

Reward-related decision-making deficits in internet gaming disorder: a systematic review and meta-analysis

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ABSTRACT

Aims To estimate the aggregated effect sizes of reward-related decision-making deficits in internet gaming disorder (IGD) and to explore potential moderators on the variability of effect sizes across studies. **Design** Review of peer-reviewed studies comparing reward-related decision-making performance between IGD and control participants identified via PubMed, Web of Science and ProQuest databases. Random-effects modeling was conducted using Hedge's g as the effect size (ES). The effects of decision-making situation, valence, sample type, testing environment, IGD severity and self-reported impulsivity on decision-making differences were examined by moderator analyses. **Setting** No restrictions on location. **Participants** Twenty-four studies (20 independent samples) were included in the meta-analysis, resulting in 604 IGD and 641 control participants and 35 ESs. **Measures** Reward-related decision-making differences between IGD and control groups. **Findings** The overall ES for decision-making deficits in IGD was small ($g = -0.45$, $P < 0.01$). The effects were comparable across risky, ambiguous and inter-temporal decision-making. Larger aggregate ESs were identified for pure-gain and mixed compared with pure-loss decision-making. Studies based on clinical and community samples showed similar effects. No significant difference between behavioral studies and those with extra measurements was observed. Decision-making alterations were not closely associated with IGD severity or self-reported impulsivity differences at the study level. **Conclusions** Internet gaming disorder appears to be consistently associated with reward-related decision-making deficits.

Keywords Behavioral addiction, decision-making, impulsivity, internet gaming disorder, meta-analysis, reward function.

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INTRODUCTION

Internet gaming disorder (IGD) has received much attention with the rapid expansion of on-line gaming use during the last two decades. There were more than 930 million active internet gamers around the world in 2020 (<https://www.statista.com/outlook/212/online-games>) and the prevalence of IGD was approximately 4.6%, according to a recent meta-analysis of 16 survey studies [1]. IGD may lead to a variety of dysfunctions related to physical health, work performance and social interactions [2,3]. Considering the large number of affected individuals

and its negative impact on both personal life and social productivity, IGD has been included in both the 11th revision of the International Classification of Diseases (ICD-11; <https://icd.who.int/browse11/l-m/en>) and the appendix of the 5th edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) [4] as a world-wide condition warranting further study [5]. Despite much effort, the psychopathology of IGD remains to be elucidated.

Individuals with IGD are characterized by persistent gaming despite potential negative consequences [2,4], which may be attributed to impaired risk evaluation and reward processing during decision-making [6].

Indeed, substance use disorders (SUDs) and gambling disorder [7–10] have been frequently associated with impaired reward-related decision-making, a pervasive process when individuals need to make a choice from several options based on subjective values [10,11]. Reward-related decision-making dysfunction was included in the Research Domain Criteria (RDoC) framework as an important transdiagnostic construct [12]. Most theories of IGD also highlight its role in the development and maintenance of this condition [6,13,14]. For example, both the Interaction of Person–Affect–Cognition–Execution (I-PACE) [6] and tripartite neurocognitive models [14] propose that the imbalance of the impulsive (or affect) and reflective (or cognitive) systems lead to poor decision-making in IGD. These theoretical models received some empirical support [15–17]; however, a few studies also showed normal or even better decision-making performance in individuals with IGD [18–20]. Although a previous meta-analysis has partly addressed the relationship between decision-making alterations and internet addiction, it focused upon general cognitive deficits and included only several reward-related decision-making studies [8]. Thus, it is not yet clear to what extent individuals with IGD may be impaired on reward-related decision-making.

A possible factor that might influence the relationship between IGD and reward-related decision-making performance is the decision-making situation. Multiple reward-related decision-making tasks have been investigated in IGD studies. These tasks may be broadly categorized into three situational types: ambiguous, risky and inter-temporal decision-making. Specifically, ambiguous decision-making involves choices in which the outcome information (e.g. risk, reward) is unclear beforehand. Therefore, to achieve better performance, participants need to learn the information related to each option from trial and error [21]. A representative example of this situation is the Iowa Gambling Task (IGT) [22], in which different monetary outcomes and winning probabilities are associated with four decks of cards but unknown to participants at the beginning. In order to earn more money, they should learn more information via feedback and try to select the decks with the highest expected values. Conversely, risky decision-making presents the outcomes and probabilities of each option explicitly. Thus, trial-and-error learning is typically not necessary for this situation [23]. This category includes a few classic tasks, including the Game of Dice Task (GDT) [24], Cambridge Gambling Task (CGT) [25] and Cups Task [26]. Finally, inter-temporal decision-making focuses upon delays to gain the reward (instead of probabilities described in the above two situations) as a discounting factor [27], so tasks assessing this form of decision-making have also been termed delay-discounting tasks [7].

Although these three decision-making situations have been widely examined, few studies have investigated if individuals with IGD may be particularly impaired on a certain domain or show comparable impairments among these situations. Different decision-making situations may depend upon overlapping but distinct cognitive processes [11]. For example, valuation and action selection are commonly involved in all these three situations [11], whereas some other processes, such as time evaluation for inter-temporal decision-making [27], are uniquely required in certain situations. Therefore, a direct comparison between decision-making situations may provide insight into which basic processes that individuals with IGD show impairments. Tailored treatments targeting these deficits may achieve better therapeutic outcomes [28].

Besides decision-making situation, valence of outcomes (e.g. gains or losses) may also contribute importantly to decision-making and have different impacts upon healthy individuals and those with IGD. Individuals are typically more sensitive to the prospect of losses than gains during decision-making [29,30]. Reduced loss aversion has been observed in SUDs and gambling disorder [31–33]. In the field of IGD, the findings are largely mixed. Although a few studies showed worse loss-related decision-making in this population [23,34], opposite findings have also been reported [35]. Thus, whether individuals with IGD behave differently when seeking gains and avoiding losses remains an open question.

Taken together, the existing literature suggests a close association between IGD and decision-making deficits. However, most studies only included a small number of participants and used heterogeneous tasks, which may yield inconsistent results. To clarify the situation, we conducted a systemic review and comprehensive meta-analysis to estimate the aggregated effect size (ES) for decision-making alterations in IGD and examine the moderating effects of decision-making situation and valence. Based on the above-mentioned evidence in IGD and other addictive disorders, we hypothesized that individuals with IGD would exhibit dysfunction related to reward-related decision-making in general, and such deficits might be particularly associated with certain types of decision-making situations (e.g. inter-temporal decision-making) [36,37] and valence (e.g. loss-related decision-making) [31,34]. As studies based upon clinical and community samples were included, we also examined systematic differences between these studies and hypothesized that clinical samples would perform worse. Moreover, some [e.g. functional magnetic resonance imaging (fMRI) or electroencephalography (EEG)] studies conducted the decision-making tasks when measuring neural activity; we thus explored the impact of the testing environments on the results. Although studies have suggested that the additional equipment may lead to motor slowing and less

attentional focus [38], neither is critical for most reward-related decision-making tasks [11]. Therefore, we hypothesized that behavioral and neuroimaging studies would yield similar results. Finally, as reward-related decision-making deficits have been proposed to relate to the development of IGD [6,13,14] and may overlap with impulsivity [39], another core component of addictions [40], we hypothesized that decision-making alterations in IGD would be associated with both IGD severity and impulsivity differences at the study level.

METHODS

Study selection

We followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to conduct the study selection [41]. Relevant studies (January 1995–June 2020) were identified via searches of PubMed, Web of Science and ProQuest databases using the following search terms: (decision OR choice OR risk OR ambiguity OR uncertainty OR gamb* OR 'Game of Dice Task' OR GDT OR 'delay discounting' OR DDT) AND ('internet gaming' OR 'computer gaming' OR 'online gaming' OR 'video gaming' OR 'gaming addiction' OR 'gaming disorder' OR 'excessive gaming').

Studies were included if they: (1) were peer-reviewed original articles on humans; (2) included at least one reward-related decision-making task; (3) included an IGD group diagnosed by predefined criteria; (4) included a healthy control group; (5) compared reward-related decision-making performance between IGD and control groups; and (6) reported sufficient information for the calculation of effect sizes (ESs). Studies that focused on off-line gaming disorder or determined IGD status after participant enrollment (e.g. based on median scores) were excluded. Moreover, as the current study focused upon reward-related decision-making, studies using perceptual and social decision-making tasks were also excluded. The study selection was independently conducted by two researchers (Y.W.Y. and L.L.). Kappa statistics showed a high agreement between reviewers for study selection ($k = 0.71$, $P < 0.01$). Discrepancies were resolved by discussion.

Quality assessment

We used the critical appraisal checklist of case-control studies from Specialist Unit for Review Evidence (SURE; <http://www.cardiff.ac.uk/insrv/libraries/sure/checklists.html>) to assess the quality of included studies. This is a 11-item checklist that covers key potential sources of bias proposed by the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guideline [42].

Data extraction

Data extraction included: (1) basic demographics of participants (e.g. sample sizes and age information); (2) diagnostic tools for assessing IGD; and (3) decision-making tasks and related dependent variables. If multiple dependent variables were reported for a task, one widely used measure (e.g. net score for IGT) was selected for that task based on the available data. The selected variables for the included studies are listed in Table 1.

The standardized ES for each variable was calculated based on Hedge's g method, which is considered to be a conservative estimate for studies with small sample sizes [56]. The direction of ES was defined as negative if worse decision-making performance was observed in IGD participants. When means and standard deviations were not reported, the ES was calculated based on the t - or p -values. For data only available in figures, they were extracted using WebPlotDigitizer (<https://apps.automeris.io/wpd/>). When the data reported in the studies were insufficient for the ES calculation, the authors were contacted.

To test the effects of valence on decision-making deficits in IGD, separate ESs for gain and loss domains were calculated whenever possible. ESs were divided into pure-gain, pure-loss and mixed domains based on the valence of the decisions. One study reported results from both the original GDT and a modified version without feedback [17]. We thus treated them as two separate ESs. In other cases, if studies only reported the information for individual conditions or sessions, a combined ES for that task was calculated based on Scammacca and colleagues' recommendations [57].

It should be noted that the current study was not pre-registered, and the results should therefore be considered exploratory. The data related to the meta-analysis are available at the Open Science Framework (<https://osf.io/9kb5s/>).

Meta-analytical approach

The ES calculation and meta-analyses were performed using R version 3.2.6 (<https://www.r-project.org>) and the metafor package (<https://www.metafor-project.org>). By convention, ES is regarded as small, medium or large when a g -value is larger than 0.2, 0.5 or 0.8, respectively [58].

We first calculated the overall mean effect on decision-making differences between the IGD and HC groups. As some studies used multiple decision-making tasks to examine the differences between the IGD and HC groups, a three-level random-effects model was conducted to account for the dependence between these ESs within the same sample. Specifically, this model accounted for three levels of heterogeneity: (1) sampling variance of all ESs; (2) variance between ESs from the same sample; and

Table 1 Studies included in the meta-analysis.

Study	Sample ID	Sample size	Mean age (SD)	IGD diagnosis	Task	Situation	DVs	Valence	Study type	Sample type	Comorbidity control
Deleuze et al. 2017 [43]	1	IGD = 32 HC = 65	IGD = 21.84 (3.21) HC = 22.38 (3.97)	DSM-5	GDT	Risky	Net score	Mixed	Behavioral	Community	No
Dong et al. 2016 [44]	2	IGD = 20 HC = 16	IGD = 21.33 (2.18) HC = 21.9 (2.33)	DSM-5 + YIAT	Risk DM	Risky	Disadvantageous choice %	Mixed	fMRI	Community	Yes (MINI)
Jiang et al. 2020 [15]	3	IGD = 30 HC = 30	IGD = 22.00 (5.00) HC = 22.00 (6.00)	DSM-5	IGT	Ambiguous	Net score	Mixed	Behavioral	Clinical	Yes (DSM-5)
Kim et al. 2018 [45]	4	IGD = 18 HC = 20	IGD = 22.17 (2.00) HC = 21.20 (2.20)	YIAT	RL	Ambiguous	Advantageous choice %	Gain + loss	fMRI	Community	Yes (self-report)
Ko et al. 2017 [35]	5	IGD = 87 HC = 87	IGD = 23.29 (2.38) HC = 23.38 (2.40)	DSM-5	Risk DM	Risky	Risky choice %	Gain + loss	Behavioral	Community	Yes (MINI)
Li et al. 2020 [46]	6	IGD = 31 HC = 32	IGD = 15.81 (1.68) HC = 15.91 (1.73)	DSM-5	Risk DM	Risky	Risky choice %	Mixed	EEG	Clinical	Yes (DSM-4, BDI, BAI)
Tian et al. 2018 [37]	6	IGD = 35 HC = 38	IGD = 15.57 (1.17) HC = 15.78 (0.94)	DSM-5	1. DDT 2. PDT	1. Inter-temporal 2. Risky	1. AUC 2. AUC	1. Gain + loss 2. Gain + loss	Behavioral	Clinical	Yes (DSM-4, BDI, BAI)
Wang et al. 2020 [34]	6	IGD = 45 HC = 43	IGD = 15.58 (1.14) HC = 15.72 (0.96)	DSM-5 + YDQ + gaming time	Mixed gambles task	Risky	Loss aversion (lambda)	Mixed	Behavioral	Clinical	Yes (MINI, BDI, BAI)

(Continues)

Table 1. (Continued)

Study	Sample ID	Sample size	Mean age (SD)	IGD diagnosis	Task	Situation	DVs	Valence	Study type	Sample type	Comorbidity control
Lin <i>et al.</i> 2019 [18]	7	IGD = 23 HC = 38	IGD = 25.39 (2.04) HC = 25.66 (2.22)	DSM-5	IGT	Ambiguous	Net score	Mixed	Behavioral	Community	No
Lin <i>et al.</i> 2015 [47]	8	IGD = 19 HC = 21	IGD = 22.20 (3.08) HC = 22.80 (2.35)	YIAT	PDT	Risky	Logged h	Gain	fMRI	Community	Yes (MINI)
Wang <i>et al.</i> 2017a [48]	8	IGD = 18 HC = 21	IGD = 22.10 (3.20) HC = 23.10 (2.00)	YIAT + gaming time	DDT	Inter-temporal	Logged k	Gain	fMRI	Community	Yes (MINI)
Liu <i>et al.</i> 2017 [49]	9	IGD = 41 HC = 27	IGD = 21.93 (1.88) HC = 22.74 (2.35)	CIAS + gaming time	Cups Task	Risky	Risky choice %	Gain + loss	fMRI	Community	Yes (BDI, BAI)
Metcalf <i>et al.</i> 2014 [19]	10	IGD = 10 HC = 13	NA	AEQ	IGT	Ambiguous	Net score	Mixed	Behavioral	Community	No
Park <i>et al.</i> 2020 [50]	11	IGD = 34 HC = 34	IGD = 25.90 (6.00) HC = 25.50 (4.30)	DSM-5 + gaming time	CGT	Risky	Risky choice %	Mixed	Behavioral	Clinical	Yes (DSM-5)
Pawlikowski <i>et al.</i> 2011 [16]	12	IGD = 19 HC = 19	IGD = 23.47 (3.88) HC = 24.32 (3.62)	YIAT	GDT	Risky	Net score	Mixed	Behavioral	Community	Yes (self-report)
Qi <i>et al.</i> 2016 [51]	13	IGD = 24 HC = 24	IGD = 17.17 (3.51) HC = 17.42 (3.05)	DSM-5 + YIAT + gaming time	BART	Ambiguous	Adjusted pumps	Mixed	fMRI	Community	Yes (MINI)

(Continues)

Table 1. (Continued)

Study	Sample ID	Sample size	Mean age (SD)	IGD diagnosis	Task	Situation	DVs	Valence	Study type	Sample type	Comorbidity control
Wang <i>et al.</i> 2017b [52]	14	IGD = 20 HC = 20	IGD = 20.95 (2.44) HC = 21.95 (2.37)	DSM-5 + YIAT + gaming time	1. DDT 2. PDT	1. Inter-temporal 2. Risky	1. Logged k 2. Logged h	1. Gain 2. Gain	fMRI	Community	Yes (self-report)
Wöfling <i>et al.</i> 2020 [53]	15	IGD = 30 HC = 27	IGD = 26.90 (5.97) HC = 25.60 (3.25)	DSM-5	1. DDT 2. IGT	1. Inter-temporal 2. Ambiguous	1. AUC 2. Total balance	1. Gain 2. Mixed	Behavioral	Clinical	Yes (clinical interview)
Wu <i>et al.</i> 2018 [54]	16	IGD = 22 HC = 22	IGD = 21.40 (1.30) HC = 22.00 (1.70)	DSM-5 + YIAT + gaming time	Slot machine task	Ambiguous	Risky choice in persistence phase	Gain	Behavioral	Community	Yes (self-report)
Yao <i>et al.</i> 2017 [36]	17	IGD = 25 HC = 21	IGD = 22.28 (1.62) HC = 22.00 (2.26)	DSM-5 + gaming time	1. DDT 2. BART	1. Inter-temporal 2. Ambiguous	1. Logged k 2. Adjusted pumps	1. Gain 2. Mixed	Behavioral	Community	Yes (MINI)
Yao <i>et al.</i> 2014 [17]	18	IGD = 26 HC = 26	IGD = 22.54 (2.10) HC = 22.00 (2.15)	CIAS + gaming time	1. GDT 2. Modified GDT	1. Risky 2. Risky	1. Net score 2. Net score	1. Mixed 2. Mixed	Behavioral	Community	Yes (self-report)
Yao <i>et al.</i> 2015a [20]	19	IGD = 34 HC = 32	IGD = 22.29 (2.07) HC = 22.47 (2.08)	CIAS + gaming time	IGT	Ambiguous	Net score	Mixed	Behavioral	Community	Yes (self-report)
Yao <i>et al.</i> 2015b [23]	19	IGD = 60 HC = 42	IGD = 22.40 (2.07) HC = 22.38 (2.10)	CIAS + gaming time	Cups Task	Risky	Risky choice %	Gain + loss	Behavioral	Community	Yes (self-report)

(Continues)

Table 1. (Continued)

Study	Sample ID	Sample size	Mean age (SD)	IGD diagnosis	Task	Situation	DVs	Valence	Study type	Sample type	Comorbidity control
Zha <i>et al.</i> 2019 [55]	20	IGD = 19 HC = 46	IGD = 20.50 (3.10) HC = 23.80 (1.70)	DSM-5	DDT	Inter-temporal	Logged k	Gain	fMRI	Community	Yes (self-report)

AEO = Addiction Engagement Questionnaire; AUC = area under the curve; BAI = Beck Anxiety Inventory; BART = Balloon Analog Risk Task; BDI = Beck Depression Inventory; CGT = Cambridge Gambling Task; CIAS = Chen Internet Addiction Scale; DDT = Delay Discounting Task; DM = decision-making; DSM = Diagnostic and Statistical Manual of Mental Disorders; DV = dependent variable; EEG = electroencephalogram; fMRI = functional magnetic resonance imaging; GDT = Game of Dice Task; HC = healthy control; IGD = Internet Gaming Disorder; IGT = Iowa Gambling Task; MINI = Mini-International Neuropsychiatric Interview; PDT = Probabilistic Discounting Task; RL = Reinforcement learning; SD = standard deviation; YIAT = Young's Internet Addiction Test.

(3) variance between ESs from different samples [59]. For completeness, a conventional two-level random-effects model that ignored the within-sample variance (i.e. ESs were treated as independent) was also performed. The likelihood ratio test was conducted to select the better model given the data.

Q and I^2 tests were used to assess the heterogeneity of ESs. The former reflects the sum of squared differences between individual weighted ES and the overall mean, whereas the latter quantifies the percentage variation within ESs that is explained by the heterogeneity of different levels; τ^2 was used as an index of heterogeneity variances. The leave-one-out method was used to verify the reliability of the results. The funnel plot and Egger's test [60] were used to assess the risk of publication bias. The trim-and-fill method was applied to calculate the adjusted effect size after accounting for publication bias [61].

Moderator analysis

Except for the meta-analysis of the overall mean effect, we used the mixed-effect model with a categorical moderator to examine the effects of decision-making situation (risky, ambiguous and inter-temporal), valence (pure-gain, pure-loss and mixed), sample status (clinical and community) and study type (behavioral and neuroimaging). It should be noted that neuroimaging studies only referred to those involving decision-making tasks that were conducted when recording neural activity. Other studies, including one that conducted a decision-making task after EEG recording [50], were assigned to behavioral studies. Finally, the mixed-effect meta-regression was also conducted to examine the relationship between decision-making alterations and other IGD characteristics (i.e. IGD severity and impulsivity differences) at the study level.

RESULTS

As shown in Fig. 1, 24 studies (20 independent samples) met the selection criteria, including 604 IGD and 641 control participants and 35 ESs. The characteristics of the included studies are summarized in Table 1. Tasks were categorized into three broad decision-making situations: risky (18 ESs), ambiguous (10 ESs) or inter-temporal (7 ESs) decision-making. Fifteen studies (23 ESs) were behavioral experiments, whereas the remaining nine (12 ESs) recorded extra measurements (i.e. fMRI or EEG) during decision-making tasks. The included studies were of high quality on most checked items (Supporting information, Table S1), except for potential risks of bias regarding study size estimation, as only one study [34] explicitly explained how this criterion was determined.

The three-level meta-analysis showed a small and negative overall ES ($g = -0.46$, $P < 0.01$, Fig. 2). The

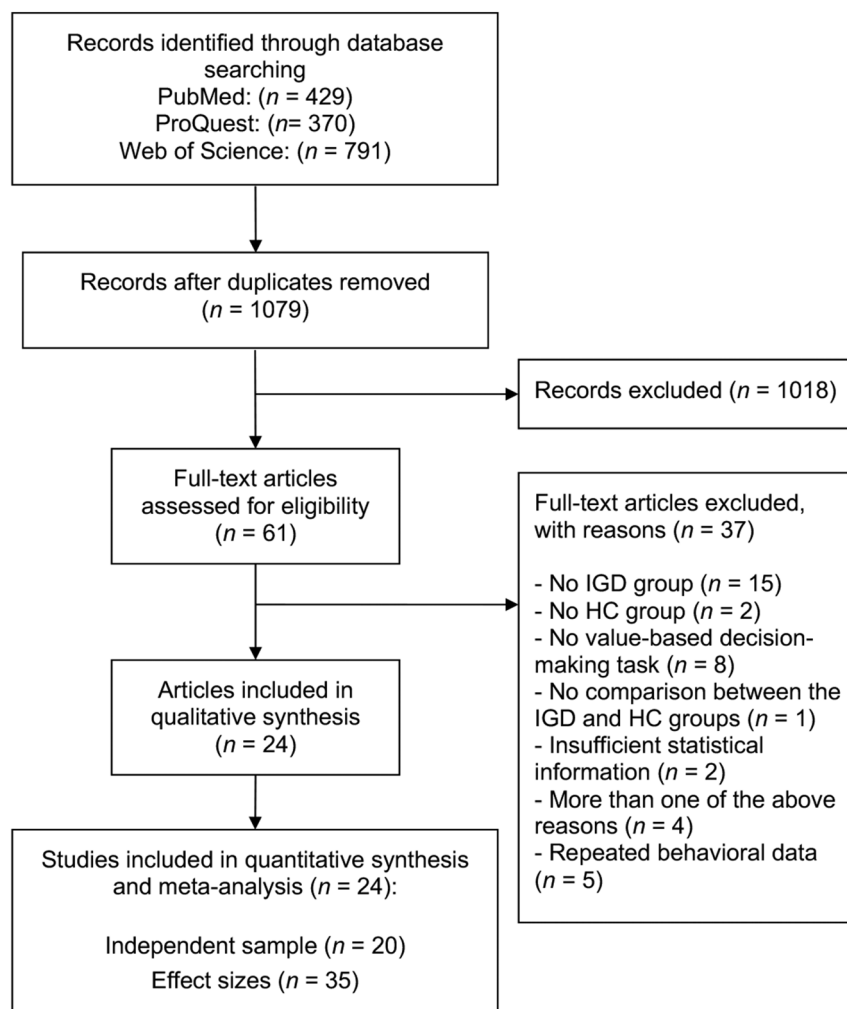


Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram

Q -test suggests significant heterogeneity among the ESs ($Q_{(34)} = 70.87$, $P < 0.01$). According to I^2 , the sample level explained less than 1% of the total heterogeneity. The two-level meta-analysis showed a similar overall ES ($g = -0.45$, $P < 0.01$; $I^2 = 0.50$). The model comparison showed that the inclusion of the level 3 (i.e. sample level) did not significantly improve the model fit, given the data [log-likelihood ratio (LLR) < 0.01 , degree of freedom (d.f.) difference = 1, $P = 0.99$]. Thus, we focused upon the two-level model in subsequent analyses.

The leave-one-out analysis showed that the overall ES ranged from -0.42 to -0.47 , suggesting that the result is reliable and not driven by individual studies. The asymmetric funnel plot and a significant Egger's test ($Z = -2.78$, $P < 0.01$) suggest the possibility of larger effect sizes in studies with smaller sample sizes. The trim-and-fill method yielded a smaller overall effect size ($g = -0.31$, $P < 0.01$, Fig. 3) after accounting for the potential publication bias.

The impacts of categorical moderators are summarized in Table 2. First, the analysis of differences between decision-making situations showed comparable ESs in ambiguous, risky and inter-temporal decision-making (LLR = 1.28, d.f. difference = 2, $P = 0.53$). Secondly, there were significant differences in ESs across valences (LLR = 6.36, d.f. difference = 2, $P = 0.04$), as larger aggregate ESs were observed for gain-related and mixed compared with loss-related decision-making. Thirdly, studies based on clinical samples did not report larger effects compared with those using community samples (LLR = 0.83, d.f. difference = 1, $P = 0.36$). Fourthly, no significant differences in ESs were found between behavioral studies and those with extra measurements (LLR < 0.01 , d.f. difference = 1, $P = 0.98$). Finally, two meta-regressions were conducted in subsets of studies reporting YIAT (Young Internet Addiction Test; 9 ESs) and BIS-11 (Barratt Impulsiveness Scale; 17 ESs) data, but these analyses did not reveal significant associations between decision-making deficits and these IGD characteristics (P s > 0.20).

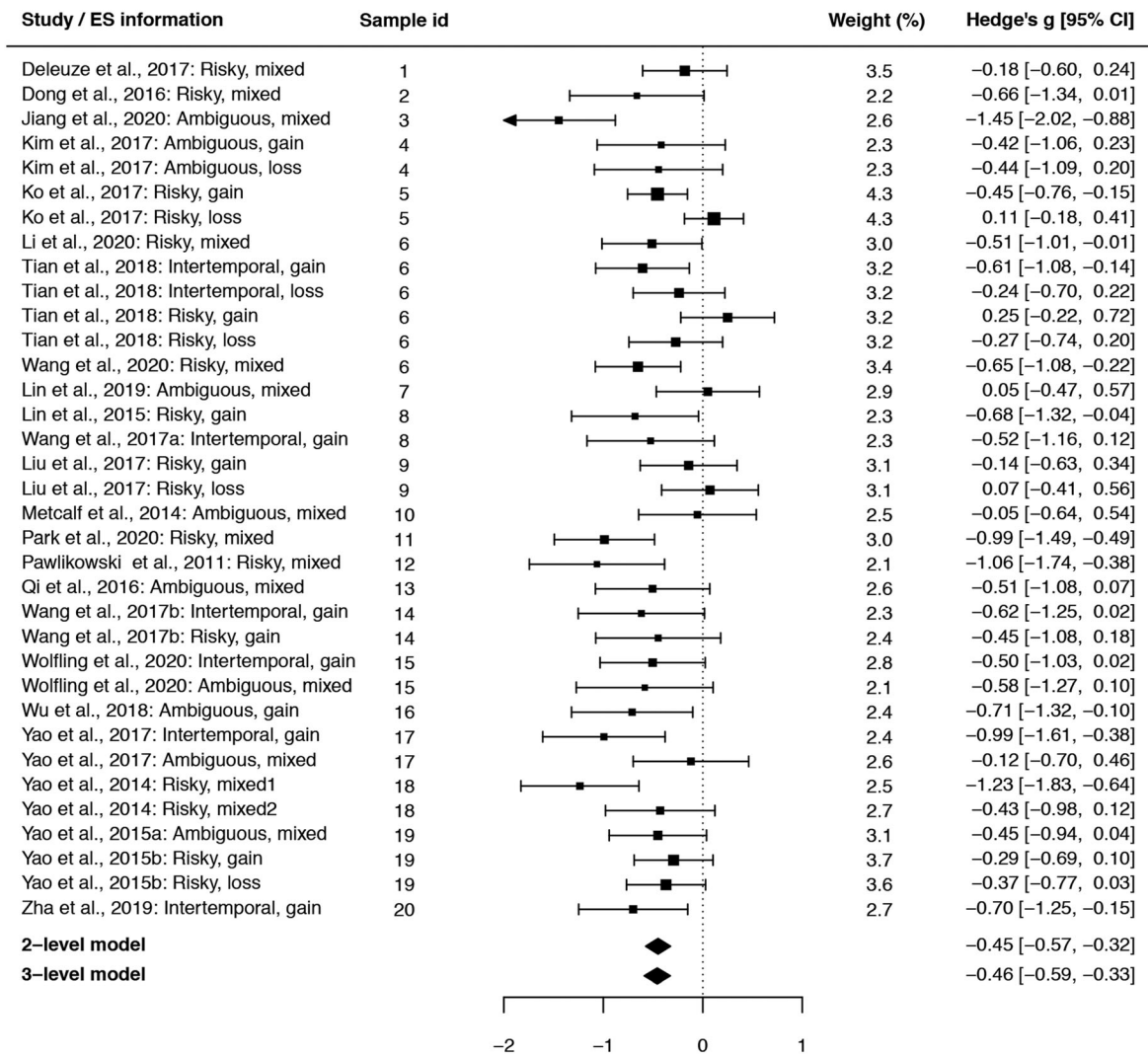


Figure 2 Forest plot of all included studies

DISCUSSION

The present meta-analysis showed a consistent association between decision-making deficits and IGD. More importantly, our results for the first time showed that such deficits were: (1) comparable across risky, ambiguous and inter-temporal decision-making; (2) larger for the pure-gain and mixed compared with pure-loss decisions; (3) similar for studies of clinical and community samples; (4) consistent in different testing environments; and (5) not significantly associated with IGD severity and self-reported impulsivity differences at the study level. These findings may help to update existing theories regarding IGD and shed new light on treatment development.

Consistent with classic theoretical models in IGD [6,13,14], we found that individuals with IGD tend to perform worse in a variety of reward-related decision-making tasks. This finding also aligns with previous meta-analyses in SUDs, gambling disorder and obesity

[7,62,63], suggesting that reward-related decision-making deficits may be a common feature across addictive disorders. These deficits may be related to frontostriatal circuitry, which is involved in a wide range of cognitive processes and is implicated in addictive disorders, including IGD [6,64–66]. More importantly, some SUD studies found that reward-related decision-making deficits were closely linked to treatment effects [67–69]. Therefore, reward-related decision-making deficits may serve as a candidate therapeutic target for IGD.

Conversely, it should also be noted that the effect size observed in IGD appears to be slightly lower than some SUDs, such as opiates dependence [63]. The potential differences between addictions may be due to the lack of direct neurotoxic effects of drug intake in IGD, which warrants more consideration in both theoretical models and empirical studies. However, longitudinal studies are needed to disentangle possible pre-existing versus drug-related effects in such studies. Moreover, publication

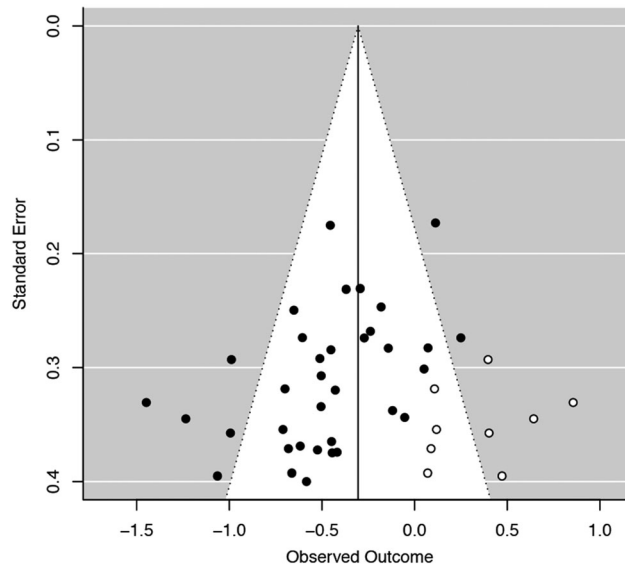


Figure 3 Funnel plot with trim-and-fill

Table 2 Overall effect and the results for moderator analyses.

Analysis	# ES	Hedge's <i>g</i>	95% CI	Z	<i>P</i>
1. Overall effect model	35	-0.45	(-0.57, -0.32)	-7.07	< 0.01
2. Model with decision-making situation					
Ambiguous	10	-0.46	(-0.70, -0.22)	-3.77	< 0.01
Inter-temporal	7	-0.58	(-0.86, -0.30)	-4.12	< 0.01
Risky	18	-0.39	(-0.56, -0.23)	-4.77	< 0.01
3. Model with valence					
Gain	14	-0.46	(0.63, -0.29)	-5.22	< 0.01
Loss	6	-0.16	(-0.40, 0.08)	-1.27	0.20
Mixed	15	-0.57	(-0.74, -0.39)	-6.39	< 0.01
4. Model with sample type					
Clinical	10	-0.54	(-0.76, -0.31)	-4.72	< 0.01
Community	25	-0.41	(-0.56, -0.26)	-5.50	< 0.01
5. Model with study type					
Behavioral	23	-0.45	(-0.60, -0.30)	-5.91	< 0.01
Neuroimaging	12	-0.45	(-0.67, -0.22)	-3.91	< 0.01
6. Model with YIAT	9	0.01	(-0.07, 0.20)	0.90	0.37
7. Model with BIS-11	17	-0.10	(-0.26, 0.06)	-1.22	0.22

BIS-11 = Barratt Impulsiveness Scale; ES = effect size; YIAT = Young's Internet Addiction Test. All listed models are two-level random-effects models.

bias may exist in the included studies, as larger effect sizes were more often observed in studies with smaller sample sizes. The trim-and-fill method, which statistically accounts for the impact of unpublished findings, yielded a smaller averaged effect ($g = -0.31$). These findings together suggest that IGD is associated with relatively mild decision-making dysfunction.

To further investigate factors that may influence decision-making alterations in IGD, we first compared the averaged effect related to risky, ambiguous and inter-temporal decision-making, and did not find systematic

differences explained by the decision-making situations. Although some studies have reported that individuals with IGD may be particularly impaired on certain specific situations [20,37], such effects may be limited to certain conditions (e.g. disadvantageous trials in risky decision-making) and may not apply to general response patterns. Reward-related decision-making is a complex cognitive function based on multiple basic processes, including valuation, action selection and learning [11]. Some processes (e.g. valuation) are commonly involved in all these three decision-making situations, whereas others (e.g. time

evaluation) may be specific to a certain situation [21,27]. As individuals with IGD exhibited comparable deficits across risky, ambiguous and inter-temporal decision-making, a speculation is that they were mainly impaired on some common processes involved in these three situations.

Another factor that may impact reward-related decision-making is the valence of outcomes [29]. To test whether individuals with IGD behaved differently when deciding to seek gains and avoid losses, we divided the ESs into the pure-gain, pure-loss and mixed domains. We observed larger between-group differences in the pure-gain and mixed compared with pure-loss domains, suggesting that individuals with IGD are mainly impaired in decision-making for potential rewards. Altered gain-related decision-making has also been frequently reported in SUDs and eating disorders [10,70]. Such deficits may be driven by (1) hypersensitivity to cues of rewards or (2) more efficient learning from positive outcomes in IGD [70,54], which remains to be tested by studies that disentangle these decision-making stages. Conversely, unlike findings in other addictions [31,32], individuals with IGD showed relatively intact ability when facing pure-loss decision-making, which thus does not lend support to the reduced loss aversion hypothesis [23,34]. Although this finding should be regarded as preliminary, as we only obtained six ESs for the pure-loss domain, it still raises the possibility that punitive approaches, such as avoidance training, may achieve a promising therapeutic effect for IGD.

We also examined a few other potential moderators, such as the sample type and testing environment. Although studies using clinical samples appeared to report slightly larger effects compared to those based on community samples, the difference between the two was not significant. However, more evidence is needed to confirm this finding, as relatively less attention has focused upon clinical samples. Regarding the testing environment, we directly compared the aggregated ESs between behavioral studies and those with extra measurements (e.g. fMRI and EEG) during decision-making tasks. The absence of a moderator effect suggests that reward-related decision-making differences between the IGD and control groups are largely independent of testing situations, which supports the reliability and consistency of decision-making performance across different environments.

Numerous theoretical models proposed a close relationship between addiction characteristics, impulsivity in particular, and decision-making dysfunction [14,39,59]. Inconsistently with our hypothesis, we found no significant associations between general IGD severity and decision-making differences at the study level. However, as heterogeneous IGD assessment tools were often used across studies, we needed to focus upon studies using the YIAT ($n = 9$). Such a limited sample size may decrease

the statistical power to detect an effect. We did not find significant associations between impulsivity and decision-making deficits either. A plausible explanation is that the BIS-11 only assesses self-reported impulsivity, and decision-making deficits in IGD may be more closely related to other dimensions of impulsivity (e.g. action impulsivity) [20]. Indeed, impulsivity has multiple facets that may best be measured by multiple questionnaires and tasks [36,72,73]. Although the current data are not yet capable of answering this question, it might be valuable for researchers to move beyond such simplistic concept and propose more concrete hypotheses about how specific impulsivity dimensions relate to decision-making alterations in IGD.

Taken together, a few theoretical and therapeutic implications related to our findings are noteworthy. First, as mentioned above, reward-related decision-making is a complex function, and individuals with IGD may be mainly impaired on some, but not all, basic aspects. However, most existing theories and empirical studies of IGD have focused upon decision-making deficits as a whole without further distinguishing the underlying facets. Thus, decomposing/disentangling decision-making subprocesses implicated in IGD could be a promising future direction to expand the current theoretical models. Moreover, although findings from SUDs provided a valuable reference for studying IGD and inspired theoretical models in this field, our study showed that some established findings in SUDs (e.g. loss-related decision-making dysfunction) may not apply to IGD. Therefore, more studies are encouraged to explore distinct cognitive mechanisms underlying IGD and SUDs, and such differences should be accounted for in theories of IGD. Last but not least, a barrier to the development of efficacious treatments is that IGD, like other psychiatric disorders, is a heterogeneous spectrum [74]. A combination of multi-task assessment and computational modeling may enable more precise mechanistic inferences to be made and help to identify IGD subgroups that exhibit different deficit patterns across involved basic processes, which could serve as the basis for the development of tailored treatments [28].

The current study has some limitations. First, the meta-analysis was based on cross-sectional evidence and thus does not have sufficient information to provide insight into causal relationships between IGD and reward-related decision-making deficits. Because we focused upon studies that compared reward-related decision-making between IGD and control groups, we only examined the effects of IGD on decision-making deficits in the current study. As most theoretical models have proposed a bidirectional relationship between these two variables [6,13,14], the role of decision-making deficits in the development of IGD remains to be elucidated. Secondly, the current study focused on reward-related decision-making situations rather than

tasks. Therefore, one should be cautious when considering generalizing these findings to a specific task. Between-task comparisons are highly encouraged when more ESs are available. Finally, most of the included studies focused on young adult male samples, which may limit the generalizability of these findings to other populations.

In conclusion, the current study showed that IGD is associated with mild decision-making dysfunction, which is comparable across different situations. Moreover, individuals with IGD may behave differently when deciding to seek gains and avoid losses. These findings highlight the necessity to precisely distinguish processes involved in decision-making, which may advance our understanding of the cognitive mechanisms underlying IGD and help to develop more tailored treatments.

Declaration of interests

The authors have no conflict of interests regarding the current manuscript. M.N.P. reports broader interests which did not influence this paper but are noted here for context. M. N.P. has consulted for and advised pharmaceutical and health-care entities including AXA, Idorsia and Opiant/Lakelight Therapeutics. He has also consulted for and advised other entities including Game Day Data and the Addiction Policy Forum; received research support from the Mohegan Sun Casino and the National Center for Responsible Gaming (now the International Center for Responsible Gaming); participated in surveys, mailings or telephone consultations related to drug addiction, impulse-control disorders, or other health topics; consulted for legal and gambling entities on issues related to impulse-control and addictive disorders; performed grant reviews for the National Institutes of Health and other agencies; edited journals and journal sections; given academic lectures in grand rounds, CME events and other clinical/scientific venues; and generated books or chapters for publishers of mental health texts.

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Author contributions

Yuan-Wei Yao: Conceptualization; data curation; formal analysis; investigation; methodology; visualization. **Jin-Tao Zhang:** Funding acquisition; validation. **Xiao-Yi Fang:** Supervision; validation. **Lu Liu:** Conceptualization; data curation; funding acquisition; investigation; methodology; project administration; validation. **Marc Potenza:** Supervision; validation.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1 Quality check based on the critical appraisal checklist of case-control studies from Specialist Unit for Review Evidence (SURE).