Laurence Steinberg
Department of Psychology
Temple University
Philadelphia, PA 19122
E-mail: lds@temple.edu

A Dual Systems Model of Adolescent Risk-Taking

ABSTRACT: *It has been hypothesized that reward-seeking and impulsivity develop along different timetables and have different neural underpinnings, and that the difference in their timetables helps account for heightened risk-taking during adolescence. In order to test these propositions, age differences in reward-seeking and impulsivity were examined in a socioeconomically and ethnically diverse sample of 935 individuals between the ages of 10 and 30, using self-report and behavioral measures of each construct. Consistent with predictions, age differences in reward-seeking follow a curvilinear pattern, increasing between preadolescence and mid-adolescence, and declining thereafter. In contrast, age differences in impulsivity follow a linear pattern, with impulsivity declining steadily from age 10 on. Heightened vulnerability to risk-taking in middle adolescence may be due to the combination of relatively higher inclinations to seek rewards and still maturing capacities for self-control.* © 2010 Wiley Periodicals, Inc. Dev Psychobiol 52: 216–224, 2010.

Keywords: adolescence; impulse control; reward-seeking; risk-taking; social neuroscience

INTRODUCTION

In the past several years, a new perspective on risk-taking and decision-making during adolescence has emerged, one that is informed by advances in developmental neuroscience (Casey, Getz, & Galvan, 2008; Steinberg, 2008). According to this view, risky behavior in adolescence is the product of the interaction between changes in two distinct neurobiological systems: a "socioemotional" system, which is localized in limbic and paralimbic areas of the brain, including the amygdala, ventral striatum, orbitofrontal cortex, medial prefrontal cortex, and superior temporal sulcus; and a "cognitive control" system, which is mainly composed of the lateral prefrontal and parietal cortices and those parts of the anterior cingulate cortex to which they are interconnected (Steinberg, 2008). According to this dual systems model, adolescent risk-taking is hypothesized to be stimulated by a rapid and dramatic increase in dopaminergic activity within the socioemotional system around the time of puberty, which is presumed to lead to increases in reward-seeking. However, this increase in reward-seeking precedes the structural maturation of the cognitive control system and its connections to areas of the socioemotional system, a maturational process that is gradual, unfolds over the course of adolescence, and permits more advanced self regulation and impulse control. The temporal gap between the arousal of the socioemotional system, which is an early adolescent development, and the full maturation of the cognitive control system, which occurs later, creates a period of heightened vulnerability to risk-taking during middle adolescence (Steinberg, 2008).

Neurobiological evidence in support of the dual systems model is rapidly accumulating. A growing literature, derived primarily from rodent studies, but with implications for human development, indicates that the remodeling of the dopaminergic system, especially with respect to projections from mesolimbic areas (e.g., striatum) to the prefrontal (Teicher, Andersen & Hostetter, 1995) cortex. These projections increase during

mid- and late adolescence and then decline (Doremus-Fitzwater, Varlinskaya, & Spear, 2010). Because dopamine plays a critical role in the brain's reward circuitry, the increase, reduction, and redistribution of dopamine receptor concentration around puberty, especially in projections from the limbic system to the prefrontal area, is likely to increase reward-seeking behavior.

There is equally compelling neurobiological evidence for changes in brain structure and function during adolescence and early adulthood that facilitate improvements in self regulation and permit individuals to modulate their inclinations to seek rewards, although this development is presumed to unfold along a different timetable and be independent of puberty (Paus, 2005). As a consequence of synaptic pruning and the continued myelination of prefrontal brain regions, there are improvements over the course of adolescence in many aspects of executive function, such as response inhibition, planning ahead, weighing risks and rewards, and the simultaneous consideration of multiple sources of information. There is also improved coordination of affect and cognition, which is facilitated by the increased connectivity between regions associated with the socioemotional and cognitive control systems.

Research on adolescent behavioral development has not kept pace with advances in our understanding of brain development, however, and the notion that the developmental course of reward-seeking (thought to increase between preadolescence and middle adolescence and then decline) differs from that of impulse control (thought to increase gradually over adolescence and early adulthood) has not been examined systematically. Thus, while there is good evidence that risk-taking is higher during adolescence than during preadolescence or adulthood (as evidenced by age differences in a wide range of risky activity, including criminal behavior, reckless driving, unprotected sex, and binge drinking; Steinberg, 2008), it is not clear whether the increase and then decline in risk-taking that occurs at this time is due to changes in reward-seeking, changes in impulse control, or some combination of the two. At least one recent study (Galvan, Hare, Voss, Glover, & Casey, 2007) indicates that individuals' self-reported likelihood of engaging in risky behavior is more strongly connected to reward processing than to impulsivity, but studies of this issue are sparse. In order to examine whether reward-seeking and impulsivity develop along different timetables, it is necessary to have conceptually and empirically distinct measures of each.

Dahl (2004) has described reward-seeking as one of a suite of developmental domains that appear to be linked to puberty-specific maturational changes. Consistent with this, animal studies indicate that increases in reward-seeking are coincident with pubertal maturation,

although it is not clear whether these increases are caused by increases in pubertal hormones or merely coincident with them (Sisk & Foster, 2004; Spear, 2000); it is plausible that changes in brain systems that subserve reward-seeking are biologically ''programmed'' to occur simultaneously with reproductive maturation, in order to encourage the sort of risk-taking that would be evolutionarily adaptive (Casey et al., 2008; Steinberg, 2008). Research linking reward-seeking to pubertal maturation among humans is scarce, but at least one study has shown that sensation-seeking and pubertal maturation are positively correlated (Martin et al., 2001). Sensation-seeking (which is highly related to reward-seeking) also is positively correlated with levels of testosterone and estradiol among both males and females of college age (Zuckerman, Buchsbaum, & Murphy, 1980). Regardless of whether sensation-seeking (or reward-seeking) is directly or indirectly associated with pubertal maturation, however, there is clear support for the prediction that this behavior increases during the first part of adolescence.

Self-report studies of age differences in impulsivity that span adolescence and adulthood are even rarer than those examining reward-seeking. Galvan et al. (2007) report a significant negative correlation between chronological age and impulsivity (using the Connors Impulsivity Scale) in a sample of individuals ranging in age from 7 to 29, suggesting that impulse control continues to develop over the course of adolescence and early adulthood. Leshem and Glicksohn (2007) likewise report a significant decline in impulsivity from ages 14–16 to 20–22 on both the Eysenk and Barratt impulsiveness scales. Another study found higher scores on the Barratt Impulsiveness Scale for high school, relative to college, students, although the authors attribute the finding to a filtering effect, whereby highly impulsive and presumably low achieving high school students do not continue on to college (Stanford, Greve, Boudreaux, Mathias, & Brumbelow, 1996). Although these studies all suggest a steady decline in impulsivity from childhood through adolescence and into adulthood, there is a clear need for normative data from a large sample across a broad age range.

The present article summarizes results from a program of research my colleagues and I have recently completed, designed to examine age differences in reward-seeking and cognitive control between the ages of 10 and 30 (Cauffman et al., 2010; Steinberg et al., 2008, 2009). It is the first study to span a wide enough age range to examine the developmental course of each phenomenon from preadolescence through early adulthood, to measure self-control and reward-seeking independently within the same sample, and to employ both self-report and performance measures. Consistent with the notion that reward-seeking and self-control are distinct phenom-

ena that are subserved by different brain systems and follow different developmental trajectories, we hypothesized that reward-seeking is curvilinearly related to chronological age, increasing during early adolescence but declining thereafter, whereas impulsivity declines gradually over this same age period.

METHODS

Participants

The study employed five data collection sites: Denver; Irvine (California), Los Angeles, Philadelphia, and Washington, D.C. The sample includes 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 young adults. In order to have cells with sufficiently large and comparably sized subsamples for purposes of data analysis, age groups were created as follows: 10–11 years ($N = 116$), 12–13 years ($N = 137$), 14–15 years ($N = 128$), 16–17 years ($N = 141$), 18–21 years ($N = 138$), 22–25 years ($N = 136$), and 26–30 years ($N = 123$). Six individuals were dropped because of missing data on one or more key demographic variables. The sample was evenly split between males (49%) and females (51%) and was ethnically diverse, with 30% African-American, 15% Asian, 21% Latino(a), 24% White, and 10% other. Participants were predominantly working and middle class.

Procedure

Participants were recruited via newspaper advertisements and flyers posted at community organizations, Boy's and Girl's clubs, churches, community colleges, and local places of business in 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 interested to participate.

Data collection took place either at one of the participating university's offices or at a location in the community where it was possible to administer the test battery in a quiet and private location. 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, reading aloud the instructions as each new task was presented and providing 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 IRB of the university associated with each data collection site.

Measures

Of central interest in the present report are our demographic questionnaire, the assessment of IQ, self-report measures of impulsivity and reward-seeking, a computerized version of the Tower of London task (used as a behavioral measure of impulsivity) and a computerized adaptation of the Iowa Gambling Task (IGT; used as a behavioral measure of reward-seeking).

Demographic. 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 SES. As such, all subsequent analyses controlled for this variable.

Intelligence. The *Wechsler Abbreviated Scale of Intelligence* (WASI) Full-Scale IQ Two-Subtest (FSIQ-2) (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 ($r = .87$). Because there were small but significant differences between the age groups in IQ, this variable was controlled in all subsequent analyses.

Self-Reported Impulsivity. A widely used self-report measure of impulsivity, the Barratt Impulsiveness Scale, Version 11 (Patton, Stanford, & Barratt, 1995), was part of the questionnaire battery; the measure has been shown to have good construct, convergent, and discriminant validity. Based on inspection of the full list of items (the scale has 6 subscales comprising 34 items) and some exploratory factor analyses, we opted to use only 18 items ($\alpha = .73$) from three 6-item subscales: motor impulsivity (e.g., "I act on the spur of the moment"), inability to delay gratification (e.g., "I spend more money than I should"), and lack of perseverance (e.g., "It's hard for me to think about two different things at the same time"). The three subscales we elected not to use measure attention (e.g., "I am restless at movies or when I have to listen to people"), cognitive

complexity ("I am a great thinker"), and self-control ("I plan for my future"), which the instrument developers describe as assessing "planning and thinking carefully" (Patton et al., 1995, p. 770). We concluded that scales measuring attention, cognitive complexity, and "planning and thinking carefully" were not components of impulsivity as we conceptualized the construct. Although our composite only includes three of the six subscales, the correlation between our measure and one that includes items from all six subscales is .87. Each item is scored on a 4-point scale (Rarely/Never, Occasionally, Often, Almost Always/ Always), with higher scores indicative of greater impulsivity. Subscales were averaged to form a total impulsivity score. Although our composite only includes three of the six subscales, the correlation between our measure and one that includes items from all six subscales is .87. The 18-item scale showed excellent fit to the data (NFI = .912, CFI = .952, RMSEA = .033), and reliability of the scale is $\alpha = .73$.

Self-Reported Reward-Seeking was assessed using a subset of 6 items from the Sensation Seeking Scale (Zuckerman, Eysenck, & Eysenck, 1978). Many of the items on the full 19-item Zuckerman scale appear to measure impulsivity, not sensation-seeking (e.g., "I often do things on impulse." "I usually think about what I am going to do before doing it."). In view of our interest in distinguishing between impulsivity and reward-seeking, we used only the six Zuckerman items that clearly index reward- or novelty-seeking (e.g., "I like to have new and exciting experiences and sensations even if they are a little frightening."; "I'll try anything once."; "I sometimes do 'crazy' things just for fun."). All items were answered as either True (coded 1) or False (coded 0), and item scores were averaged. The resulting 6-item scale showed an excellent fit to the data (NFI = .955, CFI = .967, RMSEA = .053) and good internal consistency ($\alpha = .70$).

Tower of London. This task, which is typically used to measure planning and executive function, was used to generate a behavioral index of impulsivity. In the version of the task employed in the present study (Berg & Byrd, 2002), the subject is presented with pictures of two sets of three colored balls distributed across three rods, one of which can hold three balls, one two balls, and the last, only one ball. The first picture shows the starting positioning of the three balls, and the second depicts the goal position. The subject is asked to move the balls in the starting arrangement to match the other arrangement in as few moves as necessary, using the computer cursor to "drag" and "drop" each ball. Five sets of four problems are presented, beginning with four that can be solved in three moves and progressing to those that require a minimum of seven moves. In the administration of the task, the starting and goal positions are displayed, and the subject takes as much (or as little) time as necessary before making each move. Hasty performance, particularly with respect to first moves on each problem, has been linked to response inhibition difficulties among children, adolescents, and adults (Asato, Sweeney, & Luna, 2006). Thus, in the current study, shorter latencies to first move indicate greater impulsivity.

Modified Iowa Gambling Task. In the version of the task employed here, individuals attempt to earn pretend money by playing or passing cards from four different decks, presented on the computer screen. As in the original task (Bechara, Damasio, Damasio, & Anderson, 1994), 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. The task was modified such that participants made a play/pass decision with regard to one of four decks preselected on each trial, rather than deciding to choose to draw from any of four decks on any trial, as in the original task. This type of modification permits one to independently track behavior that reflects reward-seeking (i.e., selecting advantageous decks) versus behavior that reflects cost-aversion (i.e., avoiding disadvantageous decks) (Peters & Slovic, 2000). 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). 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. The task was administered in 3 blocks of 40 trials each.

RESULTS

In order to examine whether the two behavioral tasks did, as proposed, differentially index reward-seeking and impulsivity, regression analyses were conducted in which the two self-report measures were considered as simultaneous predictors of the two behavioral tasks' principal outcome measures. As expected, in the regression predicting average time to first move on the Tower of London from self-reported impulsivity and reward-seeking, self-reported impulsivity is a significant predictor ($\beta = -.082$, $p < .05$), but self-reported sensation-seeking is not ($\beta = .059$, ns). In contrast, in the comparable regression analysis predicting draws from the advantageous decks in the final block of the IGT (when participants presumably had begaun figure out which decks were advantageous), self-reported impulsivity is not a significant predictor ($\beta = -.062$, ns) but self-reported reward-seeking is ($\beta = .091$, $p < .05$). Additionally, self-reported reward-seeking is not predictive of draws from the disadvantageous decks on the final block of the IGT ($\beta = .037$, ns), suggesting that avoidance of the bad decks is not driven by the same psychological factors as is preference for the rewarding ones.

Age Differences in Self-Reported Impulsivity and Reward-Seeking

In order to test the hypothesis that reward-seeking increases in early adolescence and then declines, but that impulsivity shows a gradual decline with age, continuing through late adolescence and into young

adulthood, age differences in these self-reports were examined via sets of two hierarchical multiple regression analyses. Age, IQ, and SES were entered on the first step, and the quadratic term for age entered on the second step.

Results of the first set of regression analyses indicate significant linear and curvilinear effects of age on reward-seeking ($\beta = -.115$, $p < .001$, and $\beta = -.437$, $p < .005$, for the linear and quadratic terms, respectively) but only a linear effect of age on impulsivity ($\beta = -.149$, $p < .001$, and $\beta = -.091$, ns, respectively). Figure 1 illustrates these two age patterns. Consistent with our hypothesis, reward-seeking increases during the first half of adolescence, and then declines steadily from age 16 on. In contrast,

impulsivity declines or remains stable over the entire 20-year period studied.

Age Differences in Impulsivity as Indexed by the Tower of London

Participants' time before first move on the Tower of London task was examined using a repeated-measures analysis of covariance (ANCOVA), with age, gender, and ethnicity as the independent variables; IQ and SES as covariates; and individuals' average time (in milliseconds) before making a first move at each level of problem difficulty (three-, four-, five-, six-, and seven-moves) as a five-level within-subjects factor. Analyses reveal a
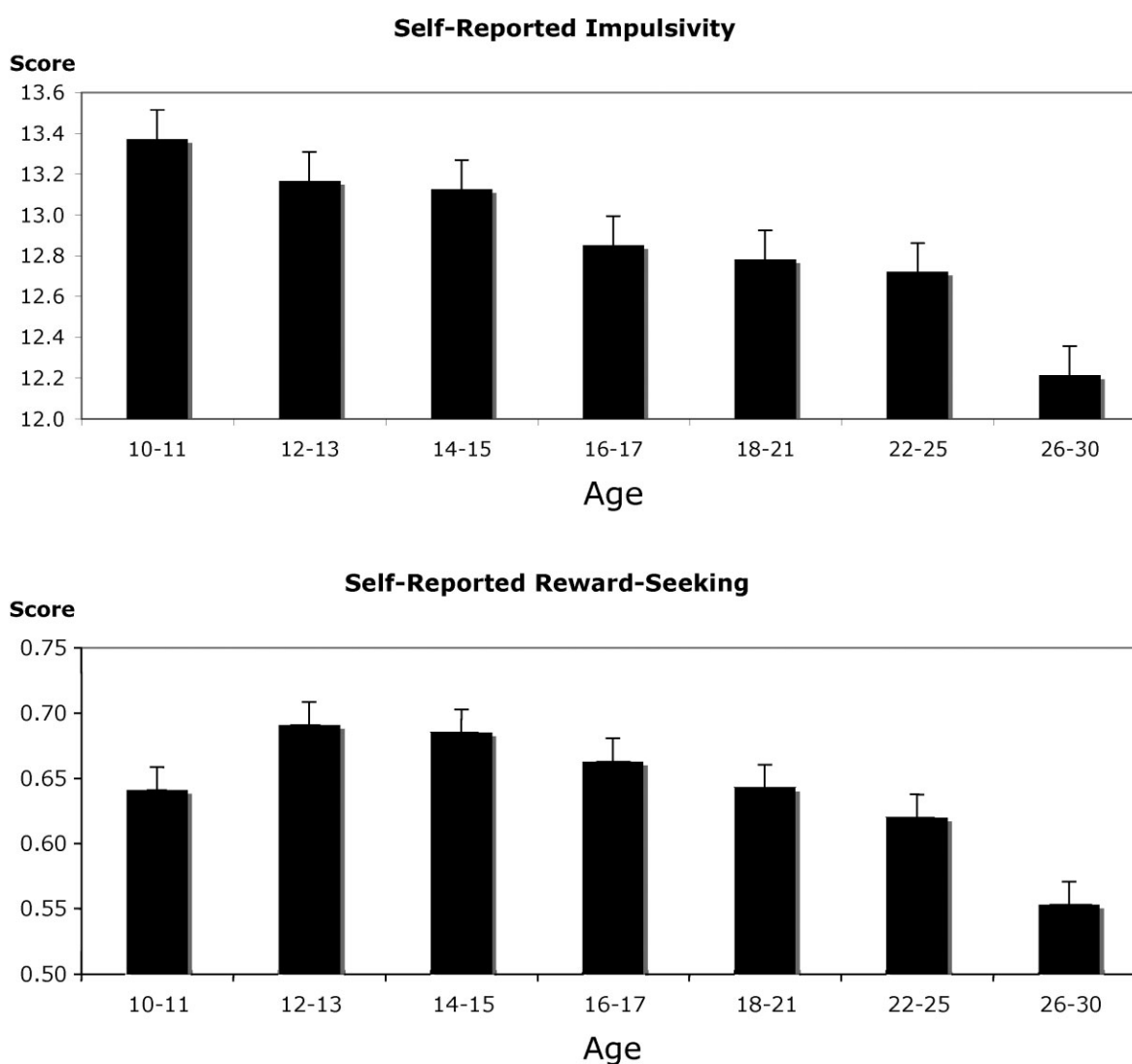

FIGURE 1 Age differences in self-reported impulsivity and reward-seeking. *Note*: Impulsivity scores can range from 6 to 24. Reward-seeking scores can range from 0 to 1. The linear trend for impulsivity is significant at $p < .001$; the curvilinear trend is not significant. The linear and quadratic trends for reward-seeking are significant at $p < .001$ and $p < .005$, respectively (Steinberg et al., 2008).
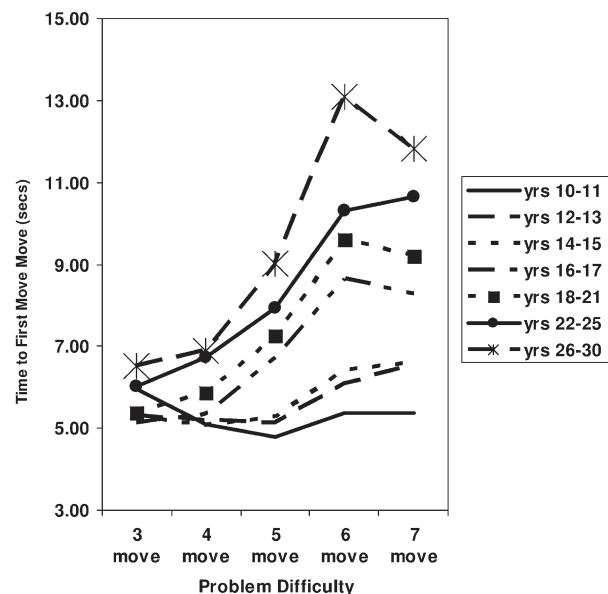
FIGURE 2 Age differences in time to first move on the tower of london task as a function of problem difficulty. *Note*: Means adjusted for IQ and SES. The age by problem difficulty interaction is significant at $p < .001$ (Steinberg et al., 2008).

FIGURE 3 Age differences in changes over time in pulls from advantageous and disadvantageous decks in the Iowa Gambling Task. *Note*: Means adjusted for IQ and SES. The curvilinear trend for advantageous pulls is significant at $p < .001$; the linear trend is not significant. The linear trend for disadvantageous pulls is significant at $p < .001$; the curvilinear trend is not significant (Cauffman et al., 2010).

significant effect of age on average time to first move, with older subjects taking more time before moving than younger ones ($F(6,813) = 17.58$, $p < .001$). More interesting, however, and as Figure 2 illustrates, there is a significant interaction between age and problem difficulty, such that with increasing problem difficulty, older, but not younger, subjects wait longer before their first move ($F(24,3252) = 8.976$, $p < .001$). Indeed, the three youngest groups generally do not wait any longer before their first move in the most difficult (seven moves) problems than in the easiest ones (three moves).

Age Differences in Reward-Seeking as Indexed by the Iowa Gambling Task

In order to examine age differences in reward-seeking on the IGT, we examined change over time in draws from the advantageous and disadvantageous decks; recall that in our modified version fo the task, these variables are independent, because participants can opt to not play at all when presented with a specific deck. Our hypothesis that reward-seeking peaks in mid-adolescence was tested via two regression analyses (one predicting change in pulls from good decks between the first and last blocks of the task, and one for change in pulls from bad decks); in each, we entered age, IQ, and SES on the first step of the regression and the quadratic term for age on the second. As expected, and consistent with self-reports
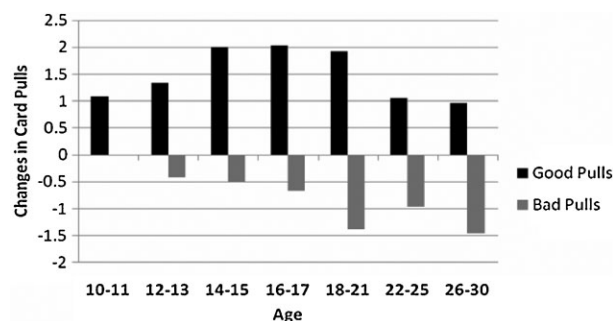
of reward-seeking, draws from the advantageous decks increase between early and mid-adolescence, and then decline between mid-adolescence and adulthood; the linear term is nonsignificant ($\beta = -.024$, ns) but the curvilinear term is ($\beta = -.577$, $p < .001$). In contrast, in the prediction of change in pulls from the bad decks show only a pattern of linear change over time, with individuals becoming more cost-averse with age ($\beta = -.114$, $p < .001$); the quadratic term is not significant ($\beta = .051$, ns) (see Fig. 3). We also analyzed these data using multi-level modeling and came to the same conclusion (Cauffman et al., 2010).

DISCUSSION

According to their own reports, and as reflected in their performance on computer tasks designed to measure reward-seeking and impulsivity, adolescents and adults differ along both dimensions in ways that are theoretically coherent with recent research on adolescent brain development, which points to extensive and dramatic remodeling of reward circuitry early in adolescence but a lengthier period of more gradual maturation of brain systems implicated in self-regulation. Consistent with this neurobiological evidence, in the present study heightened reward-seeking is most clearly and consistently seen during mid-adolescence. In contrast, we find that gains in impulse control occur throughout adolescence and well into young adulthood.

The observed pattern of age differences on the self-report and performance measures of impulsivity were very similar, with both indicating a linear decline in impulsivity between ages 10 and 30. Similarly, the self-report and performance measures of reward-seeking, both

showed the predicted curvilinear relation between reward-seeking and age, with reward-seeking generally higher in middle adolescence than before or after. It is important to note, however, that the age at which reward-seeking appears to peak is somewhat earlier in self-reports than as indexed by the IGT. Whether this discrepancy reflects differences between self-report versus behavioral indices of reward-seeking or the fact that the two measures assess different aspects of reward-seeking (the self-report items emphasize a desire for novelty and excitement, whereas the IGT outcome is a measure of how much a participant's subsequent behavior was influenced by making rewarding, versus costly, decisions) is not known. It is also worth noting the gradual and linear increase with age in the extent to which individuals' subsequent card choices were influenced by drawing cards from bad decks. This pattern may reflect the more protracted development of harm-avoidance systems relative to approach systems (see Ernst, Pine, & Hardin, 2006).

The contribution of the present research to the literature on psychological development in adolescence and young adulthood stems from its inclusion of a much wider age range than has been examined previously in one sample (from age 10 to 30), its use of both self-report and cognitive-behavioral indicators of reward-seeking and impulsivity, its socioeconomically and ethnically diverse sample, and its independent measurement of two constructs that often have been conflated both conceptually and empirically. The fact that differential patterns of age differences found in self-reports are similar to those found in conceptually linked behavioral tasks inspires more confidence in the conclusion that the developmental trajectories of reward-seeking and impulsivity differ. Although one must be cautious about drawing inferences about change over time from cross-sectional research, the current findings provide a foundation from which further longitudinal study, using both self-reports, behavioral tasks, and brain imaging, should proceed.

The heightened reward-seeking during the first part of adolescence seen here calls to mind other studies of sensation-seeking (e.g., Stephenson, Hoyle, Palmgreen, & Slater, 2003) and reward sensitivity (e.g., Galvan et al., 2006) which show increases in both during the early adolescent years; these increases are thought to be linked to increases and then declines in prefrontal and paralimbic dopamanergic activity during the period following puberty (Steinberg, 2008). To our knowledge, only one previous study (Galvan et al., 2007) has examined age differences in self-reported impulsivity over an age range comparable to that studied here. The linear decline in self-reported impulsivity seen across the entire age span we studied is consistent with the Galvan et al. investigation and with findings reported in studies of self-reported impulsivity that have included middle adolescents and

adults (e.g., Leshem & Glicksohn, 2007). Our finding of a linear decline in hasty behavior on the Tower of London is consistent with previous studies using this paradigm (e.g., Asato et al., 2006); numerous behavioral studies that compare children, adolescents, and adults on a range of self-regulatory tasks such as the antisaccade, Flanker, Go/No-Go, and Stroop (see Casey et al., 2008); and strong evidence of structural and functional maturation over the course of adolescence and well into the 20s of brain regions that subserve impulse control and other aspects of self-regulation (see Paus, 2005). Thus, converging evidence from questionnaire, behavioral, and neuro-biological studies indicates that impulse control not only improves between childhood and adolescence, but between adolescence and adulthood as well.

Aristotle (350 B.C./1954) famously observed that youth "are hot-tempered, and quick-tempered, and apt to give way to their anger," and there is a long history of anecdotal evidence, empirical investigation, and actuarial analysis indicating that adolescence is a time of heightened risk-taking and recklessness (Steinberg, 2008). One impetus for the present study was to better understand developmental differences in factors believed to contribute to this pattern. Although opportunity factors (e.g., less vigilant parental monitoring, legal driving privileges, the availability of sex partners) undoubtedly influence the extent to which individuals actually take risks (Byrnes, 1998), most indicators of risk-taking (reckless driving, delinquent behavior, attempted suicide, substance abuse, unprotected sex) follow an inverted U-shaped pattern over development, with risky behavior generally higher in middle or late adolescence than in preadolescence or adulthood.

To the extent that vulnerability to risk-taking is the product of high reward-seeking and low impulse control, the findings of the present study suggest why risk-taking may follow this inverted U-shaped pattern. Middle adolescence appears to be a time of growing vulnerability to risky behavior, as this period is characterized by relatively higher reward-seeking in the context of relatively lower impulse control; heightened reward-seeking impels adolescent toward risky activity, and immature self-regulatory capabilities do not restrain this impulse. As to the other side of the inverted U function, vulnerability toward risky behavior would be expected to decline from late adolescence on, since both reward-seeking and impulsivity diminish after this age.

The research reported here suggests that vulnerability toward heightened risk-taking during middle adolescence is likely to be normative, which poses a challenge to those interested in the health and well-being of this age group. It is important to remember, however, that individuals of the same age vary in their reward-seeking and impulse control, and that variations in these characteristics are

related to variations in risky and antisocial behavior (Steinberg, 2008). Understanding how contextual factors influence the development of reward-seeking and self-regulation, and the neural underpinnings of these processes, should be a high priority for those interested in the physical and psychological well being of young people.

Nevertheless, to the extent that normative developmental change makes adolescents more vulnerable to risky behavior, and to the extent that this vulnerability is not mainly due to lack of knowledge about risk or faulty risk perception (see Steinberg, 2008), a more effective strategy than one designed to make adolescents more informed or more thoughtful, might be to reduce adolescents' opportunities to engage in harmful risk-behavior. Strategies such as raising the price of cigarettes, more vigilantly enforcing laws governing the sale of alcohol, increasing adult supervision of adolescents during after-school hours, and graduated drivers' licensing would likely be more effective in limiting adolescent smoking, substance abuse, risky sexual behavior, and automobile fatalities than attempts to make adolescents wiser, less impulsive, or less shortsighted. Some things just take time to develop, and mature judgment is probably one of them.

REFERENCES

Aristotle, 1954. (350 B.C./1954). *Rhetoric* (W. Rhys Roberts, trans.). Available online at classics.mit.edu/Aristotle/rhetoric. html.

Asato, M., Sweeney, J., & Luna, B. (2006). Cognitive processes in the development of TOL performance. Neuropsychologia, 44, 2259–2269.

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. Cognition, 50(1–3), 7–15.

Berg, W., & Byrd, D. (2002). The Tower of London spatial problem solving task: Enhancing clinical and research implementation. Journal of Experimental and Clinical Neuropsychology, 25, 586–604.

Byrnes, J. (1998). The nature and development of risk-taking. Hillsdale, NJ: Erlbaum.

Casey, B. J., Getz, S., & Galvan, A. (2008). The adolescent brain. Developmental Review, 28, 62–77.

Cauffman, E., Shulman, E., Steinberg, L., Claus, E., Banich, M., Graham, S., et al. (2010). Age differences in affective decision making as indexed by performance on the Iowa Gambling Task. Developmental Psychology, 46, 193–207.

Dahl, R. (2004). Adolescent brain development: A period of vulnerabilities and opportunities. Annals of the New York Academy of Sciences, 1021, 1–22.

Doremus-Fitzwater, T., Varlinskaya, E., & Spear, L. (2010). Motivational systems in adolescence: Possible implications for age differences in substance abuse and other risk-taking behaviors. Brain and Cognition, 72, 114–123.

Ernst, M., Pine, D. S., & Hardin, M. (2006). Triadic model of the neurobiology of motivated behavior in adolescence. Psychological Medicine, 36, 299–312.

Galvan, A., Hare, T., Parra, C., Penn, J., Voss, H., Glover, G., et al. (2006). Earlier development of the accumbens relative to orbitofrontal cortex might underlie risk-taking behavior in adolescents. Journal of Neuroscience, 26, 6885–6892.

Galvan, A., Hare, T., Voss, H., Glover, G., & Casey, B. J. (2007). Risk-taking and the adolescent brain: Who is at risk? Developmental Science, 10, F8–F14.

Leshem, R., & Glicksohn, J. (2007). The construct of impulsivity revisited. Personality and Individual Differences, 43, 681–691.

Martin, C. A., Logan, T. K., Leukefeld, C., Milich, R., Omar, H., & Clayton, R. (2001). Adolescent and young adult substance use: Association with sensation seeking, self-esteem and retrospective report of early pubertal onset. A preliminary examination. International Journal of Adolescent Medicine and Health, 13, 211–219.

Patton, J., Stanford, M., & Barratt, E. (1995). Factor structure of the Barratt Impulsiveness Scale. Journal of Clinical Psychology, 51, 768–774.

Paus, T. (2005). Mapping brain maturation and cognitive development during adolescence. Trends in Cognitive Sciences, 9, 60–68.

Peters, E., & Slovic, P. (2000). The springs of action: Affective and analytical information processing in choice. Personality and Social Psychology Bulletin, 26(12), 1465–1475.

Psychological Corporation. (1999). Wechsler Abbreviated Scale of Intelligence. San Antonio, TX: Psychological Corporation.

Sisk, C., & Foster, D. (2004). The neural basis of puberty and adolescence. Nature Neuroscience, 7, 1040–1047.

Spear, P. (2000). The adolescent brain and age-related behavioral manifestations. Neuroscience and Biobehavioral Reviews, 24, 417–463.

Stanford, M. S., Greve, K. W., Boudreaux, J. K., Mathias, C. W., & Brumbelow, J. L. (1996). Impulsiveness and risk-taking behavior: Comparison of high-school and college students using the Barratt Impulsiveness Scale. Personality and Individual Differences, 21, 1073–1075.

Steinberg, L. (2008). A social neuroscience perspective on adolescent risk-taking. Developmental Review, 28, 78–106.

Steinberg, L., Albert, D., Cauffman, E., Banich, M., Graham, S., & Woolard, J. (2008). Age differences in sensation seeking and impulsivity as indexed by behavior and self-report: Evidence for a dual systems model. Developmental Psychology, 44, 1764–1778.

Steinberg, L., Graham, S., O'Brien, L., Woolard, J., Cauffman, E., & Banich, M. (2009). Age differences in future orientation and delay discounting. Child Development, 80, 28–44.

Stephenson, M. T., Hoyle, R. H., Palmgreen, P., & Slater, M. D. (2003). Brief measures of sensation seeking for screening

and large-scale surveys. Drug and Alcohol Dependence, 72, 279–286.

Teicher, M., Andersen, S., & Hostetter, J. Jr., (1995). Evidence for dopamine receptor pruning between adolescence and adulthood in striatum but not nucleus accumbens. Developmental Brain Research, 89, 167–172.

Zuckerman, M., Buchsbaum, M. S., & Murphy, D. L. (1980). Sensation seeking and its biological correlates. Psychological Bulletin, 88, 187–214.

Zuckerman, M., Eysenck, S., & Eysenck, H. J. (1978). Sensation seeking in England and America: Cross-cultural, age, and sex comparisons. Journal of Consulting and Clinical Psychology, 46, 139–149.