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Effects of outcome on the covariance between risk level and brain activity in adolescents with internet gaming disorder

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ABSTRACT

Individuals with internet gaming disorder (IGD) often have impaired risky decision-making abilities, and IGD-related functional changes have been observed during neuroimaging studies of decision-making tasks. However, it is still unclear how feedback (outcomes of decision-making) affects the subsequent risky decision-making in individuals with IGD. In this study, twenty-four adolescents with IGD and 24 healthy controls (HCs) were recruited and underwent functional magnetic resonance imaging while performing the balloon analog risk task (BART) to evaluate the effects of prior outcomes on brain activity during subsequent risky decision-making in adolescents with IGD. The covariance between risk level and activation of the bilateral ventral medial prefrontal cortex, left inferior frontal cortex, right ventral striatum (VS), left hippocampus/parahippocampus, right inferior occipital gyrus/fusiform gyrus and right inferior temporal gyrus demonstrated interaction effects of group by outcome ($P < 0.05$, AlphaSim correction). The regions with interactive effects were defined as ROI, and ROI-based intergroup comparisons showed that the covariance between risk level and brain activation was significantly greater in adolescents with IGD compared with HCs after a negative outcome occurred ($P < 0.05$). Our results indicated that negative outcomes affected the covariance between risk level and activation of the brain regions related to value estimation (prefrontal cortex), anticipation of rewards (VS), and emotional-related learning (hippocampus/parahippocampus), which may be one of the underlying neural mechanisms of disadvantageous risky decision-making in adolescents with IGD.

1. Introduction

Internet gaming disorder (IGD) is defined as persistent and recurrent use of the internet to engage in games, which may lead to significant psychological distress and interfere with daily social life (Young, 1999). IGD is the most prevalent form of internet addiction disorder in Asia (Dong et al., 2012b; Tang et al., 2014; Wu et al., 2013). Reduced risky decision-making ability is one of the most significant behavioral impairments in IGD individuals (Pawlikowski and Brand, 2011; Yao et al., 2015). Risky decision-making is essential for human survival because risk is ubiquitous in the natural world and human life (Hastie, 2001). However, IGD individuals tend to exhibit disadvantageous risky decision-making behavior, partly because of failure to utilize feedback (Pawlikowski and Brand, 2011; Yao et al., 2014). IGD adolescents continue to use internet games despite negative long-term consequences in the social or work domains of life (Pawlikowski and Brand, 2011); which may lead to physical dependence (Brand, 2008; Ersche et al., 2005), and eventually cause psychological, social, and/or work problems similar to other addictions (Young, 1999). Therefore, it is important to investigate the neural mechanisms underlying feedback processing impairments during decision-making in individuals with IGD.

Optimal decision-making often requires the ability to learn from the outcomes of previous choices, rewards or punishments and adjust future choices accordingly (O'Doherty et al., 2003). The neural circuits related to the ability to interpret this feedback in health adults include the dorsal and ventral prefrontal cortex (PFC), striatum, anterior cingulate cortex (ACC), nucleus accumbens and insula (Balasubramani et al., 2015; Ernst and Steinhauser, 2015; Hauser et al., 2015; Kohno et al., 2015; Liu et al., 2011; Rao et al., 2014; Tanabe et al., 2013). An impaired ability to learn from outcomes has been demonstrated in individuals

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with substance dependence disorders (Balconi et al., 2014; Tanabe et al., 2013; Worbe et al., 2014). Studies using the Iowa gambling task (IGT) have identified decreased task performance in substance-dependent individuals, which may indicate deficits in learning from feedback (Balconi et al., 2014; Tanabe et al., 2013). While performing the IGT, activation of the ventral striatum (VS) and medial orbitofrontal cortex (OFC) was found to be deceased in substance-dependent individuals compared to healthy subjects, which may be the underlying neuronal mechanism of these deficits in learning from feedback (Tanabe et al., 2013). A study by Worbe et al. (2014) using an anticipatory risk-taking task found that binge drinkers showed a higher number of risky choices in high-risk losses, and the high-risk attitude in the loss condition was associated with greater activity in the dorsal lateral prefrontal cortex (DLPFC), the lateral OFC, and the superior parietal cortices. Failure to utilize feedback has also been identified in individuals with IGD by both behavioral and neuroimaging studies (Dong et al., 2013; Pawlikowski and Brand, 2011; Yao et al., 2014). For instance, a behavioral study by Yao et al. (2014) found that IGD individuals made more disadvantageous choices during the Game of Dice Task compared with healthy controls (HCs) and that individuals with IGD could not utilize feedback to optimize their decision-making and improve their performance. A fMRI study using a continuous wins-and-losses task found that subjects with IGD exhibited enhanced sensitivity to win and decreased sensitivity to loss (Dong et al., 2013). Although preliminary studies have demonstrated that outcomes may affect brain activation during decision-making in individuals with IGD, no previous studies have focused on the effect of different outcomes on the covariance between risk level and brain activation during the risky decision-making processing in individuals with IGD.

In this study, twenty-four IGD adolescents and 24 HCs were enrolled, and fMRI data were obtained from the participants while performing the Balloon Analog Risk Task (BART) (Lejuez et al., 2002) to investigate the manner in which different outcomes affected the covariance between risk level and brain activation during decision-making processes in adolescents with IGD. The risk level in the BART was represented by the probability of balloon explosion, and task performance depended on to what extent participants learned from different previous outcomes (Kohno et al., 2015; Rao et al., 2014). Thus, the BART may then be adapted to evaluate the effect of previous outcomes on the covariance between brain activation and risk level during subsequent risky decision-making processes. Based on the previous studies that the subjects with IGD failed to utilize feedback(Yao et al., 2014) and exhibited different sensitivity to different outcomes (Dong et al., 2013), we hypothesized that different outcomes would cause different effects on the covariance between risk level and brain activation in feedback-related brain regions, mainly including the PFC and striatum in adolescents with IGD. This study may bring new insights into the understanding of the underlying neuronal mechanisms of impaired risky decision-making ability in adolescents with IGD.

2. Material and method

2.1. Participant selection

In this study, twenty-four male adolescents with IGD and 24 age- and education-matched HCs were recruited. Only male adolescents were enrolled because the prevalence of IGD is substantially higher in men than in women. All participants were recruited based on the findings of diagnostic interviews by a senior psychiatrist. Adolescents with IGD were defined according to the following criteria: five or more "yes" responses to the eight questions on the Young Diagnostic Questionnaire for Internet Addiction (YDQ) (Young, 1998), a score ≥ 50 on Young's Online Internet Addiction Test (IAT), spending an average of four or more hours per day playing internet games, right-handed, no alcohol or drug abuse, no neurologic or psychiatric diseases, and medication-free. The MINI-International Neuropsychiatric Interview (MINI) was used to exclude adolescents with diagnosis of a DSM-IV Axis I disorder. HCs were defined as adolescents not fitting the criteria for an YDQ diagnosis, spending < 2 h/day on the internet, and having an IAT score was <50. Other selection criteria for the HCs were the same as those for the adolescents with IDG. The standard Raven's Progressive Matrices (SPM) was used to test the intelligence quotient (IQ) of all participants. The Barratt Impulsivity Scale (BIS) was used to test the impulsivity of all participants. The Self-Rating Anxiety Scale (SAS) and Self-Rating Depression Scale (SDS) were used to test the levels of anxiety and depression among participants, respectively. Detailed clinical information for the two groups is listed in Table 1.

The protocol of this study was approved by the Ethical Committee of Tianjin Medical University General Hospital, and written informed consent was obtained from each subject according to institutional guidelines.

2.2. Task and procedure

The fMRI-adapted version of the BART used in this study was guided by prior imaging work (Rao et al., 2008). The details of the experimental task have previously been described (Qi et al., 2015). Briefly, the participants were presented a virtual balloon and asked to press one of two buttons to either inflate (pump) the balloon or cash out. Before the experiment, participants were informed that they would receive the equivalent amount of money earned during the experiment. As the balloon was inflated, both the monetary reward and the probability of explosion (risk level) increased. The value of the wagers corresponded to the various balloon sizes, and the cumulative earnings for the tasks were displayed underneath the balloon stimuli. In a trial, participants could stop inflating the balloon at any point to win the wager or keep inflating until the balloon exploded (loss). The maximum number of pumps that participants could use for each balloon was 12. The time of inflation was controlled by a cue (the color of a small circle changing from red to green). After the participants successfully pressed a button, the small circle immediately turned red at a random interval of between 1.5 and 2.5 s and then turned green again to indicate the next inflation. There was a varying 2–4 s interval between trials. Text indicating whether the trial was a "win" or "loss" was presented for 1.5 s. The picture of the exploded balloon was presented for 20 ms. The number of balloons depended on response speed rather than being pre-determined in the experiment. After the experiment, the participants received the equivalent amount of money earned during the experiment.

2.3. Data acquisition

The functional MRI was conducting using a Siemens 3.0 T scanner (Magnetom Verio, Siemens, Erlangen, Germany). A gradient-recalled echo-planar imaging sequence was used with the following parameters: repetition time (TR) = 2000 ms; echo time (TE) = 30 ms; field of view = 220 × 220 mm; matrix = 64 × 64; slice thickness = 4 mm; and slice gap = 1 mm. Through a mirror mounted on the head-coil, the participants viewed the stimuli that was projected onto a screen

Table 1
Demographic and clinical characteristics of subjects (Mean ± SD).

	IGD (N = 24)	HCs (N = 24)	t	P
Age (year)	17.17 ± 3.51	17.42 ± 3.05	−2.263	0.793
Education (year)	10.08 ± 2.98	11.25 ± 2.88	−1.380	0.174
IQ (SPM)	48.92 ± 6.79	48.58 ± 6.26	0.177	0.860
IAT score	70.71 ± 10.76	33.42 ± 7.75	13.852	<0.001
BIS	68.79 ± 11.83	54.13 ± 8.05	5.022	<0.001
SAS	43.13 ± 8.90	35.42 ± 5.02	3.680	0.001
SDS	49.57 ± 5.02	39.38 ± 9.16	3.442	0.001

Two-sample two-tailed t-tests. Significant level is set as $P < 0.05$.
BIS, Barratt impulsivity scale; HCs, healthy controls; IAT, internet addiction test; IGD, internet game disorder; IQ, intelligence quotient; SAS, Self-Rating Anxiety Scale; SDS, Self-rating depression scale; SPM, standard Raven's progressive matrices.