Executive Function Performance of Problematic Internet Users: A Three-Level Meta-Analysis

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Abstract

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Full Text

Preamble

Executive Function Performance in Problematic Internet Users: A Three-Level Meta-Analysis

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This study provides important implications for the intervention and treatment of Problematic Internet Use (PIU). PIU refers to a pattern of excessive internet use, and individuals with PIU may exhibit impairments in executive functions such as working memory, inhibitory control, and cognitive flexibility. Therefore,

it is recommended that individuals avoid excessive internet use in daily life to protect their executive functions and promote better work and academic performance. Additionally, the assessment and training of executive functions should be emphasized in PIU intervention and treatment.

To clarify the executive function characteristics of individuals with Problematic Internet Use (PIU), this study conducted a three-level random-effects meta-analysis of 59 studies. The results revealed that the PIU group demonstrated significantly poorer overall executive function performance compared to the healthy control group (g = -0.39, 95% CI [-0.50, -0.28]). The moderating effect of executive function components was significant (F(2, 101) = 3.64, p = 0.030), with the PIU group showing significantly worse performance than controls in working memory, inhibitory control, and cognitive flexibility, and the effect size for working memory being significantly larger than for other subcomponents. The moderating effects of gender, age, culture, PIU type, and material specificity were not significant. This study provides a foundation for theoretical research and intervention strategies for PIU.

Keywords: problematic internet use, executive function, three-level meta-analysis, moderators

Abstract

To clarify the executive functioning characteristics of individuals with Problematic Internet Use (PIU), this study conducted a three-level random-effects meta-analysis of 59 studies. Results revealed that the PIU group demonstrated significantly poorer overall executive functioning compared to the healthy control group (g = -0.39, 95% CI [-0.50, -0.28]). Significant moderating effects of executive function components were observed: the PIU group exhibited notably worse performance in working memory, inhibitory control, and cognitive flexibility compared to controls, with working memory showing a substantially larger effect size than other subcomponents. However, no significant moderating effects emerged for gender, age, cultural background, PIU type, or material specificity. These findings provide empirical foundations for both theoretical models and clinical interventions targeting PIU.

Keywords: problematic internet use, executive function, three-level meta-analysis, moderators

Introduction

According to Statista, global internet users reached 5.3 billion as of October 2023. The rapid development and widespread adoption of the internet have made it an important topic in psychological and neuroscientific research, particularly in the domain of Problematic Internet Use. Problematic Internet Use (PIU), also known as "internet addiction," "pathological internet use," or "compulsive internet use," refers to a pattern of excessive internet use (Laconi et al., 2015) characterized by salience, tolerance, conflict, mood modification, withdrawal symptoms, and relapse tendency (Griffiths, 2005). Davis (2001) defined two types of PIU based on a cognitive-behavioral model: generalized PIU, which encompasses a range of internet-based activities, and specific PIU, which involves specific online activities such as internet gaming addiction and social networking addiction. PIU negatively impacts individuals' social functioning and mental health, contributing to anxiety and depression (Odacı & Çıkrıkçı, 2022), suicidal ideation (Arrivillaga et al., 2020), and substance abuse (Rücker et al., 2015), with executive function impairments playing a key role in the development and maintenance of PIU (Brand et al., 2019; Ioannidis et al., 2019).

Executive function refers to the top-down coordination and control of thought, behavior, and emotion to achieve goal-directed outcomes, comprising key components such as inhibitory control, working memory, and cognitive flexibility (Diamond, 2013). It occupies a central position in multiple aspects of daily cognitive, social, and emotional functioning (Ganesan & Steinbeis, 2022). Various mental health conditions, including depression (Holler et al., 2014), anxiety (Shields et al., 2016), nicotine and opioid addiction (Butler & Le Foll, 2019), and internet addiction (Zhou et al., 2016), are accompanied by executive function impairments. Mounting evidence suggests that alterations in executive function constitute an important determinant of clinical symptoms in addiction (Couto et al., 2022; Crivelli et al., 2024).

The I-PACE model (Brand et al., 2019) posits that executive function efficiency is crucial for regulating impulses and desires toward addictive behaviors, and that executive function impairments may lead to increased addictive behaviors. The cognitive-behavioral model (Dong & Potenza, 2014) proposes that the neural processes of attention, response inhibition, and behavioral flexibility in individuals with Internet Gaming Disorder (IGD) are significantly related to IGD severity. Both theories support the notion that PIU patients exhibit executive dysfunction. However, some empirical findings are inconsistent with these theoretical predictions. For instance, research has shown that individuals with problematic internet use do not exhibit significant impairments in inhibitory control (Vargas et al., 2019) or cognitive flexibility (Chen & Hsieh, 2018). Additionally, Argyriou et al. (2017) employed traditional meta-analysis to demonstrate that IGD patients show impaired response inhibition. Similarly, Ioannidis et al. (2019) found through traditional meta-analysis that both generalized PIU and IGD are closely associated with impairments in inhibitory control and working memory. These discrepancies indicate that the mechanisms through which PIU affects executive function remain controversial, particularly regarding different components of executive function. Studies on executive function in PIU patients typically include multiple experimental tasks. Traditional meta-analysis, to avoid dependency issues among effect sizes, usually adopts averaging or discarding approaches when extracting multiple effect sizes from the same study, resulting in information loss and reduced statistical power. Given these limitations, this study employs three-level meta-analysis techniques (Assink & Wibbelink, 2016) to address dependency issues among multiple effect sizes extracted from the same literature (Cheung, 2014), quantitatively synthesizing executive function performance in PIU patients and exploring potential moderating factors to provide more comprehensive and deeper insights for future research and interventions.

Theoretical Models of Executive Function Impairment in PIU

The I-PACE Model According to the I-PACE model (Brand et al., 2019), executive function impairment in PIU patients is a dynamically developing process. In the early stage, individual vulnerability manifests primarily as general inhibitory control deficits, which are closely related to insufficient inhibitory control function in the dorsolateral prefrontal cortex, leading to impulsive decision-making. As cue reactivity and craving intensify, accompanied by hyperactivation of limbic structures (including the amygdala and ventral striatum) and reduced activity in prefrontal-striatal circuits, individuals exhibit progressive weakening of stimulus-specific response inhibition functions, thereby exacerbating executive function deficits. Additionally, PIU patients often show cognitive flexibility impairments, with significantly reduced adaptive behavioral regulation capacity, specifically manifested as attentional fixation on internet-related cues and rigidity in automatic thinking patterns. Neuroimaging evidence indicates that such patients show weakened functional connectivity between the dorsolateral prefrontal cortex and caudate nucleus, which may constitute the neural basis for their cognitive flexibility impairment (Dong & Potenza, 2016).

The Cognitive-Behavioral Model The cognitive-behavioral model (Dong & Potenza, 2014) posits that IGD patients exhibit decreased inhibitory control ability, performing poorly on executive inhibition tasks such as Go/No-Go (Dong et al., 2010) and Stroop (Dong et al., 2011), indicating difficulty in suppressing impulses to engage in gaming or other internet activities. Furthermore, IGD patients show difficulties in switching tasks (Dong et al., 2014), particularly when tasks involve gaming-related stimuli (Zhou et al., 2012), with impaired attentional set-shifting ability leading to failure in adaptive regulation when disengaging from gaming contexts. These executive function deficits collectively weaken behavioral control, thereby maintaining and intensifying problematic internet use behaviors. Consequently, this study proposes Hypothesis 1: **H1: The PIU group will demonstrate significantly poorer executive function performance compared to the healthy control group.**

Empirical Studies on Executive Function Performance in PIU

Numerous studies have examined executive function performance in PIU patients. Regarding inhibitory control, research has found that individuals with generalized PIU (Chamberlain et al., 2018; Qi et al., 2022; Zhou et al., 2016), IGD patients (Chen et al., 2021; Kim et al., 2017; Wang et al., 2020; Xing et al., 2014), and Problematic Social Media Use (PSMU) patients (Cudo et al., 2023) all show inhibitory control impairments. However, some studies have found no significant differences in inhibitory control function between IGD patients (Vargas et al., 2019) or PSMU patients (Reed, 2023) and healthy groups. Regarding working memory, current research is limited but results are relatively consistent, with both generalized PIU patients (Zhou et al., 2016) and IGD patients (Jiang et al., 2020) showing working memory impairments. Regarding cognitive flexibility, findings are inconsistent. Some studies indicate that generalized PIU patients (Zhou et al., 2016) and IGD patients (Jiang et al., 2020) show cognitive flexibility impairments, while other studies have not found cognitive flexibility impairments in generalized PIU patients (Chamberlain et al., 2018), IGD patients (Chen & Hsieh, 2018), or PSMU patients (Aydın et al., 2020; Reed, 2023). Consequently, this study proposes Hypothesis 2: **H2: Different types of PIU may exhibit differential impairments across executive function subcomponents.**

Moderating Variables in the Relationship Between PIU and Executive Function

PIU Type First, different types of PIU exhibit varying prevalence rates. According to statistics, global social media users reached 5.07 billion, constituting the vast majority of internet users. The high interactivity of social media may lead to addictive browsing and posting behaviors (Zivnuska et al., 2019), making PSMU more prevalent than IGD (Sánchez-Fernández & Borda-Mas, 2023) and an important risk factor for PIU (Gao, 2021). Second, different types of PIU have distinct effects on executive function. Generalized internet addiction significantly predicts impairments in all three executive function components (Zhou et al., 2016), while IGD and PSMU patients primarily show significant impairments in inhibitory control and working memory (Chen et al., 2021; Cudo et al., 2023; Jiang et al., 2020), with cognitive flexibility remaining unaffected (Chen & Hsieh, 2018; Reed, 2023). Finally, different types of PIU employ different measurement tools and diagnostic criteria, leading to divergent results when examining executive functions in PIU patients (Firoozabadi et al., 2023; Vargas et al., 2019). In summary, this study proposes Hypothesis 3: **H3: PIU type moderates executive function performance in PIU patients.**

Executive Function Components First, executive function comprises three related but independent components—inhibitory control, working memory, and cognitive flexibility (Diamond, 2013)—that differ in mechanisms and functions, with PIU affecting these three components differently (Kim et al., 2017; Reed, 2023; Soares et al., 2023). Second, laboratory measures of executive function reflect cognitive abilities under highly standardized conditions, whereas self-report measures offer greater ecological validity (Toplak et al., 2013). Some studies have shown that self-report measures produce stronger associations than laboratory tasks in certain cognitive domains (Parry & Le Roux, 2021). Finally, different laboratory tasks measuring executive function may activate different components, leading to variations in executive function results (Reed, 2023; Yan et al., 2021). In summary, this study proposes Hypothesis 4: **H4: Executive function components moderate executive function performance in PIU patients.**

Material Specificity According to incentive sensitization theory (Robinson & Berridge, 2024), addictive substances or behaviors sensitize the mesolimbic dopamine system through repeated exposure, endowing addiction-related stimuli with higher incentive salience, thereby enhancing "wanting" for these stimuli and reducing top-down control from the prefrontal cortex, which affects executive function. In contrast, when facing general stimuli without such sensitization effects, executive function does not show obvious impairments. According to the I-PACE model, addiction-related stimuli are more likely to trigger craving and impulse in addicts compared to general stimuli (Brand et al., 2019). Additionally, desire thinking can enhance attentional and motivational attraction to addiction-related stimuli, making executive function impairments more pronounced (Brandtner et al., 2021). Most empirical studies have also found that PIU patients' executive functions are significantly affected when facing addiction-related stimuli (Cudo et al., 2023; Kim et al., 2019), but show no obvious impairments when facing general stimuli (Irak & Soylu, 2023; Reed, 2023). In summary, this study proposes Hypothesis 5: **H5: Stimulus specificity moderates executive function performance in PIU patients.**

Culture Collectivism in Eastern cultures emphasizes group and social importance, leading individuals to develop greater dependence in online social environments and increasing PIU risk. In contrast, individualism in Western cultures emphasizes personal freedom and independence, potentially reducing reliance on online social networking and sense of belonging, thereby lowering PIU risk. Research indicates higher addiction rates in Asian countries (Balhara et al., 2019; Lozano-Blasco et al., 2022). Furthermore, evidence of cross-cultural decision-making differences underscores the importance of considering culture in cognitive research and evaluating whether these differences may affect task performance (Freire & Pammer, 2020). Previous studies have found cultural differences in inhibitory control (Na et al., 2010; Oh & Lewis, 2008), with proactive inhibition potentially playing a crucial role in promoting collective and interdependent behaviors typical of Eastern cultures, while reactive inhibition may be more important for effective cognitive control in Western cultural contexts that prioritize individualism and independence (Gavazzi et al., 2023). Therefore, individuals from different cultural backgrounds may exhibit different inhibitory control patterns, which in turn may influence their susceptibility to PIU and performance on cognitive tasks. In summary, this study proposes Hypothesis 6: **H6: Culture moderates executive function performance in PIU patients.**

Gender Research indicates that male IGD patients tend to have higher impulsivity and reward sensitivity (Zhang et al., 2020), making them more prone to gaming behaviors that cause more severe damage to executive functions. Additionally, males are more inclined to use maladaptive emotion regulation strategies such as expressive suppression (Rogier et al., 2019) and over-engagement (Nolen-Hoeksema & Aldao, 2011), which may cause male PIU patients to fall into a vicious cycle of PIU, further exacerbating executive function impairments. In contrast, females more frequently employ adaptive strategies such as cognitive reappraisal, problem-solving, and seeking emotional support (Nolen-Hoeksema & Aldao, 2011), giving them advantages in coping with PIU and thereby mitigating its negative effects on executive functions to some extent. In summary, this study proposes Hypothesis 7: **H7: Gender moderates executive function performance in PIU patients.**

Age First, PIU shows age differences. Adolescents, due to the ubiquity of mobile phones and the internet in their upbringing, combined with insufficient self-control capacity (Casey & Caudle, 2013) and higher social needs (Beyens et al., 2016), may develop greater dependence on the internet, increasing their risk for PIU. As age increases, individuals' self-control capacity strengthens (Strayhorn, 2002), and they may face more occupational and family responsibilities requiring them to allocate attention and time to other important matters, reducing internet dependence. Moreover, from a lifespan developmental perspective, executive functions become more sophisticated with age (Ferguson et al., 2021), which may serve as a protective factor against PIU, helping individuals better manage their internet use and reducing PIU risk. Empirical research further indicates that the negative correlation between video game use and executive function becomes more pronounced with age (Xu et al., 2023). Previous meta-analyses on PIU or executive function have also considered age as a potential moderating factor (Ioannidis et al., 2019; Kong et al., 2023). In summary, this study proposes Hypothesis 8: **H8: Age moderates executive function performance in PIU patients.**

To ensure systematicity and reproducibility, this study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was preregistered on the PROSPERO platform (registration number: CRD42024570257).

Method

Literature Search

We conducted systematic searches through university library access across Web of Science, ProQuest (including PsycINFO and other psychology databases), PubMed, and China National Knowledge Infrastructure (CNKI). The search strategy combined terms for problematic internet use: ("Problematic Internet Use" OR "Internet Addiction Disorder" OR "Smartphone Addiction" OR "social media addiction" OR "problematic social media use" OR "problematic social network use" OR "social network addiction" OR "problematic Facebook use" OR "Facebook addiction" OR "Internet Gaming Disorder" OR "game addiction" OR "gaming disorder" OR "pathological gaming") with terms for executive function: ("executive function" OR "executive control" OR "cognitive control" OR "working memory" OR "updating" OR "inhibitory control" OR "cognitive flexibility" OR "shifting" OR "task switch"). Additional manual searches were also performed. The search cutoff date was July 20, 2024, yielding 59 publications on executive function in problematic internet users.

Inclusion Criteria

The inclusion criteria for this meta-analysis were: (1) empirical studies examining differences in executive function performance between PIU and healthy control groups; (2) peer-reviewed publications in English or Chinese; (3) studies reporting sufficient original data (means, standard deviations, t-values, F-values, etc.) to calculate Hedges' g effect sizes; (4) PIU including generalized PIU, IGD, and PSMU; (5) inclusion of at least one laboratory task assessing executive function (inhibitory control, working memory, or cognitive flexibility) or self-report scale results for executive function components (Parry & Le Roux, 2021); and (6) clearly defined outcome measures (e.g., reaction time, accuracy). The literature screening process is illustrated in [Figure 1: see original paper].

Literature Coding

Two authors independently coded each included study based on: (a) first author; (b) publication year; (c) mean age (continuous variable); (d) sample size; (e) gender; (f) culture (Eastern, Western); (g) PIU type (generalized PIU, IGD, PSMU); (h) PIU measurement instrument; (i) material specificity (general stimuli, internet-related stimuli); (j) executive function component (inhibitory control, working memory, cognitive flexibility); (k) executive function task; (l) outcome measure; and (m) effect size. Coding followed these principles: (1) each independent sample was coded once; (2) if a study used different executive function tasks, effect sizes for all tasks were coded; (3) when an executive function task measured multiple outcome indicators for the same participant group (e.g., reaction time, accuracy), to avoid including highly correlated effect sizes, only the indicator most representative of task characteristics, most sensitive to changes in the executive function component, or most commonly used in previous research was selected (Kong et al., 2023; Mauger et al., 2018; Schoemaker et al., 2013; Spaniol & Danielsson, 2022)[1]; (4) clearly listed included outcome indicators (e.g., reaction time, accuracy, error rate, sensitivity; Rabi et al., 2020; Van Der Put et al., 2021). After mutual verification and cross-checking, the two authors produced the final coded dataset.

[1]Specific criteria for outcome measure selection are detailed in the coding table in the supplementary materials, available at https://osf.io/am9qt/.

[Figure 1: see original paper] PRISMA Flow Diagram of Literature Screening

Effect Size Calculation

To estimate the standardized mean difference between problematic use and healthy groups, this study employed Hedges' g for each measurement. Based on extracted data, Hedges' g was calculated using Comprehensive Meta-Analysis 3.0 (CMA3.0). Positive effect sizes indicated higher executive function levels in the problematic use group compared to the healthy group, while negative values indicated lower executive function levels. In CMA3.0, the effect size direction was set as "positive" when larger values indicated better executive function, and "negative" when larger values indicated poorer executive function.

Model Selection

Most primary studies included in this meta-analysis reported multiple effect sizes. These multiple effect sizes from the same study often originated from the same sample, making them correlated. Traditional meta-analysis typically assumes independence of effect sizes and selects only one effect size per study (Assink & Wibbelink, 2016). This approach fails to account for correlations among effect sizes and may lead to overestimation of the overall effect size (Lipsey & Wilson, 2001). Three-level meta-analysis is a statistical method for synthesizing and analyzing multiple effect sizes within studies, extending the traditional two-level structure (participant level and study level) to a three-level structure (participant level, within-study level, and between-study level), thereby better handling dependency among effect sizes (Cheung, 2014). Thus, compared to traditional meta-analysis, three-level meta-analysis more effectively handles dependency among effect sizes, retains more information, and enhances statistical power (Assink et al., 2015; Assink & Wibbelink, 2016). Therefore, this study employed three-level meta-analysis models for main effect testing, heterogeneity analysis, moderator analysis, publication bias assessment, and sensitivity analysis.

Meta-Analytic Procedure

This study used restricted maximum likelihood estimation (Viechtbauer, 2005) to: (1) assess publication bias. If effect sizes in the funnel plot were evenly distributed on both sides and presented a symmetrical inverted funnel shape, this would suggest minimal publication bias (Sterne & Harbord, 2004). Nonsignificant Egger' s regression results would further support this conclusion (Yap & Jorm, 2015). If significant publication bias was detected, the trim-and-fill method would be applied for further evaluation (Duval & Tweedie, 2000). (2) Test main effects, interaction effects, conduct sensitivity analysis, and examine heterogeneity. For interaction effect testing, we created interaction terms using R packages, categorizing PIU type and executive function components into three levels each. We then used mixed-effects models to test the interaction between PIU type and executive function components on executive function, conducting simple effects analysis and pairwise comparisons. Sensitivity analysis was performed using the "one-study-removed" method. We used one-sided log-likelihood ratio tests to examine significant differences in within-study (Level 2) and between-study (Level 3) variance. If differences were significant, moderator effects were tested by adding moderators as covariates to the model (Gao et al., 2024) to estimate sources of heterogeneity and moderator effect sizes.

Results

Study Characteristics

This meta-analysis ultimately included 59 publications[2], encompassing 104 effect sizes and 5,568 participants, spanning from 2010 to 2024.

[2]The list of 59 publications and basic information are detailed in the supplementary materials, available at https://osf.io/am9qt/.

Publication Bias Assessment

[Figure 2: see original paper] presents the funnel plot of the relationship between PIU and executive function. However, visual inspection alone is insufficient for definitive judgment of publication bias. Therefore, Egger' s test was conducted, revealing significant publication bias ($F = 5.77$, $p = 0.018$). The trim-and-fill method was applied to further evaluate bias (Ran et al., 2021), indicating 10 missing studies on the left side, likely due to nonsignificant results remaining unpublished. The adjusted effect size estimate was -0.478, demonstrating that even after accounting for publication bias, the negative impact of PIU on executive function remained significant ($p < 0.001$, 95% CI [-0.58, -0.38]). Therefore, potential publication bias must be considered cautiously when interpreting the effects of PIU on executive function.

Main Effect Testing, Interaction Effect Testing, Sensitivity Analysis, and Heterogeneity Testing[3]

Main Effect Testing. This study used a random-effects model to estimate overall executive function performance in PIU patients. Results indicated that the PIU group' s overall executive function performance was significantly poorer than the healthy control group ($g = -0.39$, $p < 0.001$, 95% CI [-0.50, -0.28]), representing a medium effect size (Cohen, 1988). Hypothesis H1 was supported.

[3]Forest plots for main effect testing, sensitivity analysis plots, and all R codes and intermediate results for analyses are included in the supplementary materials, available at https://osf.io/am9qt/.

Interaction Effect Testing. The interaction between PIU type and executive function component was not significant ($QM(df = 8) = 12.58$, $p = 0.127$). However, some interaction terms were significant: the interaction between IGD and inhibitory control was 0.530 ($p = 0.014$), between IGD and cognitive flexibility was 0.731 ($p = 0.005$), and between PSMU and inhibitory control was 0.491 (p

= 0.047). Pairwise comparisons revealed significant differences between working memory and inhibitory control (p = 0.038) and between working memory and cognitive flexibility (p = 0.016) in IGD patients, with no other significant differences across PIU types and executive function components.

Sensitivity Analysis. We conducted sensitivity analysis using the "one-study-removed" method to assess the influence of each effect size. Results showed an average difference of 0, with the combined effect size g ranging from -0.40 to -0.37 after removing any single effect size, indicating that the results remained essentially unchanged and were relatively robust.

Heterogeneity Testing. This meta-analysis used one-sided log-likelihood ratio tests to examine the significance of within-study and between-study variance. Results showed significant differences in effect sizes extracted from within-study ($\sigma^2 = 0.11$, $p < 0.001$) and between-study levels ($\sigma^2 = 0.17$, $p < 0.001$). Variance distribution across the three levels was: 25.58% (sampling variance, Level 1), 33.62% (within-study variance, Level 2), and 40.80% (between-study variance, Level 3). Heterogeneity testing indicated significant variance at both Level 2 and Level 3. Therefore, we further explored potential moderating variables to assess whether executive function performance in PIU patients was influenced by these factors.

Moderator Effect Testing

Moderator effect testing results are presented in . The moderating effect of executive function component was significant ($F(2, 101) = 3.64$, $p = 0.030$). Specifically, PIU patients performed significantly worse than controls in working memory ($g = -0.70$, $p < 0.001$), inhibitory control ($g = -0.36$, $p < 0.001$), and cognitive flexibility ($g = -0.27$, $p < 0.05$). Pairwise comparisons revealed significant differences between working memory and inhibitory control ($p < 0.05$) and between working memory and cognitive flexibility ($p < 0.05$). Hypothesis H3 was partially supported, but interpretation of these results requires caution.

TABLE:1 Moderator Effect Testing

Moderator	Intercept/g[95%CI]	β[95%CI]	F(df1, df2)	Level2	Level3
(1) Sample Characteristics					
a. Gender	-0.49[-0.82,-0.15]**	0.17[-0.31,0.64]	F(1,96)=0.49	0.08***	0.08***
b. Age	-0.17[-0.86,0.52]	-0.01[-0.04,0.02)	F(1,98)=0.35	0.08***	0.07***

Moderator	Intercept/g[95%CI]	β[95%CI]	F(df1, df2)	Level2	Level3
c. Culture (Eastern as reference)	-0.36[-0.48,-0.23]***		F(1,102)=1.22	0.16***	0.11***
(2) Study Design Characteristics					
a. PIU Type (Generalized PIU as reference)					
Problematic Social Media Use	-0.51[-0.76,-0.26]***		F(2,101)=0.79	0.17***	0.11***
Internet Gaming Disorder	-0.16[-0.43,0.12]				
b. Executive Function Component (Inhibitory Control as reference)					
Cognitive Flexibility	-0.37[-0.64,-0.10]**		F(2,101)=3.64	0.15***	0.10***
Working Memory	0.15[-0.21,0.51]				
c. Material Specificity (General as reference)					

Moderator	Intercept/g[95%CI]	β[95%CI]	F(df1, df2)	Level2	Level3
Internet-Related	-0.35[-0.49,-0.21)***		F(1,102)=0.18	0.17***	0.11***

Note: #es = number of effect sizes; CI = confidence interval; β = meta-regression coefficient; df = degrees of freedom; Level2 = within-study variance; Level3 = between-study variance; Gender = proportion of males; PIU = Problematic Internet Use. Overall test of all regression coefficients in the model, p-value for overall test. p < 0.05; **p < 0.01;** *p < 0.001.*

The moderating effects of other variables were not significant: (1) Gender: (F(1, 96) = 0.50, p = 0.484); (2) Age (F(1, 98) = 0.35, p = 0.556); (3) Culture (F(1, 102) = 1.22, p = 0.272); (4) PIU type: (F(2, 101) = 0.79, p = 0.457); (5) Material specificity: (F(1, 102) = 0.20, p = 0.657). Hypotheses H2, H4, H5, H6, and H7 were not supported.

Discussion

Based on the latest literature and theoretical models of executive function performance in PIU patients, this study employed three-level meta-analysis techniques to quantitatively synthesize existing research data, examining executive function performance in PIU patients and its moderating factors.

Executive Function Deficits in PIU Patients

Main effect analysis results supported the research hypothesis, indicating that the PIU group demonstrated significantly poorer executive function performance than the healthy control group. This finding is consistent with most empirical research (Jiang et al., 2020; Soares et al., 2023; Zhou et al., 2016), revealing that PIU may be a valid predictor of individual executive function impairment and providing partial support for the I-PACE model and cognitive-behavioral model.

Interaction effect analysis further revealed that different PIU types may have distinct mechanisms affecting executive function. IGD primarily affects individuals' inhibitory control and cognitive flexibility. The high immersion and immediate feedback characteristics of IGD may lead to overactivation of the brain' s reward system, affecting individuals' delay gratification capacity in real life and consequently impairing inhibitory control (Kuss & Griffiths, 2012). Additionally, IGD patients show impaired prefrontal cortex function (Meng et al., 2015), a region closely related to goal-directed and habitual control behaviors. Therefore, IGD patients' behavioral patterns may shift from goal-directed to habitual control, reducing their capacity to adapt to new situations (Zheng et al., 2019). This reduced adaptive capacity may explain IGD patients' poor performance on cognitive flexibility tasks. In contrast, PSMU primarily affects inhibitory control, possibly through mechanisms related to social pressure and information overload that weaken self-control capacity (Choi & Lim, 2016). PSMU effects may also relate to cognitive load, as continuous media multitasking requires constant attention switching, potentially impairing performance on tasks requiring sustained attention and consequently damaging inhibitory control (Ophir et al., 2009). Thus, although both IGD and PSMU affect inhibitory control, IGD' s impact on cognitive flexibility suggests more complex interference with executive functions. This study found significant differences between working memory and inhibitory control and between working memory and cognitive flexibility in IGD patients, indicating a specific pattern of IGD effects on these executive function components, possibly related to working memory resource depletion (Ngetich et al., 2023).

Furthermore, significant heterogeneity existed in the main effects of this meta-analysis, suggesting that main effects should not be viewed in isolation (Harrer et al., 2022) and requiring examination of moderating factors.

Significant Moderating Effect of Executive Function Components

The research hypothesis was supported, with results indicating that executive function components significantly influenced effect size heterogeneity. Specifically, problematic internet users performed worse on working memory tasks compared to inhibitory control and cognitive flexibility. Working memory plays a central role in cognitive processes, participating in most cognitive tasks (Baddeley, 2000; Engle, 2002). Problematic internet users facing massive information and multitasking demands frequently experience increased cognitive load and attentional distraction, leading to working memory impairment (Uncapher & Wagner, 2018). According to Baddeley' s (2000) working memory model, working memory impairment may affect multiple subsystems including the central executive, phonological loop, visuospatial sketchpad, and episodic buffer. Although inhibitory control and cognitive flexibility also depend on the central executive system (Baddeley & Hitch, 1994; Diamond, 2013), these tasks are typically more specialized, whereas working memory performance can predict multiple cognitive tasks (such as Stroop and Wisconsin Card Sorting tasks; Engle, 2002). Therefore, working memory impairment in problematic internet users may be more pronounced than impairments in inhibitory control and cognitive flexibility. Regarding inhibitory control, our results align with many previous studies showing that problematic internet users have poorer inhibitory control than healthy individuals (Chen et al., 2021; Cudo et al., 2023). This may relate to reduced prefrontal cortex function, a region critical for impulse control and suppressing inappropriate behaviors (Ko et al., 2014; Kuss et al., 2018). The internet' s immediate feedback and reward mechanisms weaken individuals' delay gratification capacity, making it difficult to suppress impulsive behaviors when facing immediate temptations (Savci & Aysan, 2017). Additionally, the compensatory internet use model suggests that individuals may turn to the internet for psychological relief from real-life stress, which is associated with poorer inhibitory control (Kardefelt-Winther, 2014). Notably, previous empirical research on cognitive flexibility in PIU patients has shown inconsistent results, including significant impairment (Jiang et al., 2020) and nonsignificant impairment (Chen & Hsieh, 2018). These complex results suggest potential boundary conditions. First, the diversity of internet content means users must adapt to various tasks and contexts, and prolonged internet use in multitasking environments may train individuals' capacity to switch between tasks quickly, with significant positive correlations found between higher cognitive flexibility and enhanced media multitasking ability (Seddon et al., 2021). Second, cognitive flexibility is a multidimensional concept encompassing multiple subcomponents and forms of flexibility (Diamond, 2013). Different studies employ different assessment tasks and indicators that may have varying weights and sensitivities in measuring different components of cognitive flexibility (Monsell, 2003), further increasing diversity in research findings.

Contrary to our hypotheses, the moderating effects of gender, age, and culture were not significant, indicating that executive function performance in PIU patients is relatively stable across these dimensions. Additionally, this meta-analysis found no moderating effect of PIU type, possibly because problematic technology use behaviors overlap to some extent (Marino et al., 2021). Regardless of PIU type, these behaviors share common features of attentional distraction (Marin et al., 2021) that may produce similar negative effects on brain executive functions without significant differences in psychological and neurobiological mechanisms. Notably, material specificity did not significantly moderate the relationship between variables, possibly because PIU patients show broad executive function deficits that manifest not only with addiction-related materials (Cudo et al., 2023; Zhou et al., 2012) but also with general materials (Firoozabadi et al., 2023).

Limitations and Future Directions

This study has several limitations: (1) Since individual studies included multiple outcome variables, multivariate meta-analysis would theoretically be more appropriate. However, limited by the lack of correlation coefficients among outcome variables in original publications, this study employed three-level meta-analysis as an alternative approach. Previous research using both analytical methods on the same dataset found minimal differences, and Assink and Wibbelink (2024) noted that these differences have negligible impact on clinical practice regarding overall effect size and precision estimation. Nevertheless, we must interpret results cautiously, recognizing that these subtle differences may have limited practical impact but cannot be ignored in statistical analysis. (2) Only cross-sectional studies were included, limiting interpretation of the directional relationship between PIU and executive function. PIU may be a predictor of executive function impairment or a consequence of pre-existing executive function deficits (Anderson et al., 2017). Future research should employ cross-lagged designs to explore the causal direction of this relationship. (3) Beyond executive function components, PIU patients' executive function performance may be moderated by other variables such as self-esteem (Pichardo et al., 2021), COMT haplotypes (Ioannidis et al., 2020), and affective states and stress (He & Li, 2022). Future studies should examine these moderators to deepen understanding of the underlying mechanisms of differential executive function performance in PIU patients. (4) Based on research focus, operational feasibility, sample characteristics, and existing literature, this study only included IGD and PSMU as specific PIU types. Future research should expand the scope and enrich sample diversity.

Conclusion

This study employed a three-level meta-analytic model to quantitatively synthesize available data, deepening our understanding of executive function performance in PIU patients. Results demonstrated that the PIU group exhibited significantly poorer executive function performance than the healthy control group, suggesting that PIU may be a valid predictor of individual executive function impairment. Further analysis revealed that PIU patients' executive function performance differed across components, with working memory showing the most severe impairment, along with significant impairments in inhibitory control and cognitive flexibility. Notably, an alternative explanation for the finding that PIU patients performed significantly worse than healthy controls is that individuals with poorer executive function may be more susceptible to developing and maintaining PIU—that is, executive function deficits may be a predisposing factor for PIU onset and maintenance. This issue warrants further investigation in future longitudinal research designs.

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Note: Figure translations are in progress. See original paper for figures.