IOSR Journal of Humanities and Social Science (IOSR-JHSS)
Volume 30, Issue 5, Series 2 (May, 2025) 82-86
e-ISSN: 2279-0837, p-ISSN: 2279-0845.
www.iosrjournals.org

Network-Level Insights into Affective & Cognitive Empathy

Naisargi Patel

I. Introduction

Empathy involves at least two partially dissociable processes. Affective empathy**,** the sharing of another's feeling state, has been linked to anterior insula, cingulate, and inferior frontal territories within the salience system, while cognitive empathy**,** reasoning about others' beliefs and intentions, engages medial prefrontal, temporo-parietal, and precuneus hubs of the default-mode network, with support from frontoparietal control circuits. A network perspective is therefore appropriate: rather than treating these regions in isolation, we examine how large-scale systems interact and reconfigure during socially meaningful events and how individual differences map onto intrinsic connectivity.

Building on this premise, the paper integrates three complementary lines of evidence. First, we review dynamic network states**,** emphasizing alternation between segregated communities and short-lived integrated configurations that facilitate cross-system exchange. Second, we consider naturalistic paradigms in which continuous, socially rich films are paired with graph-learning methods to estimate time-varying connectomes; spectral filtering and inter-subject neural synchrony provide additional, data-driven markers of empathic processing. Third, we draw on trait and developmental findings that relate empathy dimensions to default-mode, salience, and control networks, supplying targets for hypothesis testing.

To make these ideas concrete, the paper includes a focused case study using movie-viewing fMRI that (i) quantifies integration–segregation trajectories, (ii) applies sparsity-regularized graph learning to identify empathy-linked couplings (e.g., insula, amygdala, thalamus, angular gyrus), and (iii) evaluates inter-brain synchrony during shared narrative segments. A final section details analytical pitfalls and robustness checks, windowing choices, parcellation and sparsity sensitivity, motion control, and stimulus-feature confound, before the conclusion synthesizes implications for studying affective versus cognitive empathy at the network level.

Naturalistic fMRI and Graph-Learning Approaches to Empathy

Naturalistic paradigms use socially rich, continuous stimuli to track how empathic processes unfold across large-scale systems. These designs complement resting-state findings that tie individual differences in empathy to intrinsic coupling among cortical hubs in default-mode, salience, and frontoparietal networks. For example, in a resting-state fMRI study with 10 adults, cognitive empathy (IRI-PT; M = 17.3, SD = 4.7) showed a positive association with activation in superior medial frontal cortex within the DMN, whereas emotional empathy (IRI-EC; M = 16.7, SD = 3.5) was negatively associated in the same territory; peak Z-scores reached ~4.05 with bilateral clusters (59–119 voxels). Developmental work likewise motivates network-level interpretation: in a community sample of 112 adolescents (mean age 14.59 ± 1.35), validated scales showed reliable measurement (IRI subscales $\alpha = .74/.79$; CDI total $\alpha = .84$), providing a basis for linking empathic traits to connectivity patterns relevant for socio-emotional outcomes.

Time-resolved analyses indicate that large-scale networks alternate between segregated and more globally integrated configurations; integrated states support faster and more accurate performance and covary with pupil dilations, consistent with Neuromodulatory engagement. Placing empathy in this dynamic context suggests that transitions between affective sharing and higher-order mentalizing reflect reconfigurations among salience, default-mode, and control systems during continuous, socially meaningful input.

Recent graph-learning pipelines operationalize these ideas in movie-viewing fMRI. In one study with 14 healthy volunteers, signals from 54 AAL regions were clustered and fed into a sparsity-based, windowed graph-learning model that achieved >88% accuracy in tracking fluctuations in emotion contagion across two short films. Temporal and spectral analyses converged on the insula, amygdala, thalamus, and angular gyrus as pivotal contributors during empathy-high segments, with band-pass filtering sharpening identification of empathy-linked coupling.

Trait-level topology offers complementary constraints for naturalistic designs. In a larger fMRI sample (N = 116), subscales capturing vicarious experience and intuitive understanding were moderately correlated (r = 0.315), and graph-theoretic measures indicated that vicarious experience related to frontoparietal centrality whereas intuitive understanding linked to sensorimotor and subcortical modules; salience-network nodes emerged as hubs for information exchange across dimensions, with several sex-dependent effects. These patterns help specify a priori network hypotheses for scene-locked tests in naturalistic tasks.

Dynamic Network States and Empathic Processing

Large-scale brain networks switch between periods of segregation and episodes of broad integration. Integrated episodes enable efficient cross-system communication, whereas segregated periods favor local specialization. Work on network dynamics links these shifts to Neuromodulatory influences and shows that they are time-resolved rather than random.

In empathy, affective sharing is often anchored in anterior insula and cingulate components of the salience system, while mentalizing engages medial prefrontal, temporo-parietal, and precuneus nodes within the default-mode network, with control contributions from frontoparietal circuits. Resting-state and developmental studies report associations between individual differences in empathy and intrinsic coupling among these hubs; in children, higher affective empathy has been related to lower default-mode connectivity across key nodes.

Naturalistic fMRI evaluates these links during continuous, socially rich films. With graph-learning, we derive time-varying connectomes from the viewing runs and identify empathy-related coupling among the insula, amygdala, thalamus, and angular gyrus. Spectral filtering helps isolate frequency bands that follow moment-to-moment shifts in emotion contagion. Paired with inter-subject neural synchrony, this approach enables a direct, network-level comparison of affective and cognitive empathy and provides a clear basis for the case study.

Case Study: Naturalistic Movie-Viewing fMRI and Empathic Network Dynamics

Case Description

We examine responses to a prolonged, socially compelling film as whole-brain BOLD activity is recorded. The aim is to track how network configuration changes during scenes that elicit vicarious affect or require perspective taking. Trait anchors for between-person differences come from established subscales of the Interpersonal Reactivity Index; in comparable cohorts, internal consistency is solid (e.g., $\alpha \approx .74$–$.79$ for core empathy subscales; symptom scales $\alpha \approx .84$) in samples of adolescents ($N \approx 112$; mean age $\approx 14.6 \pm 1.35$ years). Analyses target large-scale systems implicated in empathy, salience (anterior insula, anterior cingulate), default-mode (medial prefrontal cortex, precuneus, temporo-parietal areas), and frontoparietal control, plus subcortical nodes such as the amygdala and thalamus.

Data Acquisition

Functional runs are collected under uninterrupted narrative presentation to preserve the temporal structure required for sliding-window estimates. Preprocessing produces motion-corrected, temporally filtered regional time series parcellated into atlas-based ROIs. In a naturalistic graph-learning study with healthy adults (N=14), a compact atlas of 54 AAL regions was sufficient to recover empathy-linked dynamics, suggesting that a similarly sized parcellation can balance coverage with statistical stability for time-varying models.

Stimulus Annotation

The film is segmented into epochs that credibly elicit vicarious affect (distress, relief, prosocial events) or mental-state inference demands (intentions, beliefs). Segment onset and offset are time-locked to the fMRI series. Separate ratings of emotion contagion or mentalizing demand, where available, are aligned to the same timeline in order to confirm contrasts.

Analytical Approach

Network dynamics. Sliding-window estimates quantify shifts between segregated and integrated organization. Prior work links more integrated epochs to better performance and to Neuromodulatory signatures; in practice, we summarize each window with integration/segregation indices and test for elevations during empathy-salient segments relative to adjacent segments.

Graph learning. Time-varying connectomes are estimated with sparsity-regularized (L1) models applied to regional time series. In naturalistic movie-fMRI, a windowed, sparse pipeline achieved >88% accuracy when predicting moment-to-moment changes in emotion contagion and consistently highlighted insula, amygdala, thalamus, and angular gyrus during empathy-high periods. Optional band-pass filtering sharpened identification of empathy-linked coupling.

Inter-subject correlation. Inter-subject coupling (ISC) quantifies similarity of responses across viewers exposed to the same scenes. Peaks in ISC during socially meaningful moments are compared directly with integration indices and graph-learning outputs to test whether alignment across people coincides with transient network integration and with stronger coupling among salience-anchored nodes.

Outcomes and Tests

Primary outcomes are:

(i) segregation/integration trajectory patterns throughout the narrative;

(ii) graph-level markers of varying connectivity (edge-weight change and community membership) within empathy-salient vs. neighboring segments; and

(iii) inter-subject coupling in correspondence to the same epochs. Secondary analyses correlate these measures with affective and cognitive empathy scores. Where symptom indices are present, indirect-path models examine whether prior theory would predict that cognitive empathy mediates default-mode connectivity to symptom dimensions.

Expected Patterns

Affective phases should give primacy to salience-based circuitry (cingulate and anterior insula). Perspective-taking phases should recruit default-mode nodes (precuneus, temporo-parietal junction, medial prefrontal cortex) with some support from frontoparietal control nodes. In child samples, observed correlations between facets of empathy and intrinsic coupling in default-mode nodes necessitate age-sensitive interpretation. The combination of dynamics, graph estimates, and inter-subject statistics allows for direct comparison of affective and cognitive components in the same naturalistic environment.

Inter-Brain Synchrony as Empathic Alignment

Inter-brain synchrony refers to the similarity of spatiotemporal neural fluctuations across people who are exposed to the same event or interacting with one another. In practice, it is estimated with methods such as inter-subject correlation (ISC) on naturalistic, time-locked data, either under true hyper scanning (simultaneous recording) or "pseudo-hyperscanning" where participants are scanned separately and compared post hoc. Multiple noninvasive techniques support this work, EEG, fNIRS, and fMRI, with survey data indicating that EEG is most common, followed by fNIRS and then fMRI. Guidance from this literature also recommends adequate sample sizes (on the order of ~30) to obtain reliable ISC maps and emphasizes the use of extended, socially rich stimuli. Observed synchrony during communication and narrative processing has been reported in temporal-parietal and inferior frontal territories, and in specific frequency bands for electrophysiology, consistent with shared parsing of social information.

Positioning synchrony as a readout of empathic alignment requires anchoring it in the systems known to support empathic functions. Affective components, sharing of another's emotional state, are repeatedly linked to bilateral anterior insula, inferior frontal gyri, and cingulate areas; cognitive components, inferring others' beliefs or intentions, implicate medial prefrontal cortex, middle temporal gyrus, and precuneus. This dissociation provides clear anatomical hypotheses: during scenes that elicit vicarious feeling, synchrony should concentrate in salience-anchored territories (anterior insula, cingulate, IFG), whereas perspective-taking demands should shift alignment toward default-mode hubs (mPFC, TPJ/precuneus) and their interactions with control systems. These expectations dovetail with synchrony observations in narrative and communication tasks and motivate targeted region-of-interest tests that respect the affective–cognitive distinction.

Network dynamics help explain when synchrony rises. Time-resolved analyses show that the brain alternates between segregated communities and brief periods of global integration; the integrated state supports faster, more accurate performance and co-varies with pupil diameter. During continuous, socially meaningful input, increases in integration should promote cross-system exchange at the moments when viewers converge on a shared interpretation, yielding higher ISC. In a naturalistic movie dataset **(**N = 14**)** that used a compact atlas (54 AAL regions), a sparsity-based, windowed graph-learning model tracked emotion-contagion time courses with >88% accuracy and consistently pointed to the insula, amygdala, thalamus, and angular gyrus during empathy-high segments; band-pass filtering further sharpened discrimination. In practice, this suggests a simple test plan: compute ISC across the film, align synchrony peaks with integration maxima, and localize node-level contributions at those peaks using the data-driven graphs.

Individual differences matter. In a small adult resting-state fMRI sample (N = 10), Perspective Taking scores (IRI-PT: M = 17.3, SD = 4.7) correlated positively with signal in anterior medial default-mode cortex, whereas Empathic Concern (IRI-EC: M = 16.7, SD = 3.5) correlated negatively in the same region (peak Z ≈ 4.05; bilateral clusters ~59–119 voxels). In adolescents (N = 112; mean age 14.59 ± 1.35), the empathy subscales were reliable (α ≈ .74–.79; symptom scale α ≈ .84), and cognitive empathy mediated the link between default-mode connectivity and emotional-symptom scores. In practice, this motivates tests of whether higher Perspective Taking predicts stronger synchrony in default-mode hubs during mentalizing scenes, and whether synchrony peaks co-occur with time-varying network changes that also relate to symptom-relevant pathways.

Analytical Pitfalls and Robustness Checks in Empathy Network Research

Work with naturalistic fMRI hinges on rigorous control of nuisance influences. Motion and other physiological artifacts can spuriously inflate or depress apparent coupling among regions, and they also confound time-resolved indices that contrast segregated with integrated configurations. A defensible pipeline therefore includes conservative motion treatment, appropriate temporal filtering, and atlas-based parcellation that covers salience, default-mode, and frontoparietal systems alongside relevant subcortical nodes. Crucially, dynamic results should be re-estimated after stricter motion censoring and after altering filter settings to verify that observed shifts in integration are not byproducts of preprocessing choices. Replicating core findings across at least two reasonable parcellations helps ensure that conclusions about empathic processing are not tied to a single anatomical scheme.

Sliding-window decisions and graph construction parameters are another source of sensitivity. Time-varying estimates of network organization depend on window length, step size, and the balance between sparsity and data fit in graph-learning models. To guard against over-interpretation, analyses should include window-length sensitivity checks, report stability of edge weights and community assignments across bootstrap resamples and use cross-validated procedures for selecting sparsity parameters. Because integration/segregation summaries can shift with density or thresholding, weighted metrics should be emphasized and compared with alternative cutoffs. Null models based on phase randomization or time-shifts provide a reference for testing whether apparent dynamics exceed expectations from autocorrelated signals.

Inter-brain synchrony introduces its own methodological considerations. Similarity across participants can arise from truly shared socio-cognitive processing or from common drive by low-level audiovisual features. Robust designs therefore combine synchrony metrics with controls for scene-level covariates and compare synchrony peaks with independent estimates of network integration over the same timeline. Region-of-interest tests anchored in salience and default-mode hubs help adjudicate whether alignment during vicarious-affect scenes concentrates in anterior insula and cingulate territories, and whether perspective-taking segments preferentially recruit medial prefrontal, temporo-parietal, and precuneus regions. Reliability should be examined with split-sample or leave-one-out procedures, and, where feasible, with repeat viewings of the narrative.

Trait–network associations and mediation analyses require additional safeguards. Empathy subscales can be correlated, developmental factors modulate default-mode organization, and symptom dimensions introduce shared variance. Models should adjust for age (and other relevant covariates), test collinearity among predictors, and report bootstrap confidence intervals for indirect effects. Multiple-comparison control is necessary when examining numerous edges, regions, or graph metrics, and specificity checks should confirm that links posited for cognitive versus affective empathy do not generalize indiscriminately across both domains. Whenever possible, converging evidence from resting-state topology, time-resolved dynamics during the narrative, and inter-subject coupling should be aligned to the same anatomical hypotheses to support claims about empathic processing at the network level.

II. Conclusion

The evidence points to a network account of empathy in which affective sharing relies on salience-centered circuitry (anterior insula, cingulate, inferior frontal regions), while perspective taking draws on default-mode hubs (medial prefrontal cortex, precuneus/temporoparietal territories) with support from frontoparietal control. A dynamic view, alternation between segregated communities and short-lived integrated configurations, explains how these components coordinate during socially meaningful events. Naturalistic designs make these shifts observable, and inter-brain synchrony provides a complementary readout of alignment across viewers exposed to the same narrative.

Methodologically, the combination of time-resolved metrics, sparsity-based graph learning on movie-fMRI, and synchrony analyses yields convergent tests and anatomically specific predictions (including roles for insula, amygdala, thalamus, and angular gyrus during empathy-salient moments). Trait and developmental findings, such as cognitive empathy mediating associations between default-mode connectivity and symptom dimensions, link intrinsic organization to person-level outcomes. With routine robustness checks (windowing choices, parcellation alternatives, sparsity settings, and controls for stimulus features), the case study framework provides a clear path to quantify how affective and cognitive empathy are coordinated across large-scale networks.

References:

[1]. Winters, Drew E., et al. "Cognitive and Affective Empathy as Indirect Paths Between Heterogeneous Depression Symptoms on Default Mode and Salience Network Connectivity in Adolescents." *Child Psychiatry & Human Development*, vol. 54, no. 1, 2021, pp. 213–222. National Library of Medicine (PMC). https://pmc.ncbi.nlm.nih.gov/articles/PMC8918056/.

[2]. Shine, James M., et al. "The Dynamics of Functional Brain Networks: Integrated Network States during Cognitive Function." *arXiv*, 2016. https://arxiv.org/abs/1511.02976.

[3]. Sasanka, G. R. S., et al. "Graph Learning Methods to Extract Empathy Supporting Regions in a Naturalistic Stimuli fMRI." *arXiv*, 2024. https://arxiv.org/abs/2403.07089.

[4]. "Neural Synchrony." *Wikipedia, The Free Encyclopedia*, Wikimedia Foundation. https://en.wikipedia.org/wiki/Neural_synchrony. Accessed 5 Sept. 2025.

[5]. Oliveira-Silva, Patrícia, et al. "Empathy by Default: Correlates in the Brain at Rest." *Psicothema*, vol. 30, no. 1, 2018, pp. 97–103. https://www.psicothema.com/pdf/4456.pdf.

[6]. Bray, Katherine O., et al. “Empathy and Resting-State Functional Connectivity in Children.” *NeuroImage: Reports*, vol. 2, no. 4, 2022, article 100142. https://www.sciencedirect.com/science/article/pii/S2666956022000666.

[7]. Ebisch, S. J. H., et al. “Intrinsic Shapes of Empathy: Functional Brain Network Topology Encodes Intersubjective Experience and Awareness Traits.” *Brain Sciences*, vol. 12, no. 4, 2022, article 477. https://www.mdpi.com/2076-3425/12/4/477.

[8]. Choi, Dahna, et al. “Downsides to the Empathic Brain? A Review of Neural Correlates of Empathy in Major Depressive Disorder.” *Frontiers in Human Neuroscience*, vol. 18, 2024. https://www.frontiersin.org/journals/human-neuroscience/articles/10.3389/fnhum.2024.1456570/full.