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Adolescents' Performance on the Iowa Gambling Task: Implications for the Development of Decision Making and Ventromedial Prefrontal Cortex

Catalina J. Hooper, Monica Luciana, Heather M. Conklin, and Rebecca S. Yarger
University of Minnesota, Twin Cities Campus

Healthy adolescents (79 girls, 66 boys), ages 9–17, completed the Iowa Gambling Task (IGT; A. Bechara, A. R. Damasio, H. Damasio, & S. W. Anderson, 1994) as well as working memory (digit span) and behavioral inhibition (go/no-go) tasks. Cross-sectional age-related changes were seen on all 3 tasks. Gender differences were seen in IGT deck preference and attentional variables (i.e., go/no-go hit rate and forward digit span). After age, gender, and general intellectual abilities were controlled for, IGT performance was not predicted by working memory or behavioral inhibition scores. Findings suggest that the ventromedial prefrontal cortex or its connections are functionally maturing during adolescence in a manner that can be distinguished from maturation of other prefrontal regions. Development of these functions may continue into young adulthood.

Intact functioning of the prefrontal cortex (PFC) is thought to be necessary for many higher order cognitive functions, such as working memory, set shifting, behavioral inhibition, decision making, and cognitive control of behavior (e.g., Braver & Barch, 2002; Goldman-Rakic & Leung, 2002; Krawczyk, 2002). Many of these functions are deficient in young children but emerge in a gradual fashion from late infancy onward (Luciana, 2003). These behavioral developments may have a parallel in PFC maturation. Indeed, there is considerable evidence to suggest that the PFC continues to develop throughout adolescence and into early adulthood (Giedd et al., 1999; Mukherjee et al., 2002; Paus et al., 2001; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999; Sowell, Thompson, Tessner, & Toga, 2001). Although the brain has reached its full adult size by about 5 to 10 years of age (Giedd et al., 1996; Reiss, Abrams, Singer, Ross, & Denckla, 1996), more subtle developments occur over a longer period of time, including increasing myelination of axons (leading to more efficient transmission of information between brain areas) and synaptic pruning (involving the strengthening of some connections and the elimination of others). Functional neuroimaging also supports continued prefrontal development during adolescence, in that preadolescent children and adults tend to show different patterns of activation on tasks that recruit the dorsolateral PFC (Bunge, Dudovic, Thomason, Vaidya, & Gabrieli, 2002; Casey, Giedd, & Thomas, 2000; Kwon, Reiss, & Menon, 2002).

Behaviorally, studies of children up to age 12 years have shown that they do not perform at adult levels on tasks thought to require intact functioning of the PFC. For example, recent work by Luciana and Nelson (2002) using the Cambridge Neuropsychological Testing Automated Battery (Fray, Robbins, & Sahakian, 1996) found that 11- to 12-year-old children did not perform at adult levels on several working memory tasks, including spatial memory span and spatial self-ordered search tasks and a modified Tower of London planning task. Vuontela et al. (2003) recently found that children up to age 13 years did not perform as well as adults on a visuospatial *n*-back working memory task and that their performance was well below that of adults on an audiospatial *n*-back working memory task. Welsh, Pennington, and Groisser (1991) reported continued development after age 12 on complex Tower of Hanoi planning problems, verbal fluency, and motor sequencing tests.

Despite this evidence that adolescence is an important time for continued structural and functional development of the PFC, few studies have directly and comprehensively examined performance on tasks that require different subregions of the PFC during this age period. Moreover, most studies of children and adolescents have focused on skills that have been traditionally related to the more dorsal and lateral aspects of the PFC, such as working memory and planning skills. In contrast, as we describe, there is a paucity of developmental data relevant to performance on tasks that are putatively related to the ventromedial PFC (VmPFC). Much of what is known about VmPFC function has been derived from human lesion data in adults.

Even in adults, there is some debate about the exact function of the VmPFC. The lack of data on this brain region is partly due to its proximity to the eyes and sinuses. Because of technical difficulties imposed by the need to distinguish neural signals from eye

Catalina J. Hooper, Heather M. Conklin, and Rebecca S. Yarger, Department of Psychology, University of Minnesota, Twin Cities Campus; Monica Luciana, Department of Psychology and Institute of Child Development, University of Minnesota, Twin Cities Campus.

Heather M. Conklin is now at the Kennedy Krieger Institute, Johns Hopkins University School of Medicine.

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Correspondence concerning this article should be addressed to Catalina J. Hooper, Department of Psychology, University of Minnesota, Twin Cities Campus, 218 Elliott Hall, 75 East River Road, Minneapolis, MN 55455. E-mail: hoop0044@umn.edu

movements and facial muscle activity and the sharp contrast boundary between the brain and sinuses, imaging of the VmPFC is vulnerable to artifacts. Those functional neuroimaging studies that have been conducted have generally indicated that the VmPFC is activated when individuals make choices that they are uncertain about (e.g., guessing or decision-making tasks) and that involve rewards and punishments based on those choices (Critchley, Mathias, & Dolan, 2001; Elliott, Dolan, & Frith, 2000; Elliott, Frith, & Dolan, 1997; Elliott, Rees, & Dolan, 1999; Ernst et al., 2002; Rogers et al., 1999). There is also evidence for a more general role for the orbitofrontal cortex (which overlaps with the VmPFC) in processing rewards and punishments (O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001; Rolls, 2000; Rolls et al., 2003; Small, Zatorre, Dagher, Evans, & Jones-Gotman, 2001; Tremblay & Schultz, 1999). The neuropsychological deficits of individuals with damage to the VmPFC have proven difficult to quantify using typical neuropsychological tasks. These individuals tend to have preserved levels of global intellectual function (IQ) and reportedly perform well on traditional neuropsychological measures of frontal lobe function, such as the Wisconsin Card Sorting Test, self-ordered search tasks, and short-term and working memory tasks, as well as tasks requiring solutions to social problems and ethical dilemmas (Bechara et al., 1994). However, they tend to make poor decisions in real life. The Iowa Gambling Task (IGT) was developed to experimentally capture the decision-making deficits of patients with VmPFC damage (Bechara et al., 1994). The task requires decision making in the context of personally relevant motivational influences on behavior.

The IGT requires continuous selections to be made from decks of cards with varying rewards and punishments. Some decks have high initial rewards but result in high punishments over time and thus are disadvantageous in the long run. Other decks have lower initial rewards but also lower punishments over time, making them advantageous in the long run (described later). In addition to adults with VmPFC damage, there are other groups who perform poorly on the task, including people who report being high in risk-taking behaviors and people who abuse substances, such as drugs and alcohol (Bechara et al., 1994, 2001; S. Grant, Contoreggi, & London, 2000; Mazas, Finn, & Steinmetz, 2000; Monterosso, Ehrman, Napier, O'Brien, & Chidress, 2001; Petry, 2001; Petry, Bickel, & Arnett, 1998). It may be that deficient VmPFC function, either as a consequence of an acquired lesion or because of immaturity, renders an individual vulnerable to risk-taking behaviors. Given the popularly held viewpoint that adolescents tend to make risky decisions (e.g., Furby & Beyth-Marom, 1992) and the fact that adolescence is a risk period for the initiation of maladaptive substance and alcohol use (B. F. Grant & Dawson, 1997, 1998; McGue, Iacono, Legrand, Malone, & Elkins, 2001), it is important to understand the development of the VmPFC and the development of performance on tasks such as the IGT during this age period. To our knowledge, normative developmental changes in performance on the IGT and their relation to performance on tasks that recruit other areas of the PFC have not been examined.

Some research has examined differences in IGT performance between healthy individuals and children and adolescents with externalizing disorders. Blair, Colledge, and Mitchell (2001) studied boys between the ages of 9 and 16 who had been placed in schools for children with emotional and behavioral difficulties. The boys were divided into two groups on the basis of their scores on a measure of psychopathic tendencies. It was found that the group with higher psychopathic tendencies chose more from the disadvantageous decks, particularly in later blocks of trials. A main effect of age was also reported; older children, regardless of psychopathic tendencies, chose more advantageously than younger children as the task progressed. Another study (Ernst et al., 2003) examined IGT performance in 12–14-year-old adolescents with and without behavior disorders (attention-deficit/hyperactivity disorder or conduct disorder) as compared with healthy adults. No performance differences were found between the healthy adolescents and the healthy adult sample, but adolescents with and without behavioral disorders differed from one another. The IGT was administered twice to each participant, with 1 week separating the two administrations. Most of the differences between the two adolescent groups were found in the second administration. Specifically, the healthy adolescents had much higher scores in the second administration than the first, but this was not the case for the adolescents with behavior disorders.

Another recent study (Crone, Vendel, & van der Molen, 2003) examined age-related differences in performance on an analog of the IGT (the Hungry Donkey Task) in individuals between the ages of 12 and 25 years in relation to measures of cognitive and behavioral inhibition. The Hungry Donkey Task used a similar schedule of rewards and punishments as those described in Bechara et al. (1994), but the instructions and stimuli were changed to make the task more prosocial and understandable to children. Rather than picking cards to win play money or to win actual money for themselves, the children were asked to open doors to find apples to feed a hungry donkey. Crone et al. (2003) found that Hungry Donkey Task performance was related to self-reported levels of cognitive inhibition. Groups of individuals selected for high scores on the Disinhibition subscale of the Zuckerman Sensation Seeking Scale (Zuckerman, Eysenck, & Eysenck, 1978) performed worse than those selected for low scores on the same scale. In contrast, performance on a measure of behavioral inhibition (the Matching Familiar Figures Test; Kagan, Rosman, Day, Albert, & Philips, 1964) was not found to significantly predict Hungry Donkey Task performance. Protracted development of performance on the Hungry Donkey Task was also reported, in that adults (ages 18–25 years) made more advantageous choices than the adolescents collapsed across the age range of 12 to 17 years. The equivalence of this task and the IGT has not been empirically established. There may be differences in the development of decision making that leads to personal gain versus decision making that is altruistic and helps another (the hungry donkey). This methodological difference, together with the human brain lesion data, suggests that it would be informative to measure developmental changes in performance on the traditional version of the IGT.

Although the IGT has been specifically sensitive to VmPFC damage in adults, the task may require other brain regions and a number of component processes in addition to reward-guided decision making. For example, a recent positron emission tomography (PET) study of performance of the IGT (compared with a control condition in which individuals selected from the decks in a predetermined order but received the same rewards and punishments) found that decision making in this task was associated with activation of the orbital and dorsolateral PFC, the anterior cingulate, the insula, the inferior parietal cortex, and the thalamus, as well as the cerebellum (Ernst et al., 2002). Many of these areas (e.g., the dorsolateral PFC and anterior cingulate cortex) are also activated during working memory and inhibitory control tasks (e.g., Braver, Barch, Gray, Molfese, & Snyder, 2001; Owen, 2000). Indeed, working memory and inhibitory control over prepotent response tendencies may represent component processes that are required for successful performance on the IGT.

Verbal working memory may be necessary to remember the results of past selections from a deck (or multiple decks) and to integrate this information across selections to make a determination regarding the net value of each deck. Adults with dorsolateral PFC lesions who also perform poorly on working memory tasks have been found to perform at a low normal level on the IGT (Bechara, Damasio, Tranel, & Anderson, 1998). Given the evidence for protracted development of working memory performance in middle childhood and adolescence (Luciana & Nelson, 2002; Vuontela et al., 2003; Welsh et al., 1991), it may be necessary for children to develop a certain level of working memory skill before they develop adult-like performance on the IGT. In the current study, as we describe, the Digit Span test was used as a measure of verbal working memory.

Behavioral inhibition of highly compelling or prepotent responses may also be important for performance on the IGT. The task is organized to favor the likelihood of some responses over others, at least early in the response sequence. Initially, none of the decks result in punishments, making the decks with high rewards a better choice at the beginning of the task, even though they are disadvantageous in the long run. Moreover, assuming the adoption of a left-to-right selection strategy, the high reward decks are placed spatially before the more advantageous decks. Healthy adults tend to choose more from these disadvantageous decks at the beginning of the task and then gradually shift their choices to the more advantageous decks, as the initially rewarding decks begin yielding high punishments (e.g., Bechara, Damasio, & Damasio, 2000). This shifting of preferences requires inhibition of a prepotent response to the initially rewarding disadvantageous decks. Thus, maximally advantageous performance on the IGT in adolescents may require response inhibition. To measure inhibitory control, the current study used a go/no-go response inhibition task.

The task selection for the current study was also guided by a desire to include tasks with differential brain correlates. Each of the tasks used here has been used in neuropsychological and neuroimaging research to assess the functioning of different PFC subregions. Although findings from a single PET imaging study indicated that the IGT activates both orbitofrontal and dorsolateral PFC (Ernst et al., 2002), a larger number of lesion studies have strongly implicated the VmPFC as the most critical brain area for successful IGT performance (Bechara et al., 1994, 1998; Bechara, Tranel, & Damasio, 2000). In contrast, performance on memory span tasks, such as digit span, has been primarily associated with the dorsolateral PFC, with digits backward more strongly and consistently activating this area than digits forward (Hoshi et al., 2000). Both the dorsolateral PFC and anterior cingulate cortex appear to be critical for go/no-go performance (Braver et al., 2001). Despite considerable use of each task in neuroimaging paradigms, neither has been associated with VmPFC activity. Therefore, this constellation of measures permits an analysis of how functions associated with each PFC subregion might contribute to IGT performance in an adolescent developmental sample.

The present study examined the pattern of performance on the IGT across groups of adolescents varying in age from 9 to 17 years in relation to performance on working memory and behavioral inhibition tasks. It was hypothesized that performance on each of the three tasks would show changes across predefined age groups such that older adolescents would outperform younger adolescents. It was also hypothesized that working memory and behavioral inhibition skills would contribute to IGT performance during adolescence, both because the IGT may require integration of these skills with the processing of emotional feedback and because all three tasks should rely to some extent on the development of the dorsolateral PFC. Because one study (Reavis & Overman, 2001) has demonstrated that adult men perform better than adult women on a longer version of the IGT, gender differences in performance were also examined.

Method

Sample

Participants were recruited from a database of individuals potentially interested in research activities at the Institute of Child Development at the University of Minnesota, Twin Cities Campus. Staff at the Institute of Child Development identify children through birth records and send letters to their parents asking whether they are interested in being contacted about opportunities to participate in research studies. If the parents respond affirmatively, the child's name and birth date, the parents' names, and the family's address and telephone number are included in the database. Potential participants were randomly selected from this list, and their parents were contacted by phone and invited to participate in the study. The sample consists of 145 participants (79 girls, 66 boys) between the ages of 9 and 17 (M = 12.89 years, SD = 2.75). Because this is a project that is expected to continue for several years, equal numbers of participants in each 12-month age cohort have not yet been studied. For analyses in the current study, the participants were divided into three roughly equally sized groups by age (9–10-year-olds, 11–13-year-olds, and 14–17-year-olds). The demographic characteristics of these groups are presented in Table 1. Overall, the participants were mostly Caucasian (94%) and right-handed (88%). They tended to come from families with highly educated parents (years of education for mothers, M = 16.15, SD = 2.30; for fathers, M = 16.03, SD = 2.79) and relatively high annual family incomes (M = \$89,111, SD = \$59,591). On average, the participants scored in the high average range of intellectual functioning on the Vocabulary (scaled score, M = 12.81, SD = 2.72) and Block Design (scaled score, M = 12.86, SD = 3.03) subtests of the Wechsler Intelligence Scale for Children—Third Edition (WISC–III; Wechsler, 1991) or the Wechsler Adult Intelligence Scale—Third Edition (WAIS–III; Wechsler, 1997), with above-average prorated full-scale IQs (M = 116.56, SD = 13.00). The only significant difference across the age groups in these demographic characteristics was in the mean age of participants, which, as expected, was highly significant, $F(2, 142) = 590.10$, $p < .01$.

Research Protocol

Participants and a parent came to the University of Minnesota's Center for Neurobehavioral Development for a day of testing that lasted for approximately 5 hr. On arrival, study procedures were explained and informed consent (parents) and assent (children) were obtained according to guidelines of the Institutional Review Board. Parents completed a questionnaire about their family's demographic characteristics, as well as specific developmental and medical history information about the child.

Table 1
Demographic Characteristics of the Sample

Characteristic	Age group 9–10 years	11–13 years	14–17 years	Group difference
N	49	54	42	
% female	49	56	60	$\chi^2 = 1.05$, *ns*
% Caucasian	96	93	93	$\chi^2 = 4.69$, *ns*
% right-handed	92	83	88	$\chi^2 = 2.87$, *ns*
Age (years)	9.84 (0.32)	12.92 (0.90)	16.41 (1.31)	$F(2, 142) = 590.10$, $p < .01$
Mother's education (years)	15.86 (2.20)	16.13 (2.30)	16.52 (2.42)	$F(2, 142) = 0.95$, *ns*
Father's education (years)	15.88 (2.88)	15.78 (2.59)	16.50 (2.91)	$F(2, 138) = 0.87$, *ns*
Income	$93,122 ($87,282)	$83,241 ($31,595)	$92,049 ($46,428)	$F(2, 141) = 0.42$, *ns*
Vocabulary scaled score	13.2 (3.0)	12.5 (2.3)	12.8 (2.9)	$F(2, 141) = 0.90$, *ns*
Block Design scaled score	13.1 (3.1)	13.2 (3.1)	12.1 (2.8)	$F(2, 141) = 1.86$, *ns*
Prorated full-scale IQ	118.4 (13.9)	116.6 (12.1)	114.2 (13.0)	$F(2, 141) = 1.17$, *ns*

Note. Values represent percentages or means (and standard deviations). Data were analyzed using one-way analyses of variance for continuous variables and chi-square tests for categorical variables. An alpha level of .05 was used to judge whether findings were significant.

Participants' visual acuity was screened using the Snellen Eye Chart. Then participants worked individually with a research assistant to complete a battery of neuropsychological tests. The following measures were included.

Verbal and nonverbal intellectual abilities. Nine- to 16-year-old participants completed the Vocabulary and Block Design subtests from the WISC–III (Wechsler, 1991), and 17-year-old participants completed the same subtests from the WAIS–III (Wechsler, 1997). Full-scale IQ was prorated from these two subtests using the procedures described in Sattler (2001).

The Iowa Gambling Task (Bechara et al., 1994). Participants completed a computerized version of the IGT in which they selected from among four decks of cards varying in their amounts of monetary reward and punishment. In Bechara's studies (Bechara et al., 1994, 1998; Bechara, Tranel, & Damasio, 2000), participants work to earn imaginary money or points. In the version of the task used in the current study, similar to some studies of adult IGT performance (Ernst et al., 2002; Mazas et al., 2000; Petry, 2001; Petry et al., 1998; Reavis & Overman, 2001), participants were able to earn real money. Rewards and punishments were scaled down from the amounts described in Bechara et al. (1994) so that participants could win a maximum of $5. Specifically, for each selection from Decks 1 or 2 (the "disadvantageous decks"), participants would win $0.25 but the losses were organized so that over 20 selections from these decks, participants would incur a net loss of $1.25. The difference between Decks 1 and 2 was in the frequency and magnitude of punishment: Deck 1 contained frequent (50% of cards) punishments, whereas Deck 2 contained less frequent (10% of cards) but much larger punishments. For each selection from Decks 3 or 4 (the "advantageous decks"), participants would win either $0.10 or $0.15 and the losses were organized so that over 20 selections from these decks, participants would accrue a net gain of $1.25. Again, the two advantageous decks differed from each other in the frequency of punishment, such that small punishments occurred on 50% of the cards in Deck 3 and larger punishments occurred on 10% of the cards in Deck 4. Table 2 summarizes the contingencies associated with each of the four decks used in this task. To enhance motivation, we paid participants who had positive net earnings at the end of the task that amount at the end of the study.

Go/no-go task. Participants completed a computerized version of a go/no-go task (Braver et al., 2001). For this task, participants viewed a series of letters (20% of which were *X*s) presented one by one on a computer screen. Each letter was presented for 250 ms, with a 1,000-ms interstimulus interval. Participants were asked to press the space bar in response to every letter except *X*. They were asked to withhold a response when they saw an *X*. The fact that the non-*X*s are frequent, occurring 80% of the time, sets up a prepotent tendency to respond on all trials. This response must be inhibited when the *X* appears (Braver et al., 2001).

Digit Span. Participants (regardless of age) completed the Digit Span subtest of the WISC–III (Wechsler, 1991) according to the standardized procedures described in the manual. Forward and backward spans were calculated. For Digits Forward, the participant was required to repeat increasingly longer strings of digits exactly as read by the examiner. Two trials were administered at each string length. The forward span was the length of the longest string of digits the individual was able to correctly repeat. Digits Backward followed similar procedures except that the participant was required to rearrange the digits in his or her mind and repeat the string of digits in reverse order. Backward span was calculated as the longest string of digits that the individual was able to correctly repeat in reverse order.

Participants completed these measures in the context of a larger neuropsychological battery not reported here. The battery took approximately 5 hr, and participants were given breaks as needed to reduce fatigue. Partic-

Table 2
Comparison of Decks in the Iowa Gambling Task

Deck property	Deck 1	Deck 2	Deck 3	Deck 4
Win on each card selection	$0.25	$0.25	$0.10 or $0.15	$0.10 or $0.15
% of cards with losses	50	10	50	10
Range of losses	$0.35–$0.90	$3.00–$3.25	$0.05–$0.20	$0.60–$0.65
Net winnings after 20 selections	−$1.25	−$1.25	$1.25	$1.25
Classification	Disadvantageous, frequent punishment	Disadvantageous, infrequent punishment	Advantageous, frequent punishment	Advantageous, infrequent punishment

ipants were paid $45 (plus their winnings on the IGT) for completion of the procedures.

Results

Data were analyzed with the Statistical Package for the Social Sciences for Windows, Version 11.5.0 (SPSS Inc., Chicago, IL). Data were inspected for normality to ensure that the assumptions of parametric statistics were met before analyses were performed. Data were analyzed using mixed-model one-way univariate or multivariate analyses of variance (ANOVAs), depending on the characteristics of the variables investigated. An alpha level of .05 was used to judge whether findings were significant. Significant findings were followed up with one-way ANOVAs and Tukey honestly significant difference (HSD) post hoc tests. Associations among performance on the different tasks were assessed with partial correlations (controlling for age) and hierarchical regressions.

Age-Related Trends in Performance

Iowa Gambling Task. On this task, participants were expected to begin by choosing randomly or choosing more from the disadvantageous decks (Decks 1 and 2) and then to gradually shift their choices to the advantageous decks (Decks 3 and 4) as the task progressed. As is conventional in analyses of IGT performance (Bechara, Damasio, & Damasio, 2000; Bechara, Damasio, Damasio, & Lee, 1999; Bechara et al., 2001; Bechara, Tranel, & Damasio, 2000; Ernst et al., 2003; Mazas et al., 2000), the task was divided into five blocks of 20 card selections to examine changes in performance over time. Within each block, the number of advantageous relative to disadvantageous choices was calculated. Performance was then examined using a mixed-model ANOVA, with block (five levels) as the within-subjects factor and age group (three levels) and gender (two levels) as between-subjects factors. Because the assumption of sphericity was not met (Mauchly's $W = .75$, $p < .01$), the degrees of freedom for tests of within-subjects effects were conservatively adjusted using the Greenhouse–Geisser F test. Between-subjects tests revealed a significant main effect of age group, $F(2, 139) = 4.98$, $p = .01$, but no significant main effect of gender or an Age Group × Gender interaction. Tukey HSD post hoc tests indicated that overall, the 14–17-year-olds made significantly more advantageous choices than the 9–10-year-olds ($p = .01$); the 11–13-year-old group did not differ from the other age groups.

Within-subjects tests revealed a significant main effect of block, $F(3.5, 481.4) = 23.69$, $p < .01$, and a significant Age Group × Block interaction, $F(6.9, 481.4) = 2.53$, $p = .02$. There was no significant Gender × Block, $F(3.5, 481.4) = 0.27$, *ns*, or Age Group × Gender × Block, $F(6.9, 481.4) = 1.61$, *ns*, interaction. Follow-up one-way ANOVAs indicated that there were significant differences between the age groups in Block 4, $F(2, 142) = 5.56$, $p = .01$, and Block 5, $F(2, 142) = 3.36$, $p = .04$. Tukey HSD post hoc tests showed that the 14–17-year-olds chose more advantageously in Block 4 than the 9–10-year-olds ($p < .01$) and 11–13-year-olds ($p = .05$). In Block 5, the 14–17-year-olds chose more advantageously than the 9–10-year-olds ($p = .04$) but not the 11–13-year-olds ($p > .05$).

This pattern indicates that the 14–17-year-olds are shifting their preference toward the advantageous decks earlier in the task than the younger participants, specifically by Block 4 of the task. The 11–13-year-olds start choosing similarly to the 14–17-year-olds in Block 5, but the 9–10-year-olds continue to choose fewer advantageous cards than the 14–17-year-olds even in the last block of the task. The performance of the three age groups across the blocks of the task is presented graphically in Figure 1. The variable graphed is mean number of choices from advantageous ("good") – disadvantageous ("bad") decks, so positive numbers represent a bias to choose from the advantageous decks, whereas negative numbers indicate a bias to choose from the disadvantageous decks.

Although the number of advantageous cards chosen is the traditional performance measure analyzed on the IGT (Bechara et al., 1994), the decks also differ in the frequency of punishment cards. Decks 1 and 3 yield frequent but relatively small punishments, whereas Decks 2 and 4 yield infrequent but larger punishments. Individuals who are more averse to punishment regardless of its magnitude may choose more cards from the infrequent punishment decks because these decks have a lower absolute number of punishment cards. The developmental trends and gender differences in the selection of infrequent versus frequent punishment cards were analyzed with a 3 (age group) × 2 (gender) univariate ANOVA on the net infrequent punishment choices. The net infrequent punishment choices were calculated by subtracting the number of frequent punishment deck (Decks 1 and 3) choices from the number of infrequent punishment deck (Decks 2 and 4) choices. Thus, positive numbers indicate a bias to choose from the infrequent punishment decks, whereas negative numbers indicate a bias toward the frequent punishment decks. The ANOVA indicated significant main effects of both gender, $F(1, 139) = 5.06$, $p = .03$, and age group, $F(2, 139) = 3.96$, $p = .02$, but no significant Age Group × Gender interaction, $F(2, 139) = 0.94$, *ns*. Examination of the data revealed that although both boys and girls showed a bias toward the infrequent punishment decks, girls made an even higher

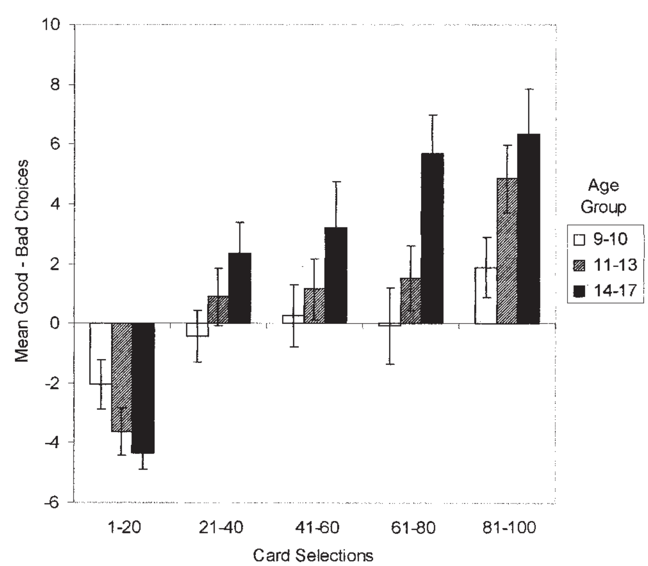

Figure 1. Mean (± *SE*) number of selections from advantageous – disadvantageous decks by healthy 9–10-year-olds ($n = 49$), 11–13-year-olds ($n = 54$), and 14–17-year-olds ($n = 42$) across blocks of 20 card selections in the Iowa Gambling Task.

number of net infrequent punishment choices (for girls, M = 23.49, SD = 17.82; for boys, M = 16.73, SD = 15.85). Following up the main effect of age group with post hoc Tukey HSD tests showed that both 11–13-year-olds (p = .03) and 14–17-year-olds (p = .03) had a stronger bias toward the infrequent punishment decks than the 9–10-year-olds. The preferences of boys and girls in each age group are graphically depicted in Figure 2.

Go/no-go task. Because optimal performance on the go/no-go task involves minimizing both misses (not responding to a go trial) and false alarms (responding to a no-go trial), summaries of go/no-go performance were calculated using signal-detection theory (Green & Swets, 1966). For each participant, the hit rate (number of correct go trials divided by the total number of go trials) and the false alarm rate (number of no-go errors divided by the total number of no-go trials) were calculated. These were used to estimate d', a measure of the overall discriminability between the go and no-go trials, assuming an equal variance Gaussian model (Wickens, 2002). A univariate ANOVA revealed significant main effects of age group, $F(2, 135) = 13.68$, $p < .01$, and gender, $F(1, 135) = 6.39$, $p = .01$, on $\hat{d}'$, but no significant Age Group × Gender interaction, $F(2, 135) = 1.98$, *ns*. Examination of the data showed that on average, girls had a higher $\hat{d}'$ than boys (for girls, M = 1.85, SD = 0.76; for boys, M = 1.50, SD = 0.81), indicating better ability to discriminate between go and no-go trials for the girls. Tukey HSD post hoc tests were calculated to examine the main effect of age group. They indicated that each age group significantly differed from the other age groups in their behavioral inhibition (as measured by $\hat{d}'$), with older adolescents better able to discriminate between go and no-go trials than younger adolescents.

Follow-up analyses revealed that the age and gender effects were operating on different components of $\hat{d}'$. There was a significant effect of age group on the false alarm rate, $F(2, 139) = 25.98$, $p < .01$, but the main effect of age group on the hit rate was only significant at a trend level, $F(2, 139) = 2.73$, $p = .07$. There was a significant effect of gender on the hit rate, $F(1, 139) = 6.06$, $p = .02$, but not on the false alarm rate, $F(1, 139) = 1.44$, *ns*. Post hoc tests revealed that the false alarm rate of each age group was significantly different from that of the others, with 9–10-year-olds having the highest false alarm rate and 14–17-year-olds having the lowest false alarm rate. This indicates that inhibitory control (as measured by decreasing numbers of false alarm errors) shows age-related differences across the age range studied, regardless of gender, but that girls, regardless of age, are better able than boys to perform the sustained attention and vigilance necessary to consistently respond to the go trials.

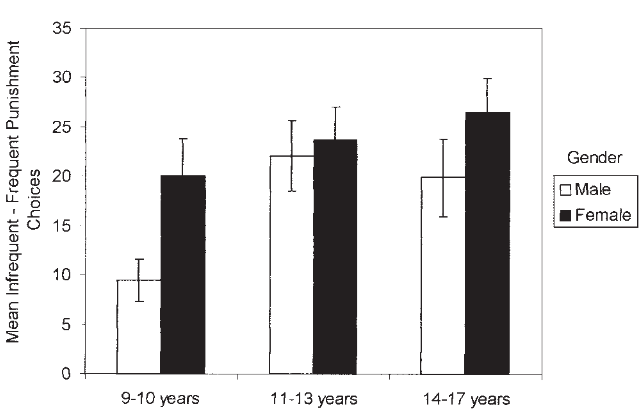

Figure 2. Mean (± SE) number of selections from decks yielding infrequent – frequent punishment in the Iowa Gambling Task by boys (n = 66) and girls (n = 79) within each of the three age groups.

Digit Span. The two components of the Digit Span test (forward vs. backward) were treated as within-subject variables when calculating the effects of age group on memory span. A mixed-model ANOVA was computed with task (two levels) as the within-subjects factor and age group (three levels) and gender (two levels) as between-subjects factors. Between-subjects tests showed a significant main effect of age group, $F(2, 138) = 13.30$, $p < .01$. Follow-up Tukey HSD post hoc tests indicated that each age group was significantly different from both other age groups, with task performance ordered by age. This indicates that, on the task as a whole, performance was improved in the older age groups compared with the younger age groups across the age range studied. Within-subjects effects indicated that there was a significant main effect of task, $F(1, 138) = 143.06$, $p < .01$, with participants having a lower backward span score than forward span score across all age groups. There was not a significant Age Group × Task or Age Group × Task × Gender interaction. The Gender × Task interaction approached significance, $F(1, 138) = 3.70$, p = .06, with girls performing slightly (but not significantly) better than boys on the forward span (span for girls, M = 6.32, SD = 1.20; span for boys, M = 6.12, SD = 1.27) and boys performing slightly (but not significantly) better than girls on the backward span (span for girls, M = 4.72, SD = 1.14; span for boys, M = 4.95, SD = 1.36).

Summary. The performance of individuals within each age group on the three cognitive tasks is presented in Table 3. Significant effects of age group were found on each of the three tasks. On the IGT, 14–17-year-olds made more overall advantageous choices than 9–10-year-olds and began to shift their choices to advantageous decks earlier in the task than either of the other age groups. Specifically, 14–17-year-olds chose more advantageously than both other groups in Block 4 of the task and chose more advantageously than the 9–10-year-olds in Block 5 of the task. The 11–13-year-olds did not significantly differ from either of the other groups in their overall advantageous choices or their performance in Block 5 of the task. Examining the bias to choose from infrequent punishment decks (regardless of whether they were advantageous or disadvantageous) indicates that both 11–13-year-olds and 14–17-year-olds had a stronger preference for infrequent punishment decks than 9–10-year-olds and that, overall, girls showed a stronger bias to choose from the infrequent punishment decks than boys.

On the go/no-go task, each age group performed better than the younger age groups in their ability to inhibit a prepotent response (as indexed by decreasing false alarm errors). Also, girls had a higher hit rate than boys across the age range studied, perhaps indicating better sustained attention and vigilance. The Digit Span test also showed age-related changes across the adolescent period, with each age group scoring significantly better than the younger age groups.

Table 3

Performance Means (and Standard Deviations) on the Three Cognitive Tasks by Age Group

Task variable	9–10 years	11–13 years	14–17 years
Gambling task			
Advantageous − disadvantageous choices	−0.41 (23.77)	4.78 (20.34)	13.19 (21.31)
Infrequent − frequent punishment choices	14.65 (15.56)	23.00 (17.68)	23.81 (17.17)
Go/no-go task			
Go/no-go hit rate	0.83 (0.15)	0.88 (0.11)	0.89 (0.12)
Go/no-go false alarm rate	0.44 (0.14)	0.34 (0.11)	0.24 (0.13)
Go/no-go *d′*	1.30 (0.78)	1.71 (0.71)	2.13 (0.70)
Digit Span test			
Forward span	5.63 (1.02)	6.30 (1.24)	6.83 (1.15)
Backward span	4.42 (1.05)	4.81 (1.27)	5.31 (1.28)

Associations Among Performance on Tasks Tapping Different Cognitive Functions

To investigate whether performance on the gambling task was related to performance on working memory and behavioral inhibition tasks, we computed partial correlations between task measures, controlling for age. These correlations are shown in Table 4. Both the net infrequent punishment choices and the backward digit span were correlated at a trend level ($p < .10$) with net advantageous choices on the IGT. Variables related to behavioral inhibition (go/no-go false alarm rate), attention (forward digit span and go/no-go hit rate), and overall cognitive abilities (full-scale IQ) were not significantly correlated with advantageous selections on the IGT after controlling for age. Go/no-go hit rate was significantly correlated with the net infrequent punishment choices on the IGT.

There were also associations between the memory measures (both Digits Forward and Digits Backward) and the false alarm rate on the go/no-go task. Overall cognitive abilities (as measured by prorated full-scale IQ) were associated with performance on Digits Forward and Digits Backward, as well as the go/no-go false alarm rate.

Because of the association between backward digit span and prorated full-scale IQ, it was unclear whether the modest association between IGT performance and backward digit span was due to the variance associated with the overall cognitive abilities or to specific variance associated with working memory. To address this question, we performed hierarchical linear regressions to predict net advantageous choices on the IGT. Age, gender, prorated full-scale IQ, and backward digit span were entered in sequential blocks. A separate analysis was performed to predict net advantageous choices on the IGT with age, gender, prorated full-scale IQ, and go/no-go variables (hit rate and false alarm rate entered in a single block) entered in separate blocks. The results of these regression analyses are presented in Table 5. Age accounted for a significant proportion of the variance in each model, but none of the other variables produced a significant increase in the predictive power of the model. Therefore, the traditional performance measure of the IGT (net advantageous choices) is higher in older adolescents, but it cannot be concluded that scores on the measures of global cognition, working memory, and behavioral inhibition significantly contribute to IGT performance during adolescence, at least in this relatively high-functioning sample.

A second set of hierarchical regression analyses was performed to examine the association of the cognitive task variables with the net infrequent punishment choices on the IGT. The results of these analyses are shown in Table 6. First, age, gender, prorated full-scale IQ, and backward digit span were entered in sequential blocks. Age again accounted for a significant proportion of the variance, indicating that older adolescents made more infrequent punishment choices. Adding gender significantly improved the model fit, such that girls made more infrequent punishment choices than boys. Neither prorated full-scale IQ nor backward digit span added significantly to the overall model fit, but both were associated with net infrequent punishment choices at a trend level (with prorated full-scale IQ predicting more infrequent punishment choices and backward digit span predicting in the negative direction). In the second set of analyses (with age, gender, prorated full-scale IQ, and the go/no-go variables added in separate blocks),

Table 4

Partial Correlations (Controlling for Age) Between Scores on Each of the Cognitive Tasks

Measure	1	2	3	4	5	6	7
1. IGT net advantageous choices	—	−.14†	.04	.09	.00	.15†	.10
2. IGT net infrequent punishment choices		—	.28**	.03	.09	−.12	.08
3. Go/no-go hit rate			—	−.05	.08	−.11	.03
4. Go/no-go false alarm rate				—	−.19*	−.16†	−.21*
5. Digits Forward					—	.28**	.24**
6. Digits Backward						—	.35**
7. Prorated full-scale IQ							—

Note. Results of two-tailed significance tests are denoted by superscripts. IGT = Iowa Gambling Task.
† $p < .10$. * $p < .05$. ** $p < .01$.

Table 5
Summary of Hierarchical Regression Analysis for Variables Predicting Net Good Choices on the Iowa Gambling Task (N = 145)

Step and variable	*B*	*SE B*	β
Step 1			
Age	1.85	0.67	.23**
Step 2			
Age	1.82	0.67	.22**
Gender	2.88	3.70	.08
Step 3			
Age	1.85	0.67	.23**
Gender	3.41	3.70	.08
Prorated full-scale IQ	0.18	0.14	.10
Step 4A			
Age	1.41	0.73	.17†
Gender	3.92	3.69	.09
Prorated full-scale IQ	0.10	0.15	.06
Backward span	2.59	1.67	.15
Step 4B			
Age	2.56	0.84	.31**
Gender	3.97	3.80	.09
Prorated full-scale IQ	0.22	0.15	.13
Go/no-go hit rate	4.26	14.57	.03
Go/no-go false alarm rate	23.40	15.70	.15

Note. $R^2 = .051$ for Step 1 ($p < .01$), $\Delta R^2 = .004$ for Step 2 (*ns*), $\Delta R^2 = .011$ for Step 3 (*ns*), $\Delta R^2 = .016$ for Step 4A (*ns*), and $\Delta R^2 = .015$ for Step 4B (*ns*).
† $p < .10$. ** $p < .01$.

age and gender still were significantly associated with net infrequent punishment choices. Adding the go/no-go variables significantly improved the model fit, with hit rate associated with more infrequent punishment choices.

Summary of Associations Among Task Variables

None of the variables associated with working memory or response inhibition significantly predicted IGT performance (as measured by net advantageous choices) above and beyond the predictive power of age. The preference for infrequent punishment decks, although also associated with age, seems to have a distinct pattern of correlates. Girls were shown to choose more infrequent punishment cards, and go/no-go hit rate added to the prediction even after controlling for age, gender, and overall cognitive abilities.

Discussion

In this study, we examined performance on the IGT in relation to measures of working memory and behavioral inhibition in a healthy adolescent sample. There are three main findings from this analysis related to (a) developmental trends observed across tasks, (b) specific characteristics of VmPFC development, and (c) gender differences observed in relation to some aspects of IGT performance.

First, performance on all three tasks showed significant differences between the age groups studied. Compared with the younger age groups, 14–17-year-olds made more advantageous selections on the IGT and shifted their choices to the advantageous decks earlier in the trial sequence. They were also better able to inhibit a prepotent response (as indexed by fewer false alarm errors on the go/no-go task) and could manipulate more pieces of information in working memory (as indexed by higher backward digit span scores). This overall pattern is consistent with others' reports of continued development of the PFC during adolescence, as assessed by postmortem studies and structural imaging techniques (Giedd et al., 1999; Mukherjee et al., 2002; Paus et al., 2001; Sowell et al., 1999, 2001) and with reports of functional changes in PFC activation during performance of behavioral inhibition and working memory tasks (Bunge et al., 2002; Casey et al., 2000; Kwon et al., 2002).

Second, these findings are informative as to the development of cognition–emotion integrative capacities that are putatively mediated by the VmPFC. The fact that differences in performance were seen between the 11–13-year-old and 14–17-year-old groups raises the possibility that performance may continue to improve even after the age of 17 years. Comparison of the scores of the oldest participants in this study with normative data published on the IGT suggests that this may be the case. For example, healthy adults typically have been found to have net advantageous choice scores of over 20 (Bechara, Damasio, & Damasio, 2000; Bechara et al., 2001; Ernst et al., 2003; Mazas et al., 2000), whereas the 14–17-year-olds studied here had an average net advantageous choice score of 13.19, with significant variability within the group (*SD* = 21.31). This might have been due to development within the age group (i.e., across the age range from 14 to 17), but even among the 17-year-olds in this sample (*n* = 21), the scores were lower than those previously reported for adults and were highly variable (*M* = 16.38, *SD* = 24.81). This pattern suggests that the VmPFC or its connections may continue to develop even into

Table 6
Summary of Hierarchical Regression Analysis for Variables Predicting Net Infrequent Punishment Choices on the Iowa Gambling Task (N = 145)

Step and variable	*B*	*SE B*	β
Step 1			
Age	1.34	0.52	.21*
Step 2			
Age	1.27	0.51	.20*
Gender	6.55	2.81	.19*
Step 3			
Age	1.30	0.51	.21*
Gender	6.94	2.82	.20*
Prorated full-scale IQ	0.14	0.11	.10
Step 4A			
Age	1.68	0.56	.27**
Gender	6.51	2.81	.19*
Prorated full-scale IQ	0.20	0.11	.15†
Backward span	−2.21	1.27	−.16†
Step 4B			
Age	1.51	0.62	.24*
Gender	5.46	2.83	.16†
Prorated full-scale IQ	0.15	0.11	.11
Go/no-go hit rate	32.17	10.85	.24**
Go/no-go false alarm rate	13.66	11.70	.12

Note. $R^2 = .045$ for Step 1 ($p < .05$), $\Delta R^2 = .036$ for Step 2 ($p < .05$), $\Delta R^2 = .010$ for Step 3 (*ns*), $\Delta R^2 = .019$ for Step 4A ($p < .10$), and $\Delta R^2 = .061$ for Step 4B ($p < .01$).
† $p < .10$. * $p < .05$. ** $p < .01$.

adulthood. However, the differences in performance between the adolescents in this study and the adults in other studies may also be due to differences in the task parameters (e.g., the use of real rather than abstract monetary rewards).

Also, when examining performance across blocks of card selections, the 14–17-year-olds only outperformed the younger groups in Blocks 4 and 5 of the task. This finding is interesting in relation to results obtained by comparing adult individuals with substance abuse with healthy controls. The biggest differences between these two groups are usually found in Block 3 of the task (Bechara et al., 2001; Ernst et al., 2003). Healthy adults begin selecting more cards from the advantageous decks in Block 3, whereas adults with substance abuse do not shift their choices to the advantageous decks until Block 4. Thus, even the 14–17-year-olds in this study generate a pattern of performance that is different from healthy adults, suggesting that even older adolescents do not have the same capabilities as adults to make decisions that will be advantageous in the long run, particularly when hedonic pulls on behavior are salient. These findings may have implications for adolescents' vulnerabilities to risk-taking behaviors when they are required to exert control over reward-seeking tendencies (Furby & Beyth-Marom, 1992; B. F. Grant & Dawson, 1997, 1998; McGue et al., 2001).

One reason for age-related changes in IGT performance could be that younger children simply did not understand the task and therefore chose randomly. However, on the basis of informal observations, even the youngest children appeared to understand the task demands and to be motivated by the possibility of winning real money on the task. They would report feeling upset when they lost a large sum of money, despite sometimes continuing to select from the disadvantageous decks. Also, even the 9–10-year-olds began to choose more cards from advantageous than disadvantageous decks by the final block of the task, indicating a nonrandom performance pattern. It would be interesting to see whether their performance would continue to improve if the task was extended to include more trials.

A novel finding from this study is that VmPFC-mediated capacities may emerge in a manner that can be distinguished from other PFC-regulated functions. On the one hand, partial correlations among task performance after controlling for age suggested a possible (albeit weak) association between working memory span, which has traditionally been related to more dorsal and lateral aspects of the PFC, and IGT performance. On the other hand, hierarchical regressions controlling for age, gender, and overall cognitive abilities did not support a specific relationship between working memory and IGT performance.

Behavioral inhibition performance was not found to be related to IGT performance, as was found by Crone et al. (2003) using a different measure of behavioral inhibition and a different gambling task. The Matching Familiar Figures Test that they used as a measure of behavioral inhibition is somewhat different than the go/no-go task used here. It requires participants to select the figure (from six to eight choices) that exactly matches a stimulus, which is thought to require visual search and hypothesis testing skills in addition to impulse control (Crone et al., 2003). The go/no-go task used here may be a purer measure of behavioral inhibition, but still no relationship to IGT performance was found. Perhaps a measure of inhibition that requires both inhibiting a response and shifting to a new response may be more closely related to IGT performance, or, as suggested by Crone et al. (2003), cognitive inhibition may be a more important predictor than behavioral inhibition. However, cognitive inhibition is a difficult construct to measure and often relies on self-report as opposed to more direct observations of actual behavior. In summary, the relative independence of IGT performance compared with the working memory and behavioral inhibition measures suggests that this task is tapping a unique aspect of cognitive development.

A third finding from this study concerns gender biases toward selections that minimize the absolute number of punishments incurred during IGT performance. Examination of task performance by gender revealed no significant difference between boys and girls in the net number of advantageous selections across blocks. This is in contrast to a study by Reavis and Overman (2001), which found that men outperformed women on a version of the IGT. This may be due to variations in the task parameters in that Reavis and Overman used 150 card selections rather than the traditional 100 card selections described by Bechara et al. (1994). Reavis and Overman found the most pronounced differences between men and women in the last 50 card selections, although they also found sex differences in card selections 50–100. Given the above evidence that task performance may continue to develop even after the age of 17 years, it is possible that gender differences may emerge later in development.

Despite the lack of gender differences in overall performance on the IGT, girls did show a stronger preference than boys for the decks yielding infrequent punishments. Perhaps girls are more averse to punishment, regardless of its magnitude. Anecdotally, this seemed to be the case for some participants, as they made disappointed comments following card selections yielding punishment, even if the net outcome of the card was positive (e.g., "You won $0.15, but you also lost $0.05"). It is interesting to note that on questionnaire measures of sensitivity to punishment, adult and adolescent females tend to rate themselves as more sensitive to punishment than males (Aluja-Fabregat, Balleste-Almacellas, & Torrubia-Beltri, 1999; Torrubia, Avila, Molto, & Casera, 2001).

Other gender differences found in task performance in this sample indicated an advantage for girls on measures tapping attention. Girls had a higher hit rate on the go/no-go task and marginally higher scores on forward digit span. This is consistent with other developmental studies that have shown a female advantage in attentional skills as assessed by continuous performance tasks (e.g., Conners, Epstein, Angold, & Klaric, 2003). Preference for decks with infrequent punishment regardless of their long-term outcome was found to be related to hit rate on the go/no-go task, a variable traditionally associated with sustained attention and vigilance, even after controlling for the effects of age, gender, and overall cognitive abilities. Thus, although this aspect of IGT performance has not been studied as frequently as preference for advantageous decks, current results suggest that it may have different cognitive, and perhaps personality trait, correlates.

Limitations

This study is not without its limitations, and certain caveats must be mentioned to temper some of our interpretations. First, because of the possibility of cohort effects, it is impossible to draw strong conclusions about developmental trajectories from the current cross-sectional design. Second, our findings regarding working memory and inhibitory control contributions (or lack thereof) to IGT performance may be limited to the specific tasks used to assess each of these domains. Although each task showed between-group differences across the age groups studied, we cannot rule out the possibility that age-related changes on the working memory and behavioral inhibition measures were artifacts of the tasks chosen. For example, perhaps a more future-guided working memory task or a behavioral inhibition task involving both set shifting and response inhibition would show stronger relationships to IGT performance. A related limitation is that it is impossible to draw conclusions about differential development of brain areas and associated cognitive skills when only one task is used to assess each brain–behavior relation. In this case, it is difficult to separate variance due to measurement error (which could vary across tasks) from variance due to development of the latent underlying cognitive skills. If each skill were measured with several tasks, then it would be possible to rule out task and developmental associations with measurement error and make stronger conclusions about cognitive development. Third, although ceiling levels of performance were not reached on any of the measures used in the present study, it is difficult to draw conclusions about differences in developmental time course between tasks that were not specifically equated for difficulty or complexity.

Conclusions

Despite these limitations, our confidence in these findings is strengthened because we used measures with strong empirical foundations in the brain–behavior literature. Our results agree with an increasing body of evidence supporting the protracted development of the PFC throughout adolescence. They expand on past findings by suggesting that the VmPFC or its connections may show protracted development similar to, or perhaps even later maturing than, that of more dorsal aspects of the PFC. Future research should include samples of young adults to determine when performance reaches stable adult levels. Although there is some indication that age-related changes in working memory and behavioral inhibition skills begin at earlier ages than those skills recruited in the course of the IGT, precise relationships among these constructs could be better elucidated in the context of prospective studies that incorporate both behavioral and brain-based assessments. For instance, a longitudinal study of adolescent cognitive development, including tasks with different known brain correlates, would greatly contribute to knowledge about the functional significance of adolescent brain development. It would also be interesting to include objective measures of brain development, such as structural or diffusion tensor neuroimaging, to be able to directly correlate task performance with structural changes in PFC subregions and/or their interconnections.

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