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The Pavlovian-to-instrumental transfer effect as predictor of problematic Internet gaming: Results of a longitudinal study

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ABSTRACT

Background and aims: Recent models on the development of behavioral addictions stress the transfer from goal-directed behavior to stimulus-response habits. Administering a Pavlovian-to-instrumental transfer (PIT) paradigm to individuals with risky or non-problematic gaming, we recently reported that shopping-related cues increase instrumental behavior for a shopping-related reward (i.e. shopping voucher) while gaming-related stimuli triggered instrumental behavior for the gaming-reward (i.e. gaming voucher). This was observed even after devaluation of the gaming-reward. We now investigated the predictive value of the 'Shopping-PIT'- and the 'Gaming-PIT'-effects regarding gaming disorder symptoms. *Methods:* Data on symptom severity of gaming disorder six months after the baseline assessment were available for 48 individuals with risky gaming and 46 individuals with non-problematic gaming. Hierarchical regression analyses with stepwise inclusion of control variables, the 'Shopping-PIT'-effect as indicator of responding for a general reward after devaluation of the gaming reward and 'The Gaming-PIT'-effect after devaluation of the gaming reward as indicator of habitual responding as well as their interaction effects with symptom severity was calculated. *Results:* Higher gaming disorder symptoms at the six-month follow-up assessment were predicted by symptom severity at baseline and the interaction of the 'Shopping-PIT'-effect with symptom severity at baseline. The 'Gaming-PIT'-effect after devaluation did not predict symptom severity. *Discussion and Conclusions:* The finding that cue-triggered responding for a general reward contributes to future symptom severity in individuals with higher symptom severity at baseline suggests a cascade model with higher symptom severity leading to stronger cue-triggered reward-related responding which in turn leads to higher symptom severity.

KEYWORDS

PIT-effect, habitual behavior, habit, gaming disorder

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INTRODUCTION

For many decades, learning mechanisms are considered key components in the development and maintenance of addictive behaviors. In 1993, Robinson and Berridge published the incentive sensitization theory of addiction which posits that cues that were repeatedly associated with substance consumption acquire appetitive properties and enhanced incentive

salience. Subsequently, the exposure to conditioned substance-associated stimuli elicits conditioned stimulus-associated responses, which motivate instrumental drug seeking behavior. This theory has been very influential as indicated by numerous citations of the original article (Vanderschuren & Pierce, 2010) as well as of updated reviews (e.g., Berridge & Robinson, 2016). Of at least similar influence has been habit theory (e.g., Everitt & Robbins, 2005; Everitt & Robbins, 2016) which assumes that drug-seeking is initially goal-directed, but as the association between substance-associated stimuli and drug-seeking behaviors strengthens stimulus-response habits develop. Compulsion theory, which is akin to habit theory, assumes that drug-seeking is goal-directed initially, then becomes a habit, and finally becomes a compulsion, i.e. a maladaptive habit characterized by inflexibility and resistance to experiences of low reinforcing properties of the drug (Everitt & Robbins, 2016). Compulsive drug use thus emerges as the result of an impairment of inhibitory control (Lüscher, Robbins, & Everitt, 2020). The theories mentioned, as well as others not outlined here like dual process models (Bechara, 2005) or the I-RISA-model (Goldstein & Volkow, 2002), have stimulated research on cognitive and affective mechanisms contributing to substance use disorders as well as behavioral addictions. Based on empirical findings (see, for example (Diers et al., 2023; Müller et al., n.d.), stimulus-associated responses and reduced self-control abilities are assumed to be important mechanisms contributing to substance-related as well as behavioral addictions including specific Internet use disorders. Brand et al. (2019) integrated several of the theories when they formulated the Interaction of Person-Affect-Cognition-Execution (I-PACE) model. In short, it is assumed that the interactions between predisposing variables (like impulsivity), affective and cognitive responses to specific stimuli (like cue-reactivity and craving), and deficits of self-control abilities (like reduced inhibitory control and disadvantageous decision-making) contribute to the development of seemingly habitual responding and resulting in addictive behaviors. Recently, Brand (2022) also describes the potential shift from more reward-oriented to more compulsivity-related use of Internet applications and suggests a cascade model with reduced self-control serving as a vulnerability factor which may lead to stronger habitual behavior and higher symptom severity but also may decline further during the addiction process (see also (Brand et al., 2025) for more detailed descriptions). However, it is still unclear whether the process of habit formation, as induced in the laboratory, is associated with the manifestation (e.g., symptom severity) of behavioral addictions.

It is important to acknowledge that cognitive and affective mechanisms are assumed to be the consequence of learning processes and a shift from goal-directed to habitual behavior. However, most of the theories on the Pavlovian and instrumental learning processes assumed to underlie these mechanisms are derived from animal studies (Doñamayor et al., 2021) and human studies are still limited (Cartoni, Balleine, & Baldassarre, 2016; Garbusow et al., 2022; Hogarth, 2020). In humans, the Pavlovian-to-instrumental transfer (PIT)-paradigm (e.g, Cartoni et al., 2016) has been used to assess more closely conditioned learning processes and the influence of conditioned stimuli on reward-related instrumental responding. In short, the task is divided into three different phases. Thus, individuals undergo a Pavlovian training in which they learn to associate abstract stimuli with different reward-related (often addiction-related) stimuli. In instrumental training individuals learn that different instrumental responses are associated with different rewards. Finally, in the transfer phase, the Pavlovian cues are presented and the influence of Pavlovian conditioned reward-related stimuli on reward-related instrumental responding is assessed. If the Pavlovian cues trigger instrumental responding for the same reward, this is called a specific PIT-effect; in contrast, a general PIT-effect refers to an increase in responding for different rewards. In an own recent study, we administered a PIT-paradigm with abstract stimuli and gaming-related and shopping-related stimuli to individuals with risky or non-problematic use of gaming (Schmid et al., 2024) and assessed whether stress increases habitual responding. Regarding Pavlovian training, our results indicated acquisition of emotional conditioned responses and attentional bias to the formerly neutral stimuli and this effect was, among other factors, predicted by the severity of problematic use (Lörsch et al., 2025). We also found specific 'Gaming-PIT'- and 'Shopping-PIT'-effects as the stimuli then triggered reward-related responding for these rewards (Schmid et al., 2024). Stress did not enhance this effect. PIT-effects in individuals with substance use disorders (e.g, Garbusow et al., 2016), individuals at risk for gaming disorder (Vogel et al., 2018), individuals with gaming disorder (Qin et al., 2023; Xu et al., 2024) individuals with risky or non-problematic use of buying-shopping applications (Vogel et al., 2018) have been demonstrated previously. However, it is important to acknowledge that contrary to previous research, the study by Schmid et al. (2024) devalued the gaming reward after the first half of the transfer phase by informing participants that the maximum amount of the gaming reward has been reached. According to several authors (e.g. Hogarth, 2020) only the use of devaluation procedures can differentiate between goal-directed and habit behaviors as insensitivity to devaluation (e.g., continuing choosing the gaming-related options even though this does not result in rewards) indicates habit behavior. Interestingly, our findings indicated that although the devaluation decreased overall responding for the gaming-related reward, the conditioned stimuli still biased responding for this reward suggesting at least partial insensitivity to devaluation and thus habitual behavior.

While there is some human-related research investigating the effect of conditioned reward-related stimuli on instrumental responding, only few studies so far implemented longitudinal designs to assess the impact of the PIT-effect on future symptom severity of the addictive behavior. Garbusow et al. (2016) found in a pilot study that patients with alcohol use disorder compared to control participants showed a stronger monetary-related PIT-effect and that the PIT-related neural activation in the nucleus accumbens

significantly predicted alcohol intake and relapse in a three-month-follow-up period. This finding was recently replicated in a larger sample (K. Chen, Schlagenhauf, et al., 2023) with a follow-up duration of six months. In line with this, Sommer et al. (2020) found a stronger monetary-related PIT-effect in patients with alcohol use disorder who relapsed in the following year compared to abstainers and control participants. In a recent longitudinal study, H. Chen, Belanger, et al. (2023) further demonstrated that the susceptibility to interference between Pavlovian and instrumental control may also be a risk factor for the development of hazardous alcohol use during young adulthood. Only recently, Xu et al. (2024) reported that the monetary-related PIT-effect is also a predictor for the weekly gaming time of individuals with gaming disorder in a four-month follow-up period. Taken together, these findings suggest that the susceptibility to cue-triggered responding for a general reinforcer (i.e. money) may be a valid marker for future symptom severity.

As far as we are aware, there are no longitudinal studies available investigating the impact of the specific, i.e. addiction-related, PIT-effect on symptom severity of addictive behaviors. Thus, the present study aimed to narrow this gap and to increase our theoretical understanding of the contribution of habitual behaviors to the development and maintenance of problematic use of internet applications given the rise of problematic usage of the internet (Fineberg et al., 2022, 2025). While this is important from a theoretical point of view, identifying a potentially modifiable process that is associated with the problem behavior is also the first important step for the development of effective prevention and intervention strategies following an experimental medicine approach (Field et al., 2020). The study focused on problematic gaming, as gaming disorder has been officially recognized as a disorder due to addictive behaviors in the 11th edition of the International Classification of Diseases in 2019 (ICD-11; World Health Organization, 2019). Different meta-analysis assessed the worldwide prevalence of (Internet) gaming disorder and estimated prevalence rates of 3.05% (Stevens, Dorstyn, Delfabbro, & King, 2021) or 3.3% (Kim et al., 2022). A more recent study (Zhou et al., 2024) indicated a pooled prevalence rate of 6.7% but also indicated several sources of heterogeneity (e.g., diagnostic procedures).

The current study used a subsample of our previous work (Schmid et al., 2024) who completed a six-month follow-up assessing the severity of problematic gaming. Based on the findings regarding the monetary-related PIT-effect we hypothesized that the 'Shopping'-PIT-effect indicating cue-triggered responding for a non-devalued general online-related reward (i.e. shopping vouchers which may be considered monetary rewards), would be a significant predictor regarding the severity of problematic gaming six months later. In addition, we assumed that the 'Gaming'-PIT-effect after devaluation of the gaming reward indicating habitual responding for a devalued addiction-related reward, would be associated with a significant additional explanation of variance of future symptom severity. Based on the cascade model suggested by Brand (2022) and Brand et al. (2025), we also assumed that the predictive value of the magnitude of the 'Shopping'- as well as the 'Gaming-PIT'-effect would be strongest when participants have already developed stronger problematic behavior. We therefore also investigated moderation effects of symptom severity. Several variables were entered as control variables (see statistical analysis).

METHODS

Procedure

The procedure applied, test battery administered, and follow-up assessment described here is part of a multi-center DFG-funded addiction research unit (FOR2974) on affective and cognitive mechanisms of specific Internet-use disorders (ACSID; Brand et al., 2021). The baseline assessment lasted about six hours and included the administration of different questionnaires and cognitive tasks as part of the FOR 2974 core battery (Brand et al., 2021) as well as the project specific Pavlovian-to-instrumental transfer (PIT) paradigm and a stress induction. Six months after the laboratory test-session participants were invited per email to take part in the 30 min-long FOR 2974 core battery follow-up assessment. A link to an online survey was provided which assessed symptoms of addictive behaviors and treatment-seeking motivation, etc.

We report here additional analysis related to research project 2 which are not part of the preregistration of research project 2 at Open Science Framework [https://osf.io/f27qw/?view_only=4bcea30152d54aab8d6c191e269cbe7d] as the follow-up assessment comprising different online questionnaires was carried out as part of the FOR 2974 core battery six months after the test session for each project (https://osf.io/6x93n/?view_only=00fe0424a3ca4eda96eebd9bfc4efb4b).

Participants

Individuals with risky gaming and non-problematic gaming were recruited from the University of Bamberg, the Hannover Medical School as well as from the general population by flyers, mailing lists, posts on social networks, and word-of-mouth recommendations. The current analyses are based on a subsample of the sample described in Schmid et al. (2024) as only participants for whom follow-up data were available were included. These were 48 individuals with risky gaming and 46 individuals with non-problematic gaming. Participants received a reimbursement of 10€/hour or course credits if they were Psychology students.

Assessment procedures at baseline in the laboratory

Clinical interview. At the test day, a standardized clinical interview for the assessment of specific internet-use disorders was performed (K. W. Müller & Wölfling, 2018a). Risky use of gaming was defined as meeting at least two, but not more than four of the proposed DSM-5 criteria for gaming disorder (American Psychiatric Association, 2013). Non-problematic gaming was defined as fulfilling not more than one DSM-5 criterion.

Assessment of Criteria for Specific Internet-use Disorders (ACSID-11). The *ACSID-11* (S. M. Müller et al., 2022) was used to provide a quantitative measure of the severity of problematic Internet gaming. This questionnaire is based on the ICD-11 criteria for gaming disorder and consists of 11 items, which are answered on a two-part response scale, capturing both the frequency (0 = never, 1 = rarely, 2 = sometimes, 3 = often) and intensity (0 = not at all intense, 1 = rather not intense, 2 = rather intense, 3 = intense) of the symptoms. The mean frequency score (ranging from 0 to 3) was used (Cronbach's α baseline = 0.89).

Barratt Impulsiveness Scale short form (BIS-15). The German version (Meule, Vögele, & Kübler, 2011) of the *BIS-15* (Spinella, 2007) was used to control for self-control abilities as a potential predictor for the severity of problematic gaming at the follow-up assessment. The BIS-15 comprises 15 items answered on a four-point Likert scale, ranging from 1 (never/rarely) to 4 (almost always/always), which are categorized into three subscales: nonplanning, motor, and attentional impulsivity. As recently found by Müller et al. (n.d.), individuals with risky use of gaming and other specific Internet applications report higher motor and attentional impulsivity compared to non-problematic users. Previous research also demonstrated especially deficits of response inhibition regarding gaming disorder (see review by Kuss, Pontes, & Griffiths, 2018). We thus concentrated here on the subscale motor impulsivity. Internal consistency of the motor impulsivity subscale was acceptable in our sample (Cronbach's α = 0.74).

Brief Symptom Inventory (BSI-53). The subscale *Depression* of the *BSI-53* (Franke, 2000) was used to control for depressive symptoms at baseline as a possible predictor of symptom severity at follow-up. The BSI-53 comprises 53 items categorized in nine different subscales. The subscale *Depression* comprises six items asking about feelings of loneliness, depression, hopelessness, etc. in the last seven days which participants answer on a five-point Likert scale ranging from 0 (not at all) to 4 (very strong). Internal consistency in this subsample was acceptable (Cronbach's α = 0.79).

The Pavlovian-to-instrumental transfer paradigm. The PIT Paradigm comprised three different phases (Lörsch et al., 2025; Schmid et al., 2024). In short, the task started with the Pavlovian training phase in which four abstract stimuli were presented in pairs of two. After each presentation, participants had to indicate whether they expected a gaming-related picture or a shopping-related picture to follow the picture pair. Participants thus learned to associate one abstract stimulus with the presentation of gaming-related pictures (CS^G), and a second abstract stimulus with the presentation of shopping-related pictures (CS^S). The other two abstract stimuli served as control stimuli. In the instrumental training phase a grey square was presented followed by the instruction "Please choose a key! Press 'S' if you want to win shopping points or 'G' if you want to win gaming points." They thus learned to press two different buttons to receive either gaming- or shopping related rewards. Participants were told that they could change the points they earned at the end of the task in a gaming and/or shopping voucher. In the transfer phase, participants could earn gaming- and shopping-related rewards as before, but the grey square was presented in only 1/3 of the trials while in the other trials the CS^G or the CS^S was displayed to assess whether conditioned stimuli bias responding. After the first half of the transfer phase, participants were told that they have reached the maximum amount of the gaming- though not shopping-voucher (i.e. devaluation of the gaming reward). If participants continue responding to the CS^G, this would indicate habitual responding.

For the research questions addressed here, the percentage choice of the gaming response after presentation of the different stimuli in the transfer phase after devaluation of the gaming reward was used as outcome measure. In addition, we calculated the magnitude of the 'Shopping'-PIT-effect after devaluation of the gaming reward as the percentage choice of the shopping response after presentation of the CS^S relative to percentage choice of the shopping response after presentation of the grey square thus indicating the increase in reward-related responding. The magnitude of the 'Gaming'-PIT-effect after devaluation was calculated as percentage choice of the gaming response after presentation of the CS^G relative to percentage choice of the gaming response after presentation of the grey square.

Stress induction. As described in detail in Schmid et al. (2024) participants were randomly allocated to the Trier Social Stress Test (TSST; (Kirschbaum, Pirke, & Hellhammer, 1993) or the Placebo-TSST as a control condition (Het, Rohleder, Schoofs, Kirschbaum, & Wolf, 2009). In short, in the TSST participants had to deliver a free speech describing their personal job-relevant traits and to perform an arithmetic task in front of a committee of a female and a male research assistant while being videotaped. In the Placebo-TSST, participants were asked to deliver a free speech about a leisure-time related topic and to perform an easier arithmetic task; the committee was not present and no video camera was installed. The TSST as well as the Placebo-TSST lasted 15 min.

Six-month-follow up assessment

Assessment of Criteria for Specific Internet-use Disorders (ACSID-11). The ACSID-11 (S. M. Müller et al., 2022) was administered again to provide a quantitative measure of the severity of problematic Internet gaming six month after the baseline assessment (Cronbach's α Follow-up = 0.89).

Treatment-seeking motivation. The follow-up assessment included the assessment of the motivation to seek help from professionals or significant others (e.g., family, friends) for any mental health problems during the last six months answered on two six-point Likert scales ranging from 0 (not at all) to very 5 (very high). In addition, the utilization of outpatient and inpatient treatment interventions in the last

six months was assessed (yes/no) as well as the reason to do so. Although none of the participants indicated to have used any health care services because of gaming, it cannot be excluded that, for example, help for depressive symptoms also affected the severity of gaming at follow-up. Therefore, for the regression analysis, a sum score indicating the motivation to seek help from professionals and/or significant others for any health problems was calculated (ranging from 0 to 10) to control for possible confounding effects.

Statistical analysis

To ensure that in this subsample a 'Shopping-PIT'- as well as a 'Gaming-PIT'-effect is observed, a mixed ANOVA was used to analyze the effects of the presentation of the CS^G and the CS^S on responding for the shopping- and gaming-related rewards. As in the first publication with this sample (Schmid et al., 2024), the between-subjects factors group (risky, non-problematic), awareness of the experimental contingencies (no, yes), and condition (TSST, Placebo-TSST) and the within-subjects factors stimulus (gaming, shopping, neutral) and devaluation (pre, post) were entered in the analyses. The percentage choice of the gaming response was used as dependent variable. The assumptions of all statistical procedures applied were checked. In the case of violation of the assumption of homogeneity of variances, the Greenhouse-Geiser-adjustment was applied and adjusted degrees of freedom are reported. Effect size statistics (partial eta^2, η_p^2) are reported for the main outcome measures. Planned contrasts were calculated for significant main or interaction effects and corrected for multiple testing using the Bonferroni-correction. A post-hoc power analysis using G*Power 3.1.9.7 (Faul, Erdfelder, Lang, & Buchner, 2007) indicated that the size of this sample allowed to detect a medium-sized effect ($\eta_p^2 = 0.17$; see Table 2) of the presentation of the different stimuli on instrumental responding for the different rewards after devaluation with a power of 0.97 given a significance level of 0.05.

An additional ANOVA was calculated to analyze the development of symptom severity from baseline to the follow-up assessment. The between-subjects factor group (risky, non-problematic) was entered and time (baseline, follow-up) as repeated measures factor. Gaming severity measured by the *ACSID-11* was the dependent variable.

We hypothesized that the 'Shopping'-PIT-effect would be a significant predictor regarding the severity of problematic gaming, and we assumed that the 'Gaming'-PIT-effect after devaluation of the gaming reward would be associated with a significant additional explanation of variance. We also assumed that the predictive value of the magnitude of the 'Shopping'- as well as the 'Gaming-PIT'-effect would be strongest when participants have already developed stronger problematic behavior. To test these hypotheses a hierarchical linear regression analysis was calculated with stepwise inclusion of predictor variables. In the first block, symptom severity at baseline, depression at baseline, motor impulsivity at baseline and motivation to seek help in the last six months were entered as control variables. Depressive symptoms have previously been demonstrated to be related to future symptom severity (e.g., Männikkö, Ruotsalainen, Miettunen, Pontes, & Kääriäinen, 2020). In addition, self-control abilities are assumed to interact with affective and cognitive processes (Brand et al., 2019). We also controlled for the motivation to seek help for mental health problems during the follow-up period (Czapla et al., 2016). In the second step, the magnitude of the 'Shopping-PIT'-effect as well as the interaction of the magnitude of the 'Shopping-PIT'-effect and symptom severity at baseline were entered. In the final step, the magnitude of the 'Gaming-PIT'-effect as well as the interaction of the magnitude of the 'Gaming-PIT'-effect and symptom severity at baseline were entered to analyze whether these predictors are associated with a significant increase in the explained variance. All continuous predictor variables were mean centered. The Durbon-Watson test indicated no autocorrelation in residuals from regression analysis (DW = 1.90). The variance inflation factor (VIF) indicated low correlation among variables (VIF $\leq$1.24). The False Discovery Rate (FDR) correction (Benjamini & Hochberg, 1995) was applied to the *p*-values obtained from the regression analyses to control for multiple comparisons and reduce the likelihood of Type I errors. A post-hoc power analysis for the hierarchical linear regression analysis using G*Power 3.1.9.7 (Faul, Erdfelder, Buchner, & Lang, 2009) indicated that the size of this sample allowed to detect an increase in R^2 of 0.04 (see Table 3) when entering in the second step six predictor variables in total and testing two predictor variables (i.e., the 'Shopping-PIT'-effect and the interaction of the 'Shopping-PIT'-effect with symptom severity) with a power of 0.40 given a significance level of 0.05.

Simple slopes were used to interpret any significant interaction effect with values corresponding to the mean, 1 standard deviation above the mean and 1 standard deviation below the mean symptom severity at baseline. The simple slopes were calculated with R (version 4.3.3, R Core Team, 2024) using the package interactions (Long, 2024). All other analyses were performed using IBM SPSS Statistics (Version 29).

Ethics

The study was approved by the respective local ethics committees (Bamberg: 2019–12/33; 18.12.2019; Hannover: 9025_BO_K_2020; 17.04.2020). All study procedures adhered to the declaration of Helsinki and all study participants provided informed consent.

RESULTS

Participants

Participants were 48 individuals with risky gaming and 46 individuals with non-problematic gaming. The risky and

non-problematic gaming group did not differ regarding age ($F(1,92) = 0.20$, $p = 0.66$) and gender $\chi^2(1) = 0.04$, $p = 0.85$). For further sample characteristics see Table 1.

Pavlovian-to-instrumental transfer effects

The results regarding the PIT effects, as reported in Schmid et al. (2024), remain stable in the subsample used in the current analyses and again no effects of the stress condition emerged, see Table 2 for details.

As depicted in Fig. 1, although overall responding for the gaming-related reward decreased after the devaluation, presentation of the CS^G was still associated with a significantly higher response choice of the gaming-related reward compared to presentation of the CS^S or the control stimuli indicating a 'Gaming-PIT'-effect for both groups (all $ps < 0.001$). In addition, response choice of the gaming-related reward before devaluation was significantly lower when the CS^S was presented compared to the control stimulus indicating that presentation of the CS^S increased responding for the shopping-related reward ('Shopping PIT'-Effect).

Changes in the severity of problematic use of gaming

Regarding changes of gaming severity between baseline and six-month follow-up, a significant main effect of time ($F(1, 92) = 34.76$, $p < 0.001$, $\eta_p^2 = 0.28$) as well as a significant main effect of group ($F(1,92) = 12.23$, $p < 0.001$, $\eta_p^2 = 0.12$) emerged. The time by group interaction effect approached significance ($F(1, 92) = 3.76$, $p = 0.06$, $\eta_p^2 = 0.04$). As depicted in Fig. 2, both groups showed a reduction of gaming severity (all $ps \leq 0.007$), but individuals with risky use of gaming showed at the follow-up assessment still a higher frequency of problem behavior than individuals with non-problematic gaming ($p = 0.02$).

Table 2. Response choice of the gaming-related reward on expense of the shopping-related reward based on trials in which participants responded

Main and interaction effects	Response choice gaming- vs. shopping-related reward
Stimulus	**$F(1.41, 121.51) = 33.18$, $p < 0.001$, $\eta_p^2 = 0.28$**
Stimulus*awareness	**$F(1.41, 121.51) = 23.95$, $p < 0.001$, $\eta_p^2 = 0.22$**
Devaluation	**$F(1, 86) = 51.54$, $p < 0.001$, $\eta_p^2 = 0.38$**
Condition	$F(1, 86) = 1.45$, $p = 0.23$, $\eta_p^2 = 0.02$
Group	**$F(1, 86) = 3.97$, $p = 0.05$, $\eta_p^2 = 0.04$**
Devaluation*stimulus	**$F(1.84, 158.40) = 16.96$, $p < 0.001$, $\eta_p^2 = 0.17$**
Devaluation*stimulus*condition	$F(1.84, 158.40) = 1.19$, $p = 0.31$, $\eta_p^2 = 0.01$
Devaluation*stimulus*group	$F(1.84, 158.40) = 0.24$, $p = 0.77$, $\eta_p^2 = 0.003$
Group*Stimulus	$F(1.41, 121.51) = 0.05$, $p = 0.91$, $\eta_p^2 = 0.001$
Group*Condition	$F(1, 86) = 1.10$, $p = 0.30$, $\eta_p^2 = 0.01$
Group*Condition*stimulus	$F(1.41, 121.51) = 1.62$, $p = 0.20$, $\eta_p^2 = 0.02$
Devaluation*stimulus*condition*group	$F(1.84, 158.40) = 0.36$, $p = 0.70$, $\eta_p^2 = 0.004$

Note. Awareness, knowledge of the experimental contingencies as indicated by subjective ratings which abstract stimulus predicted the gaming-related pictures and which abstract stimulus predicted the shopping-related picture; condition, random allocation to the Trier Social Stress Test (TSST) or Placebo-TSST; significant effects are highlighted in bold.

Table 1. Descriptive statistics and group comparison

Sample characteristics	Risky group ($n = 48$)	Control group ($n = 46$)	Group comparison
Baseline Assessment			
Gender, *n* (%)			
Female	8 (16.7)	7 (15.2)	$\chi^2(1) = 0.04$, $p = 0.85$
Male	40 (83.3)	39 (84.8)	
Age (years)	23.81 (4.52)	24.17 (3.25)	$t(92) = 0.33$, $p = 0.66$
Number of criteria in clinical interview (AICA-SKI IBS)	2.92 (0.92)	0.28 (0.46)	$t(69.41) = -17.72$, $p < 0.001$
Symptom severity gaming baseline (ACSID-11)	0.93 (0.62)	0.52 (0.39)	$t(80.13) = -3.81$, $p < 0.001$
Depressive symptoms baseline (BSI-53/D)	0.67 (0.54)	0.43 (0.44)	$t(92) = -2.32$, $p = 0.02$
Motor impulsivity baseline (BIS-15/M)	11.67 (3.24)	10.37 (2.07)	$t(80.36) = -2.32$, $p = 0.02$
Follow-up assessment			
Symptom severity gaming follow-up (ACSID-11)	0.57 (0.49)	0.34 (0.43)	$t(92) = -2.41$, $p = 0.02$
Motivation to seek help last six months	1.92 (2.86)	1.02 (1.57)	$t(73.66) = -1.89$, $p = 0.06$

Note. Means and standard deviations are displayed if not otherwise specified. To test for group differences, χ^2-test were conducted for gender, while two-sided *t*-tests were performed for continuous variables. For *t*-tests, Welch's correction was applied if the Levene-test indicated non-homogeneous variances. AICA-SKI IBS, Assessment of Internet and Computer Game Addiction – Structured Clinical Interview (K. W. Müller & Wölfling, 2018); ACSID-11, Assessment of Criteria for Specific Internet-use Disorders; BSI-53/D, Brief Symptom Inventory, subscale depression; BIS-15/M, Barratt Impulsiveness Scale – short version, subscale motor.

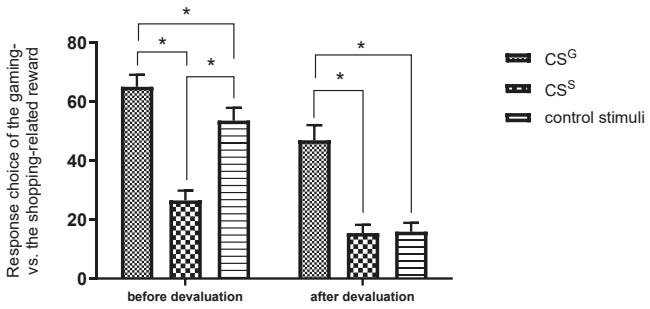

Fig. 1. Response choice of the gaming reward after presentation of the CS^G, the CS^S and control stimuli. Results are presented without differentiating between individuals with risky or non-problematic use as no group differences were observed. Only trials in which participants pressed either the gaming-associated or the shopping-associated key are used for the analysis. The devaluation applied only to the gaming-reward

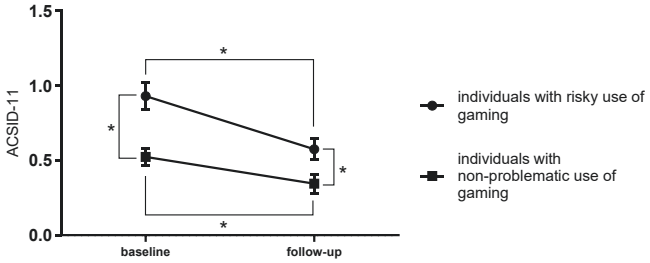

Fig. 2. Changes of severity of gaming disorder symptoms between baseline and six-month follow-up (mean, SEM); ACSID-11, Assessment of Criteria for Specific Internet-use Disorders; significant changes are highlighted *

Prediction of the severity of problematic gaming

Regarding the prediction of the severity of problematic gaming at the six-month follow-up, the model was significant in the first step ($R^2 = 0.45$, $F(4, 89) = 18.33$, $p < 0.001$) with the severity of problematic gaming reported at baseline ($ß = 0.64$, $p < 0.001$) and motor impulsivity ($ß = 0.17$, $p = 0.03$) as significant predictors for symptom severity at follow-up, see Table 3. Entering the magnitude of the 'Shopping-PIT'-effect as well as the interaction term magnitude of the 'Shopping-PIT'-effect by severity of problematic gaming at baseline in the next step significantly improved the variance explanation ($\Delta R^2 = 0.04$, $p = 0.035$). The severity of problematic gaming at baseline ($ß = 0.68$, $p < 0.001$) and impulsivity ($ß = 0.17$, $p = 0.03$) remained significant and the interaction term magnitude of the 'Shopping-PIT'-effect by severity of problematic gaming at baseline ($ß = 0.22$, $p = 0.01$) emerged as additional significant predictor. Entering the magnitude of the 'Gaming-PIT'-effect as well as the interaction term severity of problematic gaming at baseline by magnitude of the 'Gaming-PIT'-effect did, however, not significantly improve the model ($\Delta R^2 = 0.01$, $p = 0.60$), while all significant predictor variables from the previous step remained significant. After applying the FDR correction, all significant predictors but motor impulsivity remained significant.

Simple slopes analysis indicated a positive association between the magnitude of the 'Shopping-PIT'-effect and symptom severity at follow-up in individuals with high symptom severity at baseline ($B = 0.006$, $SE = 0.003$, $ß = 0.330$, $p = 0.021$), while the slopes for mean ($B = 0.002$, $SE = 0.\ 002$, $ß = 0.104$, $p = 0.217$) and low symptom severity at baseline ($B = -0.002$, $SE = 0.002$, $ß = -0.122$, $p = 0.238$) were not significant. As depicted in Fig. 3,

Table 3. Results of the hierarchical linear regression analysis to predict the severity of problematic gaming at follow-up

Variables and steps	Severity of problematic gaming at follow-up.								
	Step 1			Step 2			Step 3		
	β	*T*	*p*	*β*	*T*	*p*	*β*	*T*	*p*
Symptom severity gaming baseline (ACSID-11)	**0.636**	**7.933**	**<0.001**	**0.683**	**8.514**	**<0.001***	**0.689**	**8.50**	**<0.001***
Depressive symptoms baseline (BSI-53/D)	0.068	0.817	0.416	0.102	1.237	0.220	0.105	1.268	0.208
Motor impulsivity baseline (BIS-15/M)	**0.174**	**2.191**	**0.031**	**0.174**	**2.243**	**0.027**	**0.189**	**2.378**	**0.020**
Motivation to seek help last six months	0.108	1.294	0.199	0.128	1.551	0.125	0.119	1.413	0.161
Magnitude 'Shopping-PIT'-effect				0.092	1.121	0.266	0.103	1.243	0.217
Symptom severity by magnitude 'Shopping-PIT'-effect				**0.222**	**2.629**	**0.010***	**0.214**	**2.505**	**0.014***
Magnitude 'Gaming-PIT'-effect							0.012	0.153	0.878
Symptom severity by magnitude 'Gaming-PIT'-effect							0.082	1.013	0.314
R^2	**0.45**		**< 0.001**	**0.49**		**<0.001**	**0.49**		**<0.001**

Note. *β* is the standardized regression coefficient; significant effects are highlighted in bold; * significant after FDR correction; ACSID-11, Assessment of Criteria for Specific Internet-use Disorders; BSI-53/D, Brief Symptom Inventory, subscale depression; BIS-15/M, Barratt Impulsiveness Scale – short version, subscale motor.

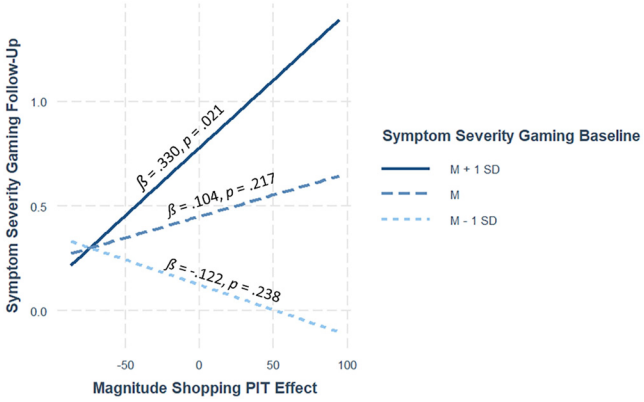

Fig. 3. Simple slopes for the association between symptom severity of gaming at the six-months follow-up assessment and the magnitude of the 'Shopping-PIT'-effect for different values of the moderator variable symptom severity of gaming at baseline assessment (M 1 SD, M, M + 1 SD). All predictors had been mean-centered

individuals with a high symptom severity at baseline and a high magnitude of the 'Shopping-PIT'-effect showed the highest symptom severity of gaming at follow-up assessment.

DISCUSSION

Regarding our main research question, our results indicate that responding for a general reward (i.e. shopping vouchers) after devaluation of the gaming reward and habitual behavior in response to gaming-related stimuli seem to contribute differently to symptom severity of gaming at the follow-up assessment. Results of a regression analysis indicated that the symptom severity at baseline as well as motor impulsivity were significant predictors in all steps, although motor impulsivity vary narrowly missed significance after applying the FDR correction. In addition, the interaction of symptom severity at baseline and the magnitude of the 'Shopping-PIT'-effect after devaluation of the gaming reward as indicator of cue-triggered responding for a general reward (i.e. shopping vouchers) significantly predicted symptom severity at follow-up. In contrast, the model did not significantly improve when the magnitude of the 'Gaming-PIT'-effect after devaluation of gaming and the interaction effect of symptom severity and the 'Gaming-PIT'-effect were entered in the analysis. The 'Shopping-PIT'-effect and the 'Gaming-PIT'-effect operationalize two different processes: The 'Shopping-PIT'-effect is conceptualized as an indicator of responding for a general reward (like money) given the widespread use of online shopping in the general population. A high 'Shopping-PIT'-effect indicates that the CS^S prompts individuals to choose the shopping reward, which can be considered as functional or goal-directed behavior given that this reward was not devalued. Interestingly, the predictive value of the 'Shopping-PIT'-effect for the symptom severity of gaming is moderated by symptom severity of gaming at baseline. Thus, cue-triggered responding for a general reward ('Shopping-PIT'-effect) contributes to future symptom severity only in individuals of the present sample who report a higher symptom severity. This suggests a cascade model in behavioral addictions (Brand, 2022; Brand et al., 2025) with higher symptom severity leading to stronger cue-triggered reward-related responding which in turn leads to higher symptom severity. This finding extends previous findings on the predictive value of general reward-related responding in alcohol use disorder. While the monetary-related PIT-effect was found to be related to future relapse in patients with alcohol use disorder, interaction effects with the severity of alcohol use disorder at baseline have not been analyzed (e.g. Sommer et al., 2020).

Interestingly, although we observed in this subsample in line with our previous results (Schmid et al., 2024) a 'Gaming-PIT'-effect even after devaluation of the gaming reward, the 'Gaming-PIT'-effect and its interaction with symptom severity were not predictive of future symptom severity. This finding suggests that in this sample of participants with risky or non-problematic use, habits are not so strong that they contribute to the development of future symptom severity, at least not within six months. However, the process of habit formation seems to be already present given the observed PIT-effects. According to the I-PACE model (Brand et al., 2019) it can be assumed that with increasing severity of problematic use, habit formation becomes a process relevant for the development of problematic behavior. Given that we observed in the present sample a decrease of the mean severity of problematic use, it would be interesting to investigate in future research whether different results are observed in a sample with an increase of symptom severity or a more severe use in general. It can be assumed that in these individuals negative reinforcement and compensation experiences are more important and less flexible and compulsive behaviors may develop (Brand et al., 2025). However, it is also important to acknowledge that the relevance of habitual behavior in addiction is also challenged by some recent reviews (e.g., Hogarth, 2020; Vandaele & Ahmed, 2021). Thus, evidence of a deficit of goal-directed behavior and an increased propensity towards habitual behavior in individuals with addiction is mixed and there seem to be a number of factors that moderate the (in) sensitivity to devaluation procedures (e.g., symptom severity, negative mood; see(Doñamayor et al., 2022). As recently outlined by Brand et al. (2025) in more detail, habit formation may be a process that contributes to "seemingly" automatic or habitual behaviors if specific goals are situation-specifically activated. Thus, specific goals (e.g., avoiding negative feelings) may be triggered by external or internal stimuli. Based on habit formation a specific behavior is then executed in terms of a learned preparedness to respond specifically when being confronted with specific stimuli/situations.

Our results indicated a decrease of mean symptom severity during the six-month-follow-up period across all participants. Such a decrease of symptom severity for

gaming, but also other Internet activities, was also reported by Konkolÿ Thege, Woodin, Hodgins, and Williams (2015) and Lopez-Fernandez et al. (2023). As recently outlined by Brand and colleagues (Brand et al., 2025) the development of problematic behavior seems to be a highly variable process and a (re)development, for example from pathological to risky or non-problematic or from risky to non-problematic behavior is possible. Thus, risky or pathological behavior may be of transient nature and it can be assumed that individual aspects and their interaction effects (e.g. cognitive and affective processes, general psychopathology, help seeking) influence this process (Brand et al., 2019).

When interpreting the present findings a few limitations are important to acknowledge. First, we report here additional analysis related to research project 2 of the FOR2974 which were not part of the preregistration and sample size estimations were based on a different main research question (see Schmid, et al., 2024). As indicated by a post-hoc power analysis, the follow-up sample available to address the research questions reported here provided a power <0.80 for the significant finding of the hierarchical linear regression analysis. Therefore, results should be replicated in a larger sample. Second, the participants of the present sample are predominantly male. While this reflects on the one hand prevalence rates observed in the general population (e.g. Stevens et al., 2021), gender differences have been observed, for example regarding neural responses to gaming cues (e.g., Dong, Wang, Du, & Potenza, 2018) or decision making (S. M. Müller et al., 2023). In addition, compared to baseline assessment, the follow-up assessment was carried out as an online survey while at baseline assessment, the ACSID-11 was administered during the laboratory test-session. Thus, we cannot exclude that the decrease of symptom severity observed from baseline to follow-up is confounded by the differences in assessment contexts.

To conclude, our findings indicate that in individuals with more severe risky use of gaming, functional reward-related responding to cues signaling a general reward may be a mechanism that contributes to an aggravation of risky gaming behavior in the following six months. In contrast, habitual responding to a devalued gaming reward was not identified as an additional relevant mechanism. Although these findings should be interpreted with caution, they suggest that for the prevention of problematic use trajectories targeted interventions, for individuals who have already developed risky use, may include sensitizing individuals to their predisposition for reward-related responding and support the development of strategies to enhance self-control. However, for future research, it is important to enhance our understanding of problematic use trajectories further and to develop interventions that attenuate the impact of mechanisms contributing to symptom aggravation.

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