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Gaming Disorder and Internet Addiction: A systematic review of resting-state EEG studies

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Abstract

Neurophysiological studies of Gaming Disorder (GD) and internet addiction (IA) are providing important insight into neurocognitive mechanisms underpinning these disorders, which will enable more accurate diagnostic classification. Electroencephalography (EEG) has been widely used to investigate addictive behaviours, and offers advantages of accessibility, low cost, and excellent temporal resolution. The present systematic review evaluates resting-state EEG studies in GD and IA. Papers (n=2313) were identified in the *PsychARTICLES, PsychINFO, Scopus,* and *Pubmed* databases. Following inclusion/exclusion criteria, ten studies remained for evaluation. Results suggest individuals with GD have raised delta and theta activity and reduced beta activity, with coherence analysis suggesting altered brain activity in the mid-to-high frequency range. IA individuals demonstrate raised gamma activity and reduced beta and delta activity. Results suggest that the altered brain activity found in GD/IA may represent distinct underlying neurophysiological markers or traits, lending further support to their unique constructs. Results are also discussed in relation to relevant psychometric measurements and similar (higher frequency) activity found in substance addiction. Future research should focus on replicating the findings in a wider variety of cultural contexts to support the neurophysiological basis of classifying GD and IA.

Keywords: EEG; videogames; gaming disorder; gaming addiction; internet addiction; resting-state; neuroimaging

1. Introduction

Negative consequences associated with the rising use of digital technology and technology-related disorders (e.g., Gaming Disorder [GD]) have been investigated in an effort to improve screening, assessment, definition, and treatment (Kuss & Billieux, 2017; Yau et al., 2012). Consequently, in the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5), Internet Gaming Disorder (IGD) was included as a tentative behavioural addiction warranting further investigation (American Psychiatric Association [APA], 2013). Furthermore, the World Health Organization (WHO) officially recognized GD in the latest International Classification of Diseases (ICD-11; WHO, 2018).

IGD and GD have undergone conceptual evolution prior to inclusion in diagnostic manuals (DSM-5, ICD-11), with several other terms used to describe disordered gaming (e.g., pathological video gaming; Lemmens et al., 2011). These terms also fall under the broad umbrella of 'Internet Addiction' (IA), containing several descriptive terms (e.g., problematic internet use; Kuss et al,, 2014). The present review evaluates both clinically defined GD as well as the less defined IA. To maintain consistency, the term 'GD' here refers to the clinically defined measures of IGD/GD as defined by DSM-5/ICD-11.

Research indicates associations between disordered gaming (and/or problematic gaming) and psychiatric disorders, including anxiety (Adams et al., 2019) and depression (Burleigh et al., 2018) – and substance use disorders (e.g., Alcohol Use Disorder [AUD], Na et al., 2017). Several studies have considered psychopathological aspects of GD (Bishop, Johnston, Wolfe, & Mull, 2015) and IA (Kuss et al., 2014) and their co-occurrence with other behavioural disorders, substance use, and psychiatric disorders (Burleigh et al., 2019). Furthermore, empirical evidence suggests that GD and IA are distinctly different disorders (Király et al., 2014), despite the terms being used interchangeably. Consequently, research examining the neurophysiological aspects of GD and IA has emerged, providing contributions to studying psychopathological dimensions of behavioural addiction disorders (Kuss et al., 2018; Sharifat et al., 2018).

The US National Institute of Mental Health (NIMH) advocates using Research Domain Criteria (RDoC) and a multidimensional approach that includes observable behaviour and neurophysiological measurements to understand complex human behaviours and the mental disorder continuum (Clark et al., 2017). Therefore, GD/IA research should also consider underpinnings of neurophysiological mechanisms.

This review focuses on EEG which has several advantages relative to other neuroimaging techniques (e.g., high temporal resolution, non-invasive scanning, mobility, accessibility and low financial cost; Wang et al., 2013). Quantitatively measured EEG (QEEG) has been used to investigate various disorders, of which spectral and coherence analyses have been used to investigate addiction (Houston & Ceballos, 2013). Power spectral analysis quantifies power and/or voltage within bandwidths: delta (1–4 Hz), theta (5–7 Hz), alpha (8–13 Hz), beta (14–30 Hz), and gamma (>31 Hz; Houston & Ceballos, 2013). Power is typically measured as either relative or absolute (Houston & Caballos, 2013). Relative power is a proportion of power in the entire spectrum and minimizes the individual differences across participants, whereas absolute power is the entire spectrum and may be obscured with group differences. Coherence analysis quantifies the interdependence or statistical correlation between scalp recording sites, as an estimate of functional connectivity between cortical areas in the time domain (Gonzalez et al., 2015). Each method can be used to measure baseline brain states ('at rest'), spontaneous activity, and/or that induced during information-processing (Barry et al., 2010; Kounios et al., 2008).

Resting-state (i.e., 'at rest') brain activity has been associated with different aspects of behaviour and event-related cognitive processes comprising attention, memory, and thinking, and demonstrates high test–retest reliability, as well as producing stable trait-like indices of brain function (Massar et al., 2014). During resting-state EEG, data are recorded using Eyes-Closed (EC) or Eyes-Open (EO) conditions. During the EC-condition, there are no external task demands, providing a functional baseline (Barry, Clarke, Johnstone, Magee, & Rushby, 2007). The EO-condition allows passive engagement with visual input, without any specific task requirements (Barry et al., 2007; Wang et al., 2015). Resting-state EEG has been used to investigate substance and behavioural addictions. For example, studies consistently show raised absolute beta power in AUD, which is positively correlated with clinical severity, suggesting higher absolute beta may be a neurophysiological AUD marker (Coutin-Churchman et al., 2006; Rangaswamy et al., 2004). However, whether this represents a vulnerability-marker or response to the illness remains unclear.

Consolidating knowledge on the underpinning neurobiological mechanisms would benefit the conceptual development of GD/IA, and carry practical implications for understanding aetiology, establishing diagnostic criteria, and improving intervention. Whilst previous reviews span a range of neurophysiological methods (Kuss & Griffiths, 2012; Kuss et al., 2018), resting-state EEG studies in GD/IA have not been systematically evaluated.

Consequently, this paper presents a systematic review of resting-state EEG studies in GD/IA, to direct further work in the field. The primary goal is to review empirical research over the past decade, providing contemporary information on resting-state EEG findings concerning GD/IA. It therefore aims to: (i) investigate resting-state EEG within GD/IA, and to (ii) determine potential for neurophysiological markers.

2. Methods

The five-stage model of conducting a rigorous systematic review was used: (i) identifying the research question, (ii) identifying relevant studies, (iii) study selection, (iv) dissemination of outcomes, and (v) summarizing and reporting the results (Siddaway, Wood, & Hedges, 2019). Inclusion criteria for review were as follows. Studies had to be (i) empirical and contain primary data, (ii) using resting state quantitative EEG techniques in GD and/or IA; (iii) published in peer-reviewed journals, (iv) written in English, and (v) be published within the past decade. The database searches included: *PsychARTICLES, PsychINFO, Scopus,* and *PubMed*.

Search terms related to GD and IA used over the past decade. Additionally, other terms identified specific neuroimaging techniques and analysis in the behavioural addiction literature, leading to the following search-strategy: (patholog* OR problem* OR addict* OR compulsive OR dependen* OR disorder*) AND (video OR computer OR internet) gam* OR internet AND (“resting stat*” OR “default mod*” OR Quantitative) AND (neuroimaging OR electroencephalogr* OR EEG OR QEEG) NOT gambling. Paper title, abstract, and content were screened for eligibility. Then, full texts of potentially relevant papers were retrieved and screened for eligibility.

A total of 2313 papers were initially identified. Duplicate papers were removed. Papers not relevant to the present review or non-English were removed, leaving 28 papers. Of these, a number were excluded because they (i) did not utilize EEG neuroimaging techniques (*n* = 5), (ii) utilized EEG but did not assess/analyse resting state (*n* = 12), or (iii) were review papers (*n* = 1). The remaining ten papers met all the inclusion criteria. This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (PRISMA statement; Moher et al., 2009), which includes a PRISMA flow diagram (see Figure 1).

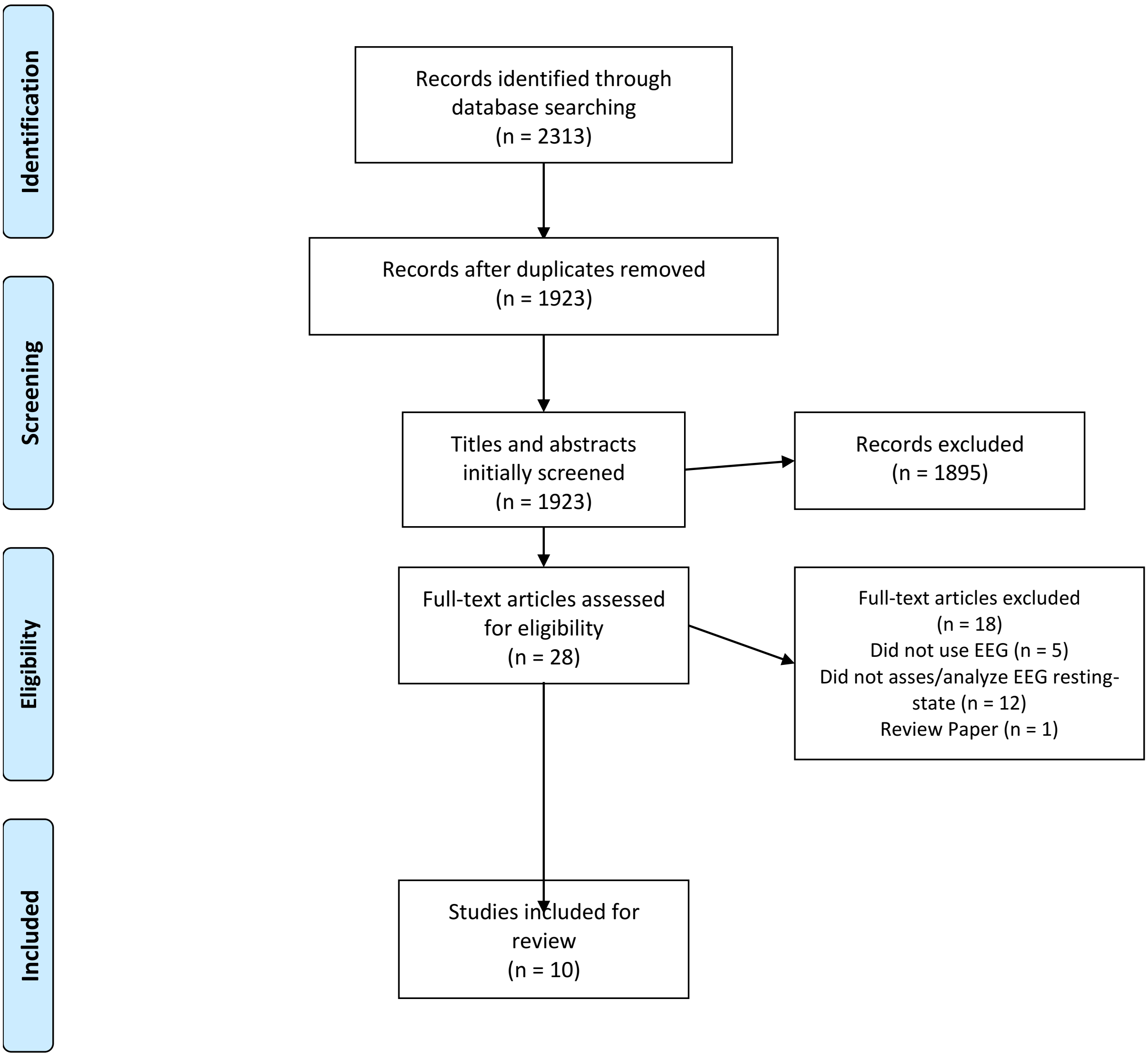

Figure 1. Flow diagram of paper selection process for the systematic review

3. Results

The ten papers meeting the inclusion criteria were separated into two groups – GD and IA. Seven papers investigated GD. Participants were diagnosed with GD by an experienced psychiatrist/clinician based on the DSM-5 criteria for IGD; symptom severity was assessed using either the Internet Addiction Scale (IAS; Young, 1998) (*n*=2) (Park, Hong et al., 2017; Youh et al., 2017) or Internet Addiction Test (IAT; Beard & Wolf, 2001) (*n*=5) (Kim et al., 2017; Lee, Choi, & Kwon, 2019; Park, Lee et al., 2017; Park et al., 2018; Son et al., 2015). Three studies investigated IA and utilized the IAS as a diagnostic tool and severity measure. However, two of these studies noted that participants reported online gaming as their primary internet use (Choi et al., 2013; Lee et al., 2014); the third paper did not report specific internet use (Son et al., 2019).

3.1 Gaming disorder

Seven studies investigated GD (Kim et al., 2017; Lee, Choi, & Kwon, 2019; Park, Hong et al., 2017; Park, Lee et al., 2017; Park et al., 2018; Son et al., 2015; Youh et al., 2017), and all conducted in South Korea. Five studies recruited participants from the SMG-SNU Boramae Medical Center, Seoul (Kim et al., 2017; Lee et al., 2019; Park, Lee et al., 2017; Park et al., 2018; Son et al., 2015), while the remaining two recruited participants from the Department of Psychiatry, Chung-Ang University Medical Center (Park, Hong et al., 2017; Youh et al., 2017). Each study recruited male-only participants. The selected papers reported power spectral analysis and/or coherence analysis (see Table 1).

Table 1. Summary of findings from Gaming Disorder studies

Paper	Aims	Sample	EEG Method	Behaviour /Substance /Psychiatric Diagnosis	Results
Kim et al. (2017)	To identify neurophysiological markers (i.e., brain waves) through associated symptom changes in GD patients who have undergone pharmacotherapy with selective serotonin reuptake inhibitors (SSRIs*).	South Korea: SMG-SNU Boramae Medical Center 49 Male Participants. GD: *n*=20 (*M*age: 22.71/*SD*: 5.47); HC: *n*=29 (*M*age: 23.97/*SD*: 4.36).	Power Spectral Analysis	GD	Patients who experienced comorbid depression and anxiety symptoms had increased resting-state Delta and Theta activity. Delta-band activity normalized after 6 months of pharmacotherapy. The findings suggest that slow wave activity may be a neurophysiological marker with changes in addiction symptoms following treatments.
Lee et al. (2019)	To determine the effects of resilience on neurophysiological correlates within GD patients compared to HCs.	South Korea: SMG-SNU Boramae Medical Center 71 (reduced from 76) Male Participants. HR: n=19 (*M*age: 25.47/*SD*: 5.04); LR: n=16 (*M*age:22.13/*SD*: 5.56); HC: n=36 (*M*age: 25.14/*SD*: 3.60).	Coherence Analysis	GD	GD patients with low resilience had increased coherence, especially in the right hemisphere when compared to GD patients with high resilience and the HCs. There were conditional indirect effects of GD on alpha coherence in the right hemisphere through depressive symptoms.
Park, Hong et al. (2017)	To identify the potential of differing neurophysiological features in individuals experiencing GD and individuals with comorbid ADHD.	South Korea: Chung-Ang University Medical Center 45 Male Participants. ADHD & GD: *n*=16 (*M*age: 14.6/*SD*: 1.9); ADHD: *n*=15 (*M*age: 13.7/*SD*: 0.8); HC: *n*=14 (*M*age: 14.4/*SD*: 1.7).	Power Spectral Analysis / Coherence Analysis	GD/ADHD	GD/ADHD showed lower relative delta band power and higher relative beta-band power in temporal regions compared to the ADHD group. Relative beta-band power between GD/ADHD and HCs was not significant. Internet games may enhance attentional ability, creating a similar relative beta power in attention deficit in GD/ADHD and HCs. The continuous activation of the brain reward and working memory systems while gaming may increase neuronal connectivity for the GD/ADHD group.

Park, Lee et al. (2017)	To compare and detail the difference in neurophysiological features of GD and AUD patients with HCs using coherence analysis.	South Korea: SMG-SNU Boramae Medical Center 96 Male Participants. GD: n=30 (*M*age: 23.26/*SD*: 5.15); AUD: n=30 (*M*age: 29.86/*SD*: 7.13); HC: *n*=32 (*M*age: 24.96/*SD*: 3.70).	Coherence Analysis	GD/AUD	GD group has significantly greater high frequency coherence – especially in gamma activity– compared to AUD and HCs. Increased gamma activity was independent of psychological comorbidity. Gamma coherence positively predicted the degree of GD tendency in all three groups. GD and AUD display different neural activity patterns. Heightened phasic synchrony in the gamma-band may be a neurophysiological marker of GD.
Park et al. (2018)	To investigate the treatment response (to SSRIs*) in relation to cortical activity in patients with GD and to determine if altered phasic synchrony is a state or trait-marker.	South Korea: SMG-SNU Boramae Medical Center 62 Male Participants. GD: *n*=30 (*M*age: 23.27/*SD*: 5.15); HC: *n*=32 (*M*age: 24.97/*SD*: 3.70).	Coherence Analysis	GD	GD group has increased beta, gamma, and delta coherence at baseline, signifying abnormal phasic synchrony. Post 6 months of pharmacotherapy (SSRIs*) showed no change in phasic synchrony despite significant improvements in GD symptoms. Heightened phasic synchrony may be a neurophysiological marker for GD.
Son et al. (2015)	To compare and detail the difference in neurophysiological features of GD and AUD patients with HCs using power spectral analysis.	South Korea: Chung-Ang University Medical Center 76 Male Participants. GD: *n*=34 (*M*age: 22.71/*SD*: 5.47); AUD: *n*=17 (*M*age:29.71/*SD*: 4.88); HC: *n*=25 (*M*age: 23.88/*SD*: 4.66).	Power Spectral Analysis	GD/AUD	GD group showed significantly lower absolute beta power than AUD and HCs. GD and AUD displayed different spectral power analyses in resting-state. Lower absolute beta-power may be a neurophysiological marker for GD.
Youh et al. (2017)	To identify the potential of differing neurophysiological features in individuals experiencing MDD and individuals with comorbid GD.	South Korea: SMG-SNU Boramae Medical Center 29 Male Participants. MDD+GD: *n*=14 (*M*age: 20.00/ *SD*: 5.00); MDD: *n*=15 (*M*age: 20.30/*SD*: 5.50).	Coherence Analysis	GD/MDD	Inter-hemispheric coherence value for the alpha-band between right and left frontal regions was significantly lower in MDD/GD than MDD. Increased intra-hemispheric coherence for the alpha-band within the left parietal-occipital area was observed in MDD/GD compared with MDD.

MDD/GD showed increased intra-hemispheric coherence values for the beta-band within the right frontal-temporal, temporal-occipital, and parietal-occipital areas compared with MDD.

Decreased inter-hemispheric connectivity in the frontal region is associated with attention problems in MDD/GD.

Excessive gaming may result in increased intra-hemispheric connectivity in the fronto-temporo-parieto-occipital areas.

*Note: GD is Internet Gaming Disorder; HC is Healthy Control; HR is High Resilience; LR is Low Resilience; ADHD is Attention Deficit Hyperactivity Disorder; AUD is Alcohol Use Disorder; MDD is Major Depressive Disorder; *Escitalopram, Fluxetine, and Paroxetine.*

3.1.1 GD studies using power spectral analysis

Three studies used power spectral analysis across several frequency bands (Kim et al., 2017; Park, Hong, et al., 2017; Son et al., 2015). Kim et al. (2017) compared GD patients with healthy controls (HCs) over a six-month period on delta and theta bands. GD participants were scanned prior to and following pharmacotherapy with selective serotonin reuptake inhibitors (SSRIs). At baseline, GD was associated with higher delta-band power across the whole scalp and higher theta-band activity centrally. Compared to baseline, following treatment, the GD group showed reduced frontal delta wave activity, and reduction in IAT scores. Furthermore, high-baseline theta activity predicted greater improvement in GD symptoms post-treatment. The authors suggested that raised slow-wave activity may represent a state neurophysiological GD marker.

Son et al. (2015) investigated resting state QEEG of individuals with GD and AUD, compared to HCs without these disorders. The GD group had lower absolute beta-power than either the AUD group or HCs, while the AUD group had higher absolute delta power than the GD group and HCs. However, there were no significant correlations between GD severity and EEG activity. The authors concluded that lower absolute beta-power may be a neurophysiological GD marker.

Park, Hong et al. (2017) noted GD is commonly comorbid with ADHD, and presence of ADHD may increase vulnerability to loss of control, which is associated with excessive gaming (Bioulac, Arfi, & Bouvard, 2008). They found individuals with comorbid ADHD/GD had lower relative delta wave power and higher relative beta-power restricted to temporal regions, compared to those with ADHD. The researchers conservatively suggested individuals vulnerable to ADHD appear to engage in continuous videogame play to subconsciously enhance attentional ability. They concluded that differences in QEEG profiles between groups provide clues to understanding neurophysiological mechanisms of GD and its ADHD comorbidity.

3.1.2 GD studies using coherence analysis

Park, Hong et al. (2017) applied coherence analysis in conjunction with power spectral analysis, while the remaining four studies used coherence analysis only (Lee et al., 2019; Park, Lee et al., 2017; Park et al., 2018; Youh et al., 2017). Park, Hong et al. (2017) investigated both inter-hemispheric and intra-hemispheric coherence (i.e., between the two hemispheres and within either of the two hemispheres). They found that intra-hemispheric coherence values in the delta-wave band were higher for the ADHD/GD group compared to the ADHD group. Furthermore, they found raised intra-hemispheric coherence (theta, alpha, beta) in the ADHD/GD group compared to ADHD-only and HCs. Inter-hemispheric coherence in the theta-band was higher in the ADHD/GD group compared to HCs.

IAS scores in the ADHD/GD group positively correlated with intra-hemispheric (but not inter-hemispheric) coherence in the delta, theta, alpha, and beta bands between parietal and occipital (i.e., P4-O2) electrodes.

Lee et al. (2019) investigated the role of resilience (i.e., personal qualities empowering individuals to thrive in the face of hardship) and relationship to neurophysiological measurements, and how it acted as a protective factor among GD individuals, using the Connor-Davidson Resilience Scale (Connor & Davidson, 2003). Association between resilience and resting-state EEG was only observed in alpha-band activity. Resilience was negatively associated with alpha inter-hemispheric and intra-hemispheric coherence. The authors concluded that participants with low resilience exhibit impaired EEG features relative to HCs, while participants with high resilience exhibited less impaired EEG features relative to HCs.

Park, Lee et al. (2017) found no differences in inter-hemispheric coherence, but found raised intra-hemispheric coherence among GD participants for higher frequencies: gamma (compared to AUD participants and HCs) and beta (compared to AUD group). Furthermore, gamma (but not beta) coherence positively correlated with IAT scores for all groups. However, EEG variables were not significantly correlated with GD severity among the GD group. These results suggest AUD and GD display different neurophysiological characteristics, and that increased gamma coherence may be a GD trait-marker.

Park et al. (2018) considered longitudinal changes that may occur in neural connectivity among GD patients before and after pharmacotherapy treatment with SSRIs. At baseline, raised intra-hemispheric coherence in the beta and gamma bands were observed in the GD group when compared with HCs. Additionally, raised right delta intra-hemispheric coherence was seen in GD compared to HCs. Six-month SSRI treatment lowered GD symptoms in the GD group. However, there were no significant changes in EEG coherence following treatment compared to HCs. It was concluded that greater intra-hemispheric activity in beta and gamma bands may be a neurophysiological trait-marker of GD individuals.

Finally, Youh et al. (2017) investigated EEG features of individuals with co-occurring GD and major depressive disorder (MDD). Inter-hemispheric coherence of the alpha-band between left and right fronto-polar (Fp1, Fp2) electrodes was lower in the MDD/GD group than MDD-only. However, the GD/MMD had higher intra-hemispheric coherence between left parietal-occipital (P3-O1) electrodes in the alpha-band and between right fronto-temporal (F8-T4), temporo-occipital (T6-O2), and parieto-occipital (P4-O2) electrode in the beta-band. Results suggested that the GD/MMD group experienced an association between decreased inter-hemispheric coherence in the frontal region of the brain and demonstrated a vulnerability to attention problems. Moreover, increased intra-hemispheric coherence in the GD/MDD group may be a result of high gaming engagement.

3.2 Internet addiction

Three studies examined resting-state EEG among individuals with internet addiction (IA). Two of the studies were conducted at the SMG-SNU Boramae Medical Center, South Korea (Choi et al., 2013; Lee et al., 2014), while the third was conducted in China (Sun, Wang, & Bo, 2019). All studies recruited males and females (see Table 2).

Table 2. Summary of findings from internet addiction studies

Paper	Aims	Sample	EEG Method	Behaviour /Substance	Results
Choi et al. (2013)	To investigate resting-state EEG activity in beta- and gamma-bands and how they relate to impulsiveness in IA patients.	South Korea: SMG-SNU Boramae Medical Center 41 Participants. IA: *n*=20 (M:12/F:9; *M*age: 23.33/*SD*: 3.50); HC: *n*=29 (M:11/F:9; *M*age: 22.40/*SD*: 2.33).	Power Spectral Analysis	IA	IA group demonstrated higher impulsive behaviour and impaired inhibitory control. IA group showed decreased absolute beta-band activity when compared to the HCs. IA group showed increased gamma-band activity when compared to HCs. Decreased beta activity was correlated with both impulsivity and IA severity. Increased gamma activity was correlated with both impulsivity and IA severity.
Lee et al. (2014)	To compare and contrast the resting-state EEG activity of treatment seeking IA patients with co-morbid depression, IA patients without co-morbid depression, and HCs in an effort to identify neurophysiological differences in IA and depression.	South Korea: SMG-SNU Boramae Medical Center 69 Participants. IA/Dp: *n*=18 (M:15/F:4; *M*age: 21.25/*SD*: 4.71); IA: *n*=17 (M:12/F:5; *M*age: 23.44/*SD*: 4.82). HC: n=34 (M:25/F:9; *M*age: 23.59/*SD*: 4.34).	Power Spectral Analysis	IA	IA group showed decreased absolute delta and beta-power in all brain regions when compared to IA/Dp group. IA/Dp group showed increased relative theta and beta-power in all regions of the brain when compared to the IA/Dp group and HCs. The neurophysiological changes were not correlated to the clinical variables.
Sun et al. (2019)	To investigate the differences in brain networks when considering resting-state EEG between IA and HCs.	China 52 Participants. IA: *n*=25 (M:6/F:19; *M*age: 20.19/*SD*: 1.83); HC: *n*=27 (M:4/F:23; *M*age: 20/*SD*: 1.74).	Functional Connectivity Analysis / Network Analysis	IA	There were no significant differences in functional connectivity between IA and HC. Individuals with IA exhibit a more random network organization in beta- and gamma-band activity compared to HCs. There were no significant correlations between EEG graph measures and clinical measures.

Note: IA is Internet Addiction; HC is Healthy Control; Dp is Depression

3.2.1 IA studies using power spectral analysis

Two of the three IA studies used spectral power analysis (Choi et al., 2013; Lee et al., 2014) and one used connectivity analysis and network analysis (Sun et al., 2019). Choi et al. (2013) investigated the relationship between impulsiveness and fast frequency (beta, gamma) activity among internet addicts. Results showed that compared to the HC group, IA participants had significantly lower absolute power in beta- and gamma-band activity in all brain regions. Moreover, both beta- and gamma-power in the frontal region significantly correlated with IA severity.

Lee et al. (2014) investigated the neurophysiology among internet addicts and comorbid depression (IA/Dp), with IA only, and HCs (without IA/Dp). The IA group showed lower absolute delta-power (widespread compared to both other groups) and beta-power (compared to HCs). In the comorbid group, relative theta-activity was higher and relative alpha-activity was lower across the scalp compared to other groups. However, there was no correlation between any EEG measure and clinical variables for IA/Dp or IA groups.

3.2.2 IA study using functional connectivity analysis and network analysis

In Sun et al.'s study (2019), an IA group (compared to HCs) exhibited a more random network organization, with decreased clustering coefficients and characteristic path length, demonstrating an alteration in the typical balance of network function. However, functional analysis did not demonstrate any significant differences in connectivity strength between the groups. However, there was a trend for increased global connectivity among internet addicts compared to HCs. Additionally, there was no significant correlation between EEG and clinical measures. The authors concluded that internet addicts demonstrate altered topological organization which shifts towards a more random state, which suggests that the associated connection paths may be reflecting alterations in the ability of information processing in IA. Thus, providing additional evidence supporting an IA neurophysiological component.

4. Discussion

This systematic review is the first to focus on resting-state EEG studies of GD and IA. Both spectral and coherence analysis were investigated. Findings demonstrate that disordered gamers have raised slower frequency (delta, theta; Kim et al., 2017; Son et al., 2015), and reduced higher frequency (beta) activity (Son et al., 2015). Furthermore, coherence analysis findings suggest that disordered gamers demonstrate altered synchronised brain activity (Lee et al., 2019; Park, Hong et al., 2017; Park, Lee et al., 2017; Park et al., 2018; Youh et al., 2017). Internet addicts appear to have raised gamma activity and reduced beta and delta activity (Choi et al., 2013; Lee et al., 2014). Multiple neurotransmitters are involved in the modulation of EEG, such as dopamine, glutamate, noradrenaline, acetylcholine, N-methyl-D-aspartate (NMDA) and γ-aminobutyric acid (GABA; Watson et al., 2009; Hansenne et al., 1995). In the context of addictive behaviours, it is well established that the mesocorticolimbic dopamine and brain stress systems are critically involved in reward function and psychomotor performance. Observed EEG changes among disordered gamers and internet addicts may reflect neuroadaptive changes in these systems associated with addictive behaviours. While current knowledge of addictive behaviours has been predominantly built on substance use research, assessing the neurophysiological aspects of GD/IA provides an important contribution in understanding the psychopathological mechanisms of behavioural addiction disorders.

4.1 Power spectral analysis

When considering the power spectral analysis, the studies reviewed suggest that disordered gamers demonstrate specific trait-like markers when compared to HCs (Park, Lee et al., 2017; Son et al., 2015). For example, Kim et al. (2017) demonstrated prior to pharmacotherapy (i.e., at baseline) disordered gamers showed increased delta- and theta-wave activity compared to HCs. However, at the completion of (SSRI) pharmacotherapy, there was a significant decrease in delta-wave activity, while theta showed no significant changes despite the significant reduction in GD severity measures. The decreased delta-activity significantly correlated with a reduction in GD severity scores, while theta-activity remained high when compared to HCs. Slow-wave activity (i.e., delta and theta) has been associated with a range of cognitive processes, such as attention, and higher-order control processes (Thatcher et al. , 2005), an increase of which has been related to impairments in attention, control processes, and inhibitory control (Schiller et al., 2013), which have been found to be psychometrically correlated with GD (Şalvarlı & Griffiths, 2019). This suggests these neurophysiological differences may be GD trait-markers, a method which has been used to indicate possible trait-markers in other fields, such as substance use addiction (e.g., AUD; Porjesz et al., 2005).

Additional findings were reported among internet addicts who experienced higher gamma-activity (Choi et al., 2013), but lower beta- and delta-activity compared to HCs (Choi et al., 2013; Lee et al., 2014). Gamma-wave activity has been understood to represent local neural communication and have been associated and binding of perceptual and conceptual information, while decreased beta-activity has been related to inattention and impulsivity (Abhang et al., 2016; Park et al., 2017; von Stein & Sarnthein, 2000). Given that dysfunctional resting-state gamma-activity is present without external stimuli, it may suggest anomalous connectivity and neural asynchrony while in a resting-state (Tallon-Baudry, 2003; Tallon-Baudry et al., 2005). Similarly, aberrant gamma activity may suggest dysfunctional activity in the dopaminergic system, which can be related to excitatory activation of the brain and seeking-behaviours related to addiction (Buzsáki & Wang, 2012; Yordanova et al., 2002). Furthermore, decreased beta activity suggests that internet addicts experience low impulse-control and therefore use increased cognitive resources, which has been associated with psychometric findings (D'Hondt et al., 2015). Taken together, it could be that increased gamma-activity among internet addicts, coupled with low beta-activity demonstrate a trait-like marker for internet addicts (Choi et al., 2013; Lee et al., 2014).

GD and IA each show lower beta-activity (Park, Hong et al., 2017; Son et al., 2015; Choi et al., 2013; Lee et al., 2014). Lower beta-activity has frequently been found among individuals with ADHD, and reported to be associated with poor cognition, inattention, and impulsiveness in ADHD (Snyder & Hall, 2006), which was also related to impulsivity trait and severity in a resting-state gambling EEG study by Lee et al. (2017). Similarly, decreased beta-activity among disordered gamers and internet addicts may implicate higher levels of impulsiveness, which is corroborated by psychometric literature (Şalvarlı & Griffiths, 2019; Zhang et al., 2015). However, unlike disordered gamers, internet addicts experienced significantly lower delta-activity compared to HCs, similar to AUD patients (Ehlers, Wall, & Schuckit, 1989). This is suggestive of dysfunctional information processing, which has been related with slow-wave changes (Howland et al., 2011; Saletu-Zyhlarz, 2004). Overall, these results suggest that although IA and GA share similar cognitive and behavioural characteristics, they can be differentiated by their distinct neurophysiological features.

4.2 Coherence analysis

When considering coherence analysis, findings suggest altered synchronised brain activity between spatially separated scalp electrodes among disordered gamers. The severity of this alteration may be related to clinical variables, including resilience and co-existing conditions. Disordered gamers with low resilience exhibited increased alpha coherence in the right hemisphere and reported severe depressive symptoms and high stress levels (Lee et al., 2019). Increased alpha coherence has been associated with poor emotional regulation (Kautz et al., 2017), which has been theorized as a mechanism in the development and maintenance of GD (Burleigh et al., 2019). Furthermore, Park et al. (2018) found that fast-frequency coherence activity was also present pre- and post-SSRI treatment and concluded that increased gamma and beta coherence may act as neurophysiological GD marker. Distinctive gamma, alpha, and beta coherence were also found when disordered gamers were compared with AUD patients (Park, Lee et al., 2017), comorbid GD/ADHD patients (Park, Hong et al., 2017), and GD/MDD patients (Youh et al., 2017).

Taken together, disordered gamers may have specific neurophysiological states when compared to HCs and other SUDs and psychiatric disorders. The consistent findings of mid- to high-frequency bands can be explained as a possible risk factor and a secondary change derived from repetitive gaming (Dong et al., 2012; Jeong et al., 2016). The increased beta and alpha coherence activity within the right hemisphere may also be associated with the repeated activation of the visuospatial working memory and executive function that is accompanied by frequent gaming (De Benedictis et al., 2014; Jeong et al., 2016).

4.3 Limitations and future directions

Despite neuroimaging studies on GD offering important contributions, there are limitations and future directions that should be considered. Firstly, the reviewed studies of GD contained all male participants. This may have created a neurophysiological bias within the data. The reviewed studies were also exclusively conducted and recruited in South Korea and China, which may compromise the generalizability of the results. Moreover, eight studies recruited participants from the same clinic, which may also compromise the generalizability of the results to a larger demographic. Furthermore, there were no studies in this review investigating other cultural populations, which may produce different results. Additionally, a majority of the reviewed studies used cross-sectional methods and therefore it is not possible to ascertain any causal relationships between GD and altered neurophysiological traits. Future research should utilise both men and women from other countries and cultures and employ longitudinal designs with male and female samples to overcome these shortcomings. Multi-cultural studies are necessary to understand the neurophysiological and potential GD trait-markers.

Additionally, there are limitations regarding the veracity of the psychometric-related conclusions drawn within the GD and IA studies. More specifically, each GD study used an IA severity measure (i.e., IAS or IAT) to assess GD, despite other measures specific to IGD or GD being available. Furthermore, two of the three IA studies reported predominantly online gamers as participants. The use of IA tools to asses GD, is a trend that has continually been observed, and scholars have debated the detrimental effect it has had on both fields (see King et al. [2020] and Pontes et al. [2017] for reviews). This issue is also present in the current review because the samples used in the IA studies (Choi et al., 2013; Lee et al., 2014) were reported as problematic online gamers. This suggests the findings may reflect problematic gaming more so than IA. However, given these studies explored IA themes and theoretical underpinnings, it is important to collate and contrast the data in the context of which they were collected. Moreover, it is important to consider that these IA studies were published before the DSM-5's IGD diagnostic criteria were conceived, further supporting the decision to present the findings in their original contexts. Finally, it is important to note that the reviewed studies employed an experienced psychiatrist/clinician to assess GD and IA (excluding Sun et al. [2019]), lending validity to the overall neurophysiological results and the behavioural constructs they explored. Future research in this area should endeavour to use psychometrically-validated constructs that are specific to GD when evaluating neurophysiological data

The present review is also subject to some limitations. Firstly, the methodology used was descriptive in nature and not quantitatively synthesized. While the review followed rigorous and transparent methods, it considered the breadth of the literature, and as such, no statistical conclusions can be drawn from the results. Secondly, due to the inclusion criteria, only peer-reviewed papers published in English were used. Given that the entirety of the papers reviewed were from south-east Asian countries, it could be that important findings published were overlooked because they may have been available in other languages or databases. Finally, despite including broad research terms in several databases, it is possible a number of studies were missed due to a lack of fit with the inclusion criteria.

4.5 Conclusion

The evidence in this review suggests that there are distinct neurophysiological features associated with GD and IA. Although both share some neurophysiological similarities to substance use disorders, the results suggest that internet addicts have higher gamma-activity and lower delta-activity, while disordered gamers show higher theta-activity and higher gamma and beta coherence than HCs. Taken together, the findings indicate possible impairments in attention and inhibitory control (i.e., impulsivity), and dysfunctional dopaminergic activity. These distinct pairings may help improve diagnosis by objectively highlighting an individual’s neurophysiological state, and in conjunction with correlated psychometric scales could allow clinicians to provide tailored interventions. Therefore, the findings support the NIMH’s suggestions of using the RDoC criteria for mental disorder diagnosis (Clark et al., 2017). Future research should focus on replicating the findings in a wider variety of cultural contexts to support the neurophysiological basis of classifying GD and related behavioural addictions.

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