Psychology of Addictive Behaviors

Abnormal Affective Decision Making Revealed in Adolescent Binge Drinkers Using a Functional Magnetic Resonance Imaging Study

Lin Xiao, Antoine Bechara, Qiyong Gong, Xiaoqi Huang, Xiangrui Li, Gui Xue, Savio Wong, Zhong-Lin Lu, Paula Palmer, Yonglan Wei, Yong Jia, and C. Anderson Johnson

Online First Publication, April 9, 2012. doi: 10.1037/a0027892

0893-164X/12/$12.00 DOI: 10.1037/a0027892

Abnormal Affective Decision Making Revealed in Adolescent Binge Drinkers Using a Functional Magnetic Resonance Imaging Study

Lin Xiao
University of Southern California, Los Angeles

Antoine Bechara
University of Southern California, Los Angeles, Douglas Mental Health University Institute, Montreal, Canada, and University of Iowa Hospitals and Clinics

Qiyong Gong and Xiaoqi Huang
West China Hospital of Sichuan University, Chengdu, China

Xiangrui Li and Gui Xue
University of Southern California, Los Angeles

Savio Wong
University of Southern California, Los Angeles, and The Hong Kong Institute of Education, Hong Kong

Zhong-Lin Lu
University of Southern California, Los Angeles

Paula Palmer
Claremont Graduate University

Yonglan Wei and Yong Jia
Chengdu Municipal Center for Disease Control and Prevention, Chengdu, China

C. Anderson Johnson
Claremont Graduate University

The goal of this study was to investigate the neural correlates of affective decision making, as measured by the Iowa Gambling Task (IGT), which are associated with adolescent binge drinking. Fourteen adolescent binge drinkers (16–18 years of age) and 14 age-matched adolescents who had never consumed alcohol—never drinkers—were recruited from local high schools in Chengdu, China. Questionnaires were used to assess academic performance, drinking experience, and urgency. Brain regions activated by the IGT performance were identified with functional magnetic resonance imaging. Results showed that, compared to never drinkers, binge drinkers performed worse on the IGT and showed higher activity in the subcomponents of the decision-making neural circuitry implicated in the execution of emotional and incentive-related behaviors, namely, the left amygdala and insula bilaterally. Moreover, measures of the severity of drinking problems in real life, as well as high urgency scores, were associated with increased activity within the insula, combined with decreased activity within the orbitofrontal cortex. These results suggest that hyperreactivity of a neural system implicated in the execution of emotional and incentive-related behaviors can be associated with socially undesirable behaviors, such as

Lin Xiao, Department of Psychology, Dana and David Dornsife Cognitive Neuroscience Imaging Center, and Brain and Creativity Institute, University of Southern California, Los Angeles; Antoine Bechara, Department of Psychology, Dana and David Dornsife Cognitive Neuroscience Imaging Center, and Brain and Creativity Institute, University of Southern California, Los Angeles, Douglas Mental Health University Institute, Montreal, Canada, and Department of Neurology, University of Iowa Hospitals and Clinics, Iowa City; Qiyong Gong and Xiaoqi Huang, Huaxi MR Research Center, Department of Radiology, State Key Laboratory of Biotherapy, West China Hospital of Sichuan University, Chengdu, China; Xiangrui Li, Gui Xue and Zhong-Lin Lu, Department of Psychology, Dana and David Dornsife Cognitive Neuroscience Imaging Center, and Brain and Creativity Institute, University of Southern California, Los Angeles; Savio Wong, Department of Psychology, Dana and David Dornsife Cognitive Neuroscience Imaging Center, and Brain and Creativity Institute, University of Southern California, Los Angeles, and Department of Psychological Studies, The Hong Kong Institute of Education, Hong Kong; Paula Palmer and C. Anderson Johnson, School of Community and Global Health, Claremont Graduate University, Claremont; Yonglan Wei and Yong Jia, Chengdu Municipal Center for Disease Control and Prevention, Chengdu, China.

Supported by the Claremont Graduate University−University of Southern California (USC) Pacific Rim Transdisciplinary Tobacco and Alcohol Use Research Center (TTUARC), the National Cancer Institute (Grant 1 P50 CA84735-02), the National Institute on Drug Abuse (Grant DA16708), the National High Technology Program of China (863 Program 2008AA02Z408), and the National Natural Science Foundation of China (Grant 30625024). We thank the USC TTUARC intervention team and Chengdu Center of Disease of Control team for their assistance with project coordination and data collection. We also thank the municipal government, Health Bureau, and Education Committee in Chengdu, China, for their support. The authors declare no competing financial interests.

Correspondence concerning this article should be addressed to Lin Xiao, PhD, Psychology Department, Brain and Creativity Institute, University of Southern California, Los Angeles, CA 90089-2520; or Qiyong Gong, Huaxi MR Research Center, Department of Radiology, West China Hospital of Sichuan University, Chengdu, China. E-mail: linxiao@usc.edu or qiyonggong@hmrrc.org.cn

binge drinking, among adolescents. These findings have social implications because they potentially reveal underlying neural mechanisms for making poor decisions, which may increase an individual's risk and vulnerability for alcoholism.

Keywords: Iowa Gambling Task, adolescence, insula, urgency, drinking

Binge drinking among adolescents has become a leading public health problem in many countries. In recent years, researchers have shown that maturational changes continue to occur in the brain until age 20 (Gogtay et al., 2004), and some have argued until age 25 (Giedd et al., 2009). This development consists of continued cortical sculpting and concomitant function that affect adolescent brain functions and their behavior (Crews & Boettiger, 2009; Overman et al., 2004; Sowell, Thompson, & Toga, 2004; Spear, 2000). Therefore, there has been increasing concern that the maturing teenage brain is particularly susceptible to acquiring substance abuse disorders compared to other phases of development (Squeglia, Jacobus, & Tapert, 2009). Indeed, a number of recent functional magnetic resonance imaging (fMRI) studies have shown that adolescent alcohol users have problems with some "cold" executive prefrontal cortex functions, such as working memory and verbal learning, and these processes have been linked to the dorsolateral sector of the prefrontal cortex (DLPC; Caldwell et al., 2005; Schweinsburg, McQueeny, Nagel, Eyler, & Tapert, 2010; Squeglia, Schweinsburg, Pulido, & Tapert, 2011; Tapert et al., 2004). Behaviorally, a few studies have also demonstrated that heavy drinking among adolescents has also been associated with impaired affective decision making, which have been linked more to the orbital/ventromedial sector of the prefrontal cortex (OFC/VMPC; Overman et al., 2004; Xiao et al., 2009). The goal in this study was to directly investigate the neural substrates of affective decision making among adolescent binge drinkers using fMRI.

Affective decision making is one of the most important social functioning in real life; it enables us to choose wisely according to long-term negative outcomes rather than short-term immediate reward. Impaired affective decision making has been shown in a variety of neurological and psychiatric conditions such as addiction (Bechara & Damasio, 2002), obsessive–compulsive disorder (Whitney, Fastenau, Evans, & Lysaker, 2004), pathological gambling (Cavedini, Riboldi, Keller, D'Annucci, & Bellodi, 2002), and schizophrenia (Sevy et al., 2007). The process of real-life decision making has been proposed to depend on neural substrates that regulate homeostasis, emotion, and feelings including the OFC/VMPC, the DLPC, the amygdala, and the insula (Damasio, 1994, 1996). In recent models, the amygdala and striatum are key neural regions that support emotional and incentive-related behaviors (Everitt et al., 2008; Everitt & Robbins, 2005), whereas the OFC/VMPC is a critical neural region that forms the executive control or inhibitory system (Bechara, 2005). Thus addictive behavior may result from hyperactivity of the bottom-up emotional system, which exaggerates the rewarding impact of available incentives, and/or hypoactivity of top-down control system, which downplays the long-term consequences of a given action (Verdejo-García, Pérez-García, & Bechara, 2006). During adolescence, the bottom-up amygdala system is densely innervated by gonadal steroids and undergoes both functional and anatomical reorganization during puberty (Stevens, 2002). On the other hand, the top-down control system is largely independent of puberty (Nelson, Leibenluft, McClure, & Pine, 2005) and matures gradually over the course of adolescence. Specifically, some portions of the prefrontal cortex, including the orbitofrontal, ventrolateral, and medial prefrontal regions, are among the last brain regions to mature and do not reach adult levels until the 20s (Giedd, 2004; Gogtay et al., 2004). Therefore, it appears that changes in arousal and motivation in the emotional system brought on by pubertal maturation precede the development of regulatory competence of the control system, creating a disjunction between the adolescent's affective experience and his or her ability to regulate arousal and motivation (Somerville, Jones, & Casey, 2010; Spear, 2000; Steinberg, 2010).

More recent evidence has suggested that there is a third neural system mediated through the insular cortex. This pathway plays a key role in translating interoceptive signals into what one subjectively experiences as a feeling of desire, anticipation, or urge to smoke (Naqvi & Bechara, 2009; Naqvi, Rudrauf, Damasio, & Bechara, 2007). Evidence has shown that the insular cortex is implicated in drug craving (Garavan, 2010). Strokes that damage this region eliminate the urge to smoke in people previously addicted to cigarette smoking (Naqvi et al., 2007). The behavioral measure of urgency, defined as an individual's tendency to give into strong impulses, specifically when accompanied by negative emotions such as depression, anxiety, or anger (Whiteside & Lynam, 2001), has been shown to correlate positively with insula activity in recent fMRI studies (Joseph, Liu, Jiang, Lynam, & Kelly, 2009; Xue, Lu, Levin, & Bechara, 2010).

Although adolescents engage in more risky behaviors than adults, the fact remains that not every adolescent ends up addicted to drugs. There is a wide variability among individuals' affective decision-making capacities due to both genetic and environmental factors (Cauffman et al., 2010). Previous behavioral studies have linked the poor decision-making capacity to various substance use behaviors among adolescents (Overman et al., 2004; Xiao et al., 2008). Therefore, the goal of the current study is to identify the brain activity involved in affective decision making among the adolescent binge drinkers. One widely used laboratory paradigm to assess decision-making ability is the Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994). One block design of the IGT task has been successfully used in our previous fMRI study (Li, Lu, D'Argembeau, Ng, & Bechara, 2010). The block design of the fMRI task has not often been used with current fMRI settings due to the inability to disentangle the subprocesses of complex decision making measured by the IGT. However, because the activated regions induced by this block design of the IGT task were consistent with the neural circuitry underlying affective decision making, we still employed this task in our study. In this study, we tested two hypotheses: (a) adolescent binge drinkers would show impaired decision making relative to never drinkers, as indicated by poor performance of the IGT, and (b) the binge drinkers would show increased activation of the affective system (i.e., the amygdala) and the insula during IGT performance, and/or decreased activation of the control system (the OFC/VMPC), in comparison to never drinkers. Moreover, because the behavioral variables such as urgency have been shown to correlate positively with insula activity, but correlate negatively with the OFC/VMPC activity (Joseph et al., 2009; Xue et al., 2010), we predicted that there would also be individual differences even among binge drinkers, with more severe binge drinkers (more drinking problem and high urgency scores) showing evidence of increased hyperactivity of their insula cortex and decreased activity of their OFC/VMPC system.

Method

Participants

Fourteen adolescent binge drinkers (8 boys, 6 girls; M_{age} (mean age) = 17.3 years, SD = 0.5) and 14 adolescent never drinkers (5 boys, 11 girls; M_{age} = mean age = 17.1, SD =0.7) were recruited from local high schools in Chengdu, China. All were enrolled in a larger longitudinal population study (Xiao et al., 2009). Binge drinkers were those who reported having had five or more drinks of alcohol in a row on at least one occasion in the past 30 days, and never drinkers were those who had never had as much as one drink of alcohol in their entire lives. All participants were right-handed, had normal or corrected-to-normal vision, and had no history of neurological or psychiatric disorder. Written informed consent was obtained from participants and their parent or legal guardians prior to participation. Research protocols and instruments were approved by the University of Southern California and the Chengdu Center for Disease Control institutional review boards.

Measures

Questionnaires.

Drinking behaviors. Drinking during the past 30 days was assessed using the following question: "During the past 30 days, on how many days did you have at least one drink of alcohol?" Response options ranged from *0 day* to *All 30 days*. The age of regular drinking was assessed using the following question: "How old were you when you first started drinking regularly?" Response options ranged from *I have never consumed alcohol regularly* to *17 years old or older*.

Drinking problems were assessed using the Rutgers Alcohol Problem Index (White & Labouvie, 1989). Adolescents responded to the following prompt: "Indicate if any of the following things may have happened to you because of drinking alcohol within the past 1 year (mark all that apply)." Participants responded yes or no to 23 situations, including "[because of drinking] I was not able to do my homework or study for a test"; "[because of drinking] I got into fights with other people (friends, relatives, strangers)"; "I went to school drunk"; "I was told by a friend, neighbor, or relative to stop or cut down drinking"; and so on. A yes response was assigned a score of 1; a no response was assigned a score of 0. The score for drinking problems was the sum of the 23 items. Higher scores indicated the respondent had more drinking problems.

Academic performance. 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 were 1 (*mostly As, or 90 or more points, or superior*), 2 (*mostly Bs, or 80–89 points, or very good*), 3 (*mostly Cs, or 70–79 points, or average*), 4 (*mostly Ds, or 60–69 points, or below average*), and 5 (*mostly Fs, or below 60 points, or failing*). Answers were reverse coded so that a higher score represented a higher academic performance.

Urgency. The urgency trait was assessed using the Urgency subscale of the UPPS Impulsive Behavior Scale (Whiteside & Lynam, 2001). We used this scale because it measures an individual's tendency to give into strong impulses, specifically when accompanied by negative emotions such as depression, anxiety, or anger (e.g., "When I am upset I often act without thinking," "I have trouble resisting my cravings (for food, cigarettes, etc.)". This section consisted of 12 items. Each of the 12 items was scored from 1 (*I disagree strongly*) to 4 (*I agree strongly*). Some items were reversed in such a way that a high score revealed high urgency trait of personality.

Functional MRI task.

Iowa Gambling Task. As described in previous studies (Bechara et al., 1994; Bechara, Damasio, Damasio, & Lee, 1999), the IGT is a computerized version of a gambling task with an automated and computerized method for collecting data (Figure 1, lower left). A detailed description of this task used in a fMRI setting (including practice trials and control task) is described elsewhere (Li et al., 2010).

In the IGT, four decks of cards, labeled A, B, C, and D, are displayed on a computer screen. 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. Turning each card can bring an immediate reward (the immediate reward is higher in decks A and B relative to Decks C and D). As the game progresses, there are also unpredictable losses associated with each deck. Total losses are on average higher in decks A and B relative to Decks C and D, thus creating a conflict in each choice, that is, Decks A and B are disadvantageous over the long term (even though they bring higher immediate reward), whereas Decks C and D are advantageous in the long term (i.e., the long-term losses are smaller than the short-term gains, thus yielding a net profit). Net decision-making scores are obtained by subtracting the total number of selections from the disadvantageous decks (A and B) from the total number selections from the advantageous decks (C and D). Thus, positive numbers reflect good decisions, while negative numbers reflect bad decisions.

Control task. The control task was designed in such a way that it matched the IGT on its sensorimotor components, but without the complex decision-making process (see Figure 1, lower right). More specifically, on each trial, the win or loss amount was displayed on each deck. The win or loss amount of the cards was randomly chosen from the same four decks so that the overall win or loss amount was similar to the real task. There were no advantageous or disadvantageous decks in this control task. Subjects simply chose the card with the maximum gain or minimum loss. Thus the control task contained all the visual and feedback characteristics of the experimental tasks and a simple decision of choosing a high or low number, but without the requirement to

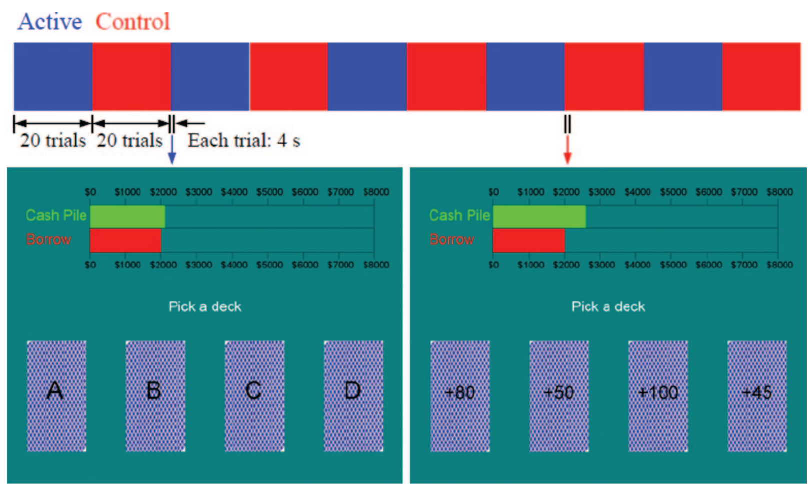

Figure 1. Diagram of a functional magnetic resonance imaging run (top) and screen snapshots of active IGT (lower left) and the control task (lower right). Each run contained five blocks of IGT (blue) and five blocks of control task (red). There were 20 trials within each block. Each trial lasted 4 s. The instruction "Pick a deck" at the center of the screen indicated the start of a trial. IGT = Iowa Gambling Task.

make a complex decision, as required in the IGT (selection of an advantageous choice).

Design and Procedures

The IGT was written in Matlab using the Psychtoolbox (Brainard, 1997; Pelli, 1997). Several technical changes were implemented to suit the fMRI environment. First, the duration of each trial was set to 4 s. If participants did not make their choices after 3.5 s had passed, the computer would randomly make a selection for them. In our previous study, we tried several trial-duration settings, and found that the 4-s duration was long enough for participants to select a card (Li et al., 2010). In the present study, participants missed only 6 of 5,600 trials. Second, blocks of trials from the control task were interspersed with blocks of trials from the IGT. Third, instead of using computer mouse to select a deck, participants used four buttons on an MRI-compatible response box.

Prior to the fMRI experiment, participants were given verbal instructions on the IGT. Details of these instructions have been published previously (Bechara, Tranel, & Damasio, 2000). Participants were given a chance to practice a few trials on a dummy IGT to become familiar with screen instructions, audio feedback, and the use of the buttons in making their choices. In each fMRI session, the five blocks of the IGT were interleaved with the five blocks of the control task (see Figure 1).

Image Acquisition

Functional MRI was performed using a standard birdcage head coil on a 3-tesla scanner (EXCITE, General Electric, Milwaukee, USA) housed at Huaxi MR Research Center, West China Hospital, in Chengdu. An eight-channel phase array head coil was used. Participants laid supine on a scanner bed and viewed visual stimuli back-projected onto a screen through a mirror built into the head coil. Foam pads were used to minimize head motion.

Structural T1-weighted images were acquired in the sagittal orientation employing a magnetization prepared rapid gradient echo sequence (repetition time [TR] = 3.4 ms, echo time [TE] = 8.5, flip angle = 12°) with a voxel size of $1 \times 1 \times 1$ mm^3. Blood oxygenation level−dependent (BOLD) signals were measured with a T2*-weighted echo planar imaging sequence (TR = 2000 ms, TE = 30 ms, flip angle = 90°, field of view = 240×180 mm, in-plane resolution = 64×64 pixels or 3.75×3.75 mm). Thirty interleaved axial slices, with thickness of 4 mm (no gap), were acquired. For each participant, one functional run was collected and it lasted about 13.6 min. The structural scan lasted about 10 min. The whole session lasted about 30 min.

Data Analysis

Behavioral data were analyzed with the SPSS for Windows. Chi-square tests were used to test for differences in frequency distributions by sex and school type, and independent sample *t* tests were used to test for differences in means of age, academic performance, and urgency. To analyze the IGT performance profile, we conducted between-within analysis of variance (ANOVA) tests with block as within-subject factor.

The BrainVoyager QX 1.9 software package was used to perform random-effects analysis on the imaging data, allowing inference to the general population. The anatomical image of each participant was corrected for image intensity inhomogeneity and transformed into the Talairach space (Talairach & Tournoux, 1988). The gray−white matter boundaries resulted from gray−white matter segmentation that were used to create a 3-dimensional surface model of the brain, which was then inflated to display the sulci and gyri on the smooth surfaces of the two hemispheres.

The functional images were first preprocessed to correct for slice timing and head motion, followed by high-pass temporal filtering (3 cycles per run). We checked the movement of all subjects' images and found that none moved more than 2 mm. Therefore, no images were excluded from the study. The average movement was 0.78 mm for the binge drinkers and 0.72 mm for the never drinkers. The difference in average movement between binge drinkers and never drinkers was not significant ($p > .10$). The functional images were aligned to the anatomical images of the same session and constructed into a 3-dimensional volume in the Talairach space for each time point. The voxel size is $3 \times 3 \times 3$ mm^3. Although functional areas across participants did not precisely follow cortical landmarks, it has been shown that a cortical matching approach substantially improves statistical group results by reducing anatomical variability, at least for some of the cortical areas (Fischl, Sereno, & Dale, 1999). We therefore aligned each hemisphere of the participants in BrainVoyager, and converted the 3-dimensional time course into the surface-based time course for each hemisphere. This allowed us to show the averaged activation on the surface of a hemisphere.

For the first-level analysis, general linear model was used to estimate the effect of the IGT blocks relative to the control blocks for each participant. The difference between the IGT and the control task was then entered into a random-effect model for group comparison. Group images were corrected for multiple comparisons across the entire brain using the false discovery rate (FDR; Genovese, Lazar, & Nichols, 2002) at $p < .05$, with an extent threshold of 10 voxels. For analyses with specific anatomical hypotheses (i.e., activation in the insular and OFC cortex), maps were corrected using the adaption of Gaussian random field theory for small volumes, which were anatomically defined according to an anatomical atlas (Damasio, 2005). Correlation analyses were performed to examine the relationship between neural activity and behavioral score reflecting urgency and drinking problems. A threshold of $p < .001$ was used for this analysis.

Results

Behavioral Results

Demographic and behavioral data are presented in Table 1. No group differences were found in the demographic variables, academic performance, or urgency. The adolescent binge drinkers reported on average 2.9 ($SD = 2.4$) drinking problems. About 64% of the adolescent binge drinkers reported that they had consumed alcohol 1 or 2 days during the past 30 days. The rest had consumed alcohol more than 3 days during the past 30 days.

IGT Performance

Figure 2 presents the IGT net scores for each participant group (binge drinkers and never drinkers) versus the block of the IGT. As the task progressed, never drinkers gradually switched their preferences to the advantageous decks (C and D), away from the disadvantageous decks (A and B), which is reflected by increasingly positive net scores. Binge drinkers, however, kept selecting from the disadvantageous decks and exhibited negative net scores throughout the task. A between-within ANOVA test showed significant main effects for groups (binge drinkers vs. never drinkers),

Table 1
Demographic and Behavioral Variables of Participants

Variables	Binge drinkers ($n = 14$)	Never drinkers ($n = 14$)	Difference between two groups
Demographic[a]			
Sex			
Male	8	5	$\chi^2(1) = 1.29, p = .26$
Female	6	9	
Age (years)	17.3 (0.5)	17.1 (0.7)	$t(26) = 0.59, p = .59$
School type			
Academic	5	6	$\chi^2(1) = 0.15, p = .70$
Professional	9	8	
Behavioral[a]			
Academic performance	3.0 (1.2)	3.3 (0.7)	$t(26) = 0.50, p = .56$
Urgency	26.7 (4.8)	24.0 (3.1)	$t(26) = 1.42, p = .18$
Drinking[a]			
Drinking problems	2.9 (2.4)	—	
How old were you when you first started drinking regularly (at least one full drink per month for 3 or more months in a row)?[b]			
I have never consumed alcohol regularly	64.3 (9)	—	
13 or 14 years old	7.1 (1)	—	
15 or 16 years old	14.3 (2)	—	
17 years old or older	14.3 (2)		
During the past 30 days, on how many days did you have at least one drink of alcohol?[b]			
1−2 days	64.3 (9)	—	
3−5 days	14.3 (2)	—	
6−9 days	7.1 (1)	—	
10−19 days	7.1 (1)	—	
20−29 days	7.1 (1)	—	

[a] Values are n or mean (standard deviation). [b] Values are percent (n).

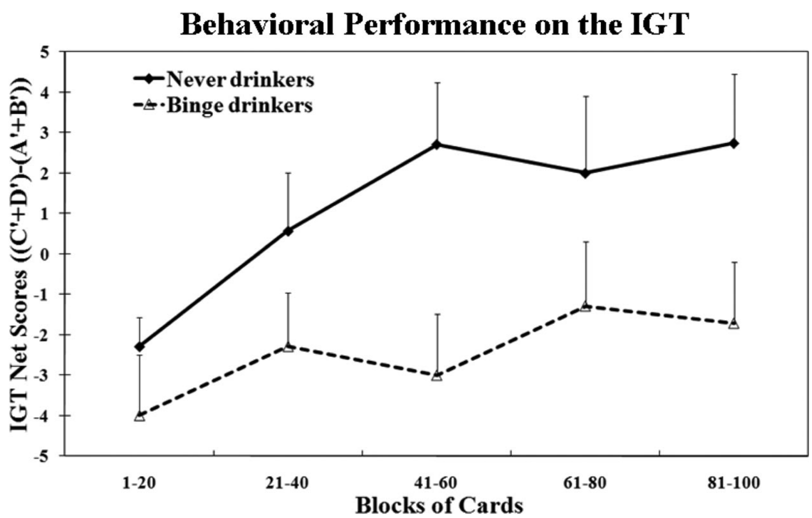

Figure 2. The Iowa Gambling Task net scores ([C + D] − [A + B]) by group (binge drinkers or never drinkers) across five blocks of 20 cards expressed as mean (*SE*). Positive net scores reflect advantageous (nonimpaired performance) while negative net scores reflect disadvantageous (impaired) performance.

$F(1, 26) = 4.31$, $p < .05$, and blocks, $F(2.5, 67.2) = 3.49$, $p < .05$, after the Greenhouse−Geisser adjustment. The interaction between groups and blocks was not significant.

Functional MRI Results

Brain activity during the active versus control conditions from both adolescent binge drinkers and never drinkers is shown in Figure 3. The cortex-based alignment among the 28 participants see (Figure 3a) revealed the activation of cortical surfaces. Because some activated brain structures are not on the surface, they were shown in the Talairach space (see Figure 3b). All activations were thresholded using $q(\text{FDR}) < 0.05$ to correct whole-brain multiple comparisons. The same statistical criterion was applied to all the subsequent statistics. Task versus control comparison showed similar activation patterns in both binge drinkers and never drinkers in the regions of prefrontal cortex, insula, and striatum (see Figure 3, Table 2).

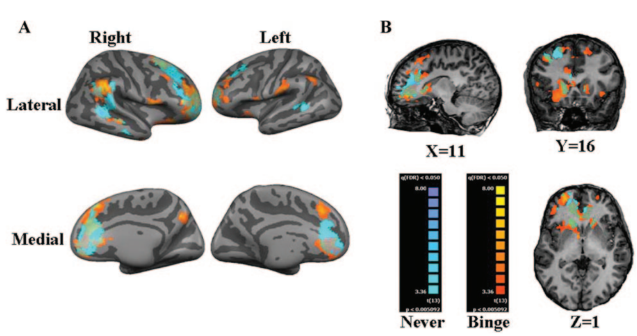

Figure 3. Brain activation during the Iowa Gambling Task, as compared to its control task, in binge drinkers (yellow), never drinkers (blue), and both groups (green overlap of blue and yellow). See Table 2 for details. All brain surfaces were aligned based on curvature (a). The functional map was transformed into the aligned surface and shown on one of partially inflated surfaces. Talairach brain activations that are not shown on the brain surface (b). A threshold applied for all activations in a and b was used $q(\text{FDR}) <$ 0.05 to correct whole-brain multiple comparisons. FDR= false discovery rate.

Binge drinkers versus never drinkers. Statistical comparison of activation maps for binge drinkers and never drinkers demonstrated greater activation in the left amygdale and left and right insula in binge drinkers relative to never drinkers (see Figure 4). There were no regions showing increased activations in the never drinkers compared to binge drinkers.

Correlation of brain activity and behavioral scores. We performed a correlation analyses between drinking problems/urgency scores and BOLD response of active block related to the control block. The results, shown in Figure 5, reveal that the higher degree of drinking problems correlated negatively with the activity in the right OFC, $r = -0.75$, $p < .001$, and positively with the activity in the right insula, $r = .81$, $p < .001$, among binge drinkers. We also found that higher urgency scores were associated with lower activity in the right OFC, $r = -0.55$, $p < .01$, and higher activity in the right insular cortex, $r = .63$, $p < .001$, in both binge drinkers and never drinkers (see Figure 6).

Discussion

Our study investigated the neural mechanisms underlying the decision-making ability of adolescent binge drinkers. These data complement recent fMRI studies that have demonstrated adolescent alcohol users show different brain activity patterns during working memory and verbal learning tasks compared to normal controls. This activity has been linked to the DLPC (Caldwell et al., 2005; Schweinsburg et al., 2010; Squeglia et al., 2011; Tapert et al., 2004). This fMRI study is perhaps the first study addressing affective decision making as measured by the IGT in a normative population of Chinese adolescents. These results therefore extend the generalizability of the relationship between affective decision making and substance use across cultures.

Our results indicate that the pattern of brain activity during the performance of the IGT among adolescents generally matches

Table 2
Regions Activated in Performing the Iowa Gambling Task (Task > Control), Averaged Across Binge Drinkers and Never Drinkers

Regions	Talairach coordinates *x*	*y*	*z*	*t*	Voxel number
Medial orbitofrontal cortex					
R	13	46	0	6.94	221
L	−8	45	−3	4.38	108
Lateral orbitofrontal cortex					
R	26	58	−2	5.1	141
L	−29	48	15	5.83	92
Anterior cingulate cortex					
R	8	34	7	6.56	152
L	−6	29	11	7.68	62
Superior frontal gyrus					
R	18	10	55	7.2	191
L	−14	16	54	3.67	83
Middle frontal gyrus					
R	32	20	41	6.15	241
L	−25	32	28	3.92	179
Inferior frontal gyrus					
R	47	11	11	3.53	270
L	−39	30	12	3.76	164
Insular cortex					
R	36	12	−2	3.48	80
L	−32	12	−4	3.33	36
Dorsal striatum					
R	15	12	14	4.26	79
L	−14	17	9	4.14	34
Ventral striatum					
R	13	19	−1	5.75	37
L	−16	22	−2	5.31	30

Note. A threshold was applied to all activations using q(FDR) < 0.05 to correct for multiple comparisons. L = left; R = right; FDR = false discovery rate.

the theoretical neural framework of affective decision making. The commonly activated regions induced by the IGT include: (a) neural systems critical for regulatory competence, namely, the OFC/VMPC and lateral prefrontal cortex in both hemispheres; (b) neural systems critical for processing emotion, namely, the insula in both hemispheres; and (c) neural systems critical for behavioral actions, namely, the dorsal striatum in both hemispheres. Other activated regions included the anterior cingulate and ventral striatum, which have been implicated in reward processing and conflict monitoring. The similar neural circuitry activated by the IGT paradigm used in this study has also been shown in a previous study of a healthy adult population (Li et al., 2010).

Behaviorally, consistent with previous studies, our study shows that binge drinkers performed worse on the IGT compared to never drinkers. Our fMRI results did not reveal any significant activity in the amygdala in both groups. This finding may due to functional

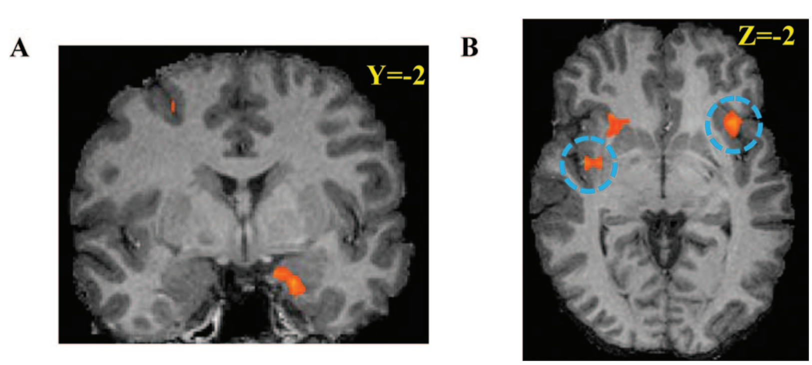

Figure 4. Activation differences in binge drinkers. As compared to never drinkers, binge drinkers showed greater activity in the left amygdala (a) and bilateral insula (b). A threshold applied to activations was used q(FDR) < 0.05 to correct whole-brain multiple comparisons.

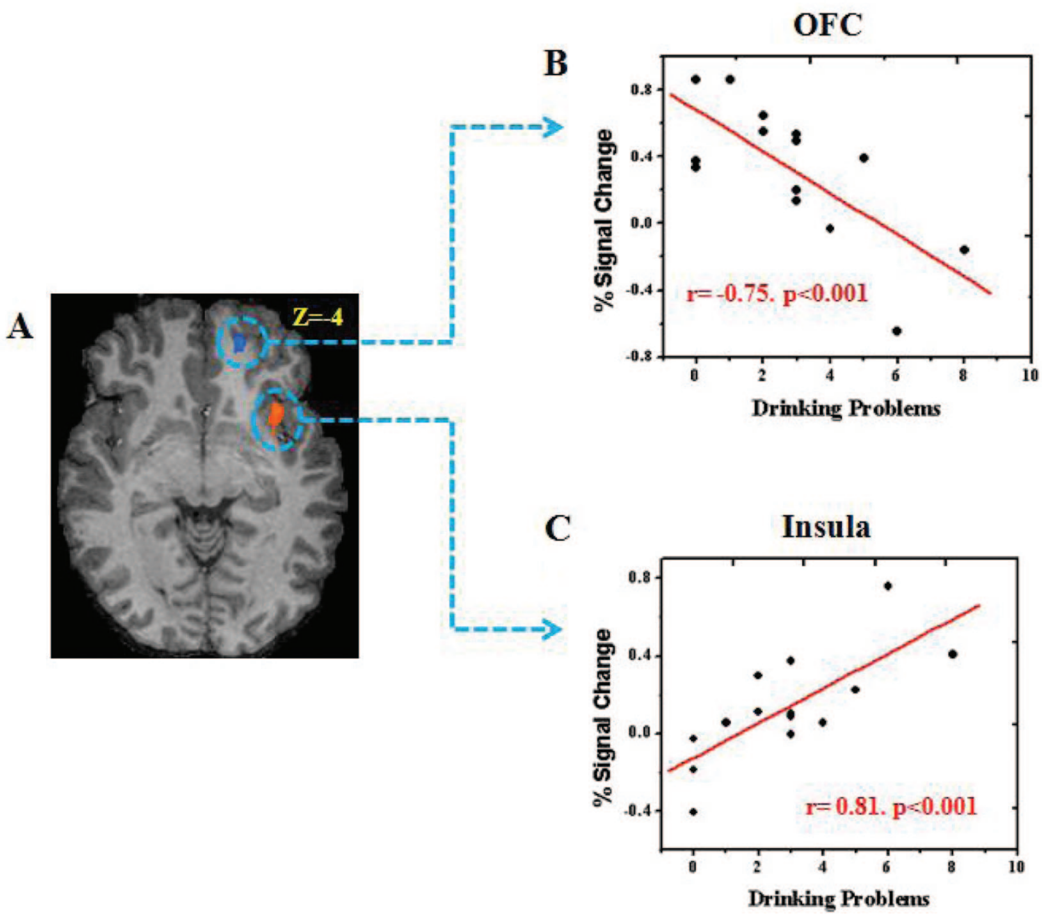

Figure 5. Functional magnetic resonance imaging correlations of drinking problems among binge drinkers. Regions show significant negative correlation (blue) between drinking problems and the OFC activation and significant positive correlation (orange) between drinking problems and the left and right insula (a). Scatterplots of correlations between drinking problems and the average covariance of parameter estimates in the OFC and insular cortex, respectively (b, c).

properties of the amygdala (e.g., rapid neuronal firing and habituation) or the experimental procedure as indicated by a previous study (Li et al., 2010). However, we found that binge drinkers showed increased activity in the left amygdala relative to their controls. The amygdala is critical for triggering emotions when the emotionally competent stimuli are in the immediate environment (Bechara & Damasio, 2005). Patients with lesions of amygdala performed worse on the IGT and were impaired in judging emotional facial expressions (Bechara, Damasio, & Damasio, 2003). Indeed, extensive experimental literature has indicated that the amygdala responds to a wide range of emotional and social stimuli, including faces with varying emotional expressions and social feedback (Costafreda, Brammer, David, & Fu, 2008). Recent studies have also shown an increase in amygdala activity in response to emotional facial expressions (Hare et al., 2008) or the omission of a "large monetary response" in adolescents relative to adults (Ernst et al., 2005). Our study employed monetary reward in a simulated gambling task (i.e., the IGT). The results revealed hyperactivity in this emotional reactivity neural system, suggesting that the altered activity of these of these neuronal systems generalizes to other rewards, including monetary rewards (Breiter, Aharon, Kahneman, Dale, & Shizgal, 2001; Breiter & Rosen, 1999). The current results provide support for recent models, which have suggested that adolescent substance use behavior may be linked to a hyperactive bottom-up affective neural system (Bechara, 2005; Somerville et al., 2010).

We also found that binge drinkers demonstrated enhanced activity in both insular cortexes. Of note, in this study, a higher urgency score correlated with higher activity in both sides of insular cortex. One important difference between urgency and other domains of impulsive behavior is its reliance on emotional factors, and it addresses the role of affect in general, and negative affect in particular, in the impulsivity behavior (Anestis, Selby, & Joiner, 2007; Whiteside & Lynam, 2001). The primary role of the insular cortex is to translate raw physiological signals into what one subjectively experiences as a feeling of desire, anticipation, or urge (Bechara & Damasio, 2005; Damasio, 1994). Our results are also consistent with a recent study that showed stronger activation in the insular cortex predicted more subsequent risky decisions and that the activity in the insular cortex also correlated with an

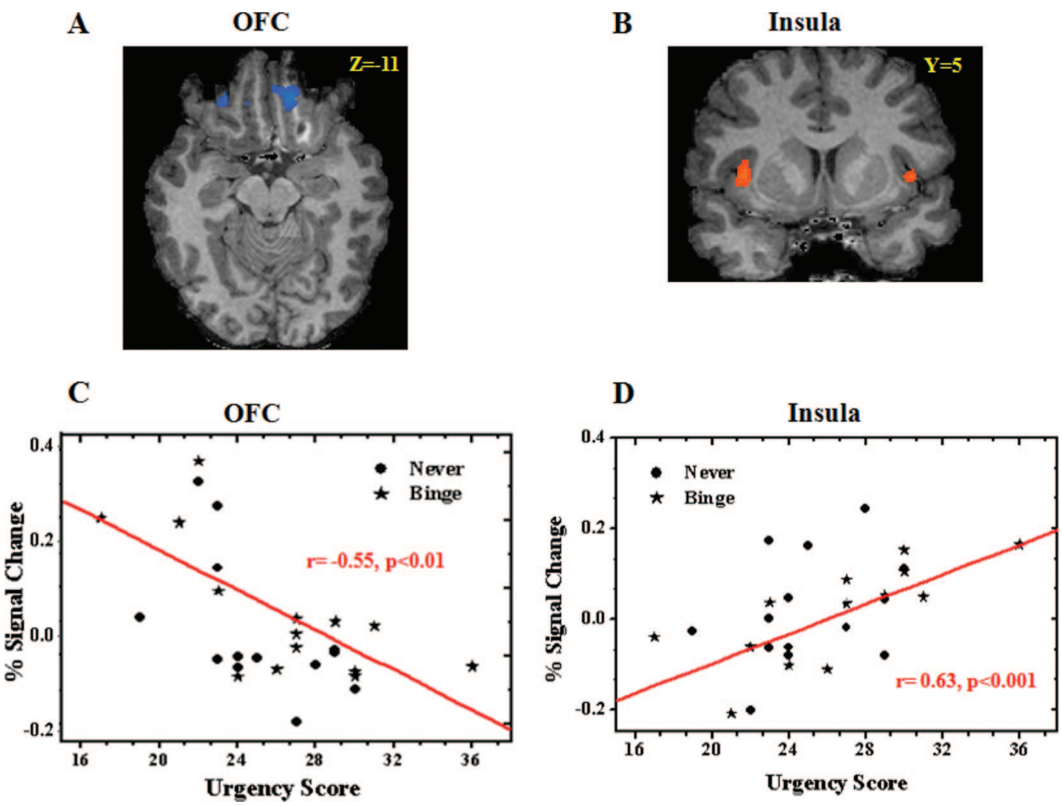

Figure 6. Functional magnetic resonance imaging correlations of urgency scores in both binge drinkers and never drinkers. Regions show significant negative correlation (blue) between urgency and the OFC activation (a). Regions show significant positive correlations (orange) between urgency and the insula (b). Scatterplots of correlations between urgency score and the average covariance of parameter estimates in the OFC and insular cortex, respectively (c, d). OFC = orbital prefrontal cortex.

individual's personality trait of urgency (Xue et al., 2010). Recent studies have also shown that strokes involving the insular cortex eliminate the urge to smoke in people previously addicted to cigarette smoking (Naqvi et al., 2007). Furthermore, interrupting insula function with a local anesthetic halts an already established amphetamine addiction in animals (Contreras, Ceric, & Torrealba, 2007). Numerous functional neuroimaging studies have revealed alteration of insular cortex activity in craving in a variety of substance use disorders (Verdejo-García & Bechara, 2009). Besides drugs, the activity of insular cortex is also implicated in the food craving (Pelchat, Johnson, Chan, Valdez, & Ragland, 2004). Consistent with these observations, our study also revealed that higher insular activity correlates with the more drinking problems among binge drinkers.

In the present study, binge drinkers did not show a significant difference in OFC activity compared to never drinkers, which may be due to lack of power. However, we found that activation in the OFC/VMPC was negatively associated with urgency and drinking problems among the binge drinkers. Our results are consistent with a previous study that demonstrated that fMRI response in the OFC correlated negatively with urgency as measured by UPPS in an emotional-induction task (Joseph et al., 2009). Although the amygdala appears to be a nuclei that detects the significance of objects or events in the immediate environment for the individual, the OFC/VMPC is the region that guides goal-directed behavior and adjusts behavior appropriately in accordance with changing conditions (Holland & Gallagher, 2004). Patients with the damage in the OFC/VMPC show severe impairments in judgment and decision making in real life as well as abnormalities in emotion and feeling: they appear to be oblivious to the consequences of their actions when faced with a choice that brings immediate reward, even at the risk of incurring future negative outcomes, such as loss of reputation, job, and family (Bechara et al., 1994; Bechara et al., 2000). Indeed, studies have found that the frontal pole area (Broadmann area 10), the most anterior part of the OFC/VMPC, is critically involved in having insight into one's future and in the planning of future actions (D'Argembeau, Xue, Lu, Van der Linden, & Bechara, 2008; Fellows & Farah, 2005; McClure, Laibson, Loewenstein, & Cohen, 2004).

On the other hand, the lack of difference between binge and never drinkers in OFC activity may be attributed to the characteristics of binge drinkers in our study. Our sample represents the general high-school student population in China. The average number of drinking problems reported by the binge drinkers in our study was three (from a list of 23). Therefore, most of the binge drinkers in our study were still in the very early stages of progression across abuse trajectories. The failure to detect group differences in OFC activity may indicate that, in the early stages, binge drinkers still have relatively normal prefrontal control functions relative to their peers. Indeed, in our longitudinal study, we found that near half of adolescent binge drinkers in our sample quit binge drinking after 1 year (Xiao et al., 2009). Although in this study we cannot compare the adolescents who quit binge drinking with the adolescents who were consistently binge drinkers 1 year later, due to the small sample size, correlation analyses revealed that among binge drinkers, more drinking problems were associated with increased activity in the insular cortex and decreased activity in the OFC. It is interesting that drinking problems reported here significantly predicted adolescent drinking behaviors of the same cohort after 1 year (Xiao et al., 2009). The more drinking problems adolescents reported, the more likely they reported consistently binge drinking 1 year later (Xiao et al., 2009). Therefore, our results suggest that, even among adolescent binge drinkers, there is variability: individuals who have poor prefrontal control function coupled with dysfunctional affective system have more difficulties inhibiting the urge and impulse from the bottom-up system. These individuals may be at higher risk of future additive behaviors, even compared to their binge drinking peers with normal OFC function. Future study should test this hypothesis.

Study Limitations

A limitation of this study is that the block design of the IGT task did not allow us to investigate the specific subprocesses of complex decision making measured by the IGT. Future implementations of this task could be used to examine whether the difference in the neural response results from the anticipation phase or the feedback phases during the IGT performance. An event-related design of the IGT task has been developed in our lab and will be applied to the study of adolescent binge drinking behaviors using a large sample size. Future studies could also investigate whether there are abnormalities in brain structure volume or white matter quality in Chinese binge drinkers as compared to those included in the American sample (McQueeny et al., 2009; Squeglia, Jacobus, et al., 2009). A longitudinal study with larger sample size could help detect a gender effect and a causal relationship (Squeglia, Spadoni, Infante, Myers, & Tapert, 2009) between binge drinking and abnormalities in brain function in decision making. To address the concern for potential confounders, we measured a number of personality traits potentially related to binge drinking, including sensation seeking, hostility, aggressiveness, attention deficit hyperactivity disorder, depression, and perceived stress, but we found no confounding effects for these variables in this study. The drinking variables (drinking problem and drinking in the past 30 days) did not correlate with any personality traits in this sample (see Appendix).

Conclusion

In this study we investigated the individual variability of affective decision making among adolescents. This preliminary study suggests that the altered activity of certain neural systems engaged in complex affective decision making, as measured by the IGT, may serve as a neurocognitive marker that signals potential risk and vulnerability to succumbing to more severe drinking at a later age, even in adolescents with relatively brief drinking histories. Thus the current study has important clinical and public health implications for its potential to identify individuals who might be at increased risk for alcoholism. This early identification could be very useful for prevention.

References

Anestis, M. D., Selby, E. A., & Joiner, T. E. (2007). The role of urgency in maladaptive behaviors. *Behaviour Research and Therapy, 45,* 3018–3029. doi:10.1016/j.brat.2007.08.012

Bechara, A. (2005). Decision making, impulse control and loss of willpower to resist drugs: A neurocognitive perspective. *Nature Neuroscience, 8,* 1458–1463. doi:10.1038/nn1584

Bechara, A., & Damasio, A. R. (2005). The somatic marker hypothesis: A neural theory of economic decision. *Games and Economic Behavior, 52,* 336–372. doi:10.1016/j.geb.2004.06.010

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition, 50,* 7–15. doi:10.1016/0010-0277(94)90018-3

Bechara, A., & Damasio, H. (2002). Decision-making and addiction (part I): impaired activation of somatic states in substance dependent individuals when pondering decisions with negative future consequences. *Neuropsychologia, 40,* 1675–1689. doi:10.1016/S0028-3932(02)00015-5

Bechara, A., Damasio, H., & Damasio, A. R. (2003). Role of the amygdala in decision-making. *Annals of the New York Academy of Sciences, 985,* 356–369. doi:10.1111/j.1749-6632.2003.tb07094.x

Bechara, A., Damasio, H., Damasio, A. R., & Lee, G. P. (1999). Different contributions of the human amygdala and ventromedial prefrontal cortex to decision-making. *The Journal of Neuroscience, 19*(13), 5473–5481.

Bechara, A., Tranel, D., & Damasio, H. (2000). Characterization of the decision-making deficit of patients with ventromedial prefrontal cortex lesions. *Brain: A Journal of Neurology, 123,* 2189–2202. doi:10.1093/brain/123.11.2189

BrainVoyager QX 1.9 [Computer software]. Maastricht, The Netherlands: Brain Innovation BV.

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision, 10,* 433–436. doi:10.1163/156856897X00357

Breiter, H. C., Aharon, I., Kahneman, D., Dale, A., & Shizgal, P. (2001). Functional imaging of neural responses to expectancy and experience of monetary gains and losses. *Neuron, 30,* 619–639. doi:10.1016/S0896-6273(01)00303-8

Breiter, H. C., & Rosen, B. R. (1999). Functional magnetic resonance imaging of brain reward circuitry in the human. *Annals of the New York Academy of Sciences, 877,* 523–547. doi:10.1111/j.1749-6632.1999.tb09287.x

Caldwell, L. C., Schweinsburg, A. D., Nagel, B. J., Barlett, V. C., Brown, S. A., & Tapert, S. F. (2005). Gender and adolescent alcohol use disorders on BOLD (blood oxygen level dependent) response to spatial working memory. *Alcohol and Alcoholism, 40,* 194–200. doi:10.1093/alcalc/agh134

Cauffman, E., Shulman, E. P., Steinberg, L., Claus, E., Banich, M. T., Graham, S., & Wollard, J. (2010). Age differences in affective decision making as indexed by performance on the Iowa Gambling Task. *Developmental Psychology, 46,* 193–207. doi:10.1037/a0016128

Cavedini, P., Riboldi, G., Keller, R., D'Annucci, A., & Bellodi, L. (2002). Frontal lobe dysfunction in pathological gambling patients. *Biological Psychiatry, 51,* 334–341. doi:10.1016/S0006-3223(01)01227-6

Contreras, M., Ceric, F., & Torrealba, F. (2007). Inactivation of the interoceptive insula disrupts drug craving and malaise induced by lithium. *Science, 318,* 655–658. doi:10.1126/science.1145590

Costafreda, S. G., Brammer, M. J., David, A. S., & Fu, C. H. (2008). Predictors of amygdala activation during the processing of emotional stimuli: A meta-analysis of 385 PET and fMRI studies. *Brain Research Reviews, 58,* 57–70. doi:10.1016/j.brainresrev.2007.10.012

Crews, F. T., & Boettiger, C. A. (2009). Impulsivity, frontal lobes and risk for addiction. *Pharmacology, Biochemistry and Behavior, 93,* 237–247. doi:10.1016/j.pbb.2009.04.018

Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain.* New York, NY: Crosset/Putnam.

Damasio, A. R. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 351,* 1413–1420. doi:10.1098/rstb.1996.0125

Damasio, H. (2005). *Human brain anatomy in computerized images.* New York, NY: Oxford University Press. doi:10.1093/acprof:oso/9780195165616.001.0001

D'Argembeau, A., Xue, G., Lu, Z. L., Van der Linden, M., & Bechara, A. (2008). Neural correlates of envisioning emotional events in the near and far future. *NeuroImage, 40,* 398–407. doi:10.1016/j.neuroimage.2007.11.025

Ernst, M., Nelson, E. E., Jazbec, S., McClure, E. B., Monk, C. S., Leibenluft, E., . . . Pine, D. S. (2005). Amygdala and nucleus accumbens in responses to receipt and omission of gains in adults and adolescents. *NeuroImage, 25,* 1279–1291. doi:10.1016/j.neuroimage.2004.12.038

Everitt, B. J., & Robbins, T. W. (2005). Neural systems of reinforcement for drug addiction: From actions to habits to compulsion. *Nature Neuroscience, 8,* 1481–1489. doi:10.1038/nn1579

Everitt, B. J., Belin, D., Economidou, D., Pelloux, Y., Dalley, J. W., & Robbins, T. W. (2008). Neural mechanisms underlying the vulnerability to develop compulsive drug-seeking habits and addiction. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 363,* 3125–3135. doi:10.1098/rstb.2008.0089

Fellows, L. K., & Farah, M. J. (2005). Dissociable elements of human foresight: A role for the ventromedial frontal lobes in framing the future, but not in discounting future rewards. *Neuropsychologia, 43,* 1214–1221. doi:10.1016/j.neuropsychologia.2004.07.018

Fischl, B., Sereno, M. I., & Dale, A. M. (1999). Cortical surface-based analysis. II: Inflation, flattening, and a surface-based coordinate system. *NeuroImage, 9,* 195–207. doi:10.1006/nimg.1998.0396

Garavan, H. (2010). Insula and drug cravings. *Brain Structure & Function, 214,* 593–601. doi:10.1007/s00429-010-0259-8

Genovese, C. R., Lazar, N. A., & Nichols, T. (2002). Thresholding of statistical maps in functional neuroimaging using the false discovery rate. *NeuroImage, 15,* 870–878. doi:10.1006/nimg.2001.1037

Giedd, J. N. (2004). Structural magnetic resonance imaging of the adolescent brain. *Annals of the New York Academy of Sciences, 1021,* 77–85. doi:10.1196/annals.1308.009

Giedd, J. N., Lalonde, F. M., Celano, M. J., White, S. L., Wallace, G. L., Lee, N. R., & Lenroot, R. K. (2009). Anatomical brain magnetic resonance imaging of typically developing children and adolescents. *Journal of the American Academy of Child & Adolescent Psychiatry, 48,* 465–470. doi:10.1097/CHI.0b013e31819f2715

Gogtay, N., Giedd, J. N., Lusk, L., Hayashi, K. M., Greenstein, D., Vaituzis, A. C., . . . Thompson, P, M. (2004). Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National Academy of Sciences of the United States of America, 101,* 8174–8179. doi:10.1073/pnas.0402680101

Hare, T. A., Tottenham, N., Galvan, A., Voss, H. U., Glover, G. H., & Casey, B. J. (2008). Biological substrates of emotional reactivity and regulation in adolescence during an emotional go-nogo task. *Biological Psychiatry, 63,* 927–934. doi:10.1016/j.biopsych.2008.03.015

Holland, P. C., & Gallagher, M. (2004). Amygdala-frontal interactions and reward expectancy. *Current Opinion in Neurobiology, 14,* 148–155. doi:10.1016/j.conb.2004.03.007

Joseph, J. E., Liu, X., Jiang, Y., Lynam, D., & Kelly, T. H. (2009). Neural correlates of emotional reactivity in sensation seeking. *Psychological Science, 20,* 215–223. doi:10.1111/j.1467-9280.2009.02283.x

Li, X., Lu, Z. L., D'Argembeau, A., Ng, M., & Bechara, A. (2010). The Iowa Gambling Task in fMRI images. *Human Brain Mapping, 31*(3), 410–423.

McClure, S. M., Laibson, D. I., Loewenstein, G., & Cohen, J. D. (2004). Separate neural systems value immediate and delayed monetary rewards. *Science, 306,* 503–507. doi:10.1126/science.1100907

McQueeny, T., Schweinsburg, B. C., Schweinsburg, A. D., Jacobus, J., Bava, S., Frank, L. R., & Tapert, S. F. (2009). Altered white matter integrity in adolescent binge drinkers. *Alcoholism: Clinical and Experimental Research, 33,* 1278–1285. doi:10.1111/j.1530-0277.2009.00953.x

Naqvi, N. H., & Bechara, A. (2009). The hidden island of addiction: The insula. *Trends in Neurosciences, 32,* 56–67. doi:10.1016/j.tins.2008.09.009

Naqvi, N. H., Rudrauf, D., Damasio, H., & Bechara, A. (2007). Damage to the insula disrupts addiction to cigarette smoking. *Science, 315,* 531–534. doi:10.1126/science.1135926

Nelson, E. E., Leibenluft, L. E., McClure, E. B., & Pine, D. S. (2005). The social re-orientation of adolescence: A neuroscience perspective on the process and its relation to psychopathology. *Psychological Medicine, 35,* 163–174. doi:10.1017/S0033291704003915

Overman, W. H., Frassrand, K., Ansel, S., Trawalter, S., Bies, B., & Redmond, A. (2004). Performance on the IOWA card task by adolescents and adults. *Neuropsychologia, 42,* 1838–1851. doi:10.1016/j.neuropsychologia.2004.03.014

Pelchat, M. L., Johnson, A., Chan, R., Valdez, J., & Ragland, J. D. (2004). Images of desire: Food-craving activation during fMRI. *NeuroImage, 23,* 1486–1493. doi:10.1016/j.neuroimage.2004.08.023

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10,* 437–442. doi:10.1163/156856897X00366

Schweinsburg, A. D., McQueeny, T., Nagel, B. J., Eyler, L. T., & Tapert, S. F. (2010). A preliminary study of functional magnetic resonance imaging response during verbal encoding among adolescent binge drinkers. *Alcohol, 44,* 111–117. doi:10.1016/j.alcohol.2009.09.032

Sevy, S., Burdick, K. E., Visweswaraiah, H., Abdelmessih, S., Lukin, M., Yechiam, E., & Bechara, A. (2007). Iowa gambling task in schizophrenia: A review and new data in patients with schizophrenia and co-occurring cannabis use disorders. *Schizophrenia Research, 92,* 74–84. doi:10.1016/j.schres.2007.01.005

Somerville, L. H., Jones, R. M., & Casey, B. J. (2010). A time of change: Behavioral and neural correlates of adolescent sensitivity to appetitive and aversive environmental cues. *Brain and Cognition, 72,* 124–133. doi:10.1016/j.bandc.2009.07.003

Sowell, E. R., Thompson, P. M., & Toga, A. W. (2004). Mapping changes in the human cortex throughout the span of life. *Neuroscientist, 10,* 372–392. doi:10.1177/1073858404263960

Spear, L. P. (2000). The adolescent brain and age-related behavioral manifestations. *Neuroscience and Biobehavioral Reviews, 24,* 417–463. doi:10.1016/S0149-7634(00)00014-2

SPSS for Windows, Version, 15.0 [Computer software]. Armonk, NY: IBM.

Squeglia, L. M., Jacobus, J., & Tapert, S. F. (2009). The influence of substance use on adolescent brain development. *Clinical EEG and Neuroscience, 40,* 31–38. doi:10.1177/155005940904000110

Squeglia, L. M., Schweinsburg, A. D., Pulido, C., & Tapert, S. F. (2011). Adolescent binge drinking linked to abnormal spatial working memory brain activation: Differential gender effects. *Alcoholism, Clinical and Experimental Research, 35,* 1831–1841. doi:10.1111/j.1530-0277.2011.01527.x

Squeglia, L. M., Spadoni, A. D., Infante, M. A., Myers, M. G., & Tapert, S. F. (2009). Initiating moderate to heavy alcohol use predicts changes in neuropsychological functioning for adolescent girls and boys. *Psychology of Addictive Behaviors, 23,* 715–722. doi:10.1037/a0016516

Steinberg, L. (2010). A dual systems model of adolescent risk-taking. *Developmental Psychobiology, 52*(3), 216–224.

Stevens, J. R. (2002). Schizophrenia: Reproductive hormones and the brain. *The American Journal of Psychiatry, 159,* 713–719. doi:10.1176/appi.ajp.159.5.713

Talairach, J., & Tournoux, P. (1988). *Co-planar stereotaxic atlas of the human brain. 3-dimensional proportional system: An approach to cerebral imaging.* New York, NY: Thieme Medical Publishers.

Tapert, S. F., Schweinsburg, A. D., Barlett, V. C., Brown, S. A., Frank, L. R., Brown, G. G., & Meloy, M. J. (2004). Blood oxygen level dependent response and spatial working memory in adolescents with alcohol use disorders. *Alcoholism: Clinical and Experimental Research, 28,* 1577–1586. doi:10.1097/01.ALC.0000141812.81234.A6

Verdejo-García, A., & Bechara, A. (2009). A somatic-marker theory of addiction. *Neuropharmacology, 56,* 48–62. doi:10.1016/j.neuropharm.2008.07.035

Verdejo-García, A., Pérez-García, M., & Bechara, A. (2006). Emotion, decision-making and substance dependence: A somatic-marker model of addiction. *Current Neuropharmacology, 4,* 17–31. doi:10.2174/157015906775203057

White, H. R., & Labouvie, E. W. (1989). Towards the assessment of adolescent problem drinking. *Journal of Studies on Alcohol, 50*(1), 30–37.

Whiteside, S. P., & Lynam, D. R. (2001). The Five Factor Model and impulsivity: Using a structural model of personality to understand impulsivity. *Personality and Individual Differences, 30,* 669–689. doi:10.1016/S0191-8869(00)00064-7

Whitney, K. A., Fastenau, P. S., Evans, J. D., & Lysaker, P. H. (2004). Comparative neuropsychological function in obsessive-compulsive disorder and schizophrenia with and without obsessive-compulsive symptoms. *Schizophrenia Research, 69,* 75–83. doi:10.1016/j.schres.2003.08.013

Xiao, L., Bechara, A., Cen, S., Grenard, J. L., Stacy, A. W., Gallaher, P., . . . Anderson Johnson, C. (2008). Affective decision-making deficits, linked to a dysfunctional ventromedial prefrontal cortex, revealed in 10th-grade Chinese adolescent smokers. *Nicotine & Tobacco Research, 10,* 1085–1097. doi:10.1080/14622200802097530

Xiao, L., Bechara, A., Grenard, L. J., Stacy, W. A., Palmer, P., Wei, Y., . . . Johnson, C. A. (2009). Affective decision-making predictive of Chinese adolescent drinking behaviors. *Journal of the International Neuropsychological Society, 15,* 547–557. doi:10.1017/S1355617709090808

Xue, G., Lu, Z., Levin, I. P., & Bechara, A. (2010). The impact of prior risk experiences on subsequent risky decision-making: The role of the insula. *NeuroImage, 50,* 709–716. doi:10.1016/j.neuroimage.2009.12.097

Appendix

Partial Correlation Among Psychological Variables and Drinking Problems After Controlling for Age, Gender, and School Type

	Drinking problem	Past 30-day drinking	Perceived stress	Depression	ADHD	Sensation seeking	Hostility	Aggressiveness
Drinking problem		0.56**	0.20	0.11	0.16	−0.04	-0.09	−0.10
Past 30-day drinking			−0.07	0.23	0.22	0.07	0.16	0.20
Perceived stress				0.44*	0.32	0.25	0.29	−0.29
Depression					−0.35	−0.04	−0.49*	−0.06
ADHD						−0.18	0.40*	0.06
Sensation seeking							0.14	0.38
Hostility								0.09

Note. ADHD = attention deficit hyperactivity disorder.
* $p < 0.05$. ** $p < 0.01$.

Received September 20, 2011
Revision received February 21, 2012
Accepted February 22, 2012 ■