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Affective decision-making deficits, linked to a dysfunctional ventromedial prefrontal cortex, revealed in 10th-grade Chinese adolescent smokers

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Abstract

This study addressed the question of whether poor decision making would be associated with adolescent *past 7-day* smoking. We conducted a cross-sectional study of 208 10th-grade adolescents in Chengdu City, China. We used the Iowa Gambling Task (IGT) to assess decision-making, and the Self-ordered Pointing Task (SOPT) to assess working memory capacity. Paper and pencil questionnaires assessed the school academic performance (SAP) and smoking variables. The results showed that a significantly higher proportion of *past 7-day* smokers (91.7%) were susceptible to future smoking and cigarette offers from best friends compared to other levels of smokers (*never*, *ever* and *past 30-day* smokers). Consistent with these behavioral data, the neuropsychological assessments revealed that relative to *never* smokers, *past 7-day* adolescent smokers (but not *ever* smokers or *past 30-day* smokers) demonstrated significantly lower scores on the IGT. Moreover, a higher proportion of *past 7-day* smokers (91.7%) performed poorly (no more than an overall net score of 10) on the IGT than nonsmokers and irregular (*ever* or *past 30-day*) smokers (about 65.3%). There were no differences on working memory performance for smokers (at any level) compared to *never* smokers after adjusting for school-type. In addition, logistic regression showed that the IGT significantly predicted *past 7-day* smoking after controlling for the working memory, school academic performance and demographic variables. These results suggest that poor affective decision making might predispose some adolescents to smoking in the future or in the social situations where their peers are smoking. Intervention targeting affective decision making might hold promise for reducing adolescents' risks for substance use.

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Introduction

While much of the research on risk factors for adolescent substance abuse has focused on psychosocial influences, several recent studies have consistently demonstrated that higher levels of neurobehavioral disinhibition pose a significant risk for the development of substance use disorders (Dinn, Aycicegi, & Harris, 2004; Knyazev, 2004; Tarter, Kirisci, Habeych, Reynolds, & Vanyukov, 2004). There are several different kinds of inhibitory functions which engage distinct neural substrates in the brain. For instance, affective decision-making, decision-making that requires appraisal of the emotional and motivational significance of stimuli (e.g., their potential for rewards or punishments), relies on the orbital prefrontal cortex/ventromedial prefrontal cortex (OFC/VMPC)-related circuitry, whereas working memory, the ability to maintain and manipulate information in an active state especially in the presence of interference, engages the Dorsolateral Prefrontal Cortex (DLPC)-related system (Damasio, 1994; Funahashi, 2006). Abnormalities in either of these neural systems may predispose adolescents to substance abuse. The primary goal of this study was to investigate whether poor inhibitory functions such as poor decision-making and/or working memory would predict *past 7-day* (more than experimental) cigarette smoking in adolescents. Specifically, we tested the hypothesis that poor decision-making as measured by the Iowa Gambling Task (IGT), which is indicative of neurologically-based deficits, would be associated with *past 7-day* cigarette smoking.

Numerous studies have demonstrated that impaired decision-making contributes to the loss of control contributing to substance abuse (Bechara & Damasio, 2002; Grant, Contoreggi, & London, 2000; Rogers et al., 1999). Some drug addicts and patients with bilateral OFC/VMPC damage share similar decision-making deficits in both the IGT performance and real-life behaviors: both prefer choices that bring immediate benefit, even if these choices are coupled with negative future consequences. However, decision-making has been shown to depend highly on other brain systems for working memory and on systems for affect/emotion (Bechara, 2001; Ernst et al., 2002). Indeed, several lines of evidence have shown that the OFC/VMPC plays a critical role in coupling (1) “cold” cognitive systems, such as working memory and other general cognitive functions, which is dependent on DLPC systems, and (2) “hot” affective and emotional systems, such as the mesolimbic reward system, which assigns affective/emotional value to individual experiences associated with reward and punishment (Bechara & Martin, 2004; Beer, John, Scabini, & Knight, 2006; Fellows & Farah, 2005a; Oya et al., 2005). Therefore, decrements in or under-development of any of these systems may lead to a compromise in the ability to make decisions that are advantageous in the long run. Thus, in addition to investigating the relationship between decision-making and substance use (tobacco use in the case of this study), we sought to study working memory as a contributor to poor decision making and smoking in adolescents.

Previous research shows clearly that smoking in adolescence predicts higher smoking rates in adulthood and more difficulty in quitting (Breslau, Fenn, & Peterson, 1993; Pierce & Gilpin, 1996). Moreover, cigarette use is often implicated as a “gateway” for subsequent abuse of alcohol and illicit drugs. Those who have smoked cigarettes are far more likely to progress to other substances of abuse such as cocaine, heroin, crack and marijuana in their later life compared to non-smokers (Johnson, Boles, & Kleber, 2000). However, it is a paradox that adolescent smokers typically acknowledge the high probability of profound health hazards associated with tobacco use, yet this abstract understanding fails to generate avoidance behavior (Cauffman & Steinberg, 2000). Indeed, much evidence confirms that adolescent smoking is largely a non-rational decision and non-planned behavior (Kremers, Mudde, & de Vries, 2004; Kremers, Mudde, de Vries, Brug, & de Vries, 2004). It is noteworthy that prevention interventions based on the assumption of rational decision processes have met with only limited success (Faggiano et al., 2005; Peterson, Kealey, Mann, Marek, & Sarason, 2000). One explanation is that some of the processes underlying smoking are supported by both non-rational and rational neurobiological systems, and that an imbalance in these systems can readily lead to non-optimal decisions (Bechara, 2005). Use of assessments that measure the functioning of these systems may provide new insights about the correlates and potential precursors of adolescent smoking as well as inform future prevention interventions.

In the present study, we used the Iowa Gambling Task (IGT) to measure decision-making. This task has been shown to tax aspects of decision-making that are guided by affect and emotions (Bechara, 2003; Turnbull, Evans, Bunce, Carzolio, & O'Connor, 2005). Compared to other tasks, which assess brain functions related to the calculation of probability or expected value, IGT requires participants to learn and infer from their past experience (such as reward and punishment encountered during the task) about outcome probabilities (Bechara, 2004). Affective and emotional systems play a critical role in such learning processes. The decision making of neurologically developed and intact participants is guided by emotional signals that assign negative value for the disadvantageous choices and positive value for advantageous choices, thereby leading behavior towards long-term favorable options. Several developmental studies have demonstrated that there is significant and steady improvement on the IGT- or IGT-analogous tasks during early adolescents to adulthood (Crone & Van Der Molen, 2004; Hooper, Luciana, Conklin, & Yarger, 2004; Kerr & Zelazo, 2004; Overman, 2004). These findings parallel other studies which show that the prefrontal cortex may not develop fully until the age of 21 (Giedd, 2004; Gogtay et al., 2004). Thus, the immature decision-making ability might render some adolescents more prone to substance use than others.

To tax the function of working memory capacity, we used the Self-ordered Pointing Test (SOPT) (Peterson, Pihl, Higgins, & Lee, 2002). In each trial, this task requires an individual to memorize a maximum number of 12 items, either visually or phonologically encoded, and hold them "online" for further operations. Because there are six trials of the SOPT, the maximum capacity is not required in the first trial but the amount of information increases cumulatively over the course of each trial. This process resembles that of transient online storage (Perry, 2001), or active monitoring and retrieving of the increasing amount of information (Petrides, 1995) in the concept of working memory. This task has been linked to neural activity within the DLPC (Petrides, Alivisatos, Meyer, & Evans, 1993), and has been used to assess working memory function in several studies (Chaytor & Schmitter-Edgecombe, 2004; Ward, Shum, McKinlay, Baker-Tweney, & Wallace, 2005). In addition, studies have shown that working memory is highly related to other general cognitive functions such as reading, mathematics and reasoning (Colom, Rebello, Palacios, Juan-Espinosa, & Kyllonen, 2004; Engle, Cantor, & Carullo, 1992; Jarrold & Towse, 2006). Therefore, we also asked the participants to report their school academic performance (SAP).

Researchers have conceptualized adolescent smoking as progressing through a sequence of developmental stages ranging from never smoking, tried smoking, experimenting, regular smoking to established/daily smoking and dependence (Mayhew, Flay, & Mott, 2000). In previous studies, those who reported smoking cigarettes in the past week were defined as regular users (Brook, Morojele, Brook, Zhang, & Whiteman, 2006; Flay, Hu, & Richardson, 1998; Sanderson Cox, Feng, Canar, McGlinchey Ford, & Tercyak, 2005). At this stage, adolescents have progressed beyond experimental (30-day) smoking to smoking on at least a fairly regular basis, but this falls well short of addictive smoking as indicated by multiple cigarettes smoked frequently at regular intervals throughout the day, beginning generally within 30 minutes after awakening in the morning (Fagerström & Schneider, 1989; Flay et al., 1998; Heatherton, Kozlowski, Frecker, & Fagerström, 1991). Although many experimental or even some regular smokers may not become established/daily smokers, as a group, a sizable percentage of the *past 7-day* smokers may move on to become established/daily smokers. In a large-scale longitudinal China Seven Cities Study (Johnson et al., 2006), the odds ratio of

12th grade daily smoking (smoked every day in past month) was 17.32 for 10th-grade *past 7-day* smokers relative to 10th-grade *never* smokers, compared to 3.99 for 10th-grade *ever* smokers and 14.06 for *past 30-days* smokers (unpublished data). Based on those previous studies, we therefore conclude that susceptibility to future regular and potentially addictive smoking as predicted by *past 7-day* smoking would be more susceptible to future smoking, and more vulnerable to progression to addictive levels of smoking compared to other smokers.

Since *past 7-day* smoking would be a suitable indicator of early transition to established/daily or poorly controlled smoking, our primary hypothesis was that *past 7-day* adolescent smokers would demonstrate signs of poorer decision-making, as indicated by poorer scores on the IGT than *never* smokers. In addition, developmental studies report that IGT performance is not predicated by working memory scores, which suggests that maturation of the OFC/VMPC might be a developmentally distinct process from maturation of other regions of the frontal lobe (Crone & Van Der Molen, 2004; Hooper et al., 2004). Therefore, we also tested the hypothesis that poor decision-making in *past 7-day* smokers would reflect a possible OFC/VMPC dysfunction, as opposed to a DLPC dysfunction, as evidenced by an impaired performance on the IGT, but a normal score on the SOPT and the SAP.

Method

Participants

The data collected in this study support the Pacific Rim Transdisciplinary Tobacco and Alcohol Use Research Center investigation of gene-environment interactions in tobacco and alcohol use and prevention among youth. With the assistance of the municipal Education Committee and the Chengdu Center for Disease Control and Prevention (CCDCP), in Chengdu City, Sichuan Province, four schools were recruited for the study. To ensure maximum variability across the student sample, two academic high schools were selected: one of high, and the other of low to middle academic status; and two vocational schools were also selected: one of middle, and the other of low academic status. School administrators and teachers from the selected schools agreed to participate in the research after receiving a thorough explanation of the project from the CCDCP staff. One 10th-grade class from each of the four schools was randomly selected, and a total of 223 students were invited to participate. CCDCP staff provided assistance to the U.S. research team in obtaining informed parental and student consent, following study protocols approved by the Institutional Review Boards of both the University of Southern California (USC) and the CCDCP. Students voluntarily took part in the study and were told that they could discontinue their participation at any time. Out of that total, fifteen participants were excluded from the data analysis due to computer malfunctions or failure to complete the survey or follow instructions on the SOPT. The analytic data set included 208 participants (93.3% of total participants).

Measurements

Study measures included two computer-assisted neurocognitive assessments and one paper-and-pencil self-report questionnaire. The questionnaires and instructions for each neuropsychological task were translated into Mandarin Chinese (the only language used in the surveys) and back-translated prior to use.

Neuropsycholgical measurements

Iowa Gambling Task (IGT)—As described in previous studies (Bechara, Damasio, Damasio, & Anderson, 1994; Bechara, Damasio, Damasio, & Lee, 1999), the IGT is a computerized version of the gambling task with an automated and computerized method for collecting data. Four decks of cards labeled A, B, C and D are displayed on the computer screen. The backs of the cards all look the same as real decks of cards. The participant starts the task with a sum of make-believe money in his or her account ($2,000), represented by a green bar that changes in length as the participant "wins" or "loses" money during the task. The subject is required to select one card at a time from one of the four decks. When the subject selects a card, a message is displayed on the screen indicating the amount of money the subject has won or lost. The preprogrammed schedules of gain and loss are controlled by the computer. Turning each card can bring an immediate reward of $100 in Decks A and B and $50 in Decks C and D. As the game progresses, there are also unpredictable losses among the card selection. Total losses amount to $1,250 in every 10 cards in Decks A and B compared to $250 in Decks C and D. Decks A and B are equivalent in terms of overall net loss, and Decks C and D are equivalent in terms of overall net gain over the course of the trials. The difference is that in Decks A and C, the punishment is more frequent but of smaller magnitude, whereas in Decks B and D, the punishment is less frequent but of higher magnitude. Thus, Decks A and B are disadvantageous because they yield high immediate gain but a greater loss in the long run (i.e., net loss of $250 for every 10 cards), and Decks C and D are advantageous in that they yield lower immediate gain but a smaller loss in the long run (i.e., net gain of $250 for every 10 cards). In this study, an overall net score of the IGT was calculated by subtracting the total number of selections from disadvantageous decks (A and B) from total number selections from advantageous decks (C and D).

Self-ordered Pointing Test (SOPT)—We used a computerized version of the SOPT (Peterson et al., 2002) based upon a task originally developed by Petrides and Milnerto (1982). The SOPT has both verbal and non-verbal components with three trials of each. In the verbal component, subjects view pictures of concrete, nameable objects (calculator, book, bus, etc.); whereas in the non-verbal component, subjects view abstract designs that are difficult to name or encode verbally. In each trial, 12 pages are presented sequentially, with each page depicting the same 12 pictures, but in a different spatial arrangement each time. Subjects are instructed to point to a different picture on each presentation. In this study, the working memory score was the total number of correct selections of different pictures for a maximum possible score of 12 on each trial and 72 for the total six trials. The internal consistency across the six trials was 0.86.

Questionnaire measurements

Smoking status—Smoking status was assessed with three items:

1. "Have you ever tried cigarette smoking, even a few puffs?" with response options "yes" or "no."
2. "During the past 30 days, on the days you smoked, how many cigarettes did you smoke per day?" with response options "I did not smoke cigarettes during the past 30 days," "Less than 1 cigarette per day," or "More than 20 cigarettes per day."
3. "Did you smoke cigarettes in the past 7 days?" with response options "yes" or "no."

Participants who did not indicate smoking on any of these three items were categorized as *never* smokers. Participants who indicated smoking, but not in the past 30 days nor in the past 7 days, were categorized as *ever* smokers; those who indicated smoking in the past 30 days, but not in the past 7 days, were categorized as *past 30-day* smokers; and those who indicated smoking in the past 7 days were categorized as *past 7-day* smokers. The latter four categories correspond accordingly to four stages of cigarette smoking (never-users, triers, experimenters and regular users) among high school students in one previous study (Flay et al., 1998).

The age of smoking for the first time—The age of smoking for the first time was assessed using the following item: "How old were you when you smoked a whole cigarette for the first time?" The response options included, "I have never smoked a whole cigarette", with other options ranging from "Eight years old or younger" to "Seventeen years old or older."

Smoking susceptibility—Smoking susceptibility, a measure of vulnerability to substance use which identifies those adolescents who have *not* made a firm commitment *not* to use a substance (Pierce, Choi, Gilpin, Farkas, & Merritt, 1996; Pierce, Farkas, Evans, & Gilpin, 1995), was assessed using the following two items: "At any time in the next 12 months, do you think you will smoke a cigarette?" and "If one of your best friends offered you a cigarette, would you smoke it?" with the possible responses being "Yes, definitely," "Maybe yes," "Maybe no," "No, definitely not." The participants were dichotomized by their responses to each question ("No, definitely no"=1; other three responses=2).

School academic performance (SAP)—Students self-reported their academic performance in school by answering the following question: "What is your usual academic performance at your current school or the last school where you received grades?" The five response options ranged from: "Mostly A's, or 90 or more points, or Superior" to "Mostly F's, or below 60 points, or Failing." The scores were reverse-coded, so the higher the score, the higher the SAP.

Procedures

Trained data collectors from the CCDCP and the USC provided written and verbal instructions to the students and administered the computer-based assessments and questionnaires in temporary computer labs set up at each school. Students completed the questionnaire and the computer-based assessments (the IGT and SOPT) during one class period. Students were provided with earphones to muffle any potentially distracting noises in the environment that might divert their attention.

Data analysis

Data were analyzed with the Statistical Package for the Social Sciences for Windows, Version, 11.5.0 (SPSS Inc., Chicago, IL). Frequencies were generated to analyze demographic characteristics such as age, gender and school-type, and smoking variables of the entire sample and each category of smokers. The demographic characteristics and smoking variables among different smokers were analyzed by chi-square tests. IGT, SOPT scores and SAP were compared by independent sample *t*-tests and Pearson's correlations, respectively. To analyze the IGT performance profile we conducted between-within analysis of variance (ANOVA) tests with "Block" as the within-subject factor and smoking status as the between factor. The proportion of participants who performed poorly (no more than an overall net score of 10) (Bechara & Damasio, 2002) on the IGT among different smokers was analyzed by chi-square test separately for different levels of smoking. Differences of means on SOPT performances and SAP were calculated using the generalized linear model adjusting for school type. Associations among neuropsychological performances and the SAP were assessed with partial correlations (controlling for age, gender and school type). To assess the independent effect of IGT on smoking, logistic regression models were used, with *past 7-day* smoking as the dependent variable and IGT overall net score as the independent variable, controlling for SOPT, SAP and demographic characteristics.

Results

Demographic characteristics

Demographic characteristics of smokers are presented in Table 1. Both gender and school-type were equally represented. Students' ages ranged from 14 to 18 years old, with more than 90%

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either 16 or 17 years old. There were significantly more smokers among the male and vocational school students than female and academic students, respectively (p<0.05). The proportions of youth with smoking experience (*ever* + *past 30-days* + *past 7-days*) were higher among vocational (54.8%) than academic (37.9%) students, and among males (50.0%) than females (32.7%). Differences were particularly great at the level of smoking in the last 7 days; 10.6% for vocational and 1.0% for academic students, and 10.6% for males and 1.0% for females overall. Males in vocational schools were at very high risk for trying smoking (31.7%) and for recent, last 7 days smoking (10.6%).

Table 2 depicts level of smoking by several predictor variables. Smokers (*ever, past 30-day* and *past 7-day*) differed significantly at the age of smoking initiation, defined as the age at which one first smoked a whole cigarette (p<0.05). Those who had progressed to 30 days or more recent smoking had their first smoking experience at an earlier age than those not smoking in the last 30 days. While there was a trend for *past 7-day* smokers to have their first smoking experience at a younger age than *past 30-day* smokers, the difference was not significant ($\chi^2(3)=4.97$, $p=0.29$). The trend for *past-7-day* smokers to smoke more cigarettes on the days they smoked than *past 30-day* smokers was also not significant ($\chi^2(3)=5.37$, $p=0.14$). Compared to other smokers (*never, ever* and *past 30-day*), *past 7-day* smokers were significantly more likely to report accepting a future offer of a cigarette from a friend ($p< 0.05$) and to smoke sometime in the next 12 months ($p< 0.05$). There was no difference in the proportion of susceptible adolescents among *ever* and *past 30-day* smokers.

Associations between outcome measures and demographic variables are presented in Table 3. Academic school participants scored significantly higher than vocational school participants on both the SOPT and the SAP ($t(206)=6.96$, $p<0.001$; $t(206)=7.71$, $p<0.001$). However, the IGT net score was not related to age, gender or school-type.

Behavioral performance on the IGT

Figure 1 presents the IGT net scores by smoking status (*never, ever, past 30-days*, or *past 7-days*) across five blocks of 20 cards each. Positive net scores reflect advantageous (non-impaired performance) while negative net scores reflect disadvantageous (impaired) performance. Comparison of the plots shows that, as the task progressed, *never* smokers and *ever* smokers showed similar learning curves. They gradually switched their preference toward the good decks (C and D) and away from the bad decks (A and B), as reflected by increasingly positive net scores. A between-within ANOVA test did not reveal any significant difference in groups (*never* vs. *ever* smokers) ($F(1, 183)=0.14$, $p=0.71$) or interaction between groups and blocks ($F(2.8, 523.5)=0.56$, $p=0.69$). Because the assumption of sphericity was not met (Mauchly’s $W=0.51$, $p<0.001$), the degrees of freedom for tests of within-subjects effects were conservatively adjusted using the Greenhouse-Geisser F-test. A blocks effect ($F(2.8, 523.5)=13.91$, $p<0.001$) was significant after Greenhouse-Geisser adjustment. Although *past 30-day* smokers performed worse after their initial improvement, comparison of *never* vs. *past 30-day* smokers also revealed only a block effect ($p<0.05$), and neither a group effect (*never* vs. *past 30-day* smokers) ($F(1, 131)=0.15$, $p=0.70$) nor an interaction (group by blocks) effect ($F(3.1, 410.9)=1.64$, $p=0.18$).

Past 7-day smokers showed a distinctly different pattern. While *past 7-day* smokers seemed to begin a shift toward the good decks (decks with more favorable payoffs) in the first two blocks, they failed to continue this adaptive shift, switching back to disadvantageous decks (A and B) in Blocks 3, 4 and 5. A between-within ANOVA test found a marginally significant interaction between groups (*never* vs. *past 7-day* smokers) and blocks ($F(3.1, 412.2)=2.21$, $p=0.08$), after Greenhouse-Geisser adjustment, and a significant main effect for groups ($F(1, 132)=4.86$, $p<0.05$). The block effect was not significant ($p>0.1$). Follow-up analysis indicated significant differences between the groups in Blocks 3, 4 and 5 ($p<0.05$). All these findings demonstrate that compared to *never* smokers, *past 7-day* smokers showed poorer IGT performance, as reflected by both deficits in the pattern of learning curves and significantly lower overall IGT net score.

A previous study found that 37% of normal adult controls performed the IGT disadvantageously and showed performance within the range of VM patients (i.e. an overall net score <10) (Bechara & Damasio, 2002). Therefore, we also use IGT net score 10 as a cut-off point. Based on this criterion, as shown in Table 4, the proportion of adolescents who performed poorly (less than an overall net score of 10) did not significantly differ among *never* smokers, *ever* smokers and *past 30-day* smokers (65.6%, 66.7%, and 45.5%, respectively). In sharp contrast, a substantial proportion (91.7%) of *past 7-day* smokers performed poorly on the IGT, marginally significantly different for *past 7-day* smokers compared to other smokers combined together (*never, ever* and *past 30-day* smokers) ($\chi^2(1)=3.54$, $p=0.06$).

SOPT and SAP

Table 5 shows SOPT and SAP scores for smokers after controlling for school-type. The general linear model revealed no differences on SOPT for smokers (at any level) compared to *never* smokers after controlling for school type ($p>0.1$). Academic performance (SAP) for *past 30-day* smokers, but not *past 7-day* smokers, was significantly lower than for *never* smokers after controlling for school type ($F(1, 130)=4.38$, $p<0.05$).

Partial correlations among performances and SAP

As shown in Table 6, associations among neuropsychological performances and the SAP were assessed with partial correlations (controlling for age, gender and school-type). IGT performance did not correlate with either the SOPT or the SAP. However, there was a significant correlation between the SOPT and the SAP ($p<0.001$).

Variables predicting past 7-day smoking

Logistic regressions were performed to predict *past 7-day* smoking behavior. The “Enter” method was used and IGT overall net score, SOPT, SAP and demographic variables such as age, gender and school type were all entered into one model at the same time. Results are presented in Table 7. Male gender and professional school status were significant predictors of *past 7-day* smokers. However, after adjusting for those demographic variables, SOPT, and SAP, the IGT was a significant predictor of *past 7-day* smoking behavior ($p<0.05$). These results demonstrate that the IGT contributed to *past 7-day* smoking independent from the SOPT, SAP, and demographic variables such as age, gender and school-type. Better IGT performance predicted less *past 7-day* smoking.

Discussion

To our knowledge, this is the first study to show that decrements in affective decision-making (as measured by the IGT) are associated with early progression along smoking trajectories toward addiction. And this is also the first study to apply laboratory-based neuropsychological assessments to the normal adolescent population in China, extending the generalizability of affective decision making’s relationship to substance abuse across cultures.

The key finding of this study supports our primary hypothesis that *past 7-day* adolescent smokers showed impaired IGT performance compared to *never* smokers, as indicated by an abnormal learning curve and significantly lower overall IGT net score. Moreover, a marginally significantly higher proportion (91.7%) of *past 7-day* smokers performed poorly (no more than an overall net score of 10) on the IGT relative to other levels of smokers (about 65.3%). In addition, the study found no differences in SOPT between *past 7-day* smokers and *never* smokers, and logistic regression analysis showed that after controlling for the SOPT, SAP and demographic variables, the IGT significantly predicted *past 7-day* smoking. These findings support our second hypothesis that decision-making impairment can be separated from general cognitive intelligence impairment, consistent with an OFC/VMPC dysfunction but not a DLPC dysfunction.

In our sample, there was a significantly larger proportion of smokers in the male and vocational school samples than in the female and academic school samples, which is consistent with an earlier seven-city study of smoking prevalence among Chinese adolescents (Johnson et al., 2006). The prevalence of past 1-month smoking, which includes both *past 30-day* and *past 7-day* smokers, was also similar to previous large-scale studies in the school students in China (Grenard et al., 2006; Johnson et al., 2006). Compared to other levels of smokers (*never*, *ever* and *past 30-day*), there was a significantly higher proportion of *past 7-day* smokers who had *not* made a firm commitment *not* to smoke in the next 12 months or cigarette offering from best friends, while there was no difference between *past 30-day* and *ever* smokers. These results suggest that *past 7-day* smokers differ in their assessments of likely future and socially-related smoking compared to those who smoke less, and are more likely than others to progress along trajectories to habitual and addictive smoking.

Consistent with the behavioral data, the IGT performance of *past 7-day* smokers, but not other smokers, was impaired relative to *never* smokers in this study. Compared to *never* smokers, *past 7-day* smokers selected significantly more cards from the disadvantageous decks which provided large rewards but even larger unpredictable future punishments instead of the advantageous decks which offered small reward but even smaller later punishments. Moreover, there was a marginally significantly higher proportion (91.7%) of *past 7-day* smokers that performed poorly (no more than an overall net score of 10) on the IGT relative to other levels of smokers, indicating that the impaired performance of *past 7-day* smokers as a group was not due to a small number of extreme cases. Taken together, these results suggest that for *past 7-day* smokers, both their higher smoking status and their greater susceptibility to future and socially-related smoking might be attributable at least in part to their poor, diminished emotional decision-making capacities.

To our knowledge, there is only one study so far to investigate affective decision-making relative to adolescent cigarette and other substance use behavior with an IGT analogous task. Although the researchers in that study did not distinguish different levels of smoking as we did, they found that poly substance use was negatively correlated with performance on the IGT analogous task (Overman et al., 2004). Our study captures an earlier stage in progression across abuse trajectories, and provides additional evidence to support diminished decision capacity as a causal factor in progression toward habitual and abusive levels of use. Our findings suggest that *past 7-day* smokers might share with the OFC/VMPC patients the failure to anticipate future outcomes. Indeed, studies have found that the frontal pole area (Broadmann 10), the most anterior part of OFC/VMPC, is critically involved in having an insight into one's future and undertaking the planning of future actions (Fellows & Farah, 2005b; McClure, Laibson, Loewenstein, & Cohen, 2004; Semendeferi, Armstrong, Schleicher, Zilles, & Van Hoesen, 2001). The smoking behavior of *past 7-day* smokers may reflect a diminished ability to anticipate the long-range negative consequences of tobacco use and more likely to be lured by immediate reward. Meanwhile, in social situations, they may be less likely to reject cigarette offering from their best friends, and thus make disadvantageous smoking decisions in the long run.

The IGT performance of *past 7-day* smokers (and to a lesser extent, *past 30-day* smokers) worsened over time after initial improvements. This response pattern can be understood, at least partially, in light of previous research showing that the IGT taps into two decision-making contexts: decisions under ambiguity in the first trials, and decisions under risk in the latter trials (Brand, Recknor, Grabenhorst, & Bechara, 2007). The tendency towards intense excitement and exploratory activity in response to reward has been considered a critical etiological concept in a number of theoretical models of substance abuse (Acton, 2003; Zuckerman, Ball, & Black, 1990). However, to distinguish different mechanisms at work in different decision contexts underlying the impaired decision-making on the IGT is beyond the scope of this study.

In China, the academic high school sample represents higher achieving students, whereas the vocational high school sample includes many students who were not accepted into academic high school (Johnson et al., 2006). This selection process explains why participants from academic schools performed significantly better on the SOPT and scored significantly higher on the SAP than those from vocational schools in this study. It is not surprising that working memory in this study was strongly correlated with the SAP since working memory is highly related to fluid intelligence (Kane & Engle, 2002) and other high-level cognitive skills such as reading, mathematics and reasoning (Colom et al., 2004; Engle et al., 1992; Jarrold & Towse, 2006). However, there was no difference in the performance on the SOPT between smokers (at any level) and *never* smokers. It is unlikely that the SOPT was too simple to detect differences since there was no ceiling effect in our study. Moreover, another study has demonstrated that compared to the brain processes assessed by other working memory tasks, the brain process taxed by an SOPT-similar task develops later in adolescence (Luciana, Conklin, Hooper, & Yarger, 2005).

After controlling for the SOPT or SAP and demographic variables, the IGT significantly predicted *past 7-day* smoking. Taken together, these results suggest that the functional maturation process of the OFC/VMPC can be distinguished from the maturation of other prefrontal regions such as the DLPC. These findings are consistent with those of previous studies which indicate that in adolescents, developmental improvements in the IGT performance could not be explained by developmental changes in working memory capacity and inductive reasoning (Crone & Van Der Molen, 2004; Hooper et al., 2004; Overman et al., 2004). Indeed, difficulty with affective regulation in adolescents cannot be explained by their cognitive intelligence (Steinberg, 2005). For instance, adolescents are often capable of explaining reward probabilities, despite making disadvantageous decisions (Crone, Jennings, & Van Der Molen, 2004; Crone, Somsen, Van Beek, & Van Der Molen, 2004). Many aspects of adolescent cognitive functions have shown to be equivalent to those of adults under laboratory situations, but they show greater deterioration under more real-life, stressful conditions (Steinberg, 2004); adolescents with well-developed decision-making abilities demonstrated under non-emotional conditions seem to have a much more difficult time making a responsible choice under intense emotional arousal (Arnsten & Shansky, 2004).

Our results are consistent with previous findings suggesting that although *past 7-day* smokers may share the same logical competencies of other adolescents, their actual decision-making ability may vary with neurodevelopmental, social and emotional factors (Steinberg, 2005).

It is unlikely that the relationship between the IGT and *past 7-day* smoking observed in this study could have resulted from structural or functional neural changes consequent to prior cigarette smoking, since the numbers of cigarettes smoked per week was not great, and only 16.7% smoked as many as 6–10 cigarettes on days when they smoked – far short of a level indicative of addiction.

It is noteworthy that approximately 65.3% of those not smoking in the last 7 days (*never* smokers, *ever* smokers and *past 30-day* smokers) performed poorly on the IGT. This result corroborates other reports of poor IGT performance of adolescents (Crone & Van Der Molen, 2004; Crone & Van Der Molen, 2003; Garon & Moore, 2004; Hooper et al., 2004; Overman et al., 2004) and of presumably immature prefrontal cortices in adolescents (Giedd, 2004; Gogtay et al., 2004). A previous study found that 37% of normal adult controls performed poorly on the IGT. These people tended to describe themselves as high-risk takers, thrill seekers or gamblers (Bechara & Damasio, 2002). Those scoring low on the IGT in our study but who had not yet progressed to *past 7-day* smoking, might still be at high risk to future smoking or other substance use abuse because of their emotional decision deficits. Environmental circumstances may be more protective of children in China than in Western countries (more time spent in school and the home, less free time with peers, and have less pocket money). This might help explain why in China, uptake and progression to regular smoking continues well into middle adulthood, rather than leveling in adolescence as in the West. However, further longitudinal studies are needed to corroborate that poor decision making precedes chronic cigarette smoking and other drug abuse, rendering some adolescents more susceptible to succumbing to addictive behaviors in the future, and that these factors contribute to progression along smoking trajectories at later as well as earlier developmental stages. Longitudinal fMRI and other studies are needed to corroborate that the dysfunctions of neural substrates postulated here are responsible for later progressions in smoking and/or other substance use toward addiction.

Better understanding of the neuroscience of decision making might direct efforts for prevention and improve on interventions for adolescent smoking and other substance abuse prevention and control. The social context may exacerbate difficulties in risk decisions. Smoking by peers has been shown to be consistently the strongest predictor of adolescent smoking across different cultures (Unger et al., 2002). Other research has demonstrated that adolescents are more like to engage in risky behaviors in the presence of friends than when acting alone (Nigg & Casey, 2005). In social situations, adolescents may be less likely to logically evaluate the pros or cons of their behavior, due to the complex feelings and emotions experienced at the moment of making a decision, such as fear of being teased or rejected by his peer, the excitement of taking risks, and the desire to impress friends (Dahl, 2003). However, decision-making interventions in traditional prevention programs typically target explicit cognitive components, including strategies for gathering information, weighing pros and cons, solving problems, and choosing appropriate actions (Faggiano et al., 2005; Sussman et al., 2004; Trudeau, Lillehoj, Spoth, & Redmond, 2003). It is unclear if these decision-making skills become automatic enough to mediate decisions in an adolescent’s life or even if they can be detected on valid tests of decision making. But the findings reported here and elsewhere (Faggiano et al., 2005; Kremers et al., 2004) suggest that the behavior of adolescents might not be easily modified by rational, voluntary-based interventions alone. Moreover, in typical interventions, decision-making processes are treated as totally different processes than affect/emotion. Although studies have demonstrated the influence of emotional intelligence on adolescents’ behavior relative to substance abuse (Engels, Hale, Noom, & de Vries, 2005; Trinidad, Unger, Chou, Azen, & Johnson 2004), very little attention has been given to the impact of affect/emotions on the decision-making process in prevention. Therefore, future studies should assess whether interventions aimed at enhancing affective regulation might also benefit decision-making ability in adolescents’ real-life situations, with potential benefit across a variety of addictive behaviors. New approaches might be developed to identify adolescents at high risk for progressing to addiction for appropriate decision making and mood regulating interventions at early stages on smoking progression trajectories. Transdisciplinary research integrating neurocognitive and prevention sciences holds promise for contributing to a better understanding of the role of real-life decision-making relative to addiction, potentially leading to improved interventions for nicotine and other substance abuse and addiction.

Limitations

There are limitations to this research. First, previous studies show that performance on the IGT is impaired in young people with antisocial personality (Mazas, Finn, & Steinmetz, 2000), conduct disorder (Kim, Lee, & Kim, 2006) and early-onset schizophrenia (Kester et al., 2006). We measured a number of psychological factors potentially related to smoking, including hostility, aggressiveness, sensation-seeking, Attention Deficit Hyperactivity Disorder (ADHD), depression, perceived stress, and impulsivity, but we did not find any confounding effect by those variables. The IGT net score did not correlate with any psychological factors, and the relationship between IGT and *past 7-day* smoking still held after adjusting for these psychological factors and demographic variables (unpublished data). We conclude that the relationship between IGT and *past 7-day* smoking was independent of the psychological variables measured (hostility, aggressiveness, sensation seeking, ADHD, depression, perceived stress, and impulsivity), despite the known relationship of some of these variables to smoking. However, we used abbreviated scales, and while the scale reliabilities were good (r=.71–.89) and similar to those reported for full scales, we cannot be sure that full scales would not have produced a different result. We also found that poor IGT performance predicted binge drinking in this sample, but the relationship between IGT and *past 7-day* smoking still held after adjusting for binge drinking behaviors (unpublished data). We have reported effects on binge drinking in a separate paper. Second, although smoking "any time in the past 30-days" or "last 7-days," measures used in the study are standard measures of smoking (Fagerström & Schneider, 1989; Flay et al., 1998; Heatherton et al., 1991), they might not classify level of smoking with an optimal degree of precision. More precise classification of smoking stages should be an objective for future study. Nevertheless, a significantly higher proportion of *past 7-day* smokers (45.4%) in the present study indicated smoking at least 1 to 2 days per week 1 year later than did *past 30-day* smokers (14%), *ever* smokers (1.8%) or *never* smokers (0.9%) (unpublished data). Third, in the study reported here, the *past 30-day* and *past 7-day* smokers sample sizes are relatively small. However, the prevalence and number of cigarettes smoked per day during the past 30 days in our sample was very similar to that found in other large-scale population studies of school students in China (Grenard et al., 2006; Johnson et al., 2006). Statistical significance on the decision task after controlling for demographic variables indicates that the effects are robust, and population representativeness of the sample, bolstered by inclusion of students from both major types of Chinese high schools, suggests that the findings are widely generalizable to Chinese youth. However, future studies are needed to establish replicability to other cultural/environmental settings.

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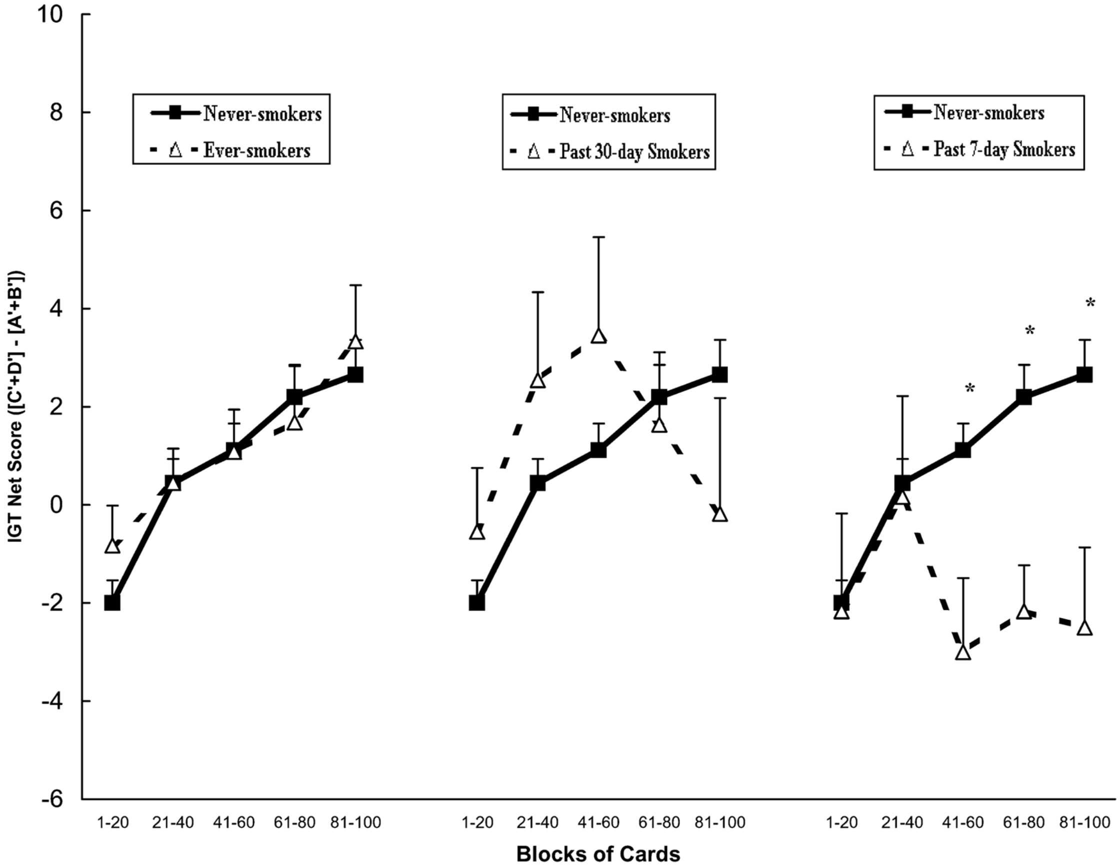

Figure 1.

The IGT net scores ((C′+D′)−(A′+B′)) by smoking status (having smoked *never, ever*, in the *past 30-days*, or in the *past 7-days*) across five blocks of 20 cards expressed as Mean+*SE*. Positive net scores reflect advantageous (non-impaired performance) while negative net scores reflect disadvantageous (impaired) performance. *Note*. *Comparing between groups. $^{*}p<.05$

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Table 1

Demographic characteristics of smokers (*N*=208).

	All *N*	*Never* smokers %(*n*)	*Ever* smokers %(*n*)	*Past 30-day* smokers %(*n*)	*Past 7-day* smokers %(*n*)	Difference among smokers
Gender						
Female	104	67.3 (70)	28.8 (30)	2.9 (3)	1 (1)	$\chi^2(3)=13.4^a$ $p=.004$
Male	104	50 (52)	31.7 (33)	7.7 (8)	10.6 (11)	
Age						
14–15	10	70 (7)	30 (3)			$\chi^2(9)=12.6^a$ $p=.18$
16	150	60 (90)	32 (48)	4.7 (7)	3.3 (5)	
17	42	50 (21)	26.2 (11)	9.5 (4)	14.3 (6)	
18	6	66.7 (4)	16.7 (1)		16.7 (1)	
School-type						
Academic	104	72.1 (75)	25 (26)	1.9 (2)	1 (1)	$\chi^2(3)=13.4^a$ $p<.0001$
Vocational	104	45.2 (47)	35.6 (37)	8.7 (9)	10.6 (11)	

Note.

[a]Comparing within *never*, *ever*, *past 30-day* and *past 7-day* smokers. Percentage by row.

Table 2

Proportion of smokers among different smoking variables (*N*=208).

	Never smokers %(*n*)	*Ever* smokers %(*n*)	*Past 30-day* smokers %(*n*)	*Past 7-day* smokers %(*n*)	Difference among smokers
How old were you when you smoked a whole cigarette for the first time?					
Did not smoke a whole cigarette	100 (122)	34.9 (22)			$\chi^2(3)=4.97^a$ $p=.29$
8 years old or younger		7.9 (5)		16.7 (2)	$\chi^{2\ b,d}$ $p<.05$
9 year old		1.6 (1)		16.7 (2)	
10–12 year old		11.1 (7)	18.2 (2)	16.7 (2)	
13–14 year old		28.6 (18)	27.3 (3)	25.0 (3)	
15–16 year old		15.9 (10)	54.5 (6)	25.0 (3)	
During the past 30 days, how many cigarettes did you smoke per day on the days you smoked?					
0	100 (122)	100 (63)			$\chi^2(3)=5.37^a$ $p=.14$
Less than 1			63.6 (7)	25.0 (3)	
1			9.1 (1)	33.3 (4)	
2–5			27.3 (3)	25.0 (3)	
6–10				16.7 (2)	
At any time in the next 12 months, do you think you will smoke a cigarette?					
No, definitely not	92.6 (113)	60.3 (38)	54.5 (6)	8.3 (1)	$\chi^{2\ a,b,c,e,f}$ $p<.05$
Other answers	7.4 (9)	39.7 (25)	45.5 (5)	91.7 (11)	$\chi^2(1)=0.13^d$ $p=.72$
If one of your best friends offered you a cigarette, would you smoke it?					
No, definitely not	86.9 (106)	50.8 (32)	54.5 (6)	8.3 (1)	$\chi^{2\ a,b,c,e,f}$ $p<.05$
Other answers	13.1 (9)	49.2 (31)	45.5 (5)	91.7 (11)	$\chi^2(1)=0.05^d$ $p=.82$

Note.

[a] *Past 7-day* vs. *Past 30-day* smokers.

[b] *Past 7-day* vs. *Ever* smokers.

[c] *Past 7-day* vs. *Never* smokers.

[d] *Past 30-day* vs. *Ever* smokers.

[e] *Past 30-day* vs. *Never* smokers.

[f] *Ever* smokers vs. *Never* smokers. Percentage by column.

Table 3

Association of outcome measures with demographic variables.

	IGT (Net Score)	SOPT	SAP
Age (*r*)	0.01	−0.05	−0.01
Gender			
F (Mean±*SD*)	3.04±19.41	61.18±6.63	3.38±1.10
M (Mean±*SD*)	5.21±24.76	61.75±6.92	3.47±1.04
School-type			
A (Mean±*SD*)	6.48±23.74	64.41±6.03**	3.93±1.00**
V (Mean±*SD*)	1.77±20.44	58.52±6.17	2.92±0.89

Note.

** Results of independent *t*-tests.

** $p<.001$. IGT=Iowa Gambling Task. SOPT=Self-ordered Pointing Task. SAP=School Academic Performance. F=Female. M=Male. A=Academic school. V=Vocational school. *SD*=Standard deviation.

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Table 4

Proportion of smokers who performed no more or more than a net score of 10 on the IGT.

IGT net score	*Never* smokers %(*n*)	*Ever* smokers %(*n*)	*Past 30-day* smokers % (*n*)	*Past 7-day* smokers % (*n*)	Difference among smokers
<10	65.6 (80)	66.7 (42)	45.5 (5)	91.7 (11)	$\chi^2(1)=4.10^{a}$, $p<.05$ $\chi^2(1)>3.42^{b,c}$ $p<.01$
≥10	34.4 (42)	33.3 (21)	54.5 (6)	8.3 (1)	$\chi^2(1)<0.60^{d,e,f}$ $p>.43$

Note. IGT=Iowa Gambling Task.

[a] *Past 7-day* vs. *Past 30-day* smokers.

[b] *Past 7-day* vs. *Ever* smokers.

[c] *Past 7-day* vs. *Never* smokers.

[d] *Past 30-day* vs. *Ever* smokers.

[e] *Past 30-day* vs. *Never* smokers.

[f] *Ever* smokers vs. *Never* smokers. Percentage by column.

Table 5

Mean SOPT and SAP scores among smokers after controlling for school-type.

	Never **smokers**	***Ever*** **smokers**	***Past 30-day*** **smokers**	***Past 7-day*** **smokers**
SOPT (Mean±*SE*)	61.73±0.55	61.07±0.76	58.78±1.83	63.23±1.68
SAP (Mean±*SE*)	3.57±0.11	3.55±1.56	2.56±0.42*	3.62±0.36

Note.

*Comparing with *Never* smokers.

*$p<0.05$. SOPT=Self-ordered Pointing Task. SAP=School Academic Performance. *SE*=Standard error.

Table 6

Partial correlations among assessments after controlling for age, gender and school-type.

Measures	SOPT	SAP
IGT	0.06	0.07
SOPT	—	0.23*
SAP		—

Note. Results of two-tailed significance tests are denoted by superscripts.

* $p<0.001$. IGT=Iowa Gambling Task. SOPT=Self-ordered Pointing Task. SAP=School Academic Performance.

Table 7

Summary of logistic regression analysis for variables predicting *Past 7-day* smoking behavior (*N*=208).

	β	***SE***	**Sig.**	**Exponential(*β*)**
Age	0.55	0.53	0.30	1.73
Gender*	2.33	1.10	0.04	10.22
School-type#	2.71	1.26	0.03	15.05
IGT net score	−0.04	0.02	0.03	0.96
SOPT	0.04	0.07	0.52	1.04
SAP	0.05	0.41	0.91	1.05

Note.

*Female as reference group.

#Academic school as reference group. IGT=Iowa Gambling Task. SOPT=Self-ordered Pointing Task. SAP=School Academic Performance. *β*=Regression coefficient. *SE*=Standard error.