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Diffusion-weighted MRI measures suggest increased white-matter integrity in Internet gaming disorder: Evidence from the comparison with recreational Internet game users

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HIGHLIGHTS

- Recreational game users were selected as control group.
- IGD subjects demonstrated enhanced FA in some brain regions.
- IGD is associated with increased white-matter integrity in reward circuitry and sensory and motor control systems.

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ABSTRACT

Several studies have suggested that Internet gaming disorder (IGD) is related to altered brain white matter integrity. However, seeming inconsistencies exist and may reflect comparison groups not matched well for certain gaming characteristics. In order to address this possible concern, we recruited in the present study individuals with recreational Internet game use (RGU) comprised of individuals who spend similar amounts of time as IGD subjects playing online games without developing IGD. Diffusion tensor imaging data were collected from 42 IGD and 44 RGU subjects. Whole-brain comparisons showed that IGD subjects demonstrated increased fractional anisotropy (FA) in the bilateral anterior thalamic radiation, anterior limb of the internal capsule, bilateral corticospinal tract, bilateral inferior fronto-occipital fasciculus, corpus callosum, and bilateral inferior longitudinal fasciculus. In addition, Internet-addiction severity was positively correlated with FA values. Taken together, we conclude that IGD is associated with measures of increased white-matter integrity in tracts linking reward circuitry and sensory and motor control systems.

1. Introduction

Internet gaming disorder (IGD) is characterized by difficulties in controlling urges to play online games despite significant negative consequences (Dong, Lin, & Potenza, 2015; Dong & Potenza, 2016; Dong, Zhou, & Zhao, 2011; King & Delfabbro, 2014). Although IGD has not yet been officially codified in all manuals of mental health disorders, IGD was included in Section 3 of the DSM-5, a part of the manual containing conditions warranting additional research (Association, 2013; Petry & O'Brien, 2013).

Diffusion tensor imaging (DTI) is a non-invasive MRI-based technique that may characterize microstructural white-matter organization by mapping water diffusion in biological tissues (Basser, 1995; Beaulieu, 2002). Four frequently used diffusion parameters have been regarded as indices of white-matter integrity: fractional anisotropy (FA), axial diffusivity (AD), radial diffusivity (RD) and mean diffusivity

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(MD). FA reflects the directionality of water diffusion and thus may estimate coherence of white-matter fiber tracts (Bosch et al., 2012; Tang et al., 2010). AD may reflect axonal morphological changes (for example, changes in axonal density); RD may reflect characteristics related to myelination (for example, a decrease in RD may reflect an increase in myelination, and vice versa) (Bennett, Madden, Vaidya, & Howard, 2010; Kumar, Nguyen, Macey, Woo, & Harper, 2012; Tang, Lu, Fan, Yang, & Posner, 2012). MD quantifies the overall magnitude of water diffusion. By analyzing FA, RD, AD and MD, insight may be provided into structural differences relating to white-matter measures in clinical and nonclinical groups (Itoh, Melhem, & Folkers, 2000; Mukherjee et al., 2002; Pierpaoli, Jezzard, Basser, Barnett, & Di Chiro, 1996; Thurnher et al., 2005).

Data suggest that although many long axonal connections are established in early brain development, the diameter and microtubular structure of axons may continue to develop through adulthood (Sagi et al., 2012) and may be affected by experience, environment and psychiatric disorders (Atkinson-Clement, Pinto, Eusebio, & Coulon, 2017; Dong, Li, and Potenza, 2017; McSweeney, Reuber, & Levita, 2017). In prior studies, IGD has been associated with functional impairments and behavioral problems (Dong, Li, Wang, and Potenza, 2017; Dong, Wang, Du, and Potenza, 2017; Wang et al., 2017). However, the extent to which features may relate to white-matter measures is not well understood.

Some recent reports have described seemingly contradictory DTI results in studies of IGD. For example, Xing et al. (2014) found decreased FA in tracts within a salience network in adolescents with IGD as compared to those without IGD. Consistently, Yuan et al. (2011) found decreased FA within the right para-hippocampal gyrus in individuals with IGD. Further, Lin et al. (2012) found deceased FA value in regions including the OFC, corpus callosum, cingulum, inferior fronto-occipital fasciculus, corona radiata, and internal and external capsules. All of these studies suggest decreased white matter integrity in IGD. However, contrary to these results, Jeong et al. (2016) found that IGD subjects showed increased FA values in the right longitudinal fasciculus and decreased RD in the anterior thalamus, as compared to healthy control subjects. In line with these results, Dong, DeVito, Huang, and Du (2012) found increased FA in the thalamus and left posterior cingulate cortex in IGD subjects (Dong et al., 2012).

Explanations for these seemingly discrepant results may be attributable to multiple factors. For example, decreased FA in regions relating to executive control functions may relate to poor cognitive control observed in IGD (Dong et al., 2015). On the other hand, increased FA in regions relating to reward-related drives or craving might potentiate aspects of IGD (Dong, Li, Wang, and Potenza, 2017; Dong, Wang, Du, and Potenza, 2017). In line with this notion, habitual gaming has been found to be positively associated with gray matter in the striatum (Kühn et al., 2011) and reliance on behaviors involving the striatum (West et al., 2015), which may relate to aspects of reward sensitivity and craving. Methodological confounds also warrant consideration. One potential confound relates to differences in time spent participating in online gaming between IGD and comparison groups. Specifically, data were collected from and compared between IGD subjects and healthy comparison (HC) subjects, with the latter typically having spent considerably fewer hours gaming. Repetitive and more frequent engagement in gaming behaviors could increase connections between brain areas responsible for visual and auditory processing and motor control. These improved connections may be reflected in measures associated with increased white-matter integrity. Thus, studying a non-IGD group with similar durations of game-playing time as a group of individuals with IGD but without significant gaming-related problems may overcome this limitation and provide greater insight into IGD.

In the present study, we recruited individuals with recreational Internet game use (RGU) as comparison subjects. Previous studies have defined RGU as a group recreational gaming without the development of problems (Griffiths, 2010; King, Delfabbro, & Zajac, 2011; Kuss & Griffiths, 2012). Specifically, individuals with RGU play online games regularly without experiencing impaired control over online game playing or the negative consequences relating to problematic gaming (Desai, Krishnan-Sarin, Cavallo, & Potenza, 2010). The inclusion of an RGU group removes a confound relating to differences in time and familiarity with gaming.

As previous studies of IGD and RGU subjects have associated IGD with impaired executive control (Dong, Wang, Du, and Potenza, 2017; Wang et al., 2017), we hypothesized that white matter in regions involved in executive-control circuitry would show decreased integrity in individuals with IGD relative to those with RGU, especially in the cingulate and medial frontal cortex. IGD has also been associated with increased reward sensitivity relative to RGU (Dong, Li, Wang, and Potenza, 2017; Dong, Wang, Du, and Potenza, 2017). Therefore, we hypothesized to observe measures associated with better white-matter integrity in reward circuitry in individuals with IGD relative to those with RGU.

2. Experimental procedures

2.1. Subjects

The experiment conforms to The Code of Ethics of the World Medical Association (Declaration of Helsinki). The Human Investigations Committee of Zhejiang Normal University approved this research. Eighty-six participants who were university students were recruited through advertisements (42 IGD, 44 RGU). Demographic information is presented in Table 1. All participants provided written informed consent and underwent structured psychiatric interviews (using the MINI (Lecrubier et al., 1997)) performed by an experienced psychiatrist. All participants were free of psychiatric disorders (including major depression, anxiety disorders, schizophrenia, and substance dependence disorders) as assessed by the MINI (Lecrubier et al., 1997), and depression measured by the Beck Depression Inventory (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961). All participants were medication-free and were instructed not to use any substances, such as coffee, on the day of scanning. To control for types for gaming, we only recruited subjects (IGD and RGU) who regularly played League of Legends (LOL) (Riot Games, Inc.) and played the game for at least

Table 1
Demographic information and group differences.

	IGD N = 42	RGU N = 44	*T*	*p*
Age (Mean ± SD)	21.42 ± 1.31	21.53 ± 1.27	0.14	0. 861
BDI score (Mean ± SD)	2.27 ± 0.91	2.03 ± 0.85	1.23	0.192
IAT score (Mean ± SD)	65.52 ± 10.92	37.21 ± 10.21	6.21	0.000***
DSM-5 score (Mean ± SD)	5.92 ± 1.14	2.58 ± 1.25	9.38	0.000***
Game playing per week (Hours) (Mean ± SD)	19.29 ± 9.25	20.65 ± 9.31	− 0.49	0.579

IGD, Internet gaming disorder; RGU, recreational game use; BDI, Beck Depression inventory; IAT, Internet addiction test.
*** $p < 0.001$.