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Striato-limbic and frontoparietal dysfunction underlying imbalance of reward-motivation and cognitive control in compulsive sexual behaviour disorder: A neuroimaging meta-analysis

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META-ANALYSIS

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ABSTRACT

Background: Compulsive sexual behavior disorder (CSBD) involves uncontrollable sexual urges and behaviors that cause distress or functional impairment. Although classified as an impulse control disorder in ICD-11, its neurobiological basis and cognitive deficits remain poorly understood. Advances in large language models (LLMs) enable scalable literature parsing and multimodal neuroimaging synthesis. This study applied an LLM-based framework for coordinate-based meta-analysis and functional decoding to generate a brain–cognition mapping of CSBD that links neurobiological alterations with cognitive dysfunctions. *Methods:* Relevant structural and functional neuroimaging studies of CSBD were identified through semantic screening in Neurosynth Compose. Coordinates were extracted and synthesized using Multi-level Kernel Density Analysis (MKDA-χ^2), with subgroup analyses conducted by study characteristics. The resulting brain maps were then functionally annotated in NeuroVault to identify associated cognitive, emotional, motivational, and behavioral dimensions. *Results:* Meta-analysis revealed consistent abnormalities in the left hippocampus, inferior parietal lobule, precentral gyrus, putamen, and angular gyrus, and in the right globus pallidus and supramarginal gyrus. Task-based studies mainly implicated the inferior parietal lobule, hippocampus, and globus pallidus, whereas resting-state studies indicated cerebellar involvement. In European samples, abnormalities appeared in the globus pallidus, precentral gyrus, and hippocampus, while East Asian samples showed alterations in the inferior parietal lobule and precuneus. Functional decoding linked these patterns to motivational delay, anxiety, social interaction, and response inhibition. *Conclusion:* CSBD may reflect a dual dysregulation mechanism involving hyperactivation of the striato-limbic reward–motivation circuitry and impaired top–down control within the frontoparietal network, together promoting persistent and compulsive sexual behaviors.

KEYWORDS

compulsive sexual behavior disorder, behavioral addiction, large language model, neuroimaging meta-analysis, cognitive decoding

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BACKGROUND

Compulsive sexual behavior disorder (CSBD) is characterized by persistent, uncontrollable sexual urges and repetitive behaviors that lead to marked distress or functional impairment. With the inclusion of CSBD as an impulse control disorder in the International Classification of Diseases, 11th Revision (ICD-11; World Health Organization, 2022), increasing attention has been directed toward its nosological status and clinical relevance (Gola et al., 2022). Epidemiological studies suggest that CSBD affects approximately 3–6% of the general population (Walton, Cantor, Bhullar, & Lykins, 2017). Those affected are typically younger, male, and exhibit heightened sexual sensation-seeking behaviour and more depressive and anxious symptoms (Castro-Calvo, Gil-Llario, Giménez-García, Gil-Juliá, & Ballester-Arnal, 2020). From a clinical perspective, CSBD is often accompanied by impaired interpersonal relationships, a diminished quality of life, and comorbid conditions such as mood disorders, substance use disorders, and other behavioral addictions (Draps, Sescousse, et al., 2021; Fuss, Briken, Stein, & Lochner, 2019; Golder et al., 2024; Rahm-Knigge, Gleason, Mark, & Coleman, 2023). Despite growing recognition, the pathophysiology of CSBD is still unclear, which hinders the development of effective diagnostic markers and treatments.

Conceptually, the clinical phenotype of CSBD can be framed around recurrent failures to regulate sexual urges and behaviors, which implicates several psychological domains that are central to impulse-control and addiction-related models. First, impaired impulse control and executive regulation may manifest as difficulty inhibiting prepotent urges and maintaining goal-directed behavior despite negative consequences (Efrati, Shukron, & Epstein, 2019, 2021; Müller & Antons, 2023). Second, altered reward processing may bias behavior toward immediate, sexually salient rewards, including heightened cue reactivity, craving, and incentive salience (Liberg et al., 2022). Third, cognitive-control processes such as attentional allocation and working-memory–supported self-regulation may contribute to the persistence of repetitive behaviors, particularly in the presence of salient cues (Draps et al., 2024; Niazof, Weizman, & Weinstein, 2019). Finally, emotion regulation is clinically relevant because sexual behavior may be used as a maladaptive strategy to modulate negative affect or stress, thereby strengthening repetition via negative reinforcement (Kowalewska, Kraus, Lew-Starowicz, Gustavsson, & Gola, 2019; Rahm-Knigge et al., 2023). While the empirical support for each domain varies across studies and samples, these domains provide a clinically meaningful framework for interpreting neuroimaging findings and motivate a cross-study synthesis of CSBD-related brain alterations.

Existing neuroimaging studies of CSBD have reported abnormalities in neural circuits related to impulse control, reward processing, cognitive regulation, and emotion-related processes. Research has suggested that the prefrontal-striatal circuit, which plays a crucial role in impulse control and reward processing, may be associated with CSBD symptoms, with dysfunction in this circuit proposed as a putative mechanism of the disorder (Draps et al., 2020; Golec, Draps, Stark, Pluta, & Gola, 2021; Puszcz, Górski, & Pierudzka, 2025). Additionally, abnormalities in the hippocampus and parietal regions, which are associated with memory and cognitive control, may relate to deficits in impulse inhibition and emotion regulation (Prantner et al., 2024; Seok & Sohn, 2018a). Furthermore, dysfunction in the cerebellum and limbic system has been implicated in emotional-regulation difficulties, particularly in emotional responses and behavior control (Engel et al., 2023; Puszcz et al., 2025). Task-based and resting-state studies have further suggested associations between CSBD and specific brain networks, such as the default mode and executive control networks (Adamus, Bielski, Szatkowska, Gola, & Draps, 2025). Taken together, available findings tentatively point to multi-system involvement, but the consistency and specificity of reported alterations remain uncertain due to methodological variability (e.g., task paradigms, thresholds, and correction strategies).

Despite these findings, there is currently no systematic meta-analysis that integrates the neuroimaging data on CSBD. Although some studies have explored the brain regions and neural circuits associated with CSBD, these studies often have small sample sizes and significant methodological differences, particularly between task-based and resting-state neuroimaging approaches, making reliable comparisons difficult. Furthermore, previous research on cognitive and emotional dimensions has largely relied on subjective interpretations by researchers, lacking objective functional decoding methods (Poldrack, 2006; Poldrack & Yarkoni, 2016). These issues have limited our deep understanding of the neurobiological mechanisms of CSBD and hindered the identification of potential intervention targets. Therefore, there is an urgent need for a more systematic and objective approach to address these knowledge gaps and provide a solid foundation for future research.

To better understand the neurobiological mechanisms of CSBD, we adopt a novel approach by combining coordinate-based meta-analysis (MKDA-χ^2) with functional decoding. Although MRI-based meta-analyses are common in other fields of neuroimaging (Janouschek, Eickhoff, Mühleisen, Eickhoff, & Nickl-Jockschat, 2018; Samea et al., 2019), no such systematic review of this kind has yet been conducted for CSBD. MKDA-χ^2 allowed us to integrate neuroimaging data across multiple studies, generating a more reliable and objective map of CSBD-related brain abnormalities (Fox, Lancaster, Laird, & Eickhoff, 2014; Jardri, Pouchet, Pins, & Thomas, 2011; Zhang, Geng, & Lee, 2017). This method allows for the synthesis of findings from heterogeneous studies, and addresses the limitations of small sample sizes and methodological inconsistencies. Furthermore, as neuroimaging features are closely linked to cognition and behaviour (Feng et al., 2023, 2024), we employed functional decoding tools such as NeuroVault to link the identified brain regions with particular cognitive, emotional and behavioural traits. This approach provides an objective,

data-driven interpretation of the neurobiological mechanisms underlying CSBD (Gorgolewski et al., 2016; Harper et al., 2017; Menuet, Meudec, Dockès, Varoquaux, & Thirion, 2022). This approach offers a comprehensive, systematic framework for understanding the disorder and addressing the limitations of previous subjective interpretations.

In this study, we performed a coordinate-based meta-analysis (MKDA-χ^2) to integrate structural and functional neuroimaging data from existing CSBD studies, creating a comprehensive map of brain abnormalities associated with the disorder. We then compared task-based and resting-state findings and explored differences across populations (European vs. East Asian). Next, we uploaded the pooled abnormality map to NeuroVault for functional decoding and summarized the top correlated cognitive, emotional, motivational, and behavioral terms. Ultimately, our goal is to provide a more systematic and comprehensive understanding of the neurobiological mechanisms of CSBD, offering insights into its pathological mechanisms and to identify candidate targets and hypotheses for future intervention research.

METHODS

Literature search and study selection

This meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines and was prospectively registered in PROSPERO (registration ID: CRD420251071407). Relevant structural and functional neuroimaging studies were identified using Neurosynth Compose (https://neurosynth.org/compose/), an advanced platform that integrates a large corpus of brain imaging literature with automated tools for coordinate-based meta-analysis. To ensure comprehensive and precise retrieval, automated semantic and keyword-based searches were combined with manual screening and verification of eligible studies. The platform enables integrated workflows for semantic screening, coordinate extraction, and meta-analytic modeling, allowing efficient identification and synthesis of neuroimaging findings across studies related to compulsive sexual behavior disorder (CSBD). The detailed study protocol has been published as a preprint on medRxiv (Feng & Wei, 2025).

The literature search was initiated using the Neurosynth Compose platform, utilizing a comprehensive set of terms related to compulsive sexual behavior and pornography use ("compulsive sexual behavior," "compulsive sexual behavior disorder," "CSBD," "sex addiction," "pornography addiction," "problematic pornography use," "porn use disorder," "cybersex addiction," "hypersexuality," "sexual compulsivity," "sexual impulsivity," "sexual craving," "sexual cue reactivity," "excessive sexual behavior," "problematic online sexual behavior," "sexual dysregulation," "sexual obsession," "online sex addiction," "erotic stimuli," "sexual stimuli," and "sexual arousal.") for studies published up to June 2024. To ensure exhaustive retrieval, this automated search was supplemented by a systematic manual search across major electronic databases, including PubMed, Web of Science, and PsycINFO. All studies identified through these additional channels that met the inclusion criteria but were absent from the initial Neurosynth dataset were manually incorporated, with their relevant statistical maps and metadata extracted. The combined dataset was then used for the final meta-analysis, employing both automated and manual verification to maximize coverage and accuracy.

Neurosynth Compose was used to identify relevant studies indexed in the Neurosynth database that reported stereotactic coordinates (in MNI or Talairach space) of brain activations or structural alterations associated with CSBD or problematic pornography use (PPU). All identified records were manually screened to ensure they met the eligibility criteria and to remove duplicates. Only peer-reviewed articles published in English were included. Additionally, the reference lists of the included papers and relevant reviews were manually examined to identify any further eligible studies.

Study selection

All search results retrieved from the Neurosynth Compose platform were processed according to its built-in PRISMA-based workflow. The platform provides structured steps for de-duplication, title and abstract screening, and full-text selection, consistent with PRISMA 2020 guidelines. Two reviewers independently screened all titles and abstracts, and full texts of potentially relevant articles were examined to confirm eligibility based on predefined inclusion and exclusion criteria. Discrepancies were resolved through discussion or by consultation with a third reviewer. The selection process followed the PRISMA 2020 workflow embedded in Neurosynth Compose, which provides structured steps for de-duplication, screening, and eligibility assessment. The numbers of included and excluded records were documented at each stage following the platform's workflow, and a PRISMA 2020 flow diagram was later created to illustrate the study selection process. A total of 77 records were screened. Of these, 58 were excluded for reasons such as being non-neuroimaging studies, lacking standardized coordinate data, being reviews or case reports, involving pediatric samples, or not directly examining CSBD. This left 19 full-text reports for eligibility assessment, of which 14 met all criteria and were included in the final meta-analysis (Seok & Sohn, 2015, 2018a, 2018b, 2020; Banca et al., 2016; Draps et al., 2024; Draps, Kowalczyk-Grębska, Marchewka, Shi, & Gola, 2021; Engel et al., 2023; Gola et al., 2017; Golec et al., 2021; Schmidt et al., 2017; Sinke et al., 2020; Wojciechowski et al., 2025). Detailed study characteristics are presented in Table 1.

Inclusion criteria. (1) Participants were adults (aged 18 years or older) diagnosed with CSBD, PPU, hypersexuality, or self-reported sexual behavior addiction. (2) Alternatively, studies enrolled individuals who scored above validated thresholds on standardized measures of compulsive sexual

Table 1. Characteristics of neuroimaging studies on compulsive sexual behavior disorder (CSBD) included in the meta-analysis

Study (Author, Year)	Country	Diagnosis term	Participants (CSBD/Control)	Age mean (SD)	Sex	SO	Imaging modality	Analysis type	Correction method	Threshold
Seok et al. (2015)	South Korea	PHB	23/22	26.12 (4.11)/ 26.27 (3.99)	M only	Het only	Task-based fMRI (Passive Viewing)	Task activation	Cluster-level FDR	$p < 0.001$ (voxel-wise) and $p < 0.05$ (cluster-level FDR)
Banca et al. (2016)	United Kingdom	CSB	22/40	25.14 (4.68)/ 25.20 (6.62)	M only	Het only	Task-based fMRI (Conditioning & Extinction)	Task activation/ seed-based FC	Cluster-level FWE	$p < 0.05$ (cluster-level FWE)
Gola et al. (2017)	Poland	PPU	28/24	30.96 (6.51)/ 30.49 (7.55)	M only	Het only	Task-based fMRI (Incentive Delay Task)	Task activation	Uncorrected	$p < 0.001$ (voxel-wise) and cluster size ≥49 voxels
Schmidt et al. (2017)	United Kingdom	CSB	23/69	26.9 (6.22)/ 25.6 (6.55)	M only	Het only	Structural MRI/Resting-state fMRI	VBM/ICA	Uncorrected	voxel-wise $p < 0.005$
Seok et al. (2018a)	South Korea	PHB	23/22	26.1 (4.1)/26.3 (3.4)	M only	Not reported	Task-based fMRI (Stroop Task)	Task activation	Voxel-wise FDR	$p < 0.05$ (voxel-wise FDR)
Seok et al. (2018b)	South Korea	PHB	17/19	26.92 (4.73)/ 25.08 (3.53)	M only	Het only	Structural MRI/Resting-state fMRI	VBM/seed-based FC	Voxel-wise FDR	$p < 0.05$ (voxel-wise FDR)
Draps et al. (2020)	Poland	CSBD	26/25	34.0 (4.29)/ 34.5 (6.25)	M only	Het only	Structural MRI	VBM	Uncorrected	voxel-wise $p < 0.001$
Sinke et al. (2020)	Germany	CSB	44/37	36.3 (11.2)/ 37.6 (11.7)	M only	Het only	Task-based fMRI (n-back)	Task activation	Cluster-level FWE	$p < 0.05$ (cluster-level FWE)
Seok et al. (2020)	South Korea	PHB	30/30	28.81 (5.26)/ 27.41 (4.01)	M only	Not reported	Task-based fMRI (go/no-go Task)	Task activation	Voxel-wise FDR	$p < 0.05$ (voxel-wise FDR)
Draps, Kowalczyk-Grębska, et al. (2021)	Poland	CSBD	36/31	31.11 (6.02)/ 31.84 (7.14)	M only	Het only	DTI	FA	Uncorrected	p from 0.05 to 0.01 and significant cluster size >50
Golec et al. (2021)	Poland	CSBD	29/24	30.93 (6.45)/ 30.46 (7.56)	M only	Het only	Task-based fMRI (Incentive Delay Task)	Task activation	Cluster-level FWE	$p < 0.001$ (voxel-wise) and $p < 0.05$ (cluster-level FWE)
Engel et al. (2023)	Germany	CSBD	30/32	35.8 (10.79)/ 37.5 (11.65)	M only	Not reported	Structural MRI/Resting-state fMRI	VBM/seed-based FC	Cluster-level FWE	$p < 0.05$ (cluster-level FWE)
Draps et al. (2024)	Poland	CSBD	29/30	33.93 (6.57)/ 33.43 (6.40)	M only	Het only	Task-based fMRI (Stroop Task)	Task activation	Cluster-level FWE	$p < 0.05$ (cluster-level FWE)
Wojciechowski et al. (2025)	Poland	CSB	33/33	28.91 (7.07)/ 27.81 (5.62)	M only	Het only	Task-based fMRI (Conditioning & Extinction Task)	Task activation	Cluster-level FWE	$p < 0.001$ (voxel-wise) and $p < 0.05$ (cluster-level FWE)

CSBD, Compulsive Sexual Behavior Disorder; PHB, Problematic Hypersexual Behavior; PPU, Problematic Pornography Use; SD, Standard Deviation; DTI, Diffusion Tensor Imaging; VBM, Voxel-Based Morphometry; FC, Functional Connectivity; ICA, Independent Component Analysis; FA, Fractional Anisotropy; FWE, Family-Wise Error correction; FDR, False Discovery Rate correction; M, males; SO, Sexual orientation; Het, Heterosexual.

CSBD, Compulsive Sexual Behavior Disorder; PHB, Problematic Hypersexual Behavior; PPU, Problematic Pornography Use; SD, Standard Deviation; DTI, Diffusion Tensor Imaging; VBM, Voxel-Based Morphometry; FC, Functional Connectivity; ICA, Independent Component Analysis; FA, Fractional Anisotropy; FWE, Family-Wise Error correction; FDR, False Discovery Rate correction.

behavior or pornography use (e.g., SAST-R, CSBD-19, Brief Pornography Screen). (3) A healthy control group or another between-group comparison relevant to CSBD or PPU was included. (4) Neuroimaging methods such as functional MRI, structural MRI, diffusion tensor imaging (DTI), or positron emission tomography (PET) were employed to examine brain structure or function in relation to CSBD or PPU. (5) Studies reported stereotactic peak coordinates (MNI/Talairach) from whole-brain voxel-wise between-group contrasts suitable for CBMA. We included both corrected and uncorrected results and conducted a sensitivity analysis limited to whole-brain corrected studies (FWE/FDR). (6) Full-text articles were available in English and published in peer-reviewed journals.

Exclusion criteria. (1) Included only healthy participants or focused solely on experimental models without comparison to an at-risk or affected group. (2) Involved individuals with sexual dysfunction secondary to unrelated medical, neurological, or hormonal conditions (e.g., stroke, Parkinson's disease, menopause). (3) Studies that did not primarily focus on CSBD or PPU, such as those examining these constructs only as comorbid conditions or secondary outcomes. (4) Failed to report stereotactic coordinates in standard space (MNI or Talairach) or such data were unavailable for analysis. (5) Included non-human subjects. (6) Focused exclusively on machine learning–based classification or prediction without reporting interpretable group-level neuroimaging differences relevant to CSBD or PPU. (7) Reviews, meta-analyses, single case reports, conference abstracts, or other non-primary research formats. (8) Reported only ROI-restricted results or small-volume–corrected (SVC) findings without eligible whole-brain voxel-wise between-group contrasts. (9) Reported only within-group associations/covariate effects (e.g., symptom-severity correlations) without between-group contrasts relevant to CSBD/PPU.

Coordinate extraction and preprocessing

All eligible studies were imported into Neurosynth Compose for structured data management. For each included study, key bibliographic and methodological information was extracted using a standardized data extraction framework, including (1) bibliographic details (authors, year, and journal), (2) sample characteristics (sample size, age, and sex), (3) diagnostic criteria or assessment tools used (e.g., clinical diagnosis, SAST-R, CSBD-19), (4) imaging modality and acquisition parameters (e.g., fMRI, structural MRI, DTI, PET), (5) task paradigm (e.g., cue reactivity, resting-state, inhibitory control), (6) reported group-level brain activations or structural differences, and (7) peak stereotactic coordinates.

Peak coordinates of significant between-group differences were independently extracted by two reviewers, and any discrepancies were resolved through discussion or consultation with a third reviewer. Each coordinate entry was manually verified against the original publication. Studies were then categorized according to imaging modality (task-based, resting-state, or structural) and geographical population (European vs. East Asian) to enable subgroup analyses. Duplicate or ambiguous data were removed after cross-validation.

Risk of bias assessment

Risk of bias was assessed using the Newcastle–Ottawa Scale (NOS). Studies were rated on Selection, Comparability (e.g., adjustment/matching for key confounders such as age and sex, and where applicable intracranial volume), and Exposure/Outcome. Ratings were completed by one reviewer and checked by a second reviewer. Assessments were used to support sensitivity analyses and did not determine study eligibility. Study-level NOS ratings are provided in Supplementary Table 1.

Meta-analytic procedure (MKDA-χ^2)

Coordinate-based meta-analyses were performed using the MKDA-χ^2 algorithm implemented in Neurosynth Compose and supported by the NiMARE framework (v0.2). This approach aggregates stereotactic coordinates across studies to assess the spatial consistency of reported brain alterations. For each study, binary indicator maps were generated by convolving peak coordinates with a 10-mm spherical kernel, and the MKDA-χ^2 statistic quantified the proportion of studies showing activation at each voxel relative to chance.

Statistical significance was determined using false discovery rate (FDR) correction ($q < 0.05$) applied to the uniformity test map, following the default workflow of Neurosynth Compose. FDR correction was preferred over family-wise error correction to enhance sensitivity given the limited number of eligible studies.

In addition to the primary significance threshold ($q < 0.05$, voxel-level $p < 0.005$), two interpretive Z-score cutoffs were adopted to balance sensitivity and specificity: a conservative threshold ($Z > 3.29$) and a liberal threshold ($Z > 2.58$). Clusters with $Z > 4.0$ were regarded as highly robust, reflecting spatial convergence across multiple studies. For subgroup analyses with relatively small sample sizes, a stricter $Z > 5.0$ criterion was applied to further reduce false-positive findings. Specifically, this stricter $Z > 5.0$ cutoff was applied only to subgroup analyses with small numbers of studies (e.g., East Asian subgroup, $n = 4$) to mitigate false positives due to low study counts.

Significant clusters were anatomically labeled using the Automated Anatomical Labeling (AAL3) and Harvard–Oxford cortical and subcortical atlases, with labeling and voxel quantification performed via DPABI (v8.1). Sensitivity and subgroup analyses were conducted, where feasible, to assess robustness and to explore potential influences of diagnostic method or imaging modality. When coordinate data were insufficient, a qualitative synthesis summarized reported brain regions and network-level alterations.

Subgroup analyses

Subgroup meta-analyses were conducted by imaging modality (task-based vs. non-task-based, the latter including resting-state and structural MRI) and by population (European vs. East Asian). In the final eligible dataset, this yielded two modality subgroups (task-based, $n = 9$; non-task-based, $n = 5$) and two analyzable regional subgroups. Region was defined a priori based on participant recruitment location and then grouped into broader geographic categories; accordingly, the included studies clustered into Europe ($n = 10$; e.g., United Kingdom, Poland, Germany) and East Asia ($n = 4$; South Korea). No other regions were represented in sufficient numbers to meet our minimum threshold of three studies per subgroup. Each subgroup was analyzed separately using the same MKDA-χ^2 framework and FDR correction as the main analysis. Given the smaller sample sizes, a stricter threshold ($Z > 5.0$) was applied to identify highly robust clusters, while results consistent across both conservative ($Z > 3.29$) and liberal ($Z > 2.58$) thresholds were regarded as reliable.

Cognitive decoding and functional annotation

To characterize the cognitive and behavioral functions associated with the identified neural patterns, the thresholded meta-analytic maps were uploaded to NeuroVault for functional decoding using the NiMARE framework. Spatial correlations were calculated between the CSBD meta-analytic map and term-based meta-analytic activation maps from the Neurosynth database. The resulting term–map correlations were used to identify cognitive domains most closely associated with the convergent neural patterns. Term–map correlations quantify spatial similarity between meta-analytic maps rather than subject-level effect sizes; therefore, correlation magnitudes are typically small. We interpret these correlations as ranking indices for functional annotation rather than measures of strong association.

The top correlated terms were then grouped into higher-order functional categories, such as motivation, executive control, social cognition, and emotional regulation based on the Neurosynth ontology and manual review of term relevance.

Visualization and reporting

All thresholded MKDA maps were visualized on the MNI152 2-mm template using DPABI (v8.1), BrainNet Viewer, and Surf Ice for volumetric and surface rendering. Cluster coordinates and voxel counts were summarized in tabular form. Visualization tools were selected to ensure compatibility, clarity, and reproducibility. The entire workflow, including search records, coordinate data, statistical maps, and decoding results, was fully documented in accordance with PRISMA 2020 and coordinate-based meta-analysis (CBMA) reporting standards.

Ethics

This study synthesized data extracted from previously published neuroimaging studies. No new human or animal data were collected, and therefore, ethical approval and informed consent were not required. The study adhered to open-science principles and is made publicly available under a CC-BY-NC 4.0 license, in accordance with its PROSPERO registration.

RESULT

Pooled meta-analysis across all studies

The study selection process, conducted in accordance with PRISMA 2020 guidelines, is summarized in Fig. 1. Fourteen studies ($n = 809$ participants) were included in the pooled MKDA-χ^2 meta-analysis, which revealed several significant clusters after false discovery rate (FDR) correction. At the conservative threshold ($Z > 3.29$), six regions showed significant convergence across studies, including the left hippocampus, left inferior parietal lobule, right middle temporal gyrus, right supramarginal gyrus, left precentral gyrus, and left angular gyrus (Table 2).

To enhance sensitivity, a liberal threshold ($Z > 2.58$) was also applied. Among the resulting clusters, nine regions exhibited peak Z values greater than 4.0 and were summarized in Table 3. These included the left inferior parietal lobule, left hippocampus, left precentral gyrus, right globus pallidus, right supramarginal gyrus, right middle temporal gyrus, left cerebellum (lobule 8), left putamen, and right fusiform gyrus. Based on these results, we created a schematic (Fig. 2) to highlight the key regions within the striatolimbic and frontoparietal networks (left hippocampus, left putamen, right globus pallidus, and left inferior parietal lobule). The complete list of clusters identified at $Z > 2.58$, including those with lower peak Z values, can be found in Supplementary Table 2 and Supplementary Fig. 1.

Meta-analysis of studies with multiple comparison correction

A total of eleven studies were included in this subgroup meta-analysis, limited to those that applied multiple comparison correction procedures (e.g., FDR, FWE). Using a conservative threshold ($Z > 3.29$), five significant clusters were identified (Supplementary Table 3), located in the left hippocampus, left inferior parietal lobule, right supramarginal gyrus, left precentral gyrus, and left angular gyrus. Applying a liberal threshold ($Z > 2.58$), we identified eight clusters with peak Z values exceeding 4.0 (Supplementary Table 4). These included the left inferior parietal lobule, left precentral gyrus, left hippocampus, right globus pallidus, and right supramarginal gyrus, as well as subcortical and posterior regions such as the left cerebellum (lobule 8), left putamen, and right fusiform gyrus.

Modality-specific meta-analysis: task-based and non-task-based studies

To assess the effect of imaging modality, separate subgroup meta-analyses were performed for task-based and non-task-

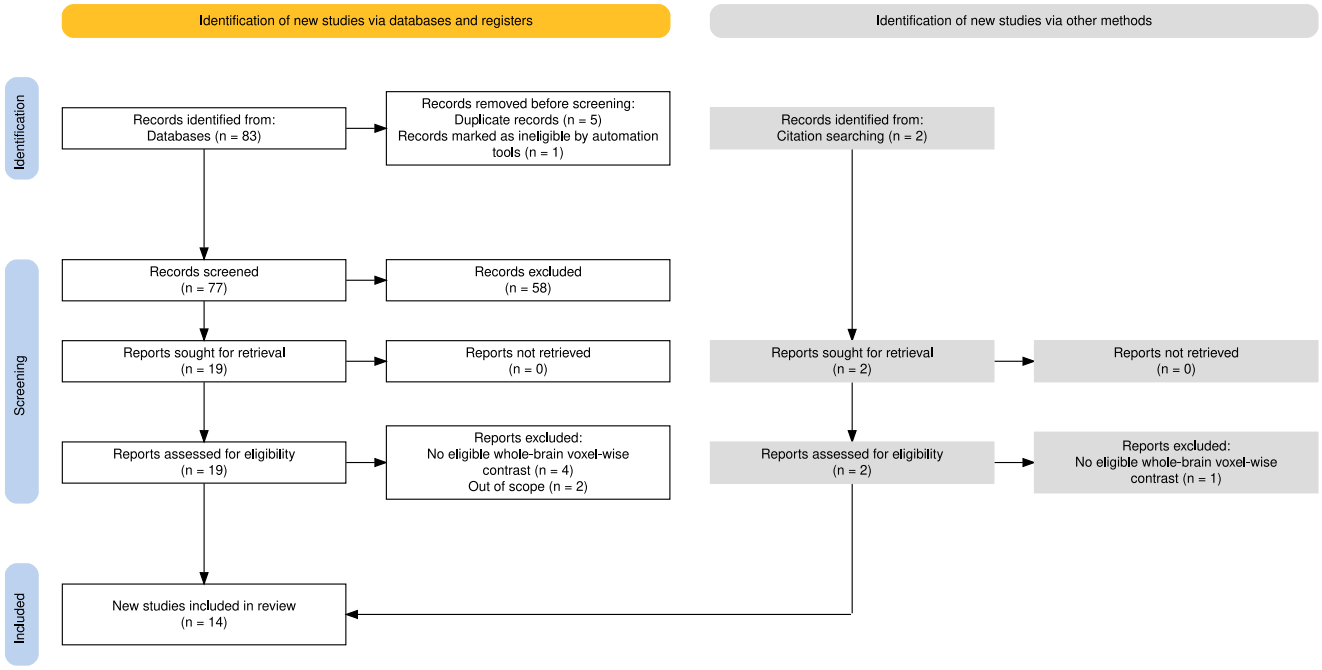

Fig. 1. PRISMA flow diagram illustrating the study selection process
The diagram summarizes the identification, screening, eligibility, and inclusion of studies for the 1meta-analysis on the neurobiology of CSBD

Table 2. Brain regions identified across all studies ($Z > 3.29$)

Brain areas of the cluster	Number of voxels	Peak coordinate			Z value
Hippocampus_L	110	32	−22	−12	6.5604
Parietal_Inf_L	58	46	−30	36	6.5604
Temporal_Mid_R	53	−46	−68	18	4.64488
SupraMarginal_R	38	−44	−36	40	4.64488
Precentral_L	32	56	2	28	4.64488
Angular_L	23	38	−60	18	4.64488

Significant clusters were identified using the MKDAChi^2 algorithm with FDR correction at $q < 0.05$. Reported peaks reflect voxels within the thresholded map at $Z > 3.29$.

based studies (including resting-state and structural MRI). A total of nine studies were included in the task-based subgroup, and five studies in the non-task-based subgroup. Together, these modality subgroups accounted for all included studies in the primary dataset (total $n = 14$). Given the small number of studies, we applied $Z > 5.0$ as a robustness criterion.

In the task-based subgroup, results were consistent across both conservative ($Z > 3.29$) and liberal ($Z > 2.58$) thresholds. A total of 18 clusters were identified (Supplementary Table 5), including peak activations in the left inferior parietal lobule, left hippocampus, right globus pallidus, right supramarginal gyrus, left precentral gyrus, left putamen, and right fusiform gyrus. These clusters exhibited peak Z values exceeding 5.0 and were marked as particularly robust. The non-task-based subgroup yielded a similarly distributed set of clusters (Supplementary Table 6), with convergence observed in the bilateral cerebellum, left frontal

Table 3. Brain regions from the liberal threshold ($Z > 2.58$) exhibiting peak Z-values >4.0

Peak region	Number of voxels	Peak coordinate			Z value	Extended regions
Parietal_Inf_L	1,198	46	−30	36	6.5604*	Postcentral_L Angular_L
Hippocampus_L	512	32	−22	−12	6.5604*	Putamen_L
Precentral_L	494	56	2	28	4.64488	–
Pallidum_R	470	−28	−4	−4	4.64488*	Putamen_R
SupraMarginal_R	364	−48	−32	28	4.64488*	–
Temporal_Mid_R	308	−46	−68	18	4.64488*	–
Cerebelum_8_L	246	30	−52	−46	4.64488*	–
Putamen_L	206	20	5	−4	4.64488*	Pallidum_L
Fusiform_L	109	40	−66	−16	4.64488*	–

Significant clusters were identified using the MKDAChi^2 algorithm with FDR correction at $q < 0.05$. This table reports a subset of clusters from the liberal threshold ($Z > 2.58$) that exhibited a peak Z-value >4.0. Asterisk (*) denotes that all clusters meet this high threshold.

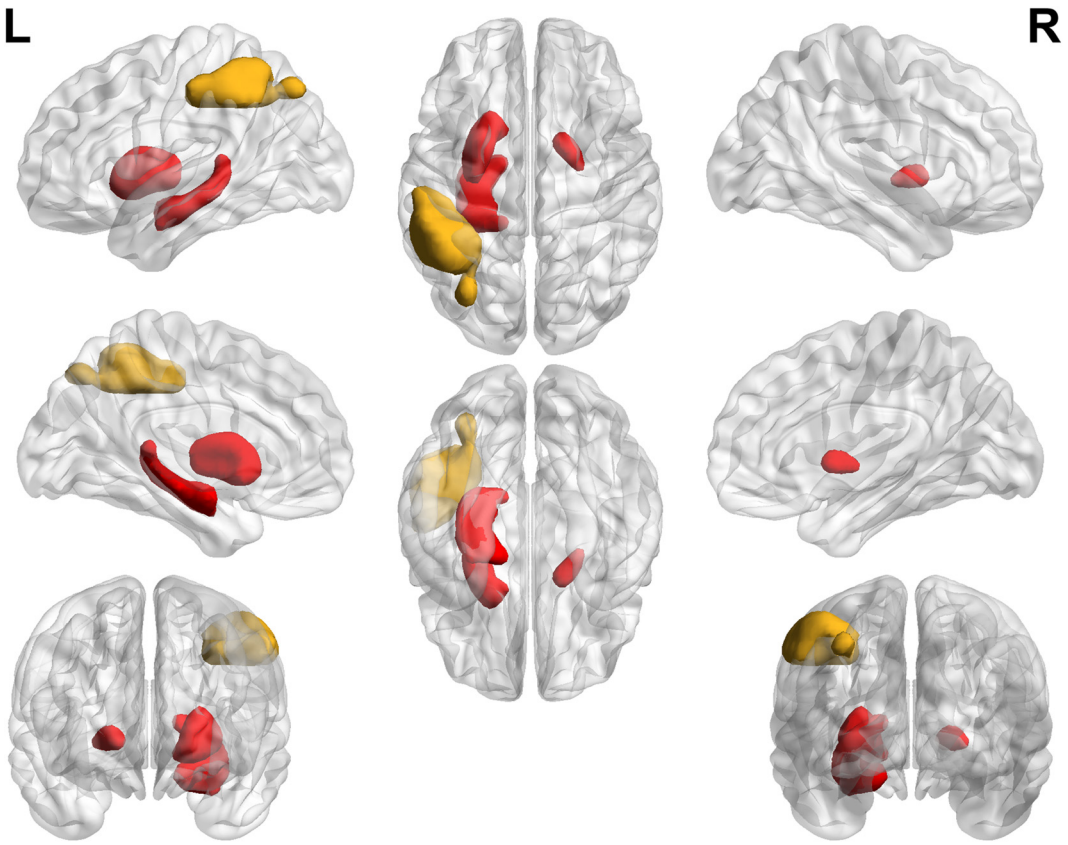

Fig. 2. Core neural networks in CSBD
This schematic illustrates the key regions identified in the meta-analysis (see Table 3), which comprise the striato-limbic network (including the left hippocampus, left putamen and right globus pallidus) and the frontoparietal network (including the left inferior parietal lobule). Red indicates striato-limbic regions; yellow indicates frontoparietal regions

medial cortex, left hippocampus, left temporal pole, and left inferior parietal lobule. As with the task-based analysis, results were consistent across thresholds, and clusters with peak $Z > 5.0$ were considered highly robust.

Population-specific meta-analysis: European and East Asian samples

To examine potential population-level differences, we conducted subgroup meta-analyses for studies conducted in predominantly European and East Asian samples. A total of ten studies were included in the European subgroup and four studies in the East Asian subgroup. Together, these regional subgroups accounted for all included studies in the primary dataset (total $n = 14$). No eligible studies from other regions were available after applying the primary inclusion criteria; studies without eligible whole-brain between-group contrasts were excluded. Given the small number of studies, we applied $Z > 5.0$ as a robustness criterion.

In the European subgroup, 14 clusters were identified (Supplementary Table 7). Robust peak activations ($Z > 5.0$) were observed in the right globus pallidus, left precentral gyrus, left hippocampus, and left inferior parietal lobule. These findings partially overlapped with those from the pooled analysis, particularly in medial temporal and parietal regions. The East Asian subgroup yielded 7 convergent clusters (Supplementary Table 8), including the left inferior parietal lobule, right precuneus, right supramarginal gyrus, and right frontal medial cortex. Notably, despite the smaller number of included studies, all clusters in this subgroup exceeded the robustness threshold ($Z > 5.0$), indicating a high level of consistency across findings.

Cognitive decoding of convergent clusters

To further interpret the functional implications of the convergent brain regions, we conducted a cognitive decoding analysis using the NeuroVault-based image decoding tool. Given that the exclusion of studies without multiple comparison correction did not significantly alter the distribution of convergent brain regions, the final cognitive decoding analysis was performed using the meta-analytic map based on all included studies to enhance robustness and generalizability. This analysis identified several cognitive terms with modest spatial correlations (ranking indices) to the meta-analytic brain map (Fig. 3). Correlation magnitudes were modest (as expected for term-based map correlations) and were interpreted primarily for functional annotation and hypothesis generation. The most strongly correlated terms included incentive delay ($r = 0.042$), attention ($r = 0.032$), response inhibition ($r = 0.019$), goal-

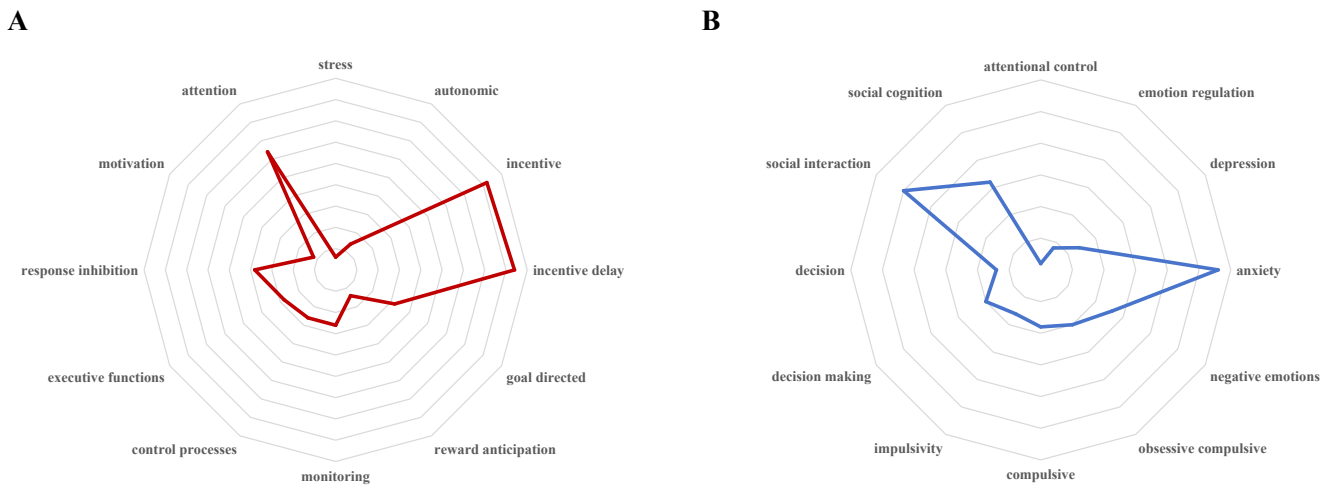

Fig. 3. Functional decoding of the meta-analytic brain map
The cognitive, emotional, and behavioral terms most strongly associated with the CSBD meta-analysis map are shown, with (A) positive correlations (e.g., motivational and executive processes) and (B) negative correlations (e.g., affective and social processing)

directed behavior ($r = 0.016$), executive functions ($r = 0.014$), and rewards ($r = 0.012$). Negative correlations were observed with terms such as anxiety ($r = -0.028$), social interaction ($r = -0.025$), and cognitive-emotional processing ($r = -0.023$).

DISCUSSION

By applying MKDA-χ^2 to 14 structural and functional imaging studies, this work provides the first systematic integration of neuroimaging evidence in CSBD, yielding a detailed map of disorder-related brain abnormalities. Our analysis revealed a set of regions showing spatially convergent alterations across studies. These regions included the left hippocampus, left inferior parietal lobule, left precentral gyrus and left angular gyrus, as well as the right globus pallidus, right supramarginal gyrus and right middle temporal gyrus. Task-based studies predominantly implicated the hippocampus, putamen, globus pallidus and parietal cortex — regions associated with reward and motivation processing — while resting-state and structural imaging revealed relatively consistent abnormalities in the cerebellum and parietal regions. These convergent patterns collectively indicate dual abnormalities in the striatal-limbic reward-motivation pathway and the frontoparietal control network centred on the inferior parietal lobule. This provides a preliminary integrative framework for understanding the neural mechanisms of CSBD.

Convergent abnormalities in reward and frontoparietal control systems

The current convergent findings primarily indicate abnormalities in the reward–motivation system centred on striatal–limbic structures (Voon et al., 2014). In particular, the hippocampus, putamen and globus pallidus emerged as the most consistently abnormal regions, all of which play a key role in reward learning, motivation-driven behavior and habit formation (Banwinkler et al., 2024; Kesner, Calva, & Ikemoto, 2022; Pei et al., 2025; Schwarz et al., 2022). The hippocampus is essential for processing contextual cues, encoding reward-related memories, and modulating cue-induced responses (Fakira, Massaly, Cohensedgh, Berman, & Morón, 2016; Wirtshafter & Wilson, 2022). Dysfunction in this region may reflect heightened sensitivity to sexually relevant cues and over-consolidation of contextual memory in individuals with CSBD (Draps et al., 2024). The putamen and globus pallidus, as key nodes of the striatal circuit, contribute to evaluating motivational value and generating action tendencies (Aron et al., 2005; Plessow et al., 2018). The consistent abnormalities observed here suggest that CSBD may involve altered reinforcement learning processes, predisposing individuals to develop compulsive sexual seeking behaviors in response to sexual cues. These co-occurring abnormalities in striatal–limbic structures closely align with activation patterns previously reported in addiction and impulse control disorder studies. This indicates that CSBD may share a common neural basis related to motivation-driven behavior and reward processing across diagnostic categories (Wojciechowski et al., 2025).

While the primary spatial convergence was observed in parietal regions such as the inferior parietal lobule and angular gyrus, these areas are core nodes of the frontoparietal control network (Berger, Friederici, & Grosse Wiesmann, 2022; Igelström & Graziano, 2017; Palaniyappan & Liddle, 2012). This network is critical for higher-order cognitive functions, including attention, working memory, and top-down regulation of behavior (Dengler et al., 2024; Niendam et al., 2012). The inferior parietal lobule and angular gyrus are involved in the integration of information from multiple senses, updating mental representations, and maintaining task-relevant attention (Fischer, Moscovitch, & Alain, 2021; Porada, Regenbogen, Freiherr, Seubert, &

Lundström, 2021). Abnormalities in these regions may impair the ability to selectively attend to sexually relevant cues and re-evaluate behavioural outcomes. The supramarginal gyrus is closely associated with the formation of action intentions, impulse control, and self-monitoring (Moro et al., 2023). It shows alterations that suggest an increased susceptibility to bottom-up drives and a reduced inhibitory capacity when individuals are exposed to highly motivating sexual stimuli. Functional decoding of the overall abnormal brain map further indicated strong associations with cognitive control processes, including response inhibition, motivational delay, attentional regulation, and goal-directed behavior, consistent with the known role of the frontoparietal network (Boshra & Kastner, 2022; Dodds, Morein-Zamir, & Robbins, 2011). Together, these findings provide key neuroimaging evidence elucidating impulsivity, attentional bias, and deficits in top-down regulation in CSBD.

The dual-dysregulation framework and clinical interpretation

This study highlights a dual dysregulation mechanism in CSBD, characterized by heightened motivational drive and weakened cognitive control. Alterations in the hippocampus, putamen, and globus pallidus suggest excessive incentive salience for sexual cues, strengthening cue-induced approach behaviors, while abnormalities in the inferior parietal lobule, angular gyrus, and supramarginal gyrus indicate deficits in top-down regulation, including attention, behavioral monitoring, and response inhibition (Seok & Sohn, 2018a, 2020). Functional analysis of the abnormal brain map revealed a strong association with key cognitive control dimensions, including response inhibition, task maintenance, goal-directed behaviour and motivational delay, providing cross-dimensional psychological evidence for this dual imbalance model (Draps et al., 2024; Gola et al., 2017; Sinke et al., 2020; Wojciechowski et al., 2025). Within such a systemic bias, behavioural impulses triggered by highly salient cues may become difficult to suppress effectively, ultimately manifesting as persistent and poorly controlled sexual behaviour patterns. This dual-dysregulation framework clarifies the neurological basis of CSBD in terms of motivational excess and cognitive control deficiency (Schmidt et al., 2017).

From a clinical perspective, this pattern maps onto hallmark features of CSBD—strong cue-triggered urges/craving and repetitive engagement despite negative consequences—together with difficulty disengaging attention and inhibiting prepotent responses in the presence of salient sexual cues. It also aligns with transdiagnostic mechanisms in addiction and impulse control disorders, providing a conceptual basis to inform interventions aimed at reducing cue-driven motivational reactivity while strengthening top-down self-regulation (Castro-Calvo, Cervigón-Carrasco, Ballester-Arnal, & Giménez-García, 2021; Mechelmans et al., 2014). Functional decoding returned some anxiety/affect-related terms; given that most primary studies did not directly assess affect-regulation processes, this signal should be interpreted as exploratory (e.g., reflecting comorbid anxiety/negative affect or a potential modulatory role of negative affect) and requires targeted validation in studies that jointly quantify affective symptoms/coping motives and neuroimaging markers (Grant Weinandy, Lee, Hoagland, Grubbs, & Bőthe, 2023; Wizła & Lewczuk, 2024).

Interpreting the absence of consistent prefrontal convergence

Although the prefrontal cortex has long been considered a crucial area for studying impulse control and addictive behaviours (Flores-Dourojeanni et al., 2021; Goldstein & Volkow, 2011), the main analysis of this study did not reveal any significant or spatially convergent clusters in the prefrontal lobe. This lack of convergence does not imply that the prefrontal cortex is irrelevant to CSBD; it is more likely due to several methodological factors. Firstly, substantial variations in task paradigms, model specifications and statistical thresholds across the included studies resulted in a highly dispersed distribution of prefrontal activation coordinates (Wager, Jonides, & Reading, 2004). Secondly, the MKDA-χ^2 method prioritises cross-study consistency and is inherently more conservative for regions with complex functional profiles and broad involvement, such as the prefrontal cortex (Fox et al., 2014). Furthermore, under more lenient thresholds (e.g. $Z > 2.58$), scattered signals were observed in the middle and superior frontal gyri (see Table 3). These regions are typically associated with the dorsolateral prefrontal functional zone, and their signal patterns generally align with previously reported abnormalities in the inferior frontal gyrus, orbitofrontal cortex and DLPFC in CSBD and related impulse control disorder literature (Cuppone et al., 2021; Draps, Adamus, Wierzba, & Gola, 2022; Golec et al., 2021; Puszcz et al., 2025). However, as these frontal signals did not meet the statistical criterion for cross-study spatial convergence in the present study, it is more reasonable to conclude that the current evidence indicates a lack of consistency in prefrontal activation rather than a lack of involvement of the prefrontal cortex in the neural mechanisms of CSBD.

Modality- and population-related exploratory findings

In supplementary analyses, divergent patterns emerged between task-based and resting-state/structural imaging. Task-based convergence predominantly involved the hippocampus, putamen, globus pallidus and parietal cortex (Fattore, Fadda, Spano, Pistis, & Fratta, 2008; Wisniewski, Reverberi, Momennejad, Kahnt, & Haynes, 2015). This reflects processes such as immediate reward processing, motivational drive and task-relevant attention regulation. In contrast, resting-state and structural studies showed more consistent alterations in cerebellar and parietal regions. This may indicate traits related to long-term behavioural patterns, baseline regulation and spontaneous neural activity. These differences suggest that different imaging modalities

capture complementary neural dimensions, though cautious interpretation remains necessary due to the limited number of studies included. Exploratory analyses of Eastern versus Western samples revealed subtle differences: Western studies emphasised reward-related regions, whereas Eastern studies demonstrated greater parietal consistency. However, none of these culture-related differences formed statistically robust spatial convergence under strict thresholds, likely due to variations in sample size, task paradigms, image quality, and study design. Taken together, these exploratory findings suggest that both the imaging modality used and the cultural background of the participants may influence the neuroimaging presentation of CSBD, but this requires further validation through larger-scale, multicentre studies (Kim, Sung, & McClure, 2012).

Implications for psychiatric classification and transdiagnostic models

From a psychiatric classification perspective, the findings of this study generally align with the current categorisation of CSBD as an impulse control disorder in the ICD-11: the neuroimaging results demonstrate notable abnormalities in nodes of the frontoparietal control network involved in cognitive control, accompanied by activation patterns in striatal-limbic structures driven by motivation (Brand et al., 2022; Briken et al., 2024). However, in terms of reward processing and motivational drive, CSBD exhibits neural features that resemble behavioural addictions (Rumpf & Montag, 2022), particularly the convergent abnormalities in the hippocampus and striatum, which are highly consistent with previous findings in gambling disorder and other behavioural addictions (Wojciechowski et al., 2025). This dual characteristic suggests that CSBD may occupy an intermediate position on the 'impulse control disorder–behavioural addiction' spectrum, incorporating impulsive drive and addictive motivational reinforcement mechanisms (Bőthe, Koós, & Demetrovics, 2022). These transdiagnostic patterns reinforce the view that CSBD reflects concurrent disruption of motivational/reinforcement and cognitive-control systems, underscoring its intermediate position along the impulse-control–addiction spectrum (Robbins & Clark, 2015; Castro-Calvo et al., 2022).

Beyond these conceptual implications, the present study also has several methodological strengths. As the first coordinate-based imaging meta-analysis to focus on CSBD, this study systematically integrates existing structural and functional neuroimaging evidence from multiple studies, offering a broader perspective on the neural basis of this emerging disorder. This research's strengths are mainly reflected in two aspects. First, the adoption of a multimodal MKDA-χ^2 approach incorporates task-based, resting-state and structural imaging results simultaneously, enabling the comparison and synthesis of abnormalities across different imaging paradigms within a unified framework (Wager, Lindquist, Nichols, Kober, & Van Snellenberg, 2009). Second, functional decoding of the overall convergence map links the aggregated patterns to specific psychological functional dimensions, thereby enhancing the interpretability and cross-level connectivity of the findings.

LIMITATIONS

This study has several limitations that warrant cautious interpretation. Firstly, the small number of studies included and the significant differences in sample characteristics, task paradigms and statistical thresholds may affect the reliability of the spatial convergence results. Secondly, the MKDA-χ^2 method relies on reported coordinates rather than full statistical maps, limiting its ability to detect subtle whole-brain effects. Thirdly, the current literature exhibits limited demographic diversity, with most studies focusing on heterosexual male populations. This restricts the generalisability of the findings to females and sexual minorities. Finally, the observed differences between task-based and resting-state modalities, as well as culture-related findings, are based on small sample sizes and should therefore be considered exploratory. Formal moderator analyses (e.g., publication year, mean age, sex composition) were considered but not performed, because these variables showed limited between-study variability in the eligible dataset and further stratification would be underpowered. Future research should prioritise multicentre, large-sample neuroimaging studies with more diverse participant recruitment and promote the sharing of statistical maps to enable more precise image-based meta-analyses and further validate the transdiagnostic neural mechanisms of CSBD.

CONCLUSIONS

This study provides the first systematic coordinate-based meta-analysis integrating structural and functional neuroimaging evidence in CSBD. Our findings highlight a dual dysregulation mechanism, characterized by heightened motivational drive in striatal–limbic circuits and weakened cognitive control in the frontoparietal network. This neural pattern offers a mechanistic explanation for compulsive sexual behaviors and attentional biases observed in CSBD, bridging clinical manifestations with underlying brain dysfunction. Moreover, the results situate CSBD along a spectrum between impulse control disorders and behavioral addictions, offering a transdiagnostic perspective. By combining multimodal imaging with functional decoding, this work establishes a framework for future studies and may inform targeted interventions aimed at restoring the balance between motivational and cognitive control systems.

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Authors' contribution: YF conceived and designed the study, conducted the literature search, performed data extraction and coordinate preparation, carried out the meta-analysis, interpreted the findings, and drafted the manuscript. XL and YL contributed to literature screening, data extraction, and verification of the included studies. CP and SJ contributed substantially to study conceptualization, methodological supervision, interpretation of the findings, and critical revision of the manuscript. HL, SZ, YC, JW, VS, WFZY, and BR contributed to data checking, methodological discussion, interpretation of results, and manuscript review and editing. All authors reviewed and approved the final version of the manuscript.

Conflict of interest: The authors declare that they have no competing interests.

SUPPLEMENTARY MATERIAL

Supplementary data to this article can be found online at https://doi.org/10.1556/2006.2025.00563.

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