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Age Differences in Affective Decision Making as Indexed by Performance on the Iowa Gambling Task

Elizabeth Cauffman and Elizabeth P. Shulman
University of California, Irvine

Laurence Steinberg
Temple University

Eric Claus and Marie T. Banich
University of Colorado at Boulder

Sandra Graham
University of California, Los Angeles

Jennifer Woolard
Georgetown University

Contemporary perspectives on age differences in risk taking, informed by advances in developmental neuroscience, have emphasized the need to examine the ways in which emotional and cognitive factors interact to influence decision making. In the present study, a diverse sample of 901 individuals between the ages of 10 and 30 were administered a modified version of the Iowa Gambling Task, which is designed to measure affective decision making. Results indicate that approach behaviors (operationalized as the tendency to play increasingly from the advantageous decks over the course of the task) display an inverted U-shape relation to age, peaking in mid- to late adolescence. In contrast, avoidance behaviors (operationalized as the tendency to refrain from playing from the disadvantageous decks) increase linearly with age, with adults avoiding disadvantageous decks at higher rates than both preadolescents and adolescents. The finding that adolescents, compared to adults, are relatively more approach oriented in response to positive feedback and less avoidant in response to negative feedback is consistent with recent studies of brain development, as well as epidemiological data on various types of risky behavior, and may have important practical implications for the prevention of adolescent risk taking.

Keywords: decision making, risk taking, adolescent development, reward sensitivity, avoidance behavior

Public health experts agree that the most significant threats to the mental and physical well-being of adolescents arise not from natural causes but from dangerous activities in which youth willingly engage (Ozer, Macdonald, & Irwin, 2002). Although children and adults also behave dangerously at times, mid- and late adolescents (i.e., ages 15–19) are disproportionately more likely than younger or older individuals to engage in many high-risk behaviors, including reckless driving (National Research Council, 2007), illicit drug use (Substance Abuse and Mental Health Services Administration, 2007), attempted suicide (Mościcki, 2001), unsafe sexual practices (Finer & Henshaw, 2006), and both violent and nonviolent crime (Piquero, Farrington, & Blumstein, 2003). Although some of these age differences, especially those between children and adolescents, are undoubtedly due to differential access to potentially risky situations, others may be attributable to developmental differences between age groups (Arnett, 1992). One key area of development that may underlie risky behavior in mid- to late adolescence is decision making, particularly under conditions of emotional engagement and uncertain outcome.

Some theorists have tried to explain adolescents' greater affinity for risky activities in terms of deficiencies in the cognitive skills necessary to make good choices (Furby & Beyth-Marom, 1992), but this proposition has not been supported empirically (Steinberg, 2007). Specifically, adolescents are no worse than adults at perceiving risk or estimating their vulnerability to it (and, like adults, adolescents overestimate the dangerousness associated with various risky behaviors; Fischhoff et al., 2000), and increasing the salience of the risks associated with making a poor or potentially dangerous decision has comparable effects on adolescents and adults (Millstein & Halpern-Felsher, 2002; Reyna & Farley, 2006). Indeed, most studies find few, if any, differences between adolescents' and adults' evaluations of the risks inherent in a wide range of dangerous behaviors (e.g., driving while drunk, having unprotected sex), in their judgments about the seriousness of the consequences that might result from risky behaviors, or in the ways that they evaluate the relative costs and benefits of

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Elizabeth Cauffman and Elizabeth P. Shulman, Department of Psychology and Social Behavior, University of California, Irvine; Laurence Steinberg, Department of Psychology, Temple University; Eric Claus and Marie T. Banich, Department of Cognitive Psychology and Cognitive Neuroscience, University of Colorado at Boulder; Sandra Graham, Department of Education, University of California, Los Angeles; Jennifer Woolard, Department of Psychology, Georgetown University.

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Correspondence concerning this article should be addressed to Elizabeth Cauffman, Department of Psychology and Social Behavior, School of Social Ecology, University of California, Irvine, 3340 Social Ecology II, Irvine, CA 92687. E-mail: cauffman@uci.edu

these activities (Beyth-Marom, Austin, Fischhoff, Palmgren, & Jacobs-Quadrel, 1993). In other words, adolescents' greater involvement in risk taking, compared with adults', does not appear to stem from youthful ignorance, irrationality, delusions of invulnerability, or misperceptions of risk (Cauffman & Steinberg, 2000b; Reyna & Farley, 2006; Steinberg, 2007). These findings have led many to suggest that age differences in risk taking are more likely due to emotional and social, rather than cognitive, factors (Cauffman & Steinberg, 2000a; Scott, Reppucci, & Woolard, 1995; Steinberg & Cauffman, 1996). Indeed, when decision-making tasks involve emotional stimuli, such as risk and reward, differences between adolescents and adults emerge, even in laboratory settings (e.g., Ernst, Jazbec, et al., 2005; Galvan et al., 2006; Gardner & Steinberg, 2005). Thus, differences in risk taking between adolescents and adults may not to be due to differences in decision making in general but to differences in affective decision making in particular.

Recent advances in developmental neuroscience provide some evidence consistent with this view. In particular, a growing body of work suggests that a temporal disjunction between the heightened arousal of brain systems implicated in reward-seeking, which occurs around the time of puberty, and the more gradual maturation of self-regulatory brain systems, which unfolds over the course of adolescence and young adulthood, creates a period of special vulnerability to suboptimal decision making in middle adolescence, when sensation-seeking is high and self-control is still maturing (Casey, Getz, & Galvan, 2008; Steinberg, 2008). Consistent with this account, a recent study of age differences in sensation-seeking and impulsivity found that the former increases between ages 10 and 15 and then declines, whereas the latter drops linearly from preadolescence through young adulthood (Steinberg et al., 2008). Similarly, compared to individuals 17 and older, when offered the choice between a smaller immediate reward and a larger delayed one, younger adolescents evince a relatively stronger preference for the former (Steinberg et al., 2009). The notion that adolescents, relative to children or adults, may be especially sensitive to the possible positive consequences of risk taking is consistent with functional magnetic resonance imaging (fMRI) studies of activation of the nucleus accumbens, a subcortical brain structure known to play a central role in reward processing. For example, in a recent study in which participants learned to associate a visual stimulus with a monetary reward, Galvan et al. (2006) found that adolescents (ages 13–17) showed a more vigorous nucleus accumbens response to reward compared to children (ages 7–11) or adults (ages 23–29). Thus there is good reason to hypothesize that adolescents engage in more risky behavior than do younger or older individuals in part because adolescents' decision making is more influenced than adults' by the potential immediate rewards of the risky activity (Millstein & Halpern-Felsher, 2002).

Risk taking is influenced not only by reward-seeking, however. In any situation in which an individual is contemplating a risky activity, the decision also may be influenced by its potential costs. Although less is known about age differences in sensitivity to costs than about age differences in sensitivity to rewards, there is some evidence that the brain systems that govern harm avoidance in anticipation of adverse outcomes mature later than those that subserve reward-seeking (Ernst, Pine, & Hardin, 2005). In a study comparing adolescents' (ages 9–17) and adults' (ages 20–40) neural responses to reward receipt and omission, Ernst, Jazbec, et al. (2005) found that adults, but not adolescents, exhibited significant suppression of the amygdala, part of the harm avoidance system, in response to reward omission. In a different study comparing adolescents to adults, Bjork et al. (2004) found that adults activated more brain areas than did adolescents when notified of a monetary loss; it is important to note that adults, but not adolescents, responded to loss in the medial prefrontal cortex, an area involved in guiding affective decision making (Bechara, Damasio, & Damasio, 2000). It appears, then, that whereas adolescents are more likely than adults to engage in reward-seeking in response to the anticipated benefits of a decision with an uncertain outcome, adults have a greater propensity than adolescents to evince harm avoidance in response to nonreceipt of reward or the prospect of punishment. The possibility that age-related changes in sensitivity to potential costs and benefits may follow different developmental trajectories is consistent with an extensive body of work showing that these processes are subserved by overlapping but distinct neural circuitry, with the ventral striatum (and especially, the nucleus accumbens) playing a more important role in reward processing and the amygdala playing a more central role in punishment processing (Ernst & Spear, 2009). The orbitofrontal cortex, which has a protracted developmental timeline (Giedd et al., 1999; Gogtay et al., 2004; Sowell et al., 2003; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999), serves to modulate responses in these subcortical regions and organize emotional inputs to determine a behavioral response (Bechara et al., 2000).

Studying age differences in decision making under conditions of uncertainty poses a considerable challenge for psychologists, for several reasons. First, because there are age differences in exposure to situations in which decisions must be made (e.g., young adolescents are not permitted to drive or purchase alcohol, which limits their opportunity to decide to drive recklessly or binge drink), it is not enough to merely ask individuals if they have ever engaged in specific risky behaviors. Second, because individuals often gain experience with various risky activities with age and may base their subsequent decisions on personal experiences (e.g., a young adult who has had unprotected sex multiple times but never contracted a sexually transmitted disease, or who has driven while drunk and not had an accident, may come to view these activities as only minimally risky), simply asking individuals whether they believe an activity is risky may yield misleading conclusions about risk perception more generally. Finally, and most important for the present article, most measures of decision making that involve uncertainty are not able to distinguish between the influence of attentiveness to potential rewards and that of inattentiveness to potential costs, either of which would lead to greater risk taking (but see Bjork et al., 2004, and Levin, Weller, Pederson, & Harshman, 2007, for examples of research that has examined age differences in sensitivity to reward and punishment as separate constructs). In order to overcome these challenges, one must employ a task in which the decision-making activity under conditions of uncertainty is equally unfamiliar to people of different ages and that yields independent measures of sensitivity to reward and sensitivity to cost. The variant of the Iowa Gambling Task used in the present study is one such instrument.

The Iowa Gambling Task

In the present article, we examine age differences in affective decision making using a version of the Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994) that was modified to allow for the separate assessment of decisions in response to positive versus negative feedback. The IGT was designed to approximate real-life decision making under conditions of uncertainty. In the IGT (both the original version and the modification used in the present study), a participant is presented with four decks of cards, each of which contains cards that reward or punish the player by adding or subtracting points or amounts of money from his or her account. Two of the decks lead to net increases over the course of repeated play (the advantageous decks) while the other two lead to net losses (the disadvantageous decks). The player is instructed to maximize his or her winnings, which requires determining which decks will lead to long-term gains and which to long-term losses. In most studies, researchers track the net difference between the number of draws from advantageous decks and the number of draws from disadvantageous decks over time and view an increase in this net score as evidence of improved performance.

The IGT was initially developed as a way of assessing cognitive–affective deficits in adults with lesions of the medial prefrontal cortex, who tend to exhibit normal cognitive functioning in some respects but who are highly impaired in their decision making in social and emotional contexts (Anderson, Bechara, Damasio, Tranel, & Damasio, 1999). Whereas normal adults learn over time which decks are advantageous and shift toward playing preferentially from those decks, adults with lesions in the ventromedial region persist in drawing from disadvantageous decks, a pattern that is generally interpreted as favoring immediate gratification at the expense of longer term adverse consequences (Anderson et al., 1999; Bechara et al., 1994; Damasio, 1994). Importantly, the deck payoff schedules in the IGT are intended to be too complicated for participants to readily discern them. Consequently, participants must rely, at least in part, on emotion-based signals to guide their decision making (Bechara, Damasio, Tranel, & Damasio, 1997). The failure of patients with ventromedial brain damage to shift toward decks that yield long-term gains suggests that this prefrontal region plays a critical role in utilizing emotional information to guide decision making, although it is likely that other cortical and subcortical brain regions influence IGT performance as well.

In light of compelling evidence that the prefrontal cortex continues to mature throughout adolescence and well into young adulthood (Giedd et al., 1999; Gogtay et al., 2004; Sowell et al., 1999, 2003), one would expect to find age-related improvement during adolescence in performance on tasks, such as the IGT, that rely (at least in part) on prefrontal regions. A handful of studies have investigated developmental differences on the IGT and their results, so far, support this conjecture. For example, Crone and van der Molen (2004), using a child-friendly variant of the IGT, found that advantageous decision making on the IGT increased with age, such that adults (ages 18–25) learned to distinguish advantageous and disadvantageous choices more readily than did adolescents (ages 13–15) who, in turn, outperformed younger children (ages 6–9 and 10–12). Notably, however, this study did not include participants between the ages of 15 and 18, which, as we mentioned earlier, is the period during which real-world risk taking is generally highest. The relation between age and IGT performance does not appear to be mediated by age-related differences in other cognitive abilities such as working memory, inhibitory control, or inductive reasoning. Hooper, Luciana, Conklin, and Yarger (2004) investigated the relation of response inhibition (on a go/no-go task) and working memory capabilities (using digit-span recall) to IGT performance in 9- to 17-year-olds. In addition to replicating the finding that IGT performance improves with age, this study found that IGT performance was unrelated to response inhibition or working memory, even after controlling for age, gender, and intelligence. Similarly, Crone and van der Molen (2004) found that age predicted task performance on their version of the IGT, even when covarying scores on Raven's Standard Progressive Matrices, which assesses working memory and inductive reasoning skills. Thus, decision making on the IGT appears to activate prefrontal processes distinct from other aspects of executive function, and observed age differences in task performance are consistent with the notion that age differences in risk taking, which is often preceded in real life by affective decision making, may have emotional and social, rather than cognitive, underpinnings.

Focus of the Current Study

The current study extends the existing literature on age differences in IGT performance in several ways. First, in contrast to samples in previous studies, our sample includes a continuous range of ages that spans preadolescence through the entire decade of the 20s. Because prefrontal regions of the brain, including the ventromedial area, continue to develop into the third decade of life, it is important to include a sample that extends beyond late adolescence in studies employing tasks designed to index frontal lobe functioning. As such, the results of our study may provide a more complete picture of the developmental course of affective decision making.

Second, there is evidence from at least one IGT study (Crone, Bunge, Latenstein, & van der Molen, 2005) and several fMRI studies (e.g., Ernst, Jazbec, et al., 2005) that sensitivity to variations in reward develops earlier than sensitivity to variations in punishment. In the IGT, the advantageous decks yield greater net rewards and the disadvantageous decks yield greater net costs. Most versions of the IGT are designed so that the selection of advantageous decks and the avoidance of disadvantageous decks are not independent, however. Typically, performance is measured only in terms of changes in individuals' net scores (i.e., changes in the difference between the number of plays from advantageous decks and the number from disadvantageous decks) or in terms of the absolute number of selections from advantageous decks. Such measures cannot distinguish between improvements that are attributable to an increase in the attractiveness of advantageous decks versus those that are attributable to an increase in the aversiveness of disadvantageous ones, either of which will lead to better performance over time. In contrast, because our adaptation of the IGT permits independent quantification of these two processes (see below), we are able to operationalize changes in task performance in three distinct ways: net score (advantageous choices minus disadvantageous choices), approach behavior (i.e., changes in the percentage of plays from just the advantageous decks over the course of the task), and avoidance behavior (i.e., changes in the percentage of plays from just the disadvantageous decks over the course of the task). Specifically, we predict that adolescents will learn more quickly to play from the advantageous decks (i.e., approach) whereas that adults will learn more quickly to eschew playing from the disadvantageous decks (i.e., avoidance).

Finally, our version of the IGT also ensures that age differences in performance are not driven simply by age differences in willingness to explore the four different decks. In the standard version of the IGT, individuals can chose any of the four decks on every trial. A potential problem with this approach is that age differences in performance could result from younger children playing perseveratively from the same deck, instead of sampling more broadly. Past research has not ruled out the possibility that observed age differences in IGT performance might be at least partially mediated by age-related search strategies rather than being attributable to age-related differences in responses to the information presented on the cards. To address this issue, we used a modified version of the IGT, modeled on that of Peters and Slovic (2000), in which an individual is given the opportunity to play or pass from each deck equally often. This play/pass modification prevents groups of participants from differentially ignoring certain decks while attending to others.

Method

Participants

To enhance ethnic and geographic diversity, the study employed five data collection sites: Denver, CO; Irvine, CA; Los Angeles, CA; Philadelphia, PA; and Washington, DC. The original sample included 935 individuals between the ages of 10 and 30 years, recruited to yield an age distribution designed both to facilitate the examination of age differences within the adolescent decade and to compare adolescents of different ages with three specific groups of young adults: (a) individuals of traditional college age (who in some studies of risk taking behave in ways similar to adolescents; Gardner & Steinberg, 2005), (b) individuals who are no longer adolescents but who still are at an age during which brain maturation is continuing, presumably in regions that subserve risk processing (Giedd et al., 1999), and (c) individuals who are older than this putatively still-maturing group. Of the original 935 participants, 34 were dropped due to missing data on one or more of the study variables. In order to have cells with sufficiently large and comparably sized subsamples for purposes of some data analyses, age groups were created as follows: 10–11 years (*n* = 108), 12–13 years (*n* = 129), 14–15 years (*n* = 122), 16–17 years (*n* = 139), 18–21 years (*n* = 147), 22–25 years (*n* = 135), and 26–30 years (*n* = 121).

The sample was evenly split between males (49%) and females (51%) and was ethnically diverse, with 29% African American, 24% White, 22% Hispanic, 15% Asian, and 10% other. Participants were predominantly working- and middle-class. Each site contributed an approximately equal number of participants, although site contributions to ethnic groups were disproportionate, reflecting the ethnic composition of each site. Table 1 shows the demographic characteristics of the sample as a whole, as well as within each site.

Procedure

Prior to data collection, all site project directors and research assistants met at one location for several days of training to ensure consistent task administration across data collection sites. The project coordinators and research assistants conducted on-site practice protocol administrations prior to enrolling participants.

Participants were recruited via newspaper advertisements and flyers posted at community organizations, Boys and Girls Clubs, churches, community colleges, and local places of business in

Table 1
Demographic Characteristics of the Study Sample as a Whole and as a Function of Study Site

Variable	Total sample (*N* = 901)	Denver, CO (*n* = 102)	Washington, DC (*n* = 186)	Irvine, CA (*n* = 206)	Los Angeles, CA (*n* = 198)	Philadelphia, PA (*n* = 209)
Sex, %						
Males	49.1	52.9	50.8	48.5	55.1	48.3
Females	50.9	47.1	49.2	51.5	44.9	51.7
Age, *M* (*SD*)	17.9 (5.6)	18.3 (5.7)	18.0 (5.8)	18.1 (5.8)	17.8 (5.6)	17.7 (5.2)
Age, *n*						
10–11 years	108	11	24	27	31	15
12–13 years	129	14	28	32	21	34
14–15 years	122	14	26	26	21	35
16–17 years	139	16	21	24	37	41
18–21 years	147	17	29	34	35	32
22–25 years	135	16	31	33	26	29
26–30 years	121	14	27	30	27	23
Race/ethnicity, %						
African American	29.2	23.5	43.5	1.5	21.7	53.6
Asian	15.4	2.0	5.9	24.8	30.8	6.7
Hispanic	21.6	13.7	5.4	42.7	38.4	3.3
White	24.1	45.1	30.6	20.9	6.1	28.2
Other	9.7	15.7	14.5	10.2	3.0	8.1
Socioeconomic status, *M* (*SD*)[a]	12.6 (2.0)	12.6 (1.7)	13.3 (1.5)	12.5 (2.5)	12.0 (2.3)	12.8 (1.1)

Note. Due to rounding error, the race/ethnicity columns do not total perfectly to 100.
[a] Educational attainment was used as a proxy for socioeconomic status, where 13 = *some college*.

neighborhoods targeted to have an average household education level of “some college” according to 2000 U.S. Census data. Individuals who were interested in the study were asked to call the research office listed on the flyer. Members of the research team described the nature of the study to the participant over the telephone and invited those who were able to read and understand English to participate. Given this recruitment strategy, it was not possible to know how many participants saw the advertisements, what proportion responded, and whether those who responded are different from those who did not.

Data collection took place either at one of the participating university’s offices or at a convenient location in the community. Before beginning, participants were provided verbal and written explanations of the study, their confidentiality was assured, and their written consent or assent was obtained. For participants who were under the age of 18, informed consent was obtained from either a parent or guardian.

Participants completed a 2-hr assessment that consisted of a series of computerized tasks, a set of computer-administered self-report measures, a demographic questionnaire, several computerized tests of general intellectual function (e.g., digit span, working memory), and an assessment of IQ. The tasks were administered in individual interviews. Research assistants were present to monitor the participant’s progress, read aloud the instructions as each new task was presented, and provide assistance as needed. To keep participants engaged in the assessment, participants were told that they would receive $35 for participating in the study and that they could obtain up to a total of $50 (or, for the participants under 14, an additional prize of approximately $15 in value) based on their performance on the video tasks. In actuality, we paid all participants ages 14–30 the full $50, and all participants ages 10–13 received $35 plus the prize. This strategy was used to increase the motivation to perform well on the tasks but ensure that no participants were penalized for their performance. All procedures were approved by the institutional review board of the university associated with each data collection site.

Measures

Of central interest in the present analyses are our demographic questionnaire, the assessment of IQ, and a modified version of the Iowa Gambling Task.

Demographics. Participants reported their age, gender, ethnicity, and household education. Individuals under 18 reported their parents’ education, whereas participants 18 and older reported their own educational attainment (used as a proxy for socioeconomic status [SES]). The age groups did not differ with respect to gender or ethnicity but did differ (modestly) with respect to household education, with older participants reporting slightly higher levels of education ($r = .11$, $p < .01$). Accordingly, all analyses controlled for SES.

Intelligence. The Wechsler Abbreviated Scale of Intelligence (WASI) Full-Scale IQ Two-Subtest (Psychological Corporation, 1999) was used to produce an estimate of general intellectual ability based on two (Vocabulary and Matrix Reasoning) out of the four subtests. The WASI can be administered in approximately 15 min and is correlated with the Wechsler Intelligence Scale for Children ($r = .81$) and the Wechsler Adult Intelligence Scale ($r = .87$). It has been normed for individuals between the ages of 6 and 89 years. Because there were small but significant differences between the age groups in IQ, this variable was controlled in all subsequent analyses.

Modified Iowa Gambling Task. The Iowa Gambling Task (Bechara et al., 1994) was modified such that participants made a play/pass decision with regard to one of four decks preselected on each trial, rather than choosing to draw from any of four decks on any trial, as in the original task. This type of modification has been shown to be more sensitive to individual differences in performance because of the ability to determine the independent effects of gains and losses on subsequent card selection (Peters & Slovic, 2000). Also, as noted earlier, forcing participants to make decisions about each deck in a pseudorandom order eliminates the possibility that individuals will employ different search strategies across the decks, as is possible with the original version of the task. In addition to modifying the response option (i.e., play/pass), we also modified the outcome feedback, such that participants received information on the net gain or loss associated with a card, rather than information on both a gain and the loss separately (Bechara et al., 1994). For example, if in the original IGT the choice of Deck A led to a card indicating (simultaneously) a $100 gain and a $250 loss, the outcome shown in our modified version of the task would be a $150 loss. This modification was made to equate working memory loads across age groups during feedback and also to ensure that participants did not unequally weight the rewards and punishments within a given trial.

In our modification of the IGT, individuals attempt to earn pretend money by playing or passing cards from four different decks, presented on the computer screen. (Although the money is not real, recall that participants are told that they will receive a bonus payment that is real at the end of the experiment on the basis of their performance.) For each trial, one of the four decks was highlighted with an arrow, and participants were given 4 s in which to decide to play or pass that card. A running total of the participant’s “earnings” appeared on each screen. If participants passed on a given card, the image of the card on the screen displayed the message “Pass” and the total amount of money earned did not change. If participants chose to play, a monetary outcome was displayed on the current card and the total amount of money earned was updated. The payoff schedules for each deck reflected the net outcomes of the original IGT. As in the original task, two of the decks are advantageous and result in a monetary gain over repeated play. The other two decks are disadvantageous and produce a net loss over repeated play. In addition, within each type of deck (advantageous vs. disadvantageous), there is one deck in which the losses experienced are infrequent but relatively large, and one in which they are consistent and relatively small. See Table 2 for a complete description of the deck characteristics. The task was administered in six blocks of 20 trials each.

Performance on the IGT was operationalized in three ways: percentage good plays, percentage bad plays, and net score. In order to gauge participants’ tendency to shift toward playing (rather than passing) when presented with an advantageous deck, we created an outcome measure called “percentage good plays” that was calculated by dividing the number of times a person played from advantageous decks during a given task block by the total number of times they were presented with advantageous decks during that block. The quotient was then multiplied by 100

Table 2
Deck Characteristics on the Modified Iowa Gambling Task

Payoff variable	Deck A	Deck B	Deck C	Deck D
Payoff range	−$250 to $100	−$1,150 to $100	−$25 to $50	−$200 to $50
Probability of gain	.50	.90	.50	.90
Probability of loss	.50	.10	.25	.10
Probability of $0 payoff	.00	.00	.25	.00
First trial where loss (potentially) occurs	3rd	10th	13th	10th
Expected value[a]	−$25	−$25	$18.75	$25

[a] The expected value of a deck is equivalent to its average payoff.

to yield the percentage of plays from advantageous decks. A similar algorithm was used to compute the outcome for "percentage bad plays." We conceptualize the rate of change across the task (i.e., slope) on percentage good plays as a measure of approach behavior, with more steeply *positive* slopes indicating increasing affinity for decks that result in monetary gains in repeated play. With regard to percentage bad plays, we conceptualize the rate of change across the task as a measure of avoidance behavior, with more steeply *negative* slopes indicating greater sensitivity to net losses produced by the disadvantageous decks. Note that the percentage bad plays on a given block is not contingent upon the percentage good plays; proportions of good and bad plays are independent of one another, as the former is calculated based on the total number of presentations of advantageous decks and the latter on the total number of presentations of disadvantageous decks.

Net score was calculated as the difference between percentage good and bad plays, with the latter being subtracted from the former. Net score can be thought of as a measure of overall performance, integrating sensitivity to gains and losses. Thus, if a participant were presented with advantageous decks (Decks C or D) on 10 trials during Block 1 and chose to play five times and pass five times, his or her good play percentage would be 50. If the same participant were presented with the disadvantageous decks (Decks A or B) on 10 trials during the same block and played three times, passing seven times, then his or her bad play percentage would be 30. The net score for this participant would be percentage good plays (50) minus percentage bad plays (30), yielding a net score of 20 for Block 1.

Results

Because we were interested in examining how performance on the IGT changed over the course of the six blocks, data were analyzed with multilevel modeling (using PROC MIXED in SAS Version 9 for Windows). This approach allows us to examine both how an individual's performance (within-subject) changes between the beginning and end of the task and how different groups' performance trajectories differ from one another (between subjects)—for example, whether the performance of 21-year-olds improves more rapidly than that of 14-year-olds. To our knowledge, only one other study (of 30 undergraduate students) has used this approach to analyze IGT performance (Zermatten, Van der Linden, d'Acremont, Jermann, & Bechara, 2005).

Before conducting analyses, the raw data were examined to evaluate the response patterns for each of the four decks separately. As expected, the patterns in the data revealed that the majority of participants learned over time to play from the advantageous decks and to stop playing from the disadvantageous decks (see Figure 1). Based on these findings, the remaining analyses collapsed across same-type decks.[1] In addition, the means and standard deviations were examined for each of the variables by age (see Table 3), and correlations among the predictor variable (age), the control variables (IQ and SES), and the outcome variables measured at Block 6 (the final task block) were computed (see Table 4). Interestingly, age was linearly related to net score and percentage bad plays (inversely) but not to percentage good plays (although, as we report in a later section, there was a significant curvilinear relation between age and percentage good plays). IQ was related to all three outcomes in the anticipated direction, whereas SES (like age) was related only to net score and percentage bad plays, with higher SES predicting higher net score and fewer bad plays on Block 6.

Building the Multilevel Model of Change in Net Score

As a first step in examining performance (in terms of net score) on the IGT, we estimated an unconditional means model wherein net score was constrained to be constant over time and people were allowed to differ only in their overall performance, averaged across task block. This model allowed us to calculate the intraclass correlation, ρ, which is the proportion of total variability in the outcome that is between (versus within) subjects. If none of the variability observed in net score were attributable to between-subjects variation, there would be no point in asking whether subjects of different ages evinced different trajectories of performance. We found that 22% of the variability in net score was between subjects and 78% was within

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[1] Models estimating the percentage of plays for Decks A and B separately reveal that age is linearly associated with slope for both decks; however, the association is greater for Deck B ($B = -0.28$, CI = −0.37, −0.20, $p < .001$) than for Deck A ($B = -0.09$, CI = −0.17, −0.00, $p < .05$). Because Deck B is characterized by $100 wins punctuated by large ($1,150) but low-probability losses, this finding is consistent with the notion that sensitivity to magnitude of punishment increases with age, a finding that has emerged in other research as well (e.g., Crone et al., 2005; Levin et al., 2007).

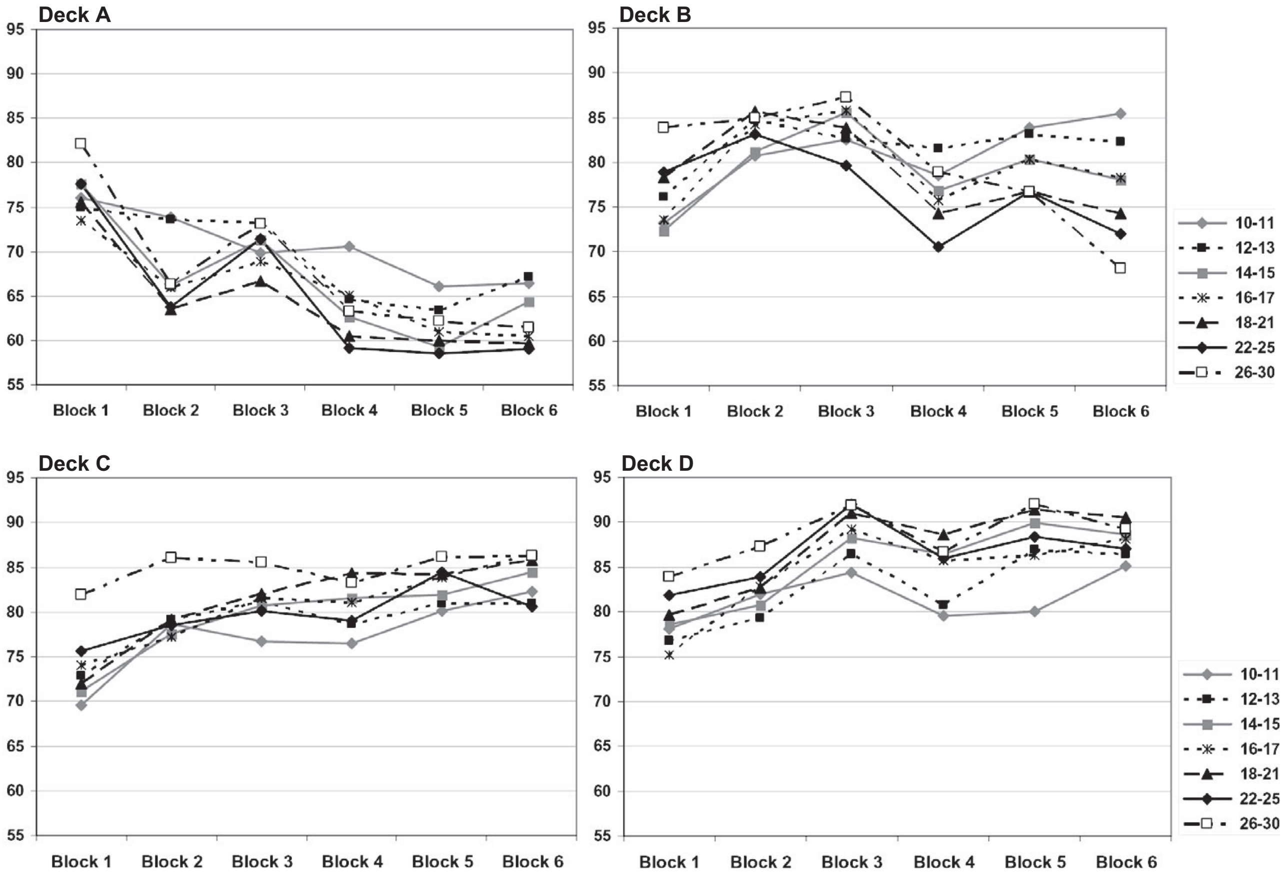

Figure 1. Percentage of trials on which participants played (rather than passed) on each block for each deck by age group.

subjects, and as such we proceeded with examining differences in performance based on age.

Next, to determine how much of the within-subject portion of the variability in net score could be attributed to learning from experience, we added time, in the form of task blocks (1–6), to the model predicting net score. Inclusion of time in the model resulted in substantially improved model fit, $\Delta -2\text{LL}(3) = -944.7$, $p < .001$. Comparison of the within-subject variability in the current model to that of the prior model (excluding time) revealed that linear change in net score over the course of the task accounted for 25% of within-subject variability in net score. Because we were more interested in individual differences in net score at the end of the task than at the beginning of the task, we centered the time variable such that the intercept for the models corresponded to Block 6. The Level 1 and 2 equations for the unconditional growth model, predicting net score for individual i at task block j, were

$$\text{Level 1: } NET\ SCORE_{ij} = \pi_{0i} + \pi_{1i}(TASK\ BLOCK_{ij}) + \varepsilon_{ij} \quad (1)$$

$$\text{Level 2: } \pi_{0i} = \gamma_{00} + \zeta_{0i} \quad (2)$$

$$\pi_{1i} = \gamma_{10} + \zeta_{1i} \quad (3)$$

where π_{0i} is the estimated intercept (net score on Block 6), π_{1i} is the estimated linear rate of change in net score (slope) across the task for individual i, and ε_{ij} represents random error for individual i at a given time point j. In the unconditional growth model, γ_{00} is the population average initial status (or intercept)—the average net score on Block 6 of the IGT—and γ_{10} is the population average rate of change (or slope)—the average rate of change in net score across the six blocks of the IGT; ζ_{0i} and ζ_{1i} represent individual i's discrepancy in initial status and slope, respectively, from the population average values of these growth parameters.

In this model, with time (i.e., task block) as the only predictor of net score, the mean intercept was 18.32 ($SE = 0.84$, $p < .001$), which was significantly greater than zero. Thus, by the end of the task, participants were more likely to play when presented with an advantageous deck than when presented with a disadvantageous deck. Rate of change in net score across the six blocks of the task was 3.47 ($SE = 0.20$, $p < .001$), meaning that there was improvement in net score over the course of the task. Next, our control variables, IQ and SES, were added to the model, and this resulted in further improvement in the model's global fit, $\Delta - 2\text{LL}(4) = -118.3$, $p < .001$.

Age Trends in Net Score

To determine whether age had a significant impact on performance (controlling for IQ and SES), we added age (as a continuous variable) to our model. Thus, our equation for this model was as follows:

$$\text{Level 1: } NET\ SCORE_{ij} = \pi_{0i} + \pi_{1i}(TASK\ BLOCK_{ij}) + \varepsilon_{ij} \quad (4)$$

$$\text{Level 2: } \pi_{0i} = \gamma_{00} + \gamma_{01}(IQ_i) + \gamma_{02}(SES_i) + \gamma_{03}(AGE_i) + \zeta_{0i} \quad (5)$$

$$\pi_{1i} = \gamma_{10} + \gamma_{11}(IQ_i) + \gamma_{12}(SES_i) + \gamma_{13}(AGE_i) + \zeta_{1i} \quad (6)$$

The model represented by Equations 4, 5, and 6 tested whether the intercept (π_{0i}) and rate of change (π_{1i}) of net score varied as a linear function of IQ, SES, and age.

Adding age to the model revealed that being older was associated with higher net scores at Block 6 as well as faster rates of improvement over time. Every year increase in age (between 10 and 30 years) corresponded, on average, to a 0.75 (confidence interval [CI] = 0.48, 1.03, $p < .001$) increase in net score on Block 6 and a 0.13 (CI = 0.06, 0.20, $p < .001$) increase in the slope. Overall model fit was improved with the inclusion of the linear age term, $\Delta{-2}\text{LL}(2) = -33.8$, $p < .001$, which suggests that performance on the IGT is substantially influenced by age.

To test whether age might be related in a curvilinear fashion to net score, we fitted quadratic age terms to the model (accomplished by adding $\gamma_{04}(AGE_i^2)$ to Equation 5 and $\gamma_{14}(AGE_i^2)$ to Equation 6 above); doing so significantly improved the model's fit, $\Delta{-2}\text{LL}(2) = -23.1$, $p < .001$. Age had significant quadratic associations with both net score at Block 6 ($B = -0.11$, CI = -0.16, -0.06, $p < .001$) and with the rate of change in net score across the task ($B = -0.02$, CI = -0.03, -0.01, $p < .01$). This finding suggests that, while performance (in terms of net score) improves with age, it does so at a faster rate during the early adolescent years compared to later adolescence and young adulthood. Results of the final model are reported in Table 5. To visualize the nature of the curvilinear relationship between age and net score, we graphed the results from the prior model split by the different age groups (see Figure 2).[2] This figure reveals that performance, in terms of net score, peaked in the 18- to 21-year-old age group.

Because we were primarily interested in the slopes for different age groups, it was necessary to ensure that people of different ages did not differ dramatically in performance on the first task block. If, for example, 30-year-olds performed much better than younger participants on the first task block, this would limit the older participants' ability to improve over the task (i.e., a ceiling effect). To test whether this was the case, we reran the previous model (including the age and age^2 terms) with the intercept set at Block 1. This model revealed only a nonsignificant trend toward net score improving linearly with

Table 3
Age Differences in IQ, SES, and Iowa Gambling Task Performance

Age group	*M*	*SD*
Ages 10–11		
% Bad plays	74%	21%
% Good plays	84%	18%
IQ	101.61	14.53
Net score	0.10	0.22
SES[a]	12.42	2.68
Ages 12–13		
% Bad plays	73%	19%
% Good plays	84%	18%
IQ	98.11	13.35
Net score	0.11	0.22
SES	12.50	2.19
Ages 14–15		
% Bad plays	70%	21%
% Good plays	87%	16%
IQ	96.20	11.94
Net score	0.17	0.24
SES	12.44	2.20
Ages 16–17		
% Bad plays	68%	21%
% Good plays	87%	15%
IQ	95.71	12.36
Net score	0.20	0.24
SES	12.61	1.86
Ages 18–21		
% Bad plays	65%	24%
% Good plays	89%	14%
IQ	98.34	12.00
Net score	0.23	0.27
SES	12.50	1.70
Ages 22–25		
% Bad plays	64%	28%
% Good plays	85%	19%
IQ	100.86	13.40
Net score	0.20	0.31
SES	12.95	1.17
Ages 26–30		
% Bad plays	64%	26%
% Good plays	88%	17%
IQ	101.11	14.87
Net score	0.24	0.29
SES	13.11	1.72
Overall		
% Bad plays	68%	23%
% Good plays	86%	17%
IQ	98.75	13.32
Net score	0.18	0.26
SES	12.65	1.96

Note. The performance variables were measured on the final task block (Block 6).
[a] Educational attainment was used as a proxy for socioeconomic status (SES), where 13 = *some college*.

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[2] To further ensure that search strategy did not drive any age-related differences in performance, we tested whether the tendency to pass (rather than play) during the first block of the task (when the reward and punishment schedules of the decks are still unknown to the participant) accounted for age differences in performance. Including passing during Block 1 and its interaction with age in the model did not eliminate any of the significant linear or quadratic effects of age on net score. The effects of Block 1 passing and its interaction with age were tested in the models for the other two outcome variables as well. Including these terms did not substantively affect the relations between age and performance. Thus, the observed effects of age on IGT performance cannot be explained by differences in search strategy on Block 1. In addition, because we had no theory regarding the effects of ethnicity on IGT performance, we examined all pairwise comparisons among the four main ethnic groups for main effects and Ethnicity × Age interactions (controlling for IQ and SES) and adjusted our alpha level accordingly. None of the main effects was significant. We did find three significant Ethnicity × Age interactions, but considered together they did not form a consistent pattern. As a consequence, we did not include ethnicity in any of the models we tested.

Table 4

Correlations Among Demographic Variables and Performance Variables

Variable	Net score	% Good plays	% Bad plays	Age	IQ	SES
% Good plays	$.48^{***}$	—				
% Bad plays	$-.78^{***}$	$.18^{***}$	—			
Age	$.17^{***}$	.05	$-.15^{***}$	—		
IQ	$.27^{***}$	$.20^{***}$	$-.16^{***}$	.06	—	
SES	$.13^{***}$	.04	$-.11^{***}$	$.11^{**}$	$.29^{***}$	—

Note. The performance variables were measured on the final task block (Block 6). SES = socioeconomic status.

$^{**}p < .01$. $^{***}p < .001$.

age at Block 1 ($B = 0.17$, CI $= -0.02$, 0.35, $p < .10$). There was no quadratic relation between age and net score on Block 1. Thus, it does not appear that older participants were substantially limited in their capacity to improve their performance over the course of the task compared to younger participants.

Age Trends in Approach Behavior

One of the unique advantages of the design of our IGT task is that it permits us to investigate whether there are different age patterns with regard to performance on two aspects of the task—learning to play from the advantageous decks and learning to refrain from playing from the disadvantageous decks. As noted in the introduction, there is evidence that different neural pathways and brain structures may be involved in approach behaviors versus avoidance, so it is possible that these abilities develop at different rates, reaching maturity at distinct ages. To analyze age differences in approach behavior, we built a multilevel model of change analogous to that for net score, but with percentage good plays (i.e., plays from advantageous decks) as the outcome (with IQ and SES controlled). For this outcome, steeper positive slopes indicate better performance with regard to detecting which decks are advantageous.

The results of this model revealed a curvilinear relationship between age and the rate of change in percentage good plays, such that approach behavior peaked in mid- to late adolescence (see Figure 3). The unconditional means and growth models revealed that 37% of variability in percentage good plays was due to between-subjects factors and 19% of within-subject variability was due to the linear effects of task block. As expected, in the model including linear and quadratic age terms (in addition to IQ and SES), the average slope was estimated to be significant and positive ($B = 2.25$, CI $= 1.88$, 2.62, $p < .001$), suggesting that participants learned to play (rather than pass) on advantageous decks as the task progressed. Age had significant linear and quadratic effects on the intercept at Block 6 ($B = 0.34$, CI $= 0.14$, 0.54, $p < .001$ for linear age; $B = -0.06$, CI $= -0.09$, -0.03, $p < .001$ for quadratic age). Age also had a significant quadratic effect on the rate of change in percentage good plays ($B = -0.02$, CI $= -0.03$, -0.01, $p < .001$), consistent with performance peaking and then declining, rather than increasing steadily with age. Results are reported in Table 5.

To examine whether a ceiling effect for approach behavior was observed for the oldest participants, we reran the previous model with the intercept set at Block 1. This model revealed that older participants were slightly more likely than younger participants to play from advantageous decks in the first task block ($B = 0.34$, CI $= 0.15$, 0.53, $p < .001$), which has the potential to create a small ceiling effect on older individuals' performance. A more definitive sign of a ceiling effect would be nearly perfect performance on Block 6 (the final task block) among the oldest participants. Rerunning the model with age centered at 30 years–the oldest age in the sample–reveals that when presented with an advantageous deck on Block 6, 30-year-olds played 84.56% of the time (on average and controlling for IQ and SES; CI = 81.03, 88.10); a percentage that differs substantially from 100%. Finally, on Blocks 2 through 6, older participants (ages 22–25 and 26–30) were never more likely than 18- to 21-year-olds (the age range with the steepest slope) to play on 100% of advantageous trials in a block (controlling for IQ and SES; odds ratios ranged from 1.48 [CI = 0.89, 2.47] for 26- to 30-year-olds on Block 3 to 0.73 [CI = 0.44, 1.42] for 26- to 30-year-olds on Block 4). Overall, then, it does not appear that older adults' learning was artificially limited by a ceiling effect.

Age Trends in Avoidant Behavior

To analyze age patterns related to avoidant behavior, we built multilevel models of change analogous to those described above, but with percentage bad plays as the outcome (again, with IQ and SES controlled). Here we would expect slopes for rate of change to be negative, as downward slopes indicate increasing reluctance to play from the disadvantageous decks as the task progresses.

The estimates for this model (reported in Table 5) revealed a linear age pattern with respect to rate of change in percentage bad plays, such that older participants had steeper slopes, suggesting greater avoidant behavior compared to younger participants (see Figure 3). The unconditional means and growth models revealed that 35% of variability in percentage bad plays was due to between-subjects factors and 27% of within-subject variability was due to the linear effects of task block. As expected, the model including linear and quadratic age terms (in addition to IQ and SES) showed the average slope to be significant and negative ($B = -2.01$, $SE = 0.24$, $p < .001$), suggesting that participants learned to avoid playing on the disadvantageous decks as the task progressed. Age had significant linear and quadratic effects on the intercept at Block 6 ($B = -0.72$, $SE = 0.14$, $p < .001$ for linear age; $B = 0.05$, $SE = 0.02$, $p < .05$ for quadratic age), but, unlike the analysis of change in percentage good plays, the quadratic age term was not significantly related to rate of change in percentage bad plays. Age had only a linear

Table 5

Results of Fitting Final Models Predicting Net Score, Percentage Good Plays, and Percentage Bad Plays, Controlling SES and IQ

		Net score		Percentage good plays		Percentage bad plays	
Fixed effects		Coeff.	95% CI	Coeff.	95% CI	Coeff.	95% CI
Level (Block 6), π_{0i}							
Intercept	γ_{00}	22.9***	20.67, 25.12	89.33***	87.86, 90.80	66.43***	64.39, 68.47
IQ	γ_{01}	0.55***	0.43, 0.67	0.27***	0.19, 0.35	−0.28***	−0.40, −0.16
SES	γ_{02}	0.72	−0.10, 1.53	0.01	−0.52, 0.54	−0.71	−1.45, 0.03
Age	γ_{03}	1.06***	0.76, 1.37	0.34***	0.14, 0.54	−0.72***	−0.99, −0.45
Age^2	γ_{04}	−0.11***	−0.16, −0.06	−0.06***	−0.10, −0.02	0.05*	0.01, 0.09
Rate of change, π_{1i}							
Intercept	γ_{10}	4.25***	3.70, 4.81	2.25***	1.88, 2.62	−2.01***	−2.48, −1.54
IQ	γ_{11}	0.08***	0.05, 0.11	0.02*	0.00, 0.04	−0.06***	−0.08, −0.04
SES	γ_{12}	0.16	−0.04, 0.37	−0.04	−0.18, 0.10	−0.20*	−0.38, −0.02
Age	γ_{13}	0.18***	0.10, 0.26	0.00	−0.06, 0.06	−0.18***	−0.24, −0.12
Age^2	γ_{14}	−0.02**	−0.03, −0.01	−0.02***	−0.02, −0.02	0.00	−0.02, 0.02
Variance components							
Within-subject	σ_ϵ^2	322.44***	307.54, 337.34	146.65***	139.87, 153.43	184.10***	175.59, 192.61
In initial status	σ_0^2	373.17***	322.50, 423.84	158.34***	136.33, 180.35	364.23***	321.46, 407.00
In rate of change	σ_1^2	15.77***	12.50, 19.04	6.71***	5.26, 8.16	14.34***	11.99, 16.69
Covariance	σ_{01}	73.87***	61.84, 85.90	19.64***	14.84, 24.44	62.92***	53.75, 72.09
ΔPseudo R^2 for addition of age variables			0.023		0.013		0.014
Pseudo R^2 for the model			0.115		0.074		0.055

Note. $N = 901$. Age was centered at 18, IQ at 100, and socioeconomic status (SES) at 13 (*some college*, where educational attainment is used as a proxy for SES). Coeff. = coefficient; CI = confidence interval.
$^* p < .05$. $^{**} p < .01$. $^{***} p < .001$.

relation to slope in this model ($B = -0.18$, $SE = 0.03$, $p < .001$), with older participants being increasingly less likely than younger participants to play from the disadvantageous decks as the task progressed ($B = -0.18$, $SE = 0.03$, $p < .001$).

Examining Sex Differences in IGT Performance

Because previous research has produced mixed results with regard to sex effects on IGT performance, we were interested in examining whether sex influenced the level or slope of performance and whether sex interacted with age (linearly or curvilinearly) to predict the intercept or slope of performance for each of our three IGT outcomes. To test this, we added six terms—sex, Sex × Age, Sex × Age^2, Sex × Block, Sex × Age × Block, and Sex × Age^2 × Block—to each of the models used to examine age effects on net score, approach behavior, and avoidant behavior. As before, the intercepts for the models were centered at Block 6. Females served as the reference group.

Net score. Results revealed no significant sex differences in the intercept of net score ($B = -0.69$, CI = −5.06, 3.69, $p = ns$) or in slope ($B = 0.00$, CI = −1.10, 1.10, $p = ns$). Nor did sex moderate the

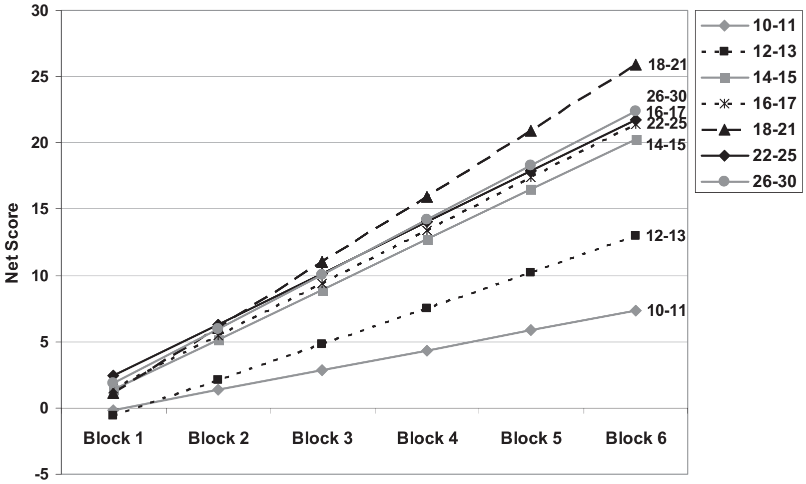

Figure 2. Estimated change in net score across the task by age group (controlling for IQ and socioeconomic status).

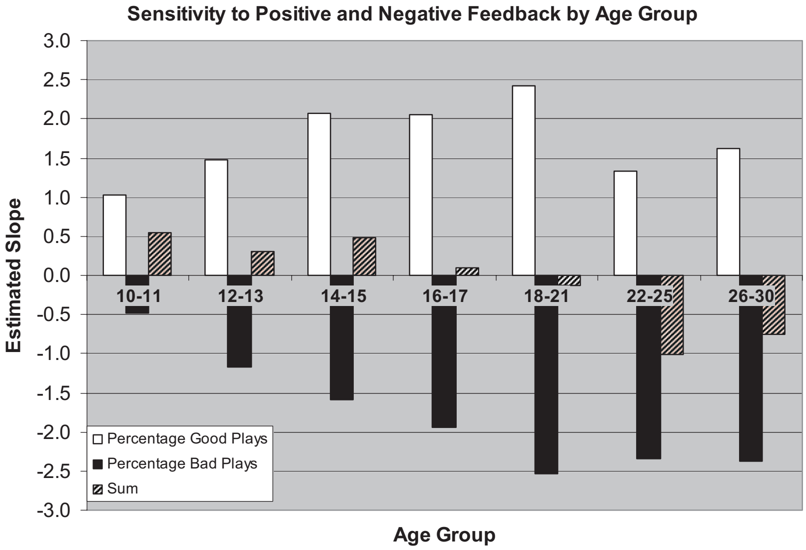

Figure 3. Bar graph demonstrating the different patterns of relations between age and sensitivity to positive versus negative feedback. The solid bars represent the estimated slopes for each age group; white for sensitivity to positive feedback and black for sensitivity to negative feedback. The black and white striped bars represent the sum of the slopes for positive and negative feedback sensitivity for each age group. Note that there is a shift from relatively greater sensitivity to positive feedback to relatively greater sensitivity to negative feedback as age increases.

linear or quadratic relations between age and the intercept or slope of net score.

Approach behavior. There was a significant effect of sex on the intercept of percentage good plays, such that male participants played more often than female participants when presented with advantageous decks ($B = 3.01$, CI = 0.14, 5.89, $p < .05$). There was no significant effect of sex on slope, however ($B = 0.30$, CI = -0.43, 1.03, $p = ns$), suggesting that male participants' greater tendency to play on advantageous decks remained consistent throughout the task. Sex did not moderate the linear or curvilinear relations between age and the intercept or slope of percentage good plays.

Avoidant behavior. Results revealed no significant main effect of sex on percentage bad plays, although there was a trend toward male participants playing more often than female participants when presented with disadvantageous decks ($B = 3.70$, CI = -0.31, 7.71, $p < .10$). Although this finding is significant only at a trend level, the greater tendency of males to play on *both* advantageous and disadvantageous decks likely explains why no significant sex differences were found in net score. There was a trend toward sex moderating the effect of age on the intercept of percentage bad plays ($B = 0.50$, CI = -0.06, 1.06, $p < .10$); age tended to be a better predictor of passing on disadvantageous decks among females than among males. Sex had no significant effect on the slope ($B = 0.30$, CI = -0.63, 1.23, $p = ns$) nor did sex moderate the linear or curvilinear relation between age and the intercept or slope of percentage bad plays.

In summary, of the 18 terms tested to examine the direct or moderating impact of sex on IGT performance, only one (males playing more often on advantageous decks) explained significant variance in the outcome, and only three more approached significance. More important, none of these terms substantially altered the relation between age and IGT performance.

Comparing Adolescents' Performance to Adults'

Whereas the final models for net score, percentage good plays, and percentage bad plays reveal the overall relation between age and performance on the IGT, we were also interested in determining the age at which adolescents' performance would be indistinguishable from adults' performance on these outcomes. Reestimating the models using age as a categorical variable (with seven levels, ages 10–11, 12–13, 14–15, 16–17, 18–21, 22–25, and 26–30), we conducted four planned contrasts for each outcome variable comparing the performance (operationalized as rate of change) of 10- to 11-year-olds, 12- to 13-year-olds, 14- to 15-year-olds, and 16- to 17-year-olds to the average performance of adults ages 18–30. The results of these contrasts (reported in Table 6) reveal that, in terms of net score, there is no significant age-related improvement in performance after age 13. Thus, if we were to conceptualize IGT performance only with respect to net score, it would appear that by age 14, adolescents' IGT performance is indistinguishable from that of adults. However, this interpretation obscures significant differences between adults and adolescents in their approach and avoidance behavior.

By examining changes in the percentage of good plays independent of changes in the percentage of bad plays, we were able to chart separate developmental patterns of approach and avoidance behavior. In theory, the more prone a person is to approach behavior, the quicker he or she will be to trust that the advantageous decks are safe, resulting in steeper slopes for these decks. Interestingly, only the middle-to-older adolescents (ages 14–15

Table 6
Contrasting the Estimated Average Slope of Performance for Each Adolescent Age Group With That of Adults (Ages 18–30) for Each Outcome

Adolescent age group	Net score			Percentage good plays			Percentage bad plays		
	Diff.	95% CI	Cohen's *d*	Diff.	95% CI	Cohen's *d*	Diff.	95% CI	Cohen's *d*
10–11 years	2.81^{***}	1.56, 4.06	0.48	0.18	−0.65, 1.01	0.05	-2.63^{***}	−3.69, −1.57	0.53
12–13 years	1.60^{**}	0.44, 2.76	0.27	−0.19	−0.96, 0.59	0.05	-1.76^{***}	−2.76, −0.77	0.35
14–15 years	0.53	−0.66, 1.72	0.09	-0.83^{*}	−1.62, −0.04	0.21	-1.36^{**}	−2.37, −0.34	0.27
16–17 years	0.32	−0.82, 1.45	0.05	-0.93^{*}	−1.69, −0.18	0.24	-1.25^{*}	−2.22, −0.28	0.25

Note. The difference (Diff.) is in estimated average slope and is calculated as the adult estimate (pooled for 18- to 30-year-olds) minus the adolescent group estimate. Thus, positive estimates indicate that the adults had a more positive (upward) slope and negative estimates indicate that the adolescent group had a more positive slope. CI = confidence interval.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

and 16–17) had slopes that differed significantly from adults' (see Table 6). This indicates that the 14- to 17-year-olds learned faster than both older and younger participants to play from the advantageous decks. To analyze age patterns related to avoidant behavior, we conducted an analysis analogous to the one just described, but with the percentage of bad plays as the outcome. Here we would expect slopes for rate of change to be negative, as downward slopes indicate increasing reluctance to play from the disadvantageous decks as the task progresses. Results indicate that with respect to avoidance, each adolescent age group differed significantly from the adult participants in how quickly they learned to refrain from playing from the disadvantageous decks. The estimated differences in slope between the adolescent age groups and adults mirrors the finding that age is linearly related to the rate of change in percentage bad plays, with the gap in performance between adolescents and adults narrowing with each successively older adolescent age group.

To better understand the relation between age and performance in terms of percentage good versus bad plays, we graphed the slopes for each age group in Figure 3. This figure clearly depicts the curvilinear relation of age to percentage good plays in contrast to the linear relation between age and percentage bad plays. The sum of the slopes is shown as well to help visualize the shift toward greater avoidance behavior that occurs in adulthood. This may explain why we see net scores ceasing to increase after age 14, because net scores reflect the combined effects of approach and avoidant behavior. However, as depicted in Figure 2, adolescents change their performance mainly by playing increasingly from advantageous decks, whereas adults—especially those between 22 and 30 years of age—achieve their net scores both by playing more often from advantageous decks and, especially, by playing less often from disadvantageous ones.

Discussion

Although middle adolescents engage in many types of risky behaviors more frequently than do adults, laboratory tasks measuring the reasoning skills and cognitive capabilities presumed to affect risky decision making have not found age differences in these abilities after age 15 (Steinberg, 2007). In the present study, we hypothesized that, in contrast to the absence of age differences observed in studies explicitly asking individuals to reason about risk, age differences would be apparent when the outcome of interest is derived from a measure of decision making that is influenced by emotional as well as cognitive factors. In support of this hypothesis, we find that adolescents and adults evince significantly different patterns of approach and avoidance behavior on the Iowa Gambling Task (IGT), a widely used measure of affective decision making.

As expected, we found age differences in performance on the IGT, with younger participants making proportionally more disadvantageous choices relative to older participants. Around 14 years of age, a shift in decision-making strategies was observed, with middle adolescents, late adolescents, and adults, but not younger adolescents (ages 10–13), showing similar overall performance by the final task block. These results replicate the findings of previous studies demonstrating a positive relation between age and IGT performance between childhood and adolescence (Crone et al., 2005; Crone & van der Molen, 2004; Crone, Vendel, & van der Molen, 2003; Hooper et al., 2004). Importantly, our modified IGT task ensures that this age pattern is not due to age-related differences in search strategy.

Our findings extended previous research by demonstrating that adolescents and adults respond to the feedback provided during the IGT in different ways—over time, adolescents played increasingly from the advantageous decks (shifting to these at a faster rate than adults), whereas adults were faster than adolescents to decrease playing from the disadvantageous decks. Affinity for the advantageous decks (approach behavior) peaked in the late adolescent years, and then declined, whereas avoidance of the disadvantageous decks increased linearly with age. These findings suggest that discrete developmental processes may underlie the inclination to play from advantageous decks and the inclination to stop playing from the disadvantageous decks, with the latter process not being fully mature until well after adolescence. Because the oldest participants in our sample were 30, we are unable to determine whether there are further increases in avoidant behavior, or declines in approach behavior, after this age.

One way to interpret affinity for the advantageous decks is as reward sensitivity; when participants play consistently from the advantageous decks, the size of their total winnings increases, which should activate reward-sensitive brain systems. Evidence from fMRI studies indicates that reward processing (e.g., anticipating a reward, gauging the magnitude of a reward, and responding to reward receipt) appears to involve regions known to mature during the age period studied here—the ventral striatum (especially the nucleus accumbens) as well as the orbitofrontal cortex (Bjork et al., 2004; Delgado, Nystrom, Fissell, Noll, & Fiez, 2000; Ernst, Jazbec, et al., 2005; Knutson, Adams, Fong, & Hommer, 2001; May et al., 2004)—although maturation of these regions may follow slightly different timetables. In the Galvan et al. (2006) reward processing study discussed earlier, although adolescents showed more nucleus accumbens activation than did children, adolescents' overall level of orbitofrontal cortex activity was more child-like than adult-like. The maturation in adolescence of the nucleus accumbens-driven "appetitive system" prior to the full development of the orbitofrontal "control system" (Galvan et al., 2006) may account for our finding of a peak in reward sensitivity during adolescence, at least as evidenced on the IGT.

Another possible interpretation of learned preference for the advantageous decks is that it reflects approach behavior; when participants play repeatedly from the advantageous decks, they are demonstrating confidence that they are not likely to sustain a large loss. In addition to playing a role in anticipating, acknowledging, and gauging the magnitude of reward, the nucleus accumbens has been theorized to affect approach behavior by motivating individuals to act (Cardinal, Parkinson, Hall, & Everitt, 2002; Ernst, Jazbec, et al., 2005); thus, the findings of greater nucleus accumbens response in adolescents reported by Galvan et al. (2006) could indicate that adolescents have stronger approach tendencies than do adults. Taken together with the finding that adults, but not adolescents, evince an amygdala response to the nonreceipt of an anticipated reward (Ernst, Jazbec, et al., 2005), it may be that adults are initially more wary than adolescents of the advantageous decks, whose payoffs are smaller on most trials than payoffs on the disadvantageous decks. The amygdala is thought to play an important role in the processing of potential threats, such as monetary punishment, and in initiating avoidant behavioral responses (LeDoux, 2000). Through this interpretive lens, our findings may reflect both a relatively greater propensity for approach behavior among adolescents than adults as well as a weaker response to nonreceipt of an anticipated reward. This pattern could be due to the relatively late development of the prefrontal cortex and its connections with the amygdala that inhibit or modulate the approach response triggered by the nucleus accumbens (Ernst, Pine, & Hardin, 2005).

The relative immaturity during adolescence of systems involved in harm avoidance may also account for our finding that adults learned faster than adolescents to stop playing from disadvantageous decks in the IGT. For example, Bjork et al. (2004) found that adults, but not adolescents, depress medial prefrontal cortical activity in anticipation of a monetary loss. As noted previously, this region is responsible for translating emotional cues into appropriate behavioral responses. In the IGT, translation of negative emotional cues into decision-making behavior is critical to the ability to cease playing from the disadvantageous decks (Bechara et al., 2000). Thus, adults' more mature prefrontal cortices and the connections of these regions with the amygdala may explain adults' greater sensitivity to negative feedback, indexed in this study by desistance from playing on the disadvantageous decks.

Some of our results were inconsistent with previous research on the development of affective decision making. In contrast to Crone and van der Molen's (2004) finding that adults (ages 18–25) perform significantly better than adolescents (ages 13–15) on the IGT, we did not find differences between adolescents (ages 14–17) and adults (ages 18–30) in net scores. This discrepancy could be due to Crone and van der Molen's use of a somewhat different gambling task paradigm, their inclusion of a condition wherein reward and punishment schedules were reversed, and/or age categories that differed from our own; with respect to this latter point, it would appear from our results that the period between ages 15 and 17, which was not included in the Crone and van der Molen study, is an exceedingly important one for the development of capacities indexed by the IGT. Also, whereas Hooper et al. (2004) found that cognitive ability was unrelated to choosing advantageously on the IGT, our study found that IQ was significantly related to both initial level of net score and rate of improvement in performance across the course of the task. This difference may be due to the greater diversity (and hence, variability in IQ) of our sample in comparison to that studied by Hooper et al. We also found less pronounced sex differences in IGT performance than some prior research has shown (Bolla, Eldreth, Matochik, & Cadet, 2004; Crone et al., 2005; Overman et al., 2004; Reavis & Overman, 2001). Although our analyses revealed no effect of sex on net score, male participants were more likely than female participants to play from advantageous decks and, to a lesser extent, from disadvantageous decks. This reflects the fact that male participants were, in general, more likely than female participants to play rather than pass, irrespective of the advantageousness of the deck; males played on 79% of trials, whereas females played on 77% of trials ($r_{pb} = .10$, $p < .01$).

One possible reason for the lack of consistency between our findings and that of previous research is that our sample, unlike the samples used by Overman and colleagues (Overman et al., 2004; Reavis & Overman, 2001), drew on noncollege populations. There is some evidence that college women may perform worse on the IGT than nonundergraduate women (Evans, Kemish, & Turnbull, 2004). Another potential reason for discrepancies between our findings and those of other studies is that the version of the IGT used in this study was different. The fact that gains and losses for each trial were presented as one amount indicating a net gain or loss rather than as distinct gains and losses (e.g., our participants saw "−$50" rather than "+$200, −$250") makes our findings less comparable to findings from studies using versions of the task where gain and loss information is presented separately on each trial. However, this modification to the task was also a strength of the present study in that it leveled the playing field for younger participants, for whom subtraction of loss amounts from gain amounts would be less facile; by calculating the net gain or loss for the participants, we removed a complexity confound that would have conferred an advantage to older participants. The fact that age differences emerge even with the easier version of task used here provides stronger support for the notion that affective decision making, and not just mathematical competence, improves during early adolescence.

Another benefit of our modification is that it made explicit discrimination among the decks a little more difficult than in the original version. Some have argued that IGT performance is the result of conscious learning of the deck payoff schedules rather than development of affective cues guiding behavior based on nonconscious learning (Dunn, Dalgleish, & Lawrence, 2006; Evans, Bowman, & Turnbull, 2005; Maia & McClelland, 2004). In the original IGT, but not in the version used in the present study, every card in the disadvantageous decks bore a $100 win (paired with a loss of varying degree) and every card in the advantageous decks bore a $50 win (paired with a loss of varying degree). Removal of this heuristic for consciously distinguishing the advantageous and disadvantageous decks may have encouraged greater reliance on emotional cues for optimal decision making. This provides added support for our position that the study results genuinely reflect age differences in affective decision making. In addition, because the ability to consciously discern the payoff schedules for the decks is likely related to intelligence, controlling for IQ should have diminished the effects of explicit knowledge about the deck payoffs in our models.

A final caveat about our findings is that, although this is one of the first studies to examine age-related changes on the IGT from preadolescence through adulthood, our conclusions are based on cross-sectional comparisons of subjects in different age groups, rather than observations of change as individuals grow older; whether similar patterns would be discerned in a longitudinal study remains to be seen. Also, because our study did not involve brain imaging, we are unable to make actual comparisons between adolescents and adults with respect to activity in different brain regions thought to undergird reward and punishment processing. Future research on age differences in IGT performance should include fMRI imaging so that more direct comparisons with regard to age differences in brain function can be made.

Despite these limitations, the present study makes several significant contributions to our understanding of decision making under conditions of uncertainty as it evolves from childhood through adulthood. As noted earlier, accounts of adolescent risk taking that emphasize the putative cognitive deficiencies of young people have not received empirical support. The present study, as well as previous work, demonstrates that decision making, which frequently precedes engaging in risk-taking behavior, indeed improves throughout adolescence and into young adulthood but that this improvement may be due not to cognitive maturation but to changes in affective processing. Whereas adolescents may attend more to the potential rewards of a risky decision than to the potential costs, adults tend to consider both, even weighing costs more than rewards.

This higher level of approach behavior during adolescence coupled with the lesser inclination toward harm avoidance may help explain increased novelty-seeking in adolescence, which can lead to various types of risk taking, including experimentation with drugs, unprotected sex, and delinquent activity. The finding that when adolescents make a decision under conditions of uncertainty they may be relatively more inclined to approach and relatively less likely to avoid also may have important implications for the design of interventions to reduce youthful risk taking. For example, if adolescents are more attentive to positive than negative outcomes, perhaps an effective alternative to advertisement campaigns showing the negative outcomes associated with drug use would be a campaign highlighting the benefits of abstaining from drug use, such as greater self-control, more respect and trust from parents, and superior athletic performance. Thus, if parents and policymakers wish to reduce adolescents' risk-taking behavior (or improve their decision making in general), strategies that employ positive reinforcement of desirable behavior may be more effective than those that emphasize the costs of the risky activity. By understanding the types of information to which adolescents are most—and least—sensitive, we may be able to improve intervention strategies intended to help adolescents make better and healthier choices.

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