Title: Can pornography be addictive? An fMRI study of men seeking treatment for problematic pornography use.

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Abstract

Importance

Pornography consumption is highly prevalent, particularly among young adult males. For some individuals, problematic pornography use (PPU) is a reason for seeking treatment. Despite the pervasiveness of pornography, PPU appears under-investigated and basic questions remain unanswered.

Objective

To investigate the neural mechanisms underlying PPU in men.

Design and participants

Using functional magnetic resonance imaging (fMRI), we examined brain reactivity towards erotic and monetary stimuli, disentangling cue-related 'wanting' from reward-related 'liking' among 28 heterosexual males seeking treatment for PPU and 24 heterosexual males without PPU. Subjects could have won either erotic pictures or monetary gains in an incentive delay task, where rewards were preceded by predictive cues.

Main outcome measures

BOLD signal activity relating to responses to erotic and monetary cue processing and measured during fMRI was analyzed and examined with respect to self-reported data on sexual activity collected over the 2 preceding months.

Results

Men with and without PPU differed in brain reactions to cues predicting erotic pictures, but not in reactions to erotic pictures themselves, consistent with the incentive salience theory of addictions. PPU subjects showed increased activation of a brain reward region (the ventral striatum) specifically

for cues predicting erotic pictures but not for cues predicting monetary gains. This brain activation was accompanied by increased behavioral motivation to view erotic images (higher 'wanting'). Ventral striatal reactivity for cues predicting erotic pictures was significantly related to the severity of PPU, amount of pornography use per week and number of weekly masturbations.

Conclusions and relevance

Our findings suggest that like in substance-use and gambling disorders the neural and behavioral mechanisms linked to anticipatory processing of cues relate importantly to clinically relevant features of PPU. These findings suggest that PPU may represent a behavioral addiction and that interventions helpful in targeting behavioral and substance addictions warrant consideration for adaptation and use in helping men with PPU.

Introduction

Pornography consumption has become highly prevalent in part given Internet availability[1]. Approximately 70% of males and 20% of females aged 18-30 years use pornography weekly[2]. Among teenagers less than 18 years of age, 90% of boys and 60% of girls have used Internet pornography[3], with 12% of children having onset of regular consumption below age 12[4]. For most people, pornography viewing is a form of entertainment, but for some individuals problematic pornography use (PPU) accompanied by excessive masturbation promotes seeking of treatment[5]. Such observations raise multiple scientifically and clinically important questions, including with respect to brain mechanisms related to PPU and their relationships to clinically relevant measures. Given the negative health measures associated with compulsive sexual behavior (CSB) broadly (e.g., childhood sexual trauma and post-traumatic stress disorder[6]), more research is need in order to better understand specific forms of CSB like PPU and develop improved intervention strategies[7–10].

The existence and clinical utility of non-substance or behavioral addictions has been debated, with gambling disorder currently being the sole non-substance disorder classified together with substance-use disorders in DSM-5[11,12]. Although a field trial for hypersexual disorder[13] was conducted, neither this condition or related behaviors such as PPU were included in DSM-5, in part given the relative paucity of data on these behaviors or conditions[8,14,15]. Whether excessive and problematic patterns of sexual behavior are best conceptualized within obsessive-compulsive-disorder (OCD), impulse-control-disorder (ICD), behavioral-addiction or other frameworks has been debated[7–10]. A recent case series reported that low dose (20 mg/day) of paroxetine treatment (found to be successful in treating OCD[16]) led to reductions in anxiety and severity of PPU[17]. Naltrexone treatment (found to be successful in alcohol-use[18] and gambling disorders[19]) may be helpful for individuals with PPU[20,21]. As naltrexone has been proposed to reduce craving through modulating activity in mesolimbic structures[22], the ventral striatum may contribute importantly to compulsive sexual behaviors including PPU. Recent MRI studies of men support this hypothesis. Among non-

problematic pornography users, an inverse relationship between right caudate volume and frequency of pornography consumption was observed[23]. Increased blood-oxygen-level-dependent (BOLD) responses in the ventral striatum were observed in response to preferred sexual pictures when compared to non-preferred ones, and this activity positively correlated with scores on the Internet Addiction Test Modified for Cybersex[24]. Men with CSB (meeting criteria for hypersexual disorder)[13] as compared to those without (comparison subjects; CSubs) demonstrated an increased striatal reactivity for sexually explicit videos[25] and decreased functional connectivity between the ventral striatum and prefrontal cortex[26]. These findings suggest similarities between CSB and addictions.

A prominent model of addiction, the incentive salience theory (IST)[27–29], posits that wanting becomes dissociated from liking. The latter is hypothesized to be linked to the *experienced* value of the reward and the former to its *anticipated* value[29]. 'Wanting' is typically evoked by predictive cues associated with reward through Pavlovian learning[28]. Learned cues (conditional stimuli) related to addiction acquire incentive salience, reflected in increased BOLD response in the ventral striatum and increased motivated behavior (i.e. shorter reaction times; RTs)[28]. According to the IST, and consistent with observations in substance addictions and gambling disorder [29,30], increased anticipatory 'wanting' is dissociated from experienced 'liking' in addiction. If PPU subjects share mechanisms of other addictions, we anticipate seeing increased BOLD response in ventral striatum specifically for cues signaling erotic pictures followed by higher motivation to obtain them (measured as shorter RTs) when compared to CSubs. These neural and behavioral measures of increased 'wanting' should be unrelated with measures of 'liking' in PPU subjects, but not in CSubs.

The current study sought to extend prior studies by examining the neural correlates of sexual and non-sexual images in men seeking treatment for PPU and men without PPU. We further sought to relate the brain activations to clinically relevant features of PPU. No prior neuroimaging studies have examined individuals seeking treatment for PPU. Additionally, as it is important to investigate

possible common neural mechanisms of addictions, we investigated cue-induced "*wanting*" of "addiction-related" reward dissociated form its "*liking*". Most studies using visual sexual stimuli do not allow for determination of whether stimuli may represent cues or rewards,[31,32] and very rarely do they permit comparisons to other incentives, making it difficult to interpret results with respect to the IST[27–29].

To investigate, we used an incentive delay task (Figure 1) previously used in studies of gambling disorder[30]. This task has three important properties; it: 1) disentangles cue- and reward-related phases related to anticipation and outcome, respectively; 2) allows measurement of neural and behavioral indicators of 'wanting' (in a cue phase) and 'liking' (in a reward phase); and, 3) provides a possibility to compare "addiction-related" stimuli (in this case erotic pictures) with another potent reward (monetary gains). As individuals with gambling disorder expressed higher ventral striatum responses to monetary cues (compared to erotic) in the cue phase[12], we hypothesized that men with PPU as compared to those without would demonstrate increased ventral striatal responses for erotic but not monetary cues. We further hypothesized that the degree of ventral striatal activation to erotic cues in the men with PPU would correlate positively with severity of PPU, amount of pornography consumed and frequency of masturbation. Finally according to the IST, we hypothesized that 'wanting' in the erotic cue phase would be associated with 'liking' in the reward phase in the CSub group but not the PPU group, representing a dissociation between 'wanting' and 'liking' in PPU.

Table 1. Characteristics of subjects, PPU symptoms and self-assessment measures collected after qualifications for groups – means (standard deviations)

	Control Sub (N=24)	PPU (N=28)	p value
Age	30.49 y.o. (7.55)	30.96 y.o. (6.51)	n.s.[A]
Monthly income[B]	3360 PLN (2264)[C]	3463PLN (2491)[C]	n.s. [A]
Average pornography consumption per week[D]	50.77 min (42.6)	287.87 min (258.4)	<.001
Longest time of pornography consumption in one day[E]	70.55 min (52.8)	284.74 min (321.3)	=.002
Average frequency of masturbation per week[D]	2.37 (1.46)	5.66 (3.04)	<.001
Max number of masturbations in one day	3.10 (1.17)	5.21 (2.75)	<.001
Sex Addiction Screening Test –Revised (SAST-R) [33,34]	2.67 (2.12)	11.46 (4.95)	<.001
Brief Pornography Screener (BPS)[F35]	2.88 (3.24)	5.91 (2.96)	=.005
Sexual Arousability Inventory (SAI) [36,37]	83.39 (19.27)	88.64 (19.89)	n.s. [A]
Obsessive Compulsive Inventory –Revised (OCI-R)[F 38]	14.13 (6.73)	15.77 (10.10)	n.s. [A]
UPPS-P Impulsive Behaviour Scale (UPPS-P)[F 39,40]	130.73 (24.97)	131.87 (25.37)	n.s. [A]
Eysenk's Impulsivity Inventory – Impulsivity (IVE-I)[41]	5.95 (3.85)	6.95 (5.01)	n.s. [A]
Eysenk's Impulsivity Inventory – Risk Taking (IVE-R)[41]	9.41 (4.01)	9.9 (3.96)	n.s. [A]
State-Trait Anxiety Inventory – State (STAI-S) [42,43]	33.79 (6.35)	37.69 (9.36)	n.s. [A]
State-Trait Anxiety Inventory – Trait (STAI-T) [42,43]	37.83 (6.96)	43.60 (9.88)	=.022

[A] Non-significant: p>.2

[B] Income after taxes

[C] 1 PLN is approximately .25 EUR. Average monthly income after taxes in Poland in 2014 was 2865 PLN or about 716 EUR.

[D] Averaged across three self-reports about 8th, 4th and last week before the fMRI recording (see Figure 1a) as all assessments at the 3 timepoints were highly related to each other within each domain (pornography use measure 1 and 3: R=.871; p<.01, and masturbation: R=.792; p<.01))

[E] Longest time spent on pornography consumption within 24 hour period (one day)

[F] Due to the time needed for development and validation of Polish language version, these questionnaires were added during the study and 16 CSubs and 22 PPU subjects completed them.

Methods

Participants

Fifty-seven heterosexual males (age range 18-48 years) participated in the fMRI study. These included thirty-one men seeking treatment for PPU (meeting criteria of hypersexual disorder[13]) and without other psychiatric diagnoses and twenty-six CSubs with comparable ages and incomes, also without psychopathology. Three PPU subjects and two CSubs were excluded from analysis due to extensive head movement (more than 7mm). Characteristics of the remaining 28 PPU subjects and 24 CSubs are presented in Table 1. All participants were financially compensated based on their winnings accumulated during the experimental procedure (M=184.84 PLN; SD=21.66; approximately 46 EUR). To ensure the anonymity of PPU individuals we applied double-blind so research team in the laboratory had no access to the data gathered by team responsible for recruitment and no knowledge who is a PPU subject and who is control. Details of recruitment and anonymity procedures were presented in Supplementary materials. All research procedures were approved by the Ethical Committee of Institute of Psychology, Polish Academy of Science. All subjects provided written informed consent.

Questionnaire assessments

In self-assessments preceding MRI (Figure 1a), subjects were asked to report their sexual activity during the week (see Table 1). During this phase, we also collected questionnaire measurements for independent verification of screening accuracy and assessment of additional data (as presented in Table 1 and described in details in the Supplementary Materials).

Incentive delay task

We used the same procedure as in previous studies[12,3530,44], schematized in Figure 1b and described in detail in the Supplementary Materials. A modification related to the amount of monetary gains. In the original studies[12,35], subjects were informed that they would receive a sum of rewards from one

randomly chosen experimental block (out of four)[30]. In our study, subjects were told they would receive the exact sum of all monetary gains (M=184.84 PLN, which was approximately 5.5% of monthly salary after taxes).

MRI data acquisition

MRI data acquisition was conducted at the Laboratory of Brain Imaging, Neurobiology Center, Nencki Institute of Experimental Biology on a 3-Tesla MR scanner (Siemens Magnetom Trio TIM, Erlangen, Germany) equipped with 12-channel phased array head coil. Functional data were acquired using a T2*-weighted gradient echo planar imaging (EPI) sequence with the following parameters: repetition time = 2500ms, echo time = 28ms, flip angle = 90°, in plane resolution = 64 × 64 mm, field of view = 224 mm, and 35 axial slices with 3.5 mm slice thickness with no gap between slices. Each of the four functional runs consisted of 286 volumes. Field mapping was done based on prior methodology[45] using double echo FLASH (echo time 1=4.92 ms echo time 2=7.38 ms time repetition = 600 ms) with the same spatial properties as the functional scans. Detailed anatomical data were acquired with a T1-weighted sequence (repetition time = 2530 ms, echo time = 3.32 ms). Head movements were minimized with cushions placed around the participants' heads. Subjects were asked to refrain from any psychoactive substance use and sexual activity during 24 hours preceding fMRI.

fMRI Analysis

Statistical Parametric Mapping (SPM12, Wellcome Trust Center for Neuroimaging, London, UK) running on MATLAB R2013b (The Math-Works Inc., Natick, MA, USA) was used for data preprocessing and statistical analyses. In order to minimize geometrical distortions in EPI images caused by field inhomogeneities, we used additional B0 field map scans. During the initial step, the FieldMap toolbox[45] was used to calculate voxel displacement maps. Then functional images were motion-corrected and un-warped using these displacement maps[46]. Next, the structural images (T1) from single subjects were co-registered to the mean functional image. T1 scans were automatically classified into grey matter, white matter and cerebrospinal fluid using the "New Segmentation" tool

based on a mixture of Gaussian models and tissue probability maps[47]. High-dimensional diffeomorphic anatomical registration through exponentiated lie algebra (DARTEL) was used to create a study-specific template and flow fields based on the segmented tissue from the T1 images[48]. The functional images were normalized to a 2 mm isotropic voxel size using compositions of flow fields and study-specific template[49]. Finally, the normalized functional images were smoothed with an 8 mm isotropic Gaussian kernel. In the first-level statistical analysis, all of the experimental conditions and head movement parameters were entered into the design matrix. The data were modeled using the canonical hemodynamic response function provided with SPM12. Data were also high-pass filtered (128 sec) to remove low-frequency signals, and an AR(1) model was applied to adjust for serial correlations in the data. Brain responses during the cue anticipatory phase and the reward outcome phase were modelled in line with previous studies[30,44] and described in details in the Supplementary Materials.

Regions of interests

We used a striatal ROI defined *a priori* based on our previous study in subjects with gambling disorder[30] (8mm spheres centered around: Left: x=-12, y=10 z=-6, Right: x=12, y=10, z=-4). To focus on our hypothesis and keep this manuscript concise, we present only analyses using the *a priori* defined ROI of the ventral striatum. For control purposes, we also defined an ROI in Heschl's gyrus based on the corresponding mask in the AAL atlas taken from the WFU PickAtlas toolbox (version 3.0.5). The percent signal change was calculated with the MarsBaR toolbox (http://marsbar.sourceforge.net). Due to the very similar effects for left and right ROIs, we present only results averaged across hemispheres.

Statistical analysis

For statistical analysis IBM SPSS 22 (IBM Corp. Released 2013, Armonk, NY: IBM Corp), and MATLAB R2014a (The Math-Works Inc., Natick, MA, USA) were used. Due to high correlations across-time (at

the three time points: 8 weeks, 4 weeks and 1 day before the fMRI) within self-assessed pornography use (R=.871; p<.01) and masturbation (R=.792; p<.01), we computed average scores across time for each variable (Figure 1a; Table 1). For testing group-by-trial-type interactions and main effects of group and trial type in BOLD signal from the ROIs, General Linear Models (GLMs) and Fisher's F tests (ANOVA with trial type as a within-subject factor and group as a between subject factor) were used (Figure 2). All *post hoc* comparisons were conducted with Bonferroni-Holms correction. Correlations between BOLD signal and measures of symptoms were computed only for measures significantly differentiating PPU subjects from CSubs (SAST-R, BPS, amount of pornography use and masturbation). Due to the discrete thresholding of SAST-R scores and skewedness of distributions of the three other measures, Spearman's Rho was used to compute covariance. We also examined BOLD activity in a "control ROI": Heschl's gyrus, where according to our predictions, no group or condition differences were observed.

Results

Between-group differences

Men seeking treatment for PPU and CSubs did not differ in age, income, impulsivity or compulsivity (Table 1). Although no subjects met criteria for anxiety disorders, men with PPU as compared with CSubs exhibited higher trait anxiety (t(50)=2.37; p=.022; STAI-T). No difference in self-declared sexual arousability (SAI) was observed; however, men with PPU as compared with CSubs showed higher sexual arousability for compensatory activities such as pornography use and masturbation on the corresponding SAI subscale (t(46)=3.348; p=.002).

As anticipated, men with PPU as compared with CSubs demonstrated higher scores on the Sex Addiction Screening Test –Revised (t(50)=8.539; p<.001) and Pornography Craving Screening Test

(t(36)=2.998; p=.005) and reported more pornography use (t(50)=3.776; p<.001) and more frequent masturbation (t(50)=5.042; p<.001) during the weeks preceding fMRI.

Behavioral results

A significant interaction between group and incentive type in RTs was observed (F(1,50)=5.112; p=.028). The shortest RTs were observed in men with PPU during erotic trials (Fig. 2a). No differences were observed in hedonic value ratings (Fig. 2c). To examine for potential dissociation between behavioral measures of 'wanting' (RTs) and 'liking' (hedonic ratings), we investigated a three-way interaction between condition (monetary vs erotic), group (CSubs vs PPU) and measure (RT vs hedonic values). This interaction was significant (F(1,50)=5.137; p=.028), showing that despite the behavioral preference (shorter RTs) for erotic trial in the cue phase among PPU subjects when compared to CSubs, both groups do not differ in the reward phase (hedonic ratings). This result indicates dissociation between behavioral measures of 'wanting' (RTs) and 'liking' (hedonic ratings) of erotic stimuli in PPU subjects, but not in CSubs. Interestingly, although overall levels of accuracy in the experimental procedure were largely comparable between men with PPU and CSubs (t(50)=1.627; p=.11), the PPU group demonstrated less accuracy than CSubs on control (non-rewarded) trials (t(50)=2.084; p=.045; Fig. 2b).

Neuroimaging results

Like with RTs, cue-related reactivity of the ventral striatum demonstrated a group x incentive interaction (F(1,50)=6.886; p=.011; Fig 2d). Men with PPU and CSubs differed significantly in reactivity for erotic (t(50)=2.624; p=.011) but not monetary (t(50)=.047; p=.963) cues. During the reward processing phase, no between-group differences were observed (F(1,50)=.061; p=.806). A main effect of incentive type was observed (F(1,50)=44.308; p<.001). Erotic rewards evoked significantly stronger reactivity than monetary rewards. We also examined the three-way interaction between group, incentive type and processing phase (cue vs reward), which was significant (F(1,50)=5.438; p=.024). Despite stronger activations of the ventral striatum for erotic versus

monetary cues in PPU subjects and CSubs in the reward phase, no between-group differences were found in response to erotic cues. This result speaks in favor of a dissociation between neuronal measures of 'wanting' (RTs) and 'liking' (hedonic ratings) of erotic stimuli in PPU subjects, but not in CSubs.

Relationships between behavioral and neuroimaging results and clinical features of PPU

In line with previous work[30,50] , we computed for each subject the differential reactivity to monetary versus erotic cues by subtracting the corresponding striatal BOLD responses. We also calculated a relative-motivation index measured as the difference in mean RTs for monetary and erotic trials. The brain-behavior correlation between these two measures was strongly significant (R=.76; p<.0001, Fig. 3a). Next, we examined how individual differences in ventral striatal reactivity for erotic versus monetary cues related to four measures differentiating both groups (Table 1): severity of CSB symptoms measured with the SAST-R (Rho=.31; p=.01; Fig. 3b), pornography craving measured with the BPS (Rho=.264; p=.055), amount of pornography consumption (Rho=.305; p=.015; Fig. 3c) and number of masturbations per week (Rho=.296; p=.018; Fig. 3d). Bonferroni-Holms correction for multiple comparisons was used.

In the next step, we checked if an analogous index of liking would be related to behavioral measures. For this purpose, we calculated an individual relative-liking index measured as differences in ventral striatal reactivity for erotic and monetary rewards. We related this index to individual differences in ratings of rewards' hedonic values and the same four measures differentiating both groups as above. No correlations were significant.

Discussion

Our results, in line with the IST[27–29], indicate that men seeking treatment for PPU when compared to CSubs show increased ventral striatal reactivity for cues predicting erotic pictures (but not for cues predicting monetary gains). Such increased striatal reactivity for cues predicting erotic content is

followed by higher motivation (reflected in shorter RTs) to view erotic rewards (Figure 2d, 2a and 3a). Consistently with the IST[27,29], these results show increased 'wanting' evoked specifically by an initially neutral cue predictive for erotic rewards. Also as predicted by the IST, both neural (BOLD response) and behavioral (RTs) indicators of 'wanting' were dissociated from measures of 'liking' among PPU, but not in CSubs, and this was reflected in three-way interactions between condition (monetary vs erotic), group (CSubs vs PPU), and experimental phase (cue vs reward). In other words, subjects who seek treatment for PPU expressed higher motivational behavior for pornography cues predictive of erotic content. This motivated behavior ('wanting' - probably related to the expectation of highly rewarding value of pornography) is dissociated form actual 'liking' - PPU subjects did not differ from CSubs in BOLD response for erotic pictures (reward phase) or hedonic values ratings (Figure 2c and 2e). Moreover, for the differential striatal reactivity to erotic versus monetary cues (but not rewards) was related not only to indicators of motivated behaviors during the study (RTs; Figure 3a), but also to severity of CSB (measured with the SAST-R; Figure 3b), as well as to the amount of pornography consumption and frequency of masturbation (Figure 3c and 3d) reported during the 2 months preceding fMRI.

This pattern of increased cue-related 'wanting' dissociated from reward-related 'liking' resembles findings in addictions[2930]. Specific cues (predictive for addiction-related rewards) evoke activations of brain-reward systems associated with striatal responses[27,51–53] and motivation to approach reward, but experienced hedonic value[28,29] or striatal response for reward[53] are not proportional to ones evoked by the preceding cue. It may suggest impaired mechanism of updating cue-related predictions about expected values of erotic stimuli, similar to mechanisms proposed for substance-use disorders[54,55]. Given the role of the ventral striatum in reward anticipation[56], initially neutral stimuli (akin to cues introduced in our experimental procedure) may become for men with PPU powerful incentives influencing motivational values of alternative sources of reward, eventually leading to pornography use. However, longitudinal studies are needed to examine this hypothesis.

Our results show that PPU is related to alterations in motivational processes. Besides increased striatal response for cues predicting erotic rewards and accompanied increase of motivated behavior, men with PPU exhibited also a decrease of motivated behaviors for non-rewarded trials (lower accuracy, fig 2b) when compared to men without PPU. This finding raises questions whether men with PPU may have more generalized impairments of reward processing, in line with a reward deficiency syndrome theory[57], which would predict decreased striatal reactivity and accompanied hedonic values for both types of rewards (erotic and monetary) in the reward phase. Here we show that this is not the case – men with and without PPU do not differ in striatal reactivity and hedonic values either for erotic or monetary rewards. The key difference between these two groups is in striatal reactivity (and accompanied behavioral reactions) in response for cues.

Interestingly, the findings indicate that increased cue-reactivity among men with PPU is not a general dysfunction, but is related to cues predictive of erotic but not monetary rewards. This selective mechanism of increased reactivity for erotic but not monetary cues among men with PPU speaks in favor of theIST[27] rather than more generalize impairments of reward processing proposed in example by theoretical frameworks such as the reward deficiency syndrome[57]. However, it is important to note that we were excluding all subjects with comorbid disorders and/or addiction (approximately 50% of treatment-seeking individuals were excluded for this reason during the initial screening procedure), so our conclusion about a lack of generalized reward processing impairment may not generalize to men with PPU and comorbid disorders. Despite this limitation, the exclusion of individuals with PPU and co-occurring psychiatric disorders permitted for a more focused study on mechanisms underlying PPU and exclude possible effects of psychopathology. Additional limitations include the exclusion of women, and future studies should examine the extent to which the findings extend to women with PPU. Additionally, future studies should examine how neurobiological and clinical measures might relate to treatment outcomes for individuals with PPU.

Conclusions

PPU subjects showed increased activation of the ventral striatum specifically for cues predicting erotic pictures but not for cues predicting monetary gains. In PPU subjects, this brain activation was accompanied by measures suggesting increased behavioral motivation to view erotic images (higher 'wanting'). Ventral striatal reactivity for cues signaling erotic pictures (but not for erotic pictures *per se*) was significantly related to severity of CSB, amount of pornography use per week and frequency of masturbation. The findings suggest similarities between PPU and addictions and an important role for learned cues in PPU. Identifying PPU-related triggers and targeting the dissociation of learned cues from problematic behaviors may be useful in the treatment of PPU. Future studies should examine specific treatments, as well as determine the prevalence and clinical correlates of PPU, and identify predisposing factors for PPU.

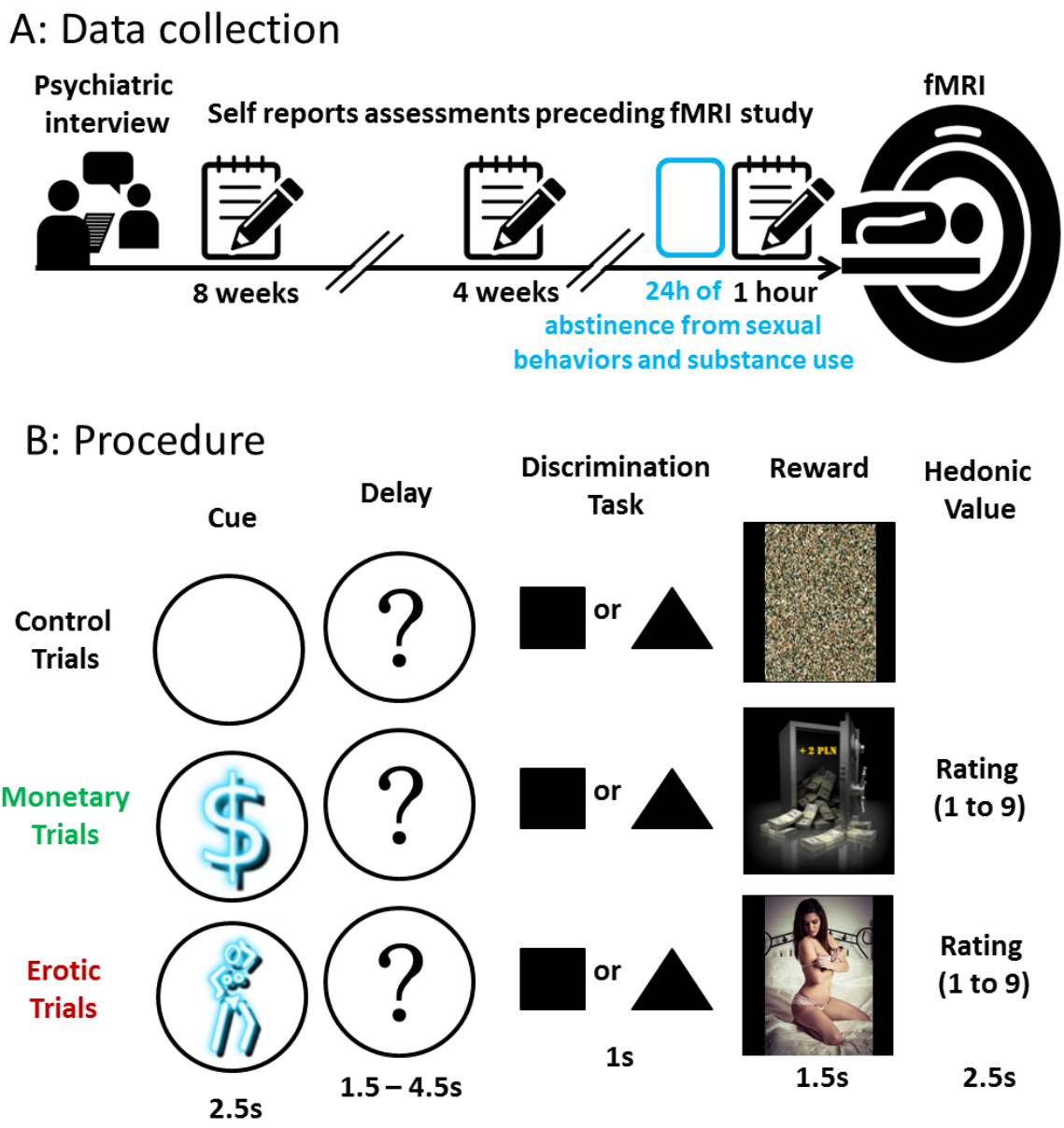

Figure 1. Data collection and experimental procedure. A: After psychiatric assessment, subjects who met study criteria (see Methods) completed questionnaires assessing self-reported sexual behavior and substance use in the weeks preceding fMRI. **B:** Incentive delay task used in the fMRI session. Subjects first saw a cue informing them about the type of an upcoming reward. Then, after the delay period (question mark), participants had to perform a target discrimination task within a maximum time of 1s. The target was either a triangle (left button press required) or a square (right button press required). The subsequent outcome depended on the participants' performance, and reaction times were thus used as an index of their motivation. In rewarded trials, subjects saw a monetary amount displayed on a safe picture (1-8 PLN, approximately: 0.25 - 2 EUR) or an erotic picture, and had to provide a hedonic rating on a continuous scale (1-don't like it : 9-like it very much). After accurate reactions in the discrimination task, rewards were delivered with 50% probability (reward was always relevant with cue). In non-rewarded and control trials, subjects saw a scrambled picture. All monetary gains were paid to the participants at the end of the experiment. Both groups had similar accuracy for monetary and erotic trials (Figure 2b) and obtained similar amounts of monetary wins (CSubs: M=187.41 PLN; SD=22.83, PPU subjects: M=182.14 PLN; SD=20.56) approximating 5.5% of an average monthly salary in Poland. Credits of Sample photo: Lies Thru a Lens, CC BY 2.0. For license terms see: CC BY 2.0 ().

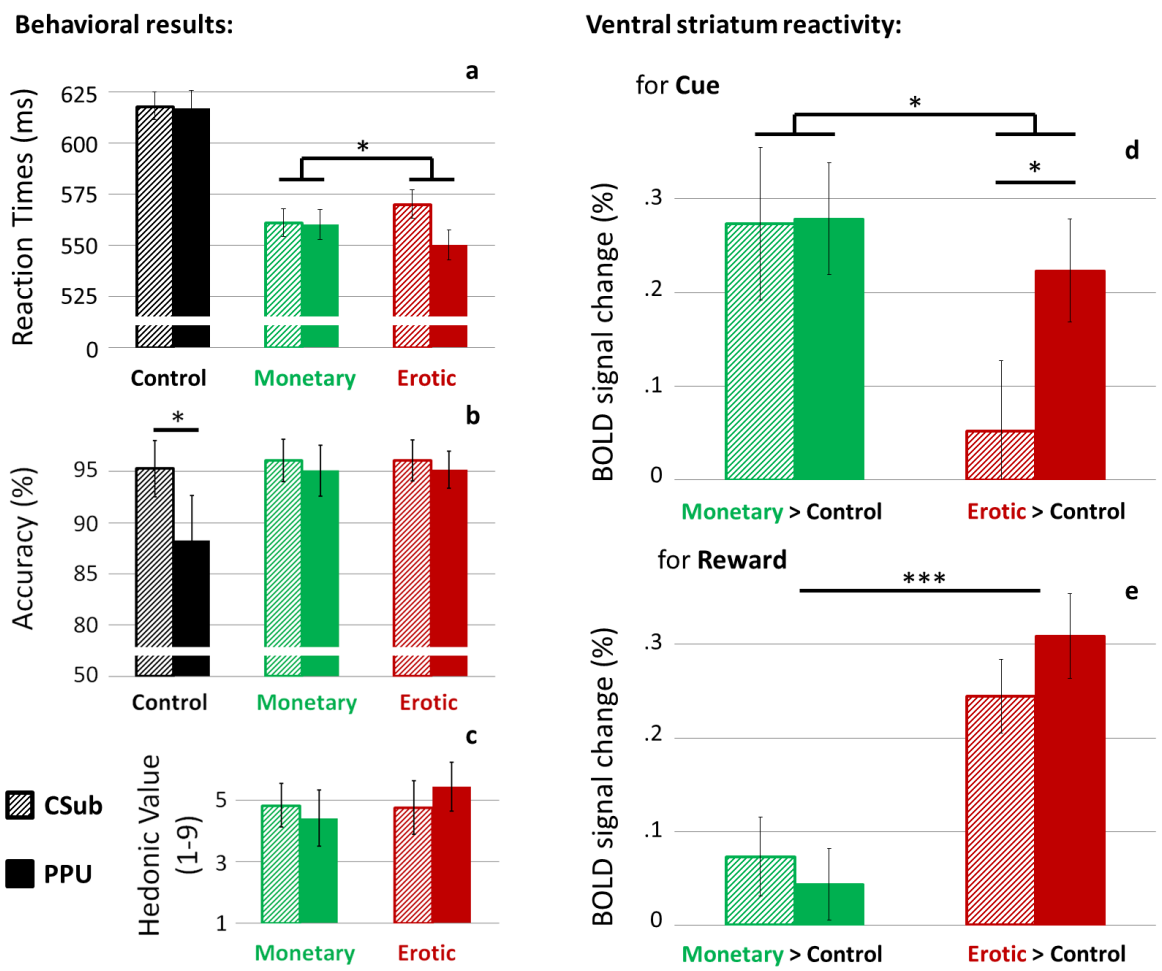

Figure 2. Behavioral and neuroimaging results. **A:** Comparison of RTs in the discrimination task (see Figure 1b). **B:** Comparison of accuracy. **C:** Comparison of hedonic value ratings (see Figure 1b). **D:** Comparison of BOLD signal response in the ventral striatum for cue presentation (BOLD signal averaged across 2 *a priori* defined regions of interests in the left and right brain hemisphere: 8mm spheres centered around: Left: x=-12, y=10 z=-6 Right: x=12, y=10, z=-4). **E:** Comparison of BOLD signal response in the ventral striatum for cue presentation. All post-hoc tests were done with Bonferroni correction for multiple comparisons. Error bars indicates SEM. *p<.05; **p<.01; ***p<.001.

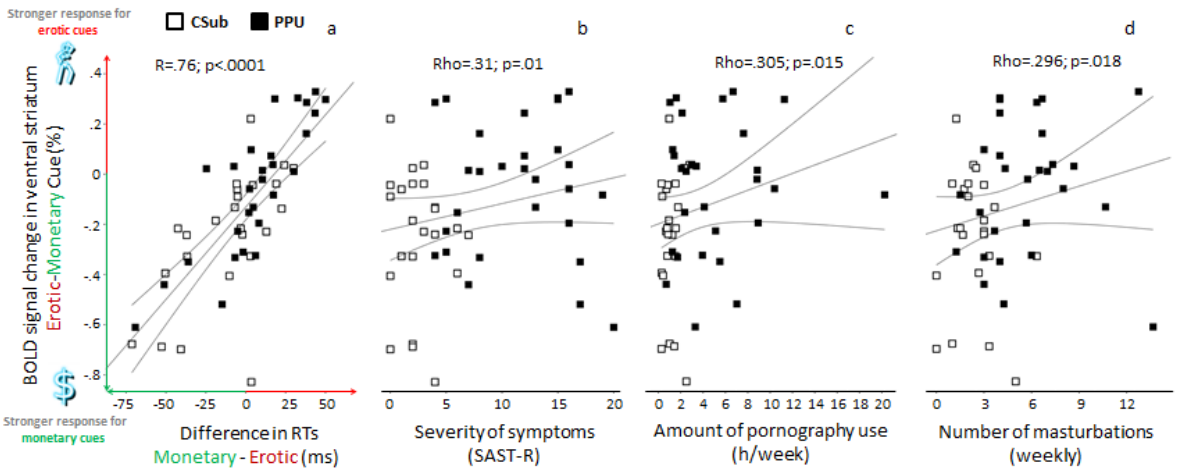

Figure 3. Correlations of ventral striatal cue-reactivity with behavioral and clinical features of PPU. The correlations between differential striatal reactivity to monetary versus erotic cues and **A:** relative-motivation index measured as difference between RTs for monetary - erotic trials; **B:** severity of CSB measured by the Sexual Addictions Screening Test – Revised (20 points scale, which was not used at recruitment phase); **C:** average amount of pornography consumption per week, and **D:** frequency of masturbation per week. Error lines depicts 95% confidence intervals. Bonferroni-Holms correction was used for multiple comparisons.

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