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Review

Off-Label Medications and Non-Invasive Brain Stimulation (NIBS) in the Treatment of Internet Gaming Disorder: A Systematic Review and Meta-Analysis

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ABSTRACT

Internet gaming disorder (IGD) has become a worldwide concern, but there are still no approved medications or treatments for IGD. The present study systematically meta-analyzed the available research regarding off-label medications and non-invasive brain stimulation (NIBS) as neurobiological treatments for IGD. A total of 18 studies met the inclusion criteria (n = 687; age range = 9 to 26 years) following PRISMA guidelines, and data from 15 studies were included in the meta-analysis. In some of the studies, IGD was a comorbid condition with major depression, alcohol use disorder, attention deficits, and/or hyperactivity disorder. The findings indicated that: (i) treatment using non-invasive neuromodulation (tDCS targeting dorsolateral prefrontal cortex [DLPFC]), bupropion, selective serotonin reuptake inhibitors (SSRIs), and methylphenidate were significant in reducing IGD; (ii) pharmacotherapy was much more effective than tDCS; (iii) there were no significant differences between tDCS, SSRIs, and methylphenidate, and all except SSRIs were outperformed by bupropion; (iv) the effect of tDCS, bupropion, and SSRIs were independent of IGD severity; (v) the effect of bupropion was independent of treatment duration, gaming level, or comorbidity with depression; (vi) the effect of bupropion remained stable after 12 weeks follow-up; (vii) the effect of methylphenidate was independent of treatment duration; and (viii) the effect of SSRIs was independent of IGD severity and treatment duration. However, this initial evidence is limited in its generalizability due to high risk of bias, overrepresentation of males, small sample sizes, lack of clinical interviews, lack of consideration of comorbidities, lack of monitoring for side effects, and insufficient details for exact replication.

1. Introduction

Online videogame playing offers a source of enjoyment to many individuals of all ages (Wang & Cheng, 2022; Akbari et al., 2025). Internet gaming disorder (IGD) refers to "*persistent and recurrent use of the Internet to engage in games, often with other players, leading to clinically significant impairment or distress*" (American Psychiatric Association [APA], 2013, p. 795). In a comprehensive meta-analysis of 53 studies encompassing 226,274 participants across 17 countries, Stevens et al. (2021) reported a global prevalence of 3.05% for IGD. Consideration of IGD as an addiction has remained contested among scholars. Scholars who favor the addiction framework note that IGD shares similar neurobiological alterations with other types of behavioral and substance-related addictions (Zheng et al., 2025), which include alterations in brain regions associated with executive functioning, reward processing, and emotional regulation. In addition, clinical observations support the resemblance of addiction-like symptoms in IGD, such as withdrawal-related affective states, anhedonia, gaming urge symptoms, and a higher heart rate during abstinence from IGD (Yen et al., 2022).

However, other scholars have criticized the addiction model of IGD. For example, alternative conceptualizations consider IGD or problematic gaming as a type of maladaptive coping mechanism, wherein individuals might use the online environment to reduce negative feelings arising from stressful life events, which may lead to problematic use and

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addictive-like symptoms (Kardefelt-Winther, 2014). This compensatory framework has been supported by empirical research indicating that emotion dysregulation predicts both escapism motives and problematic gaming, and that escapism partially mediates this relationship (Blasi et al., 2019). This suggests that IGD might be a representation of behavioral regulation failure rather than classical addiction. In addition, scholars have raised concerns regarding the current transdiagnostic approaches, claiming that there is inadequate support for the consideration of IGD as a psychiatric disorder, which may lead to moral panic among healthy gamers and children (Aarseth et al., 2017).

The diagnostic controversy has direct implications for intervention development, given that the addiction-based and compensatory coping models would lead to different treatment approaches. The scholars who favor the addiction-based model of IGD, which is drawn from the neurobiological similarities between IGD and substance-related addictions, would test neurobiologically-oriented interventions, including transcranial direct current stimulation (tDCS) and pharmacotherapy. However, the efficacy of these approaches is unclear, and their theoretical basis is critically dependent on the validity of the addiction framework. To help inform this debate, the present meta-analysis systematically evaluated the efficacy of neuro-modulatory and pharmacological interventions for IGD, providing empirical evidence that may inform both the conceptual debate regarding IGD's nosological status and the development of evidence-based treatment protocols.

Among the aforementioned treatments, there is growing interest in the effects of non-invasive brain stimulation (NIBS) techniques (Ganuza & Alegre, 2022). The capacity of these techniques to modulate brain activity painlessly (Oliviero et al., 2011), with effects that persist beyond the stimulation sessions (Ganuza & Alegre, 2022), has led to their increasing popularity. The two most well-known NIBS techniques are [*repeated*]*transcranial magnetic stimulation* ([r]TMS) and *transcranial direct current stimulation* (tDCS). TMS involves using a magnetic coil to influence the brain's natural electrical activity (Fitzgerald & Daskalakis, 2022). In tDCS, "*the dose is a waveform of single sustained direct current, except one ramp-up and one ramp-down period, applied to the head using at least one cephalic electrode*" (Venkatasubramanian, 2022, p. 74). While both of the techniques act at synaptic levels on central pathways, TMS mainly activates axons, and tDCS "*induces conformational changes in transmembrane proteins, causing potentiation or depression of certain areas*" (Ganuza & Alegre, 2022, p. 487).

The other treatment is the use of medications in treating IGD. Both of these treatment types affect brain activity through distinct mechanisms of action, yet they converge on core neurobiological targets disrupted in IGD, highlighting a unified framework for neurobiological interventions (Dong et al., 2024; Ulisse et al., 2025). In particular, IGD involves hypoactivation in reward-processing regions (e.g., striatum and mesolimbic dopaminergic pathways) and impaired executive control (e.g., dorsolateral prefrontal cortex [dlPFC]), as evidenced by neuroimaging reviews (Gao et al., 2021; Mestre-Bach & Potenza, 2023). Moreover, pharmacotherapy modulates these circuits via neurotransmitter systems (e.g., bupropion enhances dopaminergic signaling in prefrontal-striatal loops to improve inhibitory control and reduce cravings) (Seo et al., 2021), while NIBS (e.g., rTMS or tDCS targeting dlPFC) alters cortical excitability to normalize hypofrontality and striatal hyperactivity, restoring reward sensitivity (Jeong et al., 2020). These approaches share the targeting of addiction circuitry, which supports the rationale for a joint review, given that both could lead to comparable symptom reductions (e.g., IGD severity) through overlapping downstream effects on cortico-striatal connectivity.

The present systematic review and meta-analysis focused on NIBS and pharmacological treatments for IGD. Psychotherapeutic treatments were not included in the present review, as they have been previously reviewed elsewhere (Kim et al., 2022; Wang et al., 2025). A variety of psychotropic drugs have been used to treat IGD, including antidepressants (Bae et al., 2018), stimulants (Park et al., 2016), and opioid receptor antagonists (Vasiliu, 2020). There is some evidence that opioid receptor antagonists may be effective in reducing gaming time and symptom severity associated with gaming disorders (Mestre-Bach et al., 2022). In addition to psychotropic drugs, NIBS has also been used to treat gaming disorder becauses there is evidence that shows behavioral addictions such as IGD share similar psychobiological mechanisms with substance abuse addictions (Rumpf et al., 2018; Weinstein & Lejoyeux, 2015). IGD is a heterogeneous disorder with symptom clusters, and because NIBS modulates specific regions and networks, its clinical benefits might vary across symptom clusters (Ko et al., 2023). However, both of these treatment types affect brain activity, and although their mechanisms of action may differ, they ultimately aim to reduce IGD symptoms (Goerigk et al., 2021).

Some meta-analyses and/or systematic reviews have been conducted on the effectiveness of various psychotherapeutic and pharmacological treatments for IGD. Chang et al (2022) – without differentiating between internet addiction and IGD and also excluding tDCS studies – found that combining pharmacotherapy with CBT or multi-level counseling was the most effective treatment in reducing time spent online. Danielsen et al. (2024) reviewed 38 studies that used psychological, behavioral, pharmacological, and tDCS (only two studies) for IGD and reported an overall moderate-to-strong effect size across treatments. Another meta-analysis of 32 studies (Wang et al., 2023) that excluded NIBS interventions found that pharmacotherapy, psychotherapy, and combined therapies showed large to moderate effect sizes for IGD symptoms. They also reported that bupropion and CBT showed advantages over their counterparts. Two systematic reviews of pharmacological studies (Sá et al., 2023; Zajac et al., 2020) on IGD reported that this intervention is promising. One meta-analysis (Stanković et al., 2023) also indicated that tDCS could improve gaming task performance and positively affect IGD symptoms. The authors of another review (Chen et al., 2023) concluded that tDCS had no significant effect on IGD. Consequently, the efficacy of IGD interventions remains unclear due to the heterogeneity of reported outcomes and the lack of high-quality evidence (Yang et al., 2023).

The necessity and novelty of the present review are that it addresses the limitations of eight recent reviews on the treatment of IGD (Chen et al., 2023; Danielsen et al., 2024; Dong et al., 2024; Gorowska et al., 2022; Sá et al., 2023; Seo et al., 2021; Wang et al., 2023; Zajac et al., 2020). Overall, these reviews were limited by the one or more of the following issues: (i), pre/post-treatment scores were not reported, (ii), NIBS studies were either not considered or fewer than three studies on tDCS/rTMS were included (and the voltage or brain area was not specified), (iii), medication dosage was not reported, (iv), different medications with different dosage were combined for meta-analysis, (v), risk of bias was not reported or was only reported in a general way and not by treatment type, and (vi), there were limited search terms or lack of MeSH terms used. Therefore, the present study's first aim was to address the limitations of existing reviews on the treatment of IGD by reviewing the efficacy of NIBS (including the most recently published studies) and the pharmacological treatment of IGD. The second aim was to compare the treatment efficacy of pharmacological treatment with NIBS for IGD.

2. Method

The present systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021).

2.1. Search strategy, study selection, and inclusion criteria

The following databases were carefully searched from their inception up until October 5, 2025: *PubMed, MEDLINE, CINAHL, ScienceDirect, OATD, Embase, PsycINFO, Cochrane,* and *ClinicalTrials.gov*. A manual search of reference lists was also conducted using all selected papers, full-text reviews, and relevant reviews (e.g., Gorowska et al., 2022; King et al., 2017; Seo et al., 2021; Zajac et al., 2020). The relevant terms,

including MeSH terms, were used in the search for IGD, pharmacotherapy, and NIBS, using Boolean operators. The complete list of search terms is shown in Appendix S1.

Based on the following criteria, the scope of the literature review was restricted to (i) English language studies published in peer-reviewed journals; (ii) empirical studies on gaming; (iii) psychiatric interventions (defined as those requiring medical supervision or prescription by a psychiatrist, even if a psychiatrist did not perform operational delivery); (iv) research conducted using an experimental research design (delivering intervention); and (v) research that reported their sample sizes, pre-test and post-test means, and standard deviations for gaming disorder. Also, there were no restrictions on study type/design, and all study types, including case reports and RCTs, were included. Participants in each study were presumed to be free of neurological or cognitive impairments unless otherwise stated.

2.2. Data collection process

Two reviewers determined research eligibility through title screening, abstract screening, and full paper screening. The search string was used for full-text screenings. Initial evaluations of titles and abstracts were conducted independently by two reviewers. Each reviewer independently reviewed the relevant papers, and the authors reached consensus on eligibility after reviewing them together. The reference lists of eligible papers were also reviewed for potential studies to be included. Whenever necessary, authors were contacted for missing data or findings. Four corresponding authors were contacted during this process to obtain IGD pre-test/post-test scores, but none responded.

Title and abstract screening were conducted independently by two reviewers using *EndNote* (version 21.3.17), which enabled efficient searching of titles, abstracts, and keywords to identify potentially relevant studies among the initial records. Discrepancies were resolved through discussion until consensus was reached, setting the stage for the assessment of full-text studies. This dual-rater approach, aligned with PRISMA guidelines, ensured consistent application of inclusion criteria and minimized selection bias.

2.3. Data extraction and operational definition

The following data were extracted from the studies that met the inclusion criteria: authors, publication year, sample type (as specified in the papers, e.g., excessive gamers, problematic gamers, etc.), N (sample size), mean age (SD), the proportion of female participants, pre-treatment gaming mean score (from 0 to 10), pre-treatment gaming time (daily hrs), whether comorbidity was evaluated, type of intervention, intervention duration, dosage, specifics of non-invasive neuromodulation (i.e., implementation details), voltage, reported side-effect(s) (assessed or not), additional treatment, outcome measure (instrument name), post-treatment gaming mean score (with mean scores converted to a 0 to 10 scale to make their changes comparable), post-treatment gaming time (daily hrs), risk of bias (low, moderate, or high), and study design. Problematic gaming was operationalized in the included studies as the scores participants obtained exceeded the predefined cut-off for problematic gaming in the instrument used by the authors. There were no exclusions based on the problem gaming screening instrument used. Tables 1 and 2 provide general and specific details of all the studies included in the review.

2.4. Risk of bias and quality assessment

Each eligible study was independently assessed by two investigators (SJ and SS) using the Standard Quality Assessment Criteria for Evaluating Primary Research Papers from a Variety of Fields (Kmet et al., 2004) with 14 criteria, such as 'Question/objective sufficiently described?', 'Results reported in sufficient detail?', and 'Conclusions supported by the results?'. Each of these questions could be scored as yes (2), partial yes (1), or no (0), with total scores ranging between 0 and 28. A risk of bias score of 0–9 is considered high, 10–18 moderate, and 19–28 low. The reviewers' agreement was satisfactory, given the high inter-rater reliability (0.91).

2.5. Data analysis

The statistics were based on Borenstein's (2019) recommendations for avoiding common meta-analysis errors. A random-effects model was used to determine the overall pooled effect size of the treatments of interest on gaming disorder using Comprehensive Meta-Analysis Software (CMA version 3.3.070). Standardized mean difference was used as the effect size. This was calculated using the number of participants, the pre-intervention mean score, and the post-intervention score. Standardized mean difference (SMD) is an appropriate summary statistic for heterogeneous outcome measures across studies (Higgins et al., 2011). According to Cohen's (2013) recommendations, an SMD of 0.2 is considered small, 0.5 moderate, and 0.8 large.

A sensitivity analysis was performed using several techniques (externally standardized residuals, difference in fits (DFFITS) values, Cook's distances, covariance ratios, leave-one-out Tau estimates, leave-one-out residual heterogeneity test statistics, Hat values, and weights) to identify outliers and assess the robustness of the mean effect sizes. To measure heterogeneity, I^2 and the Q statistic were used, along with a random-effects model-based estimate of between-study heterogeneity (i.e., tau) (Johnson, 2021). To account for the heterogeneity, the prediction interval (PI) was also calculated (Borenstein et al., 2017).

Moreover, various types of models were used, including a (i) mixed-effects model to pool the effect sizes for each subgroup (i.e., categorical moderators; Borenstein et al., 2009), (ii) fixed-effect model to assess the differences between subgroups, and (iii) random-effect model to aggregate the effect sizes within each subgroup. To determine statistical significance, the Q-statistic, degrees of freedom, and corresponding p-values were used for omnibus testing. Egger's (1997) regression test and Begg and Mazumdar's (1994) rank correlation (Kendall's tau) were also conducted to test for publication bias (file-drawer effect), which is indicated by a significant p-value.

3. Results

3.1. Selection and inclusion of studies

Based on the titles and abstracts of 13,199 publications, two independent authors conducted a primary evaluation, leading to the retrieval of 107 papers for full-text screening; 90 records were excluded, yielding 17 studies for inclusion in the present review. At a second-round update of the search in October 2025, one additional study was added. Eighteen studies met the inclusion criteria. Fig. 1 illustrates the selection and inclusion of studies according to the PRISMA guidelines.

3.2. Risk of bias assessment

After reviewing the included studies against Kmet et al.'s (2004) standard quality assessment criteria, three studies were considered as having a low risk of bias (Lee et al., 2021; Song et al., 2016; Wu et al., 2021), eleven studies were considered as having a moderate risk of bias (Bae et al., 2018; Han et al., 2011; Han et al., 2009; Han & Renshow, 2012; Jeong et al., 2020; Jeong et al., 2024; Kim et al., 2012; Kim et al., 2025; Lee et al., 2018; Nam et al., 2017; Park et al., 2016; 2017), and three studies as having a high risk of bias (Vasiliu, 2020; Jeong et al., 2017; Cuppone et al., 2021). For more specific details on the risk of bias, please see Appendices S2 to S7.

3.3. Study characteristics

Of the 18 studies published between 2009 and 2025, 687

Table 1
General details of the included studies (N = 18).

	Study	Year	Country	N	Mean age in years (SD)	% female	Sample type	Diagnostic criteria	Study design	Risk of bias	Intervention details	Outcome	Ethics approval
1	Bae et al.	2018	South Korea	IGD: 16 IGBD: 15 Healthy: 15	25.3 (5.2) 25.0 (4.9) 25.7 (4.7)	0%	Patients with IGD	DSM-IV structural clinical interview	Multi-arm	M	At baseline and after 12 weeks of bupropion treatment, the clinical symptoms of patients with IGD or ibIGD(internet-based gambling disorder) were assessed, and brain activity was evaluated using resting state functional magnetic resonance imaging.	Clinical symptoms, including the severity of IGD or IGD, depressive symptoms, attention, and impulsivity improved in both groups.	Yes
2	Cuppone et al.	2021	Italy	1	21	0%	Excessive online gaming activity	Excessive online gaming activity(9 h/d)	Single group	H	Patient underwent a high-frequency repetitive transcranial magnetic stimulation (rTMS) protocol over the left dorsolateral pre-frontal cortex (l-DLPFC) in a multidisciplinary therapeutic setting.	A decrease of addictive symptoms and an improvement of executive control.	Yes
3	Han et al.	2011	South Korea	IAG: 11 Healthy: 8	21.5 (5.6) 20.3 (4.1)	0%	Internet video game addiction (IAG)	BDI scores more than 17/ extensive game play time(4 h/d or /30 hrs per week)/ YIAS scores more than 50 /Maladaptive behaviors or distress	Multi-arm	M	Baseline and at the end of 6 weeks of bupropion SR treatment, brain activity in response to *StarCraft* cue presentation was assessed using 1.5 Tesla functional MRI.	Craving for Internet video game play, total game play time, and cue-induced brain activity in dorsolateral prefrontal cortex were decreased in the IAG.	Yes
4	Han et al.	2009	South Korea	62	9.3 (2.2)	16.13%	Internet videogame play	DSM-IV criteria for ADHD/YIAS scores more than 50	Single group	M	Children with ADHD and excessive Internet video game play received OROS methylphenidate (Concerta) treatment for 8 weeks; no adjunctive medications permitted.	The scores and internet usage times were significantly reduced	Yes
5	Han & Renshow	2012	South Korea	Bupropion group: 22 Placebo: 23	21.2 (8.0) 19.1 (6.2)	0%	Problematic online game play	DSM-IV criteria for MDD/ extensive game play time(4 h/d)/ YIAS scores more than 50 / Maladaptive behaviors or distress	Multi-arm RCT	M	Participants with comorbid excessive online game play and MDD randomly assigned to bupropion + Education for internet use (EDU) or placebo + EDU groups.	BDI and YIAS scores are reduce in bupropion group.	Yes
06	Jeong et al.	2020	South Korea	Active: 15 Shame:15	22.2 (1.7) 23.2 (1.6)	38.46% 41.67%	Problematic online gaming	scores of 40 or higher on the Internet Addiction Test	Multi-arm RCT	M	Problematic online gamers were randomized and received 12 sessions of either active or sham tDCS to the dorsolateral prefrontal cortex over 4 weeks (anode F3/cathode F4, 2 mA for 30 min, 3 sessions per week).	Significant decreases in time spent on gaming, BIS, BAS-fun seeking, and BAS-reward responsiveness and increases in Brief Self-Control Scale were found in the active tDCS group, while decreases in Internet addiction test were shown in both groups.	Yes

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Table 1 (*continued*)

	Study	Year	Country	N	Mean age in years (SD)	% female	Sample type	Diagnostic criteria	Study design	Risk of bias	Intervention details	Outcome	Ethics approval
07	Jeong et al.	2017	South Korea	7	_	NR	Heavy game users	_	Single group	H	7 adult heavy game users received 12 tDCS treatment sessions over the dorsolateral prefrontal cortex	After the tDCS treatment reduced Internet gaming addiction symptoms.	Yes
08	Jeong et al.	2024	South Korea	Active: 10 Sham: 12	26.9 (5.2) 27.3 (5.3)	0%		Psychiatrist diagnosis based on DSM-5 criteria	Multi-arm	M	Participants self-administered bilateral tDCS over the dorsolateral prefrontal cortex (DLPFC) for 10 sessions	After tDCS, only the active group showed a decrease in the stop-signal reaction time (SSRT). Although craving decreased, there were no significant group-by-time interactions or group main effects.	Yes
09	Kim et al.	2012	South Korea	CBT-MED: 32 MED: 33	16.2 (1.4) 15.9 (1.6)	0%	Problematic online game play	BDI scores more than 19/ extensive game play time(4 h/d)/ YIAS scores more than 50/ maladaptive behaviors or distress	Multi-arm (Prospective trial)	M	65 depressed adolescents with excessive online game play were randomly assigned to a CBT group (CBT-Med group) and clinical control group (Med group. Med group was treated with bupropion for 4 week and other group was treated with CBT.	After 4 weeks Young Internet Addiction Scale scores in the CBT-Med group were reduced compared to those of the Med group, but there was no significant difference in the change of depression scores between the two groups.	Yes
10	Kim et al.	2025	South Korea	IGD: 10 Healthy: 20	23.00 (6.79) 25.45 (2.83)	0%	Internet gaming disorder	Psychiatrist diagnosis based on DSM-5 criteria	Multi-arm	M	Received 10 sessions of active tDCS (2 mA for 20 min per session; 2 sessions/day for 5 consecutive days) with anodal stimulation over the left DLPFC (F3) and cathodal over the right DLPFC (F4); Ybrain device (Korea).	After 10 sessions of tDCS, LPP amplitudes to game-related cues at CP1, P3, P1 and Pz significantly decreased and subjective craving scores were reduced, while IAT and BIS-11 scores showed no significant change.	Yes
11	Lee et al.	2021	South Korea	Active: 14 Sham: 12	23.7 (5.7) 25.3 (8.9)	0%	Internet gaming disorder	Psychiatrist diagnosis based on DSM-5 criteria	Randomized, double-blind, sham-controlled parallel group design	L	Received 10 sessions (2 sessions per day for 5 consecutive days) of active repetitive tDCS (2 mA for 20 min per session) or sham stimulation. repetitive tDCS stabilizes fast-wave activity in IGD	Active stimulation of tDCS suppressed increase of intra-hemispheric beta coherence after 1 month, which was observed in the sham group. The 1-month follow-up assessment revealed that absolute gamma power in the left parietal region was decreased in the active group relative to the sham group.	Yes
12	Lee et al.	2018	South Korea	Gamer: 15 Non gamer: 10	21.3 (1.4) 28.8 (7.5)	46.67% 40%	Excessive online gaming	Two or more IGD symptoms as defined by theDSM-5/ game play time(1 h/d)	Multi-arm (prospective trial)	M	Gamers received 12 active tDCS sessions over the DLPFC (anodal left/cathodal right, 2 mA for 30 min, 3 times per week for 4 weeks)	After tDCS sessions, weekly hours spent on games and scores of IAT and BDI-II were decreased, whereas Brief Self-Control Scale score was increased	Yes

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Table 1 (*continued*)

	Study	Year	Country	N	Mean age in years (SD)	% female	Sample type	Diagnostic criteria	Study design	Risk of bias	Intervention details	Outcome	Ethics approval
13	Nam et al	2017	South Korea	Bupropion: 15 Escitalopram: 15	22.9 (1.9) 23.9 (1.6)	NR	Excessive internet game play	DSM-IV structural clinical Interview/ Psychiatrist diagnosis/ extensive game play time(4 h/d)/ YIAS scores more than 50/	Double blind prospective trial	M	Participants were treated with bupropion and citalopram for 12 weeks in a double-blind prospective trial method.	After drug treatment, the depressive symptoms and IGD symptoms in both groups were improved. Bupropion = escitalopram	Yes
14	Park et al	2017	South Korea	IGD: 18 Healthy: 29	22.6 1 (5.10) 24.66 (3.80)	0%	Internet gaming disorder	Psychiatrist diagnosis based on DSM-5 criteria	Multi-arm (prospective trial)	M	The patients with IGD completed a 6-month outpatient management program including selective serotonin reuptake inhibitor-based pharmacotherapy.	Patients with IGD showed reduced P300 amplitude and delayed latency at baseline compared to controls. Despite symptom improvement over six months, P300 measures did not change, and Event-related potential patterns did not differ between responders and non-responders.	Yes
15	Park et al	2016	South Korea	Methylphenidare OROS: 44 Atomoxetine: 42	16.9 (1.6) 17.1 (1.0)	0%	Problematic online gaming	Structured Clinical Interview for DSM-5	Multi arm RCT	M	Participants with ADHD and internet gaming disorder divided into two group.44 patients were treated with MPH for 12 weeks, and 42 participants were treated with ATM for 12 weeks	Both MPH and ATM reduced the severity of Internet gaming disorder symptoms, and this reduction was correlated with impulsivity reduction.	Yes
16	Song et al.	2016	South Korea	Bupropion: 44 Escitalopram: 42 Observation: 36	20.0 (3.62) 19.8 (4.2) 19.6 (4.0)	0%	Internet gaming disorder	DSM-IV-TR structural clinical Interview/ Psychiatrist diagnosis	Multi-armRCT	L	44 patients were treated with bupropion for 6 weeks, and 42 participants were treated with escitalopram for 6 weeks and 36 patient any medication were observed in the community.	Both the escitalopram group and the bupropion group showed improvement on all clinical symptom scales after 6 weeks of treatment compared to the observation group. Bupropion = escitalopram	Yes
17	Vasiliu	2020	Romania	11	26.3	63.64%	Patients diagnosed with IGD andcomorbid alcohol use disorder (AUD)	DSM-5 criteria	Single group, sham-controlled, and double-blind design	H	Patients diagnosed with IGD and comorbid alcohol use disorder received open-label naltrexone 50 mg QD and cognitive-behavioral therapy focused on compulsive behaviors management. Patients were monitored every 4 weeks for 3 months	The evolution of both gaming and alcohol use was not linear, but with periods of exacerbation and improvement.	Unknown
18	Wu et al.	2021	China	33	21.21 (2.27)	0%	Internet gaming disorder	Five or more IGD symptoms as defined by the DSM-5/ YIAS scores more than	Single group	L	33 men with IGD received active (1.5 mA for 20 min) and sham tDCS over the right dorsolateral PFC (dlPFC) one	Relative to sham treatment, active tDCS reduced interference from gaming-related (versus non-gaming) distractors and	Yes

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Table 1 (*continued*)

Study	Year	Country	N	Mean age in years (SD)	% female	Sample type	Diagnostic criteria	Study design	Risk of bias	Intervention details	Outcome	Ethics approval
							50/ extensive game play time(20 h/week)			week apart in a randomized order	attenuated background craving, but did not affect cue-induced craving.	

Note. IGD: internet gaming disorder; IBIGD: internet-based gambling disorder (ibIGD); IAG: internet video game addiction; BDI: Beck Depression Inventory; CBT: cognitive behavioral therapy; DSM 5: Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition; rTMS: repetitive transcranial magnetic stimulation; h/d: hours/day; MRI: magnetic resonance imaging; ADHD: attention-deficit/hyperactivity disorder; RCT: randomized controlled trial; tDCS: transcranial direct current stimulation; DLPFC: dorsolateral prefrontal cortex. Risk of Bias = Low (L), Moderate (M), and High (H). NR = not reported

participants were included in the synthesis, with 12 studies over-representing males (in which only male participants were included). Six studies included female participants (16.3% to 63.64%). The remaining two studies did not report the gender proportion (Nam et al., 2017; Jeong et al., 2017). Of the 18 studies, 15 were conducted in South Korea, with the remaining 3 in Italy, China, and Romania. The mean ages of participants in the included studies ranged from 9 to 26 years old. It should be noted that two studies did not provide pre-test scores and post-test scores of IGD (Jeong et al., 2017; Vasiliu, 2020), and four studies did not report post-test scores of IGD (Jeong et al., 2024; Cuppone et al., 2021; Wu et al., 2021; Park et al., 2016). Of the included studies, two administered bupropion alongside either CBT (Kim et al., 2012) or psychoeducation (Han & Renshaw, 2012), while the remaining studies used monotherapy (either tDCS or pharmacotherapy alone). All included studies received ethical approval, except for the study by Vasiliu (2020), which did not report if it had received ethical approval.

4. Systematic review

4.1. Gaming disorder treatment using non-invasive brain stimulation

Six studies used tDCS to treat IGD (Wu et al., 2021; Jeong et al., 2017, 2020, 2024; Lee et al., 2018, 2021), and one study used rTMS in a single case (Cuppone et al., 2021). In terms of risk of bias, two studies scored low (Wu et al., 2021; Lee et al., 2021), three studies scored moderate (Jeong et al., 2020; 2024; Lee et al., 2018; Kim et al., 2025), and two studies scored high (Cuppone et al., 2021; Jeong et al., 2017). The tDCS interventions were delivered by trained researchers under supervision.

In two studies, the proportion of female participants was 38.46% (Jeong et al., 2020) and 46.67% (Lee et al., 2018). The remaining studies were conducted with male-only participants. In these studies, tDCS was compared against a control group in four studies (Jeong et al., 2020; 2024; Lee et al., 2021; 2018), and in three studies, it was compared to the baseline scores (Cuppone et al., 2021; Jeong et al., 2017; Wu et al., 2021). In tDCS studies, treatments ranged from 5 days to 4 weeks, and the number of sessions ranged from 2 to 12. One study did not report the treatment duration or number of sessions (Jeong et al., 2020). In all studies that used tDCS and the one that used rTMS, the brain region stimulated was the dorsolateral prefrontal cortex (DLPFC), and all reported significant reductions in IGD severity. Moreover, in two studies, the daily playing time also decreased (Jeong et al., 2020; Lee et al., 2018). None of the studies assessed potential side effects.

4.2. Gaming treatment using bupropion

The studies assessing the effectiveness of bupropion in treating IGD severity were conducted among males, apart from Nam et al. (2017), who did not report gender. Three studies compared the effectiveness of bupropion against a healthy control group or placebo tablet (Bae et al., 2018; Han et al., 2011; Han & Renshow, 2012). The treatment duration ranged from 6 to 12 weeks, and the dosage ranged from 150 mg to 300 mg. In Han and Renshow's (2012) study, participants had comorbid major depressive disorder (MDD). All three studies reported decreases in IGD severity. In addition, Han et al. (2011) reported decreases in cue-induced craving for playing the *StarCraft* videogame (real-time strategy game) based on brain activity. One study (Kim et al., 2012) compared bupropion against bupropion in conjunction with cognitive behavior therapy among participants with comorbid MDD, and they found the latter treatment was more effective in reducing IGD severity than bupropion alone. However, the depression scores across both groups were not significantly different. The risk of bias in these four studies was moderate, and no side effects were assessed.

Table 2
Specific details of included studies (N = 18).

	Study	Pre-treatment gaming mean score (0—10)	Pre-treatment gaming time (daily hrs)	Controlled comorbidity	Intervention	Intervention duration	Dosage	Specifics of non-invasive neuromodulation	Voltage	tDCS administered by	Reported side-effect	Additional treatment	Outcome measure (instrument name)	Outcome mean score (0–10)	Outcome gaming time(daily hrs)
1	Bae et al.	6.1	6.5	–	Bupropion	12 weeks		–	–	–	–	–	Symptom severity reduction (Young Internet Addiction Scale; YIAS)	4.35	_
2	Cuppone et al.	5.9	10.7	_	Non-invasive neuromodulation (repeated transcranial magnetic stimulation; rTMS)	9 weeks (26 sessions) each day was at least 30 min	–	15 Hz frequency, 100% of rTMS, 40 trains, 60 pulses per train, 15 s intertrain interval, 2,400 pulses per session, targeting the l-DLPFC	–	–	–	–	Symptom severity reduction (Internet Addiction Test; IAT)	2.6	_
3	Han et al. (2011)	7.12	6.5	_	Bupropion SR	6 weeks	150–300 mg	–	–	–	–	_	Craving reduction + playing time reduction + decreased cue-induced brain activity (Young Internet Addiction Scale; YIAS)	6.01	_
4	Han et al. (2009)	4.2	2.2	ADHD	Methylphenidate	8 weeks	30.5 ± 13.3 mg/d	_	–	–		–	Score reduction on a standardized test (Young Internet Addiction Scale; YIAS)	2.6	1.5
5	Han & Renshow	6.4	6.7	MDD	Bupropion	8 weeks	150—–300 mg	–	–	–	–	Education for internet use (EDU)	Score reduction on a standardized test (Young Internet Addiction Scale; YIAS)	2.8	3.01(8 weeks' medication) 3.12(4-week follow-up)
6	Jeong et al. (2020)	4.92	2.3	_	Non-invasive neuromodulation (tDCS)	_	_	Current intensity 2 mA over the first 30 s, remained at 2 mA for 29 min, ramped down to 0 mA over the last 30 s, over the left (F3, 10–20	2MA	The tDCS sessions were conducted by trained research staff under the supervision of nuclear medicine and radiology specialists at Incheon	–	–	Score reduction on a standardized test + playing time reduction (Internet	3.58	1.3

(*continued on next page*)

Table 2 (*continued*)

	Study	Pre-treatment gaming mean score (0—10)	Pre-treatment gaming time (daily hrs)	Controlled comorbidity	Intervention	Intervention duration	Dosage	Specifics of non-invasive neuromodulation	Voltage	tDCS administered by	Reported side-effect	Additional treatment	Outcome measure (instrument name)	Outcome mean score (0–10)	Outcome gaming time(daily hrs)
								system) and right DLPFC (F4)		St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, South Korea.			Addiction Test; IAT)		
7	Jeong et al. (2017)	–	–	–	Non-invasive neuromodulation (tDCS)	4 weeks (12 sessions)	–	Dorsolateral prefrontal cortex (DLPFC)	_	–	–	–	Score reduction on a standardized test (Internet Addiction Test; IAT)	–	_
8	Jeong et al. (2024)	5.01	2.1	_	Transcranial direct current stimulation (tDCS)	2 weeks (10 sessions)	_	Dorsolateral prefrontal cortex (DLPFC)	2MA	The tDCS sessions were conducted by trained research staff under the supervision of nuclear medicine and radiology specialists at Incheon St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, South Korea.	_	_	Score reduction on a standardized test (Internet Addiction Test; IAT)	_	_
9	Kim et al (2012)	6.1	8.55	MDD	CBT + Bupropion	8 weeks	150—–300 mg	_	_	–	–	–	score reduction on a standardized test (Young Internet Addiction Scale; YIAS)	1.9	2.52(after 8 week) 2.54(after 12 week)
10	Kim et al (2025)	5.2	_	_	Non-invasive neuromodulation (tDCS)	5 days (10 sessions)	_	Anodal stimulation over left DLPFC (F3) and cathodal over right DLPFC (F4); 10 sessions (2 sessions/ day for 5 consecutive days), 20 min per session using the Ybrain device (Korea).	2MA	Administered by trained research staff under the supervision of clinical neuropsychiatrists at SMG-SNU Boramae Medical Center, Seoul, Korea.	_	_	Young's Internet Addiction Test (IAT) Barratt Impulsiveness Scale-11 (BIS-11) Visual Analog Scale for craving (VAS) Event-related potential (LPP amplitude)	4.3	_
11	Lee et al (2021)	5.2	5.6	–	Non-invasive neuromodulation (tDCS)	5 days (10 sessions)	_	Electrode placed over the left DLPFC(F3) and the cathode over	2MA	Trained research staff under supervision of clinical psychiatrists	–	–	Change in clinical status + score	4.3	_

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Table 2 (*continued*)

	Study	Pre-treatment gaming mean score (0—10)	Pre-treatment gaming time (daily hrs)	Controlled comorbidity	Intervention	Intervention duration	Dosage	Specifics of non-invasive neuromodulation	Voltage	tDCS administered by	Reported side-effect	Additional treatment	Outcome measure (instrument name)	Outcome mean score (0–10)	Outcome gaming time(daily hrs)
								the right DLPFC (F4), current flowed continuously during two 20-min stimulation periods (2.0 mA) separated by a 20-min rest interval −(nostimulation; a 20:20:20 schedule)		at SMG–SNU Boramae Medical Center, Seoul, Korea.			reduction on a standardized test (Internet Addiction Test; IAT)		
12	Lee et al (2018)	3.75	2.4	–	Non-invasive neuromodulation (tDCS)	4 weeks (12 sessions)	–	2 mA for 30 min (current density = 0.07 mA/cm2), current ramps up to 2.0 mA over 30 s, remains at 2.0 mA for 29 min, ramps down to 0 mA over the last 30 s, the left dorsolateral prefrontal cortex (F3) and the right dorsolateral prefrontal cortex (F4)	2MA	Trained research staff under supervision of clinical radiologists and neuroscientists at Incheon St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Incheon, South Korea.	–	–	Symptom severity reduction + playing time reduction (Internet Addiction Test; IAT)	2.49	1.4
13	Nam et al	5.45	–	MDD	Bupropion	12 weeks	150–300 mg	–	_	–	–	–	Symptom severity	2.65	_
		5.9			Escitalopram		10–20 mg						reduction (Young Internet Addiction Scale; YIAS)	3.8	_
14	Park et al (2017)	7.4	–	–	Escitalopram	24 weeks	15.83 ± 9.17 mg	_	_	–	_	_	Score reduction on a standardized test (Internet Addiction Test; IAT)	5.8	_
					Fluoxetine		50.00 ± 9.17 mg								_
					Paroxetine		30.00 ± 14.14 mg								_
15	Park et al (2016)	5.3	_	ADHD	Methylphenidate OROS	12 weeks	10–40 mg	_	_	–	_	_	Score reduction on a	3.3	_
		5.4			Atomoxetine		19–60 mg						standardized test (Young Internet Addiction Scale; YIAS)	3.9	_
16	Song et al.	5.6	_	_	Bupropion	6 weeks	150–300 mg	_	_	–	_	_	Score reduction on a	2.8	_

(*continued on next page*)

Table 2 (*continued*)

	Study	Pre-treatment gaming mean score (0—10)	Pre-treatment gaming time (daily hrs)	Controlled comorbidity	Intervention	Intervention duration	Dosage	Specifics of non-invasive neuromodulation	Voltage	tDCS administered by	Reported side-effect	Additional treatment	Outcome measure (instrument name)	Outcome mean score (0–10)	Outcome gaming time(daily hrs)
		5.3 5.8			Escitalopram _		10–20 mg _						standardized test (Young Internet Addiction Scale; YIAS	3.4 5.8	_ _
17	Vasiliu	_	–	–	Naltrexone	12 weeks	_	–	–	–	–	–	Decreased craving (Internet Gaming Disorder Scale-Short Form; IGDS9-SF)	–	_
18	Wu et al.	6.5	4.13	–	Non-invasive neuromodulation (tDCS)	1 week (2 sessions)	–	Anode electrode on F4 (EEG 10–20 system), cathode onthe left superior region of the trapezius muscle near the base of neck, a direct current of 1.5 mA for 20 min with a 30-second ramp up and a 30-second ramp down time during active stimulation		–	–	–	Score reduction on a standardized test (Internet Addiction Test; IAT)	–	_

Note. mg/d: milligram/day.

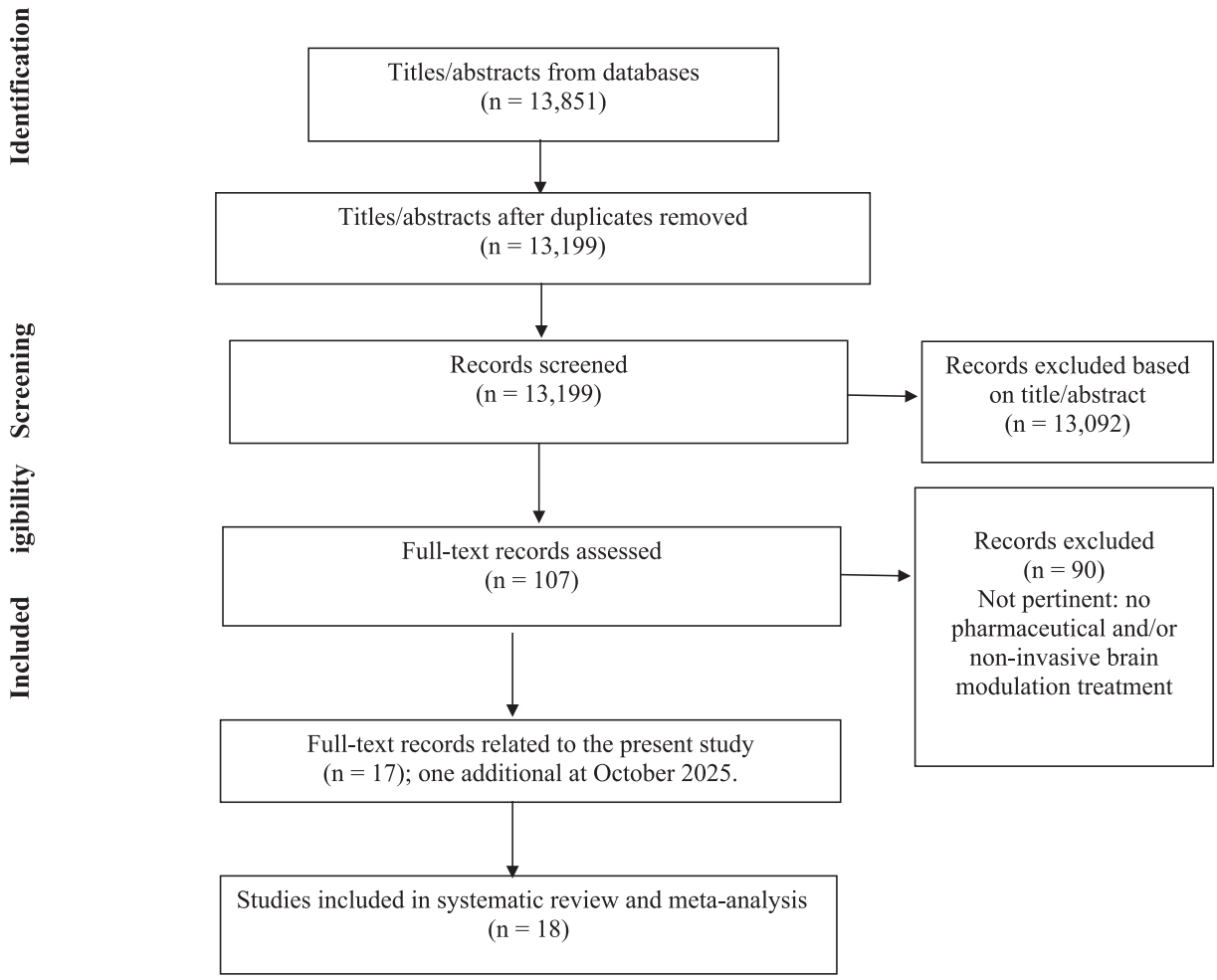

Fig. 1. The study selection procedure, the PRISMA diagram.

4.3. Gaming disorder treatment using SSRIs

One study by Park et al. (2017) used a combination of SSRIs (15 mg escitalopram, 50 mg fluoxetine, and 30 mg paroxetine) for males (mean age = 22.61 years) with a treatment duration of 24 weeks and reported decreases in IGD severity. The risk of bias was moderate, and side effects were not assessed.

4.4. Gaming disorder treatment comparing bupropion and SSRIs

Two studies compared bupropion against escitalopram (Nam et al., 2017; Song et al., 2016). Nam et al. (2017), with a moderate risk of bias, did not report the gender, whereas the participants in Song et al.'s (2016) study, with a low risk of bias, were all male. Treatment duration in the Nam et al. study (with participants who had comorbid MDD) was 12 weeks, and dosage administered for bupropion ranged from 150 mg to 300 mg, and for escitalopram ranged from 10 mg to 20 mg. Although the dosage in the Song et al. study was the same, the treatment duration was six weeks. In both studies, IGD severity was reduced, with no significant differences in the effectiveness of bupropion vs. escitalopram. Side effects were not assessed.

4.5. Gaming disorder treatment using methylphenidate and atomoxetine

Two studies evaluated the effectiveness of methylphenidate in treating IGD severity. In the first, Han et al. (2009) administered a mean of 30.5 mg (±13.3) methylphenidate for eight weeks to participants with comorbid ADHD (mean age = 9.3 years; female proportion = 16.13%). The treatment was effective in reducing IGD severity. In the second study, Park et al. (2016) administered 10–40 mg methylphenidate OROS [osmotic-controlled release oral delivery system] to one group (mean age 16 years) and 19–60 mg atomoxetine to another group (mean age 17 years) for 12 weeks. The participants in both groups were male and had comorbid ADHD. Han et al. (2009) reported a significant reduction in gaming severity. Park et al. (2016) reported that both medications (methylphenidate and atomoxetine) had significant effects. However, they did not report any comparison between the two types of medication.

4.6. Gaming disorder treatment using an opioid antagonist

One study by Vasiliu (2020) administered 50 mg of naltrexone (in conjunction with cognitive-behavioral therapy focused on compulsive behavior management) for 12 weeks to a single group of patients with comorbid alcohol use disorder and IGD (63.64% of the participants were female). There was no control group. The study reported that the change in both gaming and alcohol use was not linear, but with periods of exacerbation and improvement. The study had a high risk of bias, and side effects were not assessed.

5. Meta-analysis

5.1. Sensitivity analysis and publication bias

Eight sensitivity analyses (externally standardized residual, DFFITS values, Cook's distances, covariance ratios, leave-one-out Tau estimates,

leave-one-out residual heterogeneity test statistics, Hat values, and weights) based on outlier and influential case diagnostics were conducted to examine the robustness of the meta-analysis. The test was robust for the tDCS and SSRIs treatment groups, except for the bupropion group, leading to the removal of one study (Kim et al., 2012) flagged by all sensitivity analysis tests. Following this, all estimated pooled effect sizes were robust. It should also be noted that all tests for the methylphenidate group were significant (i.e., both were considered outliers). However, the analysis was conducted using a fixed-effects model, because meta-analyses with only two studies may yield unreliable estimates of between-study variance. Consequently, the pooled effect size for the methylphenidate group should be interpreted with caution.

Publication bias was examined, and funnel plots for all treatments are shown in Fig. 2. The tests for all treatment groups were as follows: tDCS (Egger's regression = -0.123, $p = 0.902$; Kendalls Tau = 0.0001, $p = 1.000$), SSRIs (Egger's regression = 0.447, $p = 0.655$; Kendalls Tau = 0.333, $p = 1.000$), methylphenidate (Egger's regression = -1.618, $p = 0.106$; Kendalls Tau = -1.000, $p = 1.000$), and bupropion (Egger's regression = 0.401, $p = 0.689$; Kendalls Tau = 0.200, $p = 0.719$).

5.2. Gaming disorder treatment using tDCS

Four studies (Jeong et al., 2017; Lee et al., 2018; Lee et al., 2021; Kim et al., 2025) evaluated the effectiveness of non-invasive neuromodulation (tDCS) in the treatment of gaming disorder severity for four weeks (the percentage of females was 0% to 38%; the mean age range was 21.3 to 23.7 years). As shown in Table 3, a moderate effect size was observed (SMD = −0.70). Based on a moderator analysis, the observed mean effect size did not differ significantly across the two gaming levels (gaming disorder versus problematic gaming). However, as shown in Table 3, the heterogeneity of the effects showed that tDCS affected individuals differently. In reducing gaming disorder severity, the results indicated that it could be beneficial for some individuals (SMD = −1.55), harmful to others (SMD = 0.15), or have no effect at all. The forest plot for studies on tDCS is shown in Fig. 3.

5.3. Gaming treatment using bupropion

The effectiveness of bupropion in treating gaming disorder severity among males (mean age = 15.9 to 25.3 years) was evaluated in five studies (Han et al., 2011; Bae et al., 2018; Nam et al., 2017; Song et al., 2016; Han & Renshow, 2012), apart from Nam et al. (2017), who did not report gender. Doses of 150–300 mg were administered for 6, 8, or 12 weeks. The effect sizes remained stable at the 6-week, 8-week, and 12-week follow-ups (Table 4). Based on a moderator analysis (Table 4), it was determined that the observed mean effect size did not differ significantly across different gaming levels (gaming disorder vs. problematic gaming), treatment duration (6 vs. 8 vs. 12 weeks), comorbidity (depression vs. no reported depression), and accompanying treatment (psychoeducation vs. only the treatment). Also, the analysis of the heterogeneity of the effects of bupropion (Table 4) showed it only had a protective effect if differences in the level of gaming (gaming disorder vs. problematic gaming) were not considered on the severity of gaming disorder (i.e., when the mean scores of gamers were used, bupropion was shown to be effective. However, subgroup analysis showed that some gamers may experience harmful rather than beneficial effects). Therefore, it may be beneficial for some individuals and harmful for others. The forest plot for studies on bupropion is shown in Fig. 3.

5.4. Gaming disorder treatment using SSRIs

Three studies evaluated the effectiveness of SSRIs in the treatment of gaming disorder. Two studies (Nam et al., 2017; Song et al., 2016) only used escitalopram with daily doses of 10–20 mg, whereas the other study (Park et al., 2017) used a combination of SSRIs (escitalopram 15

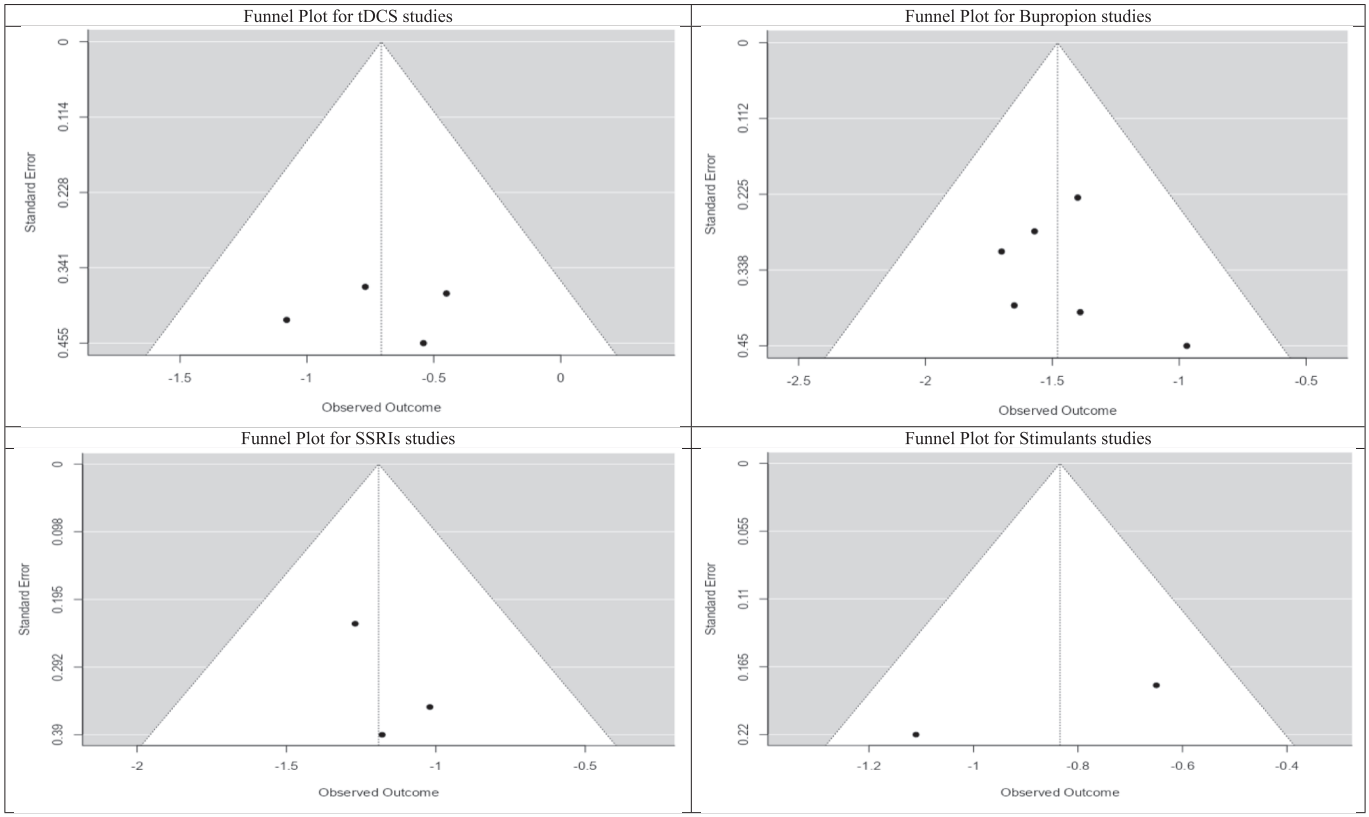

Fig. 2. Funnel plots across different treatment subgroups.

Table 3
Comparing psychiatric treatments for gaming disorder: A mixed-effects analysis of pre-post test scores.

Treatment	Study and Participants		Effect size			Heterogeneity					Prediction Interval		Omnibus test
	K	*n*	*SMD*	*Ll*	*Ul*	*Q*	*df*	*p*	*I2*	*T2*	*Ll*	*Ul*	*Q (df) = p*
tDCS (a)	4	52	−0.70	−1.10	−0.31	1.40	3	0.70	0.00	0.00	−1.55	0.15	12.8 (3) = 0.01
Bupropion (b)	6	173	−1.48	−1.73	−1.22	2.25	5	0.81	0.00	0.00	−1.84	−1.11	a = c = e
SSRIs (c)	3	66	−1.19	−1.53	−0.85	0.35	2	0.83	0.00	0.00	−3.39	1.01	b > a, e; b = c
Methylphenidate (e)	2	106	−0.83	−1.10	−0.56	2.61	1	0.10	61.8	0.06	–	–	
tDCS	4	52	−0.70	−1.10	−0.31	1.40	3	0.70	0.00	0.00	−1.55	0.15	5.17 (1) = 0.02
Pharmacotherapy	11	345	−1.23	−1.45	−1.01	16.7	10	0.08	40.2	0.05	−1.79	−0.66	

Note. The effect size for methylphenidate studies was calculated using the fixed-effect model. The omnibus test was conducted using a mixed-effects model.

mg, fluoxetine 50 mg, paroxetine 30 mg). Nam et al. (2017) conducted their study without specifying gender, whereas the other two studies were conducted with males only. Various treatment durations were used, including 6, 12, and 24 weeks. As shown in Table 3, a large effect size was observed (SMD = −1.19). Moreover, the moderator analysis (Table 4) showed that the observed effect size was not significantly different across gaming level (gaming disorder vs. problematic gaming) or treatment duration (6, 12, or 24 weeks). However, the heterogeneity of the effects (Table 3) showed that SSRIs affected individuals differently. In terms of reducing the severity of gaming disorder, it could be beneficial for some individuals (SMD = −3.39), harmful for others (SMD = 1.01), or have no effect. The forest plot for studies using SSRIs is shown in Fig. 3.

5.5. Gaming disorder treatment using methylphenidate

Two studies evaluated the effectiveness of methylphenidate in treating gaming disorder. For 12 weeks, Han et al. (2009) administered 60 mg per day to males (N = 62, mean age 16.9 years), and for 8 weeks, Park et al. (2016) administered 18 mg to 54 mg per day (N = 44, 16.1% female; mean age = 9.3 years). ADHD was diagnosed as a comorbid condition with problematic gaming among all participants. As shown in Table 3, a large effect size was observed (SMD = −0.83). Moreover, the moderator analysis (Table 4) showed that the observed effect size was not significantly different across treatment durations (8 vs. 12 weeks). Due to the small number of studies (k > 3), it was not possible to determine whether methylphenidate was beneficial, harmful, or had no effect. The forest plot for studies on methylphenidate is shown in Fig. 3.

5.6. Comparative efficacy

In treating gaming disorder, pharmacotherapy demonstrated a large effect size (SMD = −1.23) compared with tDCS, which showed a medium effect size (SMD = −0.70). According to the post-hoc omnibus test, there was no significant difference between tDCS, SSRIs, and methylphenidate in treating gaming disorder, whereas bupropion outperformed the tDCS and methylphenidate. Bupropion and SSRIs demonstrated comparable efficacy in reducing gaming severity. The omnibus test for bupropion demonstrated a significant reduction across all individuals (both upper and lower prediction intervals were negative). However, there was no evidence that treating gaming disorder with tDCS and SSRIs was effective for all individuals. This is because some groups may be at risk for harm, and others may experience no effect.

6. Discussion

The *meta*-analytic findings regarding the significant efficacy of both pharmacotherapy and NIBS in alleviating IGD severity provided preliminary empirical support for the addiction-based conceptualization of IGD (Zheng et al., 2025; Yen et al., 2022). However, it should be noted that the findings do not definitively exclude alternative explanations. The compensatory coping models acknowledge neurobiological alterations but view them as consequences of chronic emotion dysregulation (Blasi et al., 2019). Moreover, the observed effects for pharmacotherapy and NIBS in the treatment of IGD might represent normalization of stress-response systems or enhanced cognitive capacity for adaptive emotion regulation, rather than reversal of addiction-specific neural circuitry. Therefore, although the present meta-analytic findings corroborate the addiction framework, they should be considered as preliminary evidence requiring integration with research examining psychosocial mechanisms and longitudinal trajectories of IGD development from the lenses of both addiction and coping models of IGD.

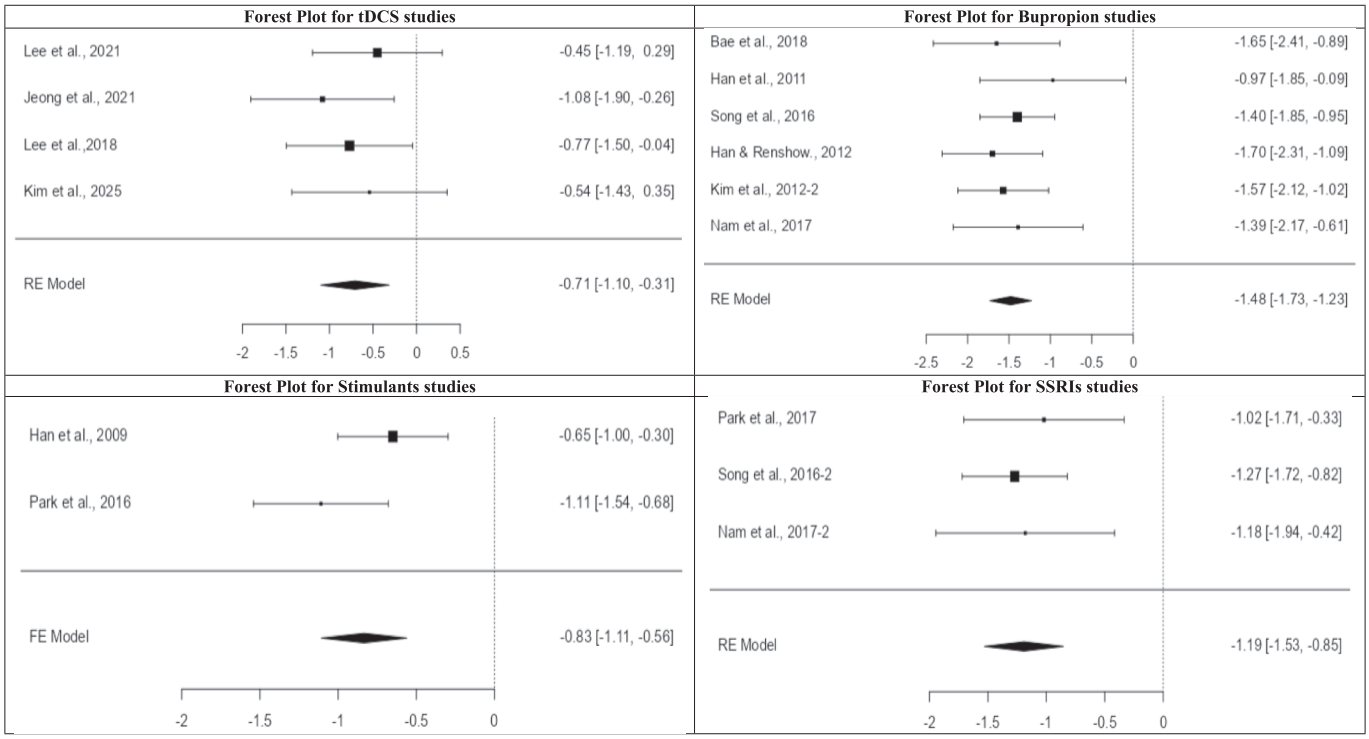

Fig. 3. Forest plot across different treatment subgroups.

6.1. *Gaming disorder treatment using non-invasive brain stimulation*

The tDCS and rTMS were effective in reducing IGD severity by targeting the DLPFC. It should be noted that the DLPFC is not an anatomical structure but rather a functional one, located in the middle frontal gyrus of the brain (Yarkoni et al., 2011). The DLPFC supports executive functioning, an umbrella term for the management of cognitive processes, including working memory, cognitive flexibility, planning, abstract reasoning, and inhibition (Miller & Cummings, 2007; Kaplan et al., 2016). Han, Wu et al. (2018) demonstrated that individuals with IGD exhibit alterations in the functional connectivity of the DLPFC, which may contribute to IGD symptoms. Given that the DLPFC is involved in executive functioning, improvements in cognitive flexibility and inhibition may help individuals gain greater control over their participation in (and preoccupation with) gaming. However, given the limited number of studies, more research is needed to provide more conclusive data on the effects of DLPFC on IGD severity and its underlying mechanisms.

In general, it was found that tDCS was effective in treating gaming disorder. However, its effectiveness was much lower than that of pharmacotherapy. The smaller effect size may result from the fact that tDCS passes through the brain from anode to cathode, modulating neural activity beneath both electrodes, making it challenging to correlate tDCS effects with specific brain regions. That is, tDCS has general rather than specific effects on brain regions (Prehn & Flöel, 2015), whereas pharmacotherapy acts more specifically through neurotransmitters (Seo et al., 2021).

6.2. *Gaming disorder treatment using pharmacotherapy*

The findings indicated that bupropion was significant in reducing IGD severity. It was not surprising that bupropion had a large effect in reducing gaming disorder and outperformed tDCS and methylphenidate, but not SSRIs. These findings corroborate previous findings on the uses of bupropion in the treatment of addiction more generally, including both substance and behavioral addictions, given that it is one of the most common treatments for methamphetamine addiction (Elkashef et al., 2008; Egerton et al., 2010), nicotine withdrawal and craving (Mooney & Sofuoglu, 2006), and gambling disorder (Goslar et al., 2019).

SSRIs, particularly escitalopram, demonstrated significant efficacy in reducing IGD severity. Escitalopram works by inhibiting serotonin reuptake, which may decrease the impulsive-compulsive characteristics of gaming disorder (Song et al., 2016). It has been demonstrated that escitalopram reduces cravings among those with alcohol dependence (Muhonen et al., 2008). Moreover, a combination of SSRIs (escitalopram, fluoxetine, paroxetine) also demonstrated reductions in IGD severity similar to those observed with SSRIs alone. Given its large effect, it may also reduce cravings among those with gaming disorder because bupropion and SSRIs had an equal effect in reducing IGD severity. Two studies compared bupropion vs. escitalopram in reducing IGD severity among individuals who had comorbid MDD and IGD, and both medications were effective. However, in both studies, there were no significant differences in the effectiveness of bupropion vs. escitalopram.

Similar to bupropion and SSRIs, methylphenidate demonstrated significant efficacy in treating IGD. The two studies using methylphenidate administered it to individuals with comorbid gaming disorder and attention-deficit hyperactivity disorder. Methylphenidate increases dopamine and norepinephrine levels in the brain, thereby improving attention and reducing impulsivity (Faraone, 2018). Only one study by Vasiliu (2020) has ever examined the effect of naltrexone among individuals with comorbid alcohol use disorder and IGD and found that it was effective in reducing IGD severity. Although the use of an opioid antagonist to treat IGD is interesting, it is unclear how exactly it reduces IGD severity.

6.3. *Limitations*

In interpreting the findings, it is important to consider the limitations. The generalizability of these findings to Western countries may be limited because most studies were conducted in South Korea. Moreover, the conclusions regarding the effectiveness of the medications/NIBS

Table 4
Categorical moderator analysis, a mixed-effects analysis.

Moderators		Study and Participants		Effect size			Heterogeneity					Prediction Interval		Omnibus test
		K	*n*	*SMD*	*Ll*	*Ul*	*Q*	*df*	*p*	*I2*	*T2*	*Ll*	*Ul*	*Q (df) = p*
tDCS														
Gaming level	Gaming disorder	2	24	−0.48	−1.06	0.09	0.02	1	0.87	0.00	0.00	–	–	0.93 (1) = 0.33
	Problematic gaming	2	28	−0.90	−1.45	0.36	0.30	1	0.58	0.00	0.00	–	–	
Bupropion														
Gaming level	Gaming disorder	3	71	−1.38	−1.74	−1.02	1.31	2	0.51	0.00	0.00	−3.71	0.95	0.56 (1) = 0.45
	Problematic gaming	3	102	−1.57	−1.94	−1.21	0.37	2	0.82	0.00	0.00	−5.87	1.85	
Treatment duration	12 weeks	2	31	−1.52	−2.07	−0.97	0.21	1	0.64	0.00	0.00	–	–	1.21 (2) = 0.54
	8 weeks	2	87	−1.62	−2.03	−1.22	0.09	1	0.75	0.00	0.00	–	–	
	6 weeks	2	55	−1.31	−1.71	−0.91	0.72	1	0.39	0.00	0.00	–	–	
Comorbidity	Depressive symptoms	3	102	−1.57	−1.94	−1.21	0.37	2	0.82	0.00	0.00	−3.90	0.76	0.56 (1) = 0.45
	Not reported	3	71	−1.38	−1.74	−1.02	1.31	2	0.51	0.00	0.00	−3.71	0.95	
Accompanying treatment	None	4	136	−1.43	−1.73	−1.14	1.62	3	0.65	0.00	0.00	−2.06	−0.79	0.25 (1) = 0.61
	Psycho-education	2	37	−1.58	−2.06	−1.10	0.37	1	0.54	0.00	0.00	–	–	
SSRIs														
Gaming level	Gaming disorder	2	60	−1.19	−1.57	−0.81	0.35	1	0.55	0.00	0.00	–	–	0.01 (1) = 0.97
	Problematic gaming	1	15	−1.18	−1.94	−0.41	–	–	–	–	–	–	–	
Treatment duration	24 weeks	1	18	−1.02	−1.70	−0.33	–	–	–	–	–	–	–	0.35 (2) = 0.83
	12 weeks	1	15	−1.18	−1.94	−0.41	–	–	–	–	–	–	–	
	6 weeks	1	42	−1.27	−1.72	−0.81	–	–	–	–	–	–	–	
Methylphenidate														
Treatment duration	12 weeks	1	44	−1.11	−1.54	−0.67	–	–	–	–	–	–	–	2.61 (1) = 0.10
	8 weeks	1	62	−0.65	−1	−0.29	–	–	–	–	–	–	–	

used should be treated cautiously because there were so few studies in the review with considerable risk of bias, and only a small number of individuals were treated for IGD. None of the included studies reported treatment response rates, so it is unknown whether remission occurred as a result of these treatments. Most studies did not evaluate comorbidities, which may have inflated the reported effect sizes (i.e., overestimated the true magnitude of the associations). Consequently, findings may not be generalizable to real-world presentations of IGD, where transdiagnostic factors are prevalent. Future research should prioritize screening for comorbidities, employing stratified designs, and utilizing adjusted models to improve clinical relevance and interpretive accuracy.

Another limitation concerns the ethical considerations of the included pharmacological studies, particularly those involving minors. Three studies (Han et al., 2009; Kim et al., 2012; Park et al., 2016) administered medications such as methylphenidate, atomoxetine, and bupropion to children or adolescents diagnosed with internet gaming disorder (IGD) or problematic online gaming comorbid with ADHD or major depressive disorder. Although all reported ethics approval by their institutional review board and parental consent, these interventions represent off-label applications and raise important ethical questions regarding developmental vulnerability and the balance between clinical benefit and potential risk. Additionally, one adult study (Vasiliu, 2020) did not specify its ethical approval status, underscoring the need for clearer reporting standards, particularly when pharmacological interventions are administered to minors or vulnerable populations.

None of the studies discussed inconsistent findings or potential null or harmful effects of the provided treatment, suggesting a non-neutral stance by the authors. Finally, it should be noted that the screening review process involved manual double-screening of a large volume of the records, which, despite its reliability for nuanced eligibility decisions, was inherently resource-intensive. Independent human verification was used to ensure precision, though this approach required substantial time and effort to maintain consistency across the large volume of outputs screened.

6.4. Psychiatric treatments for gaming disorder: What do we know and what do we not know?

The review found promising (but preliminary) evidence on the efficacy of pharmacotherapy and NIBS in reducing the severity of IGD symptoms. It is unknown if the same results would be achieved if all included studies were of high quality and less susceptible to bias. Moreover, it is unknown which types of gamers would not benefit from these treatments and experience harmful effects (worsening symptoms) due to a lack of assessment of side effects, or whether comorbidities, contextual factors such as game genres, or personality factors such as sensation-seeking or neuroticism influence efficacy (Akbari et al., 2021, 2024). Therefore, researchers are encouraged to explore and report the potential harmful or null effects of gaming disorder treatments and contextual and psychological factors, such as insomnia, that might lead to different effects for different individuals. Further studies are also needed to explore how the included interventions affect game-related characteristics, such as whether they reduce the number of hours spent gaming or reduce craving.

IGD treatment may pose a challenge because abstinence may not be possible because it is not associated with the belief or stigma that it is bad behavior, as with substance use (Yang et al., 2017) and gambling (Quigley, 2022). Therefore, even if gaming is undertaken infrequently, the reward experience and the game's functionality could still lead to relapse. Given the limited follow-up in the included studies, the temporal validity of the findings could not be confirmed. Therefore, longitudinal research is necessary to determine (i) whether remission from IGD can be maintained over time, and (ii) what factors lead to relapse after periods of remission from IGD. It should also be noted that although the efficacy of various treatment modalities was indirectly compared, randomized comparative trials are warranted to validate cross-modality differences.

7. Conclusion

Overall, the present systematic review found that: (i) treatments using tDCS, bupropion, SSRIs, and methylphenidate were significant in reducing gaming disorder, psychopharmacotherapy was much more effective than tDCS in treating gaming disorder, and all effect sizes were independent of IGD severity; (ii) IGD was sometimes comorbid with major depressive disorder, alcohol use disorder, and attention deficit hyperactivity disorder; (iii) studies on NIBS for IGD treatment stimulated the dorsolateral prefrontal cortex (DLPFC) region of the brain and the effect sizes were independent of delivering tDCS setting; (iv) the duration of NIBS treatment ranged from five days to nine weeks, with the number of sessions ranging from two to 26; (v) in the studies using bupropion for IGD, the duration of treatment varied from six to 12 weeks, with a dosage ranging from 150 mg to 300 mg, and the effect of bupropion was independent of treatment duration (6 vs. 8 vs. 12 weeks), gaming level, or comorbidity with depression; (vi) for individuals with comorbid MDD and IGD, there was a dosage of 150 mg to 300 mg bupropion for eight to 12 weeks, or a dosage of 10 mg to 20 mg escitalopram for 12 weeks; (vii) in the studies using SSRIs for IGD, one study used a combination of SSRIs (escitalopram 15 mg, fluoxetine 50 mg, paroxetine 30 mg) for 20 weeks, and the other study used escitalopram with a dosage of 10 mg to 20 mg for six to 12 weeks and SSRIs; bupropion had equal efficacy in reducing IGD severity; (viii) in studies among individuals with comorbid IGD and ADHD, 10 mg to 40 mg methylphenidate over eight to 12 weeks was used, or atomoxetine with a dosage of 19 mg to 60 mg for over 12 weeks was used; (ix) for individuals with comorbid IGD and alcohol use disorder, an opioid antagonist (50 mg naltrexone) combined with CBT (with a focus on compulsive behavior management) was used for 12 weeks; (x) all treatments for IGD were shown to be effective; however, except for bupropion, the remaining treatments may have null or harmful effects among some individuals; therefore, the temporal nature of the findings warrants further assessment; and (xi) none of the studies assessed potential side effects, and there were not enough details to allow for exact replication.

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None to declare.

CRediT authorship contribution statement

Mehdi Akbari: Conceptualization, Methodology, Formal analysis, Validation, Writing – original draft, Writing – review & editing, Supervision. **Mohammad Seydavi:** Conceptualization, Methodology, Formal analysis, Validation, Writing – original draft, Writing – review & editing. **Sonay Sheikhi:** Investigation, Data curation. **Shiva Jamshidi:** Writing – original draft, Investigation, Data curation. **Mark D. Griffiths:** Writing – review & editing, Validation, Supervision.

Declaration of competing interest

Given their roles as Editorial Board members, Mehdi Akbari, Mohammad Seydavi, and Mark D. Griffiths had no involvement in the peer-review of this article and had no access to information regarding its peer-review. Also, Mark D. Griffiths (MDG) has received research funding from *Norsk Tipping* (the gambling operator owned by the Norwegian government). MDG has received funding for a number of research projects in the area of gambling education for young people, social responsibility in gambling, and gambling treatment from *Gamble Aware* (formerly the *Responsibility in Gambling Trust*), a charitable body which funds its research program based on donations from the gambling industry. MDG undertakes consultancy for various gambling companies

in the area of player protection and social responsibility in gambling. The remaining authors declare no conflicts of interest.

Appendix. (Search terms)

S1. The search terms used to locate the relevant studies.

Keywords Used in the Literature Search.

Category	Keywords
IGD	"game" OR "gaming" OR "Technology Addictions" OR" Internet Gaming Disorder" OR "Disorder, Internet Gaming" OR "Disorders, Internet Gaming" OR "Gaming Disorder, Internet" OR "Gaming Disorders, Internet" OR "Internet Gaming Disorders" OR "Game Addiction, Video" OR "Addictions, Video Game" OR "Video Game Addictions" OR "Addiction, Video Game" OR "Video Game Addiction" OR "gamer" OR "gaming disorder"
NIBS	("Tdcs" OR "Cathodal Stimulation Transcranial Direct Current Stimulation" OR "Cathodal Stimulation Tdcs" OR "Cathodal Stimulation tDCSs" OR "Stimulation tDCS, Cathodal" OR "Stimulation tDCSs, Cathodal" OR "tDCS, Cathodal Stimulation" OR "tDCSs, Cathodal Stimulation" OR "Transcranial Random Noise Stimulation" OR "Transcranial Alternating Current Stimulation" OR "Transcranial Electrical Stimulation" OR "Electrical Stimulation, Transcranial" OR "Electrical Stimulations, Transcranial" OR "Stimulation, Transcranial Electrical" OR "Stimulations, Transcranial Electrical" OR "Transcranial Electrical Stimulations" OR "Anodal Stimulation Transcranial Direct Current Stimulation" OR "Anodal Stimulation Tdcs" OR "Anodal Stimulation tDCSs" OR "Stimulation tDCS, Anodal" OR "Stimulation tDCSs, Anodal" OR "tDCS, Anodal Stimulation" OR "tDCSs, Anodal Stimulation" OR "Repetitive Transcranial Electrical Stimulation"
Pharmacotherapy	"anti-depressant" OR "stimulant" OR "sympathomimetic" OR "opioid receptor" OR "benzodiazepine" OR "anti-psychotic" OR "atomoxetine" OR "bupropion" OR "clonazepam" OR "citalopram" OR "escitalopram" OR "fluoxetine" OR "memantine" OR "methylphenidate" OR "modafinil" OR "naltrexone" OR "olanzapine" OR "quetiapine" OR "SSRI" OR "SNRI" OR "medication" OR "medicine" OR "pharma" OR "non-invasive" OR "neuromodulation"

Appendices. (Risk of bias Assessment)

S2. Risk of bias assessment of studies on bupropion (Bae et al. [2018] / Han & Renshow [2012] / Han et al. [2011] /Kim et al. [2012]).

Criteria	Yes	Partial	No	NA
Sufficient description of the question/objective	100%			
Evident and appropriate study design	62.5%	37.5%		
Appropriate (description of) method of participant/comparison group selection or source of information/input variables	62.5%	37.5%		
Sufficient description of participant (and comparison group, if applicable) characteristics	87.5%	12.5%		
Description of interventional and random allocation (if applicable)		50%	50%	
Report of interventional and blinding of investigators (if applicable)		37.5%	62.5%	
Report of the interventional and blinding of participants (if applicable)	12.5%	37.5%	50%	
Outcome/ exposure measure(s) well defined and robust to measurement/misclassification bias + report of means of assessment	50%	25%	25%	
Appropriate sample size	75%	25%		
Description/justification and appropriateness of analytic methods	50%	50%		
Some estimate of variance is reported for the main results.		37.5%	62.5%	
Control for confounding	12.5%	25%	62.5%	
Results are reported in sufficient detail	62.5%	37.5%		
Conclusions supported by the results	25%	62.5%	12.5%	

S3. Risk of bias assessment of studies on tDCS and rTMS study (Cuppone et al., 2021).

Criteria	Yes	Partial	No	NA
Sufficient description of the question/objective	93.75%	6.25%	–-	–-
Evident and appropriate study design	56.25%	37.5%	6.25%	–-
Appropriate (description of) method of participant/comparison group selection or source of information/input variables	25%	50%	25%	–-
Sufficient description of participant (and comparison group, if applicable) characteristics	25%	62.5%	12.5%	–-
Description of interventional and random allocation (if applicable)	31.25%	6.25%	62.5%	–-
Report of interventional and blinding of investigators (if applicable)	12.5%	18.75%	68.75%	–-
Report of If interventional and blinding of participants (if applicable)	25%	25%	50%	–-
Outcome/ exposure measure(s) well defined and robust to measurement / misclassification bias + report of means of assessment	56.25%	37.5%	6.25%	–-
Appropriate sample size	56.25%	43.75%		–-
Description/justification and appropriateness of analytic methods	56.25%	31.25%	12.5%	–-
Some estimate of variance reported for the main results	25%	18.75%	56.25%	–-
Control for confounding	31.25%	31.25%	37.5%	–-
Results reported in sufficient detail	50%	37.5%	12.5%	–-
Conclusions supported by the results	25%	56.25%	18.75%	–-

S4. Risk of bias assessment of studies on Methylphenidate and atomoxetine (Han et al., 2009/ Park et al., 2016).

Criteria	Yes	Partial	No	NA
Sufficient description of question/objective	100%			
Evident and appropriate study design		100%		
Appropriate (description of) method of participant/comparison group selection or source of information/input variables		100%		
Sufficient description of participant (and comparison group, if applicable) characteristics	100%			

(*continued on next page*)

(*continued*)

Criteria	Yes	Partial	No	NA
Description of interventional and random allocation (if applicable)	25%	25%	50%	
Report of interventional and blinding of investigators (if applicable)			100%	
Report of If interventional and blinding of participants (if applicable)		50%	50%	
Outcome/ exposure measure(s) well defined and robust to measurement / misclassification bias + report of means of assessment	50%	50%		
Appropriate sample size	100%			
Description/justification and appropriateness of analytic methods	50%	50%		
Some estimate of variance reported for the main results	50%		50%	
Control for confounding		75%	25%	
Results reported in sufficient detail	100%			
Conclusions supported by the results		100%		

S5. Risk of bias assessment of studies on bupropion vs. escitalopram) Nam et al. [2017] / Song et al. [2016]).

Criteria	Yes	Partial	No	NA
Sufficient description of question/objective	100%			
Evident and appropriate study design	50%	50%		
Appropriate (description of) method of participant/comparison group selection or source of information/input variables		50%	50%	
Sufficient description of participant (and comparison group, if applicable) characteristics	25%	75%		
Description of interventional and random allocation (if applicable)	25%	75%		
Report of interventional and blinding of investigators (if applicable)		25%	75%	
Report of If interventional and blinding of participants (if applicable)		50%	50%	
Outcome/ exposure measure(s) well defined and robust to measurement / misclassification bias + report of means of assessment	100%			
Appropriate sample size	100%			
Description/justification and appropriateness of analytic methods	50%	50%		
Some estimate of variance reported for the main results	50%		50%	
Control for confounding	25%		75%	
Results reported in sufficient detail	100%			
Conclusions supported by the results	50%	25%	25%	

S6. Risk of bias assessment of the study on naltrexone (Vasiliu, 2020).

Criteria	Yes	Partial	No	NA
Sufficient description of question/objective	100%			
Evident and appropriate study design		100%		
Appropriate (description of) method of participant/comparison group selection or source of information/input variables	50%	50%		
Sufficient description of participant (and comparison group, if applicable) characteristics		100%		
Description of interventional and random allocation (if applicable)			100%	
Report of interventional and blinding of investigators (if applicable)			100%	
Report of If interventional and blinding of participants (if applicable)			100%	
Outcome/ exposure measure(s) well defined and robust to measurement / misclassification bias + report of means of assessment		100%		
Appropriate sample size		100%		
Description/justification and appropriateness of analytic methods			100%	
Some estimate of variance reported for the main results		100%		
Control for confounding		50%	50%	
Results reported in sufficient detail			100%	
Conclusions supported by the results		50%	50%	

S7. Risk of bias assessment of the study on SSRIs (combination of escitalopram, fluoxetine, and paroxetine) (Park et al., 2017).

Criteria	Yes	Partial	No	NA
Sufficient description of question/objective	100%			
Evident and appropriate study design		100%		
Appropriate (description of) method of participant/comparison group selection or source of information/input variables	50%	50%		
Sufficient description of participant (and comparison group, if applicable) characteristics	50%	50%		
Description of interventional and random allocation (if applicable)			100%	
Report of interventional and blinding of investigators (if applicable)			100%	
Report of If interventional and blinding of participants (if applicable)			100%	
Outcome/ exposure measure(s) well defined and robust to measurement/misclassification bias + report of means of assessment	100%			
Appropriate sample size	100%			
Description/justification and appropriateness of analytic methods	100%			
Some estimates of variance reported for the main results	100%			
Control for confounding			100%	
Results reported in sufficient detail	100%			
Conclusions supported by the results	50%	50%		

Data availability

This is a systematic review and meta-analysis and all data from included studies are provided in the manuscript.

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