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Neural correlates of empathy in autism: a coordinate-based meta-analysis

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Abstract

Purpose. Autistic and non-autistic people often differ in how readily they understand one another's intentions and emotional states. Although empathy is commonly invoked to explain these differences, which components of empathic processing differ in autism, and their neural underpinnings, remain unclear.

Methods. We conducted a pre-registered coordinate-based meta-analysis (activation likelihood estimation; ALE) of task-based fMRI studies of empathy in autism, examining within-group convergence, conjunction and between-group divergence separately for affective and cognitive components. Eleven studies (12 independent samples) met inclusion criteria, comprising 213 autistic and 216 non-autistic participants and 600 foci across 35 experiments; a multi-agent AI second reviewer supported screening and extraction.

Results. Both groups shared a core empathy network (precuneus/posterior cingulate cortex, right middle temporal gyrus/posterior superior temporal sulcus, left inferior frontal gyrus, dorsomedial paracingulate), but the rostral dorsomedial prefrontal cortex, a canonical cognitive-empathy hub, converged only in non-autistic participants. The between-group contrast was strongly asymmetric: non-autistic participants exceeded autistic convergence in ten regions, eight of them cognitive-empathy nodes, the largest in rostral dorsomedial prefrontal cortex; autistic participants exceeded non-autistic convergence in one region only, the posterior right temporoparietal junction. Subdomain analyses indicated relatively preserved convergence for affective empathy, with sparser, more diffuse overlap for cognitive empathy.

Conclusion. These findings are consistent with a dissociation between relatively preserved affective and altered cognitive empathy in autism, and suggest a redistribution of activation within the mentalizing network rather than a global absence of empathy-related processing.

Key words: autism spectrum disorder; empathy; activation likelihood estimation; functional magnetic resonance imaging; dorsomedial prefrontal cortex; temporoparietal junction

Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental condition characterized by persistent deficits in social communication and social interaction across multiple contexts, alongside restricted, repetitive patterns of behavior, interests, or activities (American Psychiatric Association, 2022). Its social phenotype — difficulties in reciprocal interaction, reduced joint attention, atypical interpretation of social cues — has motivated decades of research into underlying mechanisms, and empathy has occupied a central theoretical position: empathy-related behaviors are directly captured in standardized diagnostic instruments (Lord et al., 2012), and impaired empathy has been proposed as a core explanation for the social difficulties that define the diagnosis. Empathy is commonly defined as the capacity to share and understand another person's affective state while maintaining a clear distinction between self and other (Cuff et al., 2016; Decety & Jackson, 2004; de Vignemont & Singer, 2006). In non-autistic adults, quantitative meta-analyses converge on a core network comprising the anterior insula and anterior/mid-cingulate cortex, the dorsomedial prefrontal cortex, the temporoparietal junction and superior temporal sulcus, the precuneus, and the inferior frontal gyrus (Bzdok et al., 2012; Fan et al., 2011; Lamm et al., 2011; Schurz et al., 2021). These regions are not functionally equivalent, and their differential recruitment across paradigms has motivated models that parse empathy into separable components.

Contemporary neurocognitive models converge on a two-component structure of empathy (Bzdok et al., 2012; Schurz et al., 2021; Shamay-Tsoory, 2011). Cognitive empathy — inferring and representing another person's emotional state, and so closest to affective mentalizing — engages a network anchored in the dorsomedial prefrontal cortex (dMPFC), temporoparietal junction (TPJ) and superior temporal sulcus (STS) (Decety & Jackson, 2004; Fan et al., 2011; Shamay-Tsoory, 2011). Affective empathy — the vicarious sharing of

another's emotional state — recruits the anterior insula (AI), anterior cingulate cortex (ACC) and ventromedial prefrontal cortex (vmPFC), structures implicated in interoceptive and visceral representations of affect (Kanske et al., 2015; Lamm et al., 2011; Shamay-Tsoory et al., 2009). The inferior frontal gyrus (IFG), a core node of the human mirror neuron system, contributes across both domains through action understanding and the automatic simulation of observed emotional states, although it is usually associated with emotional empathy (Carr et al., 2003; Dapretto et al., 2006; Shamay-Tsoory, 2011). Empathy for pain, historically treated as a separate domain, is subsumed within affective empathy in hierarchical taxonomies of social cognition, sharing the AI–ACC core with additional recruitment of somatosensory cortices (Lamm et al., 2011; Schurz et al., 2021).

The nature of empathic alteration in autism is actively debated, and the empirical picture is more complex than a unitary “empathy deficit” framing suggests. One influential line supports selective difficulty in cognitive empathy — specifically mentalizing — with relatively preserved affective empathy (Dziobek et al., 2008; Rogers et al., 2007): autistic people are held to struggle in inferring others' mental states while retaining automatic affective resonance when the other's state is unambiguously presented. Meta-analytic work appears consistent with this view: Fatima and Babu (2023) reported a substantially larger pooled effect for lower cognitive-empathy scores ($g = 1.26$) than for affective empathy ($g = 0.58$) across 35 studies, though both were significant, and higher autistic traits in non-clinical samples are associated with lower cognitive but not affective theory-of-mind and empathy scores (Le et al., 2024).

This framing has been qualified, and in part challenged, on several grounds. The first concerns affective empathy, which the selective account holds to be preserved. Where reduced affective empathy is reported in autistic samples, it has been attributed not to autism per se but to co-occurring alexithymia, present in approximately half of autistic people and

independently predictive of reduced neural and behavioral empathy responses (Bird et al., 2010; Bird & Cook, 2013). On this “alexithymia hypothesis” (Bird & Viding, 2014), autistic people without co-occurring alexithymia show typical affective resonance, so the preservation of affective empathy is genuine but conditional: it holds once alexithymia is taken into account, and group-level estimates vary with the proportion of alexithymic participants in a sample. Atypical interoception may further contribute by disrupting the bodily signals that scaffold affective sharing (Gu et al., 2015; Shah et al., 2016). A second line comes from a large behavioral meta-analysis finding that apparent empathic difficulties are substantially modulated by measurement method, with larger differences on self-report instruments than on performance-based tasks — a pattern more consistent with alexithymia, metacognitive differences or social desirability effects than with a core empathy deficit (Cusson et al., 2025).

A third line of argument is more fundamental: the double empathy problem proposed by Milton (2012) reframes the question altogether: rather than a unidirectional deficit residing within the autistic individual, empathic difficulties in autistic–non-autistic interactions reflect a bidirectional mismatch between neurotypes in communicative style and social cognition (Milton et al., 2022; Crompton et al., 2020). Empirical work consistent with this view has shown that autistic individuals show comparable empathic accuracy when interacting with other autistic individuals, and that non-autistic individuals show correspondingly reduced empathic understanding of autistic partners (Edey et al., 2016; Sheppard et al., 2016).

The neuroimaging literature presents a parallel paradox: findings are neither consistently diminished nor consistently localized (Di Martino et al., 2009; Kana et al., 2015; Patriquin et al., 2016; Sugranyes et al., 2011). Some studies report hypoactivation of medial prefrontal and inferior frontal regions during empathy tasks in autism relative to non-autistic comparison participants (Dapretto et al., 2006; Klapwijk et al., 2016; Le et al., 2024; Schulte-

Rüther et al., 2011); others find comparable or elevated activation in temporoparietal and frontal cortices (Bird et al., 2010; Hadjikhani et al., 2014; Krach et al., 2015; Lombardo et al., 2011). This inconsistency has resisted resolution at the level of individual studies, and its source — methodological, biological, or both — remains uncharacterized. Coordinate-based meta-analysis (CBMA) offers a principled framework for identifying spatially convergent signals across heterogeneous datasets, yet no published CBMA has examined empathy-specific fMRI activations in autism using a design suited to detect the patterns predicted by competing theoretical accounts.

Hadjikhani and colleagues (2014) proposed that autistic people may process empathy-relevant information through atypical computational routes rather than failing to engage empathic circuitry altogether — a possibility which, together with the alexithymia and double empathy accounts, exposes a structural limitation in how this literature has been synthesized. Between-group contrasts identify where autistic and non-autistic groups differ in activation magnitude, but not which regions are reliably recruited within each group. A null between-group result is uninformative about whether both groups, or neither, engage a given region, and a between-group hypoactivation does not establish that the region is absent from the autistic empathy network. Within-group CBMA addresses this directly: by identifying spatially convergent activation across studies separately for autistic and non-autistic samples, it allows detection of preserved circuitry masked by difference maps and of atypical recruitment that between-group contrasts cannot reveal.

Prior meta-analyses of social cognition in autism have informed but not resolved this picture. Di Martino and colleagues (2009) identified hypoactivation of frontal and amygdala regions across a broad range of social paradigms; Philip and colleagues (2012) reported reduced activation in the right amygdala, left IFG and mPFC; and Luo and colleagues (2023) meta-analyzed emotion-recognition studies. All three relied primarily on between-group contrasts

and targeted constructs broader than empathy per se, and none examined within-group convergence for empathy-specific tasks separately by group.

The present study addresses these gaps through a pre-registered systematic coordinate-based meta-analysis of task-based fMRI studies of empathy in autism (PROSPERO CRD420261346053). The primary aim was to characterize within-group neural convergence during empathy tasks, separately for autistic and non-autistic participants, and to identify where these patterns diverge through conjunction and contrast analyses of the resulting convergence maps. A secondary aim was to examine, where the literature permitted, whether group differences varied by empathy subtype, with planned subgroup analyses for cognitive and affective empathy (pain empathy treated as a subdomain of affective empathy following hierarchical taxonomies of social cognition; Schurz et al., 2021). A methodological aim concerned data extraction itself: given the error-proneness of manually extracting peak coordinates from complex neuroimaging tables, we developed and evaluated a multi-agent artificial-intelligence pipeline as the second independent extractor, reporting coordinate-level inter-rater reliability as an assessment of the approach.

A note on terminology: identity-first language ("autistic people") is used throughout, following the preference expressed by much of the autistic community and by autism researchers (Bottema-Beutel et al., 2021; Kenny et al., 2016; Monk et al., 2022). The abbreviations ASD and TD are retained in tables, figures, and analysis labels, where they denote the diagnostic categories as reported by the primary studies.

Materials and Methods

Search Strategy

This meta-analysis is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (PRISMA; Page et al., 2021), and the protocol was registered at the International Prospective Register of Systematic Reviews (PROSPERO

CRD420261346053). PubMed, Web of Science and Scopus were searched. The strategy was initially designed to capture neuroimaging studies across all relevant modalities — fMRI, EEG/ERP, MEG and fNIRS — and combined three conceptual domains: autism spectrum disorder; empathy and related social–cognitive processes; and neuroimaging. During screening it became apparent that the number of eligible EEG, MEG or fNIRS studies within the specific domain of empathy research in autism was insufficient to support quantitative synthesis, and the meta-analysis was therefore restricted to task-based fMRI studies reporting whole-brain peak activation coordinates in standard stereotaxic space, these being the only modality with an adequate evidence base for coordinate-based meta-analysis. This decision was made before data extraction and is documented in the PROSPERO amendment record. To ensure comprehensive coverage of the empathy fMRI literature in autism, the primary database search was supplemented by manual screening of reference lists from eligible studies and key reviews, and by an AI-assisted deep search conducted using two large language models (Claude, Anthropic; ChatGPT, OpenAI) to identify additional candidate studies.

Study Selection

Retrieved records were deduplicated in Zotero prior to screening. Titles and abstracts of all deduplicated records were screened by the primary reviewer against the predefined eligibility criteria. Records deemed potentially relevant were advanced to full-text assessment. At the full-text stage, each candidate article was independently assessed against the full inclusion and exclusion criteria by the primary reviewer and, in parallel, by a multi-agent artificial intelligence pipeline comprising two large language models (Claude Opus 4.6 and Claude Sonnet 4.6, Anthropic) operating in parallel and coordinated by an orchestrator agent, each applying the same predefined eligibility criteria. Disagreements between the human reviewer and the AI pipeline at the full-text stage were resolved by the human reviewer, who retained

final authority over all inclusion and exclusion decisions. The complete selection process is documented in a PRISMA 2020 flow diagram (Fig. 1).

Eligibility Criteria

Studies were eligible if they met all of the following criteria: (1) a task-based fMRI design including both a group with formal ASD diagnosis and a non-autistic comparison group; (2) an experimental paradigm explicitly targeting empathic processing, operationalized as cognitive or affective empathy, with pain empathy classified as a subdomain of affective empathy following hierarchical taxonomies of social cognition (Schurz et al., 2021); (3) whole-brain analysis reporting peak activation coordinates in standard stereotaxic space (MNI or Talairach) with cluster-level familywise error (FWE) or false discovery rate (FDR) correction; and (4) diagnosis established using DSM-IV, DSM-IV-TR, DSM-5 or ICD-10/11 criteria and/or standardized instruments (ADOS/ADOS-2, ADI-R). Cognitive-empathy paradigms were those requiring explicit inference of another's emotional state from affective stimulus content (e.g., faux pas test, Reading the Mind in the Eyes Test, affective theory-of-mind stories, empathic accuracy tasks); they were identified by three criteria — affective stimulus content, explicit inference of another's emotional state, and an empathy framing of the task — of which at least two had to be met, which distinguishes them from mentalizing tasks without affective content. Affective-empathy paradigms were those in which the participant vicariously shares an emotional state that is directly observed rather than inferred, comprising vicarious pain, embarrassment and disgust paradigms and emotional face attribution tasks. Tasks requiring only the identification or labelling of a displayed emotion were excluded. No restrictions were placed on participant age, sex, or intellectual functioning.

Studies were excluded if they met any of the following: (1) non-fMRI modalities (EEG, MEG, fNIRS, PET); (2) resting-state or structural designs without a task-based empathy

component; (3) dimensional autistic-traits studies without a categorically diagnosed ASD group, or studies lacking a separate non-autistic comparison group; (4) tasks operationalizing emotion recognition/labelling (identifying which emotion is displayed) rather than inference of the target's internal state; (5) pure mentalizing paradigms without affective content (e.g., false belief tasks, Heider–Simmel/Castelli geometric animations, intention attribution without affective stimulus); (6) reviews, perspective/opinion papers, and meta-analyses without original empirical data; (7) results reported exclusively from region-of-interest analyses with small-volume correction; (8) primary fMRI findings limited to between-group contrasts, correlation, connectivity, conjunction, or parametric-modulation analyses without accompanying within-group [empathy task > control condition] activation maps; (9) whole-brain analyses reported only at voxel-level uncorrected thresholds.

Data Extraction

Data extraction was performed using a standardized form developed prior to screening, based on established guidelines for coordinate-based meta-analyses (Müller et al., 2018; Tahmasian et al., 2019). The form captured: study-level characteristics (authors, year, country, diagnostic criteria, medication status); sample characteristics (group, sample size, sex distribution, age, IQ); task and paradigm details (empathy type, task name, stimuli, experimental and control conditions); imaging parameters (scanner field strength, preprocessing software, smoothing kernel, coordinate space); and peak activation coordinates (brain region, hemisphere, MNI coordinates, statistic type and value). Four quality domains were rated for each study: motion control, multiple comparisons correction, sample size adequacy, and missing data management.

The unit of extraction was the experiment-level record, defined as a specific task contrast within a study. A single study could include multiple experiments, with separate contrasts reported. Within-group activations were extracted independently for autistic and non-autistic

participants; each combination of contrast and group constituted a unique experiment entry. Only task-based contrasts comparing an empathy-related experimental condition to a control or baseline condition were eligible (e.g., emotional faces > neutral faces; pain > no pain). Primary extraction was conducted by one reviewer. Independent parallel extraction was performed by a multi-agent AI system comprising an orchestrator and four specialized sub-agents: a document-mapping agent that located the relevant sections, tables and supplementary materials; two extraction agents operating in parallel (Claude Opus 4.6 and Claude Sonnet 4.6, Anthropic) applying the same standardized form; a verification agent that cross-checked every peak coordinate against the source tables; and an adversarial agent that identified inconsistencies between the two extractions and resolved them by re-examining the original publications. All agents operated with a 1M-token context window, so that full-text articles and supplementary materials were processed within a single context. Where automated PDF parsing of complex multi-column tables was unreliable, layout-preserving text extraction was used, followed by confirmation of the extracted coordinates against the original tables by the human reviewer.

Agreement between the human and AI extractions was assessed at the level of unique coordinate tuples (group, x, y, z) using the Jaccard index (intersection over union) and the Dice coefficient (positive agreement). The orchestrator agent compared the two independently compiled datasets as an exact set operation, and every discrepancy it returned was inspected by the human reviewer against the source publication; no value entered the analysis on the basis of AI output alone, yielding a fully auditable dataset in which each coded value is traceable to explicit textual evidence in the source article. Because the comparison is a set operation rather than a judgement, the procedure follows the same adjudication logic as conventional dual review: an inaccurate second extraction increases the adjudication burden rather than the risk of an erroneous value entering the dataset. The AI

pipeline thus functioned as an advisory second reviewer, with all final decisions, and responsibility for them, resting with the human reviewer — an allocation of roles that follows the position statement on AI use in evidence synthesis issued jointly by Cochrane, the Campbell Collaboration, JBI and the Collaboration for Environmental Evidence (Flemyng et al., 2025).

Quality Assessment

Methodological quality was assessed with a modified Newcastle–Ottawa Scale (NOS; Wells et al., 2000) adapted for case-control neuroimaging studies, following previous coordinate-based meta-analyses (Nickl-Jockschat et al., 2012; Shepherd et al., 2012). The adapted scale comprised nine items across three domains: Selection (0–4 stars: diagnosis confirmed with a standardized instrument such as ADOS or ADI-R, screening of the non-autistic group for psychiatric and neurological conditions, representativeness of the sample, and sample size ≥ 15 per group), Comparability (0–2 stars: groups matched or statistically controlled for age and IQ), and Outcome (0–3 stars: head motion reported and controlled, whole-brain analysis with correction for multiple comparisons, and explicit reporting of stereotaxic coordinate space). Total scores range from 0 to 9, with ≥ 7 classified as good quality, 4–6 as moderate and < 4 as poor. Ratings were made independently by the human rater and verified by the AI extraction system, and were not used as exclusion criteria.

Data Synthesis

Coordinate-based meta-analysis was conducted using Activation Likelihood Estimation (ALE) as implemented in NiMARE (Salo et al., 2023; version 0.20.0) following the theoretical framework of Eickhoff et al. (2012, 2016). All coordinates were recorded in their original stereotaxic space; Talairach coordinates were converted to MNI space prior to analysis using the Lancaster transform (Lancaster et al., 2007).

Each independent experiment — a set of peak coordinates derived from a single statistical contrast within an independent participant sample — was treated as the unit of analysis. Where a single publication reported multiple eligible contrasts (e.g., cognitive and affective empathy conditions), each was treated as a separate experiment provided it represented a distinct psychological process; this maximizes sensitivity at the cost of a modest violation of the strict independence assumption and is consistent with current ALE practice (Eickhoff et al., 2016). Each reported coordinate is modelled as a three-dimensional Gaussian probability distribution whose width reflects spatial uncertainty estimated as a function of sample size, and the resulting modelled activation maps are combined across experiments into a whole-brain ALE statistic reflecting convergence of activation foci (Eickhoff et al., 2012). Inference used Monte Carlo permutation testing (10,000 permutations) with cluster-level family-wise error correction (cluster-forming threshold $p < .001$ uncorrected; cluster-level threshold $p < .05$ FWE-corrected).

Primary analyses. Separate within-group ALE analyses were conducted for autistic and non-autistic participants independently, across all empathy tasks (all-empathy pools). Conjunction analyses identified regions of convergent activation common to both groups, computed as the voxelwise minimum z -statistic across the two cluster-level FWE-corrected within-group maps (Nichols et al., 2005). Between-group differences were assessed using the ALE subtraction procedure implemented in NiMARE (Eickhoff et al., 2011), based on 10,000 permutations of experiment labels. Subtraction results were additionally examined within an inclusive mask restricted to voxels significant in either within-group analysis, to restrict inference to the canonical empathy network and reduce Type I error inflation from voxels showing no within-group convergence in either group. The 100 mm³ minimum cluster extent was applied to the within-group and subtraction analyses; it was not applied to the

conjunction map, where cluster volumes reflect the overlap of two thresholded maps and are therefore systematically smaller.

Subgroup analyses. Within-group ALE analyses were additionally conducted separately for the affective empathy subgroup. A parallel analysis of the cognitive empathy subgroup was conducted for exploratory purposes, given the small number of experiments per group (five per group), which falls substantially below the recommended minimum of 17–20 experiments for reliable ALE inference (Eickhoff et al., 2016).

Sensitivity analyses. Leave-one-out (jackknife) sensitivity analyses were performed for each within-group all-empathy ALE by iteratively removing each experiment and re-running the analysis, using the Jackknife diagnostic implemented in NiMARE. For each significant cluster from the main analysis, the proportional reduction in the ALE statistic within the cluster after removing each experiment was computed as an index of that experiment's contribution. Clusters with contributions distributed relatively evenly across multiple experiments were considered stable; clusters with disproportionately high contribution from a single experiment (proportion > 0.50) were flagged as potentially unstable and interpreted with appropriate caution.

Anatomical localization of significant clusters was performed using the Harvard–Oxford Cortical Atlas and the SPM Anatomy Toolbox.

Results

Study Selection

The flow diagram (Fig. 1) depicts the literature search results and the study selection process. The database search identified 4,930 records (1,222 from PubMed, 2,503 from Scopus, and 1,205 from Web of Science); reference-list screening yielded no additional records, and a deep search using ChatGPT and Claude identified a further 25, giving 4,955 records in total. After 2,365 duplicates were removed, 2,590 records were screened on title and abstract, of

which 2,548 were excluded. All 42 remaining reports were retrieved and assessed for eligibility, and 31 were excluded for the reasons given in Fig. 1. Altogether, 11 articles were eligible for data extraction, yielding 600 coordinates from 35 independent experiments (18 ASD, 17 TD). Schulte-Rüther et al. (2014) contributed two independent age-stratified subsamples (adolescents and adults), whose data were treated as separate experiments in the meta-analytic framework.

Inter-Rater Reliability and Consensus Process

Initial agreement between the human extractor and the AI system, before consensus, was Dice = 69.7% (Jaccard = 53.5%). A systematic comparison of discrepancies identified two sources of error: misassignment of coordinates to the wrong group column in multi-column tables (Greimel et al., 2010; Hadjikhani et al., 2014; Schulte-Rüther et al., 2014), and failure of standard PDF extraction to preserve the column structure of a landscape-format table spanning two pages (Schulte-Rüther et al., 2011), resolved by layout-preserving extraction. After correction, agreement was Dice = 95.7% (Jaccard = 91.8%), with sensitivity of 93.9% and precision of 96.5%; study-level Jaccard values ranged from 76% to 100%. The 29 remaining discrepancies across four studies were resolved by consensus against the source articles. Final adjudication rested with the human reviewer throughout: AI output was advisory, and no coordinate or study-level value entered the analysis without human confirmation against the source article. The full error taxonomy is reported in the Supplementary Material (S2.7).

Characteristics of Included Studies

The 11 included articles were published between 2010 and 2024 and were conducted in Germany, South Korea, and multi-site European collaborations across Switzerland, France and Sweden; study-level characteristics are given in Table 2. Participants ranged in age from childhood to adulthood, with weighted mean ages of 24.1 years in both groups (SD = 9.6 and

9.1), and full-scale IQ in the average range and comparable across groups (ASD: weighted $M = 109.2$, $N = 185$; TD: weighted $M = 111.3$, $N = 188$; individual-level SDs not consistently reported). The pool was predominantly male (ASD: 18.8% female; TD: 20.6% female): one study included only female participants (Stroth et al., 2019), three were approximately sex-balanced, six included only male participants, and one did not report sex distribution. All autistic participants had a diagnosis confirmed by ICD-10 and/or DSM-IV/DSM-5 criteria together with ADOS and/or ADI-R. Groups did not differ significantly in age or IQ (Table 1). Paradigms spanned three task families — emotional face attribution (five studies), vicarious pain and disgust perception (three), and second-order mental-state inference with affective content (three) — yielding 13 affective and 5 cognitive empathy experiments per group. Scanner field strengths ranged from 1.5T to 3T and all studies reported coordinates in MNI space (Table 2).

Quality Assessment

On the adapted Newcastle–Ottawa Scale, eleven of the twelve subsamples were rated good (total scores 6–9 of 9, median 7.5); the adult subsample of Schulte-Rüther et al. (2014) scored 6 and was rated moderate. All studies confirmed diagnosis using standardized instruments (ADOS and/or ADI-R) or explicit DSM/ICD criteria, reported and controlled for head motion, and reported coordinates in MNI space. The recurring limitations were small samples (four subsamples below 15 participants per group), incomplete reporting of screening in the non-autistic group (two studies) and of recruitment source (four studies), and matching on full-scale and verbal but not performance IQ in two studies. Nine studies applied whole-brain cluster- or voxel-level familywise error correction to the within-group contrasts from which coordinates were extracted; the two that reported those contrasts at uncorrected thresholds (Jeon et al., 2024; Kim et al., 2016) were retained, and their influence was examined in a

leave-two-out sensitivity analysis (Supplementary S4.3). Per-item ratings are given in Supplementary Table S3.

Convergent Activation During Empathy Processing in Autistic Participants

Activation likelihood estimation meta-analysis of within-group empathy-related activations in the autistic group (18 experiments, 253 foci from 11 studies) revealed seven clusters of statistically significant spatial convergence after cluster-level family-wise error correction ($p < .05$; Fig. 2A; Table 3). The most robust convergence was observed in the posterior midline, where a large bilateral cluster spanned the precuneus and posterior cingulate cortex. Bilateral convergence was also identified in the temporoparietal junction, extending into the angular gyrus — a canonical set of nodes implicated in self–other distinction, agency, and social attribution. Additional convergence emerged in the left inferior frontal gyrus, pars triangularis/pars opercularis, a region central to action–perception coupling and affective mirroring, and in a midline dorsomedial focus spanning the paracingulate cortex and pre-supplementary motor area. Convergence was further observed in the right cerebellum (Crus I/II), consistent with a growing recognition of cerebellar contributions to social cognition, and in the right middle temporal gyrus adjacent to the posterior superior temporal sulcus. Notably, no cluster of significant convergence emerged in the rostral dorsomedial or ventromedial prefrontal cortex — regions that constitute canonical hubs of the mentalizing network in typical development — a null finding that formed the most conspicuous departure from the parallel TD analysis (see below)

Convergent Activation During Empathy Processing in Non-Autistic Participants

The parallel analysis of the non-autistic group (17 experiments, 347 foci from 12 independent samples) yielded ten clusters of significant convergence (cluster-level FWE-corrected, $p < .05$; Fig. 2B; Table 4), revealing both commonalities with and departures from the autistic activation pattern. As in the autistic group, robust convergence was observed in the posterior

midline, where a large cluster centered on the precuneus and posterior cingulate cortex.

However, in marked contrast to the autistic group, a comparably large cluster of convergent activation was identified in the dorsomedial prefrontal cortex (peak: 0, 56, 24; 2,816 mm³), a region critical for mentalizing and self-other distinction that showed no supra-threshold convergence in the autistic group. A second midline dorsomedial focus was also detected more posteriorly in the superior frontal gyrus/pre-SMA.

The non-autistic group further showed bilateral convergence along the middle temporal gyrus adjacent to the superior temporal sulcus, regions central to the perception of biological motion and dynamic social signals. Bilateral inferior frontal gyrus convergence was observed in the pars triangularis, with a right-lateralized cluster and two overlapping left-hemisphere clusters spanning pars triangularis and the adjacent frontal orbital cortex. Additional TD-specific convergence was identified in the left anterior insula — a hub for affective sharing and interoceptive awareness - and in the left supramarginal gyrus, extending the parietal component of the empathy network.

Shared Empathy Network: Conjunction of ASD and TD Convergence

To identify regions of convergent activation common to both groups, we computed a conjunction using the minimum-statistic approach (Nichols et al., 2005), retaining only voxels significant in both the ASD and TD within-group cluster-level FWE-corrected maps ($p < .05$ each). Four clusters of overlapping convergence emerged (Fig. 3; Table 5): the posterior midline spanning the precuneus and posterior cingulate cortex, which was the largest; the right middle temporal gyrus adjacent to the posterior superior temporal sulcus; the left inferior frontal gyrus, pars triangularis; and a small dorsomedial frontal focus in the paracingulate cortex bordering the pre-supplementary motor area. Together these constitute a compact core of the mentalizing–empathy network engaged consistently across empathy-related tasks in both groups. Regions showing convergence only in the non-autistic group —

the rostral dorsomedial prefrontal cortex, the left anterior insula, and the left temporoparietal junction/supramarginal gyrus — were absent from the conjunction, identifying them as the principal loci of the between-group divergence tested below.

Between-Group Subtraction Analysis

To directly compare activation patterns between groups, we performed an ALE subtraction analysis with 10,000 permutations, restricted to the inclusive empathy-network mask (union of ASD and TD FWE-corrected maps; $p < .05$ uncorrected within-mask; Fig. 4; Table 6). This revealed a strongly asymmetric between-group divergence, with non-autistic comparison participants exhibiting greater convergence than autistic participants across a broad set of mentalizing and affective empathy nodes. The largest cluster of greater non-autistic convergence was located in the rostral dorsomedial prefrontal cortex, extending into the superior frontal gyrus — a region consistently implicated in cognitive empathy. Additional TD > ASD divergences were observed in the left anterior insula extending into the frontal orbital cortex, right inferior frontal gyrus, pars triangularis, left middle temporal gyrus / posterior superior temporal sulcus, left supramarginal gyrus, and the medial frontal pole, with smaller foci in the left precuneus, dorsomedial superior frontal/paracingulate cortex, posterior cingulate cortex, and right middle temporal gyrus.

Conversely, the ASD > TD contrast yielded only a single region of greater convergence in the autistic group, located in the right temporoparietal junction / angular gyrus (peak: 56, -56, 22; $z = 2.01$; 320 mm³). Together, these findings suggest that between-group divergence in empathy-related activation is markedly one-sided: whereas typically developing individuals recruit a broader mentalizing–affective network - including the rostral dorsomedial prefrontal cortex, anterior insula, and bilateral inferior frontal cortex - autistic individuals show enhanced convergence in only a single right temporoparietal region, potentially reflecting a

more circumscribed and lateralized engagement of social-attribution processes during empathy tasks.

Subgroup Analysis: Affective Empathy

To probe subdomain-specific patterns, we conducted parallel ALE analyses restricted to affective empathy experiments - encompassing vicarious pain, disgust, and emotional face-perception paradigms - comprising 13 ASD experiments (200 foci from 9 studies) and 12 TD experiments (273 foci from 9 studies; Fig. 5; Table 7). The autistic group yielded four clusters of significant convergence (cluster-level FWE-corrected, $p < .05$), centered on the left inferior frontal gyrus, pars triangularis, the right cerebellum, the left angular gyrus/temporoparietal junction, and the precuneus/posterior cingulate cortex. The non-autistic group showed a more distributed pattern of nine clusters, including the rostral dorsomedial prefrontal cortex, the precuneus/posterior cingulate cortex, the bilateral inferior frontal gyrus, pars triangularis, the left anterior insula, the left angular gyrus, and the bilateral middle temporal gyrus/posterior superior temporal sulcus, with an additional small midline focus in the brainstem region. The affective subdomain thus revealed shared engagement of the left inferior frontal gyrus, precuneus/PCC, and left angular gyrus across groups, alongside a broader TD-specific recruitment of the rostral dmPFC, anterior insula, right IFG, and bilateral posterior temporal cortex - canonical nodes of affect sharing and social perception that appear under-recruited in the autistic affective-empathy network.

Subgroup Analysis: Cognitive Empathy

The cognitive empathy subdomain - comprising paradigms requiring inference of others' mental or emotional states from affective content - was based on 5 ASD experiments (53 foci from 5 studies) and 5 TD experiments (74 foci from 5 studies; Fig. 6). This experiment count falls below the minimum of 17-20 experiments per group recommended for adequately powered coordinate-based meta-analysis (Eickhoff et al., 2016). Accordingly, no cluster

survived cluster-level FWE correction ($p < .05$) in either group. As formal ALE inference was not warranted, we present the descriptive spatial distribution of the input foci (Fig. 6), showing regions covered by at least two of the five studies within each group. Descriptive overlap was more compact and stronger in the non-autistic group, with the highest three-study convergence located in the left middle temporal gyrus/posterior superior temporal sulcus and the left precentral cortex, alongside two-study overlaps in the bilateral temporal poles, left inferior frontal gyrus, and left posterior cingulate cortex. The autistic group showed a more distributed pattern of weaker overlaps (maximum of two studies), distributed across the left angular gyrus, left temporal pole, left posterior cingulate cortex, right inferior frontal gyrus (pars opercularis), and right middle temporal gyrus, without a dominant convergence node.

Sensitivity Analyses

Leave-one-out (jackknife) analyses were conducted on the within-group meta-analyses, quantifying the proportional contribution of each experiment to each cluster. For the autistic group (18 experiments, 7 clusters), the maximum single-experiment contribution was 0.26 (Greimel et al., 2010, affective contrast, right middle temporal gyrus/pSTS), and no cluster exceeded 0.30. For the non-autistic group (17 experiments, 10 clusters), the maximum was 0.31 (Hadjikhani et al., 2014, left inferior frontal gyrus, pars orbitalis; Lassalle et al., 2019 contributed 0.30 to the pars triangularis cluster), reflecting moderate but non-dominant influence. No cluster in either group depended disproportionately on any single experiment, indicating that the within-group convergence patterns are not driven by outlier studies. Full jackknife contribution matrices are provided in Supplementary Tables S4 (ASD) and S5 (TD). In the leave-two-out analysis excluding the two studies that reported the within-group contrasts at uncorrected thresholds (Jeon et al., 2024; Kim et al., 2016), nine of the ten clusters in the non-autistic group and six of the seven in the autistic group were recovered at

$p < .05$ FWE, in most cases with a larger extent than in the primary analysis. In both groups, the exception was the dorsomedial frontal cluster (superior frontal gyrus / paracingulate cortex / pre-supplementary motor area), the cluster with the highest p-value in each primary analysis, indicating that convergence in this region is the least robust of the within-group findings (Supplementary S4.3).

Discussion

This is the first coordinate-based meta-analysis to characterize empathy-related activation within each group separately in autism, synthesizing 11 fMRI studies (12 independent samples, 35 experiments, 600 activation foci). Three findings emerged. First, autistic participants recruited a largely intact core empathy network. Second, the rostral dorsomedial prefrontal cortex, a canonical hub of the mentalizing network, converged reliably in non-autistic participants but not in the autistic group - the most prominent between-group difference in both the within-group maps and the direct subtraction. Third, subdomain analyses suggested that cognitive-empathy convergence is more markedly under-recruited than affective-empathy convergence, although the cognitive-empathy subgroup fell below the minimum experiment count for stable ALE inference and this finding is therefore descriptive (see Limitations).

The conjunction analysis revealed that the fundamental architecture of cognitive and affective empathy is broadly maintained in autism. Both groups showed convergent activation in the precuneus/PCC, the right MTG/pSTS, the left inferior frontal gyrus, and the dorsomedial paracingulate cortex bordering the pre-supplementary motor area. This finding aligns with behavioral evidence that autistic people retain the capacity for empathic responding under certain conditions (Hadjikhani et al., 2014) and challenges the view that empathy is categorically impaired in autism (Bird & Viding, 2014; Gernsbacher & Yergeau, 2019).

The most striking finding was the absence of significant ALE convergence in the rostral dorsomedial prefrontal cortex in the autistic group, against a prominent dmPFC cluster in non-autistic participants (peak: 0, 56, 24; 2,816 mm³). The subtraction analysis confirmed the dissociation: the largest cluster of greater non-autistic convergence lay in the same rostral dmPFC/superior frontal region (peak: 4, 48, 30; 1,392 mm³), with additional midline foci in the dorsomedial superior frontal/paracingulate cortex and medial frontal pole extending the divergence along the medial surface. The medial prefrontal cortex is consistently identified as a core region for mentalizing, self-referential processing and the representation of others' mental states, its ventral portion linked to affective mentalizing and its dorsal subdivision to more cognitive perspective-taking (Abu-Akel & Shamay-Tsoory, 2011; Amodio & Frith, 2006; Frith & Frith, 2006; Mitchell et al., 2006; Shamay-Tsoory et al., 2009). Reduced mPFC engagement during empathy tasks is consistent with individual studies reporting diminished mPFC activation during mentalizing (Klapwijk et al., 2016; Schulte-Rüther et al., 2011) and with the broader cortical midline deficit hypothesis of autism (Kennedy & Courchesne, 2008; Lombardo et al., 2010). It may reflect difficulty in the spontaneous generation of mental-state representations - a process thought to be relatively automatic in non-autistic people but to require more deliberate processing in autism (Senju et al., 2009).

Our results converge at the neural level with the classical dissociation in autism research, on which cognitive empathy is disproportionately affected while affective empathy is relatively preserved (Baron-Cohen & Wheelwright, 2004; Bzdok et al., 2012; Dziobek et al., 2008; Rogers et al., 2007; Schurz et al., 2021; Shamay-Tsoory, 2011). The affective-empathy subgroup, with comparable experiment counts across groups (13 ASD vs 12 TD), yielded a compact autistic network (left IFG, right cerebellum, left angular gyrus, precuneus/PCC) that partially overlapped the more distributed non-autistic pattern: spatially more restricted (four clusters versus nine), but retaining its core nodes. The cognitive-empathy subgroup yielded

no cluster surviving cluster-level FWE correction in either group (5 experiments per group; below the Eickhoff et al., 2016 minimum), so the comparison rests on descriptive study-overlap maps. Read with that caveat, the asymmetry was qualitatively striking: compact three-study overlap in the non-autistic group in the left posterior superior temporal sulcus and left precentral cortex, against diffuse two-study overlaps in the autistic group with no dominant convergence node. The component that diverges is also the one whose name is contested. Quesque et al. (2024) recommend discontinuing “cognitive empathy”, on the grounds that its consensual definition is largely indistinguishable from mentalizing, and reserving “empathy” for the vicarious sharing of another’s affective state; the recommendation concerns vocabulary rather than architecture. Read through that lexicon, the present pattern states more sharply: what diverges in autism is mentalizing about affective states, and what is preserved is empathy in the narrow sense. We keep the conventional labels here because they are the language of the studies synthesized.

The single region in which the autistic group exceeded non-autistic convergence - the right temporoparietal junction/angular gyrus (peak: 56, -56, 22) - is particularly noteworthy, and its precise location is informative. The right TPJ is not functionally homogeneous: connectivity-based parcellation separates an anterior subregion coupled to the ventral attention network from a posterior subregion coupled to the mentalizing and default-mode network (Krall et al., 2015). The present peak lies 6 mm from the posterior, mentalizing-linked center reported by Krall et al. and 13 mm from the anterior, attention-linked one; the corresponding within-group ASD cluster (54, -56, 24) lies closer still to the posterior center. Greater autistic convergence here therefore falls within the mentalizing system rather than outside it. Read together with the absent rostral dmPFC convergence, the between-group divergence is better described as a redistribution within the mentalizing network - away from its anterior medial hub and towards a posterior lateral node - than as the substitution of an

attentional route for a mentalizing one. This is consistent with accounts according to which autistic adults arrive at mental-state judgements by a different, more deliberate route within the same circuitry (Livingston & Happé, 2017), and may help explain why autistic adults often perform comparably to non-autistic peers on behavioral empathy measures while engaging these regions differently (Dapretto et al., 2006; Schulte-Rüther et al., 2011).

Two frameworks offer complementary readings. The alexithymia hypothesis (Bird & Cook, 2013) holds that lower affective empathy in autism is largely attributable to co-occurring alexithymia rather than to autism per se; consistent with this, affective-network convergence was substantially preserved in the autistic group and the between-group differences concentrated in mentalizing rather than affect-sharing hubs. Only two of the included studies assessed alexithymia, precluding stratified analysis. The double empathy problem (Milton, 2012) reframes empathy differences as bidirectional cross-neurotype communication difficulties rather than unilateral autistic deficits. Our design cannot test that account directly, but the finding that autistic participants engage the posterior right temporoparietal junction rather than medial mentalizing circuitry - a shift within the network rather than away from it - is compatible with a qualitatively different, rather than quantitatively deficient, strategy for interpreting social stimuli.

A secondary contribution is the demonstration that multi-agent AI systems can serve as auditable second reviewers at the full-text and data-extraction stages. Each candidate full text was assessed against the eligibility criteria by both the primary human reviewer and a multi-agent pipeline, which also served as an independent second extractor for coordinates and metadata; concordance was evaluated at both levels, and all disagreements were catalogued and adjudicated by the human reviewer. The relevant comparison is not with idealized dual-human extraction but with the single-extractor practice that predominates in coordinate-based meta-analysis, against which an independent second pass of any kind adds error detection that

would otherwise be absent. Such workflows may prove valuable for living reviews and large-scale syntheses where dual-human extraction is impractical (Khalil et al., 2022), provided they are reported transparently and benchmarked against human dual review — calibration that remains to be established.

Several limitations apply. Only 11 primary studies met the eligibility criteria, limiting power, and the cognitive-empathy subgroup (5 experiments per group) fell well below the Eickhoff et al. (2016) minimum for stable ALE inference, so those findings are presented descriptively; jackknife analyses nevertheless showed that no single experiment contributed disproportionately to any within-group cluster. The between-group subtraction was thresholded at $p < .05$ uncorrected within an inclusive empathy-network mask (Eickhoff et al., 2011) rather than at cluster-level FWE, and is therefore exploratory. The primary studies were heterogeneous in paradigm, stimulus modality, task instructions and analytic thresholds, introducing variance that ALE cannot fully partial out. Sex and age were unevenly distributed: seven of the twelve samples comprised exclusively or predominantly male participants and only one exclusively female participants, limiting inferences about autistic women and across the lifespan. Alexithymia was assessed in only a small minority of studies, precluding the stratified analyses that the Bird and Cook (2013) framework calls for, and demographic or clinical data were incompletely reported in several studies, preventing precise pooled estimates for some variables. Including only whole-brain, multiple-comparison-corrected coordinates may have excluded relevant activations from studies reporting exclusively ROI-based results. Our screening and extraction workflow used an AI rather than a second human reviewer; we publish its agreement statistics, error taxonomy and prompts precisely so that it can be benchmarked against human dual review, which remains to be done. Finally, ALE relies on reported peak coordinates rather than full statistical maps and does not account for effect sizes.

These limitations point to priorities for future work: adequately powered studies isolating cognitive empathy, standardized empathy paradigms and shared task batteries, deliberate recruitment of female and non-binary autistic participants across the lifespan, routine assessment of alexithymia with stratified reporting, and improved adherence to reporting standards (COBIDAS, PRISMA). Systematic sharing of unthresholded statistical maps (e.g., via NeuroVault) would further enable image-based syntheses that recover effect-size information (SDM-PSI; Albajes-Eizaguirre et al., 2019), and meta-analytic connectivity modeling would test whether regional convergence differences reflect altered large-scale dynamics.

Declarations

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Competing interests. The authors have no competing interests to declare, financial or non-financial, that are relevant to the content of this article.

Ethics approval. This study is a meta-analysis of previously published, aggregated data and did not involve the collection of new data from human participants; ethical approval was therefore not required. The review was conducted in accordance with the principles of the Declaration of Helsinki.

Consent to participate and consent to publish. Not applicable. No new data were collected from human participants, and the manuscript contains no data or images from which an individual could be identified.

Author contributions. Oksana I. Talantseva: conceptualization, methodology, systematic search and screening, data extraction, formal analysis, visualization, writing — original draft. Simone Shamay-Tsoory: conceptualization, methodology, supervision, funding acquisition, writing — review and editing. Both authors read and approved the final manuscript.

Registration. The review protocol was prospectively registered with PROSPERO (CRD420261346053) on 24 March 2026 and amended on 26 September 2026; the amendment record documents each change.

Data availability. Thresholded and unthresholded statistical maps for all analyses are openly available in NeuroVault at <https://identifiers.org/neurovault.collection:24607>. The full analysis dataset — study characteristics, experiment-level coding and extracted peak coordinates — together with the screening log and codebook, is openly available on the Open Science Framework at <https://osf.io/jbfsx/>. No new primary data were collected.

Code availability. The analysis code is available from the corresponding author on reasonable request.

Use of artificial intelligence. A multi-agent artificial intelligence pipeline, built on Anthropic Claude models, was used as an independent second reviewer at the full-text screening and coordinate-extraction stages, as described in the Methods. All decisions were adjudicated by the first author against the source publications; agreement statistics, the error taxonomy and the agent specifications are reported in the Supplementary Material. No AI tool was used to generate or write the content of this manuscript.

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Table 1*Pooled Demographic Characteristics of ASD and TD Groups*

Characteristic	ASD (<i>k</i> = 12)	TD (<i>k</i> = 12)	Comparison
Total sample size (<i>N</i>)	213	216	—
Age, <i>M</i> (<i>SD</i>), years	24.10 (9.60)	24.10 (9.10)	$t(373) = 0.00, p = .99$
Age range across samples, years	12.4–32.7	11.7–34.3	—
Age <i>n</i> available	186	189	—
Full-scale IQ, weighted <i>M</i>	109.20	111.30	$t(371) = -1.87, p = .06$
IQ range across sample means	105.9–117.5	102.4–116.8	—
IQ <i>n</i> available	185	188	—
Sex, <i>n</i> female (%)	35 (18.8)	39 (20.6)	$\chi^2(1) = 0.20, p = .65$
Sex <i>n</i> available	186	189	—
Diagnostic criteria	ICD-10 and/or DSM-IV/DSM-5	—	—
Diagnostic instruments	ADOS and/or ADI-R (11/11 studies)	—	—

Note. Weighted means computed with sample size (*N*) as weight, per Cochrane conventions. Pooled SD for age computed using within-study SDs where reported. Individual-level SDs for IQ were not consistently reported across primary studies; comparability inferred from convergent sample means in the average range. Schulte-Rüther et al. (2014) contributed two age-stratified subsamples (adolescents, adults); their age data were not separately reported and are therefore excluded from the age *N*. Schneider et al. (2013) did not report IQ. Statistical tests are illustrative approximations based on aggregate values; formal between-group comparisons at the individual participant level were not possible from published summary data. *k* = number of independent samples contributing to the pool; *N* = total number of participants; n.s. = not significant.

Table 2*Characteristics of Studies Included in the Meta-Analysis*

Study	Country	<i>n</i> (ASD/TD)	Age ASD, <i>M</i> (<i>SD</i>)	Age TD, <i>M</i> (<i>SD</i>)	IQ ASD, <i>M</i>	IQ TD, <i>M</i>	% Female (ASD/TD)	Diagnosis	Task/Paradigm	Empathy Type	Scanner	Software	FWHM (mm)	<i>k</i> (ASD/TD)	Foci (ASD/TD)
Greimel et al. (2010)	Germany	15/15	14.90 (1.60)	15.00 (1.40)	109.90	112.70	0/0	ICD-10, DSM-IV; ADOS, ADI-R	Empathy for emotional faces	Aff, Cog	1.5T Siemens Avanto	SPM5	8	2/2	36/38
Schulte-Rüther et al. (2011)	Germany	14/14	27.40 (9.30)	25.10 (6.70)	106.60	112.10	0/0	ICD-10, DSM-IV; ADOS	Empathy for emotional faces	Aff, Cog	1.5T Siemens Avanto	SPM5	8	2/2	25/26
Schneider et al. (2013)	Germany	28/28	32.73 (9.97)	34.27 (9.73)	NR	NR	46.4/46.4	DSM-IV; ADOS	Dynamic emotional video task	Aff	3T Siemens Trio	SPM8	8	1/1	10/7
Hadjikhani et al. (2014)	Switzerland	36/31	23.50 (8.70)	22.50 (7.50)	107.40	112.90	8.3/9.7	DSM-IV- TR; ADI- R	Empathy for pain (facial expressions)	Aff	3T Siemens Tim Trio	SPM8	8	1/1	37/41
Schulte-Rüther et al. (2014) — children	Germany	15/15	NR	NR	107	111	NR	ICD-10, DSM-IV; ADOS	Empathy for emotional faces (self-task)	Aff	1.5T Siemens Avanto	SPM5	8	1/1	25/35
Schulte-Rüther et al. (2014) — adults	Germany	12/12	NR	NR	107	111	NR	ICD-10, DSM-IV; ADOS	Empathy for emotional faces (self-task)	Aff	1.5T Siemens Avanto	SPM5	8	1/1	30/13
Krach et al. (2015)	Germany	16/16	21.50 (2.90)	20.90 (1.80)	117.50	116.80	0/0	DSM-IV, ICD-10; ADOS	Vicarious pain & social embarrassment	Aff	3T Siemens Trio	SPM8	8	3/2	16/28
Kim et al. (2016)	South Korea	12/12	12.40 (2.30)	11.70 (2.10)	107.30	112.50	8.3/0	DSM-IV; ADOS, ADI-R	Yoni task (affective ToM)	Cog	3T Philips Achieva	SPM8	6	1/1	11/12
Rosenblau et al. (2016)	Germany	20/22	31.80 (9.30)	31.30 (8.50)	110.80	110.80	30.0/27.3	DSM-IV; ADOS, ADI-R	Naturalistic mentalising task	Cog	3T Siemens Tim Trio	FSL FEAT	8	1/1	4/15
Lassalle et al. (2019)	Switzerland, France	19/20	25.27 (8.83)	24.15 (7.57)	111.21	111.85	10.5/15.0	DSM-IV- TR; ADOS-G, ADI-R	Pain/disgust observation	Aff	3T Siemens Tim Trio	SPM8	8	1/1	20/88
Stroth et al. (2019)	Germany	9/9	18.70 (4.90)	19.90 (3.60)	112	113	100/100	ICD-10, DSM-IV;	Empathy for social/physical pain	Aff	3T Siemens Trio	SPM8	8	2/2	3/12

								ADOS, ADI-R							
Jeon et al. (2024)	South Korea	17/22	20.24 (2.92)	22.27 (3.57)	105.92	102.39	5.9/22.7	DSM- IV/DSM- 5; ADOS- 2	Pain perspective- taking	Aff, Cog	3T Philips Achieva	SPM12	8	2/2	36/32

Note. Age values are means with standard deviations in parentheses. IQ values are means; individual-level SDs were not consistently reported. Schulte-Rüther et al. (2014) contributed two age-stratified subsamples (adolescents and adults), which were treated as independent experiments in the meta-analytic pool. k = number of experiments (contrasts) contributed to the meta-analysis. Foci = number of activation peaks entered into the ALE. Empathy Type follows a binary taxonomy (Bzdok et al., 2012; Schurz et al., 2021): Aff = affective empathy (including vicarious pain, embarrassment, and disgust); Cog = cognitive empathy (mental-state inference from affective content). NR = not reported. Diagnostic instruments: ADOS = Autism Diagnostic Observation Schedule; ADI-R = Autism Diagnostic Interview–Revised. All studies used whole-brain analyses with multiple-comparisons correction and reported coordinates in MNI space. ToM = theory of mind; FWHM = full width at half maximum; SPM = Statistical Parametric Mapping; FSL = FMRIB Software Library; ASD = autism spectrum disorder; TD = typically developing

Table 3*Significant ALE Clusters for ASD Within-Group Empathy-Related Activations*

Cluster	Brain region	Hemisphere	BA	MNI <i>x</i>	MNI <i>y</i>	MNI <i>z</i>	<i>p</i> _{FWE}	Cluster size (mm ³)
1	Precuneus / Posterior cingulate cortex	L/R (midline)	7/31	0	−54	32	<.001	2,152
2	Angular gyrus / Temporoparietal junction	L	39/40	−50	−58	26	<.001	1,720
3	Angular gyrus / Temporoparietal junction	R	39/40	54	−56	24	.024	1,224
4	Inferior frontal gyrus, pars triangularis/opercularis	L	44/45	−48	26	4	.002	1,120
5	Paracingulate / Pre-supplementary motor area (dorsomedial frontal)	L/R (midline)	6/8/32	−6	16	46	.039	1,032
6	Cerebellum (Crus I/II)	R	—	26	−82	−36	<.001	984
7	Middle temporal gyrus / posterior superior temporal sulcus	R	21/37	60	−38	−2	.011	728

Note. Clusters are listed in descending order of volume. ALE was performed in NiMARE 0.20.0 (18 experiments, 253 foci, 11 studies) with 10,000 permutations, a cluster-forming threshold of $p < .001$ uncorrected and a cluster-level threshold of $p < .05$ FWE-corrected; clusters < 100 mm³ are not reported. Coordinates are those of the peak ALE voxel, in MNI space. *p*_{FWE} is the cluster-level family-wise error-corrected *p*-value for the cluster as a whole; $< .001$ denotes the resolution limit of the permutation distribution. Anatomical labels follow the Harvard–Oxford Cortical Atlas and the SPM Anatomy Toolbox; BA assignments are approximate. — = not applicable. ALE = activation likelihood estimation; ASD = autism spectrum disorder; BA = Brodmann area; FWE = family-wise error; MNI = Montreal Neurological Institute; L = left; R = right

Table 4*Significant ALE Clusters for TD Within-Group Empathy-Related Activations*

Cluster	Brain region	Hemisphere	BA	MNI <i>x</i>	MNI <i>y</i>	MNI <i>z</i>	<i>p</i> _{FWE}	Cluster size (mm ³)
1	Precuneus / Posterior cingulate cortex	L/R (midline)	7/31	0	−52	30	<.001	2,904
2	Dorsomedial prefrontal cortex	L/R (midline)	9/10	0	56	24	<.001	2,816
3	Middle temporal gyrus / posterior superior temporal sulcus	L	21/22	−58	−42	−2	<.001	1,416
4	Inferior frontal gyrus, pars triangularis	R	45/47	52	30	−6	<.001	1,216

5	Inferior frontal gyrus, pars orbitalis / frontal orbital cortex	L	47	-46	26	-8	.024	1,120
6	Middle temporal gyrus / posterior superior temporal sulcus	R	21/22	56	-38	-2	<.001	1,088
7	Anterior insula	L	13/47	-28	24	0	<.001	976
8	Superior frontal gyrus / pre-supplementary motor area	L/R (midline)	6/8	-4	26	46	.049	864
9	Supramarginal gyrus	L	40	-60	-46	32	.007	856
10	Inferior frontal gyrus, pars triangularis	L	45	-54	24	8	.025	656

Note. Clusters are listed in descending order of volume. ALE was performed in NiMARE 0.20.0 (17 experiments, 347 foci, 12 independent samples) with 10,000 permutations, a cluster-forming threshold of $p < .001$ uncorrected and a cluster-level threshold of $p < .05$ FWE-corrected; clusters $< 100 \text{ mm}^3$ are not reported. Coordinates are those of the peak ALE voxel, in MNI space. p_{FWE} is the cluster-level family-wise error-corrected p-value for the cluster as a whole; $< .001$ denotes the resolution limit of the permutation distribution. Anatomical labels follow the Harvard–Oxford Cortical Atlas and the SPM Anatomy Toolbox; BA assignments are approximate. ALE = activation likelihood estimation; BA = Brodmann area; FWE = family-wise error; MNI = Montreal Neurological Institute; TD = typically developing; L = left; R = right

Table 5

Conjunction of ASD and TD Within-Group Empathy-Related Convergence

Cluster	Brain region	Hemisphere	BA	MNI x	MNI y	MNI z	p_{FWE}	Cluster size (mm^3)
1	Precuneus / Posterior cingulate cortex	L/R (midline)	7/31	0	-52	30	<.001	1,256
2	Middle temporal gyrus / posterior superior temporal sulcus	R	21/22	58	-38	-2	.011	512
3	Inferior frontal gyrus, pars triangularis	L	45	-52	24	8	.025	224
4	Paracingulate cortex / pre-supplementary motor area	L/R (midline)	8/32	-4	20	46	.049	88

Note. Clusters are listed in descending order of volume. The conjunction was computed as the voxelwise minimum of the two within-group cluster-level FWE-corrected maps (Nichols et al., 2005), each thresholded at $p < .05$ FWE-corrected with a cluster-forming threshold of $p < .001$ uncorrected. Coordinates are those of the peak voxel of the conjunction, in MNI space. p_{FWE} is the less significant of the two groups' cluster-level corrected p values at that location

and therefore bounds the evidence that both groups converge there; $< .001$ denotes the resolution limit of the permutation distribution. Cluster size refers to the volume of overlap between the two within-group maps and is necessarily smaller than the corresponding cluster in either group alone. Anatomical labels follow the Harvard–Oxford Cortical Atlas and the SPM Anatomy Toolbox; BA assignments are approximate. ASD = autism spectrum disorder; BA = Brodmann area; FWE = family-wise error; MNI = Montreal Neurological Institute; TD = typically developing; L = left; R = right.

Table 6

ALE Subtraction Clusters Between the TD and ASD Groups

Cluster	Brain region	Hemisphere	BA	MNI x	MNI y	MNI z	Peak z	Cluster size (mm ³)
TD > ASD 1	Superior frontal gyrus / rostral dorsomedial prefrontal cortex	L/R (midline)	9	4	48	30	2.85	1,392
TD > ASD 2	Anterior insula / frontal orbital cortex	L	13/47	-26	20	0	2.52	776
TD > ASD 3	Inferior frontal gyrus, pars triangularis	R	45/47	56	26	2	2.70	480
TD > ASD 4	Middle temporal gyrus / posterior superior temporal sulcus	L	22/21	-56	-44	0	2.47	424
TD > ASD 5	Supramarginal gyrus, posterior division	L	40	-60	-50	34	2.10	408
TD > ASD 6	Frontal pole, medial	L/R (midline)	10	-8	60	12	2.30	296
TD > ASD 7	Precuneus	L	31/7	-10	-60	30	2.10	248
TD > ASD 8	Superior frontal gyrus / paracingulate cortex	L/R (midline)	8	-2	28	46	2.22	224
TD > ASD 9	Posterior cingulate cortex	L/R (midline)	31/23	-2	-44	28	1.81	112
TD > ASD 10	Middle temporal gyrus, posterior division	R	22	52	-38	-2	1.73	104
ASD > TD 1	Angular gyrus / temporoparietal junction	R	39/22	56	-56	22	2.01	320

Note. The subtraction analysis was based on 10,000 permutations of experiment labels and was thresholded at $p < .05$ uncorrected within an inclusive mask comprising voxels significant in either within-group analysis, with a minimum extent of 100 mm³. This threshold is less stringent than the cluster-level FWE correction applied in Tables 3–5, and these results are therefore exploratory; peak z values are not comparable with the cluster-level values reported in those tables. The direction of each contrast is given in the first column. Coordinates are those of the peak voxel, in MNI space. Peak z is the voxelwise z statistic of

the subtraction, indexing the difference in convergence between groups rather than a difference in activation magnitude. Anatomical labels follow the Harvard–Oxford Cortical Atlas and the SPM Anatomy Toolbox; BA assignments are approximate. ALE = activation likelihood estimation; ASD = autism spectrum disorder; BA = Brodmann area; MNI = Montreal Neurological Institute; TD = typically developing; L = left; R = right

Table 7

Significant ALE Clusters for the Affective-Empathy Subgroup Analysis, by Group

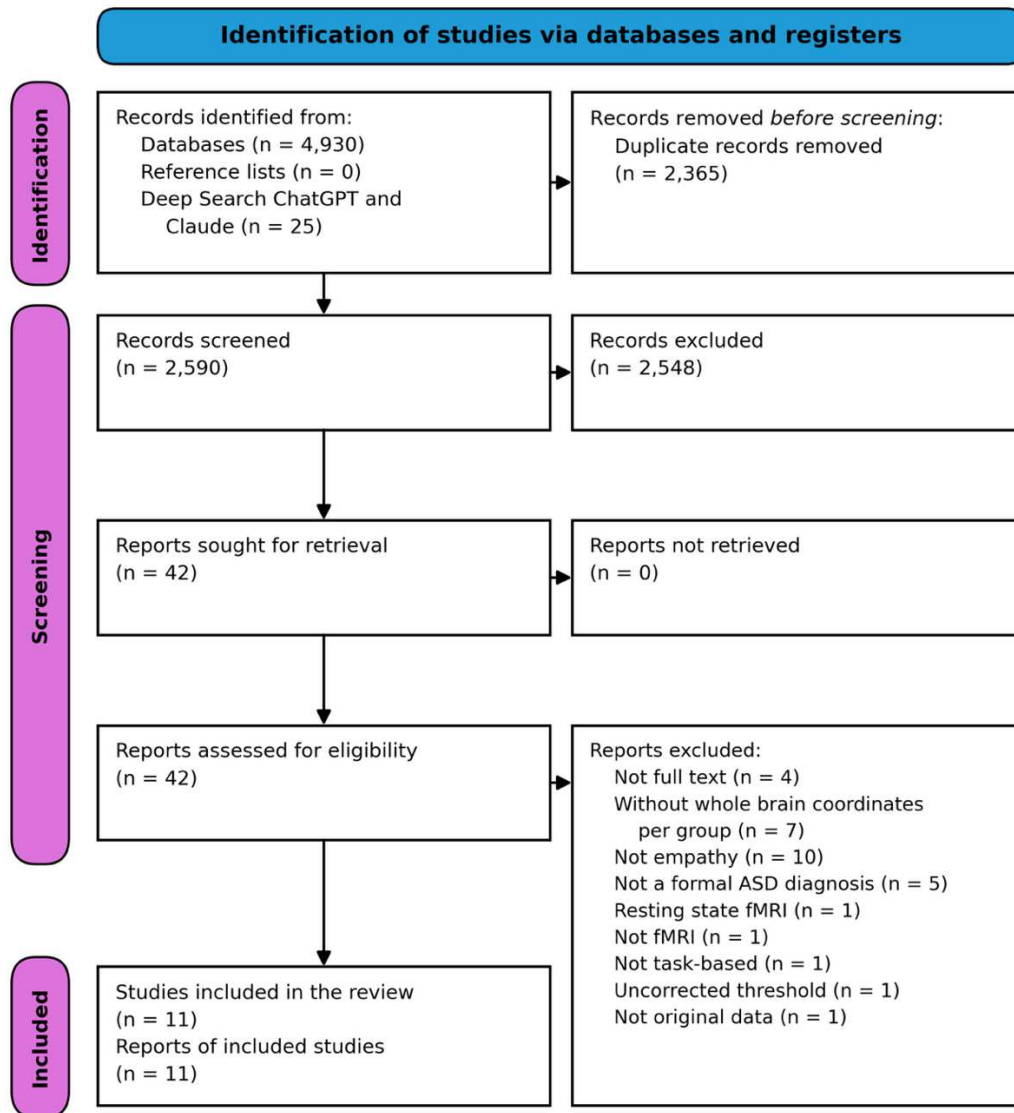
Cluster	Brain region	Hemisphere	BA	MNI x	MNI y	MNI z	p_{FWE}	Cluster size (mm ³)
ASD 1	Inferior frontal gyrus, pars triangularis	L	45/47	−48	26	4	<.001	1,328
ASD 2	Cerebellum (Crus I/II)	R	—	26	−82	−36	<.001	1,120
ASD 3	Angular gyrus / temporoparietal junction	L	39	−50	−58	26	.014	1,008
ASD 4	Precuneus / Posterior cingulate cortex	L/R (midline)	7/31	0	−54	32	.013	984
TD 1	Rostral dorsomedial prefrontal cortex	L/R (midline)	9	−4	54	28	<.001	2,032
TD 2	Precuneus / Posterior cingulate cortex	L/R (midline)	7/31	−2	−54	32	<.001	1,624
TD 3	Inferior frontal gyrus, pars triangularis	L	45	−52	26	6	.002	1,136
TD 4	Inferior frontal gyrus, pars triangularis	R	47	52	30	−6	<.001	960
TD 5	Anterior insula	L	13/47	−28	26	0	.002	864
TD 6	Angular gyrus	L	39	−46	−56	26	.029	736
TD 7	Middle temporal gyrus / posterior superior temporal sulcus	R	22/21	56	−36	−2	.026	648
TD 8	Middle temporal gyrus / posterior superior temporal sulcus	L	21	−60	−42	−4	.043	632
TD 9	Brainstem	L/R (midline)	—	0	−30	−6	.038	624

Note. Clusters are listed in descending order of volume within each group. ALE was performed in NiMARE 0.20.0 for the affective-empathy subgroup (ASD: 13 experiments, 200 foci, 9 studies; TD: 12 experiments, 273 foci, 9 studies) with 10,000 permutations, a cluster-forming threshold of $p < .001$ uncorrected and a cluster-level threshold of $p < .05$ FWE-corrected. Coordinates are those of the peak ALE voxel, in MNI space. p_{FWE} is the cluster-level family-wise error-corrected p-value for the cluster as a whole; <.001 denotes the resolution limit of the permutation distribution. Anatomical labels follow the Harvard–Oxford Cortical Atlas and the SPM Anatomy Toolbox; BA assignments are approximate. ALE =

activation likelihood estimation; ASD = autism spectrum disorder; BA = Brodmann area; FWE = family-wise error; MNI = Montreal Neurological Institute; TD = typically developing; L = left; R = right.

Fig. 1

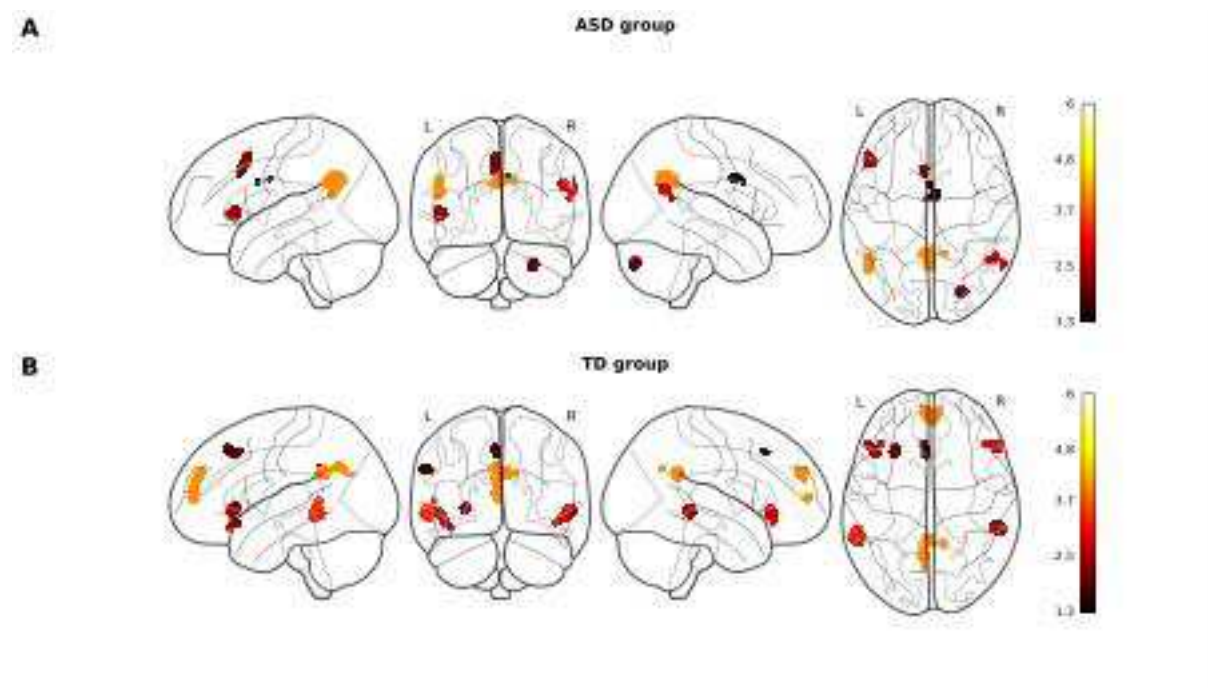
PRISMA 2020 Flow Diagram of the Study Selection Process



Note. Counts reflect records identified through database searching (PubMed, Web of Science, Scopus), reference-list checking, and AI-assisted deep search; duplicates removed before screening; and reasons for exclusion at full-text assessment.

Fig. 2

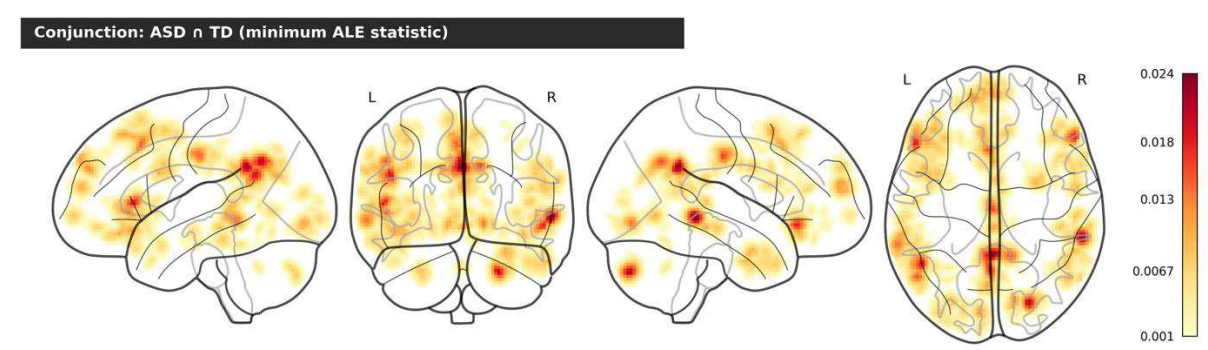
Convergent Activation During Empathy-Related Tasks in the ASD and TD Groups



Note. (A) ASD group; (B) TD group. Results of ALE meta-analysis, thresholded at cluster-level family-wise error (FWE) corrected $p < .05$ (cluster-forming threshold $p < .001$ uncorrected). Glass brain projections display sagittal (left hemisphere), coronal, sagittal (right hemisphere), and axial views. Color intensity reflects $-\log_{10}(p)$ values. The ASD group showed convergent activation in the bilateral temporoparietal junction, precuneus/posterior cingulate cortex, left inferior frontal gyrus, right middle temporal gyrus, right cerebellum, and dorsomedial frontal cortex (paracingulate/pre-SMA), but not in the rostral medial prefrontal cortex commonly associated with mentalizing. The TD group showed convergence in the precuneus/posterior cingulate cortex, rostral dorsomedial prefrontal cortex, bilateral inferior frontal gyrus, bilateral middle/superior temporal gyri (STS-adjacent), left anterior insula, and left supramarginal gyrus.

Fig. 3

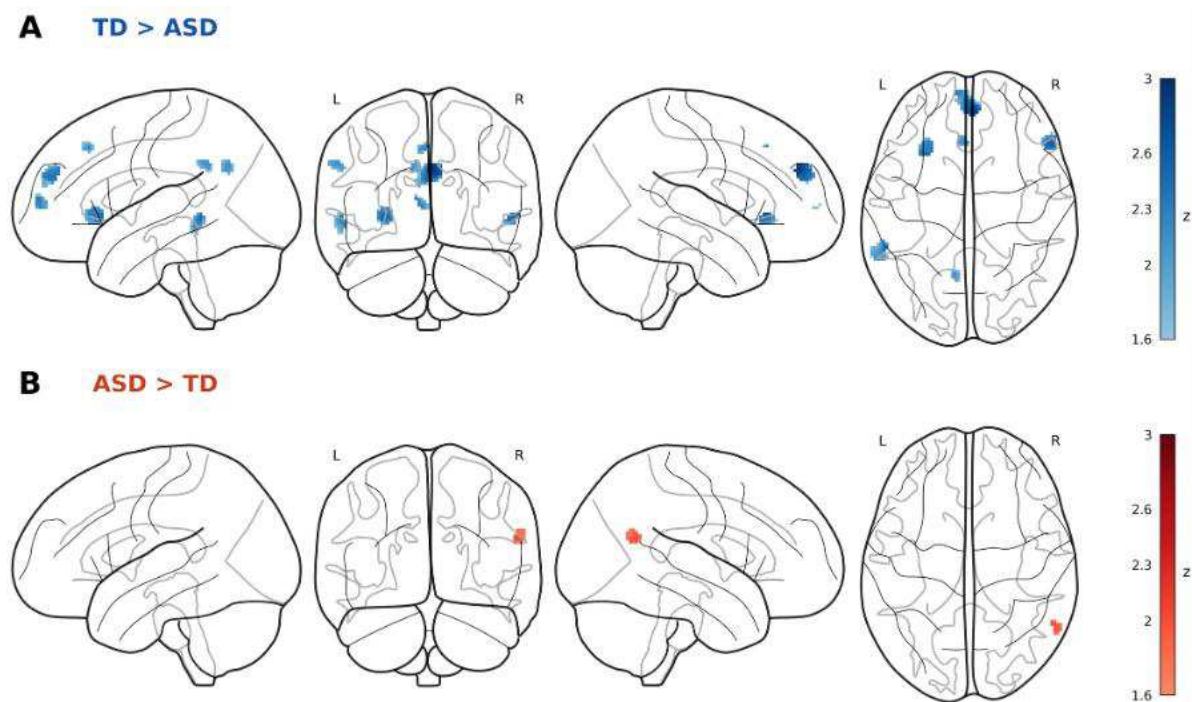
Conjunction of Empathy-Related Activations in the ASD and TD Groups



Note. Glass brain projections display regions of spatially convergent activation common to both groups, computed using the minimum-statistic approach (Nichols et al., 2005). Color intensity reflects the minimum ALE value across the two group maps, thresholded at $ALE > 0.001$. Regions of shared convergence include the precuneus/posterior cingulate cortex, right middle temporal gyrus/posterior superior temporal sulcus, left inferior frontal gyrus, and dorsomedial paracingulate cortex, indicating that a core posterior-midline and left inferior frontal component of the empathy network is preserved in ASD.

Fig. 4

Between-Group Differences in Empathy-Related Activation Convergence

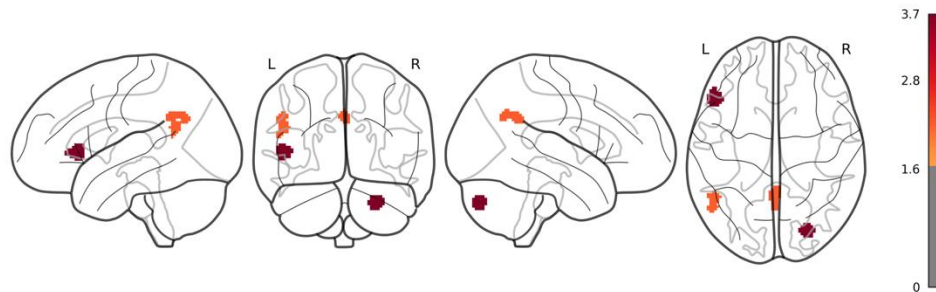


Note. ALE subtraction analysis (10,000 permutations) restricted to an inclusive empathy-network mask (union of the ASD and TD cluster-level FWE-corrected maps), thresholded at $p < .05$ uncorrected within the mask with a minimum cluster extent of 100 mm^3 . Glass-brain projections show sagittal (left hemisphere), coronal, sagittal (right hemisphere), and axial views; color indicates the subtraction z-score (display range 1.6–3.0), and circles mark the peak of the largest cluster in each contrast. **(A)** Greater convergence in typically developing controls than in ASD participants, in ten clusters: rostral dorsomedial prefrontal cortex extending into the superior frontal gyrus, left anterior insula extending into the frontal orbital cortex, right inferior frontal gyrus, pars triangularis, left middle temporal gyrus / posterior superior temporal sulcus, left supramarginal gyrus, and the medial frontal pole, with smaller foci in the left precuneus, dorsomedial superior frontal/paracingulate cortex, posterior cingulate cortex, and right middle temporal gyrus. **(B)** Greater convergence in ASD participants than in controls, in a single cluster surviving the extent criterion, in the right temporoparietal junction/angular gyrus.

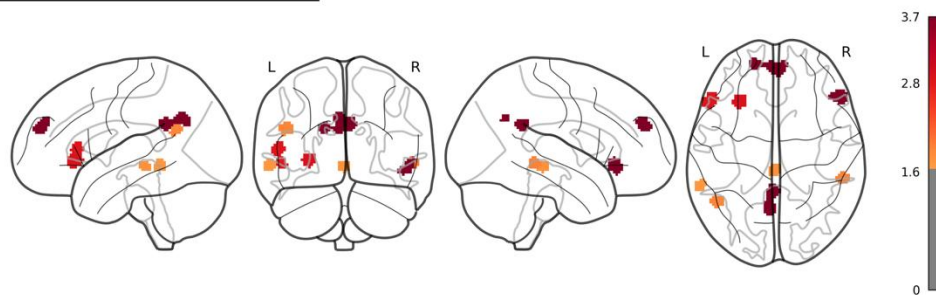
Fig. 5

Convergent Activation in the Affective-Empathy Subgroup Analysis

ASD Affective Empathy ALE (FWE cluster $p < 0.05$)



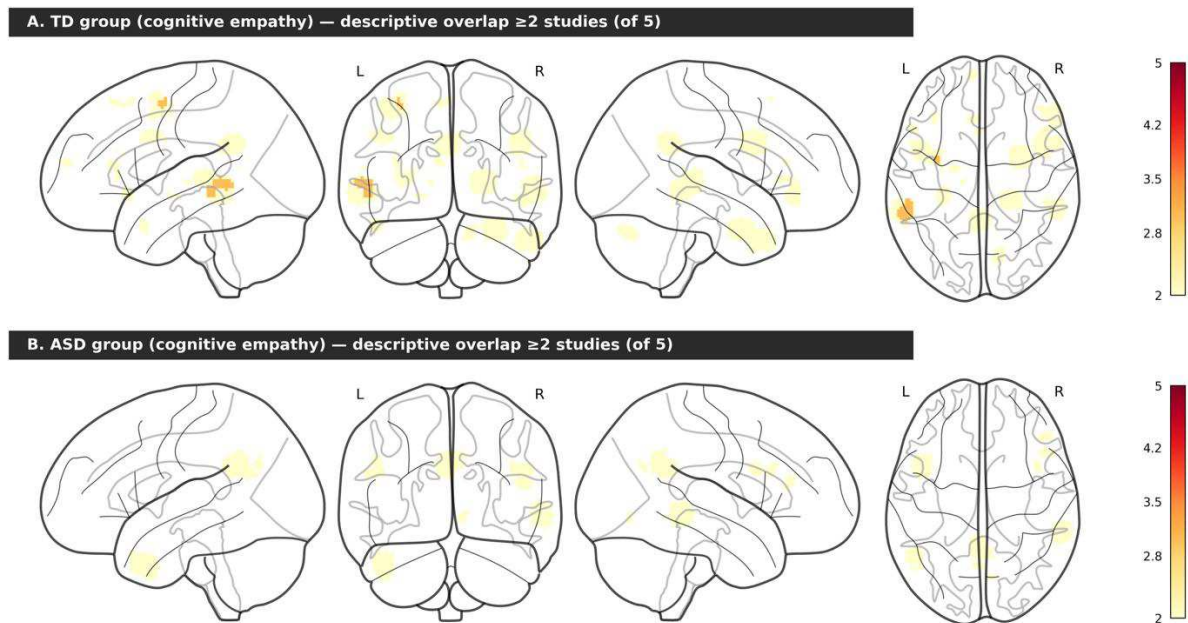
TD Affective Empathy ALE (FWE cluster $p < 0.05$)



Note. (A) ASD group (13 experiments, 200 foci, 9 studies); (B) TD group (12 experiments, 273 foci, 9 studies). Analyses were restricted to experiments using vicarious pain, disgust, and emotional face-perception paradigms, and were thresholded at cluster-level FWE-corrected $p < .05$ (cluster-forming threshold $p < .001$ uncorrected). Glass-brain projections display sagittal (left hemisphere), coronal, sagittal (right hemisphere), and axial views; color intensity reflects the cluster-level z value. The ASD group yielded four clusters, centered on the left inferior frontal gyrus pars triangularis, the right cerebellum, the left angular gyrus / temporoparietal junction, and the precuneus/posterior cingulate cortex. The TD group yielded nine clusters, including the rostral dorsomedial prefrontal cortex, the precuneus/posterior cingulate cortex, the bilateral inferior frontal gyrus pars triangularis, the left anterior insula, the left angular gyrus, and the bilateral middle temporal gyrus/posterior superior temporal sulcus.

Fig. 6

Descriptive Spatial Overlap of Activation Foci from Cognitive-Empathy Experiments



Note. (A) TD group; (B) ASD group. Because the cognitive-empathy pool was underpowered for formal ALE inference (5 experiments per group; below the Eickhoff et al., 2016 minimum), no cluster survived FWE correction; the maps therefore show the count of studies (out of five per group) whose activation foci fell within each 8-mm sphere, thresholded at ≥ 2 studies for visualization. Color intensity reflects the number of overlapping studies. The TD group showed more compact convergence, with the peak overlap (three of five studies) located in the left middle temporal gyrus/posterior superior temporal sulcus and left precentral cortex, alongside two-study overlaps in the bilateral temporal poles, left inferior frontal gyrus, and left posterior cingulate cortex. The ASD group showed a more distributed and weaker pattern (maximum of two overlapping studies), with foci in the left angular gyrus, left temporal pole, left posterior cingulate cortex, right inferior frontal gyrus (pars opercularis), and right middle temporal gyrus, without a dominant convergence node.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryMaterial.docx](#)