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Internet addiction
Neuroimaging findings

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The Internet has so radically changed the way we conduct our lives for a long time. However, maladaptive use of the internet has resulted in impairment of the individual's psychological well-being, academic failure and reduced work performance. While not yet officially codified within a psychopathological framework, Internet addiction disorder (IAD) is growing both in prevalence and within the public consciousness as a potentially problematic condition with many parallels to existing recognized disorders. Neuroimaging is a noninvasive way to reveal altered regional cerebral activity and structural changes. As there has been a recent rise in IAD, here, we review some of the neuroimaging IAD studies and discuss these findings.

Recently, Internet addiction disorder (IAD) or Problematic Internet use[1-7] has attracted research interests across the whole world. IAD appears to be a common disorder that merits inclusion in DSM-V[5,8] and is usually defined as the inability of an individual to control his/her use of the Internet, eventually causing psychological, social, and/or work difficulties.[5] It is commonly associated with depression, anger problems and anxiety disorders.[2,8] While not yet officially codified within a psychopathological framework,[9] IAD is growing both in prevalence and within the public consciousness as a potentially problematic condition with many parallels to existing recognized disorders. Understanding the biological effects of IAD on the human brain may provide insight into the pathogenesis of IAD and treatment. Although there is much debate on the diagnostic definition of IAD, emerging neuroimaging studies had been performed around the world, especially in eastern Asian nations. Numerous neuroimaging studies had highlighted structural and functional abnormalities in individuals with IAD similar to other type of addictive disorders, such as substance addiction and behavioral addiction.[8,10-19]

PET Findings

Park et al. investigated the differences of regional cerebral glucose metabolism during resting state between young individuals with IAD and normal controls using ^{18}F-fluorodeoxyglucose positron emission tomography (PET) study.[14] The imaging results showed that the IAD group had increased glucose metabolism in the right OFC, the left caudate nucleus, and the right insula and decreased metabolism in the bilateral postcentral gyrus, the left precentral gyrus, and the bilateral occipital regions compared with normal users. Subsequently, the same group had also examined the neurobiological alterations in individuals with IAD of the dopaminergic neural system by assessing dopamine D2 receptor binding potential in men with and without IAD.[20] Individuals with IAD showed reduced levels of dopamine D2 receptor availability in subdivisions of the striatum including the bilateral dorsal caudate and the right putamen. Furthermore, the significant inverse correlations between the severity of IAD and the dopamine D2 receptor availability in the left dorsal caudate, the bilateral dorsal putamen were observed. These regions implicated in impulse control, reward processing are frequently mentioned in behavioral addiction and drug addiction.[21-24] Therefore, the authors suggested that IAD shares psychological and neural mechanisms with drug addiction.

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EEG Findings

Dong et al.[13] investigated response inhibition in people with IAD by recording event-related brain potentials during a Go/NoGo task and showed that the IAD group exhibited a lower NoGo-N2 amplitude, higher NoGo-P3 amplitude and longer NoGo-P3 peak latency than the normal group. They suggested that the IAD subjects had lower activation in the conflict detection stage than the normal group; thus, they had to engage in more cognitive endeavors to complete the inhibition task in the late stage. In addition, the IAD subjects showed less efficiency in information processing and lower cognitive control.[13] The same group also assessed the executive control ability by recording event-related potentials (ERP) during a color-word Stroop task.[25] Behavior results showed that IAD students were associated with longer reaction time and more response errors in incongruent conditions than the control group. ERP result revealed that participants with IAD showed reduced medial frontal negativity (MFN) deflection in incongruent conditions than the control group. Both of the behavioral performance and ERP results indicated that people with IAD showed impaired executive control ability than the normal group.

MRI Findings

Functional. Craving had been defined as the accompanied emotional state or a strong desire that is produced by conditioned stimuli that are associated with the reward effects of substance or behavior.[26] Craving has been regarded as the central phenomenon of substance use disorder and the underlying neural mechanism of the craving is critical to the treatment. The cue-reactivity has been employed to evaluate craving for IAD. Ko et al.[15] identified the neural substrates of online gaming addiction via evaluation of the brain areas associated with the cue-induced gaming urge, which consisted of the right OFC, the right nucleus accumbens (NAc), the bilateral anterior cingulated cortex (ACC), the medial frontal cortex, the right dorsolateral prefrontal cortex (DLPFC), and the right caudate nucleus. Due to the similarity of the cue-induced craving in substance dependence, they suggested that the gaming urge/craving in online gaming addiction and craving in substance dependence might share the same neurobiological mechanisms.

The reward system is thought to play a crucial role in the development and maintenance of drug addiction and drug addicts often showed a deficient reward system.[22,27] To investigate the reward and punishment processing in IAD, Dong et al. scanning the brain of the individuals with IAD and controls when they received a guessing task.[28] The results showed that Internet addicts associated with increased activation in orbitofrontal cortex in gain trials and decreased anterior cingulate activation in loss trials than normal controls. The results suggested that Internet addicts have enhanced reward sensitivity and decreased loss sensitivity than normal comparisons.

Some researchers also detected resting-state abnormalities[11] in IAD subjects and detected the increased regional homogeneity (ReHo) in the right cingulate gyrus, the bilateral parahippocampus and some other brain regions.

Structural. Voxel-based morphometry (VBM) [29] is an automated method that allows the structural comparison of white and gray matter between patients and controls. Zhou et al.[12] employed the VBM method and revealed the lower gray matter density in the left ACC, the left posterior cingulate cortex, the left insula and left lingual gyrus.[12] This is the first study showing the brain structural changes in IAD adolescents and provides a new insight into the pathogenesis of IAD. However, they failed to detect the relationship between these structural changes and the duration of IAD. Therefore, more subjects and reliable controls were enrolled in our study,[30] the results indicated atrophy within several clusters for the entire group of internet addicts, which were the bilateral DLPFC, the supplementary motor area (SMA), the cerebellum, OFC and the left rACC. Moreover, the atrophy of the right DLPFC, the left rACC and the right SMA was negatively correlated with the duration of IAD. These brain structural abnormalities of the individuals with IAD may be, at least in part, associated with cognitive control and goal-directed behavior dysfunctions in internet, which may explain fundamental symptoms of internet addiction.

Diffusion tensor imaging (DTI) [31] is an MRI technique that allows visualization of the orientation and anisotropy of white matter. Because DTI can detect microstructural changes, it is thought to be more sensitive than conventional MRI techniques in identification of brain structural damage. Our results revealed enhanced fractional anisotropy (FA) values of the left posterior limb of the internal capsule (PLIC) in IAD subjects compared with healthy controls and reduced FA value in the white matter within the right parahippocampal gyrus (PHG). The abnormal FA value of the left PLIC may influence the sensory information transfer and processing, and finally lead to impairments in cognitive control. The lower FA value of the PHG in IAD subjects demonstrated that abnormal white matter properties maybe the structural basis of functional deficits of working memory in IAD subjects.

Conclusions

Neuroimaging studies have contributed significantly to our understanding of the effect of IAD on the brain and illustrate the broad range of brain regions involved. As outlined in this paper, the neuroimaging findings suggested that the IAD shared the similar neurobiological mechanisms of substance addiction and behavioral addiction. These noninvasive methods will play important roles in the investigation of neurobiological mechanism and adequate treatments of IAD and drug abuse. Longitudinal design and multiple imaging techniques with behavioral measurements should be necessary to improve our understanding of IAD.

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