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Compulsivity-related behavioral features of problematic usage of the internet: A scoping review of paradigms, progress, and perspectives

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REVIEW ARTICLE

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ABSTRACT

Background and aims: Compulsivity contributes to the development and maintenance of multiple addictive disorders. However, the relationship between compulsivity-related cognitive features and problematic usage of the internet (PUI), an umbrella term for various internet use disorders/interfering behaviors, remains largely unclear, partly due to the multidimensional nature of compulsivity. This scoping review utilized a four-domain framework of compulsivity to consider this topic and aimed to summarize available evidence on compulsivity-related neuropsychological characteristics in PUI based on this framework. *Methods:* A systematic literature search was conducted by applying the combination of search term to the search engines of PubMed, PsycINFO and Web of Science. A four-domain framework of compulsivity, involving cognitive flexibility, set-shifting, attentional bias, and habit learning, was used to consider its complex structure and frequently used tasks. Main findings in related PUI studies were summarized based on this framework. Our secondary aim was to compare compulsivity-related features between different PUI sub-types. *Results:* Thirty-four empirical studies were retained, comprising 41 task-results and 35 independent data sets. Overall, individuals with PUI showed more consistent deficits in attentional biases and were relatively intact in set-shifting. Few studies have examined cognitive flexibility and habit learning, and more evidence is thus needed to establish reliable conclusions. Moreover, most studies focused on internet gaming disorder, whereas other PUI sub-types were not sufficiently examined. *Conclusion:* This systematic review highlights the use of the four-domain framework for advancing understanding of mechanisms underlying compulsivity in PUI. Related therapeutic implications and future directions are discussed.

KEYWORDS

addictive behaviors, compulsivity, problematic usage of the internet, internet gaming disorder, cognitive flexibility, attentional bias

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INTRODUCTION

Problematic usage of the internet (PUI), conceptualized as excessive online activity associated with marked functional impairment and addictive, impulsive and/or compulsive features, has been recognized as a global public health problem (Fineberg et al., 2018, 2022). The umbrella term PUI encompasses multiple potential problematic internet-related behaviors, such as gaming, pornography viewing, and social networking (Brand et al., 2019). In light of increasing incidence and research, the DSM-5 and ICD-11 have recognized internet gaming disorder (IGD), a major subtype of PUI, as a non-substance (behavioral) addiction. Recently, PUI has received more attention during the COVID-19 pandemic, as individuals utilized the internet for more aspects of daily life during this period (Fineberg et al., 2022). Because of the high frequency of internet use, increasingly more people may be automatically approaching internet activities, even without clear goals in some situations (van Deursen, Bolle, Hegner, & Kommers, 2015). However, the relationships between these automatic and repetitive actions and PUI remain poorly understood (Kim et al., 2017).

Excessive and habitual internet use may be closely related to compulsivity, which may be defined as the tendency to engage in "repetitive and functionally impairing overt or covert behavior without [apparent] adaptive function, performed in a habitual or stereotyped fashion, according to rigid rules or as a means of avoiding perceived negative consequences" (Fineberg et al., 2014; van Timmeren, Daams, van Holst, & Goudriaan, 2018). Importantly, compulsivity has been included in the Research Domain Criteria (RDoC) framework as a transdiagnostic construct that is common to multiple psychiatric disorders (Insel et al., 2010). For both substance use disorders (SUDs) and behavioral addictions, addictive disorders have been proposed as the endpoint of a behavioral transition from initial goal-directed approach to eventual automatic and compulsive addictive behaviors (Everitt & Robbins, 2016; Robbins, Gillan, Smith, de Wit, & Ersche, 2012). Previous cue-reactivity fMRI studies have identified the brain regions involved in transitions across addictions (Liu et al., 2017), suggesting the involvement of compulsivity. Furthermore, questionnaires assessing internet addiction have identified internet-related compulsive behaviors in PUI populations (Demetrovics, van den Brink, Paksi, Horvath, & Maraz, 2022; Fineberg et al., 2022), echoing the syndrome of persistent and poorly controlled online activity regardless of negative consequences (Kuss, Griffiths, Karila, & Billieux, 2014; Petry et al., 2014). Thus, elucidating the cognitive mechanisms underlying compulsivity may not only advance our understanding of PUI as a set of internet-related addictions or other psychiatric conditions (e.g., related to obsessive-compulsive disorder), but also provide crucial information for the development of tailored interventions for PUI.

Compulsivity as a neuropsychological construct, with its behavioral underpinnings of inflexibility, rigidity and poor self-control, has been described in individuals with SUDs (Leeman & Potenza, 2012) and gambling disorder (van Timmeren et al., 2018). Although an increasing number of studies have investigated compulsive behaviors in individuals with PUI, most previous research has explicitly assessed compulsivity using self-report questionnaires, and this situation largely limits a mechanistic explanation of the cognitive processes underlying compulsive behaviors. On the other hand, some behavioral studies have used experimental tasks (e.g., probability learning task, set-shifting task) to compare the performance between individuals with and without PUI; however, these studies have rarely discussed their findings in the context of compulsivity. A major barrier to progress in this area is the complex construct of compulsivity and its ambiguous definition in most theoretical models of PUI (Yücel & Fontenelle, 2012). Indeed, previous studies have demonstrated that compulsivity is not a unidimensional construct. Rather, compulsivity may include at least four major components, including cognitive flexibility, set-shifting, habitual behaviors, and attentional bias (Carr, Wiedemann, Macdonald-Gagnon, & Potenza, 2021; Fineberg et al., 2014; Lee, Hoppenbrouwers, & Franken, 2019; van Timmeren et al., 2018). Thus, this four-component framework provides a suitable approach to systematically classify and summarize compulsivity-related findings in PUI.

Specifically, the four-component framework proposes that different aspects of compulsivity can be operationalized by different neurocognitive tasks (Table 1). For example,

Table 1. Domains of compulsivity in PUI

Neurocognitive domains	Definition	Tasks	Number of studies
Contingency-related cognitive flexibility	Difficulties adaptating behavior after negative feedback (devaluation or degradation of the outcome)	Probabilistic reversal learning task Deterministic reversal learning task Contingency learning task Contingency degradation task	3
Set-shifting	Difficulties frequently switching among a set of rules or response modes	Wisconsin card sorting task Intra-extra dimensional set shift Trail Making Task Switch task	13
Attentional bias/attentional disengagement	Difficulties with attentional engagement or disengagement to prepotent disorder-relevant stimuli	Dot probe task Addiction Stroop task Addiction Go/No-Go task	17
Habit learning	Limited sensitivity to goals or outcomes of actions (an imbalance between goal-directed and habitual behavior)	Two-step decision task Fabulous fruit game Devaluation task	3

cognitive flexibility is usually measured by tasks that require participants to adapt to changing rules or environments. A representative example is reversal learning task in which the best option is not fixed, and participants need to learn related information by trial and error (Izquierdo & Jentsch, 2012). Set shifting is mainly related to attentional switching between (neutral) stimuli and can be measured by tasks that rely on switching ability (e.g., Wisconsin card sorting task) (van Timmeren et al., 2018). Attentional bias, on the other hand, focuses on the hypersensitivity to salient (often addiction-related) stimuli (Field & Cox, 2008). Therefore, this process can be evaluated by tasks involving the inhibition of prepotent and automatic responses (e.g., addiction-related Stroop task). Finally, habit learning refers to the establishment of engrained/automatic over goal-directed behaviors (Vandaele & Ahmed, 2021). A classic paradigm that has been used to disentangle habitual and goal-directed behaviors during learning is the sequential two-step task (Daw, Gershman, Seymour, Dayan, & Dolan, 2011). While these tasks may assess features of compulsivity, they may also overlap with other constructs (e.g., impulsivity), and this may in part explain why some groups score high on measures of both compulsivity and impulsivity (Fineberg et al., 2014; van Timmeren et al., 2018).

In the current study, we aimed to comprehensively review previous behavioral studies that investigated compulsivity in individuals with PUI. As a wide range of tasks may be used to explore distinct parts of compulsivity, we employed the four-domain framework from the compulsivity literature to facilitate the classification of related tasks (Fineberg et al., 2014). Therefore, rather than treating compulsivity as a unidimensional construct, we examined the relationship between the four defined neurocognitive components and PUI. Finally, although the current study was not restricted to specific subtypes of PUI, most studies have focused on IGD. Since different subtypes of PUI may involve different psychopathological mechanisms, if applicable, we additionally explored the compulsivity-related differences between IGD and other subtypes of PUI.

METHODS

Information sources and search strategy

A scoping review was conducted to clarify the framework of compulsivity and to map available evidence (Munn et al., 2018; Peters et al., 2015). This review was performed in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2015). The literature search was conducted to compile existing evidence regarding the four neuropsychological components of compulsivity in PUI. Different types of PUI were considered based on their documented prevalence and psychosocial correlates (Castro-Calvo et al., 2021; Fineberg et al., 2022). Specifically, problematic online activities were selected with the restriction that the problematic usage of the particular online activity (1) was well defined and studied; (2) was identified with addictive, impulsive or compulsive features; (3) was identified with considerable prevalence estimates; (4) was mainly for entertainment and relief, largely consistent with prior descriptions of possible internet use disorders(Müller et al., 2022). However, gambling was omitted given that most studies did not distinguish between online and offline betting and smartphone use was included given that it appeared to fit the four criteria. Therefore, five subtypes of PUI were included: (1) internet gaming, (2) social media use, (3) smartphone use, (4) online shopping, and (5) internet pornography.

Relevant peer-reviewed studies (January 2000 – February 2024) published in English were identified via search engines of PubMed, PsycINFO and Web of Science by using the search terms in the Title and Abstract: (addict* OR excessive OR problematic OR pathologic* OR disorder) AND (internet OR computer OR ‘internet use’ OR ‘online gaming’ OR game OR gaming OR ‘smartphone use’ OR ‘social media use’ OR social network* OR ‘online shopping’ OR ‘online buying’ OR ‘internet pornography’) AND (compulsive OR compulsion OR habit* OR ‘cognitive flexibility’ OR ‘reversal learning’ OR ‘card playing task’ OR ‘probabilistic learning’ OR ‘set shifting’ OR ‘intra-extra dimensional’ OR ‘Wisconsin card sorting’ OR ‘trail making’ OR ‘rule shift card’ OR ‘dot-probe’ OR ‘Stroop task’ OR ‘go/no-go task’ OR ‘attentional bias’ OR ‘attentional disengagement’ OR fruit game OR ‘slips of action’ OR ‘instrumental learning’ OR ‘habit learning’ OR ‘reinforcement learning’ OR ‘two-step decision’ OR ‘two-stage task’ OR ‘model-based’ OR ‘model-free’ OR ‘goal-directed’ OR ‘sequential decision’ OR ‘sequential learning’ OR ‘contingency learning’ OR perseveration OR devaluation OR ‘contingency degradation’).

Studies were eligible if they: (1) were original peer-reviewed articles in humans; (2) included at least one PUI group screened according to predefined criteria (e.g., DSM-5-defined IGD, Young Internet Addiction Test (YIAT), Chen Internet Addiction Scale (CIAS), or other PUI scales); (3) included a healthy control group; (4) used at least one experimental task related to one of the four components of compulsivity (Table 1; Fig. 1); and, (5) compared compulsive behaviors between PUI and control groups. In addition, as the current study focused on the neuropsychological/behavioral features of compulsivity, studies that only used questionnaires to assess compulsivity in PUI were not included.

Study selection

The titles and abstracts of all identified studies were independently screened by two researchers (L.L. and Y.W.Y.). The selected studies were read in full to ensure all inclusion criteria were met. Discrepancies in these steps were resolved by consensus among the authors.

Data extraction and study quality

Data extraction included: (1) demographic and clinical characteristics (e.g., sample sizes, age, and diagnostic

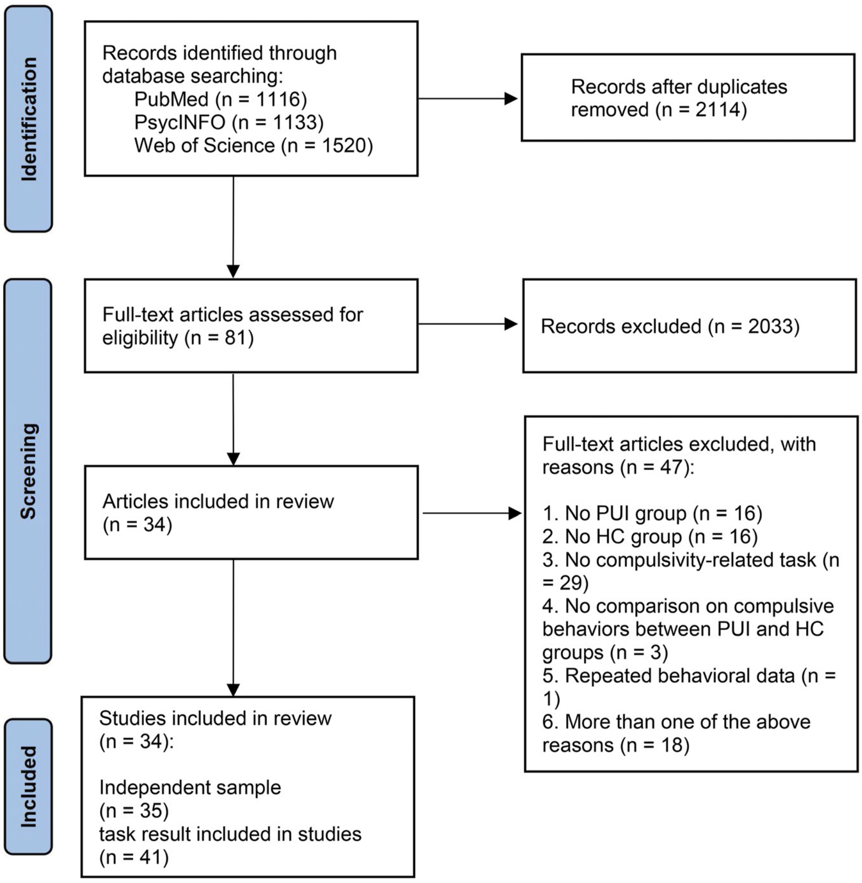

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram. PUI = problematic usage of the internet; HC = healthy control

tools); (2) neuropsychological measurements and primary related dependent variables, and (3) main results. The selected variables for the included studies are listed in Tables 2–5.

Study quality and risk of bias were assessed using the Newcastle-Ottawa-Scale (NOS; http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp) checklist for case-control studies (Wells et al., 2000; Zeng et al., 2015). The NOS makes judgement of identified studies on three criteria: the selection (max. 4 points), the comparability (max. 2 points), and the exposure ascertainment (max. 3 points), resulting in a quality score ranging from 0 to 9. Two raters (the first and second authors) assessed each study independently and then discussed together to resolve discrepancies. Most studies performed well on the checklist items, except for the item of blinded exposure assessment, as almost all studies omitted to report this. Moreover, blinding is not applicable for most case-control studies. Thirty-one of the thirty-four assessed studies had scores between 7 and 9, and the rest three studies scored 5–6 (Table S1 in the Supplementary Materials).

Ethics

The study was approved by the Institutional Review Board of the Department of Psychology, Sun Yat-sen University.

RESULTS

Identified studies

The initial search identified 2,114 unique studies, of which 34 studies representing 35 unique samples met inclusion criteria. The PRISMA flow diagram illustrates the study selection process (Fig. 1). Study descriptions and behavioral findings are summarized in Tables 2–5. The 34 studies included 41 task results (n = 1,161 individuals with PUI and n = 1,267 healthy control participants). In the following sections, we describe commonly used tasks and main findings related to each within the four-component framework for compulsivity (Tables 2–5; Fig. 2).

Neurocognition of compulsivity

Cognitive flexibility. Contingency-related cognitive flexibility describes the learning process of a rule and the adaptation of behavior after changes of the rule according to the feedback (e.g., devaluation or degradation of an outcome) (Fineberg et al., 2014). If individuals are not sensitive to outcomes associated with stimulus-response or to stimulus-outcome contingencies, they would show rigid adherence (perseveration) to rules or strategies when they change in these tasks. Two tasks were frequently used to

Table 2. Overview of included studies within the contingency-related cognitive flexibility domain

Tasks	Author(s)	Population (PUI/HC)	Mean age (SD)	Diagnosis	DVs	Major findings	Summary	Comorbidity control
PRLT	Banca et al. (2016)	IGD = 26; HC = 52	IGD = 24.69 (5.90); HC = 22.91 (4.73)	DSM-IV[a]	trials to criterion; lose-shift/win-stay	1. IGD group took more trials to reach reversal criterion in the reversal phase; 2. No significant group difference of trials to criterion in the acquisition phase; 3. No significant group difference in lose-shift or win-stay.	IGD < HC	No
PRLT	Raj et al. (2023)	PUI = 52; HC = 38;	PUI = 22.80 (4.25); HC = 22.07 (3.61)	IAT-10[b] ≥ 30	perseverative errors	1. The PIU group showed more perseverative errors compared to HCs; 2. The perseverative errors significantly statistically predicted the likelihood of an individual experiencing PUI	PIU < HC	Yes (MINI)
Probability learning	Lei et al. (2022)	IGD = 45; HC = 42	IGD = 20.82 (1.37); HC = 21.29 (1.52)	DSM-5 ≥ 5;	discrimination accuracy	No significant group difference in accuracy; 2. IGD showed blunted RPE signals in the caudate, OFC and DLPFC	IGD = HC	No

Note. DLFPC = dorsolateral prefrontal cortex; DSM = diagnostic and statistical manual of mental disorders; DV = dependent variable; HC = healthy controls; IGD = internet gaming disorder; MINI = the mini international psychiatric interview; OFC = orbitofrontal cortex; PUI = problematic usage of the internet; RPE = reward prediction error; PRLT = probabilistic reversal learning task; SD = standard deviation.

Note: a, adapted criteria of DSM-IV Pathological Gambling; b, the 10-item abbreviated version of Young's Internet Addiction Test (IAT-10).

measure this component: the probabilistic reversal learning task and contingency learning task.

Probabilistic reversal learning task. The probabilistic reversal learning task (PRLT) involves rule acquisition and rule reversal, which usually refers to reward (and loss) schedules changes (Banca, Harrison, & Voon, 2016; Fineberg et al., 2014). This task typically includes at least two phases with opposite rules, which are separated by a reversal point (see Box 1A in the Supplementary Information). For example, one stimulus in the learning phase is more advantageous (e.g., 80% winning probability) than the other one (e.g., 20% winning probability). Participants need to learn which stimulus is better by trial and error. In the reversal phase, the stimulus-reward mapping is switched. Participants should therefore adjust their behavior according to rule/environmental changes. Perseveration can be reflected in the number/ratio of correct choices after a rule change. Persevering with a response that was once rewarded but is later associated with negative consequences may reflect a lack of flexibility in learning and may thus reflect compulsive behavior (Fineberg et al., 2014).

Only two studies were identified that investigated cognitive flexibility with the PRLT in individuals with IGD (Table 2). One study found that the IGD group required more trials to learn the changed rule in the reversal phase, suggesting that individuals with IGD were likely to stick to a previously established strategy in pursuit of a reward, even when such strategy is no longer optimal due to the environmental changes (Banca et al., 2016). Importantly, the IGD group showed a similar performance to the HC group in the acquisition phase, suggesting that the perseveration observed in the reversal phase may not be driven by reward-related learning dysfunction. The other recent study also reported higher perseverative errors in the PUI group, and perseverative errors and self-reported compulsivity may significantly predict the likelihood of experiencing PUI (Raj, Segrave, Verdéjo-Garcia, & Yücel, 2023).

A related study applied a reward-related learning task with the rule change in between (Lei et al., 2022). However, instead of directly switching the rule, this task included a deterministic learning phase and a probabilistic test (contingency degradation) phase to create and measure prediction errors. The study reported no significant group differences in response accuracy (the number of correct choices) in the rule-changed phase. Despite null results at the behavioral level, this study involved fMRI scanning and identified blunted reward prediction-error signals in the caudate, orbitofrontal cortex (OFC), and dorsolateral prefrontal cortex (DLPFC), brain regions involved in reward processing and decision-making (Lei et al., 2022).

Task/attentional set-shifting. Task set-shifting involves the ability to frequently switch among settings of a task. This requires discrimination, attention maintenance and shifting on various dimensions of stimuli, and thus compulsivity may be linked to set-shifting. Three tasks were included

Table 3. Overview of included studies within the attentional/set-shifting domain

Tasks	Author(s)	Population (PUI/HC)	Mean age (SD)	Diagnosis	DVs	Major findings	Summary	Comorbidity control
Wisconsin card sorting test								
WCST	Aydin et al. (2020)	PSNSU = 100; HC = 140	PSNSU = 22.16 (3.50); HC = 23.42 (5.19)	BSMAS ≥19	perseverative errors; number of category completed	No significant group differences in both the perseverative errors and the numbers of categories completed	PSNSU = HC	No
WCST	Firoozabadi, Razavian, Saleh, and Hosseini (2023)	PUI at-risk = 30; PUI = 12; HC = 117	PUI at-risk = 22.59 (3.83); PUI = 24.17 (4.38); HC = 26.17 (9.03)	IA at-risk: YIAT 50–79; IA: YIAT 80–100	perseverative errors	No significant group differences in perseverative errors between IA and HC groups, nor between IA at-risk and HC groups.	IA = HC; IA at-risk = HC	Yes (self-report)
WCST	Han et al. (2016)	IGD-only = 60; IGD-MDD = 35; HC = 42	IGD-only = 20.20 (3.20); IGD-MDD = 20.50 (3.30); HC = 20.2 (2.90)	YIAT >50	perseverative responses; perseverative errors	IGD + MDD group had more perseverative responses and perseverative errors compared to the IGD-only and HC groups; 2. No significant group difference in both perseverative responses and perseverative errors	IGD-MDD < HC; IGD-MDD < IGD-only; IGD-only = HC	Yes (DSM-IV; BDI, BAI)
WCST	Kuo et al. (2018)	IA child = 35; HC = 39	IA = 11.60 (0.5); HC = 11.3(0.7)	CIAS> 85%	total errors; preservative responses; preservative errors	The IA group had more total errors, preservative responses, and preservative errors	IA < HC	No
WCST	Zhou et al. (2014)	IA = 22; HC = 22	IA = 28 (7); HC = 28 (7)	YDQ	total errors; perseverative errors; number of categories completed	1. The IAD group showed more total errors, perseverative errors; 2. The IAD group completed fewer categories than the HC group	IA < HC	Yes (DSM-IV)
WCST	Zhou et al. (2016)	IAD = 23; HC = 23	IA = 29 (7); HC = 28 (6)	YDQ	total errors; perseverative errors; number of categories completed	1. The IAD group showed more total errors, perseverative errors; 2. The IAD group showed decreased number of categories completed than HC group	IA < HC	Yes (DSM-IV)
Intra-extra dimensional set shift								
IED	Banca et al. (2016)	IGD = 24; HC = 36	N/A	DSM-IV[a]	extra-dimensional shift errors	No significant group difference in extra-dimensional shift errors	IGD = HC	No
IED	Chamberlain, Ioannidis, and Grant (2018)	PUI-only = 18; comp PUI = 37; HC = 67	PUI-only = 22.8 (3.0); comp PUI = 24.1 (3.7); HC = 22.4 (3.7)	YDQ ≥4	adjusted IED total errors	1. No significant group difference in adjusted IED total errors	PUI-only = comp PIU = HC	Yes (MINI)

(continued)

Table 3. Continued

Tasks	Author(s)	Population (PUI/HC)	Mean age (SD)	Diagnosis	DVs	Major findings	Summary	Comorbidity control
IED	Choi, Kim et al. (2014)	IGD = 15; HC = 15	IGD = 20.80 (5.09); HC = 25.33 (5.30)	DSM-5 ≥ 5; YIAT ≥70	IED total errors; IED total trials completed	No significant group differences in IED total errors and IED total trials completed	IGD = HC	
IED	Choi, Park et al. (2014)	IA = 23; HC = 24	IA = 23.22 (3.44); HC = 22.42 (2.47)	YIAT ≥70	IED total errors	No significant group difference in IED total errors	IA = HC	Yes (DSM-IV)
IED	Kim et al. (2017)	IGD = 86; HC = 77	IGD = 21.54 (6.91); HC = 22.84 (5.67)	DSM-5 ≥ 5;	IED total errors; IED total trials completed	The IGD group showed worse performance than the AUD group in IED total trials completed; 2. No significant group difference in IED total trials completed	IGD < AUD; IGD = HC	Yes (DSM-IV)
IED	Lim et al. (2016)	IGD = 44; HC = 40	IGD = 19.16 (5.22); HC = 21.38 (6.31)	DSM-5 ≥ 5; YIAT ≥70	IED total errors; IED total trials completed	No significant group differences in IED total errors and total trials completed	IGD = HC	Yes (DSM-IV, BDI, BAI)
Trail making task								
TMT	Choi, Kim et al. (2014)	IGD = 15; HC = 15	IGD = 20.80 (5.09); HC = 25.33 (5.30)	DSM-5 ≥ 5; YIAT ≥70	TMT-B completion time	No significant group differences in TMT-B completion time	IGD = HC	
TMT	Choi, Park et al. (2014)	IA = 23; HC = 24	IA = 23.22 (3.44); HC = 22.42 (2.47)	YIAT ≥70	TMT-B completion time	No significant group differences in TMT-B completion time	IA = HC	Yes (DSM-IV)
TMT	Tekin et al. (2018)	IA = 30; HC = 29	IA = 26.93; HC = 33.17	YIAT ≥81	TMT-B error number; TMT-B completion time	The IA group showed higher TMT-B form time than the HC group; 2. The IA group performed worse on TMT-B error numbers than HCs	IA > HC	Yes (self-report)
TMT	Lim et al. (2016)	IGD = 44; HC = 40	IGD = 19.16 (5.22); HC = 21.38 (6.31)	DSM-5 ≥ 5; YIAT ≥70	TMT-B completion time	No group differences in TMT-B completion time; 2. A short TMT-B completion time at baseline statistically predicted good prognosis for treatment of IGD	IGD = HC	Yes (DSM-IV, BDI, BAI)

Note: AUD = alcohol use disorder; BAI = Beck Anxiety Inventory; BDI = Beck Depression Inventory; BSMAS = Bergen social media addiction scale; CIAS = Chen internet addiction scale; IA = internet addiction; IAD = internet addiction disorder; IED = intra-extra dimensional set shift; MDD = major depressive disorder; PUI = problematic usage of the internet; PSNSU = problematic social networking sites use; TMT = trail making task; YDQ = Young's diagnostic questionnaire; WCST = Wisconsin card sorting test; YIAT = Young's internet addiction test.
Note: a, criteria adapted from DSM-IV pathological gambling criteria.

Table 4. Overview of included studies within the attentional bias/disengagement domain

Tasks	Author(s)	Population (PUI/HC)	Mean age (SD)	Diagnosis	DVs	Major findings	Summary	Comorbidity control
Dot probe task								
DPT	He, Zheng, Nie, and Zhou (2018)	IA = 15; HC = 15	IA = 20.80 (1.01); HC = 20.87 (1.06)	YIAT ≥80	RT; accuracy[a]	The IA group had shorter RTs in congruent conditions and longer RTs in incongruent conditions; 2. The IA group showed significantly longer RTs in incongruent vs congruent conditions	AB (RT): IA > HC	No
DPT	Jeromin, Nyenhuis, et al. (2016)	IGD = 21; HC = 30	IGD = 22.9 (2.1); HC = 24.5(3.2)	CIUS	RT; accuracy[a]	Significant interaction of group by picture-type in accuracy: IGD made more errors with computer-related pictures than with neutral pictures; 2. The IGD group had shorter RTs in general; 3. No significant group by picture-type interaction effect in RTs	AB (accuracy): IGD < HC	No
DPT	Jiang et al. (2017)	OSA high = 27; OSA low = 28	N/A	OSA-high >62; OSA-low <46	RT[b]	No significant main effects of group and congruent condition, nor interaction effect of group by congruent condition	OSA high = OSA low	Yes (self-report)
DPT	Liu et al. (2023)	PSU = 22; HC = 25	PSU = 20.72 (1.48); HC = 21.32 (2.28)	SAS-SV > 33 for females; SAS-SV > 31 for males	fixation time; RT[b]	1. First fixation duration on smartphone icon stimuli was significantly longer than that on neutral stimuli in the PSU group; 2. no significant interaction effect of congruency by group.	PSU > HC	No
DPT	Lorenz et al. (2013)	IGD = 8; HC = 9	IGD = 25 (7.4); HC = 24.8 (6.9)	ICD-10[c]	RT[b]	Significant interaction effect of congruency by group: PCGPs, but not HCs, showed longer RTs in incongruent trails than congruent trails	AB: IGD > HC (RT)	Yes (DSM-IV)
DPT	Nikolaidou, Fraser, and Hinvest (2019)	PSNSU = 16; HC = 24	PSNSU = 19.25 (1.39); HC = 20.92 (2.90)	AEQ ≥4	gazing dell time	The PSNSU group spent more time looking at SNS pictures than control pictures; 2. The PSNSU group spent less time looking at control pictures compared to the HC group	AB: PSNSU > HC	No

(continued)

Table 4. Continued

Tasks	Author(s)	Population (PUI/HC)	Mean age (SD)	Diagnosis	DVs	Major findings	Summary	Comorbidity control
DPT	Wang and Huang (2022)	PIPU high = 40; PIPU low = 40	PIPU = 19.80 (1.83); HC = 19.58 (1.72)	Median of PIPUS	engagement RT; disengagement RT[d]	The PIPU group showed enhanced engagement RTs for pornographic stimuli in short SOA; 2. HCs showed longer disengagement RTs for pornographic pictures than neutral ones in long SOA	engagement RT: PIPU > HC; disengagement RT: PIPU < HC	Yes (self-report)
DPT	Zhao et al. (2022)	PSMU = 30; HC = 30	PSMU = 20.07 (1.70); HC = 19.33 (1.40)	BSMAS ≥24	RT[b]	A significant interaction effect of group by word type: the PSMU group displayed AB toward social media-related cues; the PSMU group reacted faster to the congruent condition than to the incongruent condition; the PSMU group responded faster to congruent trials than the HC group; Whole sample, AB toward SM-related stimuli positively correlated with the severity of PSMU	AB: PSMU > HC	Yes (clinical interview)
DPT	Zhou, Zhou, Zhou, Shen, and Zhang (2022)	IGD = 30; HC = 32	IGD = 19.17 (1.26); HC = 19.03 (0.86)	DSM-5 ≥ 5; YIAT ≥50	RT[d]; accuracy	The IGD group showed higher attentional disengagement bias compared to HCs; No significant group difference in terms of attentional engagement bias; 3. No significant group differences in terms of accuracy.	IGD > HC (RT disengage)	No
Addiction Stroop task								
Stroop	Jeromin, Nyenhuis, et al. (2016)	IGD = 21; HC = 30	IGD = 22.90 (2.10); HC = 24.50 (3.20)	CIUS	RT[e]; accuracy[e]	The IGD group showed longer reaction times to computer-related words; 2. The IGD group made more errors with computer-related pictures than with neutral pictures	IGD > HC (RT)	No
Stroop	Jeromin, Rief, et al. (2016)	IGD = 27; HC = 27	IGD = 24.90 (7.40); HC = 31.20 (7.70)	CIUS ≥29	RT[e]; accuracy[e]	No significant group nor group-by-word-type interaction effects in RT and accuracy on the Stroop	IGD = HC	No

(continued)

Table 4. Continued

Tasks	Author(s)	Population (PUI/HC)	Mean age (SD)	Diagnosis	DVs	Major findings	Summary	Comorbidity control
Stroop	Jeromin, Rief, et al. (2016)	IGD = 29; HC = 29	IGD = 25.20 (5.30); HC = 23.50 (4.90)	IGDQ ≥5;	RT[e]; accuracy[e]	Addiction Stroop: no significant group main effect nor group-by-congruence-condition interaction effects in RT and accuracy; Classical Stroop: no significant group main effect nor group-by-congruence-condition interaction effects in RT and accuracy	IGD = HC	No
Stroop	Metcalf and Pammer (2011)	IGD = 20; HC = 19	IGD = 21.25 (2.53); HC = 22.53 (2.93)	AEQ ≥4	RT[e]; accuracy[e]	A significant interaction between word type and group: (1) the IGD group had significant longer RTs to MMORPG and negative words compared to neutral words; (2) the HC group showed no difference in RTs between word types	IGD > HC	No
Stroop	Zhang et al. (2016)	IGD = 19; HC = 21	IGD = 22.2 (3.1); HC = 22.8 (2.4)	DSM-5 ≥ 5; YIAT ≥50	RT[e]; accuracy[e]	No significant group main effect nor interaction effect were found in accuracy and RT; 2. Greater brain activity in the IPL, dlPFC and MOG for AB in IGD compared to HC groups	IGD = HC	Yes (self-report)
Stroop	Zhao et al. (2022)	PSMU = 30; HC = 30	PSMU = 20.07 (1.70); HC = 19.33 (1.40)	BSMAS ≥24	RT[e]	No significant group main effect nor interaction effect in RTs	PSMU = HC	No
Stroop	Wang et al. (2018)	IGD = 18; HC = 19	IGD = 21.50 (2.01); HC = 22.26 (1.82)	DSM-5 ≥ 5; YIAT ≥50	RT[e]	No significant interaction effect in group by word-type; IGD subjects showed increased FC in the temporal gyrus, and reduced FC in the PCC and MFG	IGD = HC	Yes (MINI)
Addiction go/no-go task								
Go/no-go	Liu et al. (2014)	IGD = 11; HC = 11	IGD = 23.45 (2.34); HC = 22.45 (1.70)	DCIA-C	error rate of go trials; commission errors[f]	The IGD group made more commission errors than the HC group in the game-cue distraction condition; No significant group differences in the no distraction condition (with black background)	IGD > HC (errors)	Yes (MINI)

(continued)

Table 4. Continued

Tasks	Author(s)	Population (PUI/HC)	Mean age (SD)	Diagnosis	DVs	Major findings	Summary	Comorbidity control
Go/no-go	Gou, Yuan, Zhang, Tang, and Zhang (2023)	PSMUS = 37; HC = 41	PSMUS = 19.16 (0.83); HC = 19.34 (1.09)	PSMUS >50	error rate of go trials; commission errors[f]	1. The PSMU group made more commission errors than the HC group in addiction-relevant go/no-go task; 2. The PSMU group made more commission errors in addiction-relevant go/no-go task than neutral go/no-go task; 3. No significant group differences in neutral go/no-go task	PSMU > HC (errors)	Yes (self-report)
Go/no-go	Yao et al. (2015)	IGD = 34; HC = 32	IGD = 22.29 (2.07); HC = 22.47 (2.08)	CIAS ≥67	error rate of go trials; commission errors[f]; RT	IGD subjects made more commission errors compared to HCs	IGD > HC (errors)	Yes (self-report)

Note. AB = attentional bias; AEQ = addiction engagement questionnaire; AICA = assessment of internet and computer game addiction; BSMAS = Bergen social media addiction scale; CIUS = compulsive internet use scale; DCIA-C = diagnostic criteria for internet addiction for college students; DPT = dot probe task; IPL = inferior parietal lobule; MFG = middle frontal gyrus; MMORPG = massively multiplayer online role-playing gamers; MOG = middle occipital gyrus; OSAS = online shopping addiction scale; OSVe-S = self-report questionnaire for internet addiction-related behavior (skala zum onlinesuchtverhalten bei erwachsenen); PCC = posterior cingulate cortex; PIPUS = problematic internet pornography use scale; PSMU = problematic social media use; PSMUS = Problematic Social Media Use Scale; PSU = Problematic Smartphone Use; RT = reaction time; SAS-SV = Smartphone Addiction Scale-Short Version; SM = social media; YIAT = Young's internet addiction test.

a, accuracy in congruent vs incongruent trials; b, RTs of incongruent trials – RTs of congruent trials; c, a criteria adapted from ICD-10 the diagnostic criteria of substance addiction; d, engagement RT = [RTs neutral – pornographic stimuli] in congruent trials, disengagement RT = [RTs pornographic – neutral stimuli] in incongruent trials; e, RT and accuracy in addiction vs control trials; f, commission errors, error rate of No-Go trials.

Table 5. Overview of included studies within the habit learning domain

Tasks	Author(s)	Population (PUI/HC)	Mean age (SD)	Diagnosis	DVs	Major findings	Summary	Comorbidity control
Fabulous fruit task								
FFT	Zhou et al. (2018)	IA = 21; HC = 23	all = 18.73 (range 18–22)	CIAS ≥64	accuracy in the learning phase; accuracy in devalue tests	The IA group showed lower accuracy in the learning phase; The IA group showed lower accuracy in both outcome devaluation and S–R habit tests compared to HCs	IA < HC	Yes (clinical interview)
FFT	Zhou et al. (2021)	IGD = 25; HC = 25	IGD = 22.03 (2.24); HC = 21.51 (2.10)	DSM-5 ≥ 5; YIAT >50	accuracy in the learning phase; accuracy in devalue tests	The IGD group showed lower accuracy rate in the incongruent condition (IC score) in the learning phase; 2. In the IGD group, the IC score was positively correlated with the rsFC of PN-MFG	IGD < HC	Yes (MINI)
Feedback learning task								
FLT	Kim et al. (2017)	IGD = 18; HC = 20	IGD = 22.17 (2.00); HC = 21.20 (2.20)	IGADS >20%; YIAT ≥50	correct to stay rate	IGD showed decreased correct-stay rate with symbolic feedbacks in loss condition	IGD < HC	Yes (self-report)

Note: FFT = Fabulous fruit task; IGADS = internet game addiction diagnostic scale; PN = pulvinar nucleus; rsFC = resting-state functional connectivity.

in this domain: the Wisconsin card sorting, intra-extra dimensional set-shifting, and trail making tasks.

Wisconsin card sorting test. The Wisconsin card sorting test (WCST) is widely applied to assess set-shifting depending on rule changes (Heaton, 1993). In this task (see Box 1B in the Supplementary Materials), individuals sort cards according to one of the categorical rules (color, number, or form), with correct responses learned from the feedback provided after each response. After a certain number of correct responses, the rule changes and participants need to shift to a new approach for correctly sorting. The indices related to compulsivity include the number of classifications completed and the number of perseverative errors.

Six studies have assessed set-shifting in individuals with PUI using the WCST (Table 3). Three studies reported more perseverative errors on the WCST in the PUI group (Kuo et al., 2018; Zhou et al., 2014, 2016). One study in IGD participants with and without major depressive disorder (MDD) found that only the IGD-MDD group showed more perseverative errors compared to pure IGD and HC groups (Han, Kim, Bae, Renshaw, & Anderson, 2016). Another study involving people with problematic use of social media did not show significant between-group differences (Aydin, Obuća, Boz, & Ünal-Aydın, 2020).

Intra-extra dimensional set-shift. The intra-extra dimensional set-shifting (IED) task has also been used to examine set-shifting (Robbins et al., 1998). In the task, two stimuli (a correct and an incorrect one) are presented, and participants are asked to discriminate the correct one through the feedback. After a fixed number of correct trials, the rule is changed: the stimuli initially are composed of one dimension and the changes are intra-dimensional (i.e., from one shape to another shape). After a certain number of trials, the stimuli are composed of two dimensions (i.e., shapes and lines) and changes are extra-dimensional that requires shifting of attention to a previously irrelevant dimension (i.e., from shapes to lines). Test indices of interest include the number of stages completed and the total number of errors (the number of intra-dimensional errors and extra-dimensional errors). Most studies reported here consistently used the total number of errors. In addition, the IED task could distinguish between problems with set-shifting due to distraction (intra-dimensional set-shift) and problems with shifting from a previously learned rule (extra-dimensional set-shift) (Jazbec et al., 2007).

Six studies have examined set-shifting using the IED. None have found significant group differences between individuals with and without PUI (Table 3).

Trail making task. The trail making task (TMT) measures set-shifting between letters and numbers (Reitan & Reitan, 1992). This task instructs participants to connect a sequence of consecutive targets (e.g., letters or numbers) as quickly and accurately as possible. It includes two parts: in the first part (TMT-A), all targets are numbers, and

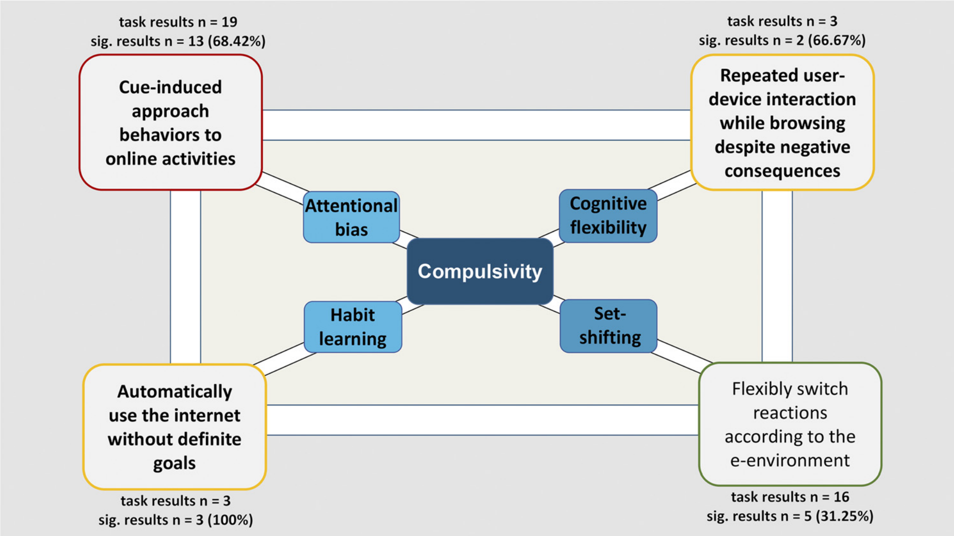

Fig. 2. Structure of compulsivity and compulsive behaviors in PUI. Schematic representation of compulsive online behaviors in PUI and the corresponding relationships with the four-domain compulsivity framework. Individuals with PUI have consistently shown a greater attentional bias to addition-related stimuli, whereas set-shifting seems to be relatively intact. As few studies have shown deficits in contingency-related cognitive flexibility and habit learning, more studies are still required. The red, yellow, or green frame indicates that the corresponding domain is altered, ambiguous, or intact in PUI, respectively. The total number of results from the studies and the percentage of significant results for each domain are shown in the margin

participants need to connect the numbers in sequential order; in the second part (TMT-B), both letters and numbers are targets, and participants are asked to sequentially connect those in alternating order (e.g., 1, A, 2, B, etc.). This requires inhibition of the automatic inclination to order numbers or letters separately (e.g., 1, 2, 3, or A, B, C). Test indices include errors and completion time of the TMT-B after controlling for individual differences in completion the TMT-A.

Only one of the four studies that applied the TMT found that the PUI group took more time to complete the TMT-B trials and showed more TMT-B errors compared to the healthy control (HC) group (Tekin, Yetkin, Adiguzel, & Akman, 2018). In addition, one study that examined intervention effects for IGD reported that shorter TMT-B completion time at baseline statistically predicted better treatment response, although no baseline TMT-B between-group differences were observed (Table 3).

Attentional bias/disengagement. Attentional bias refers to individuals' inclination to preferentially engage with disorder-relevant versus disorder-irrelevant stimuli. Attentional disengagement relates to difficulties shifting focus away from disorder-relevant stimuli (Fineberg et al., 2014). Compulsivity in this domain is thus defined by participants' difficulties with inhibiting prepotent or rigid responses related to a specific disorder, which may reflect hyper-sensitivity to disorder-relevant stimuli and difficulties in mental set-shifting in such situations. Features of attentional bias, set-shifting and cognitive flexibility may overlap (Izquierdo, Brigman, Radke, Rudebeck, & Holmes, 2017; van Timmeren et al., 2018). To further clarify boundaries between these components, we focused attentional bias only in disorder-relevant situations to emphasize the context-specific aspect of compulsivity (Fineberg et al., 2014). Therefore, paradigms related to attentional bias include the dot-probe, addiction-Stroop, and addiction go/no-go tasks.

Dot-probe task. The dot-probe task, which measures preferential attention toward disorder-relevant stimuli, is commonly used in addiction studies. This task simultaneously presents an addiction-related stimulus and a non-addiction stimulus (e.g., pictures or words) on both sides of a fixation (see Box 1C in the Supplementary Information). The stimuli disappear after a fixed duration and are followed by a probe item (e.g., a dot, an asterisk, etc.) presenting either on the addiction-stimulus side (congruent condition) or on the control-stimulus side (incongruent condition). Participants are asked to indicate the probe location as quickly as possible, and the reaction time (RT) is measured. The response latency to the probe will be reduced when it appears in an attended rather than unattended location (Mogg & Bradley, 2005). Accordingly, individual's prepotent attention allocation to one of the two lateralized cues will facilitate the response to the probe at the congruent location. By comparing the averaged reaction times for the congruent and incongruent conditions, the relatively faster responses to the former are interpreted as an attentional bias. Two types of intervals (i.e., stimulus onset asynchrony; SOA) between the presentation of the stimulus and the probe-dot have been used in previous studies. With short exposure time (short SOA), participants' attention orients to certain stimuli unconsciously, while at longer exposure time (long SOA), this orientation may be linked to conscious processing.

A total of nine PUI studies using this task were found, eight of which reported significant attention bias towards internet-related stimuli in individuals with PUI (Table 4). The only study that found no significant attention-bias effect focused on online shopping addiction (Jiang, Zhao, & Li, 2017). Besides, another two studies conceptualized PUI as a continuum and reported significantly positive correlations between internet use symptom severity scores and attention bias (Pekal, Laier, Snagowski, Stark, & Brand, 2018; van Holst et al., 2012).

Addiction-Stroop task. The Stroop task (Stroop, 1935) is a classic neuropsychological task that requires selective attention, cognitive flexibility, and inhibitory control. Since the performance on the classic Stroop task depends on the meaning of stimuli, some researchers have modified the task by using addiction-related words and neutral words to assess addiction-specific concerns activated by the meaning of the words (Faunce & Job, 2000). In the addiction Stroop task, individuals with addictive disorders tend to name the colors of addiction-related words more slowly (i.e., larger interference effect). The interference score is reflected by the increased RT difference between the incongruent and congruent trials, as attention bias to addiction-related stimuli may lead to failures to inhibit prepotent responses.

Of the six articles (seven independent results) that used the addiction Stroop task (Table 4), two found significant impairments in individuals with PUI compared to healthy controls (HCs), whereas the rest five studies did not (Jeromin, Rief, & Barke, 2016; Wang et al., 2018; Zhang et al., 2016; Zhao et al., 2022). Regarding the two studies with significant results, longer reaction times to game-relevant words in individuals with IGD were identified (Jeromin, Nyenhuis, & Barke, 2016; Metcalf & Pammer, 2011). In addition, one other study found longer reaction times in individuals with higher tendency of online shopping addiction (OSA) compared to participants with low tendency of OSA (Jiang et al., 2017). Additionally, one other study reported significant correlations between participants' game addiction scores and numbers of errors for game-related words (van Holst et al., 2012). Taken together, these findings suggest an attentional bias relating to automatic addiction-related meaning processing in people with IGD.

Other tasks of attentional bias. The addiction go/no-go task has also been used to investigate attentional bias (Table 4). Differing from the classic go/no-go task, the modified versions include addiction-related and neutral stimuli either as targets or distractors. Both versions use response accuracy in go and no-go conditions and reaction times in go condition as main outcomes. One identified study used gaming pictures as go targets and neutral pictures as no-go targets and identified more errors on no-go trials in the IGD group when compared with the HC group (Yao et al., 2015). One study used social media icons as no-go targets and neutral pictures as go targets and reported more errors on no-go trials in the group with problematic use of social media compared to that without. Another study used game-related pictures as background distractors and neutral polygons as go/no-go targets. This study showed that the IGD group made more commission errors than the control group in the gaming distracting version but not in the classic go/no-go version (Liu et al., 2014). The results suggest a preponderance of addictive cues in individuals with PUI, leading to greater difficulties with attentional disengagement and inhibitory control.

Habit learning. Habit learning refers to the decreased sensitivity to outcomes and the automation of actions through over-training. According to the double-system theory, an instrumental learning process is jointly controlled by goal-directed and habitual systems (Balleine & Dickinson, 1998). The goal-directed system guides action performance according to the context and outcomes, whereas the habitual system renders behavior automatic and actions insensitive to the outcome, over-relying on stimulus-response contingencies. Therefore, compulsive behaviors may be attributed to either impaired goal-directed control or an over-reliance on the habit system. The fabulous fruit task and two-stage task are commonly used to assess habit control in instrumental learning processes (Daw et al., 2011; de Wit, Corlett, Aitken, Dickinson, & Fletcher, 2009).

Fabulous fruit task. The fabulous fruit task measures the balance between goal-directed and habitual learning via the manipulation of outcome devaluation. The task consists of a discrimination learning phase and two outcome devaluation test phases (see Box 1D in the Supplementary Information). In the learning phase, when a particular fruit stimulus (S) is presented, the correct response (*R*) will be rewarded with a particular outcome (O), so that a S-R-O association is established. This phase relies on both the goal-directed and habit learning systems.

The learning phase is followed by two phases of devalue tests. In the first testing phase, outcomes are presented pairwised with one outcome devalued (marked with a red cross) to indicate that the specific outcome is no longer worth points, and only the valued outcome requires a correct response. The outcome-devaluation test is used to measure goal-directed control by assessing the participant's response to action-outcome associations. The second testing phase is the slips-of-action test session, where subjects are asked to press the correct key when a stimulus signals the still-valuable outcome and to refrain from responding when its outcome has been devalued. Therefore, the slips-of-action test can be used to assess the habitual system (Gillan et al., 2011).

Two studies were identified using the fabulous fruit task to assess habit learning among individuals with PUI (Table 5). One showed that individuals with PUI performed worse in learning S-R-O associations (Zhou, Wang, Zhang, Li, & Nie, 2018). Importantly, the study identified that PUI participants had lower accuracy in the outcome-devaluation test (i.e., first testing phase) and higher response frequency to devalue-paired stimuli in the slips-of-action test (i.e., second testing phase), which reflected the greater reliance on the habitual system and impaired goal-directed control in people with PUI (Zhou et al., 2018). Similarly, the other study found that the IGD group showed deficits in the incongruent condition during the learning phase (Zhou et al., 2021). However, the results of the two post-learning tests were not reported. These findings suggest that individuals with IGD may over-rely on habitual system and overlooked outcomes (deficits in goal-directed control). In addition, the IGD group showed significantly increased functional connectivity between the pulvinar nucleus and medial frontal gyrus, the connectivity of which was positively correlated with worse performance in the incongruent S-R-O learning condition (Zhou et al., 2021).

Other tasks of habit learning. Except for the above-mentioned two tasks, researchers have also used the feedback learning task (deterministic learning task) to investigate S-R-O instrumental association learning processes in individuals with IGD (Kim & Kang, 2018). This task requires participants to learn stimulus-response associations depending on the feedback in a trial-and-error fashion. There are three learning conditions (i.e., gain, loss, and neutral conditions) with each assigned to a positive and negative feedback (e.g., a monetary reward, non-monetary reward, a monetary penalty, non-monetary penalty). A significant group difference was found in the loss condition, such that the IGD patients showed lower correct-stay rates after the symbolic positive feedback, which suggested impaired S-R-O learning from abstract feedback in the loss condition. In addition, participants performed the learning task during MRI scanning: reduced correct-to-stay rate in the gain condition in IGD individuals was associated with stronger connectivity between the ventromedial prefrontal cortex and nucleus accumbens.

Compulsivity-related alterations between IGD and other subtypes of PUI

Among the 41 task results, 23 results focused on IGD participants and 11 showed significant group differences. The 11 remaining task results did not provide the information related to sub-types of PUI, and 7 reported significant results. There were 8 task results focusing on sub-types of PUI apart from IGD (e.g., problematic use of social media), and 5 reported significant group differences between people with sub-types of PUI and HCs.

DISCUSSION

We systematically reviewed the literature that tested compulsivity-related neuropsychological functioning and behaviors in PUI based on a four-components framework. We found that most studies focused on IGD, and other types of PUI have received considerably less attention. Regarding different components of compulsivity, individuals with PUI showed more consistent deficits on tasks measuring attentional bias to addiction-related stimuli, whereas findings are rather mixed for those measuring set-shifting in a neutral context. We also found some supporting evidence for deficits in cognitive flexibility and habit learning in PUI, although the number of studies for these two components may be insufficient to draw reliable conclusions. We will discuss the findings for each compulsivity component and related perspectives below.

Studies examining contingency-related cognitive flexibility are scarce and have shown mixed results. Results from the studies using the PRLT reveal significant behavioral inflexibility (perseveration) in individuals with PUI (Banca et al., 2016; Raj et al., 2023). However, such differences seem to be specific to the adaptation after the reversal instead of the rule change in general, since another study using a probability learning task with the contingency degradation (e.g., from a deterministic learning phase to a probabilistic test phase) showed similarly high accuracy in both IGD and HC groups (Lei et al., 2022). Thus, it remains an open question whether PUI is characterized by impaired inhibition to learned rules prior to reversal. One factor that possibly obscures these results is the diversity in paradigm and outcome parameters between the studies. In addition to the behavioral findings, individuals with IGD also showed blunted positive reward-prediction-error signal in brain regions involved in the reward system (e.g., caudate, OFC) (Lei et al., 2022), which may reflect a link between cognitive inflexibility and impairment in reward value updating for unexpected rewards, as often reported in drug addictions (Parvaz et al., 2015; Tanabe et al., 2013).

Similar to the contingency-related cognitive flexibility domain, few experimental studies to date have examined habit learning in PUI (Kim & Kang, 2018; Zhou et al., 2018, 2021), despite its crucial role in establishing the compulsive behavior and its close association with addictions (Everitt & Robbins, 2016). Specifically, two studies using the fabulous fruit task revealed deficits in learning S-R-O associations in individuals with PUI, especially in the incongruent condition. These findings may reflect a greater reliance on habitual learning over goal-directed control in PUI populations (Zhou et al., 2018, 2021), which are consistent with previous evidence in people with alcohol (Sjoerds et al., 2013) and cocaine use disorders (Ersche et al., 2016). Importantly, in line with theoretical proposal that addictions (including PUI) may evolve from impulsive to compulsive processes (Brand et al., 2019), the devaluation effect in the S–R habit test also negatively correlated with the severity of PUI, indicating that participants with more severe PUI were less sensitive to value changes related to their actions (Zhou et al., 2018). Besides the fabulous fruit task, previous studies using the two-stage reinforcement learning task also showed decreased goal-directed control across various addictions (e.g., methamphetamine use, alcohol use, and gambling disorders) (Sebold et al., 2014; Voon et al., 2015; Wyckmans et al., 2019). By distinguishing model-based (goal-directed) and model-free (habitual) learning processes using a computational modeling approach, analyses of data from the task can provide insight into the balance between the two learning process systems. However, to the best of our knowledge, the two-stage task has not been used in PUI studies yet, and more evidence is needed to understand relationships between habit learning and PUI.

Unlike cognitive flexibility and habit learning, set-shifting has been widely examined in individuals with PUI, yet only a small proportion of related studies (5 out of 15 studies) showed significant between-group differences. The WCST reported relatively consistent findings of poor performance for individuals with PUI (Han et al., 2016; Kuo et al., 2018; Zhou et al., 2014, 2016). In contrast, among the IED and TMT studies, only one using the TMT identified group differences in task performance (Tekin et al., 2018). The unambiguous but opposite results suggest task specificity in assessing PUI individual's set-shifting. Similar task-dependent deficits have been also reported in systematic reviews of gambling and binge eating disorders (Carr et al., 2021; van Timmeren et al., 2018). A key difference between these tasks is that the WCST includes multiple dimensions (including differences in color, shape, and quantity) that participants needed to keep in working memory (Nyhus & Barceló, 2009), whereas the IED and TMT only require participants to operate in 1–2 dimensions. Therefore, a possible explanation is that the between-group difference observed in the WCST may relate to task difficulty (e.g., working memory load) that reflect cognitive capacity rather than set shifting (Choi, Kim et al., 2014; Choi, Park et al., 2014; Roberts, Tchanturia, Stahl, Southgate, & Treasure, 2007). However, this hypothesis remains to be tested by a new paradigm that experimentally manipulates working memory load during set-shifting.

Finally, regarding the attentional bias/disengagement domain, almost all studies using dot-probe or addiction go/no-go tasks identified poor task performance in individuals with PUI compared to HCs. The results on the addiction Stroop task are more mixed (Jeromin, Nyenhuis, et al., 2016; Jeromin, Rief, et al., 2016; Metcalf & Pammer, 2011). These findings are consistent with research in gambling disorder (van Timmeren et al., 2018). A possibility may be that most of the dot-probe and addiction go/no-go tasks used addiction-related images, which may induce larger attentional biases compared to the addiction-related words commonly used in the addiction Stroop task (Fineberg et al., 2014; van Holst et al., 2012). Furthermore, the go/no-go paradigm with addiction-related cues, as an approach to measure stimulus-specific inhibitory control, is widely used in studying behavioral addiction disorders (Antons, Müller, Neumann, Müller, & Steins-Loeber, 2023). The increased commission errors identified in this review consistently confirmed the reduction of inhibitory control and the automatic approach tendency cued by internet stimuli, which may reflect the underlying mechanism of repetitive online behaviors in PUI subtypes. The enhanced attentional bias/disengagement to internet-related cues may indicate the underlying mechanisms of repetitive and continuous online activities use, suggesting hooked attention to addictive stimuli and reduced inhibitory control in the online environment (He, Pan, Nie, Zheng, & Chen, 2021; Ioannidis et al., 2019). Overall, the comparable compulsive attention tendency in individuals with behavioral addictions (e.g., IGD, gambling disorder) may explain the repetitive addictive behavior that is engaged by disorder-relevant information.

Taken together, the four-component framework provides insights into the multifaceted feature of compulsivity and helps to explain seemingly inconsistent findings in previous studies of PUI. Overall, previous evidence suggests that individuals with PUI are impaired in addiction-related attentional bias but not set shifting in the non-addictive context. The number of studies examining cognitive flexibility and habit learning are limited, and more evidence is needed to establish more reliable conclusions. Attentional bias and habit learning rely more on stimuli and established, automatic responses (Fineberg et al., 2014). These two components may serve as early components of compulsivity, reflecting a relatively automatic and less goal-directed reaction. Online activities that are replete with entertaining and self-referential information may trigger individuals to click and refresh habitually and continuously with less intention, especially for individuals with PUI (Kuss & Griffiths, 2017). Individuals with PUI may exhibit a cruise mode of online behavior, automatically and stereotypically using internet activity without definite goals. On the other hand, contingency-related cognitive flexibility and set-shifting typically require more reflection and algorithms (Fineberg et al., 2014; Izquierdo et al., 2017), and thus may serve as late components of compulsivity depending on the cognitive control. Repeated online behaviors despite negative consequences in individuals with PUI may reflect rigid and inflexible tendencies associated with deficits in executive functioning. Specifically, cognitive inflexibility may be reflected in the repeated and rigid user-device interaction (e.g., notification-touching, posting-liking) despite diminishing positive feedback or even negative consequences. The susceptibility of the early and late components to PUI may differ and may be a focus of further study.

The findings also shed new light on the development of treatments. For example, since PUI is consistently associated with attentional bias towards addiction-relevant stimuli, approach bias modification treatments could be effective in alleviating PUI. Such hypothesis has already received some supportive evidence in preliminary studies, with approach bias modification significantly decreasing IGD severity and related characteristics (e.g., gaming intention and craving level) (He et al., 2021; Rabinovitz & Nagar, 2015). As approach biases have been linked to other online behaviors (e.g., severity of problematic pornography use in both young men and women) (Sklenarik et al., 2019, 2020), such approaches warrant investigation in a broad range of PUI types. Moreover, a systematic review on neuropsychological interventions in other addictive disorders highlighted the efficacy of goal-management training and contingency management, which are closely related to attentional bias inhibition training and goal monitoring (Verdejo-García, Alcázar-Córcoles, & Albein-Urios, 2019). Thus, specific neuropsychological modification approaches may also be applied to PUI intervention studies in the future. Based on the neuropsychological and neuroanatomical and neurochemical mechanisms that contribute to compulsive responses, a four-dimensional structure has been proposed (Fineberg et al., 2014). Previous systematic reviews and meta-analytic studies have demonstrated the ability of this framework to capture different aspects of compulsive impairments in gambling disorder (van Timmeren et al., 2018), binge eating disorder (Carr et al., 2021), obsessive compulsive disorder and other conditions (Chamberlain, Solly, Hook, Vaghi, & Robbins, 2021; Fineberg et al., 2018). Moreover, in the current study, we found that individuals with PUI seemed to be impaired in attentional bias but relatively intact in set shifting, suggesting these two domains may reflect distinct aspects of compulsivity. Taken together, these studies suggest that the using four-domain framework may help promote understanding of the multidimensionality of compulsivity and provide a more precise picture of compulsivity-related concerns regarding PUI.

The current study has some limitations that should be considered in future studies. First, compulsivity is a multifaceted construct (Fineberg et al., 2014). However, most studies only focused on one specific domain, making it difficult to integrate seemingly inconsistent findings from different studies. To provide a more comprehensive picture of the role of compulsivity in PUI, studies examining the different components in the same sample are highly recommended. Furthermore, the ability of the neurocognitive tests to capture fully compulsivity was not verified. On the one hand, few empirical studies identified in the review provided evidence about the relationship between task performance and self-reported compulsivity or related neural underpinnings. On the other hand, as compulsivity was the primary interest of the review, only the convergent effect of the tasks in relation to compulsivity was assessed. We did not assess the non-compulsive deficits in PUI that may be captured by tasks (e.g., assessing executive functioning, impulsivity, or distress). Thus, future studies may investigate relationships between task-assessed compulsivity and with neurocognition, neural circuitry and self-reported compulsivity in both PUI and healthy populations. Second, different parameters (e.g., stimulus types) and dependent variables (e.g., reaction times and accuracy) of a specific paradigm were used in previous studies, making it challenging to compare findings across studies as well as between different PUI subtypes. Moreover, false positive evidence may emerge because of selective reporting. Thus, studies that report all core indexes related to compulsive components regardless of the significance and that apply multiple comparison correction should be encouraged. Third, studies have used different scales or criteria to diagnose PUI and some studies have used assessment criteria without validation provided. Such usage may impact the findings related to samples recruited as cases and controls and influence prevalence estimates, especially for generalized internet addiction (Pan, Chiu, & Lin, 2020). Taken together, this situation may increase the risk of study bias. One example involves the DSM-5 9-item criteria for IGD which has shown sound psychometric properties and has been widely used for making IGD diagnoses (Pan et al., 2020; Przybylski, Weinstein, & Murayama, 2017). Future studies should further validate different assessment approaches for other subtypes of PUI and investigate relationships with neurocognitive performance based on agreed-upon threshold, particularly threshold based on diagnostic criteria.

CONCLUSIONS

To summarize, we examined four neuropsychological domains of compulsivity in PUI. Behavioral tasks referring to contingency-related cognitive flexibility, set-shifting, attentional bias and habit learning were retained. People with PUI demonstrated impairments in attentional bias but were largely intact in set-shifting. Relatively consistent deficits in the domains of cognitive flexibility and habit learning were identified, but more evidence is still required. The results confirmed that individuals with PUI, to some extent, are characterized by compulsivity-related cognitive deficits. In addition, the evidence in different PUI sub-types was not evenly distributed. Therefore, further investigation is needed to distinguish domain-related compulsivity deficits in subtypes of PUI, which may elaborate our understanding of compulsive behaviors between PUI sub-types and help to develop specific cognitive modification treatments.

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Policy Forum; been involved in a patent application with Yale University and Novartis; received research support from the Mohegan Sun Casino, Children and Screens and the Connecticut Council on Problem Gambling; and consulted for legal and gambling entities on issues related to impulse control, internet use and addictions. Marc Potenza is an associate editor to the Journal of Behavioral Addictions. The other authors report no disclosures.

SUPPLEMENTARY MATERIAL

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