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Enhanced Pavlovian-to-instrumental transfer in internet gaming disorder

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FULL-LENGTH REPORT

ABSTRACT

Background and aims: The Pavlovian-to-instrumental transfer (PIT) effect is a phenomenon that Pavlovian conditioned cues that could influence one's instrumental behavior. In several substance and behavioral addictions, such as tobacco use disorder and gambling disorder, addiction-related cues could promote independently trained instrumental drug-seeking/drug-taking behaviors, indicating a specific PIT effect. However, it is unclear whether Internet gaming disorder (IGD) would show a similar change in PIT effects as other addictions. The study aimed to explore the specific PIT effects in IGD. *Methods:* We administrated a PIT task to individuals with IGD ($n = 40$) and matched health controls (HCs, $n = 50$), and compared the magnitude of specific PIT effects between the two groups. The severity of the IGD symptoms was assessed by the Chinese version 9-item Internet Gaming Disorder Scale (IGDS) and the Internet Addiction Test (IAT). *Results:* We found that: (1) related to the HCs group, the IGD group showed enhanced specific PIT_{game} effects, where gaming-related cues lead to an increased choice rate of gaming-related responses; (2) in the IGD group, the magnitude of specific PIT_{game} effects were positively correlated with IAT scores (rho = 0.39, $p = 0.014$). *Discussion and Conclusions:* Individuals with IGD showed enhanced specific PIT effects related to HCs, which were associated with the severity of addictive symptoms. Our results highlighted the incentive salience of gaming-related cues in IGD.

KEYWORDS

Pavlovian-to-instrumental transfer, Internet gaming disorder, incentive salience, specific PIT, goal-directed control

INTRODUCTION

Internet gaming disorder (IGD) is a type of behavioral addiction that is characterized by "persistent and recurrent use of the Internet to engage in games" according to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) (APA, 2013). A diagnosis of IGD was indicated by five (or more) of the nine criteria recommended by the DSM-5 in a 12-month period (Petry et al., 2014). IGD affects about 3.05% of the population worldwide (Stevens, Dorstyn, Delfabbro, & King, 2021), and is highly comorbid with various mental disorders, such as depression (Ostinelli et al., 2021), anxiety (Darvesh et al., 2020), and obsessive-compulsive disorder (OCD) (Pearcy, McEvoy, & Roberts, 2017). IGD is becoming a global health concern.

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The Pavlovian-to-instrumental transfer (PIT) effect is a phenomenon of Pavlovian conditioned cues that could influence one's instrumental behavior (e.g., positively valued Pavlovian cues leading to increased choice rate, increased response frequency, or faster response time) (Cartoni, Balleine, & Baldassarre, 2016; Talmi, Seymour, Dayan, & Dolan, 2008). Two types of PIT effects have been defined: general PIT and specific PIT. In general PIT, the Pavlovian stimuli impact any instrumental response, even if the instrumental response was paired with a different outcome, while in specific PIT the Pavlovian stimulus associated with a particular outcome impacts only instrumental responses associated with the same outcome (Corbit & Balleine, 2005, 2011; Dickinson & Balleine, 2002; Holland, 2004).

Although the PIT effects can be triggered by various kinds of rewards (e.g., food, money, and social reward) (Lehner, Balsters, Bürgler, Hare, & Wenderoth, 2017), the PIT effects in addiction were particularly interesting. The incentive-sensitization theory posits that drug cues that were incentive salient after repeatedly paired with drug rewards (Pavlovian conditioning), could have a motivational impact on one's instrumental behaviors through elicit "wanting" (Berridge & Robinson, 2016; Robinson & Berridge, 2008). For example, an auditory stimulus (CS) that was paired with cocaine consumption could promote independently trained instrumental drug-seeking/drug-taking behaviors in rats (LeBlanc, Ostlund, & Maidment, 2012). This enhanced specific PIT effect could reflect a greater susceptibility to addiction-related cues, due to excessive incentive salience that has been endowed after repetitively paired with drug-related rewards (Hogarth, Balleine, Corbit, & Killcross, 2013; Mahlberg et al., 2021). Moreover, PIT was also proposed to reflect the change in behavioral control (i.e., a shift from goal-directed to habitual behavior control) in addictions, however in human studies it is not clear yet how exactly specific and general PIT is related to goal-directed versus habitual behavior (Garbusow et al., 2022). Theoretically, the PIT effects can be seen as stimulus-outcome-response associations (S–O–R) resulting from the interaction of the Pavlovian conditioning (i.e., stimulus-outcome associations, S–O) and instrumental conditioning (i.e., response-outcome associations, R–O) (Holmes, Marchand, & Coutureau, 2010). The PIT effects thus indicate an impact of S on the R–O associations, only S could act differently in specific and general PIT effects. It was proposed that the specific PIT effects reflect that the Pavlovian stimulus has activated both the cue identity and its incentive value in the PIT transfer test and hence triggered a change in goal-directed control of behaviors (Hogarth et al., 2013; Mahlberg et al., 2021; Seabrooke, Hogarth, Edmunds, & Mitchell, 2019; Sebold et al., 2016). With prolonged use of drugs, the Pavlovian stimuli (S) lose the ability to trigger the specific identity of the drugs and instead retrieve only the affective value, leading to a shift from specific PIT to general PIT (Everitt & Robbins, 2016). Therefore, drug-related PIT effects may reflect the changes in behavioral control in addiction (Everitt & Robbins, 2005).

While the first use of the PIT paradigm dates back to the 1940s and most data still come from animal studies. Only in recent years, the PIT Paradigm has been used to study addictive behavior in humans. Specific PIT effects have been found in smokers (Manglani, Lewis, Wilson, & Delgado, 2017; Steins-Loeber et al., 2020) and social drinkers (Hardy, Mitchell, Seabrooke, & Hogarth, 2017; Mahlberg, Weidemann, Hogarth, & Moustafa, 2019). For example, Mahlberg et al., found that alcohol cues enhanced craving and alcohol-seeking behavior in the PIT procedure (increased key presses during the transfer phase) in a group of young male beer drinkers, and alcohol-PIT effects were positively correlated with the expectations of receiving outcomes in drinkers (Mahlberg et al., 2019). These findings suggest that addiction-related CS primed congruous outcome choices (e.g., drug-taking/seeking behaviors). In behavior addiction, patients suffering from gambling disorders, relative to HCs, showed a higher choice rate for gambling-related reward when gambling cues were present, indicating an enhanced gamble-related specific PIT effect in these individuals (Genauck et al., 2021). Assessing PIT, which has been associated with substance and behavior addiction in some studies, should now be transferred to IGD as it was newly included in the DSM-5. In terms of IGD, one previous study found that the intensity of problematic Internet gaming was associated with a stronger PIT effect in healthy participants, where gaming cues increased the selection of game-related instrumental behaviors (Vogel et al., 2018). However, they have not diagnosed the participants. It is unclear if individuals with IGD have altered specific PIT effects.

This study aimed to investigate the specific PIT effects in IGD and HCs. We hypothesize that (1) individuals with IGD would exhibit stronger specific PIT effects than HCs and that (2) severity of IGD symptoms and gaming problems would be correlated to specific PIT effects in the IGD group.

METHODS

Participants

We recruited 54 IGD and 54 healthy controls (HCs) from Luzhou, China, via poster advertisements and social media platforms. Eight participants (6 IGD and 2 HCs) did not show up for the experiment, and ten (8 IGD and 2 HCs, see Quality Control) were excluded due to quality control, resulting in 90 valid data (40 IGD and 50 HCs) for further analyses (Table 1). The diagnosis of IGD was made based on the DSM-5 criteria by qualified psychiatrists (KZL and KG). IGD was diagnosed according to the criteria of DSM-5, an individual who met five or more of the nine diagnostic criteria was deemed as IGD. Exclusion criteria for all participants include 1) current psychiatric disorders listed in axes I of DSM-IV (e.g., depression, anxiety, schizophrenia, and substance-use disorders assessed by a trained psychiatrist using the Mini International Neuropsychiatric Interview (MINI) (Lecrubier et al., 1997)), and 2) with a history of any types of drug abuse. Because pictures from the game

Honor of Kings were used as unconditioned stimuli in both Pavlovian and instrumental conditioning, all participants were required to be familiar with this game, so that they would not regard the game-related pictures as ordinary animation pictures. Moreover, to ensure that the game-related reward could effectively reinforce reward learning in IGD, for participants with IGD, *Honor of Kings* must be their favorite game.

Procedure

The PIT paradigm. We adopted the PIT paradigm used in the (Vogel et al., 2018) study. The task consists of three phases (Fig. 1): (1) Pavlovian phase (S–O): three abstract pictures (conditioned stimuli, CS) were paired with three different outcomes, game (CS^G), shopping (CS^S), and social reward (CS^T). (2) Instrumental phase (R–O): participants learn to perform an instrumental response (keypress) related to a reward, 'G' for a game-related reward, and 'F' for a shopping-related reward. (3) Transfer phase (S–O–R): the Pavlovian CS are presented whilst the instrumental response is performed to assess their influence on the instrumental response.

For the PIT paradigm participants were seated in front of a desktop computer. Four bowls were placed in front of the participant. The two bowls on the left side contained the gaming-related reward (blue coins with the heroes from the *Honor of Kings*) and the shopping-related reward (yellow coins with the symbol of money), respectively. The right bowls were empty and labeled with 'Your gaming points' and 'Your shopping points'. The experimental procedure was programmed with PsychoPy software (Peirce, 2007).

During the *Pavlovian* phase, in each trial, one of three CS stimuli (300 × 300 pixels) appeared on the screen for 4s. After the CS disappeared, the following words were presented: "Which type of picture do you think you will see? Click on the options to choose. A = shopping picture, B = social-reward picture, C = gaming- picture." After the participants made their choice, a picture of a gaming, social, or shopping reward (depending on the cue) was present for 2 s. Participants completed five blocks of twelve trials (including 20 CS^G, 20 CS^S, and 20 CS^T trials).

The *instrumental* phase was to establish two reward-related responses. Thus, by pressing either 'G' (gaming-related key) or 'F' (shopping-related key), participants could earn the coins from the left-side bowls. At the beginning of each trial, a gray square (300 × 300 pixels) was presented for 3s. Meantime participants were asked to press one of the two keys repeatedly. In each trial, only one outcome was scheduled at random to be available, thus the gaming-related and the shopping-related response were reinforced with a 50% contingency. In a trial when the desired reward (e.g., gaming reward) was available, if the participants pressed the right key (e.g., 'G') at least X times during the 3s response window, they get one point (e.g., 'gaming-point +1'), otherwise, they got nothing. X is an integer between 2 and 5, which varies randomly in each trial. The instrumental phase consisted of four blocks of 10 trials. At the end of the instrumental phase, there was a memory test. The instruction states "A memory test is coming next. Please read the prompt carefully and press the corresponding button. There is no time limit for reaction. Press the space bar to continue when you are ready". The memory test has two trials, each with one question, asking "Which key lead to gaming-related rewards, please press it?" and "Which key lead to shopping-related rewards, please press it?". No feedback was given. The second trial was present immediately after the participants made a response for the first trial.

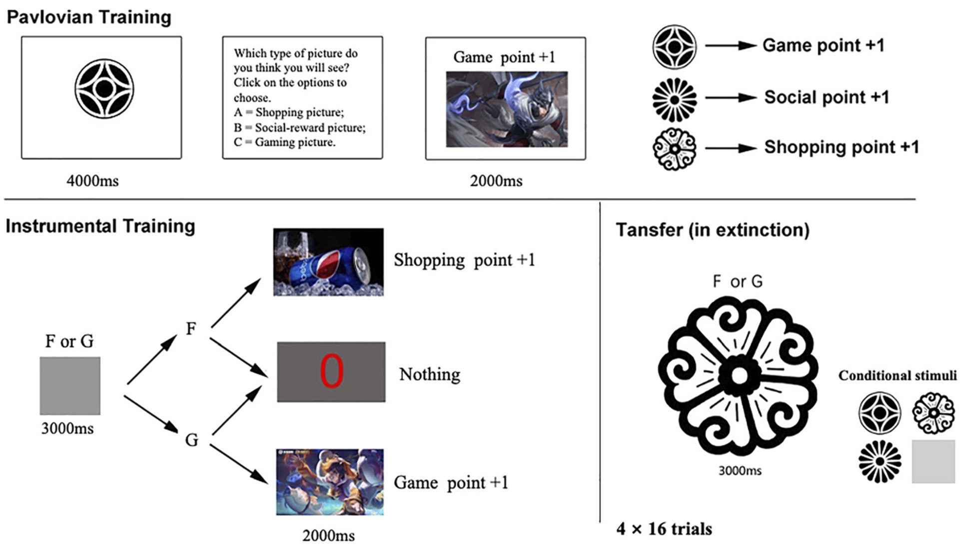

Fig. 1. Pavlovian-to-instrumental Transfer (PIT) task. (A) In the Pavlovian phase, participants learned that specific abstract pictures (CSs) predicted specific outcomes. (B) In the instrumental phase, participants could choose the 'G' key or the 'F' key to obtain gaming-related or shopping-related rewards. (C) In the transfer test, participants performed instrumental key press while one of the CSs or a gray square was present, and no outcomes were delivered during the test (extinction)

During the *transfer* phase, participants could still earn gaming or shopping coins by pressing either 'G' or 'F' key, as in the instrumental phase. However, this time the gray square was only present in 1/4 of the trials, while in the remaining 3/4 of the trials, either the CS^G, the CS^S, or the CS^T was presented in random order. There were 64 trials in the *transfer* phase. Following previous studies (Cartoni et al., 2016; Loeber & Duka, 2009; Martinovic et al., 2014), the transfer phase was conducted in nominal extinction to preclude new stimuli-response associations which might confound the PIT effect. Therefore, in the transfer phase, participants did not receive any feedback after each trial but were informed about their total winnings at the end of the experiment.

All participants were compensated with 40 RMB. Additionally, an extra gaming- or shopping-related gift was given to each participant, depending on the coins they earned in the task. Particularly, participants who earned more shopping-related coins got a deck of Poker Cards with money patterns, and participants who earned more game-related coins got a deck of Poker Cards with the portraits of heroes in the *Honor of Kings*. Participants were told that they would get an extra gift from the task but did not know what it would be.

Stimuli. Totally 20 gaming-reward, 20 social-reward, and 20 shopping-reward pictures with similar arousal and valence value were selected as reinforcers for the PIT task. All pictures were edited to 1,280 × 800 pixels and 300 ppi. In addition, 3 colorless abstract patterns were selected as CSs for the Pavlovian phase, one for each reward type, respectively. These stimuli were selected from a set of 40 gaming-, 40 shopping-, and 40 social-related pictures, and a set of 10 colorless abstract pictures based on a pilot study (See supplementary material for detail).

Measures

To assess the severity of IGD symptoms, participants completed the Chinese version 9-item dichotomous *Internet Gaming Disorder Scale (IGDS)* (Lei et al., 2020) and the *Internet Addiction Test (IAT)* (Lai et al., 2013). Additional information on the daily gaming time (DGT) in the past year, the start age of game-play, and craving for gaming (via a visual analog scale from 0 = not at all to 10 = extremely) were also collected.

Statistical analysis

Quality Control. To ensure that all participants have established the correct S–O association, we excluded participants whose accuracy in the final block of Pavlovian was <90% (Bannerman, Chapman, Kelly, Butcher, & Morris, 1994). Five IGDs and one HC were excluded due to this criterion.

To ensure that all participants have established the correct R–O association, we excluded participants whose was not reached 100% accuracy in the memory test at the end of the instrumental phase. Three IGDs and one HC were excluded due to this criterion.

Our PIT task does not have a practice phase. To ensure that participants got familiar with the response, we excluded the first block of the instrumental and transfer phase from further analyses. This strategy was adopted following previous studies (Island, Szalda-Petree, & Kucera, 2007; Kaufman, DeYoung, Gray, Brown, & Mackintosh, 2009).

Trails where participants did not make a response within the response window (3s) or when they pressed both the 'G' and 'F' keys were also removed.

Calculation of PIT effects. To assess PIT effects, the choice rate (CR), response rate (RR, in Hz), and response time (RT, the duration between trial onset and the first keypress) were calculated. We calculated the CR as the number of trials where the gaming-related key (G) was pressed divided by the total number of valid trials. We calculated RR by dividing the number of key presses by the duration of the response window (3s) so that RR indicates the number of presses per second.

During the transfer phase, to determine if there was a PIT effect, repeated measures ANOVA were performed with CR, RR, and RT as the dependent variable, respectively. Two independent variables were entered in the ANOVA model, with CS (CS^G, CS^S, and CS^T) as a within-subject variable, and group (IGD VS. HCs) as a between-subject variable. According to previous studies (Prevost, Liljeholm, Tyszka, & O'Doherty, 2012; Vogel et al., 2018), a significant group × CS interaction indicates a between-group difference in PIT effects. We then continue to calculate the magnitude of the PIT effects. The specific PIT reflects the Pavlovian cues (e.g., CS^G) only influence instrumental response with the congruous outcome (e.g., the press of the 'G' key). Therefore, for CR, the specific $PIT_{game} = CR_{CSG} - CR_{CSS}$.

Analyses of the instrumental phase data. To assess if individuals with IGD have a different reward learning pattern in instrumental conditioning with game-related rewards. Three 2-way [group (IGD VS. HCs) × block (block2, block3, block4)] repeated measures ANOVA were performed in the instrumental phase, with CR, RR, and RT as the dependent variable, separately. Note that, unlike the transfer phase, in the instrumental phase analysis, the measurements were averaged on block level, so that each subject has one CR value for each block.

For all repeated measures ANOVAs, Greenhouse-Geiser corrections were applied in case the assumption of sphericity was violated. All results of repeated measures ANOVAs were tested using corresponding Bayesian analyses ('BayesFactor' package in R (version 4.2.1) (Morey & Rouder, 2022)). The BayesFactor package v 0.9.12–4.4 with default settings was used for calculating Bayesian factors (BF_{10}) and for estimating effect sizes. BF_{10} quantified the strength of evidence in favor of the alternative hypothesis H1. We considered the degree of evidence by Jeffreys's classification: 1 for no evidence; 1–3 for anecdotal (i.e., circumstantial) evidence; 3–10 for substantial evidence; 10–30 for strong evidence; 30–100 for very strong evidence; and >100 for extreme evidence (Rouder & Morey, 2012).

Correlation analyses. To assess the clinical associations of the PIT effects, for the IGD group, Spearman's rho was calculated between the severity of IGD symptoms/problems (including the DGT, craving level, start age of game-play, scores of IGDS, and scores of IAT) and the magnitude of the specific PIT effects. All analyses were performed using SPSS Statistics (Version 23).

Ethics

Participants were informed about the study and all provided informed consent. The study was approved by the Institutional Review Board of Southwest Medical University and was conducted by the latest revision of the Declaration of Helsinki.

RESULTS

Demographical, clinical, and internet gaming characteristics

The IGD and HCs groups did not differ in age, gender distribution, and start age of game-play (Table 1). IGD had significantly higher scores of IGDS, DGT, craving level, and IAT.

Results of the instrumental phase data analysis

For CR, a significant main effect of group was found (F (1, 88) = 15.63, p < 0.001, η_p^2 = 0.15, BF_{10} = 155), post-hoc comparisons revealed higher CR for the game-related key in IGD than HCs, indicating that individuals with IGD were more receptive to game-related reward. No significant group × block interaction (F (2,176) = 0.51, p = 0.601, η_p^2 = 0.01, BF_{10} = 0.11), and block main effect (F (2,176) = 0.04, p = 0.963, BF_{10} = 0.04) were found.

For RR and RT, no significant group × block interaction effect, main effect of block, or main effect of group were found (See supplementary material for detail).

Table 1. Group differences in HCs and IGD

	HCs (n = 50)	IGD (n = 40)	t/χ2	p
Age	21.25 ± 2.18	21.84 ± 2.31	−1.25	0.214
Gender (female/ male)	19/31	15/25	0.002	1.000
DGT	2.02 ± 2.86	3.99 ± 3.30	−2.96	0.004
Craving	2.27 ± 1.88	5.88 ± 1.86	−9.02	<0.001
Start age of game-play	13.33 ± 4.17	13.08 ± 4.58	0.27	0.786
IGDS	1.26 ± 1.55	6.30 ± 1.76	−14.45	<0.001
IAT	34.22 ± 10.67	59.10 ± 14.67	−9.31	<0.001

Note: DGT, daily gaming time in the past year.

PIT results

For CR, a significant group × CS interaction was found (F (3, 261) = 6.63, p < 0.001, η_p^2 = 0.07, BF_{10} = 55.66) (Fig. 2A). Simple effect analysis indicated that, compared to CS^S, the presence of CS^G induced more increase in CR for the game-related key in the IGD group than in the HCs group. Additionally, a significant main effect of group (F (1, 87) = 6.86, p = 0.01, η_p^2 = 0.07, BF_{10} = 1.89) and a significant main effect of CS (F (3, 261) = 152.62, p < 0.001, η_p^2 = 0.64, BF_{10} = 5.19) were also found. A follow-up two-sample t-test of the magnitude of specific PIT effects confirmed stronger specific PIT_{game} effects in IGD when compared to HCs (t (88) = 3.19, p = 0.002) (Fig. 2B).

For RR, the ANOVA revealed a significant main effect of CS (F (3, 86) = 6.6, p < 0.001, η_p^2 = 0.19, BF_{10} > 1,000), but no significant group main effect (F (1, 88) = 0.35, p = 0.557, η_p^2 = 0.004, BF_{10} = 0.44), nor group × CS interaction (F (3, 86) = 0.28, p = 0.840, η_p^2 = 0.10, BF_{10} = 0.04) was found.

For RT, a significant group × CS interaction effect (F (3, 83) = 3.15, p = 0.029, η_p^2 = 0.10, BF_{10} = 2.1) was

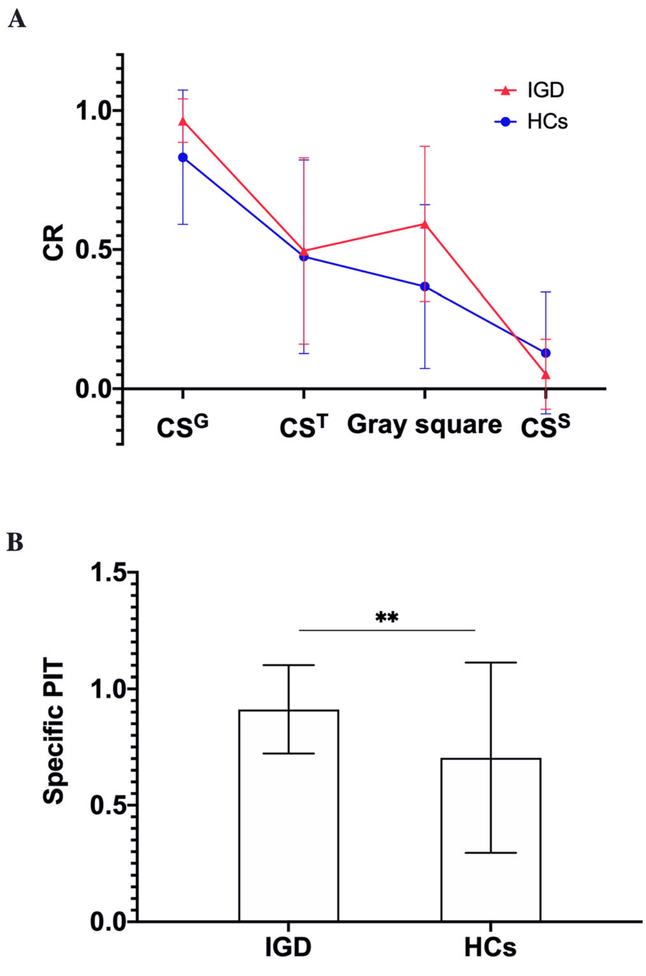

Fig. 2. (A) The interaction effect of group and CS on CR. (B) The magnitude of specific PIT effects compared between IGD and HCs. CS, conditioned stimulus. CR, choice rate. RT, response time. $^{**}p$ < 0.01

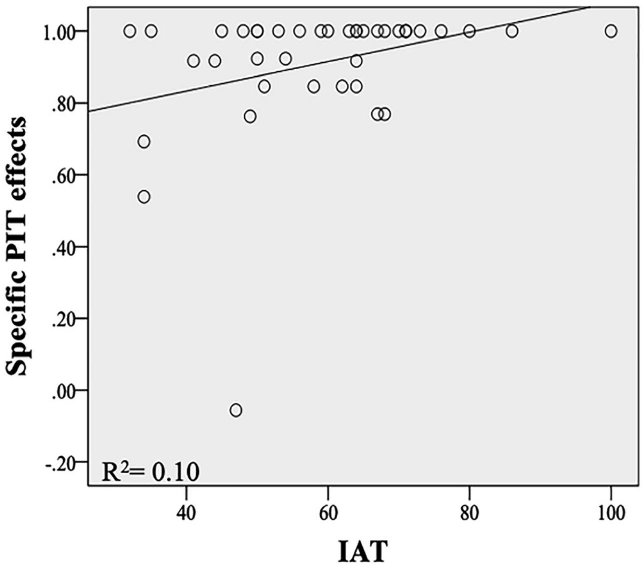

Fig. 3. Correlations between the IAT scores and PIT effects in the IGD group

found, simple effect analysis indicated that the IGD group respond significantly slower than the HCs group when the gray square was present (t (85) = −2.48, p = 0.015), but not when the other three CSs were present (t (88) = −0.32, p = 0.748; t (88) = −1.14, p = 0.257; and t (87) = −1.78, p = 0.079 for CS^G, CS^T, and CS^S, separately). However, the follow-up two-sample *t*-test revealed no significant group difference in the magnitude of specific PIT (t (88) = 1.67, p = 0.099) for RT. This ANOVA also revealed a significant main effect of CS (F (3, 83) = 16.49, $p < 0.001$, $\eta_p^2 = 0.37$, $BF_{10} > 1{,}000$), but not the main effect of group (F (1, 85) = 2.95, p = 0.089, $\eta_p^2 = 0.03$, $BF_{10} = 0.92$).

Correlations. In the IGD group, correlational analyses indicated that the magnitude of specific PIT_{game} effects were positively correlated with IAT scores (rho = 0.39, p = 0.014; Fig. 3). The correlations between specific PIT_{game} effects and DGT, craving, start age, and IGDS were not significant ($p > 0.215$).

DISCUSSION AND CONCLUSION

The present study compared the PIT effects between IGD and HCs using a PIT paradigm. To our knowledge, this is the first study that has compared the PIT effects of IGD with HCs. The key findings were: 1) the IGD group showed stronger specific PIT_{game} effects than the HCs group; 2) in the IGD group, specific PIT_{game} effects were positively correlated with IAT scores.

The individuals with IGD demonstrated stronger specific PIT_{game} effects than HCs in this study. This result was in line with previous studies by Vogel et al. (2018) where stronger specific PIT_{game} effects were associated with severer IGD symptoms. Our results are also in line with the study on gambling disorders (Genauck et al., 2021), where individuals with gambling disorders showed enhanced gamble PIT than HCs. The enhanced specific PIT suggests that individuals with IGD have a greater susceptibility to game-related cues. According to the incentive-sensitization theory, environmental cues associated with the experience of drug consumption not only trigger stronger physiological and neurobiological responses than other CSs (e.g., cue-reactivity in Starcke, Antons, Trotzke, & Brand, 2018), but also promotes instrumental behavior such as alcohol seeking and intake (Berridge & Robinson, 2016). The enhanced specific PIT effects in IGD suggest that individuals with IGD were receptive to Pavlovian-conditioned game-related cues that were salient (Berridge & Robinson, 2016; Robinson & Berridge, 2008). Moreover, we demonstrated that enhanced specific PIT effects were positively correlated with IAT scores in the IGD group. This result was in line with previous studies on problematic Internet gaming (Vogel et al., 2018) and social drinkers (Mahlberg et al., 2019), further suggesting that the enhanced specific PIT effects could reflect important aspects of IGD pathology. Moreover, it was found that specific PIT effects were sensitive to outcome devaluation and hence could reflect goal-directed controls (Mahlberg et al., 2021; Seabrooke et al., 2019). From this perspective, the enhanced specific PIT effects could also reflect changes in goal-direct behavioral control in IGD.

Our result was not consistent with previous studies on alcohol use disorder and substance use disorder (Hogarth et al., 2019; van Timmeren et al., 2020), where no case-control difference in addiction-related specific PIT effects was found. This inconsistency suggests that individuals with IGD could have different PIT alterations than alcohol use disorder and substance use disorder. However, this inconsistency could also be due to paradigm differences, which were considered as one major source of heterogeneity in PIT studies (see Garbusow et al., 2022) for a detailed discussion on this issue). Unlike the current study, these two studies did not use addiction-related rewards as reinforcers in their training (they both used snacks). The incentive-sensitization theory posits that because of long-lasting changes in dopamine-related motivation systems, susceptible individuals could become particularly sensitive to drug-related cues (Berridge & Robinson, 2016). Therefore, it may be more effective to trigger specific PIT effects using gaming-related rewards in individuals with IGD than in HCs.

We have not found a different PIT effect between IGD and HCs for RR and RT, the result is consistent with a previous study in humans (Freeman, Razhas, & Aron, 2014; Meemken & Horstmann, 2019; van Timmeren et al., 2020), but not consistent with previous animal studies (LeBlanc et al., 2012; Shiflett & Balleine, 2010; Wiltgen et al., 2012). The reason for the absence of a significant PIT effect in RR and RT could be that our (human) participants quickly learned that an extra (frequency and fast) key press was unnecessary to get the reward. Indeed, 2-way [group (IGD VS. HCs) × block (block 1–5)] repeated measures ANOVA with RR and RT as dependent variables, both revealed a significant main effect of block in the transfer phase, but no significant interaction or group main effect (See supplementary material for detail). Post-hoc tests indicated that block 1 had longer RT and lower RR compared to the other four blocks. Similar results were also obtained in the analyses of data from the instrumental phase (Fig. S1).

This study has a few limitations. First, only reward conditions, but not punishment conditions were trained during instrumental conditioning and Pavlovian conditioning. Further studies with punishment conditions are needed to test if Pavlovian cues of losing (e.g., Jahfari et al., 2019) could also influence instrumental response in IGD. Moreover, the PIT paradigm used in the current study does not have a non-rewarded CS in the Pavlovian conditioning phase (e.g., in van Timmeren et al., 2020), which limited its ability to detect changes in general PIT effects.

In summary, individuals with IGD showed enhanced specific PIT effects than HCs, which could reflect a greater susceptibility to gaming-related cues in IGD.

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Authors' contribution: CQ: formal analysis, writing – original draft. WL: conceptualization & design, methodology, writing – review & editing. JC, KG & WL: funding acquisition. JC: writing – review & editing, investigation, resources, project administration. SF, YC, XC, XL, MT, XZ, JD, & YP: investigation. KL & KG: writing – review & editing. All authors had full access to all data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Conflict of interest: None.

SUPPLEMENTARY MATERIAL

Supplementary data to this article can be found online at https://doi.org/10.1556/2006.2023.00023.

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