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Persistent appetitive memory in problematic pornography users

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FULL-LENGTH REPORT

ABSTRACT

Background and Aims: Most men consume pornography, with a small but significant percentage losing control over their use. Since ICD-11, problematic pornography use can be diagnosed as “compulsive sexual behavior disorder.” Debate persists on whether problematic pornography use is an impulse-control disorder or a behavioral addiction. Mechanisms of learning and memory play a central role in addictive disorders but are presumably less relevant for impulse control disorders. *Methods:* One hundred thirty-nine heterosexual male users of pornography and gaming participated in our study which was part of a multi-center research project on internet use disorders in Germany. We focus on a subsample of fifty-eight non-problematic ($n = 35$) and problematic pornography users ($n = 23$, labeled pathological). FMRI data were collected during appetitive conditioning, extinction and recall. Pornographic, game, and money images served as unconditioned stimuli, geometric shapes as conditioned stimuli (CS). *Results:* During appetitive conditioning pathological pornography users showed a generally stronger response in ventral striatum to all CSs, whereas altered activations in extinction and recall were specific to the porn-associated CS. Greater activations in the dorsal anterior cingulate cortex during extinction and in the medial orbitofrontal cortex during recall suggest persistence of appetitive memory for pornography in pathological users, supported by valence ratings and skin conductance responses (SCR). Sensitization to the monetary cue also emerged in SCR. *Discussion and Conclusions:* Based on these new neurobiological findings, which are consistent with current addiction theories about stimulus-specific altered reward sensitivity and appetitive memory, we argue that problematic pornography use should be considered a behavioral addiction.

KEYWORDS

pornography, cue reactivity, appetitive conditioning, extinction, reward processing, fMRI

INTRODUCTION

The advances in mobile technology and broad-band internet as well as social distancing during the COVID-19 pandemic contributed to an increase in the use of online pornography in recent years (Lewczuk, Wójcik, & Gola, 2022; Martinez-Serra & Cardenal, 2025; Mestre-Bach, Blycker, & Potenza, 2020; Von Andrian-Werburg, Siegers, & Breuer, 2023). Men are the principal consumers of online pornography and have higher rates of problematic use (Grubbs, Kraus, & Perry, 2019; Lewczuk et al., 2022; Martinez-Serra & Cardenal, 2025; Rissel et al., 2017; Von Andrian-Werburg et al., 2023). While in survey studies up to 80% of men report regular pornography use, the rate of self-reported problematic pornography consumption lies between 1.5 and 15.5% (Antons et al., 2019; Dwulit & Rzymski, 2019;

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Grubbs et al., 2019; Kraus, Voon, & Potenza, 2016; Markert et al., 2023; Mennig, Tennie, & Barke, 2022; Odlaug et al., 2013; Rissel et al., 2017). A recent online survey revealed a prevalence rate of approximately 5% among male adults (Markert et al., 2023). Most young men consume pornography, with a small but considerable proportion experiencing marked distress and psychosocial impairment because of their use. Of significance, there is a high comorbidity with anxiety and affective disorders as well as with substance use disorders (Starcevic & Khazaal, 2017). Several studies report further correlations with severity of pornography use; namely associations with quantity of use (Ben Brahim, Courtois, Vera Cruz, & Khazaal, 2024; Chen, Chaudhary, & Li, 2022), cue reactivity (Voon et al., 2014), attentional bias (Pekal, Laier, Snagowski, Stark, & Brand, 2018), craving and impulsivity (Antons et al., 2019; Ben Brahim et al., 2024), as well as dysfunctional emotion regulation (Ben Brahim et al., 2024; Cardoso, Ramos, Brito, & Almeida, 2022; Stark, Klucken, Potenza, Brand, & Strahler, 2018). Problematic pornography use is associated with increased priority, loss of control, and continuation despite negative consequences similar to behavioral addictions (Brand et al., 2020; Love, Laier, Brand, Hatch, & Hajela, 2015; Stark et al., 2018). Since ICD 11, problematic pornography use can be diagnosed as a subtype of "compulsive sexual behavior disorder" (Antons & Brand, 2021). There is still a controversy, if it should be considered an impulse control disorder or a behavioral addiction (Brand et al., 2020; Gola & Potenza, 2018; Kraus et al., 2016; Stark et al., 2018). Addiction theories assume learned cue-reward associations and persistent addiction memory as core mechanism (Bechara & Van Der Linden, 2005; Berridge & Robinson, 2016; Blum et al., 1996; Goldstein & Volkow, 2011; Robinson, 1993), whereas the focus of impulse control disorders is on within person factors (trait impulsivity; Gola & Kraus, 2021). Impulsivity contributes to problematic pornography use; however, its association with the severity of problematic use is relatively small in comparison to hypersexuality (Bőthe et al., 2019) and only few facets of impulsivity seem to be different compared to non-problematic users (Antons et al., 2019).

Sexual arousal in healthy samples is associated with activations in the reward system including the striatum consisting of the nucleus accumbens (NAcc), caudate nucleus, and putamen, as well as the medial orbitofrontal cortex (mOFC) (Krikova et al., 2024; Kühn & Gallinat, 2011; Markert, Klein, Strahler, Kruse, & Stark, 2021; Mitricheva, Kimura, Logothetis, & Noori, 2019; Poeppl, Langguth, Laird, & Eickhoff, 2014; Stoléru, Fonteille, Cornélis, Joyal, & Moulier, 2012). In addition, meta-analyses identified activations in anterior insula, dorsal anterior cingulate cortex (dACC), amygdala and thalamus (Kühn & Gallinat, 2011; Mitricheva et al., 2019; Poeppl et al., 2014; Stoléru et al., 2012). These brain regions belong to the salience network important for attentional processing (Seeley, 2019; Seeley et al., 2007). The preference for specific sexual stimuli seems to be encoded in the ventral striatum (Brand, Snagowski, Laier, & Maderwald, 2016; Klein et al., 2020). In addition, some studies found correlations of self-reported problematic use and ventral striatal responses to pornographic stimuli (Brand et al., 2016; Klein et al., 2020). Empirical evidence consistently points to altered reward processing in problematic pornography users (Klein et al., 2022). In particular, reward anticipation and reward learning related to pornography appear to be elevated in problematic pornography use (Gola et al., 2017; Klein et al., 2022; Klucken, Wehrum-Osinsky, Schweckendiek, Kruse, & Stark, 2016).

Appetitive conditioning, a process of reward learning through which a neutral stimulus acquires motivational salience (Martin-Soelch, Linthicum, & Ernst, 2007), might be important for the development of problematic pornography use. Increasing empirical evidence points to altered appetitive conditioning to pornographic stimuli and cue reactivity in pathological pornography users (Banca et al., 2016; Gola et al., 2017; Klucken et al., 2016; Voon et al., 2014; Wojciechowski et al., 2025). Compared to alternative rewards pornographic stimuli led to the strongest appetitive conditioning in non-problematic users which might depend on its role in reproduction (Krikova et al., 2024). In contrast to offline sexual behaviors, design features might further increase the addictive potential of online pornography, e.g. endless novel, sexual stimuli coupled with AI-driven recommendations (Clark & Zack, 2023; Flayelle et al., 2023; Krikova et al., 2024). Appetitive conditioning occurs when men visit pornographic websites and experience sexual gratification, an unconditioned response. With repeated exposure, stimuli like the pornographic website, the electronic device or one's own space become conditioned stimuli (CS+) triggering the expectation of sexual gratification, a conditioned response. Through appetitive conditioning cue reactivity is formed, a stronger physiological and psychological response to addiction-related cues (Koob & Volkow, 2016; Starcke, Antons, Trotzke, & Brand, 2018; Zeng et al., 2021). Cue reactivity involves increased activation to addiction-related cues in the striatum and prefrontal areas linked to reward and salience processing (Antons, Brand, & Potenza, 2020; García-Castro, Cancela, & Cárdaba, 2023; Starcke et al., 2018; Zeng et al., 2021). With respect to pornography, problematic users showed stronger reward responses to pornographic stimuli and cues (Love et al., 2015). Studies in problematic pornography users revealed stronger responses in ventral striatum, amygdala, and dACC when exposed to explicit sexual material or to conditioned pornographic cues compared to healthy controls and contrasted with non-sexual stimuli (Gola et al., 2017; Klucken et al., 2016; Voon et al., 2014). Cue reactivity is correlated to craving, a strong desire for the addictive behavior presumably increasing the likelihood of subsequent consumption (Tiffany & Wray, 2012). In accordance with this, two studies in behavioral addictions showed that craving correlated with stronger activation in the bilateral striatum and anterior insula (Limbrick-Oldfield et al., 2017; Trotzke, Starcke, Pedersen, & Brand, 2021). Another study found an association between sexual desire and cue-induced dACC activation in pornography users (Voon et al., 2014). In summary, there is empirical evidence that problematic pornography use like behavioral addictions is associated with stronger cue reactivity and craving.

Extinction learning, where a cue is newly associated with the absence of reward, forms the basis of cue exposure in addiction treatment (Conklin & Tiffany, 2002). Consistent with its function for cue reactivity, activation in the dACC is reduced through cue exposure interventions (Allenby et al., 2020; Farré-Colomés et al., 2024; Vollstädt-Klein et al., 2011). Extinction processes in appetitive conditioning are under-investigated (Konova & Goldstein, 2019) – and this applies even more so to problematic pornography consumption. In two conditioning and extinction studies, problematic pornography users showed a generally elevated reactivity to both pornographic and monetary cues across both phases (Banca et al., 2016; Wojciechowski et al., 2025). The persistence of appetitive conditioning vs. extinction memory has not been investigated before and could be tackled by adding a recall phase. If appetitive conditioning is resistant to extinction this would contribute to persistence of cue reactivity in problematic pornography users and would explain why attempts to reduce or stop pornography use are often unsuccessful.

In the present fMRI study, we monitored appetitive conditioning, extinction and recall in non-problematic and problematic pornography users. Given the parallels between problematic pornography use and behavioral addictions, for which appetitive conditioning and memory are important factors for development and maintenance, understanding these neural mechanisms remains a major knowledge gap. To expand empirical evidence, we included a recall phase to test if appetitive memory returns (Bouton, 2004). The persistence of appetitive memory may provide a mechanism for the enduring nature of problematic pornography use. By identifying altered brain activations during these three phases, the study offers insight into potential mechanisms of problematic use. The present manuscript focuses on the comparison of non-problematic and problematic pornography users (referred to as pathological) identified with a structured clinical interview. Pathological users were thought to be in the late stage of a behavioral addiction characterized by habitual use (Berridge & Robinson, 2016; Brand et al., 2019). We hypothesized that pathological pornography users compared to non-problematic users would show elevated conditioned responses, impaired extinction learning and memory for the cue conditioned to pornography.

METHODS

Participants

The original sample comprised one hundred thirty-nine heterosexual right-handed male users of pornography and/or gaming; the current analysis focuses on fifty-eight pornography users (pathological and non-problematic) who underwent fMRI. The study was part of a large multi-center research project on mechanisms of internet use disorders in Germany (Brand et al., 2021; Müller et al., 2025). Exclusion criteria were a history of psychosis, schizophrenia, bipolar disorder, Parkinson's, epilepsy, substance addiction (excluding nicotine), literacy difficulties, current use of psychoactive drugs (excluding antidepressants and stimulants), or acute suicidality. Participants were recruited via offline and online advertisements. In a telephone screening, MRI suitability and problematic use patterns were assessed (AICA-C9 Checklist (Wölfling & Müller, 2017). Consistent with the multi-center research project, participants were assigned to one of five user groups based on their target behavior (pornography or gaming) and the severity of their usage behavior (non-problematic, risky or pathological). Before the fMRI measurement, a structured clinical interview for the diagnosis of internet use disorders (AICA-SKI: IBS, Wölfling & Müller, 2017) was conducted. The assessed criteria were (1) prioritization and craving; (2) loss of other interests, (3) loss of control and unsuccessful attempts of abstinence; (4) continuation despite negative consequences; (5) tolerance; (6) withdrawal-like symptoms; (7) emotion regulation; (8) deception; (9) jeopardizing important relationships and prospects. Non-problematic users ($n = 35$) met 0–1 criteria, risky pornography users 2–4 criteria ($n = 14$; results provided in supplementary material), and pathological pornography users five or more criteria ($n = 23$). Non-problematic (25.7 years ± 4.3 SD) and pathological pornography users (25.9 years ± 4.9 SD) did not differ with respect to age ($t_{56} = .105$, $p = .917$). A total of nine participants reported a mental health diagnosis at some point in their lives. In the pathological group the diagnoses were ADHD ($n = 1$, current stimulant treatment), anxiety disorder ($n = 1$), depression ($n = 1$, current antidepressant treatment) and adjustment disorder ($n = 1$); in the non-problematic group diagnoses were ADHD ($n = 2$, one current stimulant treatment), depression ($n = 1$), burn-out syndrome and eating disorder (each $n = 1$). The study was pre-registered (https://osf.io/sx8vu/). Participants received financial compensation or course credit. Of the fifty-eight participants, two dropped out before extinction and three before recall. Movement artifacts led to the exclusion of fMRI data from four participants during acquisition, five during extinction and one during recall. Two participants were excluded from subjective ratings due to missing data; two participants were excluded from SCR analyses because of noise and artifacts. Sample sizes per analysis are provided along with the results.

Procedure

Data were acquired at the Bender Institute of Neuroimaging at the Justus Liebig University (Giessen, Germany) from January 2022 to December 2023. The study involved two sessions; in the first, participants completed the core test battery of the multi-center research project in the laboratory (Brand et al., 2021). Appetitive conditioning and extinction were scheduled for the afternoon of this first session; recall took place approximately one week later. FMRI was measured during all experimental phases each lasting

~27 min. Three sets of appetitive images (pornography, money, gaming) served as unconditioned stimuli (UCS) (Krikova et al., 2024); four geometric symbols were used as conditioned stimuli (CS). Before entering the scanner, participants selected their eleven favorite images per UCS set, they rated the CSs and the selected UCS sets, and they practiced the task. The practice session consisted of twelve trials (six reinforced) with images distinct from those used in the main task. The experiment comprised of seventeen trials per CS and phase. In the acquisition phase, three CS+ s were paired with a UCS in eleven trials per CS+. The CS− served as control stimulus and was never followed by a UCS. No UCSs (black screen) were presented during extinction, and recall. The first trial was discarded from all analyses. Ratings of valence and arousal were collected for the CSs and UCSs before practice and after each phase with the nine-point self-assessment manikins scales ranging from 1 (very unpleasant/not arousing at all) to 9 (very pleasant/very arousing) (Bradley & Lang, 1994). In addition, UCS expectancy ratings were collected after each phase (not reported here). The trial lasted from 10.5 to 12 s starting with a white fixation cross on black screen (0–2.5 s), followed by the CS (8 s), and subsequently the UCS or no UCS (2.5 s). A fixation cross was displayed during the inter-trial-interval jittered between 8.5 and 11.5 s. The assignment of stimuli to CS types and the order of trials were counterbalanced across participants. The order of trials was pseudorandomized so that no more than two trials of a CS (CS−, CS+, either reinforced or not) followed each other. Each CS appeared once in the first four trials per phase; the first trial of each CS+ was reinforced during acquisition. Participants were instructed to find out about the CS–UCS relationship and they were informed that 50 cents would be paid for each monetary image in the experiment. Figure 1 shows the study design.

Skin conductance

Skin conductance was measured during all phases with two reusable Ag/AgCl electrodes filled with isotonic (.05 M NaCl) electrolyte medium attached to the hypothenar muscles of the left hand. Data were acquired with a sampling rate of 1 kHz using the BrainAMP ExG MR amplifier with the GSR MR module (Brain Products GmbH, Gilching, Germany). Data were visually screened and participants with corrupted data excluded from analysis. SC data were analyzed with continuous decomposition analysis in Ledalab 3.4.9 (Benedek & Kaernbach, 2010) implemented in Matlab 2021a (The Mathworks Inc., Natick, Massachusetts, USA). Data were down-sampled to 10 Hz and smoothed with a 32-sample FWHM Gaussian kernel. To capture the first response to the CS, SCR (in μS) were estimated for the analysis window 1–4 s after stimulus onset. SCR smaller than .01 μS were scored as zero responses. SCR were log(μS + 1) transformed.

Image acquisition

MRI images were acquired on a Siemens 3 Tesla-Magnetom Prisma system (Siemens, Germany), using a 64-channel head coil. Foam pads were used to restrict head movement. Visual stimuli were displayed on a screen at the head end of the scanner bore and viewed via a mirror mounted on the head coil. Responses were collected with a custom-made four finger response keypad placed in the right hand. Breathing and cardiac activity were monitored during scanning. Anatomical images were acquired using a T1-weighted MPRAGE-sequence (TR = 1.58 s, TE = 2.3 s, flip angle = 8°, FOV = 240 mm, voxel size = .9 × .9 × .9 mm^3). A GRE-Field map was acquired to estimate B0 inhomogeneities. An multiband echoplanar imaging (EPI) sequence was used

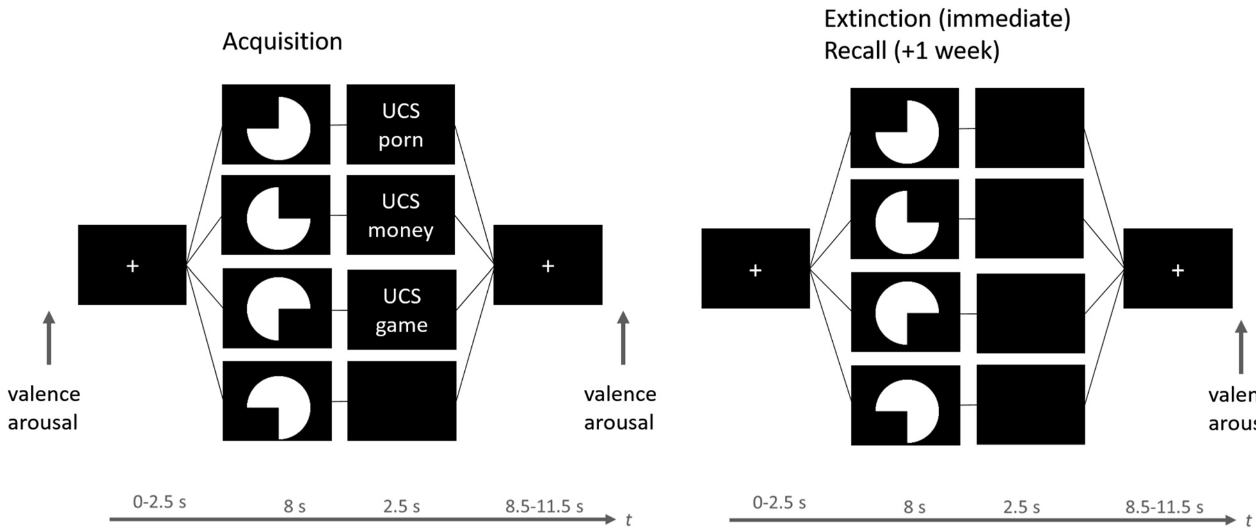

Fig. 1. **The design of the appetitive conditioning and extinction task.** Each trial began with a white fixation cross (0–2.5 s), followed by one of four geometric cues (conditioned stimuli, CS+$_{porn}$, CS+$_{game}$, CS+$_{money}$, or CS−) presented for 8 s and the presentation of one unconditioned stimulus (UCS, pornographic pictures, gaming pictures or money pictures) or a black screen (in the case of CS−) for 2.5 s. After the UCS had disappeared, the fixation cross was displayed again. The intertrial interval (ITI) was jittered between 8.5 and 11.5 s. During extinction and recall all parameters were equal except that no UCSs were displayed. Valence and arousal ratings for the CSs were collected before acquisition (and practice) and after each experimental phase

for blood-oxygen-level-dependent (BOLD) fMRI (TR = 2 s; TE = 30 ms; flip angle = 75°; FoV = 222 mm; voxel size = 3 × 3 × 3 mm^3, 42 slices; descending slice acquisition; phase encoding direction: anterior–posterior, MB acceleration factor = 2, GRAPPA = 2). The position of the field of view was automatically oriented relative to the AC–PC line tilted at −30°.

Statistical analysis

Statistical tests on valence and arousal ratings as well as SCR were performed in SPSS 29 for Windows (Armonk, NY: IBM Corp.). Repeated measures analyses of variance (rmANOVA) included the within subject factor CS type (CS_{porn}, $CS+_{game}$, $CS+_{money}$, CS_{minus}) and the between subject factor group (pathological vs. non-problematic pornography use). We additionally included the within subject factor time (valence/arousal: pre-practice, post-acquisition, post-extinction, post-recall; SCR: acquisition, extinction, recall). Post hoc independent *t*-tests were applied to compare user groups. Bonferroni-correction was applied to *p*-values by multiplying with the number of *t*-tests. For confirmatory analyses ($CS+_{porn}$ > CS−) the factor was 3 (number of outcomes). For exploratory analyses ($CS+_{money}$ > CS−, $CS+_{game}$ > CS−), the factors were 12 for ratings and 9 for SCR, reflecting the number of outcomes multiplied by experimental phases. Post hoc paired *t*-tests for CS+ vs. CS− differences in a specific group and bar plots are given in the supplementary material (Tables S1–S2, Figures S3–S4).

Image analysis

FMRI data were analyzed with SPM12 (Wellcome Trust Centre for Neuroimaging, London, UK) implemented in Matlab 2021a. Preprocessing included co-registration of the EPI images to an EPI template, co-registration of the anatomical T1-image to a T1-template, spatial realignment with unwarping, slice time correction, co-registration of the mean functional image to the anatomical T1 image, normalization to the MNI template by segmentation, and spatial smoothing with a Gaussian kernel (6 mm FWHM). EPI images were temporally high pass filtered with a cut-off of 128 s. General linear models (GLM) were fitted for each participant to model individual BOLD signal changes. The regressors of interest were $CS+_{porn}$, $CS+_{game}$, $CS+_{money}$, and CS−. Additional first level regressors were UCS_{porn}, UCS_{game}, and UCS_{money}, the first trial of each CS, and the CS offsets (noUCS). Each CS was averaged across all trials excluding the first. Regressors were modelled as stick function (0 s duration) and convolved with the canonical hemodynamic response function. Functional images were analyzed for outlying volumes (Schweckendiek et al., 2013), which were included together with the six movement parameters as covariates of no interest in the GLM. Participants with over 15% of volumes (per sequence) showing movement artefacts (framewise displacement >0.5 mm (Power, Barnes, Snyder, Schlaggar, & Petersen, 2012), were excluded from analysis. Two-sample *t*-tests were used at the second level to compare group responses to conditioned stimuli ($CS+_{porn}$ > CS−, $CS+_{game}$ > CS−, $CS+_{money}$ > CS−). For region of interest (ROI) analyses data were thresholded at p_{unc}<0.05 before small volume correction was applied with family-wise error correction at the peak level (p_{FWE}<.05). ROIs were derived from the Harvard Oxford Brain Atlas thresholded at 50% with a 2 mm resolution: NAcc, caudate nucleus, and amygdala, each for the left and right side (Desikan et al., 2006; Frazier et al., 2005; J. M. Goldstein et al., 2007; Makris et al., 2006). The dACC was addressed with the anterior midcingulate cortex mask (aMCC) also based on the Harvard Oxford Brain Atlas (Vogt, 2016). The mOFC masks were based on the Automated Anatomical Labeling Atlas (Tzourio-Mazoyer et al., 2002). All results were Bonferroni-corrected for bilateral testing.

Ethics

The study was approved by the ethics committee of the University of Siegen (reference number: ER_26/2019) and conducted in accordance with the Declaration of Helsinki. Participants gave written informed consent before study inclusion.

RESULTS

Subjective ratings

The rmANOVAs on valence and arousal ratings of the conditioned stimuli revealed that learning occurred across both user groups as indicated by significant effects of CS, time, and a significant CS × time interaction (see Table 1). To interpret the significant CS × group interaction in valence ratings, post hoc group-wise rmANOVAs were performed revealing a significant main effect of CS only in the pathological users ($F_{3,54}$ = 8.888*, p <.001, η^2 part=.331, non-problematic: $F_{3,93}$ = 2.180, p=.096, η^2 part=.066). All statistics for group-wise post hoc rmANOVAs are given in the supplementary material Table S3. Arousal ratings showed a significant group effect driven by generally higher ratings in pathological pornography users. Follow-up, independent *t*-tests revealed elevated valence ratings for the $CS+_{porn}$ compared to the CS− in the pathological compared to the non-problematic pornography users after acquisition (t_{49} = 2.501*, p_{BC}=.024, Cohen's d=.724) and recall ($t_{29.899}$ = 2.661*, p_{BC}=.018, Cohen's d=.831, Fig. 3A) implying a stronger reward learning and persistence of appetitive memory for the $CS+_{porn}$ in the pathological pornography users. As a secondary finding, valence ratings for the $CS+_{money}$ were also marginally higher in pathological pornography users during recall (t_{49} = 1.978, p_{BC}=.324, Cohen's d=.573).

Skin conductance

The rmANOVA on SCR revealed significant main effects of time and CS. There was no CS × time interaction and no

Table 1. Main effects and interactions in subjective ratings and SCR for conditioned stimuli tested with rmANOVAs

Outcome		*F*	*df*	df_{error}	*p*	η^2 *part*
valence	CS	10.722*	3	147	<.001	.180
	time	26.033*	2.192	107.419	<.001	.347
	CS × time	5.30*	5.419	265.547	<.001	.098
	group	.598	1	49	.443	.012
	CS × group	5.258*	3	147	.002	.097
	time × group	1.547	2.192	107.419	.216	.031
	CS × time × group	1.109	5.419	265.547	.357	.022
arousal	CS	15.896*	3	147	<.001	.245
	time	23.547*	3	147	<.001	.325
	CS × time	12.527*	6	294.020	<.001	.204
	group	5.610*	1	49	.022	.103
	CS × group	.458	3	147	.712	.009
	time × group	1.548	3	147	.205	.031
	CS × time × group	1.045	6	294.020	.396	.021
SCR	CS	2.908*	3	147	.037	.056
	time	18.185*	1.463	71.684	<.001	.271
	CS × time	1.459	4.794	234.887	.207	.029
	group	.610	1	49	.438	.012
	CS × group	2.752*	3	147	.045	.053
	time × group	.369	1.463	71.684	.626	.007
	CS × time × group	1.463	4.794	234.887	.205	.029

Note. **p* <.05. CS, conditioned stimuli; SCR, skin conductance responses. In case of violations to sphericity, Greenhouse Geisser correction was applied (see adapted df and df_{error}). The factors for the rmANOVAS were CS type ($CS+_{porn}$, $CS+_{money}$, $CS+_{game}$, CS−), group (non-problematic, pathological users), and time (valence/arousal: pre-acquisition, post-acquisition, post-extinction, post-recall; SCR: acquisition, extinction, recall). Sample sizes for valence and arousal ratings were $n = 51$ (pathological $n = 19$, non-problematic $n = 32$). The sample size for SCR was $n = 51$ for (pathological $n = 19$, non-problematic $n = 32$).

group effect but a significant CS × group interaction (see Table 1). Post hoc group-wise rmANOVAS revealed a significant CS effect only in pathological users ($F_{3,48} = 2.957^*$, p=.040, η^2 part=.141, non-problematic: $F_{3,93} = 0.214$, p=.886, η^2 part=.007, also see supplementary material Table S3). Independent *t*-tests revealed no significant group differences for appetitive conditioning and extinction implying that learning was successful in both groups. Nevertheless, pathological pornography users differed significantly from non-problematic users during recall regarding the $CS+_{porn}$ and the $CS+_{money}$ ($CS+_{porn}$ vs. CS−: $t_{49} = 2.470^*$, p_{BC}=.027, Cohen's d=.715, $CS+_{money}$ vs. CS−: $t_{49} = 2.828^*$, p_{BC}=.027, Cohen's d=.819, see Fig. 3A). In summary, SCR during recall were higher in pathological pornography users to both $CS+_{porn}$ and $CS+_{money}$.

Neuroimaging results

During appetitive conditioning pathological compared to non-problematic users showed stronger activation to the $CS+_{porn}$ > CS− contrast in left NAcc (see Table 2). In addition, the pathological compared to non-problematic pornography users showed stronger responses in left NAcc, dACC/aMCC and left mOFC to the monetary CS+ ($CS+_{money}$ > CS−). In terms of the game-related CS+ ($CS+_{game}$ > CS−), the left NAcc was more active in pathological compared to non-problematic users. Findings for appetitive conditioning indicate that pathological users showed a generally stronger striatal response to all CS+ s. An overview of one sample *t*-tests for all groups, CSs and phases is provided in the supplementary material (Figures S5–S7, Table S4).

In appetitive extinction, activation to the $CS+_{porn}$ > CS− contrast was stronger in the dACC/aMCC for pathological compared to non-problematic pornography users (see Table 2 and Fig. 2B). Thus, attentional processing of the $CS+_{porn}$ was elevated in pathological pornography users implying persistent cue reactivity, and appetitive memory exclusively preserved for the $CS+_{porn}$.

In the recall phase, we observed stronger activation to the $CS+_{porn}$ > CS− contrast in right mOFC for the pathological pornography users compared to the non-problematic users (see Table 2, Fig. 3B). Results point to persistence of the appetitive memory for the $CS+_{porn}$ throughout recall in the pathological pornography users only. Summarizing our findings, the pathological pornography users differed from non-problematic users in their responses towards the $CS+_{porn}$ in all experimental phases.

DISCUSSION

Correlational approaches have often been used to investigate problematic pornography use in non-clinical samples (Brand et al., 2016; Klein et al., 2020; Markert et al., 2021). One major strength of our study is the inclusion of a group of problematic pornography users identified with a structured clinical interview (Brand et al., 2019; Wölfling & Müller, 2017). Pornographic stimuli elicited the highest appetitive

Table 2. Region of Interest analyses for appetitive conditioning (acquisition), extinction and recall for the group comparison pathological > non-problematic pornography users

Contrast			Region	MNI	*z-score*	$p_{svc,\ BC}$	*k*
acquisition							
	$CS+_{porn} > CS-$	L	NAcc	−10, 12, −8	2.875*	.046	64
	$CS+_{money} > CS-$	L	NAcc	−6, 8, −4	3.295*	.015	58
		L	dACC/aMCC	−6, 10, 36	3.641*	.032	1,233
		L	mOFC	−12, 34, −14	4.074*	.014	433
	$CS+_{game} > CS-$	L	NAcc	−10, 12, −6	2.981*	.036	51
extinction							
	$CS+_{porn} > CS-$	L	dACC/aMCC	−4, 28, 42	3.671*	.026	463
	$CS+_{money} > CS-$		no significant group differences				
	$CS+_{game} > CS-$		no significant group differences				
recall							
	$CS+_{porn} > CS-$	R	mOFC	12, 40, −8	3.936*	.022	991
	$CS+_{money} > CS-$		no significant group differences				
	$CS+_{game} > CS-$		no significant group differences				

Note. $^{*}p_{svc,\ BC}<.05$. Sample sizes for fMRI were $n = 54$ for acquisition (pathological $n = 22$, non-problematic $n = 32$), $n = 51$ for extinction (pathological $n = 20$, non-problematic $n = 31$) and $n = 53$ for recall (pathological $n = 20$, non-problematic $n = 33$). The initial inclusion threshold was $p_{unc}<.05$; small volume correction (SVC) with $p_{FWE}<.05$ was applied and *p*-values were Bonferroni-corrected (BC) for bilateral testing. z-Scores are given for the peak voxel with the given MNI-coordinates. aMCC, anterior midcingulate cortex; dACC, dorsal anterior cingulate cortex; mOFC, medial orbitofrontal cortex; NAcc, nucleus accumbens.

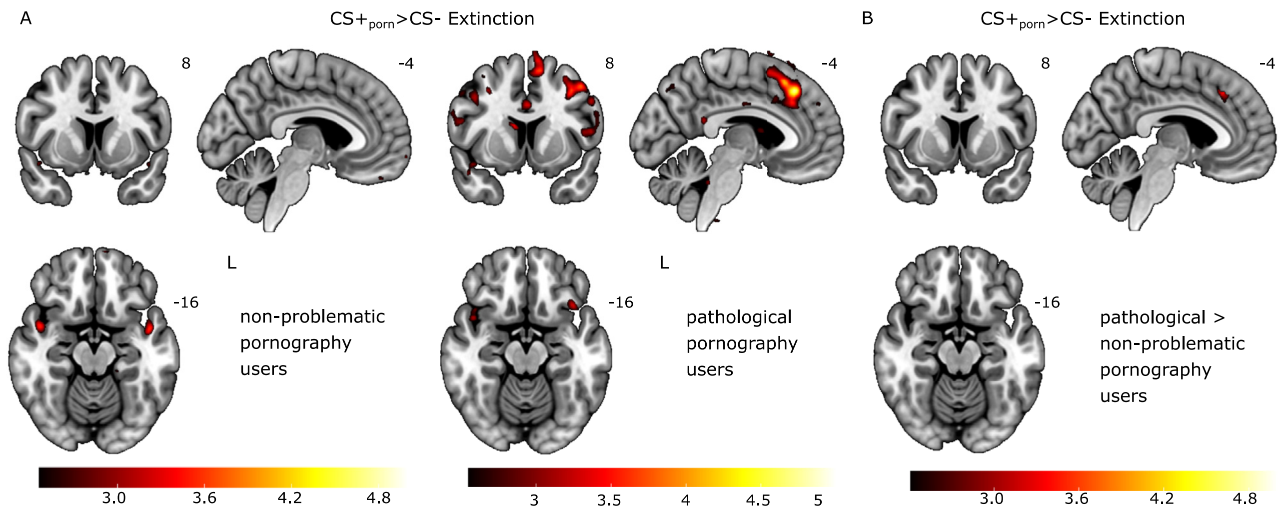

Fig. 2. **Stronger cue reactivity in extinction.** A) The $CS+_{porn} > CS-$ elicited no significant activations in the non-problematic pornography users ($n = 31$), but elevated activation in the dorsal anterior cingulate cortex (dACC) in pathological pornography users ($n = 20$). B) The two sample *t*-test confirmed stronger activation in the dACC in pathological compared to non-problematic pornography users which implies persistence of the appetitive memory throughout extinction. Note. All activation maps were thresholded at $p_{unc}<.01$. Only significant activations were plotted in the activation map of the two sample *t*-test

conditioning in both problematic and non-problematic pornography users. Assuming that both learning and memory are important factors for the maintenance of problematic pornography use, our fMRI study included appetitive conditioning (Banca et al., 2016; Klucken et al., 2016), extinction (Wojciechowski et al., 2025) and an additional recall phase. The inclusion of a recall phase and the comparison with two alternative reward cues are major strengths of our study (money, game). We found evidence of altered appetitive conditioning, extinction, and persistence of appetitive memory for the pornographic cue when compared to non-problematic users. Pathological pornography users yielded generally stronger activation in nucleus accumbens (NAcc) in appetitive conditioning, in dorsal anterior cingulate cortex (dACC) in extinction, and in medial orbitofrontal cortex (mOFC) in recall. While ventral striatal responses in appetitive conditioning were stronger to all conditioned stimuli implying a generalized reward sensitivity, altered activations during extinction, and recall were limited to the $CS+_{porn}$. Based on the fMRI data, pathological pornography users seem to extinguish associations for gaming and monetary CS+ s as good as non-problematic users but their appetitive memory for the $CS+_{porn}$ persisted implying impaired extinction learning and memory.

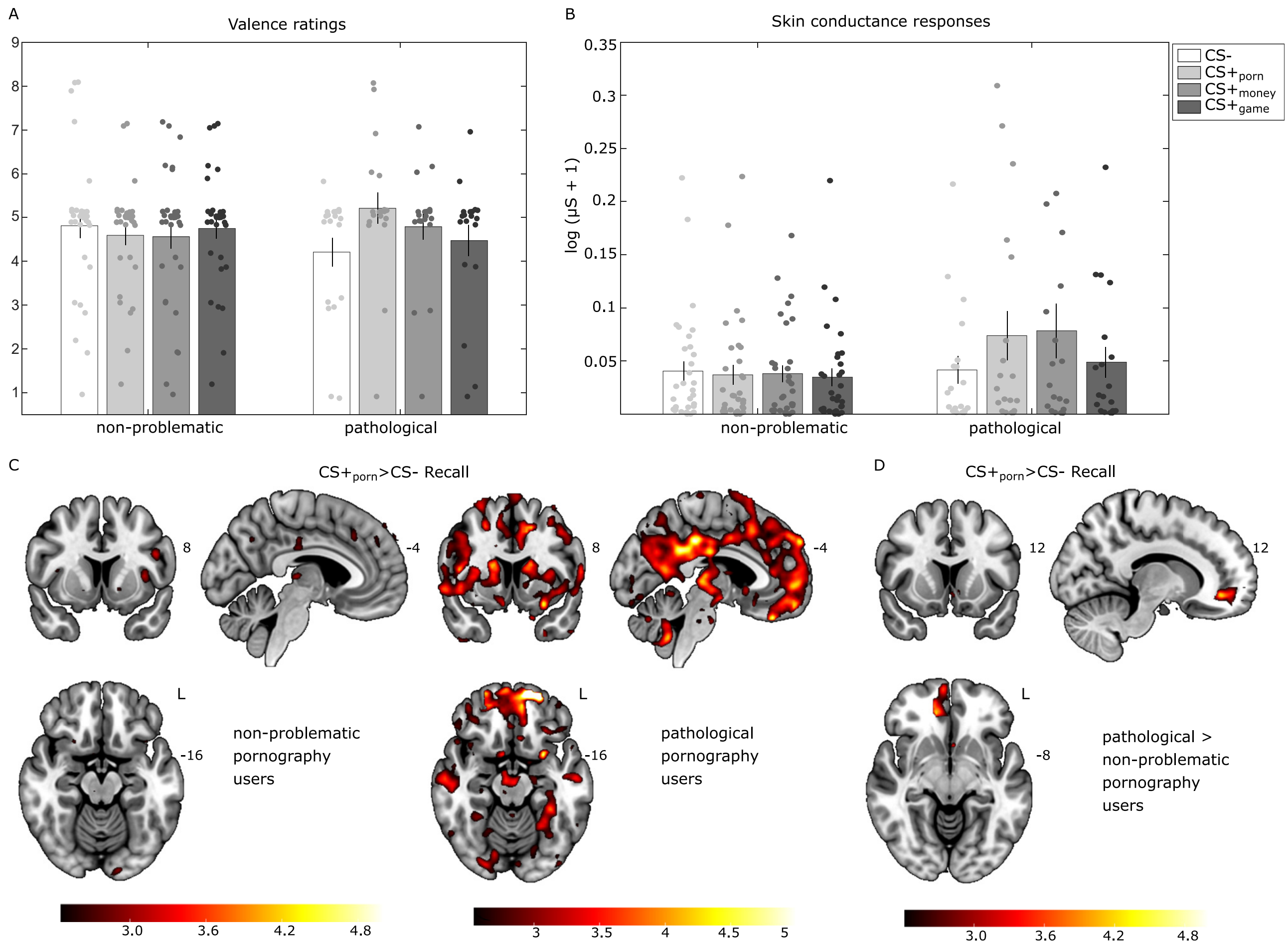

Fig. 3. **Persistence of appetitive memory in recall.** A) Valence ratings and B) skin conductance responses (SCR) for each group and CS. The bar charts show means ± standard errors of mean, individual data points are overlaid. Pathological pornography users (n = 19) rated the $CS+_{porn}$ and marginally the $CS+_{money}$ as significantly more positive than the CS− (see A) compared to the non-problematic users (n = 32). In addition, SCR for the $CS+_{porn}$ vs. CS− and for the $CS+_{money}$ vs. CS− were elevated (see B) in pathological pornography users (n = 19) compared to non-problematic users (n = 32). SCR were log(μS + 1) transformed. C) The one sample t-test for the $CS+_{porn}$ > CS− contrast in recall revealed suprathreshold activations in salience and reward regions in the pathological (n = 20) but not in the non-problematic users (n = 33). D) The two sample t-test for the $CS+_{porn}$ > CS− confirmed stronger activation in the left medial orbito-frontal cortex in the pathological compared to the non-problematic pornography users. Note. All activation maps were thresholded at p_{unc}<.01. Only significant activations were plotted in the activation map of the two sample t-test

Generally stronger responses in ventral striatum during acquisition

Our study revealed a stronger NAcc activation during acquisition for all CS+ s, either associated with pornography or to alternative rewards. The NAcc is crucial for reward experience and motivation (Bartra, McGuire, & Kable, 2013; Chen et al., 2022; Oldham et al., 2018). Elevated striatal responses to addiction-related cues are a sign of enhanced cue reactivity (García-Castro et al., 2023; Koob & Volkow, 2016; Starcke et al., 2018). Consistent with meta-analyses on cue reactivity in behavioral and substance addictions, several studies observed a sensitization to pornographic cues in problematic pornography users (Banca et al., 2016; Gola et al., 2017; Golec, Draps, Stark, Pluta, & Gola, 2021; Klucken et al., 2016; Liberg et al., 2022; Voon et al., 2014; Wojciechowski et al., 2025). Among these, we identified four fMRI studies that included an erotic and a monetary cue (Banca et al., 2016; Gola et al., 2017; Golec et al., 2021; Wojciechowski et al., 2025). The first observed a generalized preference for both CS+s conditioned to erotic and monetary images compared to the CS− (Banca et al., 2016). The second observed faster reaction times, heightened valence and arousal ratings to both CS+ s compared to the CS− as well as a stronger activation in the anterior OFC in late conditioning (Wojciechowski et al., 2025). The last two studies were based on the same data set both pointing to stronger activation in ventral striatum for the erotic compared to the monetary cue (Gola et al., 2017; Golec et al., 2021). Whole-brain-analyses from the second study support a sensitization to erotic cues compared to healthy controls across additional brain regions—including frontal, occipito-parietal, and subcortical structures (Golec et al., 2021). In summary, the increased activation in ventral striatum to the $CS+_{porn}$ in pathological pornography users fits to meta-analyses on cue reactivity but is only partially supported by the few studies in problematic pornography users. The ventral striatum is not the only locus of sensitization (e.g. Starcke et al., 2018); particularly in later stages of addiction, other regions become increasingly important, including the dorsal striatum (e.g., caudate) and prefrontal areas (e.g., mOFC, dACC) (Brand et al., 2019; Everitt & Robbins, 2016). The increased NAcc response to alternative reward cues ($CS+_{game}$, $CS+_{money}$) in appetitive conditioning, contradicts the reduced sensitivity to non-addictive cues typically found in drug addiction (R. Z. Goldstein et al., 2007; Hogarth & Field, 2020; Qiu & Wang, 2021; Sedighim et al., 2021), in smoking (Jastreboff et al., 2015; Peters et al., 2011), and for some behavioral addictions (Hahn et al., 2014). The rewarding stimuli in our study were presented along with the addictive $CS+_{porn}$ in the same experimental context. Of interest, a recent rat study found a generalized sensitization of dopamine neurons to both drug and natural reward cues when in the same spatiotemporal context (Lehmann et al., 2025). The co-occurrence with the addictive cue could have elevated the excitability of dopamine neurons. To disentangle the effects of pornographic and alternative rewards they should be investigated in different experimental contexts. In addition, future research should compare pornographic with other reward cues than money (e.g., shopping, social networks, food) to elaborate on a generalized reward sensitivity in problematic pornography users.

Stronger cue reactivity in extinction

We found stronger activation in the dACC in appetitive extinction to the $CS+_{porn}$ in pathological compared to non-problematic pornography users. The ACC as part of the salience network is involved in stimulus evaluation, attentional processes, and expectancy formation (Seeley et al., 2007). The elevated dACC activation in extinction was stimulus-specific to the $CS+_{porn}$. Consistent with our finding for extinction, participants with gambling disorder compared to controls showed stronger activation in ACC and left insula towards addiction-relevant but not to addiction-irrelevant pictures (Limbrick-Oldfield et al., 2017). A recently published fMRI study in pathological pornography users also observed heightened dACC activation in extinction but to both erotic and monetary cues (Wojciechowski et al., 2025). Further empirical evidence stems from alterations through cue exposure therapy in patients with alcohol use disorder in activation and functional connectivity of ACC, insula and ventral striatum, presumably as a sign of reduced cue reactivity (Farré-Colomés et al., 2024; Vollstädt-Klein et al., 2011). In addition, a study in abstinent smokers showed that stronger ACC activation to smoking cues predicted the likelihood for relapse (Allenby et al., 2020). In conclusion, our finding of elevated activation in the dACC during extinction in the pathological pornography users points to persistent cue reactivity.

Persistence of the appetitive memory in recall

The most significant finding of our study was that the appetitive memory for the $CS+_{porn}$ persisted across all outcome measures, whereas it was successfully extinguished for the non-relevant $CS+_{game}$. Appetitive memory for the $CS+_{money}$ seems to partially persist as indicated by higher SCR and marginally higher valence ratings during recall. In fMRI results, however, we did not observe group differences for the reactivity to the $CS+_{money}$ in recall. There are two studies implying a bias for monetary cues in problematic pornography users as well, but unfortunately they did not include a recall phase (Banca et al., 2016; Wojciechowski et al., 2025). Regarding the $CS+_{porn}$, it was rated as more positive and elicited higher SCR as well as stronger activation in the right mOFC in the problematic users. The mOFC is involved in the evaluation of rewards and the formation of outcome expectations based on appetitive memory, particularly via its downstream connections to the amygdala (Lichtenberg et al., 2021). It becomes dysregulated in addiction impairing decision making and contributing to continuation of drug abuse (Dom, Sabbe, Hulstijn, & Van Den Brink, 2005; Schoenbaum, Roesch, & Stalnaker, 2006). The mOFC is typically hyperactive during craving and hypoactive after withdrawal or prolonged abstinence (Dom et al., 2005; Schoenbaum et al., 2006; Volkow et al., 2005). Even structural changes of the mOFC have even been found in abstinent substance addicts in form of reduced grey matter (Tanabe et al., 2009). The stronger activation in mOFC in pathological pornography users likely implies a persistence of appetitive memory in pathological pornography users which contributes to the maintenance of the problematic behavior.

Limitations

The present study was pre-registered but differed in some respects from pre-registration. Notably, the recruitment of pathological pornography users was lower than anticipated ($n = 24$ vs. planned $n = 31$). Consequently, group sizes were slightly unequal, which may have influenced statistical power. We did not include the group of risky users in the manuscript because of the small sample size ($n = 14$) but provide results in the supplementary material. In agreement with the large multi-center research project the number of criteria to be included as non-problematic was increased from 0 to 1 before data curation. We included additional ROIs derived from meta-analyses on cue reactivity, the caudate nucleus important in habit formation and the dorsal anterior cingulate cortex as part of the salience network (Starcke et al., 2018). Pathological pornography users were not diagnosed with a compulsive sexual behavior disorder according to ICD 11, instead, the clinical interview was based on DSM-V criteria (Wölfling & Müller, 2017) which were adopted from the gaming disorder group also included in our study. The selection of an all-male sample could be seen as another limitation. Ultimately, applying addiction models to problematic pornography use is often criticized (e.g. tolerance/withdrawal, potential subtypes, risk of overpathologizing), requiring a more nuanced behavioral addiction framework (Ince, Gaudet, & Bőthe, 2025; Snaychuk, Dermody, & Kim, 2025).

Conclusions

Pornographic stimuli elicited the strongest appetitive conditioning in both non-problematic and problematic users. Problematic pornography users showed generally increased ventral striatal responses to all reward cues in conditioning which could be a potential vulnerability factor. In addition, neural responses imply persistent cue reactivity to the $CS+_{porn}$ compared to the non-problematic users and contrasted with the control cue throughout extinction and recall one week later. The gaming cue elicited no lasting appetitive memory, nor were there any significant findings in other outcomes. Although some sensitization to the monetary cue was evident in recall, it was not reflected in neural responses. Consistent with prominent addiction theories the reward system was persistently sensitized toward the problem-associated pornographic stimulus but not to non-related stimuli in problematic users (Brand et al., 2019; Everitt & Robbins, 2016; Koob & Le Moal, 2001). In addition to phenomenological similarities of problematic pornography use with behavioral addictions (Brand et al., 2020; Love et al., 2015; Stark et al., 2018), this new neurobiological evidence further supports a diagnostic classification of pornography use disorder under behavioral addictions.

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Generative AI in scientific writing: During the preparation of this work the author(s) used DeepL/translation service, Microsoft copilot/AI-powered assistant and Perplexity/AI-powered assistant in order to rephrase and paraphrase parts of the text for better readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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SUPPLEMENTARY MATERIAL

Supplementary data to this article can be found online at https://doi.org/10.1556/2006.2025.00452.

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