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Biased processing of game-related information in problematic mobile gaming users

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ABSTRACT

Background and aims: The present study investigated processing bias for game-related cues in problematic mobile gamers (PMGs) under or above the threshold of conscious awareness. *Methods:* In Experiment 1, all participants (20 PMGs and 23 casual players (CPs)) finished a masked visual probe task during a brief (17ms) masked exposure condition. In Experiment 2, an unmasked visual probe task was conducted by an additional forty participants (20 PMGs and 20 CPs) at two exposure durations (200 and 500ms). *Results:* Results showed that PMGs, but not CPs, had an attentional bias for game-related cues which had been presented with two exposure durations (17 and 200ms). *Discussion and conclusion:* In conclusion, the present study provides evidence that bias in PMGs could be observed both preconsciously and consciously. The results are discussed with reference to incentive sensitization theory and automatic action schema theory.

KEYWORDS

problematic mobile gaming, game-related cues, attentional bias

INTRODUCTION

Problematic mobile gaming (PMG) is a behavior whereby users strongly rely on mobile games and play mobile games repeatedly in a comparatively long period (Sun, 2015). Such behavior is associated with functional impairment and emotional difficulties, i.e., enhanced depression and anxiety, as well as more social isolation (Stockdale et al., 2018). PMG belongs to the officially recognized Gaming Disorder (GD) diagnosis in ICD-11, whereas many other online addictive behaviors at the moment are not officially recognized (Montag, Wegmann, Sariyska, Demetrovics, & Brand, 2021), e.g., problematic social media use and problematic shopping. As a category of the GD-diagnosis, the behavior manifests itself in particular on the smartphone device (see also for investigation of GD and devices the work by Montag et al., 2021).

Attention bias for addiction-related cues is a typical characteristic of addictive disorders (Cousijn et al., 2013). Multiple theories in the context of substance use disorders offer relevant perspectives on this phenomenon. Among others, incentive sensitization theory (Robinson & Berridge, 1993) predicts that addiction-related stimuli are highly attractive, and "grab attention" because such stimuli acquire motivational salience. Thus, addictive disorders are accompanied by automatic and uncontrolled bias processing even in the absence of

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awareness (Robinson & Berridge, 1993, 2000). Going further, Tiffany (1990) proposed that an automated action schema is formed during the development of addiction. Such a schema can promote addictive disorders by allocating their attentional resources more quickly to addiction-related stimuli without awareness. When the addictive stimuli are unavailable, they still exhibit an attentional bias toward addiction-related stimuli at the conscious level. In summary, according to the aforementioned theories, addiction-related cues can attract the attention of a person being afflicted with an addictive disorder and this can be below or above the threshold of conscious awareness. However, these theories may also be applicable to behavioral disorders, e.g., individuals who are addicted to Internet (IAs) (Balconi, Venturella, & Finocchiaro, 2017; He, Zheng, Nie, & Zhou, 2018). So, if PMGs have biased processing for game-related cues below or above the threshold of conscious awareness, it would provide evidence that PMG could be defined as a behavioral addiction (Gaming Disorder represents an officially recognized disorder in ICD-11), and help us to understand better how PMG works in attention processing. To our knowledge, no prior studies focused on the different aspects of attentional processing in PMGs.

Previous studies have used pictorial versions of the masked visual probe task to assess preconscious attention for addiction-related cues (Bradley, Field, Mogg, & De Houwer, 2004; Mogg & Bradley, 2002). In each trial, both addiction-related and neutral pictures were briefly presented and masked to ensure processing of the stimuli to be below awareness. Immediately after the masks disappeared, a probe was presented (or not) at the same location as the earlier presented addiction-related picture. Participants were required to respond to the probe as fast as possible. When participants perform faster in the congruent condition (this means that the addiction-related-stimulus and probe are presented in the same location) compared to the condition where the probe appeared in the opposite region where the neutral picture was presented, then there is a bias for addiction-related pictures preconsciously.

So far, studies using the masked visual probe task have provided inconsistent results in the context of substance use disorders. For example, there was no evidence that smokers have preconscious attentional bias towards smoking cues presented with 17 ms (Bradley et al., 2004; Mogg & Bradley, 2002). However, individuals who have alcohol use disorder had a stronger initial heart rate deceleration after 30 ms exposure to masked alcohol pictures compared with masked neutral pictures, indicating a pre-attentive processing of alcohol stimuli (Ingjaldsson, Thayer, & Laberg, 2003). The only study in behavioral addictions observed that IAs have a preconscious bias for internet-related pictures when pictures were shown for 14 ms and also in a masked condition (He et al., 2018). It is reasonable to consider that incentive sensitization theory and automated action schema theory can be extended to behavioral disorders (Berridge, 2009; Hellberg, Russell, & Robinson, 2019).

One method of assessing attentional bias in the field of addiction is the visual probe task (Zhang, Fung, & Smith, 2019). It can provide a snapshot view of this process by manipulating exposure duration of the pictures (Kerr-Gaffney et al., 2018). When the pictures are shown with a screen duration of 200 ms or less, it can be used to examine how quickly the stimulus can be captured, i.e., early vigilance. When duration is prolonged to 500 ms and above, there is a greater opportunity to reflect on the extent of sustained processing of information, i.e., late maintenance (Field & Cox, 2008). If people respond faster to the probe in the congruent condition during 200 ms or 500 ms, it means vigilance or maintenance may be playing an important role in mediating the attentional bias.

Studies using the visual probe task have indicated the initial orienting and late maintenance of attention bias for alcohol pictures in alcohol drinkers (Field, Mogg, & Bradley, 2004), and smoking-related pictures in smokers (Bradley et al., 2004). However, behavioral disorders may show a distinct pattern in attentional bias. Here, using a modified version of the Posner Task (Posner, 1980), it has been observed that only vigilance for addiction-related cues works in the attentional processing of problematic gamblers (Ciccarelli, Nigro, Griffiths, Cosenza, & D'Olimpio., 2016), and there is no definitive conclusion for other subtypes, such as gaming disorders. To the best of our knowledge, only one study found that bias processing for game stimuli in video gamers was primarily characterized by rapid orienting, using the visual probe task (Juncai, Tiantian, Jun, & Ping, 2017). This may suggest that the influence of "game experience" on cognitive processing, but not the role of "problematic extent induced by the game using," plays a pivotal role in the development of PMG. This said, it remains unclear that how PMG works in attention processing. According to incentive sensitization theory, individuals who are addicted automatically direct their attention to salient stimuli because of their strong attraction (Robinson & Berridge, 2000). It seems that attentional biases are more likely to manifest instead of initial orientation. If PMG could be defined as a behavioral addiction, such a group of persons should also be characterized by attentional bias for game-related cues, and processing would be specific to the early stage.

Against this background, the present study investigated attentional bias for salient stimuli presented below and above the threshold of awareness in PMGs. Experiment 1 used a masked visual probe task with a presentation time of 17 ms to explore preconscious biases for game-related pictures in PMGs, and Experiment 2 adopted the same but unmasked task to examine whether PMGs have a bias for game-related pictures in initial orienting (200 ms) and in the maintenance of attention (500 ms). An awareness check was given after the masked visual probe task to restrict participants' perception of the content of pictures. The main hypotheses are as follows: PMGs would show preconscious bias and vigilance for game-related pictures, but CPs would have no bias below or above awareness; thus, a Group × Probe location interaction effect on RTs to probes in the masked (17 ms) and unmasked visual probe task (200 ms) were expected to be observed. Specifically, compared to neutral pictures, when using game-related pictures PMGs (but not CPs) should have a faster response time to probes in the masked (17 ms) and unmasked visual probe task (200 ms).

STUDY 1

METHOD

Participants

Based on the previous study (Jeromin, Nyenhuis, & Barke, 2016), the sample size required for the 2 × 2 mixed design was computed a priori with G*Power (version 3.1.9.4). After setting α (0.05), f (0.25), and power (0.80) respectively, it showed an overall sample size of 34 participants needed (same with Experiment 2).

An online survey was conducted in a university in Tianjin, China. 238 students were recruited and screened for their mobile game usage. A question appeared at the start of the survey: "What would you do first to spend your free time?" When the students reported they regard playing games on mobile phone as their first (preferred) pastime, they could continue to the next question: "What's a video game you will choose first?" According to the Gaming Industry Report, published in 2022 by Gama data, which is a strategic partner of the China Game Industry Research Institute, "Honor of Kings" and "Game for Peace" are most popular mobile games in China. Thus, students who considered these two games as the favorite mobile game were subsequently given the Chinese version of Young's Internet Addiction Test (IAT). The Chinese version of IAT have been used widely in previous studies (Dong, Yang, Lu, & Hao, 2020; He et al., 2018). The present study used it to measure excessive mobile gaming usage by changing the keywords of "Internet" to "playing mobile games". It contains 20 items and is rated on a 5-point (1 = hardly, 2 = occasionally, 3 = often, 4 = sometimes, 5 = always), with higher scores indicating more use. In this study, Cronbach's alpha for internal consistency was 0.95. On the basis of IAT diagnostic criteria, 20 participants and 23 participants were assigned to the PMGs group (IAT score of 50 or more, 12 men and 8 women) and the CPs group respectively (IAT score less than 50, 13 men and 10 women). They had no significant difference in age (PMGs: $M = 20.70 \pm 0.92$; CPs: $M = 21.30 \pm 1.79$; $t\ (41) = -1.36$, $p = 0.182$, Cohen's $d = -0.42$) or sex ($\chi^2 = 0.05$, $p = 0.82$, Cohen' s $d = 0.03$), but PMGs showed higher levels of problematic gaming than CPs as assessed by IAT scores (PMGs: $M = 62.10 \pm 11.16$; CPs: $M = 36.87 \pm 6.90$; $t\ (41) = 9.04$, $p < 0.001$, Cohen's $d = 2.72$). All subjects were right-handed, and none of them had a history of major disease or mental illness. After fully understanding the study procedure, they signed informed consent, and received a reward after completing the tasks.

Materials

Because all participants recruited in this study considered *Honor of Kings* or *Game for Peace* (It is the same type of game as Player Unknown's Battle Grounds) as their favorite mobile game, materials only included these two games. The stimuli consisted of 10 game scenes from "Honor of Kings" and "Game for Peace". Each was paired with a landscape or scene picture matched as closely as possible for color and visual-space distribution. We calculated the entropy of each picture to represent the perceptual complexity (Wang & Ren, 2018), using Python. The paired *t*-test showed there was no significant difference across administration time ($M_{game} = 14.10$, $SD_{game} = 0.41$; $M_{neutral} = 14.50$, $SD_{neutral} = 0.50$; $t\ (9) = -1.85$, $p = 0.097$). 123 students, who did not participate in the following experiments, rated the pictures' valence, arousal, and game representation rated on 7-point scales (1 = very negative, very calm, or very unavailable and 7 = very positive, very excited, or very available) (Table 1). An additional 10 pairs of landscape pictures were prepared as fillers, and 20 pictures as practice pictures. Two masking images were identical to those used in the Gao, Schneider, and Li (2017) study. Each picture was adjusted in size as 10.63 cm wide and 5.91 cm high, and the distance between the inner edges of the pairs was 2.40 cm. When the stimulus was on the left (right), the visual angles from the distance from center to right (left) edges or middle of the stimuli were 1.1° or 5.7° respectively.

Procedures

Participants completed the tasks on a computer monitor (16 × 29 cm) and used a regular keyboard with a constant distance of 65 cm from the screen. All tasks were programmed and run with E-prime 2.0 (Schneider, Eschman, & Zuccolotto, 2007).

The structure of Experiment 1 is based on a masked visual probe task adopted by Bradly et al. (2004). The masked visual probe task consisted of 10 practice trials, followed by 80 experimental trials (40 critical trials and 40 filler trials) randomly. Each trial started with a central fixation cross shown for 1000 ms. The picture pair and a mask were presented sequentially for 17 and 67 ms. Immediately after the offset of the masks, a probe was presented in the position of one of the preceding pictures, until the participant pressed the key 'f' (left) and 'j' (right) as quickly as possible to indicate the position of the probe. There was an inter-trial of 2000 ms (Fig. 1). In the experimental trials, each game-related or filler picture appeared twice on the left side of the screen, and twice on the right. The probe replaced one of the pairs an equal number of times in each location, and the distance between the two probe positions was 13.20 cm.

Next, an awareness check was conducted to ensure participants' awareness of the content of the pictures was restricted under the same presentation condition (i.e., 17

Table 1. Material information

Picture	Valence	Arousal	Representation
Game	5.43 (0.77)	5.18 (0.11)	5.92 (0.14)
Neutral	5.52 (0.12)	5.12 (0.16)	4.50 (0.14)
T	−1.85	0.97	6.70
P	0.10	0.36	<0.001
Cohen's d	−0.16	0.43	10.14

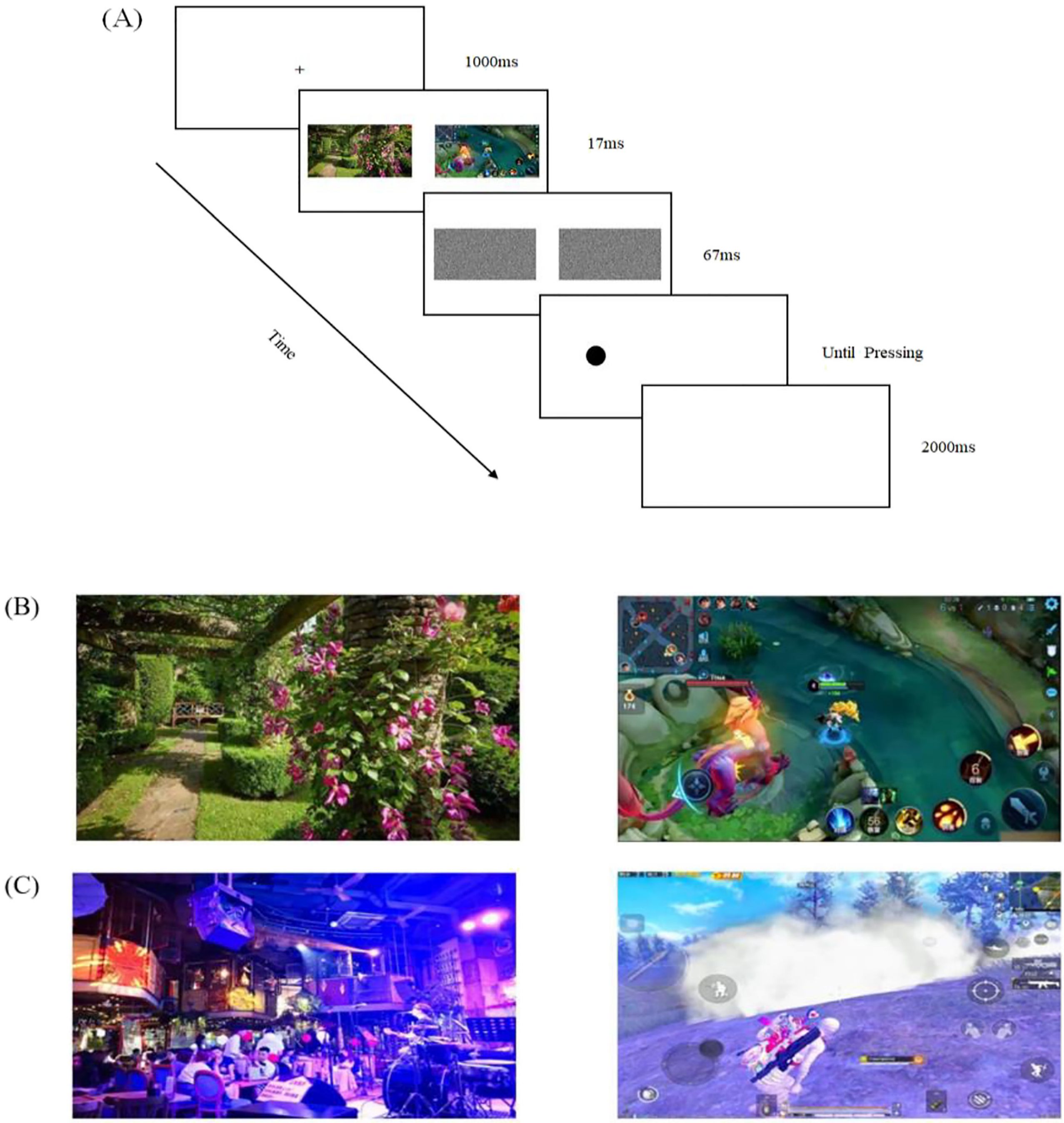

Fig. 1. Masked visual probe task. (A) An example of an "incongruent" trial, participant should press "f" to be a correct answer. However, if the probe was presented on the right side, this should be a "congruent" trial, and participant should press "j" to be a correct answer. (B) An example of material include game, selected from "Honor of Kings", and neutral condition. It was also the example of material presented in (A). (C) An example of material include game, selected from "Game for Peace", and neutral condition

and 67 ms of picture pairs or masks respectively). The procedure in this task was nearly the same as with the masked visual probe task, but the probe changed to a question mark (?). Participants were asked to indicate whether either of the pictures that were presented before the masks contained game-related images. There were 10 practice trials, followed by 40 experimental trials (20 game-neutral picture pairs and 20 neutral-neutral pictures).

All tasks were presented on a 14.1-inch monitor, 1,366 × 768 pixels, attached to a standard keyboard. The refresh rate was 60Hz.

Ethics

All experiments in our research were carried out in accordance with the Declaration of Helsinki and approved by the Ethical Committee of Tianjin Normal University (No. 2022031501). All participants signed informed consent.

Results

Awareness check

If participants cannot consciously be aware of the content of pictures, it would be expected that their responding is at chance levels, so the average percentage of error responses was compared with 0.5 (it means that each group should have an average error rate of 50%). A one-sample *t*-test showed no significant difference between the average error rates and 0.5 in each group (PMGs: $M = 0.44$, $SD = 0.22$; $t\ (19) = -1.61$, $p = 0.26$, Cohen's $d = 0.27$; CPs: $M = 0.45$, $SD = 0.18$; $t\ (22) = -1.26$, $p = 0.22$, Cohen's $d = 0.27$).

The masked version of visual probe task

RTs were discarded based on the followings conditions (2.17% of all RTs): (1) filler trials and trials with errors, (2) RTs less than 100 ms or greater than 1000 ms, and (3) RTs were more than 3 SDs above the mean. A 2 × 2 ANOVA was carried out with group (PMGs, CPs) as the between-subject variable and probe position (probe in same versus different location to the game-related picture) as within-subject variables. The results showed no significant main effects of group [$F\ (1, 41) < 0.01$, $p = 0.98$, $\eta^2 < 0.001$], nor probe location [$F\ (1, 41) = 1.50$, $p = 0.23$, $\eta^2 = 0.04$], but a significant Group × Probe location interaction was found [$F\ (1, 41) = 5.73$, $p = 0.02$, $\eta^2 = 0.12$] (Table 2). *Post hoc* tests showed PMGs had faster RTs when the probes replaced game-related pictures than neutral pictures [$F\ (1, 41) = 6.12$, $p = 0.02$, $\eta^2 = 0.13$], but this pattern was not found in CPs ($F\ (1, 41) = 0.73$, $p = 0.40$, $\eta^2 = 0.02$).

Discussion

In Experiment 1, PMGs and CPs performed differently during the masked visual task with a 17 ms presentation time. It suggests that bias for game cues operated preconsciously in PMGs. The present data speak for the idea that PMG involves automatic and preferred processing for salient stimuli under preconscious awareness. In Experiment 2, we aimed to extend these findings above the threshold of awareness, and further examined the components of attentional biases for game-related pictures at 200 and 500 ms exposure durations.

STUDY 2

METHODS

Participants

238 participants were recruited from college students in Tianjin, China by using the same measurement as Experiment 1. The PMGs and CPs groups each contained 12 men and 8 women, with a mean age of 20.75 years ($SD = 1.07$) and 21.15 years ($SD = 1.81$) respectively (85% of them participated in Experiment 1). In the PMG group, 17 participants in experiment 2 were from experiment 1, and the same allocation was found in the CP group. They were no significant difference in age ($t\ (38) = -1.85$, $p = 0.40$, Cohen's $d = -0.27$), but the PMGs had higher IAT scores than the CPs group ($M = 62.80$, $SD = 11.12$; $M = 37.1$, $SD = 7.29$) ($t\ (38) = 8.62$, $p < 0.001$, Cohen's $d = 3.21$).

Table 2. Mean RTs (M ± SD) in each condition of Experiment 1

	Same	Different
PMGs group	342 ± 51	349 ± 49
CPs group	348 ± 50	345 ± 44

Materials

The pictorial materials and questionnaires were the same as those in Experiment 1, and the Cronbach's alpha of IAT was 0.95.

Procedures

There were 10 practice trials, followed by 40 critical trials and 40 filler trials. The procedure in each trial was similar to the masked task (i.e., fixation cross shown for 1000 ms, an inter-trial of 2000 ms). Picture pairs were presented for either 200 ms or 500 ms (Fig. 2), and they were directly replaced by probes. 90 trials were presented in a new fully random order for each participant.

Results

RTs were excluded from trials with the same criteria as in the masked visual probe task (2.59% of all RTs). A mixed ANOVA 2 × 2 was conducted on 200 ms or 500 ms RTs respectively, with group as the between-participant factor (PMGs vs. CPs) and probe position (probe in same versus different location to the game-related picture) as the within-subject variable. When the presentation time was 200 ms, there was no significant main effect of group [$F\ (1, 38) = 0.33$, $p = 0.57$, $\eta^2 = 0.01$] or probe location [$F\ (1, 38) = 0.56$, $p = 0.46$, $\eta^2 = 0.01$], but the Group × Probe location interaction was significant ($F\ (1, 38) = 5.34$, $p = 0.03$, $\eta^2 = 0.12$). *Post hoc* tests showed that PMGs had faster RTs when the probes replaced game-related pictures than neutral pictures [$F\ (1, 38) = 4.68$, $p = 0.04$, $\eta^2 = 0.11$], but this finding was not revealed in CPs ($F\ (1, 38) = 1.22$, $p = 0.28$, $\eta^2 = 0.03$). All main effects and interactions were non-significant ($Fs < 1.42$, $\eta^2 < 0.04$) when the presentation time was 500 ms. Mean RTs in each condition are shown in Table 3.

Discussion

The results showed that PMGs had an attentional bias for game-related images only at a shorter exposure condition of 200 ms. This finding suggests that PMGs put more processing resources towards game cues in the early stage of attentional bias. PMG behaviors seem to be associated with altered attentional processing for game cues and led them to exhibit a game-related attentional bias that is specific to initial orientation of attention.

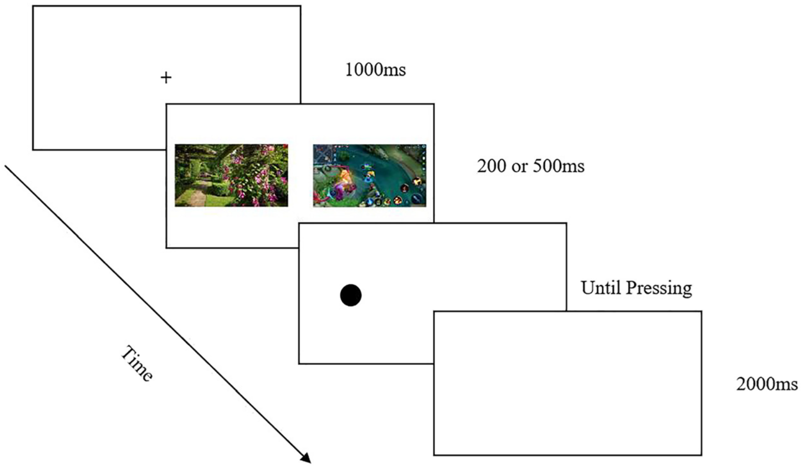

Fig. 2. Visual probe task. It's an example of an "incongruent" trial, participant should press "f" to be a correct answer. However, if the probe was presented on the right side, this should be a "congruent" trial, and participant should press "j" to be a correct answer. The pictorial materials of Experiment 2 were the same as those in Experiment 1, so the Figure1. (B) and (C) were also the example of materials in Experiment 2

Table 3. Mean RTs (M ± SD) in each condition of Experiment 2

		Same	Different
200 ms	PMGs	396 ± 42	406 ± 46
	CPs	395 ± 50	390 ± 44
500 ms	PMGs	387 ± 37	389 ± 41
	CPs	373 ± 45	371 ± 49

GENERAL DISCUSSION

The present study focused on two issues: (a) whether PMGs have a bias to game-related pictures below the threshold of conscious awareness; and (b) whether attentional biases for game-related pictures play a role both in early vigilance and late maintenance above the level of awareness. The results indicated that PMGs showed significant attention bias for game-related pictures in the 17 and 200 ms duration conditions. There was no evidence of a processing bias for game-related stimuli being exposed 500 ms. These results are discussed below.

Regarding the masked visual probe task, only PMGs had a faster response to probes presented in the same position with game-related cues. This result is consistent with the findings of He et al. (2018). They also found a faster response when the location of the probe and the Internet cues were congruent in IAs on the same task, but with a 14 ms presentation time. Results demonstrated IAs showed a bias for Internet information in preconscious processing. Mogg and Bradley (1999) assumed that the masked visual probe task could explore the individual's unconscious processing toward related stimuli with brief presentation (≤30 ms). It seems reasonable to suggest that preconscious attentional bias for salient stimuli exists both in PMG and other behavioral addictions, but further studies are necessary. Of note and regarding substance use disorders, many studies did not confirm that subliminal processing of addiction-related information can work unconsciously (Bradley et al., 2004; Franken, Kroon, Wiers, & Jansen, 2000; Mogg & Bradley, 2002; Yan et al., 2009). Of interest, few studies showed evidence that substance use disorders have a preconscious bias for related stimuli (Ingjaldsson, et al., 2003; Zhao, et al., 2016). Again, future research needs to choose other types of behavioral addictions to further examine the pre-attentive bias of salient cues, such as problematic social media use and problematic shopping.

The results from Experiment 1 are consistent with the ideas put forward by incentive sensitization theory. According to this theory, game-related stimuli have higher salience, and therefore they might lead PMGs to allocate more attentional resources to them even in the condition below awareness. Thus, the salience of game stimuli plays an important role in preconscious processing, and it might promote PMGs to attend to game-related pictures before these pictures are (unconsciously) perceived. From our perspective, results of the present study are also compatible with automatic action schema theory. According to this cognitive model, automated action schema contributes to automatic processing of game-related stimuli in an unconscious state in PMGs. It can be concluded that incentive sensitization and automated action schema theory are good explanations for what we observed in the present study, and perhaps also other additive behaviors (He et al., 2018; Ingjaldsson et al., 2003; Zhao et al., 2016). Further research needs to also provide neurophysiological evidence to find further support for the preconscious bias in PMGs, such as mismatch negative wave (MMN) induced in the event-related potential (ERP) experiment (He et al., 2018). It would be expected to observe that MMN induced by game-related cues would be significantly enhanced in PMGs relative to the controls.

On the visual probe task, PMGs had a significant attentional bias for game-related pictures at an exposure condition of 200 ms. This result replicates the findings of

Juncai et al. (2017), and further indicates that PMGs had an attentional bias towards salient information. The attentional bias of PMGs is specific to the early stage of attention. So, the present study implied that the development of problematic behaviors is not affected by changes in the device (computer vs. mobile phone). Previous studies in behavioral addictions also support that initial vigilance plays a role in attentional processing (Ciccarelli et al., 2016). However, biases to drug-related cues in persons afflicted with substance use disorders operate both in the vigilance and maintenance of attention processing (Bradley et al., 2004; Field et al., 2004). It appears that attentional bias to addictive stimuli may differ between substance use disorders and other addictive behaviors. Bias to behavior-related cues may operate both in initial orienting and sustained attention in substance use disorders, but might be specific to initial orienting in behavioral addiction. This idea is not supported by all studies. Thomson, Hunter, Butler, and Robertson (2021) found problematic social media users did not have an attentional bias to social stimuli. Noel, Colmant, Linden, Bechara, and Verbanck (2006) proposed alcohol-dependents only had an initial vigilance to alcohol information. Alcorn, Marks, Stoops, Rush, and Lile (2019) did not find that cocaine users have a bias processing for drug cues. Although attentional bias is a core feature in addictive disorders (Cousijn et al., 2013), there may be special conditions that result in this processing to disappear or partially appear, e.g., content specificity of stimuli. Alcorn et al. (2019) found an attentional bias towards cannabis cues in cannabis users, but not cocaine users. Future research should focus on these conditions in PMGs to offer insight into the cognitive processing characteristics.

The results of Experiment 2 also seem to confirm incentive sensitization theory (Robinson & Berridge, 1993). Game-related stimuli are attractive to PMGs, so it can grab their attention, and lead them to have relatively early, automatic processes to those stimuli, but not slowly, unautomatic processes. These results are also compatible with Tiffany's (1990) model. According to this model, PMGs would subjectively seek game-related stimuli when they are unable to engage in the game. This would promote PMGs to show an attentional bias to game stimuli when exposed to game and non-game information at the conscious level.

The current study has several limitations. First, there were no non-gamers in the control group to exclude the effect of material familiarity on the results. However, it cannot solve the question of whether bias processing above and below awareness changes during the development of problematic behavior (here longitudinal designs can help). Second, only two games were selected. This manipulation may reduce the generalizability of the present conclusions. However, some studies only selected World of Warcraft players when investigating the biased processing of game stimuli in gaming disorders (Decker et al., 2011), hence also other studies show comparable limitations. Third, the present study cannot investigate the time course of attentional processing (Lazarov, Pine, & Bar-Haim, 2017). Eye-tracking methods can directly track the participant's gaze during exposure to stimuli. Some indicators can examine the initial vigilance of attention, e.g., the first fixation time (Kou, Su, Luo, & Chen, 2015), while others can reflect sustained attention, e.g., the total fixation time (Kou et al., 2015). Many researchers have proposed that eye-tracking method is more sensitive than behavioral measures to investigate attentional bias to addiction-related stimuli (Christiansen, Schoenmakers, & Field, 2015; Dias et al., 2015). Future studies can use eye-tracking methods to measure attentional bias to addiction-related stimuli by directly tracking the PMGs' gaze (Alcorn et al., 2019; Soleymani, Ivanov, Mathot, & de Jong, 2020; Zhao et al., 2017). Event-related potential (ERP) techniques can also investigate the time course of attentional bias based on neurophysiological measures (Li, Li, Xu, Diao, & Zhang, 2019). For example, the N2pc (180–200 ms atter stimuli onset) reflects initial orientation. The sustained posterior contralateral negativity (300–650 ms after stimulus onset) reflects maintenance at the later stage of attentional selection. Future studies also need provide neurophysiological evidence to support current results. Fourth, only attentional bias toward game stimuli was studied. Field and Cox (2008) considered that classical conditioning may cause attentional biases. Several studies have tested this bias in relation to internet gaming, with mixed results. Although Jeromin, Rie et al. (2016) did not find attentional bias toward computer stimuli in GDs on web-based addiction Stroops tasks, others revealed this bias processing in an addiction Stroops task (Jeromin et al., 2016) or a visual search task (Heuer, Mennig, Schubö, & Barke, 2021), and further indicated that the attentional bias of GDs is specific to the maintenance of attention processing. However, it is still unknown whether PMGs have bias towards phone-related stimuli presented below or above the threshold of awareness. Fifth, attentional bias for addictive cues in PMGs should be studied in other tasks. Visual dot probe paradigms are commonly used to measure bias processing (Manchery, Yarmush, Luehring-Jones, & Erblich, 2017; Monem & Fillmore, 2019), but evidence showed it may suffer from low reliability (Ataya et al., 2012; Jones, Christiansen, & Field, 2018; Thigpen, Gruss, Garcia, Herring, & Keil, 2018). Thigpen et al. (2018) found that faster responses to probes had a poor relation with the selective attention to previous congruent cues. Future studies should use multiple tasks to validate our results, e.g., addiction Stroop (Metcalf & Pammer, 2011), visual search task (Heuer et al., 2021).

In summary, the two experiments reported here provide evidence of attentional bias for game-related stimuli both below or above the threshold of conscious awareness in PMGs. A preconscious bias for game-related pictures could be observed when the contents of those pictures could not be perceived (17 ms), and vigilance when pictorial stimuli were presented for a relatively longer duration (200 ms). These results support the views of incentive sensitization theory and automatic action schema theory. On the one hand, incentive sensitization theory and automated action schema theory can be extended to behavioral disorders; on the other hand, these attentional biases toward game-related stimuli can be the sensitive markers of PMG as an addictive disorder, and may be a reference to assign a diagnosis of PMG.

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Authors' contribution: HY and YB designed the study protocol. YB completed the experiment and data analysis. YB also wrote the first draft of the paper. HY, JDE and MC substantially revised the manuscript.

Conflict of interest: All authors declare that they have no conflicts of interest with this study. However, outside the scope of the present paper, the authors report the following: Ms. Yu Bai notes that she is a doctoral student at Tianjin Normal University. Dr. Elhai notes that he receives royalties for several books published on posttraumatic stress disorder (PTSD); is a paid, full-time faculty member at University of Toledo; occasionally serves as a paid, expert witness on PTSD legal cases; and has recently received grant research funding from the U.S. National Institutes of Health. Dr. Montag notes that he is a paid full-time faculty member at Institute for Psychology and Education of Ulm University and is a visiting professor of the Clinical Hospital of Chengdu Brain Science Institute of University of Electronic Science and Technology of China. Dr. Haibo Yang notes that he is a paid full-time faculty member at Tianjin Normal University.

Data availability: Data and experimental materials will be made available upon request.

REFERENCES

Alcorn, J. L., Marks, K. R., Stoops, W. W., Rush, C. R., & Lile, J. A. (2019). Attentional bias to cannabis cues in cannabis users but not cocaine users. *Addictive Behaviors*, *88*, 129–136. https://doi.org/10.1016/j.addbeh.2018.08.023.

Ataya, A. F., Adams, S., Mullings, E., Cooper, R. M., Attwood, A. S., & Munafò, M. R. (2012). Internal reliability of measures of substance-related cognitive bias. *Drug and Alcohol Dependence*, *121*(1–2), 148–151. https://doi.org/10.1016/j.drugalcdep.2011.08.023.

Balconi, M., Venturella, I., & Finocchiaro, R. (2017). Evidences from rewarding system, FRN and P300 effect in Internet-addiction in young people. *Brain Sciences*, *7*(7), 81. https://doi.org/10.3390/brainsci7070081.

Berridge, K. C. (2009). 'Liking' and 'wanting' food rewards: Brain substrates and roles in eating disorders. *Physiology & Behavior*, *97*(5), 537–550. https://doi.org/10.1016/j.physbeh.2009.02.044.

Bradley, B., Field, M., Mogg, K., & De Houwer, J. (2004). Attentional and evaluative biases for smoking cues in nicotine dependence: Component processes of biases in visual orienting. *Behavioural Pharmacology*, *15*(1), 29–36. https://doi.org/10.1097/00008877-200402000-00004.

Christiansen, P., Schoenmakers, T. M., & Field, M. (2015). Less than meets the eye: Reappraising the clinical relevance of attentional bias in addiction. *Addictive Behaviors*, *44*, 43–50. https://doi.org/10.1016/j.addbeh.2014.10.005.

Ciccarelli, M., Nigro, G., Griffiths, M. D., Cosenza, M., & D'Olimpio, F. (2016). Attentional bias in problem and non-problem gamblers: An experimental study. *Journal of Affective Disorders*, *206*, 135–141. https://doi.org/10.1016/j.jad.2016.07.017.

Cousijn, J., Watson, P., Koenders, L., Vingerhoets, W. A. M., Goudriaan, A. E., & Wiers, R. W. (2013). Cannabis dependence, cognitive control and attentional bias for cannabis words. *Addictive Behaviors*, *38*(12), 2825–2832. https://doi.org/10.1016/j.addbeh.2013.08.011.

Decker, S. A., & Gay, J. N. (2011). Cognitive-bias toward gaming-related words and disinhibition in World of Warcraft gamers. *Computers in Human Behavior*, *27*(2), 798–810.

Dias, N. R., Schmitz, J. M., Rathnayaka, N., Red, S. D., Sereno, A. B., Moeller, F. G. G., & Lane, S. D. (2015). Anti-saccade error rates as a measure of attentional bias in cocaine dependent subjects. *Behavioural Brain Research*, *292*, 493–499. https://doi.org/10.1016/j.bbr.2015.07.006.

Dong, H., Yang, F., Lu, X., & Hao, W. (2020). Internet addiction and related psychological factors among children and adolescents in China during the coronavirus disease 2019 (COVID-19) epidemic. *Frontiers in Psychiatry*, *11*, 751. https://doi.org/10.3389/fpsyt.2020.00751.

Field, M., & Cox, W. M. (2008). Attentional bias in addictive behaviors: A review of its development, causes, and consequences. *Drug and Alcohol Dependence*, *97*(1–2), 1–20. https://doi.org/10.1016/j.drugalcdep.2008.03.030.

Field, M., Mogg, K., & Bradley, B. P. (2004). Cognitive bias and drug craving in recreational cannabis users. *Drug and Alcohol Dependence*, *74*(1), 105–111. https://doi.org/10.1016/j.drugalcdep.2003.12.005.

Franken, I. H., Kroon, L. Y., Wiers, R. W., & Jansen, A. (2000). Selective cognitive processing of drug cues in heroin dependence. *Journal of Psychopharmacology*, *14*(4), 395–400. https://doi.org/10.1177/026988110001400408.

Gao, Y. Y., Schneider, B., & Li, L. (2017). The effects of the binocular disparity differences between targets and maskers on visual search. *Attention, Perception. & Psychophysics*, *79*(2), 459–472. https://doi.org/10.3758/s13414-016-1252-y.

Hellberg, S. N., Russell, T. I., & Robinson, M. J. F. (2019). Cued for risk: Evidence for an incentive sensitization framework to explain the interplay between stress and anxiety, substance abuse, and reward uncertainty in disordered gambling behavior. *Cognitive, Affective, and Behavioral Neuroscience*, *19*(3), 737–758. https://doi.org/10.3758/s13415-018-00662-3.

Heuer, A., Mennig, M., Schubö, A., & Barke, A. (2021). Impaired disengagement of attention from computer-related stimuli in Internet Gaming Disorder: Behavioral and electrophysiological evidence. *Journal of Behavioral Addictions*, *10*(1), 77–87. https://doi.org/10.1556/2006.2020.00100.

He, J., Zheng, Y., Nie, Y., & Zhou, Z. (2018). Automatic detection advantage of network information among internet addicts: Behavioral and ERP evidence. *Scientific Reports*, *8*(1), 1–11. https://doi.org/10.1038/s41598-018-25442-4.

Ingjaldsson, J. T., Thayer, J. F., & Laberg, J. C. (2003). Preattentive processing of alcohol stimuli. *Scandinavian Journal of Psychology*, *44*, 161–165. https://doi.org/10.1111/1467-9450.00334.

Jeromin, F., Nyenhuis, N., & Barke, A. (2016). Attentional bias in excessive Internet gamers: Experimental investigations using an addiction Stroop and a visual probe. *Journal of Behavioral Addictions*, *5*(1), 32–40. https://doi.org/10.1556/2006.5.2016.012.

Jones, A., Christiansen, P., & Field, M. (2018). Failed attempts to improve the reliability of the alcohol visual probe task following empirical recommendations. *Psychology of Addictive Behaviors*, *32*(8), 922. https://doi.org/10.1037/adb0000414.

Juncai, S., Tiantian, D., Jun, C., & Ping, L. (2017). Attentional bias and reactive attacks in video game player. *Journal of Neurological Disorders*, *5*, 357. https://doi.org/10.4172/2329-6895.1000357.

Kerr-Gaffney, J., Harrison, A., & Tchanturia, K. (2018). Eye-tracking research in eating disorders: A systematic review. *International Journal of Eating Disorders*, *52*(1), 3–27. https://doi.org/10.1002/eat.22998.

Kou, H., Su, Y., Luo, X., & Chen, H. (2015). Attentional bias toward face-related words among females with facial negative physical self: Evidence from an eye-movement study. *Acta Psychologica Sinica*, *47*(10), 1213–1222. https://doi.org/10.3724/SP.J.1041.2015.01213.

Lazarov, A., Pine, D. S., & Bar-Haim, Y. (2017). Gaze-contingent music reward therapy for social anxiety disorder: A randomized controlled trial. *American Journal of Psychiatry*, *174*(7), 649–656. https://doi.org/10.1176/appi.ajp.2016.16080894.

Li, B., Li, X., Xu, M., Diao, L., & Zhang, D. (2019). Electrocortical evidence for the time course processes of attentional bias toward infant faces. *Neuroscience Letters*, *696*, 74–78. https://doi.org/10.1016/j.neulet.2018.12.020.

Manchery, L., Yarmush, D. E., Luehring-Jones, P., & Erblich, J. (2017). Attentional bias to alcohol stimuli predicts elevated cue-induced craving in young adult social drinkers. *Addictive Behaviors*, *70*, 14–17. https://doi.org/10.1016/j.addbeh.2017.01.035.

Metcalf, O., & Pammer, K. (2011). Attentional bias in excessive massively multiplayer online role-playing gamers using a modified Stroop task. *Computers in Human Behavior*, *27*(5), 1942–1947. https://doi.org/10.1016/j.chb.2011.05.001.

Mogg, K., & Bradley, B. P. (1999). Orienting of attention to threatening facial expressions presented under conditions of restricted awareness. *Cognition & Emotion*, *13*, 713–740. https://doi.org/10.1080/026999399379050.

Mogg, K., & Bradley, B. P. (2002). Selective processing of smoking-related cues in smokers: Manipulation of deprivation level and comparison of three measures of processing bias. *Journal of Psychopharmacology*, *16*(4), 385–392. https://doi.org/10.1177/026988110201600416.

Monem, R., & Fillmore, M. T. (2019). Alcohol administration reduces attentional bias to alcohol-related but not food-related cues: Evidence for a satiety hypothesis. *Psychology of Addictive Behaviors*, *33*(8), 677–684. https://doi.org/10.1037/adb0000522.

Montag, C., Wegmann, E., Sariyska, R., Demetrovics, Z., & Brand, M. (2021). How to overcome taxonomical problems in the study of Internet use disorders and what to do with "smartphone addiction". *Journal of Behavioral Addictions*, *9*(4), 908–914. https://doi.org/10.1556/2006.8.2019.59.

Noel, X., Colmant, M., Linden, M., Bechara, A., & Verbanck, P. (2006). Time course of attention for alcohol cues in abstinent alcoholic patients: The role of initial orienting. *Alcoholism Clinical and Experimental Research*, *30*(11), 1871–1877. https://doi.org/10.1111/j.1530-0277.2006.00224.x.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*(1), 3–25. https://doi.org/10.1080/00335558008248231.

Robinson, T. E., & Berridge, K. C. (1993). The neural basis of drug craving: An incentive-sensitization theory of addiction. *Brain Research Review*, *18*(3), 247–291. https://doi.org/10.1016/0165-0173(93)90013-p.

Robinson, T. E., & Berridge, K. C. (2000). The psychology and neurobiology of addiction: An incentive-sensitization view. *Addiction*, *95*, S91–S117. https://doi.org/10.1080/09652140050111681.

Schneider, W., Eschman, A., & Zuccolotto, A. (2007). *E-prime. Psychology software tools, Inc. learning research and development center*. Pittsburg: University of Pittsburgh.

Soleymani, A., Ivanov, Y., Mathot, S., & de Jong, P. J. (2020). Free-viewing multi-stimulus eye tracking task to index attention bias for alcohol versus soda cues: Satisfactory reliability and criterion validity. *Addictive Behaviors*, *100*, 106117. https://doi.org/10.1016/j.addbeh.2019.106117.

Stockdale, L., & Coyne, S. M. (2018). Video game addiction in emerging adulthood: Cross-sectional evidence of pathology in video game addicts as compared to matched healthy controls. *Journal of Affective Disorders*, *225*, 265–272. https://doi: 10.1016/j.jad.2017.08.045.

Sun, Y., Zhao, Y., Jia, S. Q., & Zheng, D. Y. (2015). Understanding the antecedents of mobile game addiction: The roles of perceived visibility, perceived enjoyment and flow (2015). PACIS 2015 Proceedings. 141. https://aisel.aisnet.org/pacis2015/141.

Thigpen, N. N., Gruss, L. F., Garcia, S., Herring, D. R., & Keil, A. (2018). What does the dot-probe task measure? A reverse correlation analysis of electrocortical activity. *Psychophysiology*, *55*(6), e13058. https://doi.org/10.1111/psyp.13058.

Thomson, K., Hunter, S. C., Butler, S. H., & Robertson, D. J. (2021). Social media 'addiction': The absence of an attentional bias to social media stimuli. *Journal of Behavioral Addictions*, *10*(2), 302–313. https://doi.org/10.1556/2006.2021.00011.

Tiffany, S. T. (1990). A cognitive model of drug-use behavior: Role of automatic and nonautomatic processes. *Psychological Review*, *97*(2), 147–168. https://doi.org/10.1037/0033-295x.97.2.147.

Wang, C., & Ren, X. (2018). An entropy-based approach for computing the aesthetics of interfaces. In Proceedings of the 2018 ACM Companion International Conference on Interactive Surfaces and Spaces, pp. 57–61.

Yan, X., Jiang, Y., Wang, J., Deng, Y., He, S., & Weng, X. (2009). Human study: Preconscious attentional bias in cigarette smokers: A probe into awareness modulation on attentional bias. *Addiction Biology*, *14*(4), 478–488. https://doi.org/10.1111/j.1369-1600.2009.00172.x.

Zhang, M., Fung, D. S., & Smith, H. (2019). Variations in the visual probe paradigms for attention bias modification for substance use disorders. *International Journal of Environmental Research and Public Health*, *16*(18), 3389. https://doi.org/10.3390/ijerph16183389.

Zhao, H., Yang, B., Zhu, Q., Zhang, G., Xiao, Y., Guo, X., … Zhang, Z. (2016). The pre-attentional bias on drug-related cues in heroin dependent patients. *Chinese Journal of Clinical Psychology*, *24*(5), 795–799. https://doi.org/10.16128/j.cnki.1005–3611.2016.05.006.

Zhao, H., Yang, B., Zhu, Q., Zhang, G., Xiao, Y., Guo, X., … Zhang, Z. (2017). Eye movement evidence of attentional bias for substance-related cues in heroin dependents on methadone maintenance therapy. *Substance Use & Misuse*, *52*(4), 527–534. https://doi.org/10.1080/10826084.2016.1264967.