Original Investigation

Brain Structure and Functional Connectivity Associated With Pornography Consumption
The Brain on Porn

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IMPORTANCE Since pornography appeared on the Internet, the accessibility, affordability, and anonymity of consuming visual sexual stimuli have increased and attracted millions of users. Based on the assumption that pornography consumption bears resemblance with reward-seeking behavior, novelty-seeking behavior, and addictive behavior, we hypothesized alterations of the frontostriatal network in frequent users.

OBJECTIVE To determine whether frequent pornography consumption is associated with the frontostriatal network.

DESIGN, SETTING, AND PARTICIPANTS In a study conducted at the Max Planck Institute for Human Development in Berlin, Germany, 64 healthy male adults covering a wide range of pornography consumption reported hours of pornography consumption per week. Pornography consumption was associated with neural structure, task-related activation, and functional resting-state connectivity.

MAIN OUTCOMES AND MEASURES Gray matter volume of the brain was measured by voxel-based morphometry and resting state functional connectivity was measured on 3-T magnetic resonance imaging scans.

RESULTS We found a significant negative association between reported pornography hours per week and gray matter volume in the right caudate ($P < .001$, corrected for multiple comparisons) as well as with functional activity during a sexual cue–reactivity paradigm in the left putamen ($P < .001$). Functional connectivity of the right caudate to the left dorsolateral prefrontal cortex was negatively associated with hours of pornography consumption.

CONCLUSIONS AND RELEVANCE The negative association of self-reported pornography consumption with the right striatum (caudate) volume, left striatum (putamen) activation during cue reactivity, and lower functional connectivity of the right caudate to the left dorsolateral prefrontal cortex could reflect change in neural plasticity as a consequence of an intense stimulation of the reward system, together with a lower top-down modulation of prefrontal cortical areas. Alternatively, it could be a precondition that makes pornography consumption more rewarding.

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Depictions of sexual content in films, music videos, and the Internet have increased in recent years.[1] Because the Internet is not subject to regulations, it has emerged as a vehicle for circulation of pornography. Pornographic images are available for consumption in the privacy of one's home via the Internet rather than in public adult bookstores or movie theaters. Therefore, the accessibility, affordability, and anonymity[2] have attracted a wider audience. Research in the United States has shown that 66% of men and 41% of women consume pornography on a monthly basis.[3] An estimated 50% of all Internet traffic is related to sex.[4] These percentages illustrate that pornography is no longer an issue of minority populations but a mass phenomenon that influences our society. Interestingly, the phenomenon is not restricted to humans; a recent study found that male macaque monkeys gave up juice rewards to watch pictures of female monkeys' bottoms.[5]

The frequency of pornography consumption has been shown to predict various negative outcome measures in humans. A representative Swedish study on adolescent boys has shown that boys with daily consumption showed more interest in deviant and illegal types of pornography and more frequently reported the wish to actualize what was seen in real life.[1,6-8] In partnerships, a decrease in sexual satisfaction and a tendency to adopt pornographic scripts have been associated with frequent Internet pornography consumption.[9] A longitudinal study following Internet users has found that accessing pornography online was predictive of compulsive computer use after 1 year.[10] Taken together, the aforementioned findings support the assumption that pornography has an impact on the behavior and social cognition of its consumers. Therefore, we assume that pornography consumption, even on a nonaddicted level, may have an impact on brain structure and function. However, to our knowledge, the brain correlates associated with frequent pornography consumption have not been investigated so far.

Similar to theories taken from addiction research, it has been speculated in popular science literature that pornography constitutes a prewired, naturally rewarding stimulus and that high levels of exposure result in a downregulation or habituation of the neural response in the reward network. This is assumed to elicit adaptive processes in which the brain is hijacked, becoming less responsive to pornography.[11] There is common agreement that the neural substrates of addiction consist of brain areas that are part of the reward network such as midbrain dopamine neurons, the striatum, and the prefrontal cortex.[12,13] The striatum is assumed to be involved in habit formation when drug use progresses towards compulsive behavior.[14] The ventral striatum in particular has been shown to be involved in cue-reactivity processing of various drugs of abuse[15] but also in processing of novelty.[16] Compromised prefrontal cortex function is among the major neurobiological modifications discussed in the research on substance abuse disorders common in humans and animals.[17] In studies on pharmacological addiction in humans, volumetric alterations have been shown in the striatum and prefrontal cortex.[18-20]

Within the present study, we set out to investigate the neural correlates associated with frequent—not necessarily addictive—pornography use in a healthy population to explore whether this common behavior is associated with the structure and function of certain brain regions.

Methods

Participants

Sixty-four healthy male participants (mean [SD] age, 28.9 [6.62] years, range 21-45 years) were recruited. In the advertisement, our focus on pornography consumption was not mentioned; instead, we addressed healthy participants interested in participating in a scientific study including magnetic resonance imaging (MRI) measurements. We restricted our sample to males because men are exposed to pornography at a younger age, consume more pornography,[21] and are more likely to encounter problems compared with women.[22] According to personal interviews (Mini-International Neuropsychiatric Interview[23]) participants did not have any psychiatric disorders. Other medical and neurological disorders were excluded. Substance use was carefully screened. Exclusion criteria for all individuals were abnormalities in the MRI. The study was approved by the local ethics committee at Charité University Clinic in Berlin, Germany. After complete description of the study, we obtained informed written consent from participants.

Scanning Procedure

Structural images were collected on a 3-T scanner (Siemens) with a 12-channel head coil using a T1-weighted magnetization-prepared gradient-echo sequence (repetition time = 2500 milliseconds; echo time = 4.77 milliseconds; inversion time = 1100 milliseconds, acquisition matrix = 256 × 256 × 176; flip angle = 7°; 1×1×1 mm^3 voxel size).

Functional resting state images were collected using a T2*-weighted echoplanar imaging sequence (repetition time = 2000 milliseconds, echo time = 30 milliseconds, image matrix = 64 × 64, field of view = 216 mm, flip angle = 80°, slice thickness = 3.0 mm, distance factor = 20%, voxel size of 3 × 3 × 3 mm^3, 36 axial slices, 5 minutes). Participants were instructed to close their eyes and relax. The same sequence was used to acquire the task-related images.

Questionnaire

We administered the following questions to assess pornography consumption: "How many hours on average do you spend watching pornographic material during a week day?" and "How many hours on average do you spend watching pornographic material during a day of the weekend?" From this, we computed hours on average spent with pornographic material during the week (pornography hours [PHs]). Because the distribution of the reported PHs was skewed and not normally distributed (Kolmogorov-Smirnov, $Z = 1.54$; $P < .05$), we transformed the variable by means of square root (Kolmogorov-Smirnov, $Z = 0.77$; $P = .59$). In addition to their current consumption, we also asked participants how many years they had consumed pornography.

Furthermore, we used the Internet Sex Screening Test[24] (in its German translation), a 25-item self-rating instrument designed to assess an individual's sexual use of the Internet, and

a short version of the Sexual Addiction Screening Test[25] (in its German translation) designed to assess symptoms of sexual addiction. To control for effects of Internet addiction, we used the Internet Addiction Test[26] (in its German version; see also the study by Barke et al[27]) consisting of 20 items. Moreover, to assess markers of psychiatric disease, namely substance use and depressivity, we administered the Alcohol Use Disorder Identification Test[28] and Beck Depression Inventory.[29]

Cue-Reactivity Task

We used 60 explicit sexual images from pornography websites and 60 nonsexual images, matched to the number and sex of individuals in the sexual images, during nonsexual activities, namely physical exercise. The images were presented in 6 blocks with 10 images each for the sexual and nonsexual conditions. Each image was shown for 530 milliseconds to avoid detailed inspection of the picture content. Intertrial intervals varied in steps of 500 milliseconds between 5 and 6.5 seconds. Blocks were interspersed with eight 60-second fixation periods.

Data Analysis

Voxel-Based Morphometry

Structural data were processed with voxel-based morphometry (VBM8, http://dbm.neuro.uni-jena.de/vbm.html) and statistical parametric mapping (SPM8, http://www.fil.ion.ucl.ac.uk/spm) using default parameters. Bias correction, tissue classification, and affine registration are involved in VBM8. The affine-registered gray matter (GM) and white matter (WM) segmentations were used to build a customized diffeomorphic anatomical registration through an exponentiated lie algebra template. Warped GM and WM segments were created. Modulation with Jacobian determinants was applied to preserve the volume of a particular tissue within a voxel leading to a measure of GM volume. Images were smoothed with a full-width at half maximum kernel of 8 mm. Whole-brain correlation of GM and WM volume and reported PHs was computed. Age and whole-brain volume were entered as covariates of no interest. The resulting maps were thresholded with $P < .001$ and statistical extent threshold was used to correct for multiple comparisons combined with a nonstationary smoothness correction based on permutation.[30]

Cue-Reactivity Functional MRI Analysis

Preprocessing of the functional MRI data was performed using SPM8 and comprised slice-timing correction, spatial realignment to the first volume, and nonlinear warping to Montreal Neurological Institute space. Images were then smoothed with a Gaussian kernel of 8 mm full-width at half maximum. Each block (sexual, nonsexual, and fixation) was modeled and convolved with a hemodynamic response function. Movement parameters were included in the design matrix. We were interested in the contrast comparing sexual cues against fixation and the nonsexual control condition. We performed a second-level analysis correlating PHs with the contrast sexual cue vs fixation. A height threshold of $P < .001$ was used and a cluster-size correction by Monte Carlo simulation. The resulting maps were thresholded as just described (cluster extend threshold = 24).

Mediation Analysis

To investigate the relationship between structural and functional task-related findings, signals from the significant clusters in the main analysis were incorporated into a confirmatory mediation analysis, testing whether the covariance between 2 variables (X and Y) could be explained by a third mediating variable (M). A significant mediator is one whose inclusion significantly affects the association between X and Y. We tested whether the effect of the source variable GM volume in the right striatum onto pornography consumption, the outcome variable, was mediated by the functional activation of the left striatum during sex-cue presentation. The analysis was carried out using a MATLAB code (http://wagerlab.colorado.edu/) based on a 3-variable path model with an accelerated bias-corrected bootstrap test of statistical significance. The following paths were tested: the direct path a (source mediator); indirect path b (mediator outcome); and mediation effect ab, the product of a and b, defined as the reduction of the relationship between source and outcome (total relationship, c) by including the mediator into the model (direct path, c').

Functional-Connectivity Analysis

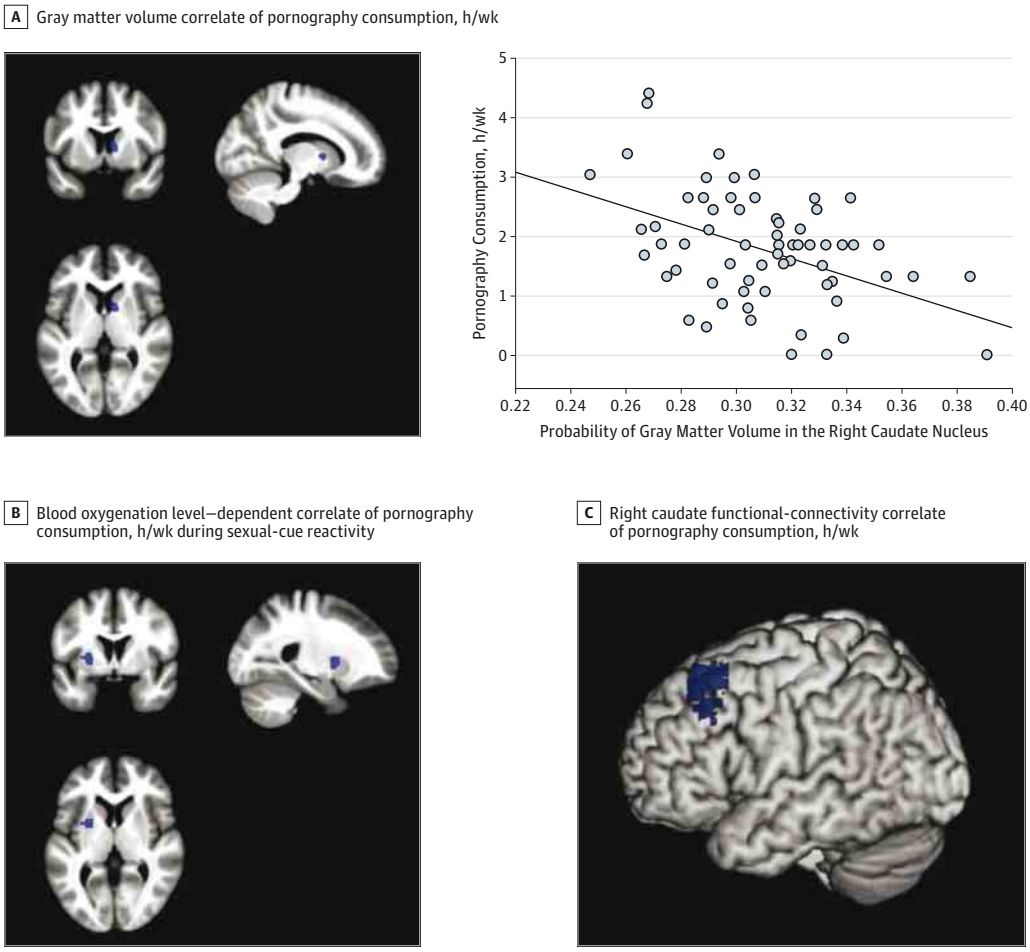
The first 5 volumes were discarded. Data preprocessing, including slice timing, head-motion correction, and spatial normalization to the Montreal Neurological Institute template were conducted using SPM8 and the Data Processing Assistant for Resting-State functional MRI.[31] A spatial filter of 4 mm full-width at half maximum was used. Linear trends were removed after preprocessing and a temporal band-pass filter (0.01-0.08 Hz) was used.[32] Moreover, we removed effects of the nuisance covariates including global mean signal, 6 motion parameters, signal from cerebrospinal fluid, and WM.[33] We conducted an exploratory analysis computing functional connectivity maps with a seed region consisting of the cluster in caudate. Resulting functional-connectivity maps were correlated with the PHs to identify brain regions that were jointly activated with right caudate weighed according to pornography consumption. The maps were thresholded as previously described (cluster extend threshold = 39).

Results

On average, participants reported 4.09 PHs (SD, 3.9; range, 0-19.5; not square rooted). According to the criteria of the Internet Sex Screening Test, 21 participants were classified as at risk of Internet sex addiction but not as addicted. The overall Internet Sex Screening Test score was positively correlated with the reported PHs ($r_{64} = 0.389$, $P < .01$). On the Sexual Addiction Screening Test, participants scored 1.35 on average (SD, 2.03). A positive correlation was observed between PHs and Alcohol Use Disorder Identification Test score ($r_{64} = 0.250$, $P < .05$) and Beck Depression Inventory score ($r_{64} = 0.295$, $P < .05$).

When correlating PHs (square root) with GM segmentations, we found a significant negative association in the right striatum, namely caudate nucleus (based on the automated

Figure 1. Brain Regions and Pornography Consumption



A, Brain region showing a significant negative correlation (r_{64} = −0.432, P < .001) between hours of pornography consumption per week (square rooted) and gray matter volume (Montreal Neurological Institute coordinates: x = 11, y = 5, z = 3) and the scatterplot illustrating the correlation. B, Negative correlation between hours of pornography consumption per week and blood oxygenation level–dependent signal during sexual cue–reactivity paradigm (sex cue > fixation) (Montreal Neurological Institute coordinates: x = −24, y = 2, z = 4). C, Negative correlation between hours of pornography consumption per week and functional-connectivity map of the right striatum in the left dorsolateral prefrontal cortex.

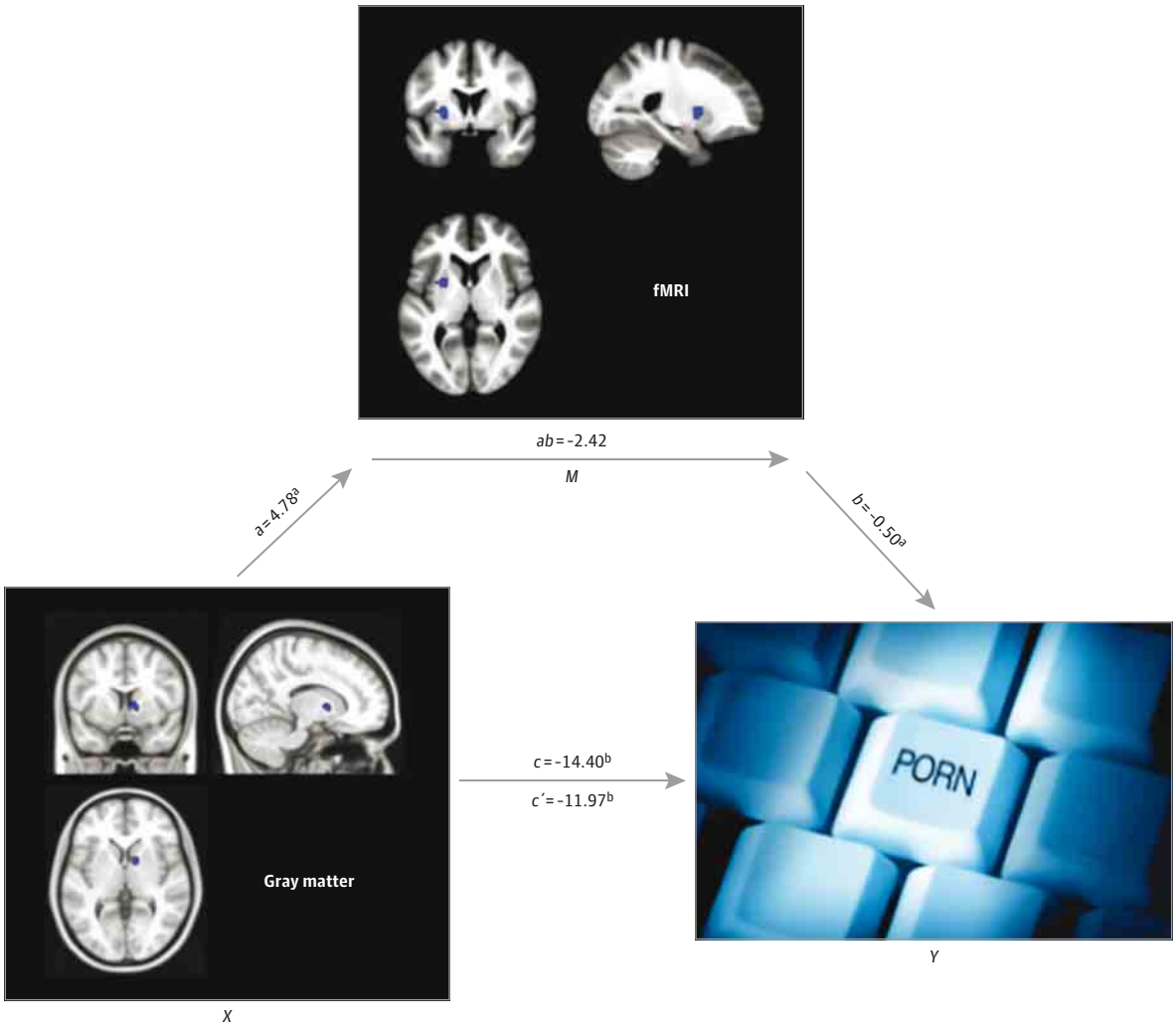
anatomical labeling atlas[34]; peak voxel: x = 11, y = 5, z = 3; P < .001; corrected for multiple comparisons) (**Figure 1**A). When we used a lower threshold of P < .005, an additional cluster in the left caudate reached significance (x = −6, y = 0, z = 6), showing that the effect is not clearly lateralized. We refer to the cluster as the striatum; however, for the subsequent discussion, it is noteworthy that the cluster overlaps with a reward processing literature-based probabilistic region of interest of the ventral striatum, created by means of in-house software[35] (predominantly monetary-incentive delay task, see eAppendix in Supplement for details).

The GM values extracted from the cluster in the right caudate were negatively associated with the cumulative pornography consumption, computed based on the currently reported PHs and the estimate of years the pornography use had been at the same extent (r_{64} = −0.329, P < .01); this confirmed that acute consumption and the accumulated amount over the lifetime were associated with lower GM values in the striatum. No region showed a significant positive correlation between GM volume and PHs and no significant correlations were found in WM.

Because PHs were positively correlated with the Internet addiction and sex addiction scores (Internet Adddiction Test, r_{64} = 0.489, P < .001; Sexual Addiction Screening Test, r_{64} = 0.352, P < .01) we computed a correlation between PHs (square root) and GM in the right caudate while controlling for Internet Addiction Test scores and Sexual Addiction Test scores to exclude the influence of confounding factors of frequent Internet use and sex addiction. Even when controlling for Internet addiction, we found a negative association between PHs and the right caudate GM volume (r_{61} = −0.336, P < .01); similarly, the association was still significant when controlling for sex addiction (r_{61} = −0.364, P < .01).

In a cue-reactivity paradigm in which we presented explicit sexual pictures collected on pornography websites, we found a negative association between the left putamen blood

Figure 2. Mediation Analysis



The negative association between gray matter (*X*) in the right striatum identified in the voxel-based morphometry analysis and pornography consumption (*Y*) is not strongly mediated by the functional task-related activity in the left striatum (*M*), showing that structural, as well as functional, effects contribute independently to the prediction of pornography consumption. *a*, *b*, *ab*, and *c*/*c*′ indicate path coefficients.
[a]*P* < .05.
[b]*P* < .001.

oxygenation level-dependent (BOLD) signal (peak voxel: $x = -24, y = 2, z = 4$; putamen) (Figure 1B) in the contrast sexual cue vs fixation and self-reported PHs. When using a lower threshold of $P < .005$, an additional cluster in the right putamen reached significance ($x = 25$, $y = -2$, $z = 10$). No significant clusters were observed when correlating PHs with signal of the contrast nonsexual cue vs fixation using the same threshold. When extracting percentage signal changes in the left putamen cluster during the sexual cue and the nonsexual cue blocks, we found significantly higher activity during sexual cues compared with nonsexual cues ($t_{63} = 2.82$, $P < .01$), suggesting that the left putamen is specifically activated by sexual image content. Moreover, we found a significant difference between sexual cues and fixation ($t_{63} = 4.07$, $P < .001$) and no difference between nonsexual cues and fixation ($t_{63} = 1.30$, $P = .20$).

To disentangle the relationship between the task-related BOLD finding and the structural finding in the striatum, we conducted a mediation analysis testing whether the functional finding mediates the assumedly causal association between the structural finding and pornography consumption. The association between GM in the right caudate (*X*) and PHs (*Y*) is significant whether the mediator consisting of task-related BOLD activation in the left putamen (*M*) is included ($c' = -11.97$, $P < .001$) in the analysis or not ($c = -14.40$, $P < .001$). The path coefficient between *X* and *M* ($a = 4.78$, $P < .05$) as well as between *M* and *Y* ($b = -0.50$, $P < .05$) are significant (**Figure 2**).

To investigate brain regions functionally associated with the region in the right caudate of the striatum related to PHs, we computed functional connectivity of this cluster. The resulting connectivity maps were correlated with the PHs (square

root). We found that a region within the left dorsolateral prefrontal cortex (DLPFC) (x = −36, y = 33, z = 48) (Figure 1C) was negatively associated with PHs, implicating that participants who consumed more pornographic material had less connectivity between the right caudate and left DLPFC. The results did not change when the global mean signal was not regressed out.[36]

Discussion

Within the scope of the present study, we investigated structural and functional neural correlates associated with self-reported PHs in men. Our findings indicated that GM volume of the right caudate of the striatum is smaller with higher pornography use. Furthermore, task-related functional activation of the left putamen of the striatum was found to be lower with higher PHs when sexually explicit material was presented. Signal change during pornography cues was higher than during matched nonsexual cues, indicating that the left putamen is involved in processing sexual content. We conducted a mediation analysis to disentangle the relationship between PHs and the structural finding of GM volume decrease in the right striatum (caudate) as well as the BOLD decrease in the left striatum (putamen) with higher PHs while viewing sexually explicit material. In light of the very limited mediation effect, we regard the functional and structural effects as separable explanatory factors of pornography consumption. Lastly, we explored functional connectivity from the structural cluster in right caudate and found that connectivity to the left DLPFC was lower with more PHs.

A vast array of research implicates the importance of the striatum in reward processing.[37,38] Neurons in the nonhuman primate striatum have been shown to respond to the delivery[39] and anticipation[40] of reward. Striatal neurons code reward magnitude and incentive salience, as well as fire more vigorously for preferred rewards.[41] The observed GM cluster in the striatum we found is within the range of locations that have been shown in reward processing.

Our results of the sexual cue–reactivity paradigm show a negative correlation between PHs and the left putamen activation during sex cues compared with fixation. This is in line with the hypothesis that intense exposure to pornographic stimuli results in a downregulation of the natural neural response to sexual stimuli.[11] An involvement of the striatum in sexual arousal has previously been demonstrated in the literature. Several studies exploring cue reactivity in response to sexual stimuli and sexual arousal have reported enhanced activity in the striatum compared with control stimuli.[42-46] Two recent meta-analyses that included studies presenting sexual stimuli showed consistent involvement of the striatum.[47,48]

The observed results of the functional-connectivity analysis are in line with the anatomical organization of the brain. The caudate nucleus, in particular its lateral aspect, receives connections from the DLPFC.[49,50] The prefrontal cortex has mostly been implicated in cognitive control[51] as well as in response inhibition, behavioral flexibility, attention, and future planning. The DLPFC, in particular, is interconnected well with other parts of the prefrontal cortex and represents many types of information, reaching from object information to response and reward outcomes as well as action strategies.[51] Therefore, the DLPFC is considered a key area for the integration of sensory information with behavioral intentions, rules, and rewards. This information integration is thought to result in the facilitation of the most relevant action by exerting cognitive control over motor behavior.[52] It has been proposed that the frontostriatal network is involved in this behavior. The afferent connections from the basal ganglia convey information regarding valence and saliency to the prefrontal cortex that houses the internal representation of goals and the means to achieve them.[51,53] Dysfunction of this circuitry has been related to inappropriate behavioral choices, such as drug seeking, regardless of the potential negative outcome.[54]

The brain regions found in the present investigation are associated with relatively frequent, but not by definition, addictive pornography consumption. The striatum and DLPFC correspond to brain regions implicated in Internet addiction by past investigations. Previous studies on Internet addiction have reported decreases in prefrontal cortical thickness;[55] decreases in functional,[56] as well as structural, connectivity[57] of the frontostriatal network; and decreased striatal dopamine transporter levels in the striatum measured with single photon emission–computed tomography. This fits well with the present findings of a negative correlation of GM in the right caudate, in particular to the lower functional connectivity between the right caudate and lateral prefrontal cortex, and a reduction of task-related BOLD activity in left putamen. The present results clearly showed that the observed structural correlates associated with moderate pornography consumption are not a mere byproduct of an accompanying Internet addiction because the partial correlation of GM volume in the right caudate and PHs, while controlling for the influence of Internet addiction, is significant.

On the other hand, volumetric differences in the striatum have previously been associated with addiction to all kinds of pharmacological drugs such as cocaine,[58] metamphetamine, and alcohol.[59] However, the direction of the reported effects in pharmacological drugs is less unequivocal; some studies have reported addiction-associated increases while others have reported reductions of the striatal volume that could be owing to neurotoxic effects of drugs of abuse.[59] If the striatal effects observed in the current study are indeed a consequence of pornography consumption, its study might present an interesting opportunity to explore structural changes in addiction in the absence of neurotoxic substances for future studies, similar to gambling behavior[60] or video gaming.[61,62] Future research is needed to disentangle the causal relationship between the observed functional and structural effects and pornography consumption.

We chose to refrain from diagnostic categories or normative assumptions and instead investigated the pure dosage effects of PHs in a healthy sample. At the current state of research, normative statements are not warranted because a clinical definition of pornography addiction has not been unequivocally agreed on so far. The positive association be-

tween PHs and depressivity, as well as alcohol use, suggests that pornography consumption should be explored further in the context of psychiatric research. Future investigations should compare groups of individuals diagnosed as having pornography addiction with individuals who are not addicted to identify whether the same brain regions are involved. We anticipate this line of research will yield valuable insights into the question of whether pornography addiction is on a continuum with normal pornography use or should be treated as a distinct category.

A potential limitation of the study was that we had to rely on self-reported PHs and that the topic may have been sensitive for some participants. However, during a telephone interview before participation, individuals were told that participation would encompass filling in questionnaires related to sexual behavior and pornography use and we had no dropouts at this stage. As a precaution against underreporting, we had participants fill in the questionnaire on a computer to prevent the potential worry that the experimenter might link the answers to the individual. Furthermore, the experimenters repeatedly stressed the confidentiality and anonymization procedures used. Future studies may consider using objective data from the individuals' search history on the Internet.

The striatal cluster reported does not only contain GM but extends into adjacent WM between the caudate and putamen. Whether this is meaningful or a problem of normalization cannot be solved at the current stage. However, it may be interesting to explore the associations between diffusion tensor imaging and pornography use.

Conclusions

Taken together, one may be tempted to assume that the frequent brain activation caused by pornography exposure might lead to wearing and downregulation of the underlying brain structure, as well as function, and a higher need for external stimulation of the reward system and a tendency to search for novel and more extreme sexual material. This hypothesized self-perpetuating process could be interpreted in light of proposed mechanisms in drug addiction where individuals with lower striatal dopamine receptor availability are assumed to medicate themselves with drugs.[63] However, the observed volumetric association with PHs in the striatum could likewise be a precondition rather than a consequence of frequent pornography consumption. Individuals with lower striatum volume may need more external stimulation to experience pleasure and might therefore experience pornography consumption as more rewarding, which may in turn lead to higher PHs. Future studies should investigate the effects of pornography longitudinally or expose naïve participants to pornography and investigate the causal effects over time to provide further evidence for the proposed mechanism of intense exposure to pornographic stimuli, resulting in a downregulation of the reward system.

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Acquisition, analysis, or interpretation of data: Both authors.
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Statistical analysis: Kühn.
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