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FULL-LENGTH REPORT

Blunted sensitivity to expected value during risky decision making in individuals with problematic pornography use

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ABSTRACT

Background and aims: Neurobiological models of addiction posit that addiction manifests through an amplified salience towards addiction-associated stimuli and a diminished responsiveness to non-addiction-related incentives. However, existing research on reward processing in individuals with problematic pornography use (PPU) has primarily been limited to sexual cue reactivity. *Methods:* In this event-related potential (ERP) study, we employed a risky decision-making task involving 30 individuals with PPU and 33 healthy controls (HCs) to examine the effects of PPU on non-pornographic (money) reward valuation. *Results:* Compared to HCs, individuals with PPU exhibited compromised sensitivity to monetary rewards. Specifically, while the HC group demonstrated a differential response in late positive potential (LPP) amplitude to various expected value (EV) levels, this pattern was absent in the PPU group. This impairment was associated with poorer adaptive decision-making, as evidenced by PPU participants' inability to adjust risk choices based on changes in EV, leading to a propensity for riskier decisions in disadvantageous situations. *Discussion and conclusions:* The findings of impaired monetary evaluation in individuals with PPU may potentially explain why they continually pursue pornographic rewards while showing insensitivity to other rewards in daily life. Consequently, treatment development strategies may prioritize improving sensitivity to non-pornographic rewards within this population.

KEYWORDS

problematic pornography use, reward valuation, risky decision-making, event-related potential, late positive potential

INTRODUCTION

The anonymity, ubiquity, and ease of access afforded by the internet have contributed to the rampant spread of online pornography. While the majority of individuals consume pornography for entertainment purposes (Campbell & Kohut, 2017; Malki, Rahm, Öberg, & Ueda, 2021), a minority may develop problematic pornography use (PPU), characterized by prolonged engagement with or preoccupation with pornography, diminished interest in alternative activities, unsuccessful efforts to curtail usage, and a persistent reliance on pornography despite negative consequences (Kafka, 2010; Wéry & Billieux, 2017). Prevalence estimates for PPU generally range from approximately 3–10% in men and about 1–7% in women (Bőthe, Lonza, Štulhofer, & Demetrovics, 2020; Grubbs, Kraus, & Perry, 2019). There remains controversy over the classification of PPU. It can be regarded as a subtype of compulsive sexual behavior disorder (CSBD; Antons & Brand, 2021; Gola et al., 2022), a disorder recently included as an impulse control disorder in ICD-11 by the World Health Organization (WHO, 2019). However, some scholars argue that PPU resembles an addictive disorder (Brand et al., 2020; Kowalewska et al., 2018; Stark, Klucken, Potenza, Brand, &

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Strahler, 2018). Recent research indicates significant similarities between PPU and substance use disorders, alongside behavioral addictions, in symptom presentation and neurobiological mechanisms (Antons & Brand, 2021; Klein et al., 2022; Stark et al., 2018).

Contemporary theoretical models posit that alterations in the neural circuits governing reward processing are pivotal in shaping the progression and persistence of addictive behaviors: Repeated drug administration enhances the motivational significance of the drug and associated cues while diminishing the motivational significance of natural rewards (Berridge & Robinson, 2016; Goldstein & Volkow, 2011; Koob & Volkow, 2016). For example, the incentive sensitization theory proposes that individuals who are chronically exposed to drugs gradually become more sensitive to these stimuli. When encountering drugs and drug-related cues with incentive salience, they experience stronger desires and responses, thereby driving individuals to continually seek out and use drugs (Berridge & Robinson, 2016; Robinson & Berridge, 1993). The impaired response inhibition and salience attribution (IRISA) model posits that addiction involves an increased salience to drug-related stimuli coupled with a decreased sensitivity to natural, non-substance-related reinforcers, leading to impaired response inhibition and disadvantageous decision-making (Goldstein & Volkow, 2011). Similarly, the reward deficiency hypothesis proposes that reduced sensitivity to non-drug rewards serves as a predisposing factor for drug abuse, driving individuals to engage in activities (such as substance use) that activate the reward circuitry (Blum, Gardner, Oscar-Berman, & Gold, 2012).

Supporting these theories, recent research has indicated that individuals with PPU show altered evaluations of pornographic rewards. For example, using incentive delay tasks incorporating erotic and monetary cues of varying intensity and probability, Gola et al. (2017) observed heightened activation of the ventral striatum in individuals with PPU when exposed to erotic stimuli, and that the magnitude of erotic cues further modulated this relationship. Brand, Snagowski, Laier, and Maderwald (2016) noted an increased ventral striatum response to preferred pornographic images compared to less favored ones, and this variation in activity correlating with self-reported symptoms of PPU. Furthermore, in general population samples, behavioral studies have indicated correlations between symptoms of PPU and both sexual arousal ratings (Brand et al., 2011; Laier, Pawlikowski, Pekal, Schulte, & Brand, 2013) and viewing durations of preferred images (Laier et al., 2013). The findings derived from the aforementioned investigations indicate that people with PPU demonstrate an augmented sensitivity to sexual rewards, as manifested by a heightened discriminative response in the ventral striatum to the incentive value associated with sexual rewards.

While prior empirical research has provided evidence for the notion that individuals with PPU perceive sexual-related rewards and cues as stimuli with motivational salience, scant attention has been devoted to examining whether such individuals display diminished sensitivity to non-pornographic rewards. As posited by addiction models (Berridge & Robinson, 2016; Goldstein & Volkow, 2011; Koob & Volkow, 2016), the development of addiction may not only stem from an abnormally heightened salience of addictive cues but also from a potential attenuation in the motivational relevance of non-addictive rewards. Studying the responsiveness of individuals with PPU to non-pornographic rewards is crucial, given that diminished sensitivity to such stimuli has been documented in those with substance use disorders (Carmona-Perera, Sumarroca-Hernandez, Santolaria-Rossell, Perez-Garcia, & Del Paso, 2019; Diggs, Froeliger, Carlson, & Gilbert, 2013; Dunning et al., 2011; Martins et al., 2022) and has been implicated in predicting relapse among smokers (Versace et al., 2012) and alcoholics (Heinz et al., 2007). Consequently, examining brain responses to non-pornographic rewards in the context of PPU not only allows for theoretical exploration of similarities between PPU and addiction but also holds potential for providing clinically pertinent insights into treatments and interventions for PPU.

Only a few studies have examined the responses of individuals with PPU to non-pornographic rewards, and the findings have been inconsistent. Banca et al. (2016) reported that individuals with CSBD displayed a general preference for cues associated with sexual and monetary outcomes compared to healthy controls (HCs). Additionally, two fMRI investigations revealed that both individuals with PPU and HCs displayed analogous brain activation in the ventral striatum and orbitofrontal cortex when anticipating monetary rewards (Gola et al., 2017; Golec, Draps, Stark, Pluta, & Gola, 2021). However, a recent event-related potential (ERP) study by Wang and Li (2023) revealed that whereas HCs displayed increased P3 amplitudes in reaction to pleasant pictures compared to neutral stimuli, individuals with PPU did not exhibit this pattern, indicating their diminished sensitivity to non-pornographic rewards. It should be noted that previous studies have not specifically focused on the evaluation of non-pornographic rewards by PPU individuals, which entails the process of computing the reward value of an expected outcome based on magnitude and probability (Klein et al., 2022). Instead, they have predominantly examined the individuals' responses to non-pornographic rewards. Many classic paradigms for reward valuation, such as risky decision-making and probability discounting (see Peters & Büchel, 2010), have yet to be applied in the PPU domain.

The aim of this study is to investigate whether the heightened discriminative responses to sexual rewards in the PPU come at the expense of diminished discriminative responses to non-pornographic rewards (monetary rewards). To this end, we employed a modified version of the Cup task (Levin & Hart, 2003; Weller, Levin, Shiv, & Bechara, 2007), which requires participants to make choices between risky and riskless options. This task manipulated the probability levels and outcome magnitudes of monetary gains or losses, resulting in changes in the relative expected values (EV; i.e., the product of

probability levels and outcome magnitudes) of risky and riskless options across trials. The quality of decisions can be assessed by making choices consistent with the relative EV of the options, termed as EV sensitivity (Weller & Fisher, 2013). Risk-taking is advantageous when relative EV tend towards uncertain options, whereas risk avoidance is advantageous when relative EV tend towards riskless options. Furthermore, decision-making is a continuous process involving multiple stages, including option assessment, selection, and outcome feedback (Gowin, Mackey, & Paulus, 2013; Xue et al., 2009). To focus on the risk assessment stage in decision-making, we utilized high-temporal-resolution ERP technology to monitor the brain's neural activity in real-time during the reward valuation process. We particularly focus on the late positive potentials (LPP) component, which typically peaks around 600 ms after stimulus presentation and is primarily distributed over the central-parietal scalp region (Hajcak & Foti, 2020). Prior research has consistently demonstrated that LPP reflects stimulus categorization and motivational salience (Polich, 2007; Polich & Kok, 1995), and is linked to activation of ventral striatum, responsible for reward processing, during the evaluation process (Pfabigan et al., 2014). The amplitude of the LPP is influenced by the reward magnitude, irrespective of its actual attainment (Yeung & Sanfey, 2004). Hence, the LPP may reflect reward evaluation as well as encoding the subjective value of risky options (Botelho et al., 2023). The amplitude of the LPP increases with the reward value.

Based on previous studies (e.g., Wang & Li, 2023), we hypothesized that compared to HCs, PPU participants would exhibit impaired discriminative responses to monetary rewards. Behaviorally, this manifested as an inability to adjust their risk decisions based on changes in EV (i.e., diminished EV sensitivity). Electrophysiologically, this was reflected in their LPP amplitude being unable to differentiate between different EVs.

METHODS

Participants

Thirty-five young adults with PPU and 35 matched HCs were enrolled for this study. Considering the rising prevalence of PPU among college students (Chen, 2022), participants were sourced from local universities via a combination of advertising, posters, and word-of-mouth referrals. Moreover, considering the tendency for PPU to exhibit a higher prevalence among males compared to females (Bőthe et al., 2020; Grubbs et al., 2019), this study exclusively comprised male participants.

The assessment methodologies for PPU vary among research studies (Fernandez & Griffiths, 2021). Based on recent systematic reviews (Fernandez & Griffiths, 2021) and comparative analyses of PPU assessment tools (Chen & Jiang, 2020), this study selected the Problematic Pornography Consumption Scale (PPCS; Bőthe et al., 2018) for evaluating PPU. The PPCS employs a validated threshold score of 76 (out of 126) to distinguish between problematic and non-problematic pornography consumption. All participants were adult males aged 18 or older, heterosexual, right-handed, and disclosed no history of illicit substance use or psychiatric disorders. Seven participants (five excluded due to excessive eye movement artifacts and two due to technical issues) were omitted from the analysis, resulting in a final sample of 30 individuals with PPU and 33 HCs (Table 1).

Procedure

The screening questionnaires were distributed utilizing Wenjuanxing (www.sojump.com), a prevalent survey platform in China. Interested participants accessed the questionnaire through a QR code. There was a total of 703 participants involved in the survey. Following the predefined screening criteria for PPU, individuals who met the requirements were subsequently invited to take part in the ERP study.

Table 1. Demographic and clinical characteristics

Variables	PPU (n = 30)	HC (n = 33)	t/χ^2	p
Age, *M* (*SD*)	20.23 (1.31)	20.15 (1.42)	0.24	0.813
Years of education	14.57 (1.07)	14.33 (1.16)	0.83	0.413
BAI, *M* (*SD*)	27.97 (6.15)	25.27 (3.80)	2.11	**0.039**
BDI, *M* (*SD*)	29.07 (6.07)	26.18 (4.33)	2.19	**0.033**
Alcohol use (at least once per month)	16/0.53[a]	15/0.45[a]	0.39	0.532
AUDIT, *M* (*SD*)	2.69 (1.20)[b]	2.80 (1.57)[c]	−0.23	0.823
Cigarette use (at least once per month)	5/0.17[a]	2/0.06[a]	1.79	0.181
FTND, *M* (*SD*)	2.60 (0.89)[d]	2.50 (0.71)[e]	0.14	0.895
PPCS, *M* (*SD*)	84.53 (7.10)	20.03 (2.53)	48.89	**<0.001**

Abbreviations: AUDIT, Alcohol Use Disorder Identification Test; BAI, Beck Anxiety Inventory; BDI, Beck Depression Inventory; FTND, Fagerstrom Test for Nicotine Dependence; HC, Healthy Control; PPU, Problematic Pornography Use; PPCS, Problematic Pornography Consumption Scale.

Bold values indicates statistical significance at the $p < 0.05$ level.

[a] Number of participants (percentage).

[b] n = 16.

[c] n = 15.

[d] n = 5.

[e] n = 2.

Clinical assessment

The current levels of depression and anxiety were evaluated using the Beck Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) and the Beck Anxiety Inventory (BAI; Beck, Epstein, Brown, & Steer, 1988), correspondingly. Cigarette and alcohol consumption were documented, and nicotine dependence was assessed using the Fagerstrom Test for Nicotine Dependence (FTND; Fagerström, 1978), while hazardous alcohol use was evaluated using the Alcohol Use Disorders Identification Test (AUDIT; Babor, Higgins-Biddle, Saunders, & Monteiro, 2001).

The Cups task

The computerized version of Cups task was modified based on the original task conceived by Weller et al. (2007). The Cups task comprises both gain and loss domains. During the risk evaluation phase, participants were presented with a trial offering a choice between a risky and a safe option. They were instructed to select an option aiming to maximize gains in the gain domain and minimize losses in the loss domain. The safe option entailed winning or losing ¥ 10 with a certainty of 100%, while the risky option involved a chance to win or lose a larger sum (¥ 20, ¥ 30, ¥ 50) with probabilities of 20, 33, or 50%, respectively, and otherwise, win or lose nothing (¥ 0). Different combinations of probabilities and outcome magnitudes led to the establishment of two conditions:[1] (1) risk advantageous (RA), where the EV favored the risky choice over the safe choice: ¥ 30 × 50%, ¥ 50 × 33%, ¥ 50 × 50% in the gain domain; ¥ 20 × 20%, ¥ 20 × 33%, ¥ 30 × 20% in the loss domain. (2) risk disadvantageous (RD), where the EV favored the safe choice over the risky choice: ¥ 20 × 20%, ¥ 20 × 33%, ¥ 30 × 20% in the gain domain; ¥ 30 × 50%, ¥ 50 × 33%, ¥ 50 × 50% in the loss domain.

The task comprises 360 trials evenly distributed across gain and loss domains. In each domain, every combination of probability level and outcome magnitude repeats 30 times. Commencing each trial, a central fixation point is displayed for a randomly varied duration of 600–1,000 ms. Subsequently, both a risky and a certain option are concurrently presented on the screen. Participants are instructed to press the "F" key if they select the option shown on the left side of the screen, or the "J" key if they opt for the option displayed on the right side. The positioning of the two options (risky and certain) alternates randomly between the left and right sides of the screen for each trial. After participants made their choices, feedback on the outcome of the current trial and the cumulative amount of money at present were provided (see Fig. 1). The dependent variable was the proportion of risky decisions at each of the two EV levels (RA and RD) within both the gain and loss domains. To emphasize the real monetary stakes involved, participants were informed that their actual monetary compensation would be determined by the final cumulative amount accrued during the experiment.

[1]The combination of probabilities and outcome magnitudes can also produce a risk-neutral condition, where the EV of safe and risky options are equal: ¥ 20 × 50%, ¥ 30 × 33%, ¥ 50 × 20% in the gain and loss domains. However, considering that there have been too many trials in this ERP experiment, in order to alleviate subject fatigue, we did not include the risk-neutral condition.

ERP recording and analysis

EEG activity was recorded using a 64-electrode cap based on the international 10-20 system. The EEG signals were amplified through a BrainAmp amplifier (Brain Products GmbH, Munich, Germany). During online recording, the ground electrode was positioned at the middle of the forehead, with left and right mastoids serving as reference electrodes. The vertical electrooculogram (EOG) electrode was placed 1.5 cm below the right eye. All electrode impedances were maintained below 5 kΩ. Both EEG and EOG were continuously sampled at a rate of 500 Hz. After data collection, offline analysis was conducted using Brain Vision Analyzer 2.0. The data were band-pass filtered from 0.01 to 30 Hz (24 dB/octave), and trials with amplitudes exceeding ±75 μV were deemed artifacts and were excluded from analysis. To mitigate ocular interference, independent component analysis was utilized on EEG channels (Jung et al., 2000), with ocular artifacts detected through topographic visual inspection. Additionally, muscle or movement artifacts were identified and removed based on specific criteria: a maximum voltage step of over 50 μV/ms or an absolute difference exceeding 100 μV within a 200 ms timeframe.

The EEG activity under four conditions for each participant (RA and RD in both gain and loss domains) was averaged. The ERP epoch was 1,000 ms, ranging from 200 ms before stimulus presentation to 800 ms after. Based on visual inspection of the grand average ERP and previous research (Botelho et al., 2023; Hajcak & Foti, 2020; Pfabigan et al., 2014), the mean LPP amplitude was quantified in the 500–800 ms timeframe using the arithmetic average across central-parietal and parietal electrodes (CPz, CP3, CP4, Pz, P3, and P4).

Statistical analysis

Statistical analyses were performed using SPSS 20.0. Initially, independent sample *t*-tests were employed for between-group comparisons of demographic characteristics and clinical variables. Subsequently, for both the percentage of risky choices (behavioral dependent variable) and the mean LPP amplitudes (electrophysiological dependent variable), ANOVA with repeated measures were conducted, with group as a between-subjects factor, and EV level (RA, RD) and domain (gain, loss) as within-subjects factors. To further detect PPU-related differences in the ability to adjust decision strategies based on EV, we constructed an EV sensitivity index using residualized scores. Residualized scores were obtained by regressing the $RD_{risky\ ratio}$ onto the $RA_{risky\ ratio}$ to compute the behavioral EV sensitivity index, and similarly by regressing the RD_{LPP} onto the RA_{LPP} to derive the ERP EV sensitivity index (Dalecki & Willits, 1991;

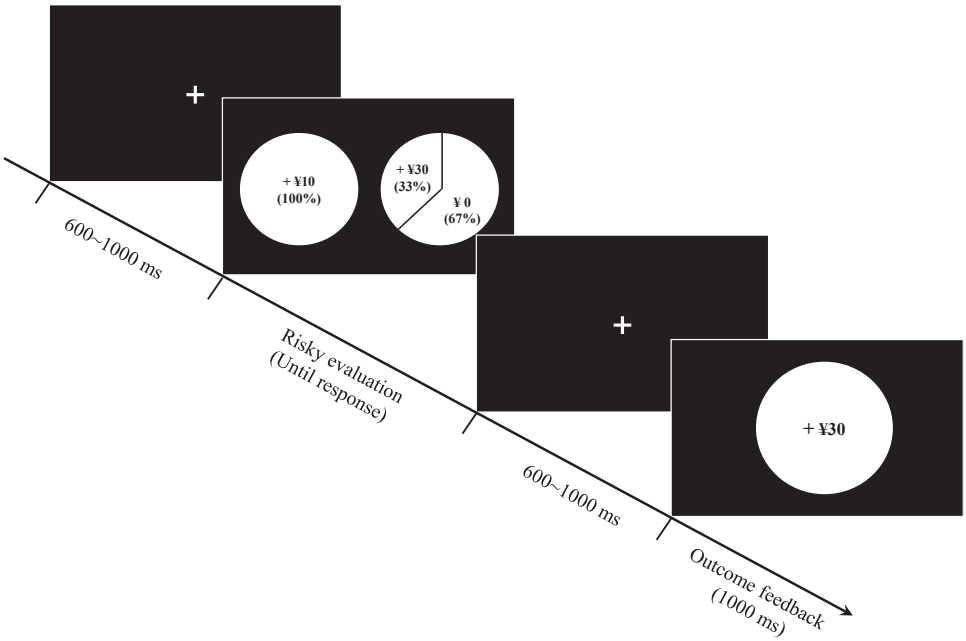

Fig. 1. Schematic representation of the Cups task. Participants were tasked with selecting between safe and risky options across both gain and loss domains. Safe options appeared on the left side of the screen, while risky options were displayed on the right

Meyer, Lerner, De Los Reyes, Laird, & Hajcak, 2017). We then calculated Spearman's rank correlation between the behavioral EV sensitivity index and ERP EV sensitivity index to explore their distinct relationship.

Ethics

The study protocol received approval from the Ethics Committee of Chengdu Medical College. All participants provided written informed consent and were compensated for their time.

RESULTS

Demographic and clinical characteristics

Table 1 presents the demographic and clinical characteristics. As per inclusion criteria, PPU participants exhibited notably higher PPCS scores compared to HCs. Additionally, in line with prior research (Raymond, Coleman, & Miner, 2003; Wang, Chen, & Zhang, 2021), individuals with PPU demonstrated significantly elevated scores on both the Beck Depression Inventory and the Beck Anxiety Inventory compared to HCs. However, no differences were found between the two groups in terms of age, years of education, cigarette use, and alcohol use.

Behavioral results

A 2 (Group) × 2 (Domain: gain or loss) × 2 (EV level: RA or RD) repeated measures ANOVA was conducted to assess group differences in risk-taking behavior (i.e., proportion of times participants opted for the risky choice) based on EV differences between choice options within each domain. A main effect for the Domain ($F_{(1,\ 61)} = 23.02$, $p < 0.001$, $\eta = 0.27$) showed more risk-taking in the gain domain than in the loss domain. A main effect for the EV ($F_{(1,\ 61)} = 414.77$, $p < 0.001$, $\eta = 0.87$) showed more risk-taking with higher EV levels. Furthermore, we discovered a Group × EV interaction ($F_{(1,\ 61)} = 4.56$, $p = 0.037$, $\eta = 0.07$), indicating that while there were no differences between the two groups in risk-taking during RA trials (0.70 ± 0.22 vs. 0.75 ± 0.19), t (61) = −0.93, $p > 0.35$, the PPU group (0.19 ± 0.15) exhibited more risk-taking during RD trials compared to the HC group (0.12 ± 0.13), t (61) = 2.03, $p = 0.046$, Cohen's $d = 0.51$ (see Fig. 2 and Table 2). Additionally, there was

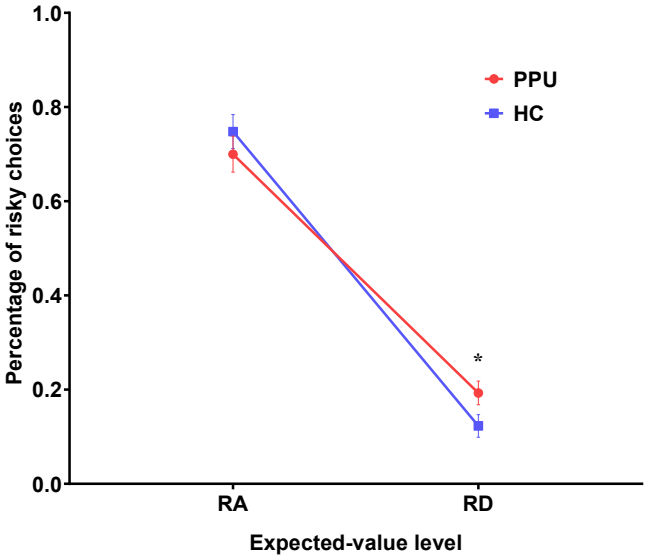

Fig. 2. The proportion of risky selections across risk advantageous (RA) and risk disadvantageous (RD) conditions in both gain and loss domains for the PPU and HC groups

Table 2. The mean and standard deviations of the percentage of risky choices and LPP amplitudes for PPU participants and HCs

	PPU				HC			
	Gain-RA	Gain-RD	Loss-RA	Loss-RD	Gain-RA	Gain-RD	Loss-RA	Loss-RD
Risky choice	0.78 ± 0.24	0.21 ± 0.19	0.62 ± 0.29	0.18 ± 0.19	0.86 ± 0.20	0.19 ± 0.22	0.64 ± 0.27	0.06 ± 0.08
LPP	2.47 ± 2.48	1.53 ± 2.01	1.55 ± 1.88	2.02 ± 2.08	1.89 ± 2.28	1.63 ± 2.29	1.69 ± 2.26	1.55 ± 1.91

Abbreviations: HC, Healthy Control; LPP, Late Positive Potential; PPU, Problematic Pornography Use; RA, risk advantageous; RD, risk disadvantageous.

a significant difference between the PPU and HC groups in the behavioral EV sensitivity index ($p = 0.037$, Cohen's $d = -0.54$), with PPU participants (0.51 ± 0.24) demonstrating decreased EV sensitivity compared to the HCs (0.63 ± 0.20).

ERP results

The ANOVA on LPP indicated a significant main effect of EV ($F_{(1, 61)} = 4.61$, $p = 0.036$, $\eta = 0.07$), with the LPP amplitude larger under the RA condition compared to the RD condition. Moreover, both the Domain × EV interaction ($F_{(1, 61)} = 10.10$, $p = 0.002$, $\eta = 0.14$) and the Group × Domain × EV interaction ($F_{(1, 61)} = 7.26$, $p = 0.009$, $\eta = 0.11$) were significant (see Figs 3 and 4). Simple effect analysis revealed a significant Domain × EV interaction for the HC group ($F_{(1, 32)} = 14.15$, $p = 0.001$, $\eta = 0.31$). Specifically, within the gain domain, the LPP amplitude was greater under the RA condition compared to the RD condition (2.47 ± 2.48 vs. 1.53 ± 2.01 μV; $p < 0.001$), whereas within the loss domain, the LPP amplitude was greater under the RD condition compared to the RA condition (1.55 ± 1.88 vs. 2.02 ± 2.08 μV; $p = 0.034$). However, for the PPU group, the Domain × EV interaction was not found to be statistically significant ($F_{(1, 29)} = 0.16$, $p = 0.69$, $\eta = 0.01$). This suggests that compared to PPU participants, HCs demonstrate enhanced sensitivity to EV during risk assessment, exhibiting differential LPP responses under different EV levels.[2] On the other hand, between-group analysis reveals no significant differences between the PPU group and the HC group in terms of RA and RD conditions within the domains of gain and loss (all $ps > 0.33$). Overall, these results suggest that compared to HCs, individuals with PPU may not show a significant difference in the overall response strength to monetary rewards. However, they seem to exhibit lower differentiation in response to monetary incentive value signals, potentially reflecting a reduced sensitivity to the value information of monetary rewards.

[2]It is noteworthy that, in the gain domain, the RA conditions (¥ 30 × 50%, ¥ 50 × 33%, ¥ 50 × 50%) were associated with higher subjective expected values compared to the RD conditions (¥ 20 × 20%, ¥ 20 × 33%, ¥ 30 × 20%). Conversely, in the loss domain, the RD conditions (¥ 30 × 50%, ¥ 50 × 33%, ¥ 50 × 50%) were associated with higher subjective expected values compared to the RA conditions (¥ 20 × 20%, ¥ 20 × 33%, ¥ 30 × 20%). Therefore, in both gain and loss domains, the LPP amplitudes for RA and RD conditions exhibited opposite directions.

LPP-behavioral correlations

To examine the potential association between behavioral risk-taking and LPP amplitude in reward valuation, we conducted Spearman's rank correlation analyses separately for the gain and loss domains, investigating the relationship between behavioral EV sensitivity index and ERP EV sensitivity index. The results revealed a significant negative correlation between the two variables in the loss domain ($r_{(63)} = -0.26$, $p = 0.043$; see Fig. 5). This indicates that participants who demonstrate differential LPP responses to various EV levels during risk evaluation are more likely to exhibit adaptive risk decision-making behavior, especially in the context of loss.

DISCUSSION

This study represents the inaugural endeavor employing ERP measurements to probe the neural correlates of monetary reward assessment during risky decision-making among individuals with PPU. Our aim in undertaking this investigation was to ascertain whether individuals with PPU manifest diminished responsiveness to non-erotic rewards (monetary incentives). As anticipated, sensitivity to monetary reward was diminished in the PPU participants: although there was a differential response of LPP amplitude to different EV levels in the HC group, this pattern was not seen in the PPU group. This impairment was accompanied by poorer adaptive decision-making, rendering PPU participants unable to adjust risk choices based on changes in EV.

On the behavioral level, in contrast to HCs, individuals with PPU were less inclined to utilize the relative EV of choice options in reaching normatively appropriate decisions. This lack of sensitivity seemed predominantly influenced by an elevated selection of disadvantageous risky options by PPU individuals during RD conditions. Our outcomes align with prior investigations in gaming disorder (Yao, Chen, et al., 2015; Yao, Wang, et al., 2015) and similar observations in pathological gamblers (Brevers et al., 2012) and people with alcohol use disorder (Brevers et al., 2014), indicating potential common impairments in decision-making across individuals with PPU and other addictive disorders. Our results furnish initial evidence of impaired risk decision-making among individuals with PPU.

By recording the LPP component during risk assessment processes, we further validate that this impaired risk

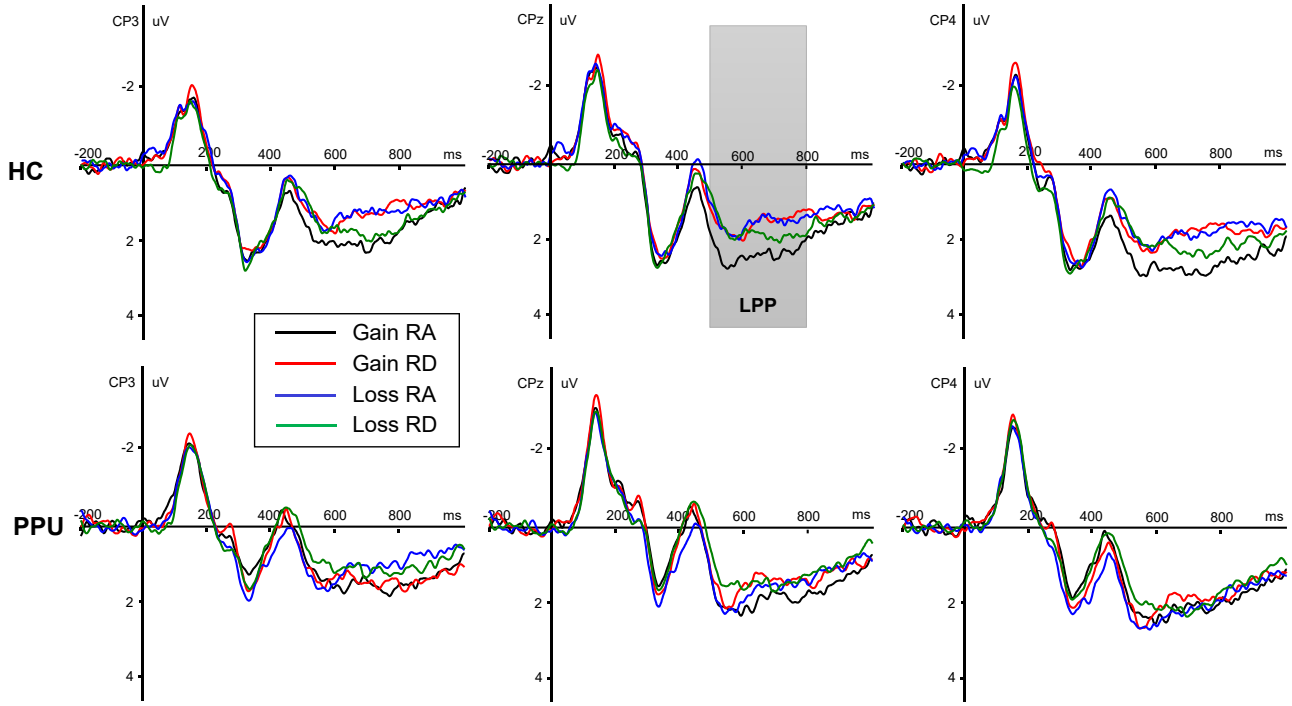

Fig. 3. The grand averaged ERP waveforms of LPP components at electrodes CP3, CPz, and CP4 during the risk evaluation stage in individuals with PPU and HCs. The LPP was assessed between 500 and 800 ms following stimulus presentation

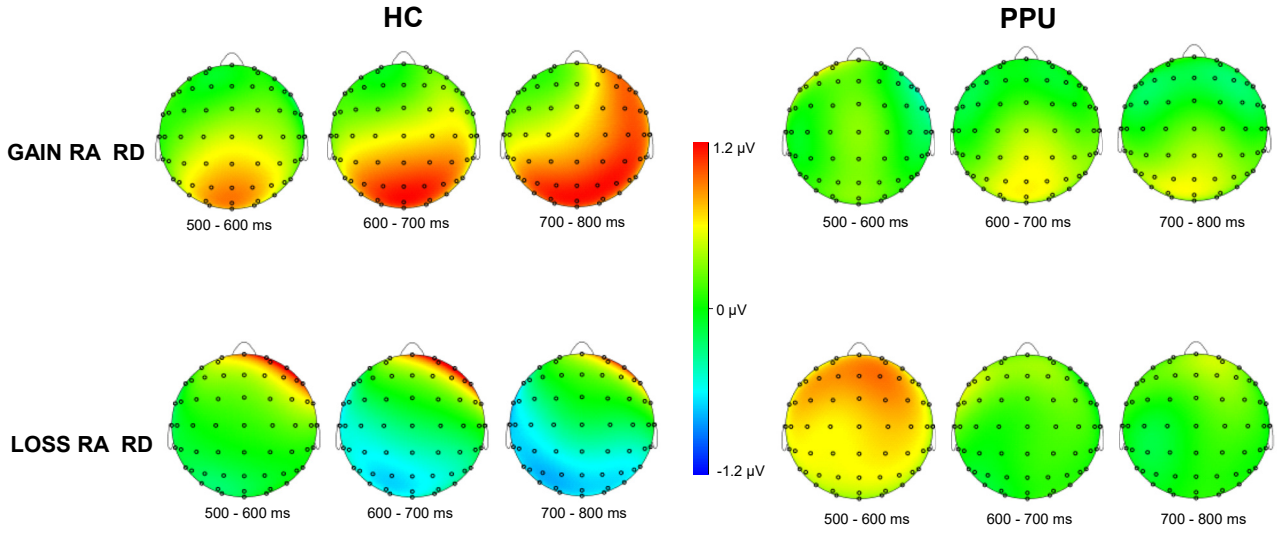

Fig. 4. Scalp topographies of the LPP amplitudes difference between RA and RD conditions (across 500–800 ms) for individuals with PPU and HCs in both gain and loss domains

decision-making may stem from the insensitivity of PPU participants to the value of monetary rewards. The LPP, indicative of stimulus categorization and motivational significance (Polich, 2007; Polich & Kok, 1995), is modulated by the realized or expected magnitude of rewards (Yeung & Sanfey, 2004). As a result, it functions as an indicator for evaluating rewards and encoding the anticipated value of risky choices (Botelho et al., 2023). Our findings in HCs corroborate the modulation of the LPP by the EV of monetary rewards. However, such EV-driven modulation of the LPP is lacking in PPU participants. This finding aligns with a recent study that reported individuals with PPU showing a lack of the typical enhancement of the LPP amplitude in reaction to pleasant emotional pictures compared to neutral pictures, as observed in HCs (Wang & Li, 2023). This finding is also consistent with recent fMRI research on pathological gamblers (Sescousse, Barbalat, Domenech, & Dreher, 2013) and binge alcohol drinkers (Tolomeo, Baldacchino, & Steele, 2023). Using incentive delay tasks that incorporated monetary and erotic rewards, Sescousse et al. (2013) observed

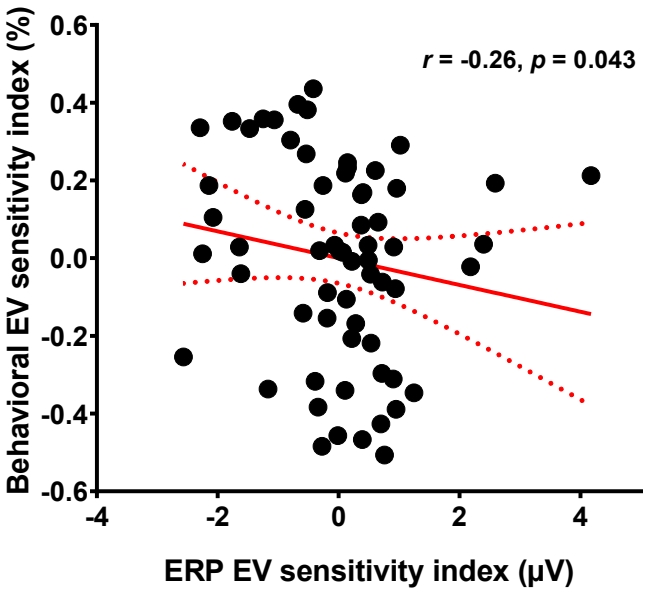

Fig. 5. Correlation between the ERP EV sensitivity index (residualized RA_{LPP}) and the behavioral EV sensitivity index (residualized $RA_{risky\ ratio}$) in the loss domain for all participants

differential sensitivity in pathological gamblers, characterized by heightened responsiveness to addictive (monetary) rewards but diminished sensitivity to non-addictive (erotic) rewards. Similarly, Tolomeo et al. (2023) employed a reward-gain instrumental learning task where participants chose between pairs of fractal images (one with a high reward probability and one with a low reward probability) to maximize gains. Their results indicated that, compared to HCs, binge drinkers exhibited significantly blunted encoding of expected reward value at the decision time, when the two fractal images were presented.

The constrained sensitivity to monetary reward EV observed in this study aligns with the IRISA model and the reward deficiency hypothesis (Blum, Cull, Braverman, & Comings, 1996; Blum et al., 2012; Goldstein & Volkow, 2011). As posited by the IRISA model (Goldstein & Volkow, 2011), prolonged supraphysiological stimulation from drugs leads to adaptive changes in the reward circuitry. Individuals with addiction disorders tend to exhibit increased salience to drug-related rewards and cues, alongside diminished sensitivity to natural, non-substance-related reinforces. As a result of this interaction, individuals experience diminished control over their addictive behaviors and a decreased ability to inhibit disadvantageous decision-making. Applied to PPU, pornography as a supranormal stimulus can also induce neural plasticity adaptations (Hilton, 2013), resulting in heightened salience of pornographic rewards within the reward circuitry of individuals with PPU, while simultaneously reducing sensitivity to non-pornographic rewards. Previous research has indicated that individuals exhibiting stronger cue-reactivity to pornography stimuli tend to have lower desire for partnered sexual activity (Steele, Staley, Fong, & Prause, 2013). In essence, they show a preference for artificial stimuli over the powerful natural reward of partnered sex. Here, our behavioral and electrophysiological findings provide more direct support for altered non-pornographic reward valuation in individuals with PPU. Alternatively, the reward deficiency hypothesis posits that a genetically determined deficiency in dopamine DRD2 receptor availability leads to a diminished neural response to natural rewards (Blum et al., 1996, 2012). This blunted reward response is believed to predispose individuals to seek drugs of abuse. Consequently, reduced sensitivity to natural rewards may be a predisposing factor for PPU, driving individuals to engage in behaviors that activate reward circuits, such as pornography consumption. In summary, both models suggest that attenuated responsiveness to natural rewards is crucial for understanding the incentive salience of addictive cues. However, they differ in their causal interpretations of this blunted responsiveness. It remains unclear whether pornography use causes this reward dysregulation or if individuals with a pre-existing low reward set point are more likely to engage in pornography use to enhance their brain's reward response.

Our findings regarding the LPP in individuals with PPU align with other ERP studies demonstrating diminished P300 sensitivity to monetary reward in cocaine use disorders (Goldstein et al., 2008; Parvaz et al., 2012). Specifically, these studies found that, unlike HCs, individuals with cocaine use disorders do not exhibit modulation of P300 amplitude by changes in different monetary amounts. The compromised P300 response is also evident in other forms of substance addiction (Porjesz, Begleiter, Bihari, & Kissin, 1987) and may serve as an indicator of susceptibility to addiction. For instance, impaired P300 responses to incentives have been observed not only in individuals diagnosed with substance use disorder (Goldstein et al., 2008; Parvaz et al., 2012) but also in non-addicted individuals with a parental history of substance use disorder (Euser et al., 2013).

This study holds importance both theoretically and practically. Theoretically, our research suggests that PPU exhibits similarities to both internet gaming disorder and substance use disorder, both behaviorally (impaired risk decision-making) and electrophysiologically (comprised LPP response to monetary reward). The classification of PPU (and CSBD) remains highly contentious, with our findings supporting the view of PPU as akin to a behavioral addiction. From a practical standpoint, our results align with clinical assessments of individuals with PPU, who often report experiencing minimal pleasure in their everyday lives. For instance, previous studies have indicated that individuals with PPU often describe feelings of emptiness and boredom across various aspects of their lives, such as family interactions, romantic relationships, and sexual experiences (Efrati & Gola, 2018; Engel et al., 2023; Steel et al., 2013). The diminished sensitivity of LPP to the expected value of monetary rewards might explain the decreased capacity to derive pleasure from regular rewarding stimuli, thereby raising the likelihood of people with PPU turning to pornography. This research underscores the importance of integrating non-pornographic rewards into clinical approaches for addressing and treating PPU. A recent study utilized Mindfulness-Oriented Recovery Enhancement, a novel behavioral intervention that combines mindfulness

training with the savoring of natural rewards to amplify natural reward processing (Garland et al., 2023). This approach has demonstrated the ability to enhance motivated attention to natural reward cues and reduce subjective anhedonia among chronic pain patients undergoing long-term opioid therapy. Consequently, by increasing the salience of natural incentives and enhancing the responsiveness of individuals with PPU to such stimuli, we can create new pathways for positive reinforcement. An area worth investigating is whether enhancing the sensitivity to reward value gradients could influence decision-making, potentially leading individuals to prefer non-pornographic rewards over pornography consumption. Simultaneously, future research should aim to elucidate the ontogeny of reward dysregulation. Previous studies highlight the pivotal role of dopamine receptors in regulating risk-taking and reward assessment (Burke et al., 2018; Gabriel, Liley, Freels, & Simon, 2021; Guadarrama-Bazante & Rodríguez-Manzo, 2019). For example, lower availability of dopamine D2 receptors is linked to dopamine-mediated activation of brain reward areas and cue-induced craving (Heinz et al., 2004). Preclinical studies provide additional support, demonstrating that dopamine D2 receptor knockout rats exhibit heightened incentive motivation for drugs (De Jong et al., 2015). These findings imply that dopamine D2 receptor activity directly impacts how rewards are subjectively valued, suggesting potential strategies to modify reward preferences in individuals with PPU.

There are several limitations to this study. Firstly, this study is unable to ascertain whether the diminished sensitivity to reward EV preceded pornography use or resulted from prolonged pornography abuse. Considering the relatively young age and nonclinical status of the current sample, it appears probable that some degree of the LPP's insensitivity to reward reflects premorbid vulnerability rather than neuroadaptations arising from long-term pornography consumption. However, it must be pointed out that the current research design precludes causal inferences. Future research could gain advantages from utilizing longitudinal study methodologies. Secondly, this study employed a non-clinical sample of university students, given the increasing prevalence of PPU among them. Future investigations should contemplate using clinical samples, including patients with CSBD, to validate the results of this study. Moreover, future research should also include female participants to enhance the generalizability of this study's findings. Thirdly, decision-making is a continuous process involving reward assessment and outcome feedback. This study did not assess whether individuals with PPU exhibit abnormalities during the outcome feedback stage. Therefore, an intriguing avenue for future research is to utilize ERP (particularly the feedback-related negativity component) to investigate the response patterns of individuals with PPU during this stage. Finally, the study did not explore responses to pornographic cues in the same participants as it was beyond the scope of this research. However, we anticipate that such responses would show an increase, aligning with findings from previous fMRI studies.

CONCLUSION

Individuals with PPU appear to exhibit a shift in their value system, whereby they frequently disregard valuable everyday activities in favor of being dominated by pornographic thoughts or behaviors. The findings of this study for the first time provide behavioral and electrophysiological evidence for alterations in non-pornographic reward processing among individuals with PPU, revealing impaired sensitivity to non-pornographic rewards (money). Given that reduced sensitivity to such stimuli has been implicated in predicting relapse among substance use disorders (Heinz et al., 2007; Versace et al., 2017), and considering that the imbalance in responsiveness to addictive rewards compared to non-addictive rewards can be reversed (Parvaz et al., 2017), these findings underscore the significance of developing treatment approaches aimed at enhancing sensitivity to non-pornographic rewards.

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