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REVIEW ARTICLE

Gaming disorder: Neural mechanisms and ongoing debates

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ABSTRACT

Background and aims: The inclusion of gaming disorder as a new diagnosis in the 11th revision of the International Statistical Classification of Diseases (ICD-11) has caused ongoing debate. This review aimed to summarise the potential neural mechanisms of gaming disorder and provide additional evidence for this debate. *Methods:* We conducted a comprehensive literature review of gaming disorder, focusing on studies that investigated its clinical characteristics and neurobiological mechanisms. Based on this evidence, we further discuss gaming disorder as a psychiatric disorder. *Results:* The present review demonstrated that the brain regions involved in gaming disorder are related to executive functioning (e.g., anterior cingulate cortex and dorsolateral prefrontal cortex), reward systems (e.g., striatum and orbitofrontal cortex), and emotional regulation (e.g., insula and amygdala). Despite the inclusion of gaming disorder in the ICD-11, the debate remains on the benefits and harms of classifying it as a mental health disorder. Opponents argue that the current manifestations that support gaming disorder as a psychiatric disorder remain inadequate, it could cause moral panic among healthy gamers, and that the label of gaming disorder is stigmatising. *Discussion:* Evidence suggests that gaming disorder shares similar neurobiological alterations with other types of behavioural and substance-related addictions, which further supports gaming disorder as a behavioural addiction. Ongoing debates on whether gaming disorder is a psychiatric disorder push for further exploring the nature of gaming disorder and resolving this dilemma in the field.

KEYWORDS

gaming disorder, gaming addiction, behavioural addiction, neurobiology, neural mechanisms, ongoing debate

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INTRODUCTION

Gaming disorder (GD) has been a topic of increasing debate over the past two decades. In 2019, the World Health Organization (WHO) included GD as a new mental health disorder in the 11th revision of the International Statistical Classification of Diseases (ICD-11; WHO, 2019). In the ICD-11, GD is characterised by impaired control over gaming, prioritisation of gaming over other activities, and continuation or escalation of gaming despite the occurrence of negative consequences (World Health Organization, 2019). These symptoms are normally evident for at least 12 months, although the required duration may be shortened if the symptoms are severe. With the official recognition of gaming disorder, further research on this topic is expected to gain support (King & Potenza, 2019).

A growing body of literature has focused on the mechanisms underlying GD and reported that GD has neurobiological alterations similar to those typically seen in other addictions. One review summarised the neurobiological mechanisms underlying internet gaming disorder (IGD) and reported that the following alterations are involved: (i) activation of brain regions related to reward, (ii) reduced activity in impulse control areas and decision-making, and (iii) reduced functional connectivity in brain networks involved in cognitive control, executive function, motivation, and reward. Additionally, there are structural alterations such as a reduction in grey matter volume and white matter density (Weinstein & Lejoyeux, 2020). Evidence also suggests that GD shares similar neurobiological mechanisms with addiction, further suggesting that it is a pathological disease (Weinstein, Livny, & Weizman, 2017).

In 2013, IGD was included in the Section 3 Appendix of the Fifth Edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Publishing, 2013) and classified as a behavioural addiction with gambling disorder. Similarly, GD was classified with gambling disorder in the ICD-11 under "disorders due to addictive behaviours", which may be online or offline. Despite the inclusion of GD in the ICD-11, the associated concepts and present diagnosis of GD are still under debate among individuals from the medical, scientific, and gaming communities. Whether GD is a psychiatric disorder remains controversial and there is no consensus on its status. Many scholars and experts are convinced that GD is a behavioural addiction based on its (i) clinical features, (ii) underlying neurobiological evidence, and (iii) public demand for treatment (Kiraly & Demetrovics, 2017; Király, Griffiths, & Demetrovics, 2015; Rumpf et al., 2018; Saunders et al., 2017). However, opponents argue that current manifestations of GD remain inadequate, it could cause moral panic among healthy gamers, and the label of gaming disorder is stigmatising (Aarseth et al., 2017). Specifically, the inclusion of GD as a mental disorder still lacks the requisite scientific support and sufficient clinical applicability as a recognised diagnostic category (King, Billieux, Carragher, & Delfabbro, 2020; van Rooij et al., 2018). Formalising GD may offer some benefits, yet these do not outweigh the wider social and public health risks.

The purpose of this review was to summarise the clinical characteristics and neurobiological mechanisms of GD and compare these characteristics with those of other types of addiction, including both behavioural and substance-related addictions. Based on this evidence, we discuss the debate on GD as a psychiatric disorder.

EPIDEMIOLOGY, CLINICAL CHARACTERISTICS, AND NEGATIVE CONSEQUENCES OF GAMING DISORDER

The prevalence of gaming disorders varies between countries and regions. Systematic reviews and meta-analyses have reported that the worldwide prevalence of IGD ranges from 3.05% to 4.06%, although the prevalence tends to be lower among higher-quality studies (e.g., nationally representative surveys) (Fam, 2018; Stevens, Dorstyn, Delfabbro, & King, 2021). Nevertheless, diverse confounding variables, such as sampling techniques, sample types, assessment instruments, age, region, and cultural factors, can considerably influence the prevalence of GD (Kim et al., 2022). It has also been reported that the prevalence of IGD is higher among adolescents, with estimates of 10%–15% in Asian countries and 1%–10% in several Western countries (Mihara & Higuchi, 2017; Saunders et al., 2017). Furthermore, the COVID-19 pandemic has changed people's lifestyles, and GD appears to be a potential health issue during the COVID-19 pandemic. The prevalence of GD was estimated to range from 5.3% to 8.3% during the COVID-19 period (Alimoradi, Lotfi, Lin, Griffiths, & Pakpour, 2022; Meng et al., 2022).

Individuals with GD generally exhibit symptoms such as withdrawal, tolerance, and unsuccessful attempts to control gaming, despite knowing its adverse consequences (Király, Koncz, Griffiths, & Demetrovics, 2023). These features strongly overlap with core characteristics of other substance-related addictions (Potenza, 2006; Yau, Crowley, Mayes, & Potenza, 2012). Clinical symptoms of withdrawal mainly comprise affective symptoms, such as irritability, anxiety, and sadness, which are common in GD (Yen, Lin, Wu, & Ko, 2022). However, withdrawal symptoms have not been reported or identified in some cases, such as in a previous study of treatment-seeking gamers (Kaptsis, King, Delfabbro, & Gradisar, 2016). In addition, adolescents with GD have characteristics similar to those with substance use disorders, such as high behaviour activation (Ko et al., 2008), novelty seeking, and low reward dependence (Ko, Yen, Yen, Chen, & Chen, 2012).

The negative consequences of GD further support the argument that the behaviour could be a mental health disorder. GD is typically comorbid with other mental health disorders. For example, one meta-analysis revealed that GD is strongly associated with depression, anxiety, attention-deficit hyperactivity disorder, and social phobia, with depression having the strongest association (Carli et al., 2013;

Gonzalez-Bueso et al., 2018). GD has also been reported to be associated with an increase in suicidality, even after adjusting for potential confounding variables such as depression (Cheng et al., 2018). Psychological complications related to GD (but which are not comorbid disorders) include sleep disturbances, reduced working productivity, decreased cognitive ability, and difficulties with interpersonal relationships (Kuss & Griffiths, 2011). Other reported detrimental effects include school burnout and some unexpected deaths due to exhaustion caused by playing games for excessive periods (Salmela-Aro, Upadyaya, Hakkarainen, Lonka, & Alho, 2017). These significant clinical features and the severity of their consequences contributed to the inclusion of GD in the ICD-11. It was also thought that the decision to establish a new diagnostic category of GD as a mental health disorder in the ICD-11 would facilitate more appropriate diagnosis and treatment (Lin & Kim, 2019).

NEUROLOGICAL MECHANISMS UNDERLYING GAMING DISORDER

The neurological mechanisms underlying GD have been widely explored, with the following regions involved: those related to executive functioning (e.g., anterior cingulate cortex [ACC] and dorsolateral prefrontal cortex [DLPFC]), reward systems (e.g., striatum and orbitofrontal cortex [OFC]), and emotional regulation (e.g., insula and amygdala) (Fig. 1). A summary of resting-state, structural, and task-related functional connectivity studies concerning GD is presented in Tables 1 and 2.

Alteration of brain areas related to executive function (mainly ACC and DLPFC)

It has been widely reported that GD is associated with alterations in brain areas related to executive function, mainly the ACC and DLPFC (Wang et al., 2016). The ACC is the frontal part of the cingulate cortex and plays a role in specific higher-level functions, including reward anticipation, decision-making, impulse control, and emotion regulation. The DLPFC is an area of the prefrontal cortex (PFC) in the brains of humans and nonhuman primates. The DLPFC is recognised for its involvement in executive functioning, a comprehensive term for the management of cognitive processes.

Individuals with GD generally exhibit lower grey matter and white matter densities in the ACC than healthy controls (Lee et al., 2021b; Sun et al., 2023; Zhou et al., 2011). Moreover, compared to healthy controls, individuals with IGD exhibit stronger functional connectivity between the

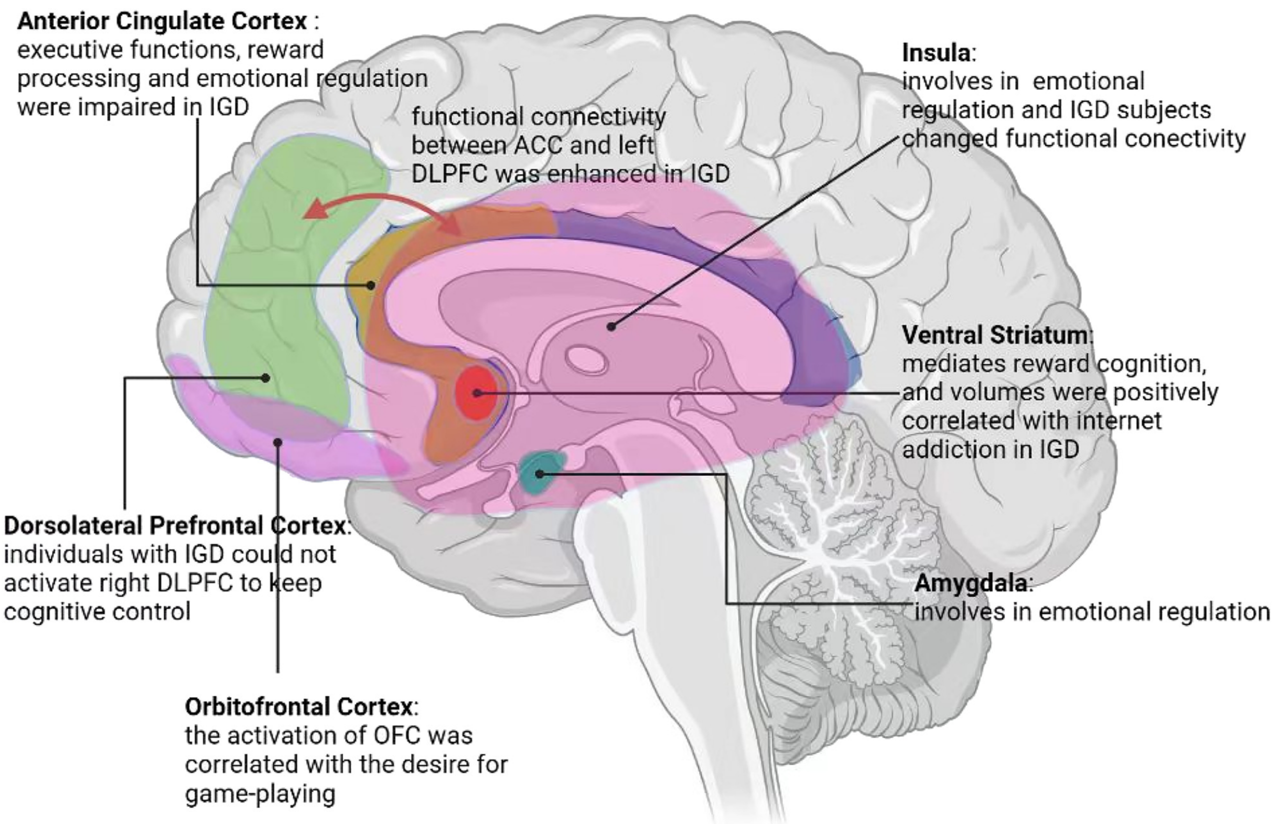

Fig. 1. **Alterations of brain areas related to gaming disorders.** The following brain regions are related to gaming disorders: 1) executive function: ACC and DLPFC; functional connectivity between ACC and left DLPFC also played an important role in gaming disorder; 2) reward system: striatum and OFC; and 3) emotional regulation: insula and amygdala. ACC, anterior cingulate cortex; DLPFC, dorsolateral prefrontal cortex; IGD, internet gaming disorder; OFC, orbitofrontal cortex

Table 1. Structural and resting state functional connectivity of gaming disorder

Reference	Nation	Participants	Methods	Main findings
Yuan et al. (2014)	China	18 adolescence with OGA and 18 controls	Structure	Increased cortical thickness in the left precentral cortex, precuneus, middle frontal cortex, inferior temporal and middle temporal cortices; decreased cortical thicknesses of the left lateral OFC, insula, lingual gyrus, the right postcentral gyrus, entorhinal cortex and inferior parietal cortex.
Lin et al. (2015)	China	36 HCs, and 35 IGA participants	VBM	Lower GMD in the bilateral IFG, left cingulate gyrus, insula, right precuneus, and right hippocampus, lower white matter density in the IFG, insula, amygdala, and ACC.
Seok and Sohn (2018)	Korea	20 individuals with IGD and 20 HCs	VBM	IGD severity was positively correlated with GMV in the left caudate, and negatively associated with functional connectivity between the left caudate and the right middle frontal gyrus.
Chen et al. (2021)	China	230 young adults	VBM	Individuals with greater IGD severity had increased GMV in the midline components of the DMN, namely, the right mPFC and precuneus. Structural covariance network results revealed impaired patterns of structural covariance between the DMN-related regions and areas associated with visuospatial attention and reward craving processing as the addiction severity of IGD worsened.
Weng et al. (2013)	China	17 participants with OGA and 17 controls	VBM/ DTI	OGA individuals showed significant gray matter atrophy in the right OFC, bilateral insula, and right SMA, and reduced FA in the right genu of corpus callosum, bilateral frontal lobe white matter, and right external capsule.
Wei et al. (2021)	China	49 IGD patients and 52 normal controls	VBM/ DTI	IGD group had greater synchronizability and modal controllability compared to that of the control group, and different morphological-based brain communities had different controllability properties.
Lee et al. (2021a)	Korea	18 young males with IGD and 18 controls	VBM/ RSFC	Participants with IGD had smaller GMV in the ACC and middle cingulate cortex compared with controls during initial and follow-up assessments. They exhibited decreased functional connectivity between the left dorsal putamen and left mPFC compared with controls, and increased functional connectivity strength between the right dorsal putamen and right middle occipital gyrus during follow-up.
Dong et al. (2012)	China	16 IGD and 15 healthy controls	DTI	IGA subjects showed higher FA, indicating greater white matter integrity, in the thalamus and left PCC relative to healthy controls.
Jeong, Han, Kim, Lee, and Renshaw (2016)	Korea	58 IGD participants without psychiatric co-morbidity as well as 26 male healthy comparison participants	DTI	Increased FA values within forceps minor, right anterior thalamic radiation, right corticospinal tract, right inferior longitudinal fasciculus, right cingulum to hippocampus and right IFOF as well as parallel decreases in radial diffusivity value within forceps minor, right anterior thalamic radiation and IFOF.
Dong et al. (2018a)	China	42 IGD and 44 RGU participants	DTI	Increased 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.
Rahmani, Sanjari Moghaddam and Aarabi (2019)	Iran	123 healthy adults	DTI	A direct correlation between connectivity in the splenium of CC, parts of bilateral corticospinal tracts, and bilateral arcuate fasciculi, and an inverse correlation of the connectivity in the genu of CC and right fornix.
Wang et al. (2019b)	China	33 IGD and 28 HCs	DTI/ RSFC	Both the NAc and mOFC showed lower RSFC with VTA in IGD participants compared with controls. The IGD participants also showed lower structural connectivity in bilateral VTA-NAc tracts compared with controls.
Dong et al. (2012)	China	15 IGA participants and 14 HCs	RSFC	Enhanced ReHo in brainstem, inferior parietal lobule, left posterior cerebellum, and left middle frontal gyrus. In addition, IGA participants show decreased ReHo in temporal, occipital and parietal brain regions.

(continued)

Table 1. Continued

Reference	Nation	Participants	Methods	Main findings
Ding et al. (2013)	China	17 adolescents with IGA and 24 normal control	RSFC	Increased functional connectivity in the bilateral cerebellum posterior lobe and middle temporal gyrus, and decreased functional connectivity bilateral inferior parietal lobule and right inferior temporal gyrus. Connectivity with the PCC was positively correlated with CIAS scores in the right precuneus, PCC, thalamus, caudate, NAc, SMA, and lingual gyrus. It was negatively correlated with the right cerebellum anterior lobe and left superior parietal lobule.
Dong et al. (2015b)	China	35 IGD and 36 HCs	RSFC	IGD participants show decreased functional connectivity in the ECN and increased functional connectivity in the reward network when comparing with the HCs. When examining the correlations between the NAc and the executive control/ reward networks, the link between the NAc - ECN is negatively related with the link between NAc - reward network.
Hong et al. (2015)	Korea	12 male adolescents with IGD and 11 matched HCs	RSFC	Reduced dorsal putamen functional connectivity with the posterior insula-parietal operculum. More time spent playing online games predicted significantly greater functional connectivity between the dorsal putamen and bilateral primary somatosensory cortices, and significantly lower functional connectivity between the dorsal putamen and bilateral sensorimotor cortices in HCs.
Kim et al. (2015)	Korea	16 participants with IGD, and 15 HCs	RSFC	Increased ReHo in the PCC, and decreased ReHo in the right superior temporal gyrus. Scores on Internet addiction severity were positively correlated with ReHo in the medial frontal cortex, precuneus/PCC, and left inferior temporal cortex.
Ko et al. (2015)	China	30 males with IGD and 30 controls	RSFC	A lower GMD over the bilateral amygdala; lower functional connectivity with the left amygdala over the left DLPFC and with the right amygdala over the left DLPFC and orbital frontal lobe. They also had higher functional connectivity with the bilateral amygdala over the contralateral insula than the controls.
Lin et al. (2015)	Chinar	26 IGD, 26 HCs	RSFC	Decreased fALFF values in the cerebellum posterior lobe and increased fALFF values in superior temporal gyrus. Significant interactions between frequency bands and groups were found in the cerebellum, the ACC, the lingual gyrus, the middle temporal gyrus, and the middle frontal gyrus.
Wang et al. (2015)	China	17 participants with IGD and 24 HCs	RSFC	Decreased VMHC between the left and right superior frontal gyrus, IFG, middle frontal gyrus and superior frontal gyrus. Further analyses showed CIAS-related VMHC in superior frontal gyrus and CIAS.
Zhang et al. (2015)	China	35 male participants with IGD and 24 HCs	RSFC	Individuals with IGD had significantly decreased RSFC between the VTA and right NAc. RSFC strength between the VTA and right NAc was negatively correlated with self-reported subjective craving for the Internet.
Chen et al. (2016)	China	30 males with IGD and 30 controls	RSFC	A lower functional connectivity with the left insula over the left DLPFC and orbital frontal lobe and a higher functional connectivity with the insula with the contralateral insula. The inter-hemispheric insula connectivity positively correlated with impulsivity. Further, they had lower functional connectivity with the left NAc over the left DLPFC and with the right NAc over the left DLPFC, and insula and a higher functional connectivity with that over the right precuneus.
Liu et al. (2016)	China	19 IGD individuals and 19 matched HCs	RSFC	Increased activation in the right superior parietal lobule, right insular lobe, right precuneus, right cingulated gyrus, right superior temporal gyrus, and left brainstem.

(continued)

Table 1. Continued

Reference	Nation	Participants	Methods	Main findings
Park et al. (2016)	Korea	24 adults with OGA	RSFC	At baseline, the OGA group showed a smaller ALFF within the right middle frontal gyrus and reduced functional connectivity in the cortico-striatal-limbic circuit. In the virtual reality therapy group, connectivity from the PCC seed to the left middle frontal and bilateral temporal lobe increased after intervention.
Wang et al. (2016)	China	37 IGD participants and 35 matched HCs	RSFC	Reduced regional centralitiecs in the PFC, left PCC, right amygdala, and bilateral lingual gyrus, and increased functional connectivity in sensory-motor-related brain networks compared to the HC participants.
Zhang et al. (2016a)	China	74 young adults with IGD and 41 age- and gender-matched healthy control participants	RSFC	Enhanced RSFC between the anterior insula and a network of regions including ACC, putamen, angular gyrus, and precuneous; stronger RSFC between the posterior insula and postcentral gyrus, precentral gyrus, SMA, and superior temporal gyrus (STG). Furthermore, IGD severity was positively associated with connectivity between the anterior insula and angular gyrus, and STG, and with connectivity between the posterior insula and STG. Duration of Internet gaming was positively associated with connectivity between the anterior insula and ACC.
Zhang et al. (2016b)	China	36 young adults with IGD and 19 healthy comparison	RSFC	The results showed that IGD participants showed decreased amplitude of low fluctuation in the OFC and PCC, and exhibited increased RSFC between the PCC and DLPFC, compared with HC participants. Compared with IGD participants who did not receive the intervention, those receiving CBI demonstrated significantly reduced RSFC between the: (i) OFC with hippocampus/parahippocampal gyrus; and (ii) PCC with SMA, precentral gyrus, and postcentral gyrus.
Zhang et al. (2016c)	China	19 IGD participants and 19 HCs	RSFC	Decreased functional connectivity between left posterior insula and bilateral SMA and middle cingulated cortex, between right posterior insula and right superior frontal gyrus, and decreased functional integration between insular subregions.
Du et al. (2017)	China	27 male IGD adolescents and 35 demographically matched HCs	RSFC	The IGD adolescents exhibited higher global/long-range RSFC in the bilateral DLPFC and the right inferior temporal cortex/fusiform compared with the HCs.
Ge et al. (2017)	China	27 IGD, 29 smokers with nicotine dependence, and 33 HCs	RSFC	The IGD and smokers with nicotine dependence groups showed decreased RSFC with DLPFC in the right insula and left IFG with DLPFC. Compared with smokers with nicotine dependence group, the IGD participants exhibited increased RSFC in the left inferior temporal gyrus and right inferior orbital frontal gyrus and decreased RSFC in the right middle occipital gyrus, supramarginal gyrus, and cuneus with DLPFC.
Han et al. (2017)	Korea	78 adolescents with IGD and 73 comparison participants, subgroups with no other psychiatric comorbid disease, with MDD and with ADHD	RSFC	Patients with IGD showed an increased functional correlation between seven pairs of regions: left frontal eye field to dorsal ACC, left frontal eye field to right anterior insula, left DLPFC to left temporoparietal junction, right DLPFC to right temporoparietal junction, right auditory cortex to right motor cortex, right auditory cortex to SMA and right auditory cortex to dorsal ACC.
Lee et al. (2017)	Korea	44 young, male IGD participants with and without childhood ADHD and 19 age-matched, healthy male controls	RSFC	IGD participants without childhood ADHD showed expanded functional connectivity between DMN-related regions (PCC, mPFC, thalamus) compared with controls. These participants also exhibited expanded functional connectivity between the PCC and brain regions implicated in salience processing (anterior insula, OFC) compared with IGD participants with childhood ADHD. IGD participants with childhood ADHD showed expanded functional connectivity between the PCC and cerebellum, a region involved in executive control.

(continued)

Table 1. Continued

Reference	Nation	Participants	Methods	Main findings
Yuan et al. (2017)	China	43 young IGD individuals and 44 HCs	RSFC	In IGD participants, we demonstrated an increased volume of right caudate and NAc as well as reduced RSFC strength of DLPFC-caudate and OFC-NAc. The caudate volume and DLPFC-caudate RSFC was correlated with the impaired cognitive control in IGD.
Lee et al. (2018)	Korea	21 male young adults with IGD with comorbid depression (IGDdep + group), 22 male young adults without IGD with comorbid depression (IGDdep- group), and 20 male HCs	RSFC	Both IGD groups had stronger pgACC functional connectivity with the right precuneus, PCC, and the left IFG/insula than the control group. The IGDdep + group had stronger dACC functional connectivity with the left precuneus and the right cerebellar lobule IX, weaker pgACC functional connectivity with the right dorsomedial PFC and the right SMA, and weaker sgACC functional connectivity with the left precuneus, the left lingual gyrus, and the left postcentral gyrus than the control and IGDdep- groups. In addition, the IGDdep- group had stronger sgACC functional connectivity with the left DLPFC than the other groups.
Han et al. (2019)	Korea	26 patients with ADHD but without IGD, 29 patients with ADHD and IGD, and 20 patients with IGD but without ADHD	RSFC	Patients with ADHD and IGD shared similar brain functional connectivity at baseline and functional connectivity changes in response to treatment.
Sun, Wang, and Bo (2019)	China	30 male participants with IGD, 23 female participants with IGD, and 30 male and 22 female age-matched HCs	RSFC	The ALFF values in the orbital part of the left superior frontal gyrus were lower in IGDm than in HCm, which were negatively correlated with BIS-11 scores. IGDm also demonstrated lower connectivity between the orbital part of the left SFG and the PCC, the right angular gyrus, and the right DLPFC than HCm. Furthermore, IGDm had lower seed connectivity between the orbital part of the left SFG and the PCC than ICDf. These findings suggest that (i) the altered ALFF values in the orbital part of the left SFG represent a clinically relevant biomarker for the behavioral inhibition function of IGDm; and (ii) IGD may interact with sex-specific patterns of functional connectivity in male and female participants.
Wang et al. (2019c)	China	58 RGU (male = 29) and 46 IGD participants (male = 23)	RSFC	Significant sex-by-group interactions were found associated with the brain features in the right PCC, left middle occipital gyrus, right middle temporal gyrus, and right postcentral gyrus. Post-hoc analysis revealed that comparing with same-sex RGUs, male IGD showed decreased ReHo in the rPCC. Moreover, male IGDs showed increased ReHo, but female ones showed decreased ReHo, in both left middle occipital gyrus and right middle temporal gyrus, when comparing with same-sex RGUs.
Wang et al. (2019a)	China	64 IGD and 63 well-matched RGU	RSFC	Compared with RGU, IGD showed reduced effective connectivity from the mPFC to the PCC and from the left IPL to the mPFC, with reduced self-connection in the PCC and the left IPL.
Zhang et al. (2020a)	China	24 IGD and 26 RGUs	RSFC	Higher activation in the left dACC, right ventral ACC, left claustrum and bilateral insula was observed in IGD during emotion reappraisal relative to that of the RGU. IGD participants had stronger functional connectivity between the right insula and bilateral DLPFC than the RGU.
Chun et al. (2020)	Korea	45 adults with IGD and 45 HCs	RSFC	IGD participants showed lower functional connectivity between the DLPFC and other regions in theECN, reduced functional connectivity between the dorsal anterior cingulate cortex and other regions in the SN and lower functional connectivity in the medial prefrontal cortex of the anterior DMN.

(continued)

Table 1. Continued

Reference	Nation	Participants	Methods	Main findings
Dong et al. (2021a)	China	174 IGD and 244 RGUs	RSFC	IGD participants showed lower ventral-striatum-to-middle frontal gyrus (mostly involving SMA) and higher dorsal-striatum-to-middle frontal gyrus functional connectivity. spectrum dynamic causal model revealed that left dorsal-striatum-to-middle frontal gyrus connectivity was correlated with IGD severity. Longitudinal data within IGD and RGU groups found greater dorsal striatal connectivity with the middle frontal gyrus in IGD versus RGU participants.
Dong et al. (2021b)	China	130 IGD and 207 RGUs	RSFC	Decreased functional connectivity was predominantly observed in IGD participants, with IGD participants showing decreased functional connectivity between the putamen and superior frontal gyrus, middle frontal gyrus, and IFG and the VS and IFG, superior temporal gyrus, and middle frontal gyrus. Disorder severity and craving scores were negatively correlated with functional connectivity between striatal and frontal brain regions.
Dong et al. (2021c)	China	57 IGD and 81 RGUs	RSFC	We observed reduced RSFC between the left DLPFC and the left precentral and the postcentral gyri and the SMA. The RSFC of the DLPFC-precentral gyrus and the DLPFC-postcentral gyrus moderated the relationship between IGD severity and loneliness scores. Additionally, we also found that the RSFC of the left DLPFC-precentral gyrus, the DLPFC-postcentral gyrus and the right DLPFC-SMA moderated the relationship between self-reported gaming craving and the UCLA scores.
Kim et al. (2021)	Korea	23 IGD patients with high impulsivity, 27 IGD patients with low impulsivity, and 22 HCs	RSFC	Connectivity of the vmPFC with the left temporo-parietal junction and NAc-left insula connectivity were significantly decreased in the patients with high impulsivity, compared with the patients with low impulsivity and HCs. On the other hand, amygdala-based connectivity with the left IFG showed decreases in both patient groups, compared with the HCs.
Lee et al. (2021a)	Korea	18 young males with IGD and 18 controls	RSFC	They exhibited decreased functional connectivity between the left dorsal putamen and left medial prefrontal cortex compared with controls. They exhibited increased functional connectivity strength between the right dorsal putamen and right middle occipital gyrus during follow-up. Participants with IGD showed a significant correlation between changes in the dorsal putamen-middle occipital gyrus functional connectivity and gaming time per day. Young males with IGD showed an altered functional connectivity pattern in the DS during follow-up. functional connectivity of the DS in IGD increased in the medial prefrontal cortex and decreased in the middle occipital gyrus.
Lee et al. (2021b)	Korea	33 young males with IGD and 29 controls	RSFC	Participants with IGD showed decreased functional connectivity between the right DLPFC and the right IFG, corresponding to the cognitive control network. They showed decreased functional connectivity between the right ACC and the superior parietal lobule. They also showed increased functional connectivity between the left dorsal putamen and the postcentral gyrus, corresponding to the sensorimotor network.
Turel et al. (2021)	China	26 IGD and 26 HCs	RSFC	The IGD score positively correlated with activity in the right VS and negatively with activity in the right DLPFC. Left insular cortex activity was the highest when observing video gaming cues under deprivation. Lastly, there was an increased coupling between the left insula and left VS and a decreased coupling with left DLPFC when observing video gaming cues compared with when watching control videos in the deprivation condition.

(continued)

Table 1. Continued

Reference	Nation	Participants	Methods	Main findings
Wang et al. (2021)	China	22 IGD participants and 18 HCs	RSFC	IGD participants exhibited decreased functional connectivity between the left DS (putamen) and the left insula, whereas connectivity between the right VS (NAc) and the left insula was relatively stable over time. An inhibitory effective connectivity from the left putamen to the right NAc was found in IGD participants during the follow-up scan.
Zhou et al. (2021)	China	65 (32 males) IGD participants	RSFC	When facing gaming cues, lower regions of brain activation were observed in males compared to females, including the left ACC, the superior frontal gyrus and the PCC; Granger causal analysis results, using the PCC as the ROI, showed higher middle temporal gyrus-PCC-right ACC/ parahippocampal gyrus effective connectivity in males as compared with females, when exposed to gaming cues.
Zeng et al. (2022)	China	148 IGD participants and 169 RGUs	RSFC	IGD participants showed inhibitory effective connectivity from the right OFC to the right caudate and from the right DLPFC to the left OFC. Excitatory effective connectivity was observed from the thalamus to the left OFC. Correlation analyses results showed that the directional connection from the right OFC to the right caudate was negatively associated with addiction severity.

Abbreviations: ACC, anterior cingulate cortex; ALFF, amplitude of low-frequency fluctuation; CC, corpus callosum; CIAS, Chen Internet Addiction Scale; DLPFC, dorsolateral prefrontal cortex; DMN, default mode network; DS, dorsal striatum; DTI, diffusion tensor imaging; ECN, executive control networks; FA, fractional anisotropy; GMD, gray matter density; GMV, gray matter volume; HCs, healthy controls; IFG, inferior frontal gyrus; IFOF, inferior fronto-occipital fasciculus; IGA, Internet gaming addiction; IGD, Internet gaming disorder; IPL, inferior parietal lobule; mOFC, medial orbitofrontal cortex; NAc, nucleus accumbens; OFC, orbitofrontal cortex; OGA, online gaming addiction; PCC, posterior cingulate cortex; PFC, prefrontal cortex; RGU, recreational Internet game use; RSFC, resting functional connectivity; SFG, superior frontal gyrus; SMA, supplement motor area; VBM, voxel-based morphometry; VMHC, voxel-mirrored homotopic connectivity; vmPFC, right ventromedial prefrontal cortex; VS, ventral striatum; VTA, ventral tegmental.

ACC and left DLPFC (Lee, Lee, Namkoong, & Jung, 2018), right precuneus (Lee et al., 2018), posterior cingulate cortex (PCC) (Lee et al., 2018), insula (Zhang et al., 2016c), left frontal eye field (Han, Kim, Bae, Renshaw, & Anderson, 2017), and right auditory cortex (Han et al., 2017), as well as reduced functional connectivity between the ACC and the superior parietal lobule (Lee et al., 2021b) and other regions in the central executive network (CEN) (Chun et al., 2020). It has also been suggested that young males with IGD and comorbid depressive disorder display reduced functional connectivity within the PFC and altered functional connectivity within the default mode network (DMN), which is thought to be involved in brain activation during self-thought and introspection. This altered functional connectivity pattern may be involved in the close association between IGD and depression (Lee et al., 2018). Additionally, adolescents with IGD exhibit significantly higher global cerebral blood flow in the right ACC than do controls (Feng et al., 2013).

The duration of online gaming has been positively associated with connectivity between the anterior insula and the ACC (Zhang et al., 2016d). Executive function is widely reduced among individuals with IGD, with the ACC activity mostly maladaptively altered. Moreover, individuals with GD generally exhibit higher ACC activation when performing executive tasks, such as the Go/No-Go task (Ding et al., 2014; Ko et al., 2014) and cue-reactivity tasks (Zhang et al., 2021). However, when participants are forced to stop their gaming behaviour, individuals with IGD showed decreased activation in the ACC (Zhang et al., 2020a).

In addition to executive functioning, both reward processing and emotional regulation are decreased in individuals with GD. Individuals with IGD have also shown (i) increased activation in the ACC when given online gaming cues (Zhang et al., 2016a), and (ii) decreased activation in the right ACC (Wang et al., 2017), which might indicate a decreased ability to inhibit the urge for gaming-related stimuli. Reduced activation has also been observed in the ACC and ventromedial prefrontal cortex (vmPFC) areas in response to both reward types among individuals with IGD (Kim, Kim, & Kang, 2017). When faced with negative stimuli, individuals with GD exhibit neural changes in the ACC (Yip et al., 2018; Zhang et al., 2020b).

In addition to the ACC, the DLPFC, which is known for its involvement in executive functioning, is altered in GD. Compared to healthy controls, individuals with GD have shown an increased functional correlation between the left DLPFC and both sides of the amygdala (Ko et al., 2015), the left temporoparietal junction, the right DLPFC, and the right temporoparietal junction (TPJ). Individuals with IGD have also demonstrated (i) reduced resting-state functional connectivity between the left DLPFC and the left precentral and postcentral gyri (Dong et al., 2021a), and (ii) functional connectivity between the right DLPFC and the right inferior

Table 2. Task-based functional connectivity of gaming disorder

Reference	Nation	Participants	Tasks	Main findings
Reward processing				
Liu et al. (2014)	China	11 cases of IGD and 11 controls	gaming cue	The control group increased their brain activations more over the right DLPFC and superior parietal lobe under gaming cue distraction in comparison with the IGD group. Individuals with IGD could not activate right DLPFC and superior parietal lobe to keep cognitive control and attention allocation for response inhibition under gaming cue distraction.
Zhang et al. (2016a)	China	40 IGD and 19 HCs	Internet-gaming cue-reactivity task	Activation in DS, brainstem, substantia nigra, and ACC, but lower activation in the posterior insula. The craving behavioral intervention decreased IGD severity and cue-induced craving, enhanced activation in the anterior insula and decreased insular connectivity with the lingual gyrus and precuneus.
Zhang et al. (2016b)	China	19 IGD and 21 HCs	gaming-related cues during an Addiction Stroop Task	Compared with HC group, IGD participants showed higher activations when facing Internet gaming-related stimuli in regions including the inferior parietal lobule, the middle occipital gyrus and the DLPFC.
Liu et al. (2017)	China	39 male IGD participants and 23 male matched HCs	cue-reactivity task	Higher cue-induced activations within both the VS and DS. Within the IGD group, activity within the left VS was correlated negatively with cue-induced craving; positive associations were found between activations within the DS and duration of IGD. Cue-induced activity within the left putamen was negatively associated with right VS volumes among IGD participants.
Wang et al. (2017)	China	40 RGU and 30 IGD participants	event-related cue reactivity task	Enhanced activation in the left OFC and decreased activation in the right ACC, right precuneus, left precentral gyrus and right postcentral gyrus in comparison with the RGU participants.
Dong et al. (2017)	China	27 individuals with IGD and 43 individuals with RGU	gaming-related stimuli	The comparison between post- and pregaming measures showed that for IGD, gaming was associated with increased craving and increased brain activation of the lateral cortex and PFC, the striatum, and the precuneus when exposed to gaming-related stimuli.
Kim et al. (2017)	Korea	IGO and age-matched control participants	monetary and symbolic rewards and penalties	The IGO individuals were more likely to fail to choose the response previously reinforced by symbolic (but not monetary) reward. Reduced activations in the rostral ACC/vmPFC in response to both reward types. However, the responses to reward in the inferior parietal region and medial OFC/vmPFC were affected by the types of reward in the IGO group. Furthermore, the more severe the IGO symptoms in the IGO group, the greater the activations of the VS for monetary relative to symbolic reward.
Dong, Wang, Du, and Potenza (2018b)	China	40 female and 68 male Internet gamers	pre- and post-gaming cue-craving task	Prior to gaming, males demonstrated greater activations in the striatum, OFC, inferior frontal cortex and bilateral declive. Following gaming, male participants demonstrated greater activations in the medial frontal gyrus and bilateral middle temporal gyri. In a post-pre comparison, male participants demonstrated greater thalamic activation than did female participants.
Dong et al. (2018c)	China	99 participants with IGD (27 males and 22 females) or RGU (27 males and 23 females)	cue-elicited-craving tasks	In pre-, post-, and post-pre tests, significant gender-by-group interactions were observed in the left DLPFC. Further analyses of the DLPFC cluster showed that in post-pre comparisons, results were related to less engagement of the DLPFC in IGD, especially in females. In addition, at post-test, significant interactions were observed in the caudate, as females with IGD showed greater activation as compared to those with RGU.

(continued)

Table 2. Continued

Reference	Nation	Participants	Tasks	Main findings
Kim and Kang (2018)	Korea	18 young males with IGO and 20 age-matched controls,	monetary or non-monetary rewards	For non-monetary reward processing, no differences in functional connectivity were found. In contrast, for monetary reward, connectivity of the vmPFC with the left caudate nucleus was weaker for the IGO group relative to controls, while vmPFC connectivity with the right NAc was elevated. The strength of vmPFC-NAc functional connectivity appeared to be behaviorally relevant, because individuals with stronger vmPFC-NAc connectivity showed lower learning rates for monetary reward. In addition, the IGO group showed weaker VS functional connectivity with various brain regions, including the right ventrolateral prefrontal cortex, dorsal ACC, and left pallidum.
Dong et al. (2019)	China	29 male IGD, 25 female IGD, 34 male RGU, 31 female RGU	gaming and immediate abstinence during a mandatory break	During gaming in males but not in females, the functional connectivity between the DLPFC and superior frontal gyrus was relatively decreased, and that between the striatum and thalamus was relatively increased. During the mandatory break, changes in the functional connectivity between DLPFC and superior frontal gyrus and the functional connectivity between the striatum and thalamus varied by gender with greater RGU-IGD differences observed in females. Significant correlations between functional connectivity and self-reported craving were observed.
Turel et al. (2021)	China	26 gamers, and 26 controls	video reactivity task	The IGD score positively correlated with activity in the right VS and negatively with activity in the right DLPFC. Left insular cortex activity was the highest when observing video gaming cues under deprivation. Lastly, there was an increased coupling between the left insula and left VS and a decreased coupling with left DLPFC when observing video gaming cues compared with when watching control videos in the deprivation condition.
Yao et al. (2020)	China	22 IGD and 27 HCs	monetary incentive delay task	Relative to controls, individuals with IGD exhibited blunted caudate activity associated with loss magnitude at the outcome stage, but did not differ from controls in neural activity at other stages.
Dong et al. (2020)	China	65 IGD participants (33 males, 32 females)	cue-craving task	IGD severity was positively correlated with precuneus activation, the volume of precuneus and connectivity from the hippocampal gyrus to the precuneus. IGD severity was negatively correlated with connectivity from the middle frontal gyrus to the precuneus.
Zhang et al. (2020a)	China	49 IGD and 49 RGU	cue-reactivity task	the IGD showed decreased activation in the ACC, parahippocampal gyrus, and DLPFC. Significant negative correlations were observed between self-reported gaming cravings and the baseline activation level (bate value) of the ACC, DLPFC, and parahippocampal gyrus.
Zhang et al. (2021)	China	21 IGD and 23 RGUs	cue-craving task	IGD participants showed enhanced brain activation in the right ACC, PCC, OFC and middle temporal gyrus and in the left DLPFC and thalamus during the regulation of craving task. IGD participants showed decreased functional connectivity between the right PCC and right inferior parietal lobule compared to that in RGU participants.
Executive function				
Ding et al. (2014)	China	17 adolescents with IGA and 17 HCs	cognitive control tasks (Go/No-Go task)	There were no differences in the behavioral performance between the groups. However, the IGA group was significantly hyperactive during No-Go trials in the left superior medial frontal gyrus, right ACC, right superior/middle frontal gyrus, left inferior parietal lobule, left precentral gyrus, and left precuneus and cuneus; the bilateral middle temporal gyrus, bilateral inferior temporal gyrus, and right superior parietal lobule were significantly hypoactive.

(continued)

Table 2. Continued

Reference	Nation	Participants	Tasks	Main findings
Ko et al. (2014)	China	26 men with IGD for at least 2 years and 23 controls	cognitive control tasks (Go/No-Go task)	The IGD group exhibited a higher score for impulsivity than the control group. The IGD group also exhibited higher brain activation when processing response inhibition over the left OFC and bilateral caudate nucleus than controls. Both the IGD and control groups exhibited activation of the insula and ACC during error processing. The activation over the right insula was lower in the participants with IGD than the control group.
Liu et al. (2014)	China	11 cases of IGD and 11 controls	cognitive control tasks (Go/No-Go task)	Brain activation of the right DLPFC and superior parietal lobe were negatively associated with performance of response inhibition among the IGD group.
Yuan et al. (2014)	China	18 adolescence with OGA and 18 controls	cognitive control tasks (Stroop task)	Cortical thicknesses of the left precentral cortex, precuneus and lingual gyrus correlated with duration of online gaming addiction and the cortical thickness of the OFC correlated with the impaired task performance during the color-word Stroop task.
Chen et al. (2015)	China	15 men with IGD, and 15 controls	cognitive control tasks (Go/No-Go task)	The control group exhibited activation of the right SMA, DLPFC, and caudate for response inhibition. However, the IGD group had a higher impulsivity and lower activity of the right SMA/pre-SMA in comparison to the control group.
Dong et al. (2015)	China	35 IGD and 36 HCs	cognitive control tasks (Stroop task)	Higher functional connectivity in ECNs may underlie better executive control and may provide resilience with respect to IGD.
Lin et al. (2015)	China	19 IGD participants and 21 HCs	decision-making task (Probability discounting task)	IGD participants prefer the probabilistic options to fixed ones and were associated with shorter reaction time. IGD participants show decreased activation in the IFG and the precentral gyrus when choosing the probabilistic options than HC.
Qi et al. (2015)	China	23 adolescents with IGD and 24 HCs	decision-making task (Balloon analog risk task)	Reduced modulation of the risk level on the activation of the right DLPFC during the active balloon analog risk task was found in IGD group compared to the HCs. In the IGD group, there was a significant negative correlation between the risk-related DLPFC activation during the active balloon analog risk task and the Barratt impulsivity scale scores, which were significantly higher in IGD group compared with the HCs.
Cai et al. (2016)	China	27 IGD and 30 matched HCs	cognitive control tasks (Stroop task)	Relative to controls, the IGD committed more incongruent condition response errors during the Stroop task and showed increased volumes of caudate and NAc. In addition, caudate volume was correlated with Stroop task performance in the IGD group.
Dong and Potenza (2016)	China	20 IGD participants and 16 healthy control participants	decision-making task (Risky decision-making)	During risk-taking and as compared to HCs, IGD participants selected more risk-disadvantageous trials and demonstrated less activation of the anterior cingulate, posterior cingulate and middle temporal gyrus. During risky decision-making and as compared to HCs, IGD participants showed shorter response times and less activations of the inferior frontal and superior temporal gyri.
Han, Kim, Bae, Renshaw, and Anderson (2016)	Korea	42 HCs and 95 volunteers seeking treatment for compulsive video game playing, including 60 participants without major depression and 35 participants comorbid with major depression (IGD + major depressive disorder)	cognitive flexibility tasks (Wisconsin Card Sorting Test)	For Wisconsin Card Sorting Test >Fixation contrasts, the IGD + major depressive disorder group exhibited greater relative activation within the left hippocampus, compared to healthy control participants. For Wisconsin Card Sorting Test > Fixation contrasts, the IGD + major depressive disorder group exhibited greater relative activation within the left hippocampus and the right parahippocampal gyrus immediately posterior to the hippocampus, compared to the pure IGD group.

(continued)

Table 2. Continued

Reference	Nation	Participants	Tasks	Main findings
Lee et al. (2016)	Korea	24 young adults with IGD 24 HCs	decision-making task (Risky decision-making)	The healthy control group showed stronger activations within the dorsal attention network and the anterior insular cortex, which were not found in the IGD group.
Qi et al. (2016)	China	24 adolescents with IGD and 24 HCs	decision-making task (Risky decision-making)	The covariance between risk level and activation of the bilateral vmPFC, left inferior frontal cortex, right VS, left hippocampus/parahippocampus, right inferior occipital gyrus/fusiform gyrus and right inferior temporal gyrus demonstrated interaction effects of group by outcome
Wang et al. (2016)	China	19 IGD participants and 21 HCs	decision-making task (Probability discounting task)	IGD participants prefer the risky to the fixed options and showed shorter reaction time, and showed higher task-related activity in DMN and less engagement in the ECN than HC when making the risky decisions.
Liu et al. (2017)	China	41 males with IGD and 27 healthy comparison	decision-making task (Risky decision-making)	During risk evaluation, the IGD group, showed weaker modulation for experienced risk within the bilateral DLPFC and inferior parietal lobule for potential losses. The modulation of the left DLPFC and bilateral inferior parietal lobule activation were negatively related to addiction severity within the IGD group. During outcome processing, the IGD group presented greater responses for the experienced reward within the VS, vmPFC, and OFC for potential gains, as compared to HC participants. Within the IGD group, the increased reward-related activity in the right OFC was positively associated with severity of IGD.
Wang et al. (2017)	China	18 IGD participants and 21 matched HCs	decision-making task (Delay discounting task)	IGD showed a higher discount rate than HC, and exhibited reduced brain activations in the DLPFC and bilateral IFG compared to HC during performing delay trials relative to immediate ones.
Yuan et al. (2017)	China	43 young IGD individuals and 44 HCs	cognitive control tasks (Stroop task)	An increased volume of right caudate and NAc as well as reduced RSFC strength of DLPFC-caudate and OFC-NAc in IGD participants. The caudate volume and DLPFC-caudate RSFC was correlated with the impaired cognitive control in IGD.
Wu et al. (2020)	China	26 with ICD and 28 HCs	decision-making task (Regulation-of-craving task) and cognitive control tasks (Stroop task)	Provided initial empirical support suggesting regulation impairments for both addiction-related and primary rewards among individuals with IGD. Suggesting that impaired regulation of craving may be a relevant transdiagnostic construct across SUDs and behavioral addictions.
Shin et al. (2021)	Korea	20 IGD and 21 HCs	cognitive control tasks (Go/No-Go task)	Patients with IGD showed a failure in response inhibition and increased activation of widespread brain regions, including prefrontal, motor-sensory, parietal, occipital, insula, and striatal regions across tasks. Among these regions, involvement of the DLPFC and VS was observed only during the task with high demands on working memory. Moreover, it was also only during the high-load task that interaction between response inhibition and emotional states was observed in the dorsomedial prefrontal cortex, with observations revealing that its alteration in patients with IGD was associated with number of hours spent on Internet gaming.
Emotional processing				
Yip et al. (2018)	China	28 with IGD, 28 matched controls	negative affective stimuli	Compared to controls, youth with IGD exhibited significantly blunted neural responses within distributed subcortical and cortical regions including the striatum, insula, lateral PFC and ACC in response to negative affective cues, as well as during emotion regulation.

(continued)

Table 2. Continued

Reference	Nation	Participants	Tasks	Main findings
Zhang et al. (2020a)	China	24 IGD and 26 RGU	visual stimuli	Higher activation in the left dACC, right ventral ACC, left claustrum and bilateral insula was observed in participants with IGD during emotion reappraisal relative to that of the RGU participants. In addition, generalized psychophysiological interaction analysis also showed that IGD participants had stronger functional connectivity between the right insula and bilateral DLPFC than the RGU participants.
Social function				
Dieter et al. (2015)	Germany	15 addicted and 17 nonaddicted players	Giessen-Test-derived paradigm	Addicts showed significantly lower scores on the self-concept subscale of 'social resonance,' that is, social popularity. Addicted players to exhibit significantly higher brain activations in the left angular gyrus.

Abbreviations: ACC, anterior cingulate cortex; dACC, dorsal anterior cingulate cortex; DLPFC, dorsolateral prefrontal cortex; DMN, default mode network; DS, dorsal striatum; ECN, executive control networks; functional connectivity, functional connectivity; HCs, healthy controls; IAD, Internet addicted disorder; IAG, Internet video game addiction; IFG, inferior frontal gyrus; IGD, Internet gaming disorder; IGO, Internet game overuse; mPFC, medial prefrontal cortex; NAc, nucleus accumbens; OFC, orbitofrontal cortex; OGA, online gaming addiction; PCC, posterior cingulate cortex; PFC, prefrontal cortex; RGU, recreational Internet game use; RSFC, resting functional connectivity; SMA, supplement motor area; vmPFC, ventromedial prefrontal cortex; VS, ventral striatum.

frontal gyrus (IFG) (Lee et al., 2021b). Moreover, individuals with IGD show decreased resting-state functional connectivity with the left DLPFC on both sides of the insula (Chen et al., 2016), similar to individuals with nicotine dependence. Compared to healthy controls, individuals with IGD showed decreased resting-state functional connectivity with the DLPFC in the right insula and left IFG (Ge et al., 2017), decreased functional connectivity strength of the DLPFC-caudate (Yuan et al., 2017), and increased functional correlation between the DLPFC and the left TPJ (Han et al., 2017). Patients with IGD exhibit decreased connectivity in multiple areas, including the cerebellum, amygdala, OFC, DLPFC, striatum, ACC, thalamus, and insula (Weinstein et al., 2017). Moreover, IGD scores are negatively correlated with activity in the right DLPFC (Turel, He, Wei, & Bechara, 2021). These findings suggest that individuals with IGD exhibit aberrant functional connectivity in the DLPFC with multiple brain regions.

Apart from aberrant resting-state of functional connectivity, individuals with GD also show altered brain activity during tasks. In response to game cues, individuals with IGD show higher brain activation in the left DLPFC (Han, Hwang, & Renshaw, 2010; Liu et al., 2014; Zhang et al., 2021), and individuals with IGD are incapable of activating the right DLPFC to maintain cognitive control and attention allocation for response inhibition under gaming-cue distraction (Liu et al., 2014). In addition, brain activation in the right DLPFC is negatively associated with response inhibition performance in individuals with IGD (Liu et al., 2014). In contrast to findings that showed reduced activation of the DLPFC during the response inhibition task, a study also reported that patients with IGD show a failure in response inhibition and increased activation of widespread brain regions; moreover, increased activation of the DLPFC and ventral striatum was observed when performing tasks with high demands on working memory (Shin, Kim, Kim, & Kim, 2021). Additionally, individuals with IGD show lower functional connectivity in executive control networks than healthy controls during the resting state (Dong et al., 2015a). Moreover, the connection between the nucleus accumbens (NAc) and executive control network is negatively correlated with the connection between the NAc and reward network (Dong et al., 2015a).

Overall, these findings demonstrate brain areas related to executive function that exhibit both structural and functional alterations. The main brain regions related to alterations in executive function in GD include the ACC, DLPFC, and regions involved in the DMN and CEN. GD participants generally exhibit low ACC volume; however, the exact increase or decrease in functional connectivity during the resting state or task could not be concluded due to contradictory results between the studies.

Alteration of brain areas related to the reward system (mainly the striatum and OFC)

Similar to other addictive disorders, IGD is associated with an aberrant reward system. The reward system consists of a group of brain structures and neural pathways responsible for reward-related cognition. The striatum, a critical component of the reward system, is a nuclei located within the subcortical basal ganglia of the forebrain. The striatum has ventral and dorsal subdivisions based on function and connections: the ventral part is composed of the NAc and olfactory tubercle, and the dorsal part is composed of the putamen and caudate nucleus. The ventral striatum, particularly the NAc, primarily mediates reward cognition and motivational salience, whereas the dorsal striatum primarily mediates cognition involving motor function and inhibitory control. The OFC, located in the frontal lobe of the brain, is thought to play a crucial role in the reward system.

Structural imaging studies have demonstrated alterations in the volume of the ventral striatum, possibly due to changes in reward (Weinstein & Lejoyeux, 2015). Another study also found an increased volume of the right caudate and NAc in individuals with IGD (Yuan et al., 2017). Individuals with IGD show lower structural connectivity in the bilateral ventral tegmental area (VTA)-NAc tract than controls (Wang et al., 2019b; Zhang et al., 2015). In patients with IGD, the NAc and medial OFC have lower resting-state functional connectivity with the VTA (Weinstein & Lejoyeux, 2020). Individuals with IGD have lower functional connectivity with the left NAc over the left DLPFC and with the right NAc over the left DLPFC and insula, and higher functional connectivity with these areas over the right precuneus (Chen et al., 2016). Overall, participants with GD exhibit increased NAc volume and aberrant connectivity between the NAc and related brain regions, indicating that the NAc is involved in GD.

Additionally, individuals with IGD show reduced functional connectivity between the left dorsal striatum and the left insula, while connectivity between the right ventral striatum and the left insula remains stable (Wang et al., 2021). Moreover, inhibitory effective connectivity between the left putamen and right NAc has been reported (Wang et al., 2021). Individuals with IGD show lower functional connectivity between the ventral striatum and middle frontal gyrus but higher functional connectivity between the dorsal striatum and middle frontal gyrus (Dong et al., 2021a). Dysregulation of D2 receptors has also been observed in the striatum and is correlated with years of gaming overuse. Moreover, low levels of D2 receptors in the striatum are significantly associated with decreased glucose metabolism in the OFC (Tian et al., 2014). In addition, individuals with GD exhibit higher cue-induced activation within both the ventral and dorsal striatum than healthy controls (Liu et al., 2017). IGD scores are also positively correlated with activity in the right ventral striatum (Turel et al., 2021). These findings suggest that the striatum and alterations in functional connectivity with wide brain regions are involved in GD and that dysregulation of dopamine receptors may also indicate potential brain alterations.

Bilateral alterations in the putamen have been widely reported in patients with GD. Compared to healthy controls, individuals with IGD exhibit decreased functional connectivity between the left dorsal putamen and left medial prefrontal cortex (mPFC) (Lee et al., 2021a). Adolescents with IGD have shown significantly reduced functional connectivity of the dorsal putamen with the posterior insula parietal operculum (Hong et al., 2015). Moreover, individuals with IGD exhibit higher cue-induced activation within both the ventral and dorsal striata than healthy controls (Liu et al., 2017). Individuals with IGD also demonstrate decreased functional connectivity between the putamen and the superior frontal gyrus (SFG) and middle frontal gyrus (MFG), and GD severity and craving scores are negatively correlated with functional connectivity between the striatal and frontal brain regions (Dong et al., 2021a).

These findings suggest that alterations in the OFC are also involved in individuals with GD. Structural analyses have suggested that the cortical thickness of the OFC is decreased in adolescents with GD (Hong et al., 2013; Weng et al., 2013; Yuan et al., 2013). Voxel-based morphometry (VBM) analysis has revealed that individuals with gaming addiction show significant grey matter atrophy in the right OFC (Altbacker et al., 2016; Weng et al., 2013). Participants with IGD show a reduced amplitude of low fluctuation in the OFC (Zhang et al., 2016a). Individuals with IGD demonstrate effective inhibitory connectivity from the right OFC to the right caudate and from the right DLPFC to the left OFC, as well as effective excitatory connectivity from the thalamus to the left OFC (Zeng, Wang, Dong, Du, & Dong, 2022). In addition, reduced resting-state functional connectivity strength in the OFC-NAc has been demonstrated in individuals with IGD (Yuan et al., 2017). Individuals with IGD show stronger resting-state functional connectivity between the OFC and IFG (Liu et al., 2022) and have enhanced activation in the left OFC, which is correlated with the desire for gaming (Wang et al., 2017; Zhang et al., 2021). Responses to rewards in the medial OFC/vmPFC are affected by the types of reward among online gaming overusers (Kim et al., 2017). Similarly, risk decision-making impairments are associated with decreased OFC activation in individuals with internet use disorder (Li et al., 2023b).

Overall, these findings suggest that brain alterations in the reward system, including those in the striatum and OFC, are similar to changes in other types of behavioural and substance addictions.

Alteration of brain areas related to emotional regulation (mainly the insula and amygdala)

It has been suggested that addiction of all kinds is associated with emotional dysregulation (Koob & Volkow, 2016), which is also found in GD. The main brain areas related to emotional regulation in individuals with IGD are the insula and amygdala. The insula and amygdala are believed to be involved in consciousness and play a role in diverse functions typically associated with emotion or regulation of the body's homeostasis, which comprises perception, motor control, self-awareness, and interpersonal experience.

Alterations in structural and resting-state functional connectivity in the insula have been reported in patients with GD. Among older adolescents with GD, the cortical thickness of the insula is decreased (Weng et al., 2013; Yuan et al., 2013; Zhou et al., 2011). VBM analysis has shown that individuals with gaming addiction have significant bilateral grey matter atrophy in the insula (Lin, Dong, Wang, & Du, 2015; Zhou et al., 2011). Additionally, individuals with IGD have reduced functional connectivity of the left insula with the left DLPFC and orbitofrontal lobe, as well as higher functional connectivity of the insula with the contralateral insula, in comparison with controls (Chen et al., 2016). Interhemispheric insular connectivity is positively correlated with impulsivity (Chen et al., 2016). The NAc-left insula connectivity is significantly decreased in individuals with

IGD who have high impulsivity (Kim et al., 2021; Li et al., 2023a).

In addition, individuals with IGD exhibit increased resting-state functional connectivity between the anterior insula and a network of regions, including the ACC, putamen, angular gyrus, and precuneus, which are thought to be involved in salience, craving, self-monitoring, and attention (Zhang et al., 2016d). Individuals with IGD have also demonstrated significantly stronger resting-state functional connectivity between the posterior insula and multiple regions, such as the postcentral gyrus, precentral gyrus, supplementary motor area (SMA), and superior temporal gyrus (STG), compared to healthy controls (Zhang et al., 2016d). In addition, enhanced connectivity between the DMN and insula within the ventral attention network has been reported (Yan, Li, Yu, & Zhao, 2021). These findings suggest that alterations in the connectivity of the insula with a network of brain regions are associated with GD.

Individuals with IGD have stronger functional connectivity between the right insula and the bilateral DLPFC (Zhang et al., 2020a). Furthermore, the severity of IGD is positively correlated with connectivity between the anterior insula and angular gyrus, STG, and connectivity between the posterior insula and STG (Zhang et al., 2016d). Compared to controls, adolescents with IGD show significantly higher global cerebral blood flow in the insula (Feng et al., 2013). Individuals with IGD have also shown stronger activation in the posterior insula, and the craving behavioural intervention group in the study showed decreased IGD severity and cue-induced craving, increased activation in the anterior insula, and decreased insula connectivity with the lingual gyrus and precuneus after receiving treatment (Shin et al., 2021; Zhang et al., 2016b).

Task-based functional connectivity alterations in the insula have also been reported in patients with GD. When gaming cues were deprived, the activity in the left insula cortex was the highest. Moreover, there was increased connectivity between the left insula and left ventral striatum as well as decreased connectivity with the left DLPFC when observing gaming cues (Turel et al., 2021). When exposed to gaming cues, recreational online game use was positively correlated with the putamen-MFG-insula neural pathway, which is not observed in individuals with IGD (Wang, Dong, Zheng, Du, & Dong, 2020). Individuals with IGD have reduced regional centralities in the right amygdala (Wang et al., 2016). The anterior insula projects toward the amygdala and is involved in emotion regulation.

The amygdala is also involved in emotional regulation, and patients with IGD have aberrant activity in the amygdala. Individuals with IGD demonstrate reduced functional connectivity with the left amygdala over the left DLPFC as well as with the right amygdala over the left DLPFC and orbitofrontal lobe (Ko et al., 2015). Among individuals with impulsivity and IGD, the connectivity between the amygdala and the left inferior frontal gyrus decreases (Kim et al., 2021; Li et al., 2023b). Finally, compared to controls, adolescents with IGD show significantly higher global cerebral blood flow in the amygdala (Feng et al., 2013).

In summary, individuals with GD exhibit alterations in brain areas related to emotional regulation, mainly the insula and amygdala, which may explain the clinical symptoms as well as the high prevalence of mental health issues associated with GD.

Other brain areas related to gaming disorder

IGD may be associated with dysfunction of the sensory-motor-related network (Wang et al., 2016). Individuals with IGD show reduced resting-state functional connectivity between the left DLPFC and SMA, and the right DLPFC-SMA moderates the relationship between self-reported gaming craving and loneliness (Dong et al., 2021a). The right SMA shows significant grey matter atrophy in individuals with gaming addiction (Sun et al., 2023; Weng et al., 2013). Adolescents with IGD also show significantly higher global cerebral blood flow in the left SMA (Feng et al., 2013).

The PCC, precuneus, IFG, and hippocampus are involved in cognition, particularly memory. Individuals with IGD have reduced regional centralities in the left PCC (Wang et al., 2016; Zhou et al., 2011). Individuals with IGD also demonstrate a lower amplitude of low fluctuation in the PCC and higher resting-state functional connectivity from the PCC to the DLPFC and the whole brain compared to healthy controls (Sun et al., 2023; Zhang et al., 2016a). Individuals with IGD show higher fractional anisotropy in the thalamus and left PCC than healthy controls (Dong, DeVito, Huang, & Du, 2012). Compared to recreational online gamers, individuals with IGD show reduced effective connectivity from the mPFC to the PCC (Wang et al., 2019b) and decreased functional connectivity between the right PCC and right inferior parietal lobule (Zhang et al., 2021).

When performing cue-craving tasks, individuals with IGD show enhanced brain activation in the PCC (Zhang et al., 2021). Moreover, when facing gaming cues, male participants demonstrate increased connectivity between the middle temporal gyrus-PCC-right ACC and the parahippocampal gyrus compared to females (Zhou et al., 2021). Generally, individuals with IGD show significantly lower grey matter density in the bilateral IFG, right precuneus, and right hippocampus compared to healthy individuals (Lin et al., 2015). In addition, greater IGD severity is associated with increased grey matter volumes in the right mPFC and precuneus (Chen et al., 2021). Compared to controls, individuals with IGD show increased activation in the right precuneus (Liu et al., 2016) and hyperactivation in the left precuneus (Niu et al., 2022). IGD is associated with increased cravings and brain activation of the precuneus when exposed to gaming-related stimuli (Dong, Wang, Du, & Potenza, 2017). During a cue-craving task, IGD severity is positively correlated with precuneus activation, precuneus volume, and connectivity from the hippocampal gyrus to the precuneus, and negatively correlated with connectivity between the middle frontal gyrus and precuneus (Dong et al., 2020).

Comparison of GD with other types of addiction

Several reviews have discussed the neurobiological mechanisms underlying behavioural and substance-related addictions. Koob and Volkow (2016) reported that addiction signifies a significant dysregulation of motivational circuits brought about by a combination of exaggerated incentive salience and habit formation, reward deficits, excessive stress, and compromised executive function, mostly involving dysregulation of the PFC, insula, and amygdala. The reinforcing effects of drugs rely primarily on dopamine signalling in the NAc. Altered dopaminergic functioning has been observed in participants with IGD and tobacco use disorder (Ma et al., 2024). Moreover, chronic exposure to drugs triggers glutamatergic-mediated neuroadaptations in the striato-thalamo-cortical (predominantly in the PFC regions, including the OFC and ACC) and limbic (amygdala and hippocampus) pathways. In addition, some scholars have proposed that the development of addiction may be partly attributed to the pathological learning and memory of abused drugs (Torregrossa, Corlett, & Taylor, 2011), and that dopamine projections from the VTA to the NAc are the key components of the brain reward circuitry (Hyman, 2005). More interestingly, the impaired response inhibition and salience attribution model proposes that individuals with addictions show increased activation of these networks during drug-related processing but a diminished response during non-drug-related processing (Zilverstand, Huang, Alia-Klein, & Goldstein, 2018).

Evidence suggests that GD shares similar neurobiological alterations with other types of addiction, including dysregulation of regions related to executive function, reward systems, and emotional function. However, few studies have shown the distinct mechanisms underlying GD from other types of addiction. One study demonstrated that two types of addiction (GD and tobacco use disorder) demonstrated differences in the thalamus and frontostriatal circuits, and similar alterations were found in the cerebellum and mPFC regions (Zheng et al., 2022). In addition, one study demonstrated potential differences in the neurobiological mechanisms underlying model-based behaviour, with insula and prefrontal activation associated with model-based reward prediction errors in IGD and alcohol use disorder, respectively (Kwon, Choi, Park, Ahn, & Jung, 2024). One study found that individuals with IGD demonstrated increased functional connectivity within the cognitive network compared to the those with internet-based gambling disorder, while sharing the characteristic of decreased functional connectivity in the DMN (Bae, Han, Jung, Nam, & Renshaw, 2017). The exact similarities and differences between GD and other types of addiction should be further explored and summarised.

THE ONGOING DEBATE ON GAMING DISORDER AS A MENTAL DISORDER

Established evidence suggests that the clinical characteristics and neurobiological mechanisms of GD are highly similar to those of other types of addiction. Based on this evidence, GD has been included in the ICD-11 and has received strong support from clinical psychologists, psychiatrists, and public health practitioners. However, there are different views of GD as a mental health disorder. A summary of the opinions supporting or not supporting GD as a mental health disorder is presented in Fig. 2.

First, some scholars have remained sceptical of the current evidence supporting the formal diagnosis of GD, claiming that it is far from clear whether these problems can be attributed to a new disorder (Aarseth et al., 2017). Notwithstanding the numerous studies conducted on GD or something similar, its epidemiology, clinical features, and related neurological and biological mechanisms have remained ambiguous due to considerable heterogeneity in screening instruments, diagnostic criteria, and intervention methodology (Griffiths & Szabo, 2014; King et al., 2017; Stavropoulos et al., 2018) and the alleged low quality of the research base (Aarseth et al., 2017). However, robust scientific standards are lacking as well (van Rooij et al., 2018). It has also been argued that current diagnostic and screening instruments lean too heavily on substance use and gambling criteria. Significant differences exist between GD and substance disorders, such as in the understanding of withdrawal effects or tolerance of problematic gaming (Griffiths et al., 2016; van Rooij & Prause, 2014). Moreover, distinct addictions may not manifest in the same brain regions (Zilberman, Lavidor, Yadid, & Rassovsky, 2019), further indicating potentially different mechanisms of GD from those of other types of addictions.

Second, it has been claimed (mainly by a group of media scholars) that the inclusion of GD in the ICD-11 will create moral panic (Aarseth et al., 2017), and the definition of GD is very narrow and only defines the most extreme cases, such as individuals with attention-deficit hyperactivity disorder-GD comorbidity (Salerno, Becheri, & Pallanti, 2022). Some

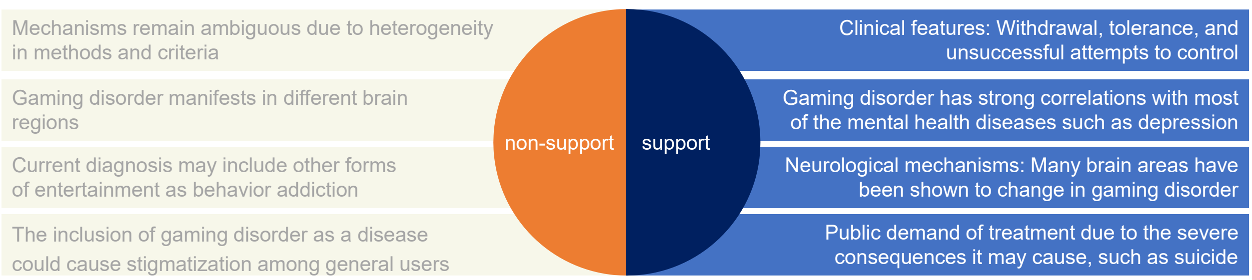

Fig. 2. Summary of opinions supporting or non-supporting gaming disorder as a mental disorder

claim that the current diagnosis may lead to other forms of everyday behaviour being classified as formal types of behavioural addiction, which may bring fear to the general public (Rumpf et al., 2018; Wang et al., 2019b).

Third, it has been claimed that the inclusion of GD as a mental health disorder in the ICD-11 is premature and could cause stigmatisation in general gamers, leading to unnecessary and excessive medical treatment (Quandt, 2017; Rumpf et al., 2018). General gamers who spend a significant amount of time playing games without any underlying mental health issues could be incorrectly targeted. The rush to diagnose GD could lead to unnecessary medical interventions, including prescribed medications or therapies that may not be appropriate for the situation.

Apart from the current controversy over whether GD should be considered a mental disorder, there are some other ongoing debates, including: (i) whether compulsive digital gaming should be classified as a behavioural addiction or compulsive disorder (Singh, 2019), (ii) the magnitude of harm of GD (Aarseth et al., 2017; Rumpf et al., 2018), and (iii) whether GD is a separate clinical entity, or a manifestation of psychiatric disorders (Berloffa et al., 2022; Petry, Zajac, & Ginley, 2018; Salerno et al., 2022; van Rooij et al., 2018). Better quality research on gaming is needed to explore the nature of GD and resolve current debates in the field.

PERSPECTIVES AND FUTURE DIRECTIONS

Despite the inclusion of GD in the ICD-11, the controversy over GD as a mental disorder continues. By reviewing the neural mechanisms of GD, multiple brain regions related to executive functioning (e.g., ACC and DLPFC), reward systems (e.g., striatum and OFC), and emotional regulation (e.g., insula and amygdala) were found to be involved. Evidence supports GD as a behavioural addiction based on its clinical features, underlying neurobiological evidence, and public demand for treatment (King et al., 2017). However, opponents argue that the current manifestations of GD remain inadequate, it will cause moral panic among healthy gamers, and the label of gaming disorder is stigmatising. Nevertheless, a non-dogmatic, intensified, and broader debate can be beneficial before consensus is reached (Quandt, 2017).

However, further investigation is required. First, current neuroimaging findings of GD are mainly based on MRI and fMRI. Owing to their contradictory results, it is difficult to determine the concrete mechanism underlying GD. Multimodal approaches (e.g., combined EEG-fMRI studies) should be applied and developed in the future. Second, regardless of whether GD is a psychiatric disorder, the overlap and comorbidity of GD with other psychiatric disorders, such as addiction, ADHD, or anxiety disorders, should not be neglected. Third, the current debate on GD as a psychiatric disorder is influenced not only by experts and psychiatrists, but also by culture, government, and even commercial interests. We hope to make additional scientific contributions to future debates. These debates require interdisciplinary collaboration among researchers, clinicians, technologists, and policymakers to address the complex nature of GD and its societal implications. Fourth, longitudinal studies are necessary to track the trajectory of gaming disorder over time, including risk factors, protective factors, symptom progression, and treatment outcomes. Fifth, with more evidence supporting GD as a psychiatric disorder, the development of evidence-based interventions and treatment strategies for GD, such as incorporating cognitive behavioural therapy and mindfulness techniques, is important (Ko et al., 2023).

CONCLUSION

Despite the recent inclusion of GD as a mental health disorder in the ICD-11, the debate on whether gaming disorder is a psychiatric disorder continues. Clinical features and the severity of their consequences contributed to the inclusion of GD in the ICD-11. However, different views exist, arguing that the current manifestations that support gaming disorder as a psychiatric disorder remain inadequate, it will cause a moral panic among healthy gamers, and the label of gaming disorder is stigmatising. By reviewing the neural mechanisms underlying GD, we found that brain regions related to executive functioning (e.g., ACC and DLPFC), reward systems (e.g., striatum and OFC), and emotional regulation (e.g., insula and amygdala) are involved. Evidence suggests that GD shares similar neurobiological alterations with other types of behavioural and substance addictions, which further supports GD as a behavioural addiction. Ongoing debates on whether GD is a psychiatric disorder push us to further explore the nature of GD and resolve this dilemma in the field.

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