Journal of Behavioral Addictions

15 (2026) 1, 429–444

DOI:
10.1556/2006.2025.00098

FULL-LENGTH REPORT

Deficits in loss-related feedback processing and risky decision-making among heterosexual males at risk for problematic pornography use

XINRAN JIANG[1†], XI YANG[1†], YUSHAN WANG[1] and JIANFENG WANG[1,2*]

[1] School of Psychology, Chengdu Medical College, Chengdu, 610500, China

[2] Sichuan Research Center for Applied Psychology, Chengdu, 610500, China

Received: July 30, 2025 • Revised manuscript received: October 25, 2025; November 19, 2025 • Accepted: December 7, 2025
Published online: January 12, 2026

ABSTRACT

Background and aims: Problematic pornography use (PPU) has been associated with impaired risk-based decision-making, possibly stemming from disrupted feedback processing. However, the underlying cognitive and neural mechanisms remain unclear. This study examined behavioral risk-taking and feedback-related electrophysiological responses in individuals at risk for PPU. *Methods:* Thirty-five male university students at risk for PPU ($M = 20.51$, $SD = 0.89$) and thirty-four matched controls ($M = 20.79$, $SD = 1.70$) completed the Balloon Analogue Risk Task (BART) while EEG data were recorded. Self-report questionnaires assessing impulsivity traits were also administered. *Results:* At the behavioral level, individuals in the PPU risk group exhibited significantly more balloon explosions and lower total earnings than controls, while no group difference was found in the adjusted number of pumps. At the neural level, there were no group differences in the feedback-related negativity (FRN), suggesting intact early evaluation of feedback valence. However, the PPU risk group exhibited significantly reduced P300 amplitudes in response to negative (loss) feedback, suggesting impaired attentional allocation and feedback integration, which may reflect a diminished capacity to adapt behavior based on aversive outcomes. Furthermore, individuals at risk for PPU reported elevated levels of impulsivity, particularly in emotion-driven components such as positive and negative urgency. *Conclusion:* This neurocognitive profile may contribute to the persistence of maladaptive behaviors despite adverse consequences and highlights potential intervention targets to improve feedback sensitivity and self-regulation in individuals with PPU.

KEYWORDS

problematic pornography use, risk-taking behaviors, feedback processing, P300, impulsivity, ERPs

INTRODUCTION

Problematic pornography use (PPU) refers to persistent, repetitive pornography consumption that leads to significant distress and functional impairment, despite the individual's attempts to control or reduce such behavior (Kowalewska et al., 2018; Wéry & Billieux, 2017). PPU is increasingly recognized as one of the most prevalent manifestations of compulsive sexual behavior disorder (CSBD; Antons & Brand, 2021), which has been classified as an impulse control disorder in the ICD-11 (WHO, 2020). However, an expanding body of literature argues that CSBD, including its pornography-use subtype, is better conceptualized within an addiction framework rather than an impulse-control perspective (Antons & Brand, 2021; Brand et al., 2025; Klein et al., 2022; Kowalewska et al., 2018; Stark, Klucken, Potenza, Brand, & Strahler, 2018). Furthermore, a large-scale cross-cultural survey across 42 countries estimated the global prevalence rate of PPU to be approximately 3.2% (Bőthe et al., 2024), highlighting its growing public health relevance. Individuals with PPU frequently report negative consequences such as impaired mental health, interpersonal difficulties, and reduced

[†]These authors contributed equally to this work.

[*]Corresponding author.
E-mail: wjfzy1985@163.com

daily functioning (Wéry & Billieux, 2017). However, despite increasing clinical and empirical attention, the underlying mechanisms of PPU remain insufficiently understood.

Individuals with PPU tend to continue using pornography even when facing adverse outcomes, possibly due to deficits in evaluating risks and processing rewards during decision-making (Mestre-Bach, Fernández-Aranda, Jiménez-Murcia, & Potenza, 2020; Schiebener & Brand, 2017). Impaired decision-making is considered a core feature of addictive behaviors (Hüpen, Habel, Votinov, Kable, & Wagels, 2023; Ioannidis et al., 2019; Verdejo-Garcia, Chong, Stout, Yücel, & London, 2018), including PPU (Castro-Calvo, Cervigón-Carrasco, Ballester-Arnal, & Giménez-García, 2021; Mestre-Bach et al., 2020; Testa, Mestre-Bach, Montejo-González, & Chiclana-Actis, 2024). Neurocognitive models like the Impaired Response Inhibition and Salience Attribution (IRISA) framework emphasize that addiction is characterized by a dysregulation between "hot" reward-driven processes and "cold" top-down control, leading to a preference for immediate rewards over long-term benefits (Goldstein & Volkow, 2011). Similarly, dual-process theories highlight the imbalance between an impulsive system (e.g., ventral striatum) and a reflective system (e.g., dorsal prefrontal cortex) that underlies poor self-control and maladaptive choices (Bechara, 2005; Everitt & Robbins, 2016). The Interaction of Person-Affect-Cognition-Execution (I-PACE) model further proposes that addictive behaviors emerge from interactions among predisposing personality traits, cue-induced affective and cognitive responses, and reduced inhibitory control, which together bias decision-making toward compulsive behavior (Brand, Young, Laier, Wölfling, & Potenza, 2016, 2019). These perspectives converge on the notion that impaired decision-making, especially diminished consideration of long-term consequences, plays a central role in the development and maintenance of addictive behaviors.

A growing body of empirical research supports these theoretical models across both substance-related and behavioral addictions. In substance use disorders, studies employing decision-making paradigms consistently demonstrate impairments in selecting advantageous options, often accompanied by a pronounced preference for immediate over delayed rewards (e.g., Bechara et al., 2001; Brand, Roth-Bauer, Driessen, & Markowitsch, 2008; Burnette et al., 2021). Similarly, individuals with behavioral addictions, such as gambling disorder and Internet gaming disorder, exhibit comparable deficits in risk evaluation, delay discounting, and feedback-based learning (Brand et al., 2005; Wang et al., 2021; Yao et al., 2014). Recent meta-analytic evidence consolidates these findings by demonstrating that disadvantageous risky decision-making is a transdiagnostic characteristic across various forms of problematic internet use (Müller et al., 2023), highlighting the importance of investigating specific underlying mechanisms within behavioral addictions.

However, empirical research directly examining the decision-making mechanisms underlying PPU and more broadly, CSBD, remains scarce. Only a few studies have employed laboratory-based decision-making tasks, and the findings to date are mixed. Research using the Approach–Avoidance Task (AAT) suggests that symptoms of cybersex addiction are associated with both approach and avoidance tendencies toward sexual stimuli (Snagowski & Brand, 2015). Subsequent studies in non-clinical samples have shown that individuals classified as high in PPU based on questionnaire scores exhibit stronger approach bias toward sexual stimuli compared to those with lower scores (Sklenarik et al., 2019, 2020). In addition, individuals with PPU have demonstrated steeper delay discounting curves, favoring smaller immediate rewards over larger delayed ones, indicative of heightened impulsivity (Lawyer, 2008; Negash, Sheppard, Lambert, & Fincham, 2016).

While findings on approach bias and delay discounting offer valuable insights into certain aspects of decision-making in PPU, these studies capture only a narrow portion of a multifaceted process. Risk-taking, a fundamental component of decision-making, has received considerable attention in the context of substance use disorders due to its critical role in adaptive behavior. Effective decision-making involves evaluating uncertain outcomes and rapidly balancing potential gains and losses to guide future actions. When this process is compromised, individuals may exhibit heightened risk-taking tendencies, favoring immediate gratification despite potential negative consequences (Bechara, 2005).

Empirical investigations into risk-taking in the context of PPU/CSBD remain relatively scarce. Using the Iowa Gambling Task (IGT), Mulhauser et al. (2014) found that individuals with CSBD who identified PPU as their primary symptom tended to prefer disadvantageous decks associated with frequent losses. In contrast, Messina, Fuentes, Tavares, Abdo, and Scanavino (2017) reported no significant differences in IGT performance between CSBD patients and healthy controls. Sexual cues appear to modulate risk-taking behavior: in a modified IGT administered to healthy male participants, riskier and less advantageous decisions were observed when sexual images were paired with disadvantageous decks, an effect further amplified by self-reported sexual arousal (Laier, Pawlikowski, & Brand, 2014). In a more recent study employing a modified Cups Task, individuals with PPU demonstrated reduced sensitivity to expected value, resulting in riskier choices under disadvantageous conditions (Wang, Qu, Li, Tang, & Li, 2024). More recent studies using decision-making tasks without pornography-related stimuli (Engel et al., 2025; Müller & Antons, 2023) reported no severe impairments. Taken together, these findings indicate that the existing evidence remains preliminary and heterogeneous, and the mechanisms underlying altered risk-taking in PPU are still not well understood.

One possible mechanism underlying aberrant risk-taking in PPU is impaired feedback processing. Feedback processing relies heavily on the function of the anterior cingulate cortex (ACC) and is crucial for monitoring errors, integrating outcome information, and adapting behavior to maximize future rewards (Walton, Devlin, & Rushworth, 2004). Attenuated ACC responses to errors, which is a key mechanism underlying adaptive behavioral control, have been consistently documented in substance-related disorders (Kluwe-Schiavon et al., 2020). This impairment is thought to reduce the ability to utilize feedback effectively, leading to reward-biased impulsive behavior and decreased sensitivity to punishment (Garavan & Stout, 2005). Evidence from behavioral addictions closely related to PPU further supports this view. For example, excessive internet gamers have been shown to exhibit reduced error-related negativity (ERN) and diminished utilization of negative feedback during decision-making tasks, indicating impaired feedback monitoring and reduced adaptive control (Littel et al., 2012; Yao et al., 2014). These findings suggest that deficits in feedback processing may represent a transdiagnostic mechanism underlying maladaptive decision-making across addictive behaviors, including PPU.

Although direct evidence on feedback processing in PPU is lacking, neuroimaging studies of PPU and CSBD suggest alterations in ACC function. Sexually explicit cues have been shown to elicit heightened responses in the dorsal ACC and reward-related brain regions (Politis et al., 2013; Seok & Sohn, 2015; Voon et al., 2014). Abnormal ACC habituation to sexual stimuli has also been reported (Banca et al., 2016), and electrophysiological data indicate reduced N2 amplitudes during response inhibition tasks in individuals at risk for PPU, reflecting impaired conflict monitoring and diminished ACC engagement (Wang & Dai, 2020). Recent studies further support these findings. Using appetitive conditioning and extinction paradigms, Wojciechowski et al. (2025) observed altered activity in dorsal ACC and ventral striatum in men with CSB, reflecting enhanced incentive salience attribution and maladaptive persistence of conditioned responses. Structural imaging studies demonstrate that CSBD patients exhibit reduced gray matter volume in the right anterior cingulate cortex, with symptom severity correlating specifically with reductions in this region (Draps et al., 2020). Additionally, CSBD patients show lower cortical surface area in the right posterior cingulate cortex compared with healthy controls (Görts et al., 2023). Taken together, these findings suggest broader abnormalities in the cingulate cortex in compulsive sexual behavior. Given the close relationship between ACC function and feedback evaluation, these findings imply that individuals with PPU may also exhibit impaired feedback processing, potentially contributing to maladaptive decision-making patterns.

Event-related potentials (ERPs) offer a temporally precise method for examining how the brain processes feedback during risky decision-making. Two components are particularly informative: the feedback-related negativity (FRN) and the P300. The FRN is a fronto-central negative deflection that peaks approximately 200–300 ms after feedback and is commonly interpreted as an automatic response to outcomes that are better or worse than expected. This interpretation is grounded in a reinforcement learning framework, in which dopaminergic prediction-error signals influence ACC activity (Holroyd & Coles, 2002). The FRN rapidly signals expectancy violations, allowing the ACC to update action strategies for subsequent trials and thereby linking feedback monitoring with adaptive control. The P300 is a positive deflection that occurs around 300–500 ms after feedback. It reflects a later stage of processing that is sensitive to attentional demands and involves a more detailed evaluation of motivational significance (Hajcak & Foti, 2020; Twomey, Murphy, Kelly, & O'Connell, 2015; Yeung & Sanfey, 2004). Neural generators include the ACC as well as broader fronto-parietal regions, consistent with its role in reallocating attention and incorporating feedback into future behavior (Nieuwenhuis, Aston-Jones, & Cohen, 2005).

Both components show alterations across addictive phenotypes. Previous studies have reported reduced or dysregulated FRN and P300 responses among those with substance use disorders, as well as among individuals exhibiting problematic Internet behaviors (Fein & Chang, 2008; Li et al., 2020; Liu, Chen, & Muggleton, 2025; Morie et al., 2018; Yau, Potenza, Mayes, & Crowley, 2015). These abnormalities may impair the ability to use negative outcomes to guide future decisions, thereby biasing behavior toward anticipated rewards and increased risk-taking (Garavan & Stout, 2005). Given that PPU has been associated with aberrant risk-taking and potential ACC dysfunction, FRN and P300 measures may serve as useful tools for examining feedback-processing mechanisms that contribute to maladaptive sexual reward seeking in this population.

The present study examined whether altered feedback processing contributes to risky decision-making in individuals at elevated risk for PPU. Participants at risk for PPU and matched healthy controls completed a monetary Balloon Analogue Risk Task (BART) while electroencephalography (EEG) was recorded to assess feedback processing through the FRN and P300 components. The BART is widely used to evaluate risk-taking and feedback sensitivity in addiction research and consistently elicits robust FRN and P300 responses to outcome feedback (Euser et al., 2013; Lejuez et al., 2002). On each trial, inflating a virtual balloon increases the potential monetary reward but also raises the probability of an explosion, which results in forfeiture of earnings for that trial. We predicted that the at-risk PPU group would demonstrate greater risk-taking behavior, indicated by a higher average number of pumps on unexploded trials, and attenuated feedback processing, reflected in reduced FRN and P300 amplitudes in response to negative (explosion) outcomes compared to controls.

In addition, we hypothesized that higher PPU severity, as measured by the Problematic Pornography Consumption Scale (PPCS; Bőthe et al., 2018), would be negatively associated with the amplitudes of the FRN and P300. Given prior evidence of elevated impulsivity in individuals with PPU (Testa et al., 2024) and its established relationship with BART performance (Lejuez et al., 2002), we assessed trait impulsivity using both the UPPS-P Impulsive Behavior Scale (Lynam, Smith, Whiteside, & Cyders, 2006) and the Barratt Impulsiveness Scale (BIS-11; Patton, Stanford, & Barratt, 1995) to capture its multidimensional structure. We further hypothesized that the PPU group would exhibit higher impulsivity scores, which would also be negatively correlated with FRN and P300 amplitudes.

METHODS

Participants

Eighty male participants were recruited, including 40 individuals at risk for problematic pornography use (PPU) and 40 healthy controls. Eleven participants were excluded due to excessive EEG artifacts or an insufficient number of balloon explosions, which prevented reliable averaging for the negative feedback condition. The final sample thus included 69 participants, with 35 in the at-risk group and 34 in the control group. Recruitment was conducted through campus flyers, peer referrals, and online advertisements, with participants drawn from a pool of 495 male university students. Some individuals in the at-risk group had also participated in our previous study (Yang, Wang, Tang, Li, & Wang, 2025). As previous research indicates that PPU is more prevalent in males (Bőthe et al., 2024; Grubbs, Kraus, & Perry, 2019), the sample was limited to male participants.

Participants in the at-risk PPU group met the following criteria: (a) pornography use for at least six months; (b) an average frequency of three or more viewing episodes per week during the past month (Twohig & Crosby, 2010); and (c) a score of 76 or higher on the PPCS (Bőthe et al., 2018). Individuals were included in the control group if they reported fewer than three pornography-viewing episodes per week and had a PPCS score below 76. No minimum level of pornography use was required for inclusion in the control group. Participants, including those who reported no pornography use in the past month ($n = 6$), were retained as long as they met the criteria for low-risk pornography use. Exclusion criteria for both groups included risky alcohol use (Alcohol Use Disorders Identification Test, AUDIT score ≥8; Babor, Higgins-Biddle, Saunders, Monteiro, & World Health Organization, 2001), nicotine dependence (Fagerström Test for Nicotine Dependence, FTND score ≥6; Fagerström, 1978), gaming disorder (Internet Gaming Disorder Scale, IGDS score ≥36; Pontes & Griffiths, 2015), gambling disorder (Problem Gambling Severity Index, PGSI score ≥8; Ferris & Wynne, 2001), moderate to severe depression (Beck Depression Inventory-II, BDI-II score ≥20; Beck, Steer, Ball, & Ranieri, 1996), moderate to severe anxiety (Beck Anxiety Inventory, BAI score ≥16; Beck, Epstein, Brown, & Steer, 1988), current or past illicit drug use, history of neurological or psychiatric disorders, age under 18 years, or sexual minority status. Sexual minority individuals were excluded because the experiment included additional tasks involving erotic stimuli validated specifically for heterosexual males, and therefore stimulus relevance and validity could not be ensured.

Measures

Problematic Pornography Consumption Scale (PPCS). The PPCS (Bőthe et al., 2018) consists of 18 items covering six dimensions: salience, mood modification, conflict, tolerance, relapse, and withdrawal. Items are rated on a seven-point Likert scale ranging from 1 (never) to 7 (always), with total scores of 76 or higher indicating problematic pornography use (PPU). The scale demonstrated excellent internal consistency in the current sample (Cronbach's $\alpha = 0.98$).

UPPS-P impulsive behavior scale. The UPPS-P (Lynam et al., 2006) assesses five facets of impulsivity: negative urgency, positive urgency, lack of premeditation, lack of perseverance, and sensation seeking. It comprises 59 items rated on a four-point scale ranging from 1 (strongly agree) to 4 (strongly disagree). The UPPS-P has been widely used to examine the role of impulsivity in substance use, risk-taking behaviors, and various psychological conditions. The total scale demonstrated good internal consistency (Cronbach's $\alpha = 0.87$).

Barratt impulsiveness scale (BIS-11). The BIS-11 (Patton et al., 1995) is a 30-item self-report instrument designed to assess trait impulsivity, covering three dimensions: attentional, motor, and non-planning impulsivity. Items are rated on a four-point scale ranging from 1 (rarely/never) to 4 (almost always/always), with higher scores indicating greater levels of impulsivity. The internal consistency for the total scale was high (Cronbach's $\alpha = 0.92$).

Screening instruments. To evaluate the exclusion criteria, participants completed the BDI-II (Beck et al., 1996), BAI (Beck et al., 1988), FTND (Fagerström, 1978), AUDIT (Babor et al., 2001), IGDS (Pontes & Griffiths, 2015), and PGSI (Ferris & Wynne, 2001). Details of these instruments are provided in the Supplementary Material.

Behavioral task. The BART paradigm (see Fig. 1) was adapted from previous research (Fein & Chang, 2008; Xu et al., 2019). On each trial, participants were instructed to inflate a blue balloon, with each pump increasing the balloon's size and the potential monetary reward by five cents. Participants could choose to continue inflating the balloon by pressing the "F" key or to stop and collect the accumulated reward by pressing the "J" key. If the balloon exploded, a silent burst animation appeared along with a message indicating the loss of earnings for that trial. The delay between response and feedback was randomly set between 500 and 1,000 ms.

Each balloon allowed a maximum of 12 pumps. The probability of explosion increased with each pump, beginning at 9.1 percent (1/11) after the first pump and reaching 100 percent on the twelfth. Although the cumulative earnings and the current value of the balloon were displayed, the exact chance of explosion remained undisclosed to participants. Before beginning the main task, participants completed practice trials designed to expose them to both successful and unsuccessful outcomes.

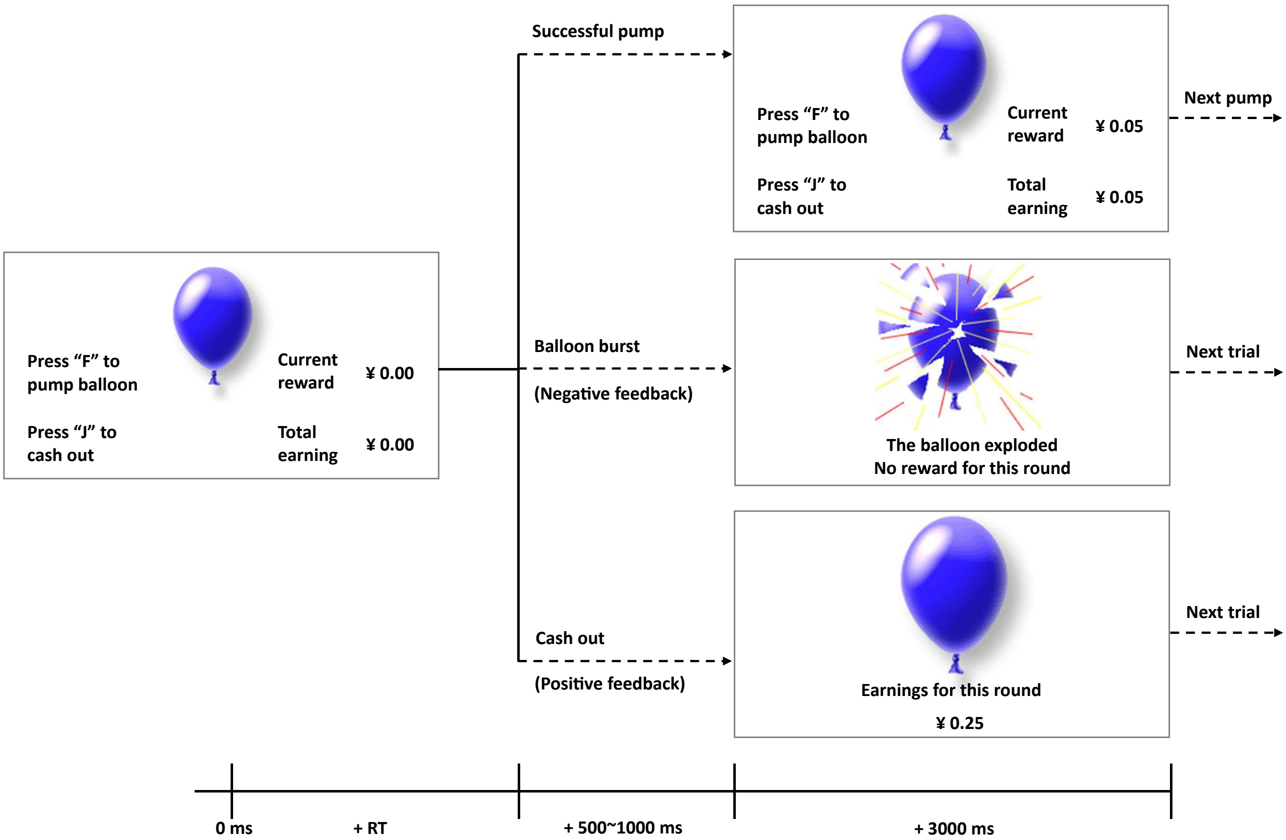

Fig. 1. Schematic representation of the Balloon Analogue Risk Task (BART). Participants repeatedly chose to inflate a virtual balloon to increase potential monetary gains or to stop and collect accumulated earnings. Each pump increased both the balloon's size and the potential reward by 5 cents. If the balloon exploded, participants lost the earnings for that trial. Feedback indicating explosion or reward was presented after a variable delay ranging from 500 to 1,000 ms

The full task included 100 trials, and participants were instructed to maximize their total earnings. To enhance motivation, they were told that their total earnings would be awarded as a monetary bonus.

Procedure. Interested participants were recruited through advertisements and flyers featuring QR codes that directed them to an online screening questionnaire. This questionnaire included the PPCS and a customized survey assessing pornography-related behaviors, such as the frequency of pornography viewing and masturbation over the past month. Based on predefined inclusion criteria, individuals at risk for PPU and healthy controls who met eligibility requirements were contacted by phone and invited to complete a second screening to assess exclusion criteria. Participants who met all screening criteria were invited to the ERP recording session.

Upon arrival, they provided written informed consent and completed a battery of self-report questionnaires. EEG data were subsequently recorded while participants performed the BART and a picture-viewing oddball task that included sexual and emotionally salient stimuli; the oddball task is not reported in the present study.

EEG acquisition and preprocessing. Continuous EEG data were recorded using BrainAmp amplifiers and 64 Ag/AgCl active electrodes mounted in an elastic cap, arranged according to the international 10–20 system. Data were acquired with BrainVision Recorder 2.0 (Brain Products GmbH, Germany). FCz served as the online reference electrode. Vertical electrooculogram (VEOG) was recorded from an electrode placed below the right eye. Electrode impedances were kept below 5 kΩ. EEG signals were digitized at 512 Hz and filtered online with a bandpass of 0.05–100 Hz.

Preprocessing was conducted in BrainVision Analyzer 2.1. Data were re-referenced offline to the average of the left and right mastoids. Because different frequency ranges enhance the detection of specific components, we applied component-specific filters: a 2–12 Hz bandpass for FRN to reduce slow activity and component overlap (Donkers, Nieuwenhuis, & van Boxtel, 2005), and a 0.1–30 Hz bandpass for P300 analysis (Euser et al., 2013). Ocular artifacts were corrected using independent component analysis (ICA), and eye-related components were removed based on their characteristic scalp distributions. Segments with voltage steps greater than 50 μV/ms, amplitude fluctuations exceeding 100 μV within 200 ms, or absolute values beyond ±100 μV were excluded.

EEG data were segmented into epochs ranging from −200 to 800 ms relative to feedback onset and baseline-corrected using the −200 to 0 ms interval. Only artifact-free epochs following negative feedback (i.e., balloon explosions) were averaged for each participant.[1] The average numbers of valid trials for FRN were 40.79 ± 14.40 (PPU-risk) and 38.62 ± 10.02 (control), and for P300 were 30.21 ± 10.07 and 28.49 ± 10.83, with no significant group differences.

Based on previous studies and topographical distributions (Euser et al., 2013; Fein & Chang, 2008; Xu et al., 2019), the FRN was quantified as the mean amplitude from 200 to 250 ms post-feedback at Fz, FCz, and Cz. The P300 was defined as the mean amplitude from 300 to 400 ms post-feedback at FCz, Cz, and CPz.

Statistical analysis. All statistical analyses were conducted using SPSS 22.0 (SPSS Inc., Chicago, USA). Two-tailed tests were applied, with significance set at $p < 0.05$. Results are reported as mean ± standard deviation. Data normality was assessed using the Shapiro–Wilk test. Except for total earnings and P300 amplitudes, all dependent variables met the assumption of normality and were analyzed using parametric tests. Although the Shapiro–Wilk test indicated significant deviations for total earnings and P300 amplitudes, the degree of skewness and kurtosis was mild (total earnings: skewness = −0.63, kurtosis = −0.02; P300: skewness = 0.26, kurtosis = −0.53). As these values fell within the acceptable range of ±1, both distributions were considered approximately normal, and no data transformations were applied.

Between-group differences in demographic characteristics (age, education) and self-report measures were analyzed using independent-samples t tests or chi-square tests, as appropriate. To control for inflation of Type I error due to multiple comparisons, Bonferroni correction was applied to the p values when conducting t tests across subscales of the self-report instruments. Behavioral indices of risk-taking, including the mean adjusted number of pumps on unexploded balloons, the total number of explosions, and total monetary earnings, were also compared between groups using independent-samples t tests. Consistent with prior research employing the BART paradigm (e.g., Euser et al., 2013), these indices were conceptualized as theoretically interrelated components of a single risk-taking construct rather than independent outcomes; therefore, no correction for multiple comparisons was applied to these behavioral measures.

ERP amplitudes were analyzed using two separate mixed-design ANOVAs: one 2 (group: PPU risk vs. control) × 3 (electrode: Fz, FCz, Cz) ANOVA for the FRN, and another 2 (group: PPU risk vs. control) × 3 (electrode: FCz, Cz, CPz) ANOVA for the P300. Significant effects were followed by Bonferroni-corrected post hoc comparisons. To explore the potential functional relevance of ERP responses, Pearson's correlation analyses were conducted across all participants to examine associations between ERP amplitudes and impulsivity traits (UPPS-P and BIS-11), risk-taking behavior on the BART, and PPU severity (PPCS scores, pornography viewing frequency, and masturbation frequency). Given the exploratory nature of these analyses and the large number of correlations, no Bonferroni correction was applied to avoid unnecessary loss of statistical power.

[1]We did not analyze ERPs elicited by positive feedback due to a key limitation of the traditional BART. In this version of the task, participants freely choose when to stop inflating the balloon and cash out. As a result, the decision to secure a reward occurs internally at the moment of the key press, before the visual feedback is presented. This makes it impossible to precisely time-lock the ERP signal to the actual moment of outcome recognition (Heffer & Willoughby, 2020). Consequently, positive feedback merely confirms a known outcome, reducing its salience and the interpretability of associated ERP components such as the FRN and P300. As shown in the Supplementary Material, ERPs elicited by positive feedback were also extremely weak in amplitude.

Ethics

All procedures were conducted in accordance with the Declaration of Helsinki and were approved by the Chengdu Medical College Ethics Committee (Approval No. 2023NO.72). Participants provided informed written consent and were financially compensated, which included a fixed participation fee of 100 RMB and additional task-based earnings (mean = 11 RMB, range = 9–13 RMB).

RESULTS

Demographic and clinical features

Group comparisons for demographic and clinical characteristics are summarized in Table 1. No significant group differences were observed for age or years of education. Regarding trait impulsivity, the PPU risk group scored higher on both the UPPS-P total score and the BIS-11 total score. At the subscale level, Bonferroni-adjusted significance thresholds were applied ($\alpha = 0.01$ for the five UPPS-P subscales; $\alpha = 0.017$ for the three BIS-11 subscales). Under these adjusted criteria, the PPU risk group exhibited significantly higher negative urgency and positive urgency on the UPPS-P. For the BIS-11, none of the subscale differences survived the adjusted significance threshold.

Behavioral results

Descriptive statistics for BART performance are summarized in Table 2. Although the mean number of pumps on unexploded trials did not significantly differ between groups ($t_{(67)} = 1.76$, $p = 0.084$, $d = 0.42$), the PPU risk group showed a tendency toward more pumps than controls. Importantly, they experienced significantly more balloon explosions ($t_{(67)} = 2.22$, $p = 0.030$, $d = 0.54$) and earned significantly less money than controls ($t_{(67)} = -2.28$, $p = 0.026$, $d = 0.55$) (see Fig. 2). Taken together, these findings indicate that, despite a non-significant trend in pump behavior, the PPU risk group demonstrated a riskier decision-making style, as evidenced by more frequent losses and lower overall gains.

ERP results

FRN. A 2 (group: PPU risk vs. control) × 3 (electrode: Fz, FCz, Cz) mixed ANOVA revealed a significant main

Table 1. Participant demographics and clinical measures (mean ± SD)

Variables	PPU risk (n = 35)	Control (n = 34)	t/χ^2	p
Age (years)	20.51 (0.89)	20.79 (1.70)	0.85	0.393
Years of education	14.43 (0.95)	14.68 (1.67)	0.76	0.452
PPCS	94.91 (13.89)	23.27 (4.27)	29.14	**<0.001**
Anxiety (BAI)	7.40 (5.32)	4.97 (4.14)	2.11	**0.038**
Depression (BDI-II)	11.03 (8.16)	7.00 (7.24)	2.17	**0.034**
Alcohol use (at least once per month)	25/0.71[a]	28/0.82[a]	1.16	0.282
AUDIT	3.80 (2.00)[b]	2.96 (2.01)[c]	1.52	0.136
Cigarette use (at least once per month)	14/0.40[a]	12/0.35[a]	0.16	0.687
FTND	2.50 (1.45)[d]	3.08 (1.00)[e]	−1.17	0.253
Gaming disorder (IGDS)	10.74 (7.51)	8.09 (7.77)	1.44	0.154
Gambling disorder (PGSI)	0.86 (1.35)	0.38 (1.33)	1.47	0.146
Pornography frequency (per week)[f]	4.09 (1.22)	1.18 (1.06)	10.56	**<0.001**
Masturbation frequency (per week)[f]	4.26 (1.70)	1.12 (1.12)	9.07	**<0.001**
UPPS-P total	145.80 (10.40)	136.12 (15.22)	3.09	**0.003**
Negative urgency	31.00 (3.70)	27.71 (5.16)	3.05	**0.003**
Positive urgency	36.49 (4.53)	32.03 (5.22)	3.79	**<0.001**
Lack of premeditation	23.66 (2.95)	22.62 (3.67)	1.30	0.198
Lack of perseverance	23.09 (3.09)	21.97 (3.30)	1.45	0.152
Sensation seeking	31.57 (3.84)	31.79 (5.44)	−0.20	0.844
BIS-11 total	79.26 (12.34)	72.00 (16.79)	2.05	**0.044**
Attentional impulsiveness	15.54 (2.68)	13.88 (4.10)	2.00	0.052
Motor impulsiveness	24.37 (4.22)	21.79 (5.62)	2.16	0.034
Non-planning impulsiveness	39.34 (6.85)	36.32 (8.10)	1.67	0.099

Abbreviations: AUDIT, Alcohol Use Disorder Identification Test; BAI, Beck Anxiety Inventory; BDI-II, Beck Depression Inventory-II; BIS-11, Barratt Impulsiveness Scale-11; FTND, Fagerstrom Test for Nicotine Dependence; IGDS, Internet Gaming Disorder Scale; PGSI, Problem Gambling Severity Index; PPU, Problematic Pornography Use; PPCS, Problematic Pornography Consumption Scale; UPPS-P, UPPS-P Impulsive Behavior Scale.
[a]Number of participants (percentage).
[b]$n = 25$.
[c]$n = 28$.
[d]$n = 14$.
[e]$n = 12$.
[f]During the last month.
Bold font indicates statistical significance.

Table 2. Behavioral and ERP results from the Balloon Analogue Risk Task

	PPU risk (n = 35)	Control (n = 34)	t	p	d
Number of pumps	4.20 ± 0.83	3.88 ± 0.66	1.76	0.084	0.42
Number of explosions	45.77 ± 12.70	39.38 ± 11.13	2.22	**0.030**	0.54
Total earnings	10.89 ± 0.96	11.43 ± 0.98	−2.28	**0.026**	0.55
FRN mean (μV)	−7.15 ± 4.64	−8.94 ± 5.04	1.53	0.130	0.37
Fz	−5.70 ± 4.77	−7.14 ± 5.23	1.19	0.237	0.29
FCz	−7.92 ± 5.06	−9.89 ± 5.34	1.57	0.120	0.38
Cz	−7.85 ± 4.52	−9.80 ± 4.94	1.71	0.091	0.41
P300 mean (μV)	23.45 ± 7.95	28.16 ± 8.17	−2.43	**0.018**	−0.58
FCz	24.67 ± 9.16	29.20 ± 8.84	−2.09	**0.041**	−0.50
Cz	25.01 ± 8.23	29.74 ± 8.39	−2.36	**0.021**	−0.57
CPz	20.67 ± 7.43	25.54 ± 8.26	−2.58	**0.012**	−0.62

Abbreviations: FRN, Feedback-related Negativity; PPU, Problematic Pornography Use.
Bold font indicates statistical significance.

effect of electrode, $F_{(2,\ 134)} = 65.70$, $p < 0.001$, $\eta^2_p = 0.50$, with more negative amplitudes at FCz and Cz compared to Fz. Neither the main effect of group, $F_{(1,\ 67)} = 2.35$, $p = 0.13$, $\eta^2_p = 0.03$, nor the group × electrode interaction, $F_{(2,\ 134)} = 0.76$, $p = 0.425$, $\eta^2_p = 0.01$, reached significance (see Fig. 3).

P300. For the negative feedback-related P300, a 2 (group: PPU risk vs. control) × 3 (electrode: FCz, Cz, CPz) mixed

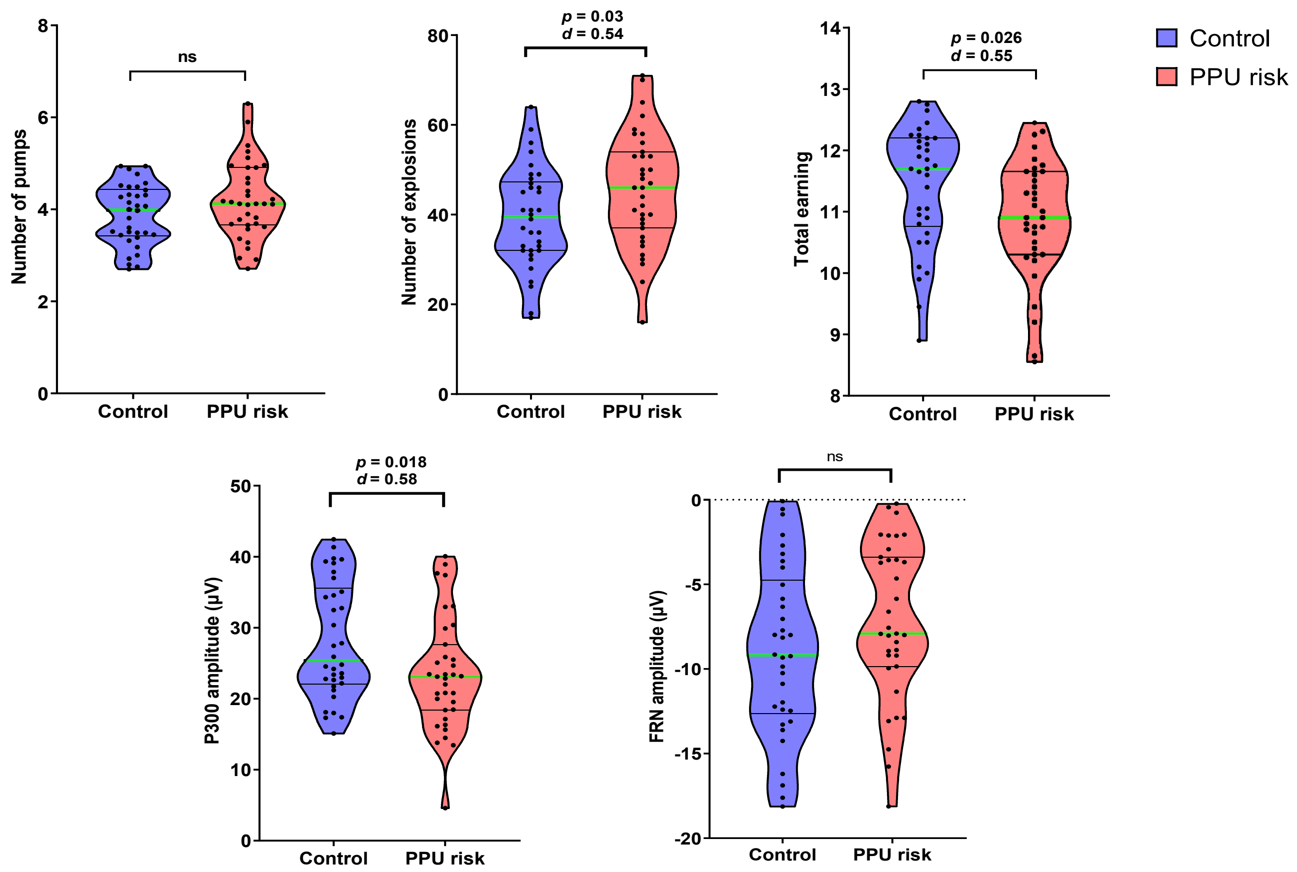

Fig. 2. Violin plots illustrating group differences in behavioral and ERP measures. The plots compare individuals at risk for problematic pornography use (PPU) and control participants on behavioral indices (adjusted number of pumps, number of explosions, total earnings) and ERP components (FRN and P300 amplitudes)

ANOVA showed a significant main effect of group, $F_{(1, 67)} = 5.89$, $p = 0.018$, $\eta^2_p = 0.08$, with smaller amplitudes in the PPU risk group compared to controls (see Fig. 4). A significant main effect of electrode was also observed, $F_{(2, 134)} = 45.62$, $p < 0.001$, $\eta^2_p = 0.41$, with amplitudes at FCz and Cz exceeding those at CPz. The group × electrode interaction was not significant, $F_{(2, 134)} = 0.06$, $p = 0.85$.

Correlational analyses

Correlation analyses revealed that P300 amplitudes were significantly negatively correlated with the number of pumps on non-exploded trials ($r_{(69)} = -0.296$, $p = 0.014$) and the number of exploded balloons ($r_{(69)} = -0.309$, $p = 0.009$), indicating that reduced P300 responses were associated with greater risk-taking behavior. No significant correlations were found between P300 amplitudes and impulsivity traits (UPPS-P, BIS-11) or PPU severity indices (PPCS scores, pornography viewing frequency, and masturbation frequency). However, PPCS scores were significantly negatively correlated with total earnings on the BART ($r_{(69)} = -0.265$, $p = 0.028$), suggesting that greater PPU severity was associated with poorer task performance. No significant correlations were observed for FRN amplitudes with any of the examined variables. Correlation results involving P300 amplitudes are summarized in Figs 5 and 6.

Additional analyses controlling for confounding variables

Given significant group differences in anxiety, depression, and impulsivity, we conducted additional analyses controlling for these variables. The primary results remained robust, with most effects even becoming stronger. Detailed ANCOVA results are reported in the Supplementary Materials.

DISCUSSION

Using a combined behavioral (BART) and electrophysiological (ERP) approach, the present study investigated risk-related decision-making and feedback processing in individuals at risk for PPU. Although no group differences were observed in the primary measure of risk-taking (i.e., average number of pumps), the PPU risk group exhibited a higher number of balloon explosions and reduced total earnings, indicating impairments in feedback-based learning and reduced sensitivity to negative consequences. At the neural level, attenuated feedback-related P300 amplitudes to balloon bursts further suggest diminished allocation of attentional and motivational resources to adverse outcomes. Together, these findings provide converging behavioral and neural evidence for

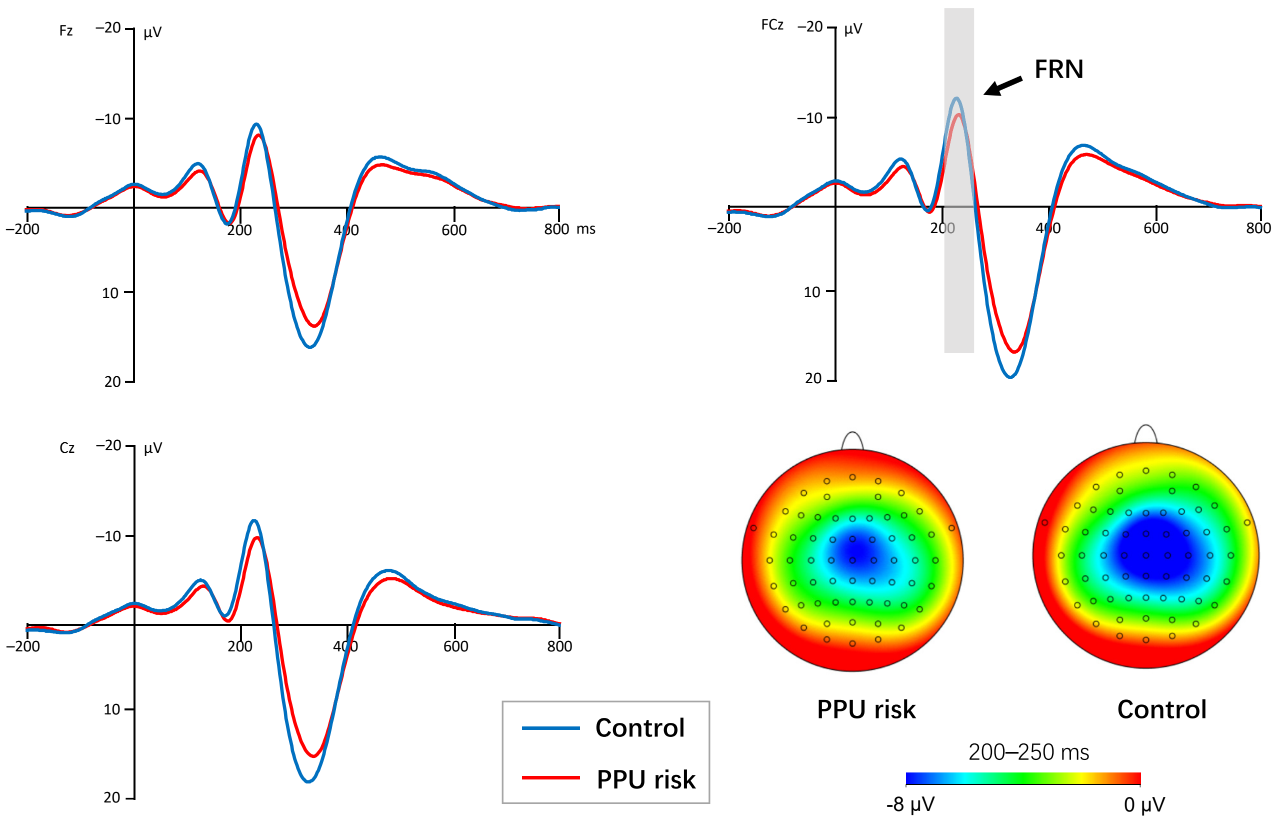

Fig. 3. Grand-average waveforms and scalp topographies of FRN responses to negative feedback. FRN waveforms recorded between 200 and 250 ms are shown for both PPU and control groups at three midline electrode sites (Fz, FCz, and Cz). Data were filtered between 2 and 12 Hz. Scalp maps display the topographical distribution of FRN amplitudes within the 200–250 ms time window for each group

alterations in reinforcement learning mechanisms in individuals at risk for PPU.

In the present study, no group differences were observed in the primary behavioral indicator of risk-taking, namely the average number of pumps on unexploded balloons. Consistent with recent work (Draps et al., 2021; Engel et al., 2025; Müller & Antons, 2023), this suggests that individuals at risk for PPU do not exhibit generalized impairments in risky decision-making under non-sexual conditions. These findings tentatively suggest that decision-making deficits in PPU/CSBD may be context-dependent (Engel et al., 2025), potentially emerging in the presence of sexual or affectively salient cues; nevertheless, additional research is required to substantiate this interpretation. In line with this interpretation, (Messina et al., 2017) demonstrated that although CSBD participants performed similarly to controls at baseline, only the control group showed improved performance following exposure to erotic stimuli. CSBD participants failed to benefit from the motivational enhancement typically induced by sexual arousal, suggesting a disruption in feedback-based learning and behavioral adaptation when sexual cues are present. Rather than reflecting trait-level impairments, these findings indicate that decision-making deficits in PPU/CSBD may be driven by altered motivational and affective states.

In contrast, significant differences emerged in secondary task outcomes, including a higher number of balloon explosions and reduced total earnings in the PPU risk group. These findings point toward impairments in feedback-based learning and reduced sensitivity to negative consequences. The increased frequency of losses, despite comparable risk-taking behavior, suggests inefficient behavioral adjustment following adverse outcomes. This pattern is consistent with reinforcement learning models of addiction, which highlight deficits in updating action values after negative feedback as a core mechanism contributing to compulsive behavior (Bechara, 2005; Brand et al., 2019).

This interpretation aligns with growing evidence that individuals with PPU/CSBD exhibit altered appetitive conditioning and impaired extinction processes. Studies have shown blunted differentiation between cues predicting sexual reward, reduced extinction of conditioned responses, and persistent motivational salience attributed to reward cues (Finke & Klucken, 2025; Wojciechowski et al., 2025). Neuroimaging data further support this mechanism, revealing heightened amygdala activation and disrupted ventral striatum–prefrontal connectivity in CSBD individuals during conditioning tasks (Klucken, Wehrum-Osinsky, Schweckendiek, Kruse, & Stark, 2016). Together, these findings suggest that altered learning mechanisms may contribute to difficulty disengaging from maladaptive reward-seeking behaviors.

Taken together, these lines of evidence suggest that PPU-related behavioral alterations may reflect domain-general impairments in feedback-based learning and loss sensitivity, which may be further amplified in the presence of sexual

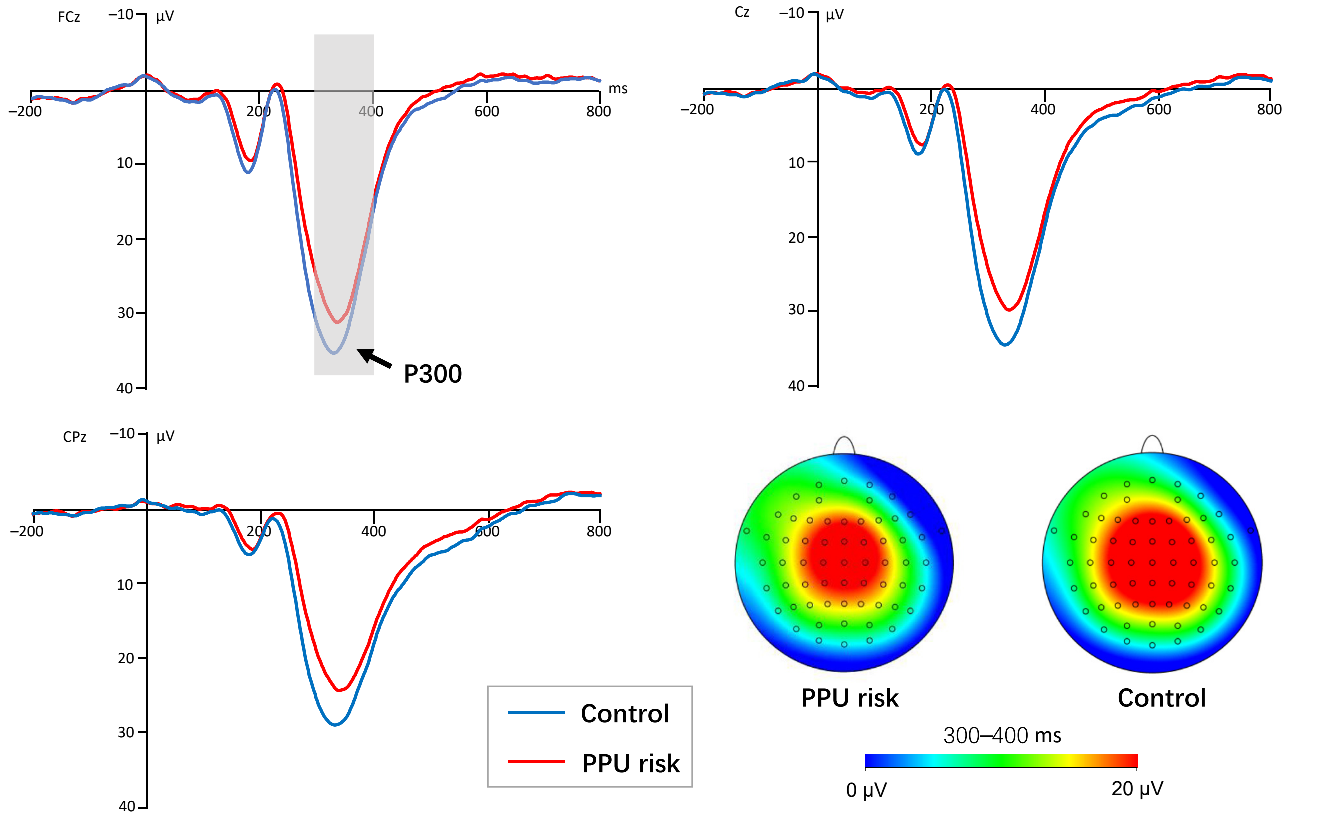

Fig. 4. Grand-average waveforms and scalp topographies of P300 responses to negative feedback. P300 waveforms recorded between 300 and 400 ms are presented for both groups at three electrode sites (FCz, Cz, and CPz). Data were filtered between 0.1 and 30 Hz. Scalp maps illustrate the topographical distribution of P300 amplitudes within the 300–400 ms time window for each group

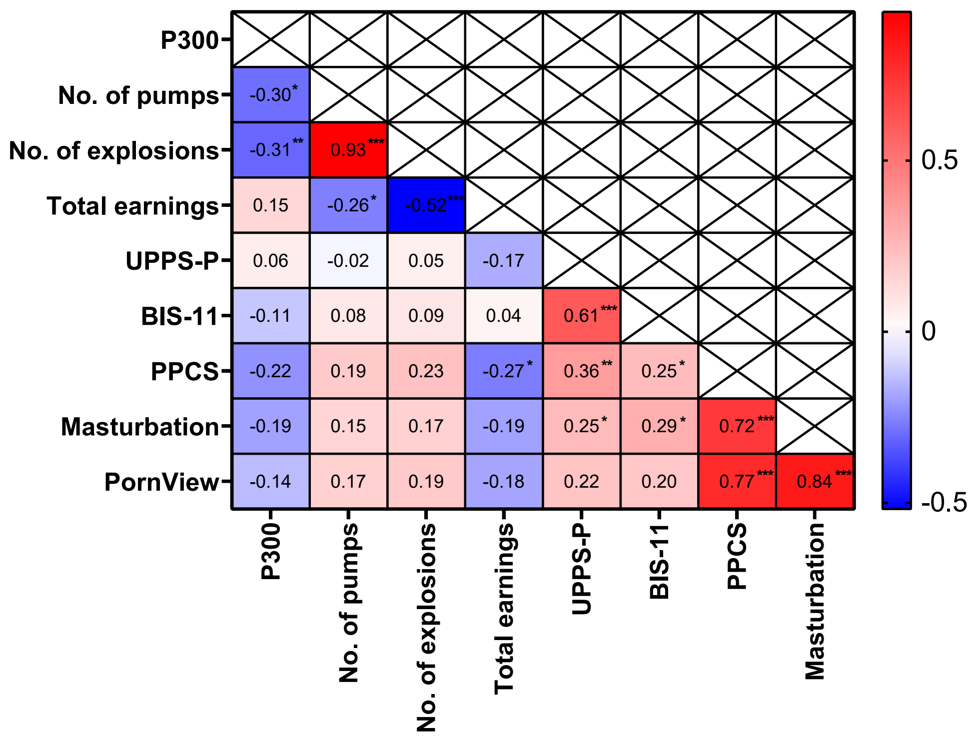

Fig. 5. Correlation matrix heatmap showing relationships among BART behavioral indices (adjusted number of pumps, number of explosions, total earnings), PPU severity (PPCS score, pornography viewing frequency, masturbation frequency), impulsivity traits (UPPS-P, BIS-11), and P300 amplitude

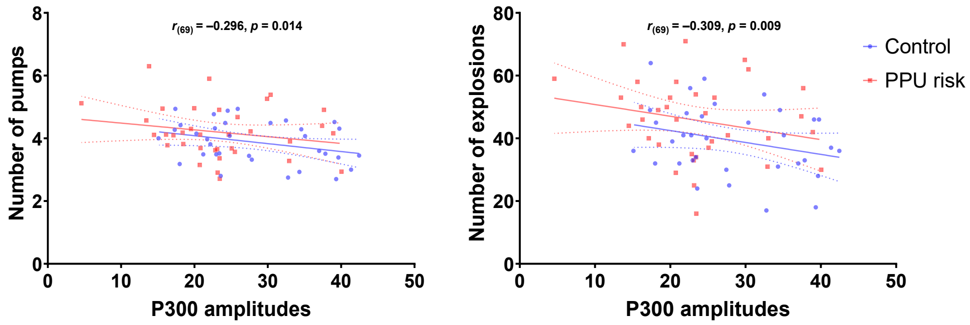

Fig. 6. Correlations between P300 amplitude and BART behavioral indices (adjusted number of pumps and number of explosions) shown separately for the PPU risk group and the control group. The reported correlation coefficients represent values calculated across the entire sample

stimuli. While primary indices of risk-taking under non-sexual conditions appear intact, secondary behavioral outcomes and converging findings from conditioning studies point to subtle, learning-related vulnerabilities that could underlie maladaptive sexual behaviors.

Importantly, this behavioral pattern provides a strong theoretical basis for examining neural responses to feedback. The FRN is a well-established index of early reward prediction error signaling, whereas the P300 reflects the allocation of attentional resources to outcome evaluation. Thus, analyzing these ERP components allows us to determine whether individuals at risk for PPU show neural evidence of altered reinforcement learning processes that may underlie maladaptive behavioral patterns.

Our findings revealed a dissociation between early and late stages of outcome evaluation, indexed by the FRN and P300 components, respectively. Contrary to our hypothesis, no significant group differences were found in FRN amplitudes, replicating previous results observed in a similar PPU sample (Wang, Li, Tang, & Li, 2024). The FRN and P300 are thought to reflect distinct aspects of outcome processing: the FRN is associated with rapid detection of feedback valence, while the P300 is linked to deeper evaluation of outcome significance and motivational relevance (Yeung & Sanfey, 2004). Prior research has shown that these components relate differently to various forms of psychopathology (Kallen, Perkins, Klawohn, & Hajcak, 2020; Luking et al., 2021). Accordingly, our findings suggest that individuals at risk for PPU retain an intact ability for early-stage evaluation of feedback valence, at least in the context of monetary loss.

In contrast, the most notable neural difference emerged at the later stage of feedback processing. Individuals in the PPU risk group exhibited significantly reduced P300 amplitudes following negative feedback. The P300 has often been implicated in cognitive functions such as attentional allocation, evaluation of stimulus relevance, and memory updating (Polich, 2007). In decision-making contexts, it is thought to reflect assessments of outcome probability and the integration of prior experience to anticipate future events (Morie et al., 2018). Inefficiencies in feedback integration may contribute to maladaptive behaviors, including risk-taking (Morie et al., 2021). In this study, reduced P300 responses may indicate deficits in the sustained cognitive engagement required to learn from negative outcomes. Rather than signaling an impaired capacity to detect negative feedback itself, the diminished P300 may reflect a failure to allocate sufficient attentional resources to feedback that has motivational relevance. This, in turn, may undermine reinforcement learning and adaptive decision-making in individuals at risk for PPU.

Supporting the functional relevance of these findings, P300 amplitude was negatively correlated with behavioral risk indicators, including the number of balloon explosions and total earnings. This suggests that individuals who exhibited lower P300 responses to negative feedback were more prone to risky behavior. These findings highlight the P300 as a potential neural mechanism linking impaired outcome evaluation to maladaptive behavioral patterns in PPU.

Importantly, these group differences remained significant after controlling for individual differences in trait impulsivity and affective symptoms. The persistence of effects in ANCOVA suggests that altered feedback processing in PPU is not merely a byproduct of general psychopathology or personality traits. Instead, it may reflect a core neurocognitive feature of the PPU risk profile.

An alternative, though not mutually exclusive, explanation for the reduced P300 in the PPU group is a diminished sensitivity to non-sexual rewards. According to the IRISA model and reward deficiency theories, individuals with addiction may show heightened reactivity to addiction-related stimuli but reduced responsiveness to natural rewards (Blum, Gardner, Oscar-Berman, & Gold, 2012; Goldstein & Volkow, 2011). Consistent with this perspective, our prior research demonstrated blunted ERP responses to monetary magnitudes in individuals with high PPU symptoms (Wang, Qu, et al., 2024). This broader insensitivity to non-pornographic rewards may contribute to reduced neural reactivity to monetary losses and help explain persistent engagement in risky behavior despite negative outcomes.

Interestingly, we found no significant associations between PPU symptom severity, as measured by PPCS scores, pornography viewing frequency, or masturbation frequency, and the ERP components FRN and P300. Similarly, impulsivity traits were not correlated with neural feedback indices.

These null findings suggest that although categorical group differences exist, individual variation in PPU symptoms may not be linearly related to feedback-related neural activity. This dissociation may indicate a categorical rather than a dimensional effect or point to the need for more sensitive and ecologically valid symptom measures.

Consistent with previous literature, individuals in the PPU risk group scored significantly higher on multiple dimensions of impulsivity (Testa et al., 2024). In particular, elevated scores on both the negative urgency and positive urgency subscales of the UPPS-P indicate a tendency to act impulsively under emotional distress or excitement. These findings support dual-process models of addiction, which emphasize emotion-driven impulsivity as a key mechanism in compulsive behavior (Bechara, 2005; Brand et al., 2019), and align with prior research showing higher urgency scores in individuals with more severe PPU (Müller & Antons, 2023). Overall, these results highlight the important role of emotionally triggered impulsivity in the development and persistence of PPU.

However, the literature on the relationship between impulsivity traits and PPU remains inconsistent (Gaudet et al., 2025). While some studies have reported significant associations between PPU and impulsivity (Antons & Brand, 2018; Bőthe et al., 2019; Müller & Antons, 2023), others have not found such links (Varfi et al., 2019; Wang & Dai, 2020). Several factors may account for these inconsistencies. Methodological differences in assessment tools, sample characteristics, and diagnostic criteria can produce divergent results. Total impulsivity scores might obscure the distinct effects of specific subtypes, such as urgency or lack of perseverance. The association between impulsivity and PPU may also depend on variation in emotion regulation, executive functioning, or comorbid symptoms. Furthermore, impulsivity might play a greater role in the onset rather than the maintenance of PPU, or it could be particularly relevant among individuals with high emotional reactivity. Further research is necessary to clarify these complex dynamics.

From a broader perspective, these findings have important theoretical and clinical implications. The observed alterations in feedback-based learning align PPU with reinforcement learning dysfunctions commonly reported in both substance-related and behavioral addictions. Impaired processing of negative outcomes may contribute to the persistence of maladaptive sexual behaviors despite awareness of adverse consequences. Clinically, the feedback-related P300 component may serve as a neurophysiological marker for identifying individuals at elevated risk and for monitoring treatment efficacy. Moreover, it represents a promising target for neuromodulatory interventions designed to enhance feedback sensitivity and promote adaptive behavioral regulation.

Several limitations should be noted. First, the cross-sectional design limits causal inferences, and longitudinal studies are required to determine whether altered neural responses predict the onset or worsening of PPU. Second, the current sample was limited to heterosexual male university students, which may constrain the extent to which the results can be applied to broader populations. To enhance external validity, future investigations should consider incorporating participants of varied genders, sexual identities, and age groups. Third, although the standard BART effectively captures incremental risk-taking, it presents challenges for ERP analysis. Due to the task structure, positive feedback trials were not temporally aligned with outcome presentation (Heffer & Willoughby, 2020), resulting in reduced ERP responses and their exclusion from statistical analyses. Future studies might consider using an automated BART version in which participants preselect the number of pumps at the start of each trial (Euser et al., 2013; Yau et al., 2015). In this version, successful outcomes are revealed only during feedback, enhancing the salience of gains. While this modification reduces the dynamic decision-making aspect of the original task, it allows precise time-locking of ERPs to positive feedback.

In conclusion, our study provides novel evidence of impaired feedback processing in individuals at risk for PPU. While early feedback evaluation indexed by the FRN remains intact, later-stage integration reflected by the P300 is disrupted, indicating a diminished capacity to learn from negative outcomes. This neurocognitive profile may underlie the persistence of maladaptive behaviors despite adverse consequences and highlights potential intervention targets aimed at improving feedback sensitivity and self-regulation in individuals with PPU.

Funding sources: This work was supported by grants from the Ministry of Education for the Humanities and Social Science Project (23YJC190021), the Organized Scientific Research Project of Chengdu Medical College (CYYZZ25-22), the Sichuan Provincial Philosophy and Social Science Planning Project (SC24E010), and the Planned Project of the Sichuan Psychological Society (SCSXLXH202402005).

Authors' contribution: XJ, XY, and JW involved in study concept and design. XJ, XY, and YW involved in data preparation, statistical analysis, and wrote the manuscript. JW involved in study supervision and edited the manuscript. All authors had full access to all data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Conflict of interest: The authors declare no conflict of interest.

SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1556/2006.2025.00098.

REFERENCES

Antons, S., & Brand, M. (2018). Trait and state impulsivity in males with tendency towards internet-pornography-use disorder.

Addictive Behaviors, *79*, 171–177. https://doi.org/10.1016/j.addbeh.2017.12.029

Antons, S., & Brand, M. (2021). Diagnostic and classification considerations related to compulsive sexual behavior disorder and problematic pornography use. *Current Addiction Reports*, *8*(3), 452–457. https://doi.org/10.1007/s40429-021-00383-7

Bőthe, B., Nagy, L., Koós, M., Demetrovics, Z., Potenza, M. N., International Sex Survey Consortium, … Van Hout, M. C. (2024). Problematic pornography use across countries, genders, and sexual orientations: Insights from the International Sex Survey and comparison of different assessment tools. *Addiction*, *119*(5), 928–950. https://doi.org/10.1111/add.16431

Bőthe, B., Tóth-Király, I., Potenza, M. N., Griffiths, M. D., Orosz, G., & Demetrovics, Z. (2019). Revisiting the role of impulsivity and compulsivity in problematic sexual behaviors. *The Journal of Sex Research*, *56*(2), 166–179. https://doi.org/10.1080/00224499.2018.1480744

Bőthe, B., Tóth-Király, I., Zsila, Á., Griffiths, M. D., Demetrovics, Z., & Orosz, G. (2018). The development of the problematic pornography consumption scale (PPCS). *The Journal of Sex Research*, *55*(3), 395–406. https://doi.org/10.1080/00224499.2017.1291798

Babor, T. F., Higgins-Biddle, J. C., Saunders, J. B., Monteiro, M. G., & World Health Organization. (2001). *AUDIT: The alcohol use disorders identification test: Guidelines for use in primary health care* (No. WHO/MSD/MSB/01.6 a). World Health Organization.

Banca, P., Morris, L. S., Mitchell, S., Harrison, N. A., Potenza, M. N., & Voon, V. (2016). Novelty, conditioning and attentional bias to sexual rewards. *Journal of Psychiatric Research*, *72*, 91–101. https://doi.org/10.1016/j.jpsychires.2015.10.017

Bechara, A. (2005). Decision making, impulse control and loss of willpower to resist drugs: A neurocognitive perspective. *Nature Neuroscience*, *8*(11), 1458–1463. https://doi.org/10.1038/nn1584

Bechara, A., Dolan, S., Denburg, N., Hindes, A., Anderson, S. W., & Nathan, P. E. (2001). Decision-making deficits, linked to a dysfunctional ventromedial prefrontal cortex, revealed in alcohol and stimulant abusers. *Neuropsychologia*, *39*(4), 376–389. https://doi.org/10.1016/S0028-3932(00)00136-6

Beck, A. T., Epstein, N., Brown, G., & Steer, R. A. (1988). An inventory for measuring clinical anxiety: Psychometric properties. *Journal of Consulting and Clinical Psychology*, *56*(6), 893–897. https://doi.org/10.1037/0022-006X.56.6.893

Beck, A. T., Steer, R. A., Ball, R., & Ranieri, W. F. (1996). Comparison of Beck Depression Inventories-IA and-II in psychiatric outpatients. *Journal of Personality Assessment*, *67*(3), 588–597. https://doi.org/10.1207/s15327752jpa6703_13

Blum, K., Gardner, E., Oscar-Berman, M., & Gold, M. (2012). "Liking" and "wanting" linked to reward deficiency syndrome (RDS): Hypothesizing differential responsivity in brain reward circuitry. *Current Pharmaceutical Design*, *18*(1), 113–118. https://doi.org/10.2174/138161212798919110

Brand, M., Antons, S., Bőthe, B., Demetrovics, Z., Fineberg, N. A., Jimenez-Murcia, S., … Potenza, M. N. (2025). Current advances in behavioral addictions: From fundamental research to clinical practice. *American Journal of Psychiatry*, *182*(2), 155–163. https://doi.org/10.1176/appi.ajp.20240092

Brand, M., Kalbe, E., Labudda, K., Fujiwara, E., Kessler, J., & Markowitsch, H. J. (2005). Decision-making impairments in patients with pathological gambling. *Psychiatry Research*, *133*(1), 91–99. https://doi.org/10.1016/j.psychres.2004.10.003

Brand, M., Roth-Bauer, M., Driessen, M., & Markowitsch, H. J. (2008). Executive functions and risky decision-making in patients with opiate dependence. *Drug and Alcohol Dependence*, *97*(1–2), 64–72. https://doi.org/10.1016/j.drugalcdep.2008.03.017

Brand, M., Wegmann, E., Stark, R., Müller, A., Wölfling, K., Robbins, T. W., & Potenza, M. N. (2019). The interaction of person-affect-cognition-execution (I-PACE) model for addictive behaviors: Update, generalization to addictive behaviors beyond internet-use disorders, and specification of the process character of addictive behaviors. *Neuroscience and Biobehavioral Reviews*, *104*, 1–10. https://doi.org/10.1016/j.neubiorev.2019.06.032

Brand, M., Young, K. S., Laier, C., Wölfling, K., & Potenza, M. N. (2016). Integrating psychological and neurobiological considerations regarding the development and maintenance of specific internet-use disorders: An interaction of person-affect-cognition-execution (I-PACE) model. *Neuroscience & Biobehavioral Reviews*, *71*, 252–266. https://doi.org/10.1016/j.neubiorev.2016.08.033

Burnette, E. M., Grodin, E. N., Ghahremani, D. G., Galván, A., Kohno, M., Ray, L. A., & London, E. D. (2021). Diminished cortical response to risk and loss during risky decision making in alcohol use disorder. *Drug and Alcohol Dependence*, *218*, 108391. https://doi.org/10.1016/j.drugalcdep.2020.108391

Castro-Calvo, J., Cervigón-Carrasco, V., Ballester-Arnal, R., & Giménez-García, C. (2021). Cognitive processes related to problematic pornography use (PPU): A systematic review of experimental studies. *Addictive Behaviors Reports*, *13*, 100345. https://doi.org/10.1016/j.abrep.2021.100345

Donkers, F. C. L., Nieuwenhuis, S., & van Boxtel, G. J. M. (2005). Mediofrontal negativities in the absence of responding. *Cognitive Brain Research*, *25*(3), 777–787. https://doi.org/10.1016/j.cogbrainres.2005.09.007

Draps, M., Sescousse, G., Potenza, M. N., Marchewka, A., Duda, A., Lew-Starowicz, M., … Gola, M. (2020). Gray matter volume differences in impulse control and addictive disorders—An evidence from a sample of heterosexual males. *The Journal of Sexual Medicine*, *17*(9), 1761–1769. https://doi.org/10.1016/j.jsxm.2020.05.007

Draps, M., Sescousse, G., Wilk, M., Obarska, K., Szumska, I., Żukrowska, W., … Gola, M. (2021). An empirical study of affective and cognitive functions in compulsive sexual behavior disorder. *Journal of Behavioral Addictions*, *10*(3), 657–674. https://doi.org/10.1556/2006.2021.00056

Engel, J., Liebnau, J., Müller, S. M., Veit, M., Kneer, J., Sinke, C., & Kruger, T. H. (2025). Further insights on decision-making abilities in compulsive sexual behavior disorder: Findings from the Sex@ brain-study. *Sexual Health & Compulsivity*, *32*(3), 185–204. https://doi.org/10.1080/26929953.2025.2465778

Euser, A. S., Greaves-Lord, K., Crowley, M. J., Evans, B. E., Huizink, A. C., & Franken, I. H. (2013). Blunted feedback processing during risky decision making in adolescents with a parental history of substance use disorders. *Development and Psychopathology*, *25*, 1119–1136. https://doi.org/10.1017/S0954579413000412

Everitt, B. J., & Robbins, T. W. (2016). Drug addiction: Updating actions to habits to compulsions ten years on. *Annual Review of*

Psychology, *67*(1), 23–50. https://doi.org/10.1146/annurev-psych-122414-033457

Fagerström, K. O. (1978). Measuring degree of physical dependence to tobacco smoking with reference to individualization of treatment. *Addictive Behaviors*, *3*(3–4), 235–241. https://doi.org/10.1016/0306-4603(78)90024-2

Fein, G., & Chang, M. (2008). Smaller feedback ERN amplitudes during the BART are associated with a greater family history density of alcohol problems in treatment-naïve alcoholics. *Drug and Alcohol Dependence*, *92*(1–3), 141–148. https://doi.org/10.1016/j.drugalcdep.2007.07.017

Ferris, J. A., & Wynne, H. J. (2001). *The Canadian problem gambling index* (pp. 1–59). Ottawa, ON: Canadian Centre on Substance Abuse.

Finke, J. B., & Klucken, T. (2025). Trait sexual motivation shapes cue reactivity in visual, but not auditory, sexual reward learning: Psychophysiological and computational evidence. *Biological Psychology*, *198*, 109046. https://doi.org/10.1016/j.biopsycho.2025.109046

Görts, P., Savard, J., Görts-Öberg, K., Dhejne, C., Arver, S., Jokinen, J., … Abé, C. (2023). Structural brain differences related to compulsive sexual behavior disorder. *Journal of Behavioral Addictions*, *12*(1), 278–287. https://doi.org/10.1556/2006.2023.00008

Garavan, H., & Stout, J. C. (2005). Neurocognitive insights into substance abuse. *Trends in Cognitive Sciences*, *9*(4), 195–201. https://doi.org/10.1016/j.tics.2005.02.008

Gaudet, É., Teumeni, F. N., Popova, N., Coulombe, S., Demetrovics, Z., & Bőthe, B. (2025). Compulsive sexual behavior and problematic pornography use on the impulsivity-compulsivity axis: A systematic review. *Current Addiction Reports*, *12*(1), 1–35. https://doi.org/10.1007/s40429-025-00637-8

Goldstein, R. Z., & Volkow, N. D. (2011). Dysfunction of the prefrontal cortex in addiction: Neuroimaging findings and clinical implications. *Nature Reviews Neuroscience*, *12*(11), 652–669. https://doi.org/10.1038/nrn3119

Grubbs, J. B., Kraus, S. W., & Perry, S. L. (2019). Self-reported addiction to pornography in a nationally representative sample: The roles of use habits, religiousness, and moral incongruence. *Journal of Behavioral Addictions*, *8*(1), 88–93. https://doi.org/10.1556/2006.7.2018.134

Hüpen, P., Habel, U., Votinov, M., Kable, J. W., & Wagels, L. (2023). A systematic review on common and distinct neural correlates of risk-taking in substance-related and non-substance related addictions. *Neuropsychology Review*, *33*(2), 492–513. https://doi.org/10.1007/s11065-022-09552-5

Hajcak, G., & Foti, D. (2020). Significance?… Significance! Empirical, methodological, and theoretical connections between the late positive potential and P300 as neural responses to stimulus significance: An integrative review. *Psychophysiology*, *57*(7), e13570. https://doi.org/10.1111/psyp.13570

Heffer, T., & Willoughby, T. (2020). Sensitivity to negative feedback among children and adolescents: An ERP study comparing developmental differences between high-worriers and low-worriers. *Cognitive, Affective & Behavioral Neuroscience*, *20*(3), 624–635. https://doi.org/10.3758/s13415-020-00791-8

Holroyd, C. B., & Coles, M. G. H. (2002). The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review*, *109*(4), 679–709. https://doi.org/10.1037/0033-295X.109.4.679

Ioannidis, K., Hook, R., Goudriaan, A. E., Vlies, S., Fineberg, N. A., Grant, J. E., & Chamberlain, S. R. (2019). Cognitive deficits in problematic internet use: Meta-analysis of 40 studies. *The British Journal of Psychiatry*, *215*(5), 639–646. https://doi.org/10.1192/bjp.2019.3

Kallen, A. M., Perkins, E. R., Klawohn, J., & Hajcak, G. (2020). Cross-sectional and prospective associations of P300, RewP, and ADHD symptoms in female adolescents. *International Journal of Psychophysiology*, *158*, 215–224. https://doi.org/10.1016/j.ijpsycho.2020.08.017

Klein, S., Krikova, K., Antons, S., Brand, M., Klucken, T., & Stark, R. (2022). Reward responsiveness, learning, and valuation implicated in problematic pornography use—A research domain criteria perspective. *Current Addiction Reports*, *9*(3), 114–125. https://doi.org/10.1007/s40429-022-00423-w

Klucken, T., Wehrum-Osinsky, S., Schweckendiek, J., Kruse, O., & Stark, R. (2016). Altered appetitive conditioning and neural connectivity in subjects with compulsive sexual behavior. *The Journal of Sexual Medicine*, *13*(4), 627–636. https://doi.org/10.1016/j.jsxm.2016.01.013

Kluwe-Schiavon, B., Viola, T. W., Sanvicente-Vieira, B., Lumertz, F. S., Salum, G. A., Grassi-Oliveira, R., & Quednow, B. B. (2020). Substance related disorders are associated with impaired valuation of delayed gratification and feedback processing: A multilevel meta-analysis and meta-regression. *Neuroscience & Biobehavioral Reviews*, *108*, 295–307. https://doi.org/10.1016/j.neubiorev.2019.11.016

Kowalewska, E., Grubbs, J. B., Potenza, M. N., Gola, M., Draps, M., & Kraus, S. W. (2018). Neurocognitive mechanisms in compulsive sexual behavior disorder. *Current Sexual Health Reports*, *10*(4), 255–264. https://doi.org/10.1007/s11930-018-0176-z

Laier, C., Pawlikowski, M., & Brand, M. (2014). Sexual picture processing interferes with decision-making under ambiguity. *Archives of Sexual Behavior*, *43*(3), 473–482. https://doi.org/10.1007/s10508-013-0119-8

Lawyer, S. R. (2008). Probability and delay discounting of erotic stimuli. *Behavioural Processes*, *79*(1), 36–42. https://doi.org/10.1016/j.beproc.2008.04.009

Lejuez, C. W., Read, J. P., Kahler, C. W., Richards, J. B., Ramsey, S. E., Stuart, G. L., … Brown, R. A. (2002). Evaluation of a behavioral measure of risk taking: The balloon analogue risk task (BART). *Journal of Experimental Psychology: Applied*, *8*(2), 75–84. https://doi.org/10.1037//1076-898X.8.2.75

Li, Q., Wang, Y., Yang, Z., Dai, W., Zheng, Y., Sun, Y., & Liu, X. (2020). Dysfunctional cognitive control and reward processing in adolescents with internet gaming disorder. *Psychophysiology*, *57*(2), e13469. https://doi.org/10.1111/psyp.13469

Littel, M., Van den Berg, I., Luijten, M., van Rooij, A. J., Keemink, L., & Franken, I. H. (2012). Error processing and response inhibition in excessive computer game players: An event-related potential study. *Addiction Biology*, *17*(5), 934–947. https://doi.org/10.1111/j.1369-1600.2012.00467.x

Liu, Y. H., Chen, C. Y., & Muggleton, N. G. (2025). Reduced sensitivity to negative feedback may lead to risky decision-making in amphetamine users. *Addiction Biology*, *30*(5), e70041. https://doi.org/10.1111/adb.70041

Luking, K. R., Gilbert, K., Kelly, D., Kappenman, E. S., Hajcak, G., Luby, J. L., & Barch, D. M. (2021). The relationship between depression symptoms and adolescent neural response during reward anticipation and outcome depends on developmental timing: Evidence from a longitudinal study. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *6*(5), 527–535. https://doi.org/10.1016/j.bpsc.2020.11.001

Lynam, D. R., Smith, G. T., Whiteside, S. P., & Cyders, M. A. (2006). *The UPPS-P: Assessing five personality pathways to impulsive behavior*. West Lafayette: Purdue University.

Müller, S. M., & Antons, S. (2023). Decision making and executive functions in problematic pornography use. *Frontiers in Psychiatry*, *14*, 1191297. https://doi.org/10.3389/fpsyt.2023.1191297

Müller, S. M., Antons, S., Wegmann, E., Ioannidis, K., King, D. L., Potenza, M. N., … Brand, M. (2023). A systematic review and meta-analysis of risky decision-making in specific domains of problematic use of the internet: Evidence across different decision-making tasks. *Neuroscience & Biobehavioral Reviews*, *152*, 105271. https://doi.org/10.1016/j.neubiorev.2023.105271

Messina, B., Fuentes, D., Tavares, H., Abdo, C. H., & Scanavino, M. D. T. (2017). Executive functioning of sexually compulsive and non-sexually compulsive men before and after watching an erotic video. *The Journal of Sexual Medicine*, *14*(3), 347–354. https://doi.org/10.1016/j.jsxm.2016.12.235

Mestre-Bach, G., Fernández-Aranda, F., Jiménez-Murcia, S., & Potenza, M. N. (2020). Decision-making in gambling disorder, problematic pornography use, and binge-eating disorder: Similarities and differences. *Current Behavioral Neuroscience Reports*, *7*(3), 97–108. https://doi.org/10.1007/s40473-020-00212-7

Morie, K. P., Wu, J., Landi, N., Potenza, M. N., Mayes, L. C., & Crowley, M. J. (2018). Feedback processing in adolescents with prenatal cocaine exposure: An electrophysiological investigation. *Developmental Neuropsychology*, *43*(3), 183–197. https://doi.org/10.1080/87565641.2018.1439945

Morie, K. P., Wu, J., Potenza, M. N., Krishnan-Sarin, S., Mayes, L. C., Hammond, C. J., & Crowley, M. J. (2021). Daily cannabis use in adolescents who smoke tobacco is associated with altered late-stage feedback processing: A high-density electrical mapping study. *Journal of Psychiatric Research*, *139*, 82–90. https://doi.org/10.1016/j.jpsychires.2021.05.022

Mulhauser, K. R., Struthers, W. M., Hook, J. N., Pyykkonen, B. A., Womack, S. D., & MacDonald, M. (2014). Performance on the Iowa gambling task in a sample of hypersexual men. *Sexual Addiction & Compulsivity*, *21*(2), 170–183. https://doi.org/10.1080/10720162.2014.908333

Negash, S., Sheppard, N. V. N., Lambert, N. M., & Fincham, F. D. (2016). Trading later rewards for current pleasure: Pornography consumption and delay discounting. *The Journal of Sex Research*, *53*(6), 689–700. https://doi.org/10.1080/00224499.2015.1025123

Nieuwenhuis, S., Aston-Jones, G., & Cohen, J. D. (2005). Decision making, the P3, and the locus coeruleus–norepinephrine system. *Psychological Bulletin*, *131*(4), 510–532. https://doi.org/10.1037/0033-2909.131.4.510

Patton, J. H., Stanford, M. S., & Barratt, E. S. (1995). Factor structure of the Barratt impulsiveness scale. *Journal of Clinical Psychology*, *51*(6), 768–774. https://doi.org/10.1002/1097-4679

Polich, J. (2007). Updating p300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, *118*(10), 2128–2148. https://doi.org/10.1016/j.clinph.2007.04.019

Politis, M., Loane, C., Wu, K., O'Sullivan, S. S., Woodhead, Z., Kiferle, L., … Piccini, P. (2013). Neural response to visual sexual cues in dopamine treatment-linked hypersexuality in Parkinson's disease. *Brain*, *136*(2), 400–411. https://doi.org/10.1093/brain/aws326

Pontes, H. M., & Griffiths, M. D. (2015). Measuring DSM-5 internet gaming disorder: Development and validation of a short psychometric scale. *Computers in Human Behavior*, *45*, 137–143. https://doi.org/10.1016/j.chb.2014.12.006

Schiebener, J., & Brand, M. (2017). Decision-making and related processes in internet gaming disorder and other types of internet-use disorders. *Current Addiction Reports*, *4*(3), 262–271. https://doi.org/10.1007/s40429-017-0156-9

Seok, J. W., & Sohn, J. H. (2015). Neural substrates of sexual desire in individuals with problematic hypersexual behavior. *Frontiers in Behavioral Neuroscience*, *9*, 321. https://doi.org/10.3389/fnbeh.2015.00321

Sklenarik, S., Potenza, M. N., Gola, M., & Astur, R. S. (2020). Approach bias for erotic stimuli among heterosexual female college students who use pornography. *Addictive Behaviors*, *108*, 106438. https://doi.org/10.1016/j.addbeh.2020.106438

Sklenarik, S., Potenza, M. N., Gola, M., Kor, A., Kraus, S. W., & Astur, R. S. (2019). Approach bias for erotic stimuli in heterosexual male college students who use pornography. *Journal of Behavioral Addictions*, *8*(2), 234–241. https://doi.org/10.1556/2006.8.2019.31

Snagowski, J., & Brand, M. (2015). Symptoms of cybersex addiction can be linked to both approaching and avoiding pornographic stimuli: Results from an analog sample of regular cybersex users. *Frontiers in Psychology*, *6*, 653. https://doi.org/10.3389/fpsyg.2015.00653

Stark, R., Klucken, T., Potenza, M. N., Brand, M., & Strahler, J. (2018). A current understanding of the behavioral neuroscience of compulsive sexual behavior disorder and problematic pornography use. *Current Behavioral Neuroscience Reports*, *5*(4), 218–231. https://doi.org/10.1007/s40473-018-0162-9

Testa, G., Mestre-Bach, G., Montejo-González, Á. L., & Chiclana-Actis, C. (2024). Impulsivity in the context of pornography use and compulsive sexual behavior. In Y. Richard, & A. Moustafa (Eds.), *The psychology and neuroscience of impulsivity* (pp. 3–30). Elsevier, https://doi.org/10.1016/B978-0-443-13437-1.00007-0

Twohig, M. P., & Crosby, J. M. (2010). Acceptance and commitment therapy as a treatment for problematic internet pornography viewing. *Behavior Therapy*, *41*(3), 285–295. https://doi.org/10.1016/j.beth.2009.06.002

Twomey, D. M., Murphy, P. R., Kelly, S. P., & O'Connell, R. G. (2015). The classic P300 encodes a build-to-threshold decision variable. *European Journal of Neuroscience*, *42*(1), 1636–1643. https://doi.org/10.1111/ejn.12936

Varfi, N., Rothen, S., Jasiowka, K., Lepers, T., Bianchi-Demicheli, F., & Khazaal, Y. (2019). Sexual desire, mood, attachment style, impulsivity, and self-esteem as predictive factors for addictive cybersex. *JMIR Mental Health*, *6*(1), e9978. https://doi.org/10.2196/mental.9978

Verdejo-Garcia, A., Chong, T. T.-J., Stout, J. C., Yücel, M., & London, E. D. (2018). Stages of dysfunctional decision-making in addiction. *Pharmacology, Biochemistry and Behavior*, *164*, 99–105. https://doi.org/10.1016/j.pbb.2017.02.003

Voon, V., Mole, T. B., Banca, P., Porter, L., Morris, L., Mitchell, S., … Irvine, M. (2014). Neural correlates of sexual cue reactivity in individuals with and without compulsive sexual behaviours. *Plos One*, *9*(7), e102419. https://doi.org/10.1371/journal.pone.0102419

Wéry, A., & Billieux, J. (2017). Problematic cybersex: Conceptualization, assessment, and treatment. *Addictive Behaviors*, *64*, 238–246. https://doi.org/10.1016/j.addbeh.2015.11.007

Walton, M. E., Devlin, J. T., & Rushworth, M. F. (2004). Interactions between decision making and performance monitoring within prefrontal cortex. *Nature Neuroscience*, *7*(11), 1259–1265. https://doi.org/10.1038/nn1339

Wang, J., & Dai, B. (2020). Event-related potentials in a two-choice oddball task of impaired behavioral inhibitory control among males with tendencies towards cybersex addiction. *Journal of Behavioral Addictions*, *9*(3), 785–796. https://doi.org/10.1556/2006.2020.00059

Wang, J., Li, R., Tang, S., & Li, H. (2024). Differentiating anticipatory and consummatory reward processing in problematic pornography use: An event-related potential analysis of reward dynamics. *Computers in Human Behavior*, *158*, 108277. https://doi.org/10.1016/j.chb.2024.108277

Wang, J., Qu, S., Li, R., Tang, S., & Li, H. (2024). Blunted sensitivity to expected value during risky decision making in individuals with problematic pornography use. *Journal of Behavioral Addictions*, *13*(3), 779–790. https://doi.org/10.1556/2006.2024.00043

Wang, L., Yang, G., Zheng, Y., Li, Z., Qi, Y., Li, Q., & Liu, X. (2021). Enhanced neural responses in specific phases of reward processing in individuals with internet gaming disorder. *Journal of Behavioral Addictions*, *10*(1), 99–111. https://doi.org/10.1556/2006.2021.00003

Wojciechowski, J., Draps, M., Kublik, E., Dubiejko, P., Wolak, T., & Gola, M. (2025). Enhanced conditioning and disrupted extinction processes in men struggling with compulsive sexual behaviors. *Journal of Behavioral Addictions*, *14*(1), 191–203. https://doi.org/10.1556/2006.2025.00012

World Health Organization. (2020). International classification of diseases 11th revision. https://icd.who.int/dev11/l-m/en [Accessed July 2025].

Xu, S., Luo, L., Xiao, Z., Zhao, K., Wang, H., Wang, C., & Rao, H. (2019). High sensation seeking is associated with behavioral and neural insensitivity to increased negative outcomes during decision-making under uncertainty. *Cognitive, Affective & Behavioral Neuroscience*, *19*(6), 1352–1363. https://doi.org/10.3758/s13415-019-00751-x

Yang, X., Wang, Y., Tang, S., Li, L., & Wang, J. (2025). Effects of transcranial direct current stimulation of the right dorsolateral prefrontal cortex on craving and negative emotion regulation in individuals at risk for problematic pornography use: A double-blind, placebo-controlled study. *Journal of Behavioral Addictions*, *14*(2), 1064–1078. https://doi.org/10.1556/2006.2025.00030

Yao, Y.-W., Chen, P.-R., Chen, C., Wang, L.-J., Zhang, J.-T., Xue, G., … Fang, X.-Y. (2014). Failure to utilize feedback causes decision-making deficits among excessive internet gamers. *Psychiatry Research*, *219*(3), 583–588. https://doi.org/10.1016/j.psychres.2014.06.033

Yau, Y. H. C., Potenza, M. N., Mayes, L. C., & Crowley, M. J. (2015). Blunted feedback processing during risk-taking in adolescents with features of problematic internet use. *Addictive Behaviors*, *45*, 156–163. https://doi.org/10.1016/j.addbeh.2015.01.008

Yeung, N., & Sanfey, A. G. (2004). Independent coding of reward magnitude and valence in the human brain. *Journal of Neuroscience*, *24*(28), 6258–6264. https://doi.org/10.1523/JNEUROSCI.4537-03.2004