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with long-term gains. These speculations are testable. If we are correct, in previous studies with the traditional design, there should have been a difference between males and females in anticipatory SCRs to the disadvantageous (US$ 100) yellow deck. We encourage researchers to conduct post hoc analyses of their data to determine if our speculations are correct.

There are complex and multiple decisional elements in the Iowa Card Task, as in real-life decisions. Indeed, it is probable that individuals respond differentially to various components of such problems. This fact seems to be reflected in the literature of the Iowa Card Task: some normal participants perform well, some do not (there is always a range of scores); some substance-abusing participants perform well and some do not; and there are sub populations of substance abusers who score differently on variations of the task (Bechara et al., 2002).

In the present paper we demonstrate, but do not fully explain, that there are several subgroups of "normal" participants who perform differently on this laboratory decision-making task: adolescents versus young adults, males versus females. Perhaps a better understanding of individual differences in "normal" populations will lead the way to understanding of why some individuals respond to those elements of decision contexts that lead to personal and societal negative consequences.

We fully agree with Bechara et al. (2002) that a full understanding of the cognitive mechanisms underlying multiple prefrontal mechanisms involved in decision-making and impulse control will require a wide variety of experimental approaches.

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with long-term gains. These speculations are testable. If we are correct, in previous studies with the traditional design, there should have been a difference between males and females in anticipatory SCRs to the disadvantageous (US$ 100) yellow deck. We encourage researchers to conduct post hoc analyses of their data to determine if our speculations are correct.

There are complex and multiple decisional elements in the Iowa Card Task, as in real-life decisions. Indeed, it is probable that individuals respond differentially to various components of such problems. This fact seems to be reflected in the literature of the Iowa Card Task: some normal participants perform well, some do not (there is always a range of scores); some substance-abusing participants perform well and some do not; and there are sub populations of substance abusers who score differently on variations of the task (Bechara et al., 2002).

In the present paper we demonstrate, but do not fully explain, that there are several subgroups of "normal" participants who perform differently on this laboratory decision-making task: adolescents versus young adults, males versus females. Perhaps a better understanding of individual differences in "normal" populations will lead the way to understanding of why some individuals respond to those elements of decision contexts that lead to personal and societal negative consequences.

We fully agree with Bechara et al. (2002) that a full understanding of the cognitive mechanisms underlying multiple prefrontal mechanisms involved in decision-making and impulse control will require a wide variety of experimental approaches.

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would males. Rather, it appears as if, within the context of this particular task, females and males are responding differently to specific components within the task.

The sex difference on the ICT appeared to be related to differential reactions to the probability of immediate gain or loss. Within the two types of cards, advantageous and disadvantageous, males and females had different response patterns. As shown in Fig. 6, both males and females quickly learned to avoid the disadvantageous (US$ 100) blue deck that had five rather large penalties per 10 trials. Also both males and females quickly learned to choose the advantageous (US$ 50) red deck, that had only one rather small penalty per 10 trials. The sexes differed on choices of the other two decks. Males learned to choose the advantageous (US$ 50) green decks and avoid the disadvantageous (US$ 100) yellow deck, that has one large loss per 10 trials. In contrast, females choose the disadvantageous (US$ 100) yellow cards fairly constantly throughout the task.

Perhaps females were guided by the absolute number of pluses and minuses: maybe they approached pluses and avoided minuses. Stated another way, females perhaps selected cards from decks in which winning had a high ratio pluses to minuses (90% of the time for the yellow and red decks).

If this interpretation is correct, males and females might respond similarly on a version of the Iowa Card Task in which every card had a "+" and a "−". For a pilot study, we constructed a version of the Iowa Card Task in which there were wins (pluses) and losses (minuses) on every card, regardless of being advantageous (red and green) or disadvantageous (yellow and blue). The card values were constructed so that the net outcome of each card in the new-version deck equaled the net outcome of each corresponding card in the regular Iowa Card Task. For example, the 1st blue card in the regular deck was +US$ 100 while the 1st blue card in the new version was +US$ 150, −US$ 50 (both had net outcomes of +US$ 100). The 1st red card in the regular deck was +US$ 50 while the 1st red card in the new version was +US$ 75, −US$ 25 (both had net outcomes of +US$ 50).

Sixty young adults, college students (30 females), were tested on the new version of the Iowa Card Task. The results showed that males and females did not significantly differ in the number of US$ 50 cards (red and green) chosen during the task. Both males and females significantly improved in their performance as training progressed. Thus, by equating the number of plus and minus signs on both advantageous decks, males and females chose equal numbers of advantageous cards during training.

However, despite this manipulation, females still chose significantly more disadvantageous (US$ 100) yellow cards than did males, at least in the last 50 trials of the task. Furthermore, over the course of 200 trials females chose, on average, 57 yellow cards while males chose, on average, 37 yellow cards. This result was unexpected, but an explanation may lie within our speculation about females being attracted to high probability of immediate gain. In the manipulated deck of disadvantageous yellow cards, a subject won US$ 100 on 9 of 10 trials (e.g. +200 −100; +175 −75; +300 −200) and lost US$ 1250 on one of the 10 trials (+100 −1350). In other words, the subject won US$ 100 on 90% of the yellow cards.

In summary, on the modified task, both males and females improved their performance across training and chose an equal number of red and green advantageous decks. In addition, females chose significantly more disadvantageous (US$ 100) yellow decks. Perhaps, we can understand this in the context of studies that have measured anticipatory SCRs. In the original series of Iowa Card Task studies (Bechara et al., 1994, 1997) anticipatory SCRs preceded card choices from the disadvantageous (US$ 100) that which were associated with large amounts of money (gained and lost). These gains and losses were of greater magnitude than that for the advantageous (US$ 50) decks. Tomb et al. (2002) replicated this finding using the original design of the card task. However, when they modified the task so that advantageous decks were associated with higher magnitude of reward and punishment, anticipatory SCRs were greater for the advantageous cards than for disadvantageous decks. Thus, these authors show that anticipatory somatic markers are associated with "higher magnitude decision" cards.

In reply to these findings, Damasio et al. (2002) agree that SCRs can relate to the magnitudes of reward or punishment hidden in the deck from which subjects are about to select. Nevertheless, Damasio et al. (2002) argue that higher SCRs can still guide decision-making regarding long-term consequences and that patients with ventromedial prefrontal damage are impaired whether SCRs are associated with high magnitude advantageous choices or high magnitude disadvantageous choices. In other words, somatic markers can be driven by the immediate act to be performed as well as the long-term consequences of those actions (Damasio et al., 2002).

This multi stage process may provide an explanation for the results of the present study. We found that females were attracted, more than males, to the disadvantageous (US$ 100) yellow deck that was associated with the highest probability of immediate high reward of any deck. Yet, females still showed learning in that they eventually picked more long-term advantageous (US$ 50) cards than disadvantageous cards. We do not see these results as paradoxical.

It is possible that females had emotional associations to two elements of the task, while males had emotional responses primarily to one element of the task. Specifically, perhaps females experienced an emotional response (and attraction) to the disadvantageous (US$ 100) yellow deck because it was associated with the highest magnitude of gains and losses, and a 90% probability of a substantial gain per 10 trials. Perhaps they also experienced an emotional response to the two advantageous (US$ 50) decks because they were associated with long-term gains. In contrast, males may have experienced primarily the second type of response, i.e. emotional responses to the two advantageous decks associated of feedback during a task. Breiter et al. (2001) attribute the lack of orbital prefrontal involvement in the WCST to the lack of emotional salience of feedback in that task as compared with other paradigms such as reception of monetary gains and reception of reward or penalty in tasks not requiring set shifting ((Elliot, Friston, & Dolan, 2000; Zalla et al., 2001). However, during tasks that involve both reversal shifts and monetary loss (that is emotionally salient), the mid-ventral PFC and the lateral orbital prefrontal cortex are active (O'Doughtery et al., 2001).

In addition, in the present study, performance on the WCST was not correlated with the age of the participant. This finding is consistent with WCST norms showing that by about 12 years of age, subjects perform at approximately adult levels on number of categories achieved, number of perseverative errors, and failure to maintain set (Chelune & Baer, 1986).

4.2. Relationship to impulsivity, excitement-seeking and substance use

Our data concerning drug use were similar to those contained in NIDA's Report for the Future (2001). We found increases in alcohol and other drugs from grade 9 to young adulthood. Tobacco use plateaued by grade 10. Also, in agreement with epidemiological data (Report for the Future, 2001) our data revealed low frequency of use until grade 9 after which use increased in grade 12 and young adulthood.

We failed to find significant correlations between ICT performance and measures of impulsivity, excitement-seeking, or use of individual substances. In retrospect, this is not surprising since our subject population contained relatively few heavy substance users. The present study relied on volunteer participants who went to the inconvenience of staying after school. It is probable that students with heavier substance abuse would not, and did not, volunteer for this extra-curricular activity.

However, in agreement with our third hypothesis, there was at least an indication that synergistic properties of drugs (use of alcohol multiplied by use of other drugs) may be related to impairments on the Iowa Card Task in adolescents. Despite, the inclusion of few heavy substance-abusing adolescents in our sample, the synergistic measure accounted for 8% of the variance of performance. For a current review of fMRI studies of orbital prefrontal cortex and substance abuse, see (London, Ernst, Grant Bonson, & Weinstein, 2000).

In our sample of participants, the evidence for a drug effect was tenuous, at best. The important remaining question is whether serious substance-abusing adolescents depart from the pattern of normal decision-making shown in this study. Future research will determine if adolescent substance abusers show different developmental patterns of decision making, as is the case for adult substance abusers versus non-abusers. If this were shown to be the case, the next important step would be to determine if adolescent decision-making could be monitored and changed for the better.

4.3. Sex effect

The present data revealed that adolescent females and males perform differently on the Iowa Card Task. This confirmed our second hypothesis and replicated our previous findings with adults (Reavis & Overman, 2001). Males chose significantly more advantageous (US$ 50) cards and stated the rule earlier and more frequently than did females. In addition, significantly more males than females stated the basic rule of the task, that red and green decks "were advantageous", than did females, and males stated the rues significantly earlier in training (trial 73 on average) than did females (trial 97 on average). This male "superiority" on the Iowa Card Task parallels the male "superiority" we documented in young children on an object reversal task (Overman & Bachevalier, 1999). Because both the Iowa Card Task and the object reversal task depend on the ventromedial prefrontal task, we speculate, as we have done before (Overman & Bachevalier, 1999) that this brain system may be functionally different in males and females early in life, during adolescence, and in young adulthood.

4.4. Possible reasons for sex differences on the Iowa Card Task

There are a number of possible explanations for our finding of sex differences in ICT performance.

First, it is possible that there was simply a difference in math ability. Perhaps, males calculated the net effect of the cards more accurately than females. Studies have shown a male advantage across cultures (Christiansen, 1993; Harnisch, Steinkamp, Tsai, & Walberg, 1998) in certain mathematical domains (Benbow, 1998). However, three factors speak against math ability as the critical factor for the sex differences. At the subjective level, it is difficult to believe that females chose more yellow cards because they could not calculate the simple math (+US$ 100 or +US$ 100–1250). In addition, females did not differ from males in their choice (i.e. avoidance) of disadvantageous (US$ 100) blue cards that required the most complicated math in the task (e.g. +US$ 100–250 or +US$ 100–350). Finally, the results of a pilot study, discussed below, speak against the math-ability hypothesis.

Secondly, it is possible that with regard to future outcomes, males make "better decisions" than do females. This speculation seems fatuous in light of the fact that significantly more males than females are substance abusers in real life (Diagnostic and Statistical Manual of Mental Disorders, 1994; Lex, 1995). If females were inferior decision-makers, in a general sense, there should be more female substance abusers than male substance abusers. We do not interpret the poorer performance by females in this study as an indication that females would make poorer real-life decisions than

Throughout training females continued to choose disadvantageous (US$ 100) yellow cards at a fairly high rate. Fig. 6 and Table 5 also indicate that, as training progressed, males chose significantly more advantageous (US$ 50) green cards than did females (Ryan's Q-test, $P < 0.05$). The disadvantageous (US$ 100) yellow cards had more wins (9) than losses (1) per 10 trials. The advantageous (US$ 50) green cards had an equal number wins (5) and losses (5) per 10 trials; however the magnitudes of the losses were small.

Summary: Females were drawn to advantageous (US$ 50) red and disadvantageous (US$ 100) yellow cards, perhaps because those cards had a high ratio of wins to losses, despite the fact that the yellow yielded long-term losses. In contrast, males were drawn to the advantageous (US$ 50) red and advantageous (US$ 50) green decks (five wins and five losses) perhaps because both decks yielded long-term gains.

3.16. Analysis by card valence: plus versus minus

Choices of the two "minus" cards [disadvantageous (US$ 100) blue and advantageous (US$ 50) green] were compared with choices of the two "plus" cards [disadvantageous (US$ 100) yellow and advantageous (US$ 50) red] across gender and grade. Across training females chose significantly more "plus" cards than did males ($F(7, 426) = 3.78, P < 0.0005$). This was the case in each of the four blocks of training (Ryan's Q-test, P's < 0.05).

3.17. Summary of primary results

(1) Performance, choice of US$ 50 cards, on the Iowa Card Task improved with age during adolescence.
(2) Across age, males chose more advantageous US$ 50 cards than did females.
(3) Reports of individual substance use, impulsivity, and excitement-seeking were not significantly correlated with performance on either task. However, there was some evidence that polydrug use was correlated with decreased performance on the ICT.
(4) Performance on the WCST was not correlated with sex, reported substance use, impulsivity, or excitement-seeking.
(5) With regard to type of cards chosen, females and males had different response patterns. Females tended to choose cards associated with immediate wins as well as net outcome while males tended to choose cards on the basis of net outcome.

4. Discussion

To our knowledge, this is the first demonstration of performance changes on the original Iowa Card Task from early adolescence to adulthood. Hopefully, this characterization in normal adolescents can be used as a base line in future comparisons of substance-abusing or other at-risk adolescents.

In support our first hypothesis, as age increased, male and female adolescents significantly improved their performance on the Iowa Card Task (Fig. 1). Post hoc tests showed that participants in grades 6 and 7 were inferior to participants in grade 9 or higher, those in grade 8 were inferior to those in grade 11 or higher and those in grade 9 and above were equal. We expect that larger samples of participants would have revealed more detailed differences between age groups. To the extent that ICT performance measures sensitivity to future consequences of decisions (Bechara et al., 1997), participants appeared to become more sensitive to future outcomes as age increased. Participants also became more sensitive to future consequences as acquisition progressed within a test session. Learning across blocks of trials showed that during the first 50 trials, participants of all ages differed only slightly in choice of US$ 50 cards. This probably reflected experimentation with card types during initial trials of the task. However, in the second block of 50 trials, it was obvious that older participants improved their performance more than did younger ones, and the same was true in the subsequent blocks of trials. It appeared as if older participants learned both earlier in the task and, to a greater extent, the basic principal that smaller, immediate gains resulted in greater long-term payoffs.

We must be cautious in interpreting the present behavioral data without corroborating information from other methodologies. However, it is tempting to speculate that these age-related improvements on this laboratory decision-making task reflect neuroanatomical and neurochemical maturation of underlying brain systems involving ventral prefrontal areas. It is possible that, as these systems mature during adolescence, they become more efficient in evaluating, predicting, and responding to stimulus saliency in order to guide decisions. The improvement across adolescence on the Iowa Card Task also adds to the existing neuropsychological evidence for improving prefrontal functions during adolescence found by Levin et al. (1991).

4.1. Wisconsin Card Sort Test

In our sample of participants we did not find a significant correlation between performance on the WCST and the ICT task. This agrees with previous reports of separation of the two tasks, e.g. no impairment on the WCST despite impairments on the ICT (Bechara et al., 1994, 1997; Grant et al., 2000). A functional MRI study by Monchi et al. (2001) has revealed relative independence between ORB and other frontal circuits. That study found no involvement of orbital prefrontal cortex during WCST performance. In contrast, four distinct prefrontal and striatal circuits were found to be active during different cognitive stages required in WCST performance. There is evidence (Breiter, Aharon, Kahneman, & Shizgal, 2001) that involvement of orbital prefrontal cortex depends on the degree of emotional salience

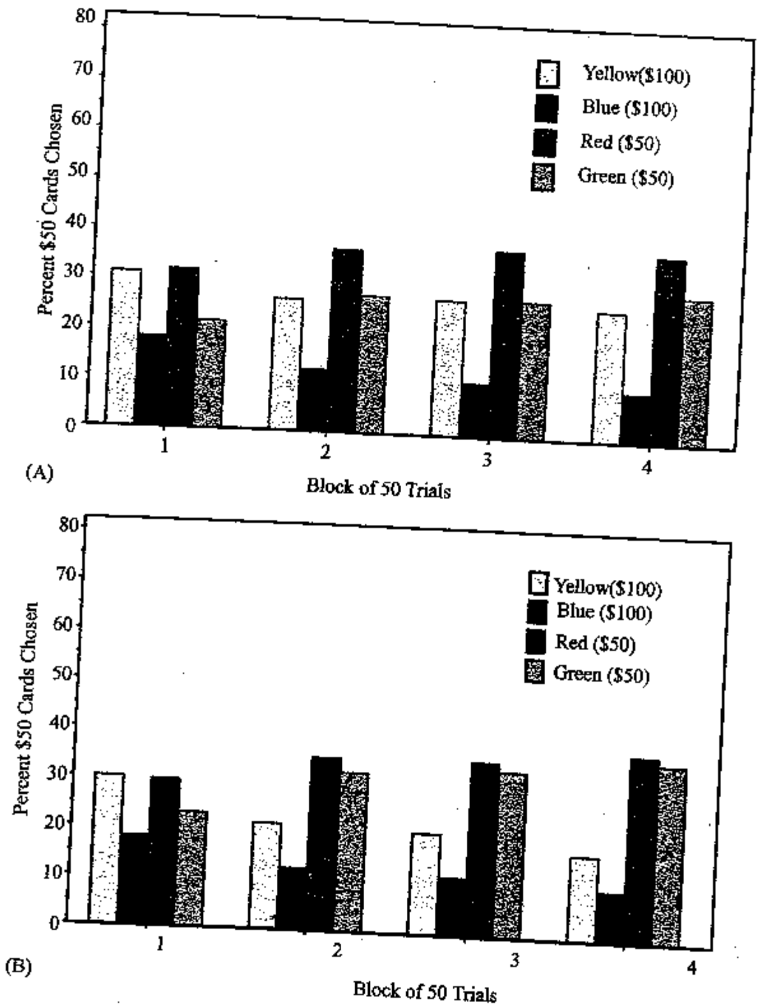

Fig. 6. (A) Average percent of each colored card in four blocks for females (upper graph). (B) Males (lower graph).

card valence (pluses and minuses) revealed significant and interesting similarities and differences between males and females in how they responded to various types of cards. Fig. 6a and b shows female (a) and male (b) responses to card type in each block of 50 trials.

3.14. Females and males have similar response patterns to red and blue cards

As shown in Fig. 6 and Table 5, as training progressed, females and males were statistically equivalent (Ryan's Q-test, $P > 0.05$) in choosing more and more advantageous (US$ 50) red cards and fewer and fewer disadvantageous (US$ 100) blue cards.

The advantageous red cards had many more wins (9) than losses (1) per 10 trials. The disadvantageous blue cards had an equal number of wins (5) and losses (5) per 10 trials, however, the magnitude of the losses were large.

3.15. Females and males have dissimilar response patterns to yellow and green cards

As shown in Fig. 6 and Table 5, as training progressed, males chose significantly fewer disadvantageous (US$ 100) yellow cards than did females (Ryan's Q-test, $P < 0.05$).

Table 5
Selection of each card type by grade, sex, and grade X sex

Yellow (−)	Blue (−)	Red (+)	Green (+)
Grade			
$P < 0.001$ Young > old	$P < 0.011$ Old > young	$P > 0.05$ Young = old	$P < 0.0001$ Old > young
Sex			
$P < 0.001$ Female > male	$P > 0.05$ Female = male	$P > 0.05$ Female = male	$P < 0.0001$ Male > female
Grade X sex			
$P > 0.05$	$P > 0.05$	$P > 0.05$	$P > 0.05$

Table 3
Pearson correlation coefficients probability levels

Blocks of 50 trials	Alcohol	Tobacco	Other drugs	Impulse	Excitement
1	0.458	0.052	0.167	0.166	0.119
2	0.136	0.433	0.251	0.674	0.931
3	0.161	0.583	0.789	0.732	0.389
4	0.067	0.049	0.750	0.348	0.563
Average of 200 trials	0.113	0.134	0.442	0.657	0.421

Criterion alpha level was 0.0009 with correction for multiple correlations.

3.10. Drug interactions and impaired performance on the Iowa Card Task

Clearly there was no evidence that the use of any one drug was correlated with performance on the ICT. However, some researchers have reported impairments on this task in adults who use multiple drugs (Grant et al., 2000). Consequently, we explored our data with several different regression analyses to determine if polydrug use might be related to task performance. The incorporation of tobacco use onto the analyses showed nothing significant. However, operating on evidence that the conjoint use of alcohol and other drugs can have a synergistic or potentiation effect (Levinthal, 1996; Maisto et al., 1999) we found a significant relationship between performance on the ICT and the use of alcohol multiplied by the use of other drugs. For example, a person who reported five drinks a week and two uses of other drugs received a score of 10. As polydrug use increased, performance on the Iowa Card Task significantly decreased ($R^2 = 0.082$). In other words, the drug-use variable in this analysis accounted for 8% of the variance in the Decision-Making Task scores.

3.11. Impulsivity and excitement-seeking

There were no differences between females and males on either measure of impulsivity or excitement-seeking in any grade (Ryan's Q-test, P's > 0.05). Scores on both components of this survey are normed slightly differently for males and females (Costa & McCrae, 1992). Scores can range from very low, to low, to average, to high or to very high. In every grade females and males scored in the average range on the impulsivity measure and in the high range on the excitement-seeking range. As shown in Fig. 5 impulsivity did not increase with age, but excitement-seeking was linearly and positively correlated with age ($r = 0.073$, $P < 0.05$); and this score remained in the high range across all ages.

3.12. Wisconsin Card Sort

No measure of the WCST (percentage of total errors, percentage of perseverative errors, categories completed or

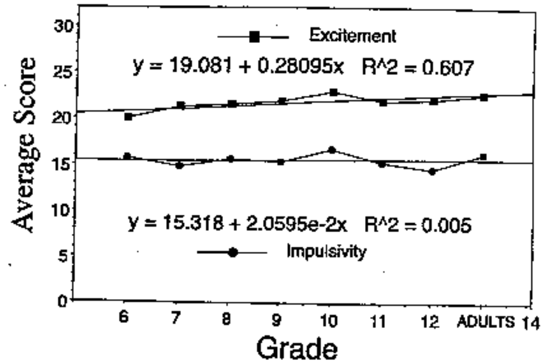

Fig. 5. Average score on excitement and impulsivity surveys as a function of grade.

trials to complete the first category) was significantly correlated with age, sex, performance on the Iowa Card Task, or any measure of substance or impulsivity (Ryan' s Q-test, all P's > 0.05. In addition, unlike performance on the ICT, performance on the WCST was not correlated with age of the participant.

3.13. Additional analyses

There are a number of ways to make an error (choose a US$ 100 card) on the Iowa Card Task. We noted that some subjects appeared to be responding on a basis other than which decks were advantageous or disadvantageous. Thus, performance on the present task was measured in a novel manner. In the Iowa Card task the decks differ on two different dimensions: (1) dollar amount won or lost; and (2) the number of plus ('+') and minus ('−') signs in each color deck. As shown in Table 4, both the advantageous (US$ 50) red deck and the disadvantageous (US$ 100) yellow deck have a high ratio of "wins" (pluses) to " losses" (minuses) per 10 trials. Across 10 trials for either of these decks, there are 9 net wins and 1 net loss. In contrast, both the disadvantageous blue (US$ 100) deck and the advantageous green (US$ 50) deck have an equal number of net wins and losses per 10 trials (5 net wins and 5 net losses). Analysis by

Table 4
Summary of each colored deck with respect to monetary wins and losses, and number of pluses and minuses

	Red (+)	Green (+)	Yellow (−)	Blue (−)
Amount won or lost per 10 trials (US$)	+250	+250	−250	−250
Number of plus card per 10 trials	9	5	9	5
Number of minus cards per 10 trials	1	5	1	5
Number of break-even cards per 10 trials	0	3–5	0	0

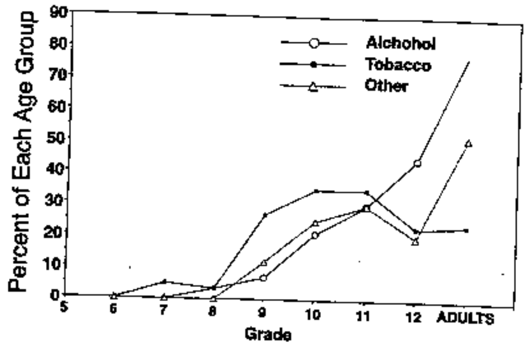

Fig. 3. Percent of each age group reporting use of alcohol, tobacco, or other drugs.

on average on the 73rd trial whereas women stated the rule on the 97th. There was an age effect in rule stating such that stating the correct rule at some point during training increased as age increased.

3.6. Substance use

As shown in Fig. 3, use of alcohol, tobacco, and other drugs was nonexistent or very low through grade 8. From grade 9 to young adulthood the use of alcohol increased steadily. Tobacco use plateaued by grade 10 and the use of other drugs increased steadily from the 9th through young adulthood.

3.7. Frequency of substance use

Fig. 4 shows the average number of reported times participants in each age group used alcohol and tobacco (incidents per week) and "other" drugs (uses per month). Frequency of use was low until grade 9 after which use increased, quite dramatically in grade 12 and in young adulthood.

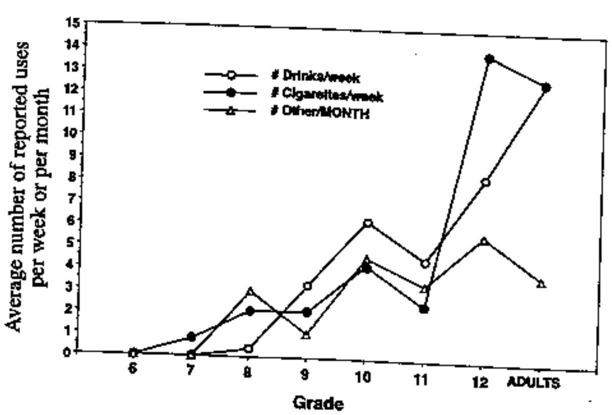

Fig. 4. Average number of reported uses per week (alcohol and tobacco) or per month (other drugs) as function of grade.

Table 2
Percent of heavy substance users by grade

Grade	Alcohol (%)	Tobacco (%)	Other drugs (%)
(6)			
Females	0	0	0
Males	0	0	0
(7)			
Females	0	0	0
Males	0	0	0
(8)			
Females	0	0	0
Males	0	0	0
(9)			
Females	0	0	1
Males	3	0	3
(10)			
Females	0	0	3
Males	13	7	17
(11)			
Females	3	0	7
Males	10	1	17
(12)			
Females	13	7	21
Males	20	7	17
Adults			
Females	20	30	23
Males	60	30	30

Heavy is defined as 5 drinks or more per week, 10 cigarettes or more per week, 1 "other" drug or more per week.

3.8. Heavy substance use

Table 2 shows the percent of each age group who reported "heavy" substance use. We defined "heavy" use as follows: Alcohol, five drinks or more per week (because this number indicates either steady drinking or binge drinking as defined in a number of sources (e.g. Maisto, Galizio, & Connors, 1999) Tobacco, 10 uses or more per week; Other drugs, one use or more per week. None of the participants in grade 6–8 met these criteria.

As shown in this table, heavy substance use was reported less than 10% of the population until grade 10. At each grade, males reported more heavy use than did females.

3.9. Substance use and performance on the Iowa Card Task

Correlations were run between performance on the Iowa Card Task (by the entire subject population) and measures of substance use, impulsivity, and excitement-seeking. Because 25 pair-wise correlations were run, the risk of a Type 1 error was substantial. Therefore, we ran a standard correction for multiple correlations. This generated a criterion alpha level of 0.0009. It is obvious from Table 3 that were no significant correlations within any of the four blocks of training or across all four blocks.

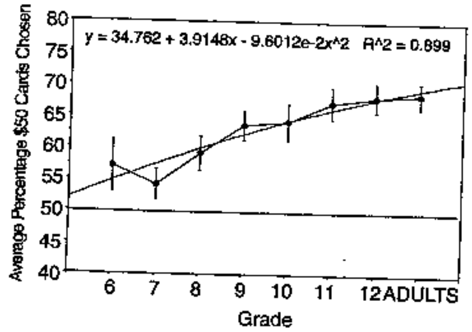

Fig. 1. Average percent of US$ 50 cards chosen as a function of grade. Vertical bars represent standard error of the mean.

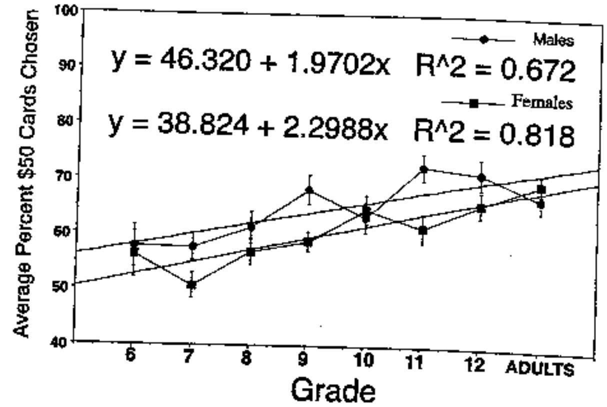

Fig. 2. Average percent of US$ 50 cards chosen as a function of grade and sex. Vertical bars represent standard error of the mean.

green) chosen. Performance was analyzed for grade and sex across all 200 trials and within each block of 50 trials.

3.2. Improvement with age

A 2 (sex) × 8 (grade) ANOVA was conducted across blocks. The ANOVA showed a significant main effect of grade (F (7, 429) = 8.89, $P < 0.0001$) such that participants in lower grades chose significantly fewer US$ 50 cards compared to participants in the higher grades. Fig. 1 shows the overall percentage of US$ 50 cards chosen as a function of grade and sex. The results of post hoc analyses (Ryan's Q-test) are shown in Table 1. This table shows that participants in grades 6 and 7 were inferior to participants in grade 9 or higher. Those in grade 8 were inferior to participants in grade 11 or higher. Participants in grade 9 and higher were statistically equivalent with each other.

3.3. Males outscore females

The ANOVA also showed a significant effect of sex (F (1, 429) = 14.40, $P = 0.0002$) such that males chose significantly more US$ 50 cards than females (Fig. 2). The sex × grade interaction was not significant (F (7, 429) = 1.84, P = 0.0776). Post hoc analysis showed significant sex differences in the 7th, 9th, 11th, and 12th grades (all P's < 0.05).

3.4. Learning across blocks of trials

A 4 (block) × 2 (sex) ANOVA was conducted across grades. There was a significant effect of block (F (3, 429) = 76.67, $P = 0.0001$) such that choice of US$ 50 cards increased across the test session. Post hoc (Ryan's Q-tests) analyses showed that choice of US$ 50 cards in block 1 was lower compared to all other blocks ($P < 0.05$) while percentage of US$ 50 cards chosen in blocks 2 and 3 did not differ ($P > 0.05$), those means were significantly lower than the mean in Block 4 ($P < 0.05$). There was a significant effect of grade in every block such that participants in younger grades chose fewer US$ 50 cards than did participants in older grades (all P's < 0.0007). There was a significant effect of sex in every block except the first one (trials 1–50) such than males choose more US$ 50 cards than did females (all P's < 0.011). The Grade × sex interaction was significant only in Block 2 (trials 51–100) (F (7, 435) = 2.68, P = 0.0099).

3.5. Rule stating data

Significantly more adolescent males stated the correct rule than did females (Ryan's Q-test, $P < 0.05$). Males also stated the rule significantly earlier in training than did females (Ryan's Q-test, $P < 0.05$). On average, males stated the rule

Table 1
Significant differences between age groups on the Iowa Card Task

Grade	6	7	8	9	10	11	12	Adult
6	–	–	–	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$
7	–	–	–	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$
8	–	–		–	–	$P < 0.05$	$P < 0.05$	$P < 0.05$
9	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–
Adult	–	–	–	–	–	–	–	–

participants were given oral instructions as published previously (Reavis & Overman, 2001). No other information about the task was given to the subject. During the task, choice of US$ 50 cards resulted in small gains but very small losses while choice of US$ 100 cards resulted in large gains, but even greater long-term losses. Thus, if a player consistently chose the US$ 50 cards, he/she won more than he/she lost. But if US$ 100 cards were consistently chosen, he/she lost more than he/she won. The predetermined win–lose schedule was arranged so that after drawing 10 cards from a deck the player would have won US$ 250 for picking advantageous red or green cards and would have lost US$ 250 for picking disadvantageous blue or yellow cards (Bechara et al., 1997). For each deck, groups of 10 cards were pseudorandomly prearranged so that wins and losses could not be predicted at any time in the task. In order to compare the present results with previous results from adults, we used the identical prearranged sequence as used previously with adults (Bechara et al., 1997; Reavis & Overman, 2001). At the end of each block of 10 trials, the experimenter asked the participant "which do you think are the two good decks?" The experimenter wrote down the response.

2.4. Wisconsin Card Sort Task

The computerized WCST was administered following completion of the ICT. The participants heard the following instructions:

> This task is a little unusual because I am not allowed to tell you very much about how you do it. You will be asked to match each of the response cards at the bottom of the computer screen to one of the four stimulus cards at the top of the screen. I cannot tell you how to match the cards, but the computer will tell you each time if your are correct or incorrect. If you are incorrect go on, and try to get then next one correct. There is no time limit. You may begin.

No other information about the task was given to the participant. During the task, the subject was asked to match each response card to one of the four stimulus cards either by form (cross, circle, triangle, or star), color (red, blue, yellow, or green), or number of figures (one, two, three, or four). The subject was not told the correct sorting principle, but only if their response was correct or incorrect. The participant was required, but not told, to match the cards by color, then by form, and next by number of figures. The subject had to match ten correct, consecutive cards before the sorting principle shifted without warning. The tasks continued among the three sorting principles until the criterion was met or until the subject had selected 128 cards. Performance was measured by the percentage of total errors, the percentage of perseverative errors, number of categories completed, and the number of trials to complete the first category.

2.5. Impulsivity and excitement-seeking assessments

Immediately following the WCST, each participant completed a survey of self-reported impulsivity and excitement-seeking. The survey consisted of 24 items adapted from the Neuroticism, Extraversion, and Openness (NEO) Personality Inventory (Costa & McCrae, 1992). The survey contained 3 types of items, 8 each appearing in random order in a list of 24 items. The participant rated each statement on a five-point scale ranging from "strongly agree" to "strongly disagree". The first type was from the Impulsivity subscale, and two typical items were: "I have trouble resisting my cravings" and "Sometimes I do things on impulse that I later regret". The second type of statement was from the excitement-seeking subscale, and two examples were: "Most people I know like me" and "I tend to avoid movies that are shocking or scary". The third type of statement was neutral, and two examples were: " I enjoy talking to people" and " I enjoy solving puzzles or problems". Impulsivity scores were combined with excitement-seeking score for a final score.

2.6. Assessment of substance use

As a last requirement in the test session, the participant completed an age-adapted Quantity–Frequency Index of Substance Use (Polich, Armor, & Braiker, 1981). Before the subject began, he/she was assured that the information that they provided would be kept confidential and that they would be identified by a predetermined subject number, not by name. The questionnaire asked about the use of tobacco, alcohol, marijuana, cocaine, ecstasy and "other" drugs. The survey asked for the frequency and amount of a given substance used in the previous 3 months. The same scoring system was used to generate a "use" score for each substance. If, for example, an individual reported the use of tobacco one to 3 days per month, the person received a frequency score of 2. If he/she reported that they had smoked one to two cigarettes on each occasion, the person received a quantity score of 2. The two scores were then multiplied to result in a final tobacco score of 4. The alcohol survey was comprised of a combination of use of beer, wine, and hard liquor. The combined alcohol score was scored as tobacco use was scored.

While not timed, there were no noticeable differences in session length for any age group or sex group.

3. Results

3.1. Iowa Card Task

As in previous studies (e.g. Bechara et al., 1997; Reavis & Overman, 2001) the measure of performance on the ICT was the percentage of US$ 50 (advantageous cards red and

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:ely than the comparison
:ageous deck. This study
ıe age of 14 years or any

Task performance was
›lescents (17 males, 14
ıd 14 years), 33 adoles-
behavior disorders (30
›f 12 and 24 years), and
e abusing ($n = 22$) and
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vior disordered adoles-
d not report an analysis
ver the age of 14 years.

From these previous studies adolescent and the Iowa Card Task, nothing is known about the relative performance of males and females, or the performance of subjects over the age of 14 years.

1.8. Summary of background and present study

From the review above, six points are clear: (1) for some individuals, adolescence is a period of poor decision-making and risky behaviors; (2) adolescence is a period of significant brain changes, notably in the balance between prefrontal motivational and cognitive systems; (3) males and females differ in patterns of adolescent brain reorganization; (4) one area of PFC, the ventromedial prefrontal cortex, when dysfunctional in adults, leads to poor decision-making and risky behaviors; (5) the Iowa Card Task is sensitive to ventromedial prefrontal dysfunction; and (6) the Iowa Card Task has not been administered to male and female adolescents on a systematic basis.

In the present study, we tested adolescents ranging in age from 11 to 18 years and a group of adults on the Iowa Card Task and the Wisconsin Card Sorting Task. The WCST was administered because the clinical populations listed above Bechara et al., 1994, 1997; Grant et al., 2000) perform normally on this task of executive functioning. Normal performance on the WCST, plus impaired performance on the Iowa Card Task, suggests localized dysfunction (ventromedial prefrontal system) rather than dysfunction of other frontal circuits such as mid-ventrolateral and mid-dorsolateral areas. These areas differentially participate in different processing stages when performing the WCST task (Monchi et al., 2001). Because of reported associations between performance on the Iowa Card task and substance abuse Bechara et al., 2002; Grant et al., 2000) and between adolescent brain changes and impulsivity/risk-taking (Spear, 2000), the present participants were also given assessments of substance abuse, impulsivity, and excitement-seeking.

1.9. Hypotheses

The information reviewed above leads us to three hypotheses. First, across adolescent years, subjects should become more proficient on the Iowa Card Task. Specifically, they should become guided less by "emotional" temptation for immediate gain and more by "cognitive" realizations of gradual and long-term gain. This should be reflected by age-related increases in selection of US$ 50 cards and should result in long-term gain. Secondly, based on the fact that adult males and females differ on the Iowa Card Task (Reavis & Overman, 2001) plus the evidence for sexual dimorphism in adolescent brain changes, there should be a difference between males and females in performance on the Iowa Card Task in adolescence. Finally, as in the case of substance-abusing adults (Grant et al., 2000) adolescents who routinely abuse drugs should be impaired on the Iowa Card Task relative to non-abusing adolescents.

2. Methods

2.1. Participants

A total of 420 adolescents participated in this study: 30 females and 30 males in each of the grades 6–12 (ages 11–18 years). Data from some participants could not be used due to computer malfunctions or participant noncompliance. Thus, for the grades 6, 8 and 9, the number of subjects was reduced (6th grade, 18 females, 17 males; 8th grade 29 females, 28 males; 9th grade 29 females, 30 males). Adolescent participants were tested one at a time at their school in the afternoon after classes. Both child and parent gave written consent for participation. Adolescent participants received movie passes and a gift certificate for use at a local music store. A total of 60 (30 females and 30 males) young adults also participated. These participants selected this study as part of a research requirement for the general psychology courses at UNC-Wilmington. They were tested, individually, at the University at either 10:00 or 11:30 a.m. These participants ranged in age from 17 to 23 years and their average age was 20.1 years.

2.2. Procedure

The study was approved by the UNC-W Institutional Review Board. Each participant was individually administered (in the following order) the Iowa Card Task, the Wisconsin Card Sort Task, an impulsivity survey, excitement-seeking survey, and a quantity-frequency-of-use substance-use inventory.

2.3. Iowa Card Task

The procedure for this task was the same as used before in our laboratory (Reavis & Overman, 2001) except that in the present study, the task consisted of 200 trials rather than 150 [earlier studies, e.g. Bechara et al., 1994, 1997]. We used additional trials because we suspected that our youngest participants might require more acquisition trials than adults who were tested previously.

The four decks were differentiated by color. The experimenter mimicked each of the participant's card choice by selecting a corresponding card on a computer screen. For each choice, there was a computer animation of "cash chips" being added or subtracted as per the participant's choice. As in our previous studies (Reavis & Overman, 2001), we used color designation for the decks because our pilot studies showed that color names, rather than letter names, were easier for the experimenter to attend to and mimic the participant's choice and vocalizations. Prior to testing, participants were asked if they were color blind, and none said they were. Next, they were asked to point to each of the decks and name the color. During the entire task, the subject named the color of the card being chosen. All of the participants were accurate in naming colors. The hood and adolescence up to at least 22 years of age (Caviness et al., 1996; Geidd et al., 1999; Jernigan et al., 1991; Pfefferbaum et al., 1994; Rajapakse et al., 1996).

1.5. Neurochemical maturation during adolescence

Neurotransmitter systems also undergo significant alterations during adolescence. These include dopamanergic, serotonergic, glutamate and GABA circuits in humans and animals (for review see Spear, 2000). Changes in mesocorticolimbic brain regions are especially relevant for the present research, because these areas form part of the circuitry implicated in reward processes, assessing stimulus values, and translating motivational stimuli into adaptive behavior. Spear (2000) speculates that shifts in balance between mesocortical and mesolimbic circuitry during adolescence are related to a number of outcomes including responses to stressors, reward deficiency syndrome, mood disturbances, adolescent anhedonia which, in turn, may be related to behaviors such as novelty-seeking, risk-taking and propensity for drug use.

1.6. Neuropsychological implications of adolescent brain development

Adolescent synapse proliferation and elimination undoubtedly have neuropsychological consequences, particularly for functions of the prefrontal cortex. During adolescence performance improves on several tasks that measure frontal function. Levin, Culhane, Hartmann, Evankovitch, and Mattson (1991) administered a battery of tests that measure frontal lobe functioning to three groups of children: (a) 7–8-years of age; (b) 9–12 years of age; and (c) 13–15 years of age. The tests included the Wisconsin Card Sorting Task (WCST), California Verbal Learning Test—Child Version (CVLT), Word Fluency (WF), Animal Naming and Design Fluency, 20 Questions Task, Tower of London, Delayed Alternation and Go-No Go Task. Significant developmental improvements were found on all tests except the Delayed Alternation Task. Presumably, improvements on these tasks were related to neuroanatomical and neurochemical remodeling during late childhood and early adolescence.

There is more direct evidence that age-related brain changes are correlated with cognitive indices during these ontogenetic periods. Thinning of frontal cortical gray matter has been associated with increasing performance on delayed verbal memory tests in participants between the age of 7 and 16 years (Yurgelun-Todd, Killgore, & Young, 2002). Reiss et al. (1996) found that greater total cerebral volume and cortical gray matter, in particular, was associated with higher scores on a standard measure of intellectual ability. The volume of prefrontal cortex in adolescents has been associated with greater ability to inhibit behavioral response (Casey et al., 1997). Yurgelun-Todd et al. (2002) also found that, in healthy adolescents (13–17 years of age), cognitive performance was significantly associated with proportional volumes of white matter, gray matter and cerebral spinal fluid.

In a provocative and preliminary fMRI-based report, Yurgelun-Todd (1998) reported differences between adolescents and adults in brain systems that are involved in identification of emotional states from facial expressions. Adolescent participants exhibited greater amygdala activity while adult participants exhibited greater activity in the frontal lobes. The author speculates that the adolescents may be responding with more of an emotional reaction than an executive or cognitive reaction (Yurgelun-Todd, 1998). In a more recent fMRI study from that laboratory (Killgore, Oki, & Yurgelun-Todd, 2001) male and female children and adolescents differed in pattern of amygdala versus prefrontal activation while viewing photographs of faces expressing fear. With increasing age, females, but not males, progressively increased in prefrontal activation relative to amygdala activation in the left hemisphere. Taken together these studies indicate that there are changes during adolescence in prefrontal systems involved with executive and motivational processes.

1.7. Performance of adolescents on the Iowa Card Task

To our knowledge, there are two reports of testing adolescents on the original Iowa Card Task. In one study, the performance of a small group ($n = 23$) of young, normal boys (10 years and 5 months to 13 years 9 months) was compared with a small group ($n = 20$) of boys (9 years 8 months to 16 years) diagnosed with psychopathic tendencies (Blair, 2001). There was an overall effect of age such that, as compared to younger participants, older participants were more likely to avoid disadvantageous decks in the last block of training. In addition, boys with psychopathic tendencies were more likely than the comparison group to choose from the disadvantageous deck. This study did not test healthy males beyond the age of 14 years or any females.

In the second study, Iowa Card Task performance was compared between 31 healthy adolescents (17 males, 14 females between the ages of 12 and 14 years), 33 adolescents diagnosed with externalizing behavior disorders (30 males, 2 females between the ages of 12 and 24 years), and two groups of adults: non-substance abusing ($n = 22$) and poly-substance-abusing ($n = 30$) (Ernst et al., 2003). Adults with substance abuse were impaired relative to healthy adults during early stages of the task. Performance was similar in healthy adolescents and healthy adults. Healthy and behavior-disordered adolescents were equal in performance on the first administration of the task, but not on a second administration 1 week later. On the second administration, healthy adolescents improved their performance as compared to the first test, but the behavior disordered adolescents did not improve. This study did not report an analysis by sex and did not test adolescents over the age of 14 years.

formance among normal participants who are depleted of tryptophan.

Individuals in these identified groups make maladaptive decisions not only on these tasks but also in their personal lives. These individuals continue to make poor decisions despite long-term negative personal consequences.

1.2. Prefrontal cortex and decision making

In recent years, neuroimaging studies and decision-making experiments have provided new insights about prefrontal cortical systems and their relative roles in goal-directed behavior. A major goal has been to elucidate the relationship between executive processes and motivational processes in goal-directed actions. Recent fMRI data indicate that emotion/reward valuation circuits in the ventromedial prefrontal areas are linked to more cognitive circuits by a system that involves ventromedial prefrontal cortex, dorsolateral prefrontal cortex and lateral frontopolar areas (Monchi, Petrides, Petre, Worsley, & Dagher, 2001; O'Doughtery, Kringelbach, Rolls, Hornak, & Andrews, 2001). The ventromedial prefrontal areas appear to provide the dorsal and lateral prefrontal areas with information that is associated with contextual values of a task. Humans, monkeys and rats with damage to ventromedial cortex and amygdala are impaired in their ability to use information about positive and negative outcomes that is needed to efficiently guide their behavior, i.e. make good decisions (Baxter, Parker, Linder, Izquierdo & Murray, 2000).

One well-known perspective of ventromedial prefrontal cortex function is the somatic marker hypothesis (Bechara et al., 1997; Damasio, 1994; Damasio, Bechara, & Damasio, 2002). In this system "somatic markers" are anticipatory emotional feelings that gradually come to be connected, by learning, to predicted outcomes. These emotional markers, measured by skin conductance responses (SCRs), are thought to act as an "early warning system" that eventually guides decisional behavior. Poor performance on the Iowa Card Task is thought to represent a deficit in this warning system. The deficit may result in "myopia" for future consequences similar to that observed in substance addicts and other populations that engage in poor real-life decisions (Bechara, Dolan, & Hindes, 2002).

A recent study by Tomb, Hauser, Deldin, and Caramazza (2002), reported that, during the Iowa Card Task, anticipatory SCRs were related to the valence of the immediate act to be performed, not to the long-term value of the decision. Thus, by changing the values of advantageous and disadvantageous cards (in their study the advantageous cards contained very high reward and high losses), Tomb et al. (2002) found that anticipatory SCRs came to precede choice of advantageous cards, not disadvantageous cards as in Bechara and Damasio's studies (e.g. Bechara et al., 1997). In reply, Damasio et al. (2002) suggest that SCRs can relate to the magnitude of reward or punishment inherent in the decision-making task.

Regardless of the exact operations, it is clear that ventromedial prefrontal areas, together with other areas, e.g. the striatum, play an indispensable role in processing reward, including evaluation, prediction, anticipation and response to reward in order to guide behavioral decisions (Montague & Berns, 2002).

1.3. Poor real-life decision making in adolescents

In addition to the populations listed above, adolescents, as a group, exhibit a disproportionate amount of poor decisions that result in reckless behavior, sensation-seeking, and risk-taking (Arnett, 1992; Moffitt, 1993; Spear, 2000). This experimentation may involve health-damaging behaviors including substance use, precocious or risky sexual behavior, risky vehicle use, eating disorders, homicidal and suicidal behavior (Igra & Irwin, 1996). Obviously, not all adolescents engage in risk-taking behaviors, but among those who do, engaging in one risky behavior increases the probability of engaging in others (Dryfoos, 1991). Interestingly, and perhaps not coincidently, the adolescent period of heightened poor decision-making overlaps a period of significant brain remodeling as described below.

1.4. Neuroanatomical maturation during adolescence

During the second decade of life, the human brain undergoes extensive neuroanatomical and neurochemical remodeling (Casey, Giedd, & Thomas, 2000; Caviness, Kennedy, Richelme, Rademacher, & Filipek, 1996; Durston et al., 2001; Giedd et al., 1999; Pfefferbaum et al., 1994; Rajapakse et al., 1996; Reiss, Abrams, Singer, Ross, & Denkla, 1996; Sowell, Delis, Stiles, & Jernigan, 2001; Spear, 2000). MRI-based studies reveal significant increases in cortical gray matter in early adolescence followed by significant decreases in later adolescence. (Geidd et al., 1999). These gray matter changes are nonlinear and regionally specific. MRI studies show that frontal lobes attain peak volume (that precede declines) around 12.1 years in males and 11.0 years in females. Gray matter in parietal lobe attains maximum size around age 11.8 years in males and 10.2 years in females, followed by a decline in both sexes (Caviness et al., 1996; Giedd et al., 1996, 1999). Gray matter in temporal lobe reaches maximum size at 16.5 years in males and 16.7 years in females with a slight decline thereafter. In every case, the increases and decreases are less for females than for males (Giedd, Castellanos, Rajapakse, Viatuzis, & Rapoport, 1997; Giedd et al., 1999). The rise and fall of cortical volume is thought to reflect synapse overproduction followed by synapse elimination or pruning. The magnitude of this synapse loss may be extremely large. Rakic, Bourgeois, and Goldman-Rakic (1994) have estimated that, in monkey brain, up to 30,000 synapses are lost per second over the entire cortex during the pubertal/adolescent period.

In contrast to post-adolescent decreases in gray matter, cerebral white matter increases linearly throughout child-

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Performance on the IOWA card task by adolescents and adults

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Abstract

Performance on the Iowa Card Task (ICT) is impaired in several populations that demonstrate poor decision-making and risk-taking including patients with damage to the ventromedial prefrontal cortex. For some individuals, adolescence is a period of poor decision-making and risk-taking. Adolescence is also a period of neuroanatomic and neurochemical remodeling. There is evidence that neuropsychological functions of the prefrontal cortex change during adolescence; however, decision-making, as measured by the ICT, has not been systematically studied in adolescents over the age of 14 years.

In the present study, 60 participants (30 female) in each of grades 6–12, and 60 young adults were administered the Iowa Card Task, the Wisconsin Card Sorting Task (WCST), a survey of impulsivity and excitement-seeking, and a quantity-frequency index of substance use.

Results showed significant and steady improvement on the Iowa Card Task from the 6th grade to adulthood. Performance on the Iowa Card Task was not correlated with measures of impulsivity, excitement-seeking or reported individual substance use. There was one indication that poly-substance use was negatively correlated with performance on the ICT. Performance on the WCST was not significantly correlated with performance on the Iowa Card Task or any other measure. Across age, males and females had a different response pattern on the ICT. Females tended to choose cards associated with both immediate wins and with long-term outcome. Males tended to choose on the basis of long-term outcome. Results are discussed in terms of adolescent brain development and decision-making differences between males and females.

Keywords: Decision making; Sex differences; Development

1. Introduction

1.1. Iowa Card Task assessment of decision-making

The Iowa Card Task (ICT) has been widely used with clinical and normal populations to assess decision-making processes (Bechara & Damasio, 2002; Bechara, Damasio, Damasio & Lee, 1999; Bechara, Damasio, Tranel & Damasio, 1997). This task requires the participant to choose cards from four decks. Cards in two of the decks are associated with low reward but even lower sporadic loss of reward (advantageous decks). Cards in the other two decks are associated with high reward but with even higher sporadic losses (disadvantageous decks). Consistent choice of advantageous cards results in long-term gain, whereas consistent choice of disadvantageous cards results in long-term loss of money. Over the course of 100–200 trials, normal control participants formulate the strategy of picking from the low-paying (advantageous) decks, which results in gain in the long run.

In contrast, the following groups show impaired performance, as defined by the continued selection of cards from the high-paying (disadvantageous) decks, resulting in loss in the long run: (a) patients with damage centered on the ventromedial prefrontal cortex (Bechara, Damasio, Damasio, & Anderson, 1994; Bechara et al., 1997); polysubstance abusers (stimulants or opioids) (Grant et al., 2000); cocaine abusers (versus abstinent cocaine abusers and non abusers (Bartzokis et al., 2000); alcohol abusers (Mazas, Finn, & Steinmetz, 2000); opiate abusers (Petry, Bickel, & Arnett, 1998); violent offenders versus non violent offenders (Fishbein, 2000); pathological gamblers (Cavedini, Riboldi, Keller, D'Annucci, & Bellodi, 2002b); and patients with obsessive–compulsive disorder (Cavedini et al., 2002a). Patients in the first three studies above were tested on the Wisconsin Card Sorting Task (WCST) and performed normally (Bechara et al., 1994, 1997; Grant et al., 2000). In addition, using a somewhat different decision-making task Rogers et al. (1999) have discovered impaired per-

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