avoidance tendencies in the best-fitting model. Table 6 provides additional information on the best-fitting adjusted model. When

BIS/BAS subscales rather than total scores were examined, age and overall experience remained significant positive predictors of decision-making under ambiguity. Similar to overall IGT performance, none of the BAS subscales were uniquely significant predictors. The BIS subscales and participant sex were not significant predictors. See Supplemental Materials for model comparisons and detailed results.

Decision-making under risk (blocks 3, 4, and 5)—Blocks 3 through 5 represent the phase within which individuals are acquainted with deck contingencies and make informed decisions, albeit with some uncertainty, based on that information. The linear effect of age and between-subjects intelligence were positive predictors of advantageous decisions during this phase, whereas between-subjects BAS remained a negative predictor. The quadratic effect of age was also a significant negative predictor, reflecting a decrease in predicted values at the older age range of the sample. In contrast to what was observed for the earlier task phase, there was no significant effect of overall task experience. There was also a significant, negative effect of participant sex whereby females performed about six points worse than males. A person scoring 1 standard deviation above the mean in estimated intelligence would score approximately 6 points higher on the last three blocks of the IGT than a person scoring 1 standard deviation below the mean. A person scoring 1 standard deviation above the mean in overall BAS would also score approximately 6 points lower on the last three blocks of the IGT than a person scoring 1 standard deviation below the mean. Affective avoidance tendencies were not significant in the best-fitting model (Table 7). When BIS/BAS subscales rather than total scores were examined, the linear effect of age and between subjects intelligence remained significant positive predictors of decisions under risk. Participant sex remained a significant negative predictor, as did the quadratic effect of age. Between-subject differences in the BAS-RR subscale emerged as a negative predictor of decision-making under risk when the subscales were modeled ($\hat{\beta} = -1.04$, $p < .05$). The BIS subscales were not significant predictors. See Supplemental Materials for model comparisons and detailed results.

Discussion

To the best of our knowledge, this is the first study to prospectively examine three metrics of longitudinal IGT performance spanning a full decade in an adolescent sample in conjunction with measures of cognitive ability and affective tendencies. The main finding of an age-related increase in advantageous decision-making is consistent with previous cross-sectional research (e.g., Beitz et al., 2014; Cassotti et al., 2014; Cauffman et al., 2010; Crone & van der Molen, 2004; Hooper et al., 2004; Prencipe et al., 2011). The results indicate that the age-related improvement in advantageous decision-making is linear, observed for both advantageous and disadvantageous decks. This finding runs counter to our hypothesis of a quadratic trajectory as well as the cross-sectional results reported by Smith and colleauges (2012) among a sample of 8–17 year olds. While there was a significant quadratic effect of age for decision-making under risk (i.e., IGT blocks 3 to 5), this effect was negative and did not support an adolescent specific decline. Similarly, we failed to observe an adolescent peak in approach behavior (BAS sensitivity), although higher initial levels were associated with relatively less advantageous decision-making across all performance metrics and regardless of participant age. In addition, higher intelligence conferred more advantageous decision-making overall and, specifically, in the later task phase, presumably following the learning of task contingencies. There was also a significant effect of overall experience on performance, consistent with prior studies (e.g., Waters-Wood et al., 2012). While task experience significantly impacted decision-making under ambiguity (i.e., in the course of learning), it did not affect decision-making under risk. Lastly, males outperformed females under conditions of risk. Overall, while these findings generally replicate other reports of age-related improvements in affective decision-making, the results raise new questions about what is unique about the adolescent period and which processes are most strongly indexed by the IGT.

Dual systems models suggest that cognitive control improves in a linear fashion from childhood, through adolescence and into young adulthood (e.g., Steinberg et al., 2017). In contrast, approach motivation (Luciana et al., 2012), sensation-seeking (Casey et al., 2008; Steinberg, 2010) and perhaps other aspects of reward-sensitivity are hypothesized to peak during adolescence relative to both childhood and adulthood, a conjecture that is supported by functional neuroimaging data (Silverman, Jedd & Luciana, 2015). This dynamic suggests that emergent capacities for cognitive control will be overcome under motivationally-salient circumstances, perhaps leading to risk-taking behaviors (Luciana & Collins, 2012). We expected the IGT to be sensitive to the imbalance between reward sensitivity and cognitive control in adolescence. Our failure to observe a decrement in IGT performance during the adolescent period, as would be expected if cognitive control had faltered in the context of salient motivational demands, replicates some of the prior literature but raises questions.

Given the pattern of our findings, it may be that the overall IGT performance, and particularly performance under conditions of risk, index cognitive control functions more so than reward sensitivity and should therefore be conceptualized as cognitive control measures (Shulman et al., 2016). This interpretation would challenge the replicability of others' cross-sectional observations of a quadratic influence of age on overall IGT performance (Smith et al., 2012). Even when IGT performance was examined cross-sectionally at baseline for all 189 subjects in this study, the age trajectory was found to be linear (See Supplemental Materials). The wider baseline age-range of the current study compared to the work by Smith and colleagues (ages 9–23 here vs. 8–17 in their report), demographic differences in the number of participants at each age, race/ethnicity, and intelligence, as well as a relatively greater number of observations in late adolescence and adulthood may be reasons for the discrepant results. That said, the observed linear pattern is consistent with studies where age is modeled categorically (e.g., Crone & van der Molen, 2004; Hooper at al., 2004; van Duijvenvoorde et al., 2012). Moreover, while Smith and colleagues (2012) found evidence of a quadratic effect on performance, they also qualify this as a J-curved age trajectory, where decision-making ability increased linearly after early adolescence and younger children did not show a preference for either type of deck (good/bad). Our results align with what was observed in their report for participants beyond late childhood/early adolescence. Similarly, Duell et al. (2016) reported a monotonic increase in advantageous decision-making during adolescence using the pass/play variant, finding that a performance decline was not observed until ages 22 to 25. While direct comparisons between studies are difficult, the various task versions implemented across laboratories are largely faithful to the original conceptualization of the IGT. Overall, a general observation is that late adolescence and early adulthood represent periods when individuals learn to make more advantageous than disadvantageous decisions. Thus, the age-related findings observed in the context of this longitudinal study are largely similar to previous work and consistent with a recent meta-analysis of risky decision-making (Defoe et al., 2015).

Nonetheless, as expected, initial levels of BAS sensitivity were negatively related to overall IGT performance, consistent with the hypothesis that decision-making is compromised by high levels of reward sensitivity. The negative relation of BAS sensitivity held across both decision-making under ambiguity and decision-making under risk phases. This appears to be consistent with the schedule of the IGT, as the disadvantageous decks initially provide higher rewards, and only later (after several selections from each deck) yield punishments. Thus, individuals who are relatively high in reward sensitivity (BAS total) demonstrate a proclivity for these decks in the beginning of the IGT, but also a bias against choosing the more advantageous decks later on (risk). When the BIS and BAS subscales were modeled, BAS-RR was a significant negative predictor, consistent with prior research (Suhr & Tsanadis, 2007) but only for decision-making under risk. The other BAS subscales were not significant.

While we failed to replicate our earlier finding of an adolescent peak in BAS sensitivity (Urošević et al., 2012), we did find through this more comprehensive analysis that BAS total and BAS-RR scores decline in adulthood (e.g., the mid to late twenties), suggesting that a developmental peak in reward sensitivity is, indeed, valid but that it occurs later than expected. Future work can further assess the age-related trajectories of the BIS/BAS subscales, especially since the cohort-sequential design of the study results in individuals contributing to distinct pieces of the average age trajectory. Assessing measurement invariance in these scales over time, by age and/or by sex, also represent important analyses to conduct to further characterize the development of these affective tendencies (e.g., Pagliaccio et al., 2016).

Despite the clear relevance of reward sensitivity for IGT performance, it may be that cognitive influences on performance overshadowed its motivational component, at least as measured in our healthy sample within the laboratory. For instance, intelligence was a significant predictor of longitudinal IGT performance. An earlier review found limited support for positive correlations between cool executive functions, intelligence, and IGT performance (Toplak et al., 2010). Nonetheless, significant effects of intelligence on IGT performance have been observed in several studies since the 2010 review (e.g., Cauffman et al., 2010; Duell et al., 2016; Gansler et al., 2011b; Icenogle et al., 2016). These discrepant findings may be due to correlating IQ with *overall* performance, without considering specific task phases. The absence of an effect of intelligence for decision-making under ambiguity and presence of an effect for decision-making under risk in the current study speaks to the interpretive utility of dividing the IGT into these two phases (e.g., Brand et al., 2007; Tuvblad et al., 2013). In their recent meta-analysis of 25 adolescent decision-making studies, Defoe et al. (2015) concluded that adolescent risk taking declines for tasks involving objective (i.e., non-ambiguous) risks. Perhaps the IGT serves as such a measure, particularly during the later task phase and following repeat administrations. Adolescent imbalance models may not pertain to these types of risks, or imbalance models must be considered differently in relation to each task phase. Thus, the results of the current study indicate that the IGT is not only a measure of reward sensitivity, but a multi-faceted task that also calls on cognition in accord with others' conceptualizations of decision-making (Schiebener and Brand, 2015).

Adolescent risk-taking outside of the lab is a complex combination of self-regulation in cognitive and affective domains, individual differences in affective tendencies and personality traits, as well as sex differences that may influence how situations are approached or avoided. In a large cross-national study, self-regulation/cognitive control and reward sensitivity had independent effects on lab-based risk-taking (Duell et al., 2016). If the value of the adolescent imbalance model is the prediction of the specific interactions among age, cognitive control, and reward sensitivity, then the study conducted by Duell and colleagues (2016) and the current study support the view that adolescent imbalance models may need thoughtful reconsideration and/or specification (e.g., Pfeifer & Allen, 2016; van den Bos & Eppinger, 2016) or that more work should be done to devise tasks that can better separate and integrate both arms of the dual systems.

We observed a significant effect of participant sex on IGT performance only for decision-making under risk, where males performed better than females. This is consistent with some (e.g., van den Bos et al., 2013; Weller et al., 2010) but not all (e.g., Cauffman et al., 2010; Hooper et al., 2004) prior studies. Interestingly, both the van den Bos and Weller studies found sex effects for decision-making under risk, the later task phase, consistent with the current study. Among a cross-national sample of over 3000 adolescents (age 9–17), pubertal status predicted greater approach towards disadvantageous decks for males, whereas age predicted avoidance of disadvantageous decks to a greater extent in males (Icenogle et al., 2016). Observed sex differences may be related to differential effects of pubertal hormone levels on males and females for the constructs associated with IGT performance (e.g., sensation-seeking, see Icenogle et al., 2016) and/or sex differences in the brain regions associated with IGT performance (e.g., Bolla, 2004). Future research should continue to explore potential sex differences as contributors to distinct phases of IGT performance in the context of pubertal development.

An important goal for future research is to assess how longitudinal IGT performance across multiple time points relates to real-life decision-making such as drug initiation and other behaviors (e.g., Johnson et al., 2008; Malone et al., 2014). The neural correlates of this decision-making trajectory are also important to investigate (e.g., Buelow & Suhr, 2009; Malone et al., 2014), perhaps by integrating trial-by-trial data with models that provide parameters to index specific cognitive processes (e.g., Steingroever, Wetzels, & Wagenmakers, 2013; Yechiam, Busemeyer, Stout, & Bechara, 2005).

The strengths of the current study include a longitudinal assessment of IGT performance across the full range of adolescence and the use of statistical methods to disaggregate between- and within-person change. These methods account for both individual differences in initial levels of intelligence and affective tendencies and change over the duration of the study. Our IGT variant cannot differentiate between approach and avoidance of good or bad decks, as a selection to play one deck indicates an avoidance of the other three and these three decks are not uniformly advantageous or disadvantageous. As with all longitudinal studies, participant attrition and subsequent missing data is a limitation. The sample of individuals studied here was relatively advantaged with above average intelligence at the study baseline and without obvious risk factors for maladaptive behavior. Older individuals at baseline were more likely to complete fewer sessions. This selection strategy may have introduced biases. Given the cohort-sequential longitudinal design, the amount of data contributing to IGT performance and covariates in the tails of the age-ranges of the study (e.g., 9 and 10 year olds, 30 years of age and older) are lower than the data contributing to the middle ages. Extending the study into middle and late adulthood when a performance decline would be expected (e.g., Beitz et al., 2014; Schiebener & Brand, 2016) may also aid in interpretation of age-related trajectories. While a strength of the study is that the most substantiated performance estimates occur during time periods characterized by increases in risk-taking (ages 18–21; Mahalik et al., 2013; Shulman et al., 2016), following a same-aged sample of individuals for ten years could provide a useful perspective on developmental trajectories. That said, a benefit of the current study design is the ability to disentangle the roles of age and task experience on observed outcomes.

In summary, the results of the study replicate prior work by showing that age-related improvements in decision-making are linear in the context of a longitudinal design. Initial intelligence was also a significant, positive predictor of overall IGT performance and decision-making under risk, whereas initial levels of BAS were negatively associated with all three metrics of IGT performance. These associations held when controlling for the number of times individuals completed the IGT. Males outperformed females for decision-making under risk. This pattern of results suggests that longitudinal IGT performance may be best construed as a measure of cognitive-control under affective conditions. While this study is the first to investigate IGT performance longitudinally with mixed effects models among an adolescent sample, future analyses should address how these IGT trajectories are associated with brain development and real-world decision-making.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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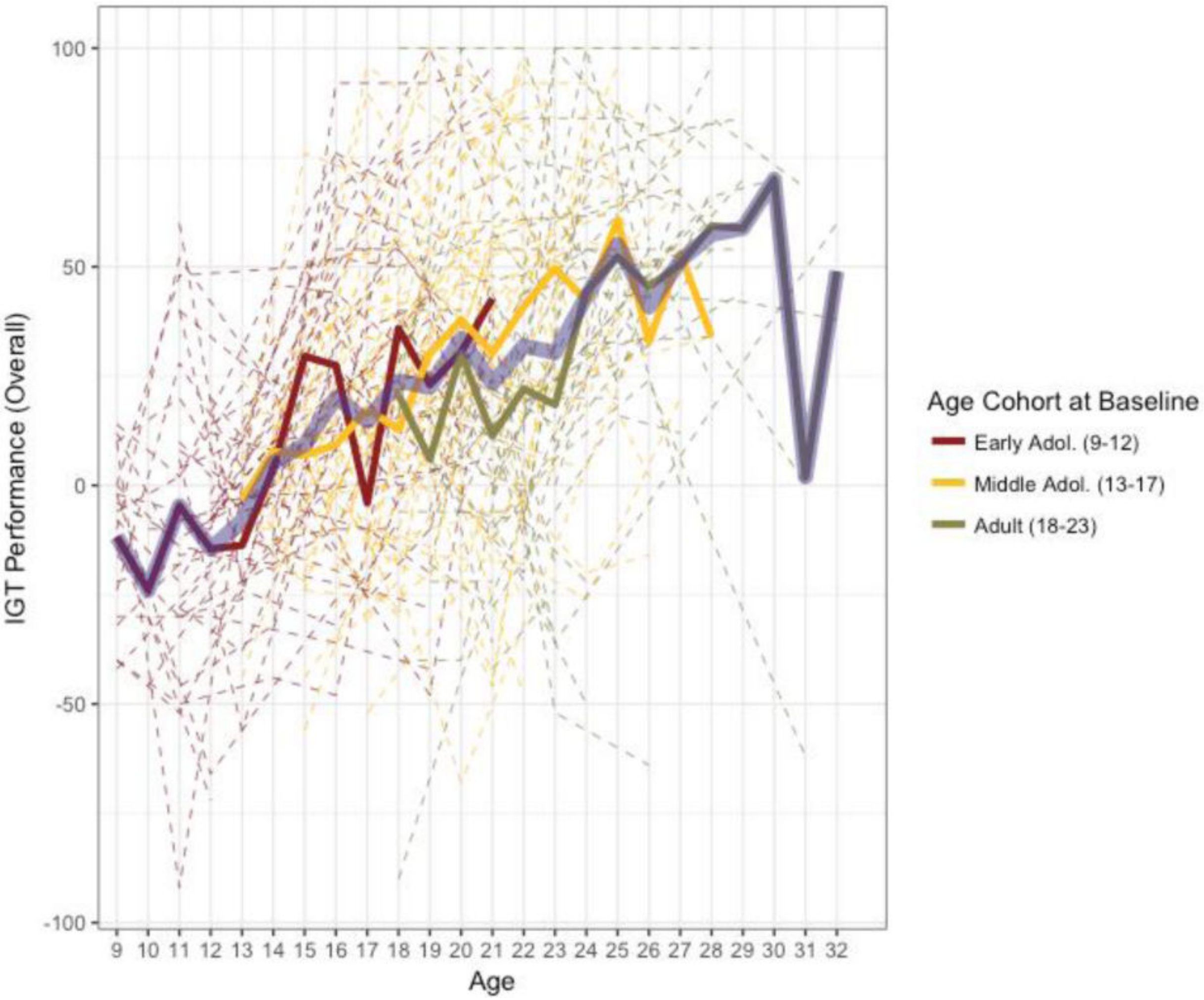

Figure 1.

Overall Iowa Gambling Task (IGT) performance for all subjects (dashed lines) during the study. The three opaque lines represent the average of a cohort at a given age. The transparent, purple line represents the average IGT performance at each age across cohorts. Adol. = adolescent.

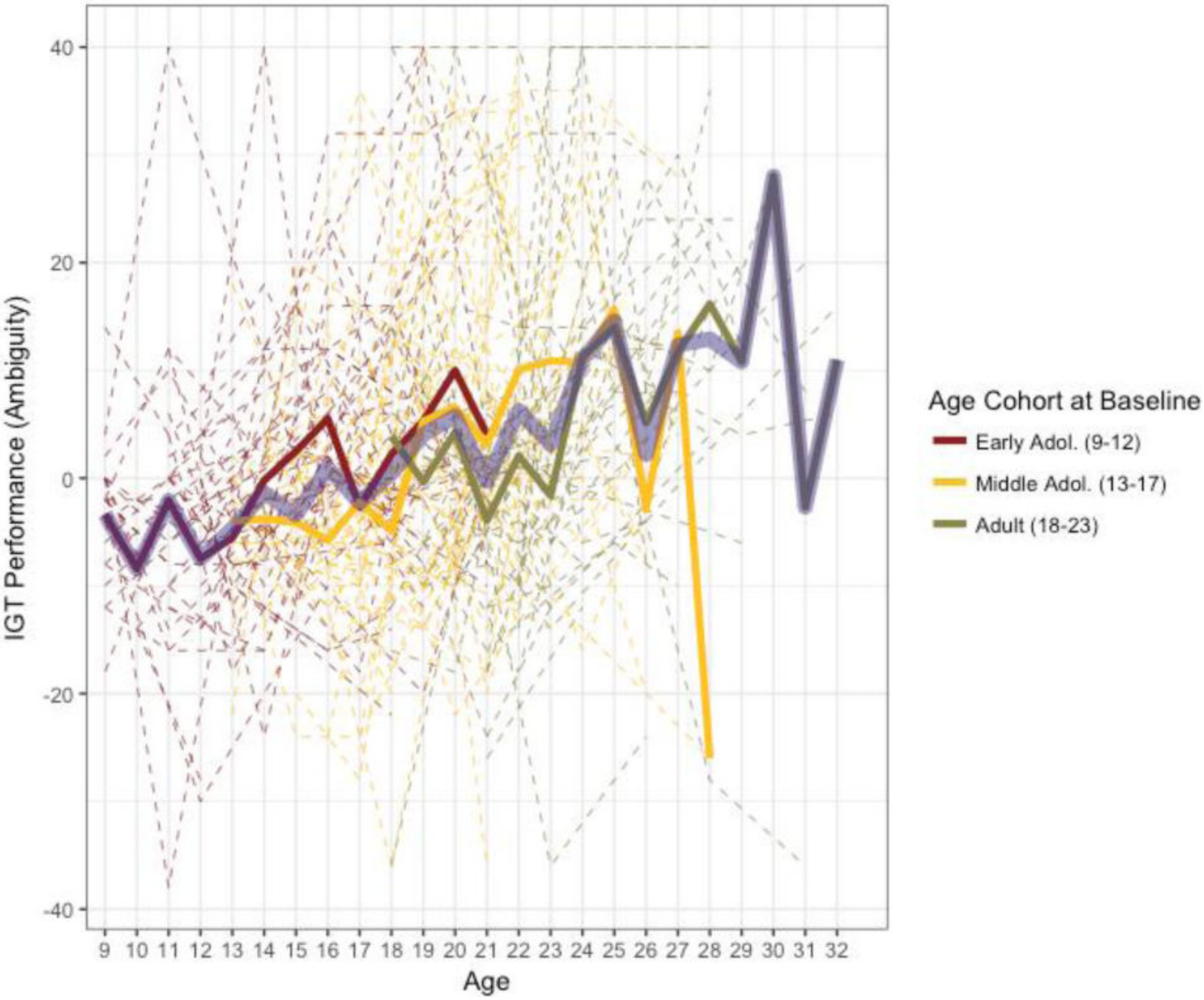

Figure 2.
Decision-making under ambiguity (blocks 1 and 2) for all subjects (dashed lines) during the study. The three opaque lines represent the average of a cohort at a given age. The transparent, purple line represents the average performance at each age across cohorts. IGT = Iowa Gambling Task. Adol. = adolescent.

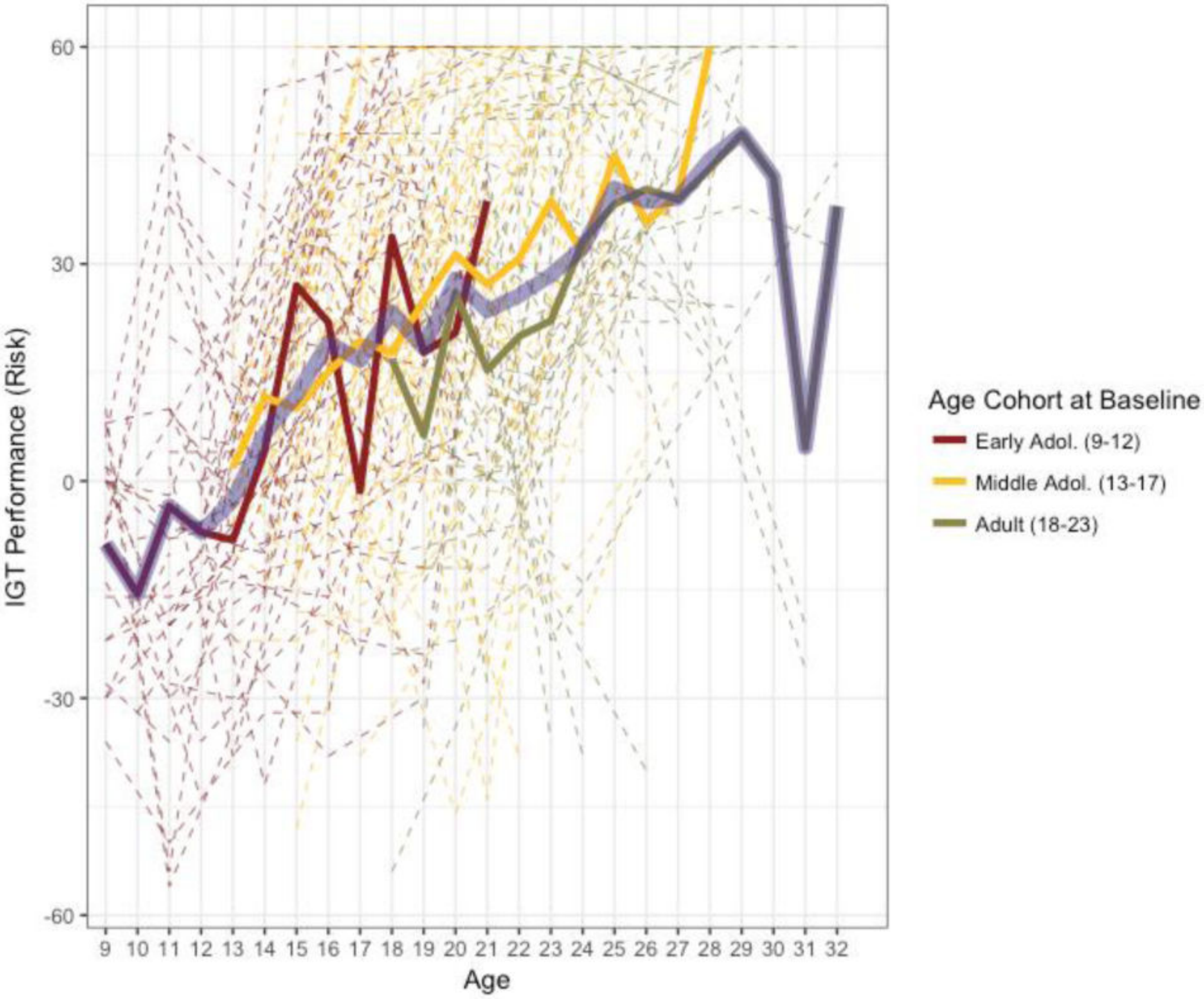

Figure 3.

Decision-making under risk (blocks 3, 4, and 5) for all subjects (dashed lines) during the study. The three opaque lines represent the average of a cohort at a given age. The transparent, purple line represents the average performance at each age across cohorts. IGT = Iowa Gambling Task. Adol. = adolescent.

Table 1

Participant Demographics

Demographic	**Early Adolescent** **_N_ = 46**	**Middle Adolescent** **_N_ = 73**	**Adult** **_N_ = 70**
Mean BL Age (SD)	10.76 (1.19)	15.72 (1.51)	20.57 (1.63)
BL Age Range	9–12	13–17	18–23
Percent Female	52	48	64
Percent Caucasian	87	93	81
Mean BL Maternal Years of Education (SD)	15.74 (1.57)	15.92 (1.75)	15.42 (2.44)
Mean BL Paternal Years of Education (SD)	16.33 (2.85)	15.95 (2.86)	16.15 (3.09)
Mean Waves Completed (SD)	4.11 (0.99)	3.58 (1.36)	2.79 (1.30)

Note. BL = baseline/year 0 of study. SD = standard deviation. Age is presented in years.

Table 2

Number of Participants with Analyzed Iowa Gambling Task Data for Each Assessment Wave

Year	*N*
0	189
2	159
4	78
6	113
8	99

Note. Year 0 represents the baseline of the study. Year 4 was not budgeted within the award that supported the work. We assessed as many participants as was feasible given available resources. Attrition is due to resource limitations and not to participants' willingness to contribute data.

Table 3

Means and Standard Deviations (in Parentheses) for Measures Across the Duration of the Study

Variable (Theoretical Range)	**Study Year**				
	0	**2**	**4**	**6**	**8**
IGT: Overall (−100 – 100)	5.8 (28.6)	10.8 (36.5)	27.7 (40.8)	41.5 (37.1)	40.4 (35.2)
IGT: Ambiguity (−40 – 40)	−2.9 (10.8)	−0.9 (14.6)	2.6 (16.5)	9.3 (15.8)	6.7 (15.0)
IGT: Risk (−60 – 60)	8.7 (23.5)	11.6 (28.7)	25.1 (28.1)	32.2 (26.0)	33.7 (25.2)
WASI: Two-Scale IQ (40 −160)	114.0 (10.5)	114.3 (9.6)	117.9 (9.8)	118.5 (9.9)	115.4 (10.5)
BIS Total (7 – 28)	19.4 (3.3)	19.8 (3.8)	19.8 (3.9)	20.6 (3.8)	21.3 (3.6)
BAS Total (13 – 52)	39.9 (4.8)	39.6 (4.6)	41.3 (4.0)	40.1 (4.5)	39.6 (4.8)
BIS Subscale: Anxiety (5 – 20)	14.2 (2.7)	14.6 (3.0)	14.6 (3.1)	15.1 (2.9)	15.7 (2.8)
BIS Subscale: Fear (2 – 8)	5.2 (1.3)	5.2 (1.5)	5.2 (1.5)	5.6 (1.6)	5.6 (1.5)
BAS Subscale: Drive (4 – 16)	10.5 (2.3)	10.4 (2.3)	11.2 (2.0)	10.7 (2.1)	10.4 (2.5)
BAS Subscale: Fun-Seeking (4 – 16)	12.1 (2.0)	11.8 (2.0)	12.4 (2.1)	12.0 (2.0)	11.6 (2.2)
BAS Subscale: Reward Responsiveness (5 – 20)	17.3 (1.9)	17.4 (1.8)	17.7 (1.5)	17.4 (2.0)	17.6 (1.6)

Note. IGT = Iowa Gambling Task. WASI = Wechsler Abbreviated Scale of Intelligence. BIS = Behavioral Inhibition System. BAS = Behavioral Activation System.

Table 4

Comparison of Bayesian Information Criterion (BIC), Weight of Evidence for BIC (bWeight), Akaike Information Criterion (AIC), and Weight of Evidence for AIC (aWeight) for Unadjusted Models of Iowa Gambling Task Performance Metrics

Overall Performance Model	**BIC**	**bWeight**	**AIC**	**aWeight**
1. Null model (intercept only)	6382.7	< .001	6324.8	< .001
2. Linear effect of age and random effect of intercept	**6283.8**	**.51**	6221.4	.01
3. Linear effect of age and random effects of intercept and age	6284.2	.43	**6212.8**	**.82**
4. Quadratic and linear effects of age and random effect of intercept	6287.9	.07	6221.0	.01
5. Quadratic and linear effects of age and random effects of intercept and age	6305.3	< .001	6216.1	.16
Decision-Making Under Ambiguity Model	BIC	bWeight	AIC	aWeight
1. Null model (intercept only)	5271.9	< .001	5213.9	< .001
2. Linear effect of age and random effect of intercept	5236.0	.18	5173.6	.002
3. Linear effect of age and random effects of intercept and age	**5233.0**	**.81**	**5161.7**	**.93**
4. Quadratic and linear effects of age and random effect of intercept	5242.2	.01	5175.3	.001
5. Quadratic and linear effects of age and random effect of intercept and age	5256.3	< .001	5167.1	.06
Decision-Making Under Risk Model	BIC	bWeight	AIC	aWeight
1. Null model (intercept only)	6008.5	< .001	5950.5	< .001
2. Linear effect of age and random effect of intercept	**5899.0**	**.54**	5836.6	.02
3. Linear effect of age and random effects of intercept and age	5906.5	.01	5835.2	.04
4. Quadratic and linear effects of age and random effect of intercept	5899.4	.45	5832.5	.16
5. Quadratic and linear effects of age and random effects of intercept and age	5918.5	< .001	**5829.4**	**.77**

Note. Bolded font indicates best-fitting model for the criterion. Likelihood ratio tests comparing linear and quadratic models with the same random effects (Model 2 vs. Model 4; Model 3 vs. Model 5) were significant ($p \leq .01$). Bolded font indicates best-fitting model for the criterion

Table 5

Comparison of Best-Fitting Model with Unadjusted Model of Overall Iowa Gambling Task Performance

Between-Subjects Effects	**Within-Subjects Effects**	**Unadjusted Model**	**Final Model**
Intercept (SE)		20.13^{**} (1.88)	23.98^{**} (2.74)
Age (SE)		3.74^{**} (.31)	3.65^{**} (.31)
Participant Sex (SE)		–	−6.14 (3.70)
Intelligence (SE)		–	$.38^{*}$ (.18)
BIS (SE)		–	.76 (.53)
BAS (SE)		–	$-.91^{**}$ (.31)
Overall Experience (SE)		–	2.98^{*} (1.49)
	Intelligence (SE)	–	.36 (.25)
	BIS (SE)	–	.11 (.66)
	BAS (SE)	–	.25 (.62)
Variance Components			
Intercept		429.80	343.55
Residual		718.61	706.48
Model Fit			
BIC		6284	6270

Note. BIS = Behavioral Inhibition System. BAS = Behavioral Activation System. SE = standard error. BIC = Bayesian Information Criterion. Age, estimated intelligence, overall experience, and BIS/BAS are grand-mean centered. Participant sex is dummy-coded where 0 = male, 1 = female.

[*] = $p < .05$.

[**] = $p < .01$.

Table 6

Comparison of Best-Fitting Model with Unadjusted Model of Decision-Making Under Ambiguity

Between-Subjects Effects	Within-Subjects Effects	Unadjusted Model	Final Model
Intercept (SE)		1.73 * (.69)	1.54 (1.00)
Age (SE)		.85 ** (.13)	.91 ** (.13)
Participant Sex (SE)		–	−.59 (1.29)
Intelligence (SE)		–	.02 (.06)
BIS (SE)		–	.25 (.20)
BAS (SE)		–	−.21 * (.10)
Overall Experience (SE)		–	1.70 ** (.57)
	Intelligence (SE)	–	.17 (.11)
	BIS (SE)	–	−.01 (.31)
	BAS (SE)	–	.01 (.31)
Variance Components			
Intercept		68.89	58.72
Age		0.28	0.24
Residual		125.38	126.39
Model Fit			
BIC		5233	5231

Note. BIS = Behavioral Inhibition System. BAS = Behavioral Activation System. SE = standard error. BIC = Bayesian Information Criterion. Age, estimated intelligence, overall experience, and BIS/BAS are grand-mean centered. Participant sex is dummy-coded where 0 = male, 1 = female.

[*] = $p < .05$.

[**] = $p < .01$.

Table 7

Comparison of Best-Fitting Model with Unadjusted Model of Decision-Making Under Risk

Between-Subjects Effects	Within-Subjects Effects	Unadjusted Model	Final Model
Intercept (SE)		20.38^{**} (1.56)	24.17^{**} (2.16)
Age (SE)		2.89^{**} (.22)	2.81^{**} (.22)
Age^2 (SE)		$-.08^{*}$ (.03)	$-.08^{*}$ (.03)
Participant Sex (SE)		–	$-.5.69^{*}$ (2.79)
Intelligence (SE)		–	$.31^{*}$ (.13)
BIS (SE)		–	.53 (.40)
BAS (SE)		–	$-.60^{*}$ (.23)
Overall Experience (SE)		–	1.31 (1.11)
	Intelligence (SE)	–	.14 (.19)
	BIS (SE)	–	.03 (.50)
	BAS (SE)	–	.38 (.45)
Variance Components			
Intercept		239.80	249.29
Residual		390.64	331.50
Model Fit			
BIC		5899	5894

Note. BIS = Behavioral Inhibition System. BAS = Behavioral Activation System. SE = standard error. BIC = Bayesian Information Criterion. Age, estimated intelligence, overall experience, and BIS/BAS are grand-mean centered. Participant sex is dummy-coded where 0 = male, 1 = female.

* = $p < .05$.

** = $p < .01$.