Multiscale structural connectome eigenmodes constrain human brain functional activity

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Introduction

- The human brain is an intricate network organized across multiple spatial scales [1,2]. Understanding the relationship between structure and function in human at different scales remains a long-term goal of neuroscience.
- Multiscale structural organization arises from complex biological mechanisms and provides the anatomical foundation for functional interactions [3,4].
- However, the extent to which multiscale structural connectome constrains functional activity remains largely uncharted.
- Here, we deciphered the relationship between multiscale structural connectome and cortical activity using graph signal processing.

Methods

- **Dataset**: 100 unrelated healthy adults (N = 100; 54 females; 22-36 years) from the Human Connectome Project (HCP).
- **Atlas**: The HCP multimodal parcellation (HCP-MMP) atlas.
- **Construction of multiscale structural connectome (MSC)**: The MSC was constructed by integrating three complimentary features [3,4]: geodesic distance (GD), microstructural profile covariance (MPC), and tract strength (TS).
- **Modal decomposition of brain activity**: Spontaneous and task-evoked cortical activity derived from functional MRI was decomposed into a weighted linear combination of orthogonal MSC eigenmodes [5].
- **Quantifying multiscale structure-function decoupling (MSFD)**: The MSFD was quantified as the logarithmic ratio between the L2-norm of high-frequency to low-frequency components over time points [6,7].

Results

Multiscale structural connectome eigenmodes

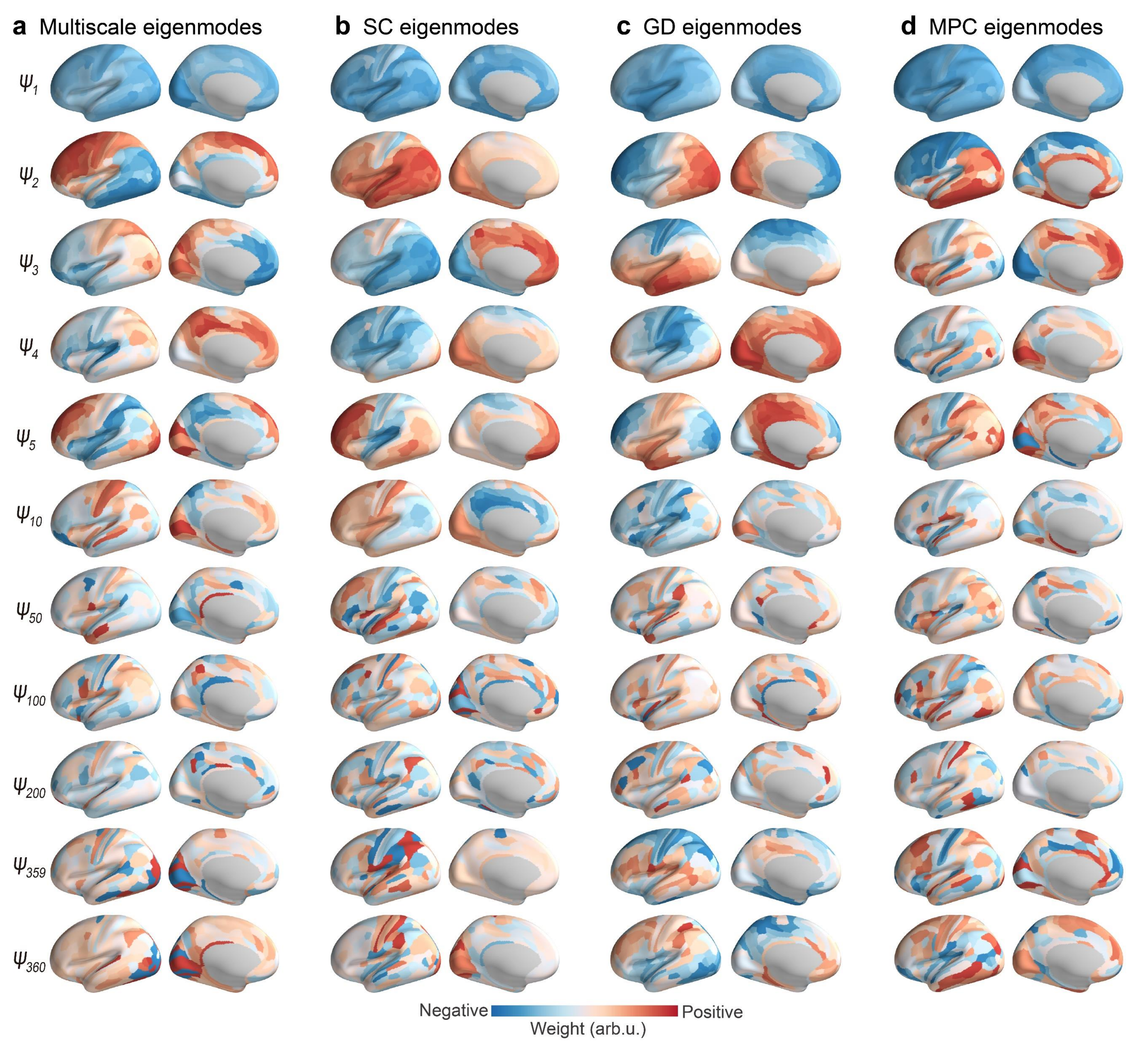

Fig. 1 Eigenmode basis sets. Negative–zero–positive values are coloured as blue–white–red.

Multiscale structural connectome eigenmodes constrain brain activity

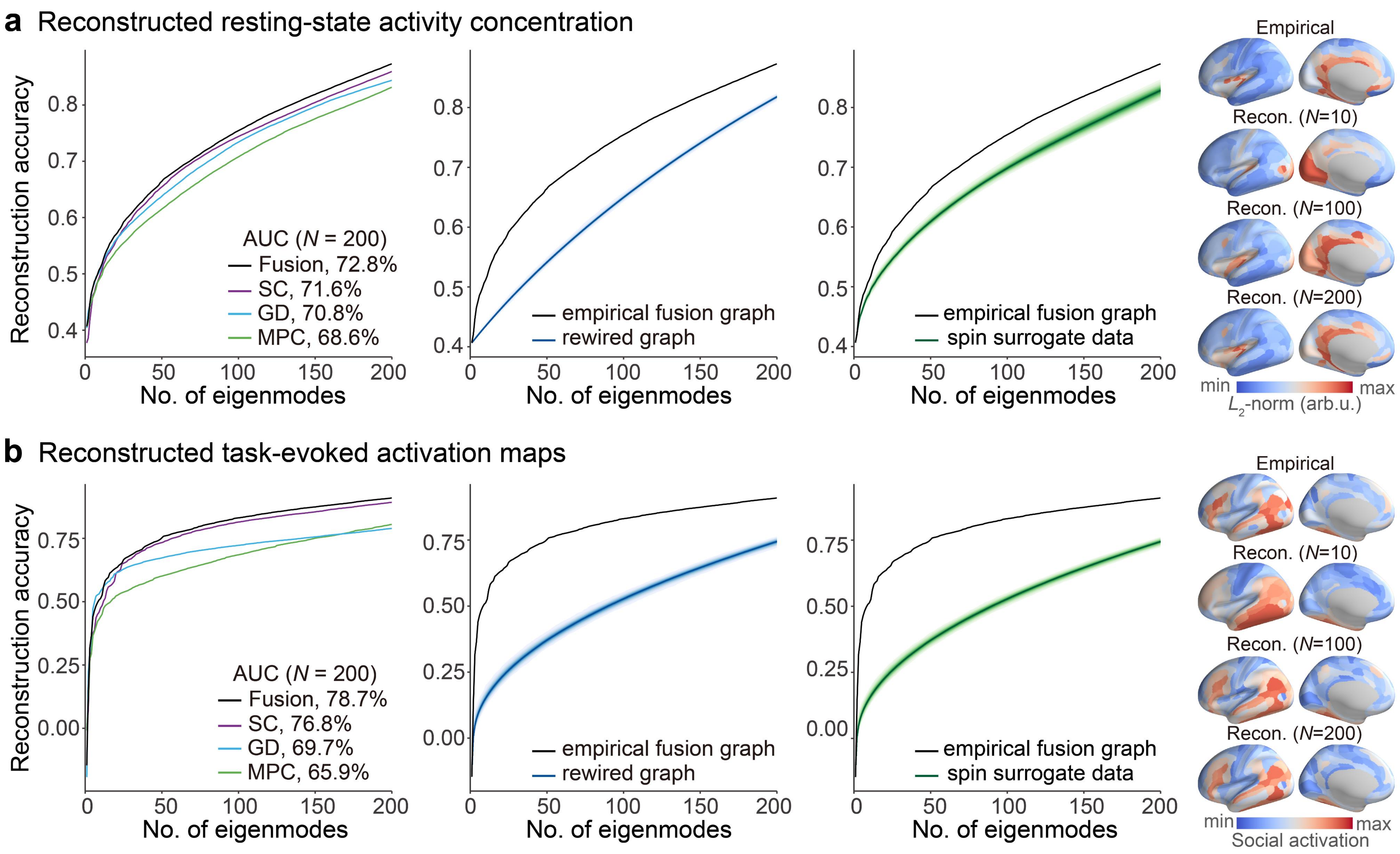

Fig. 2 (a) Reconstruction accuracy of resting-state activity concentration achieved by four distinct eigenmodes. **(b)** Mean reconstruction accuracy of 47 HCP task-evoked activation maps.

Multiscale structure-function decoupling (MSFD)

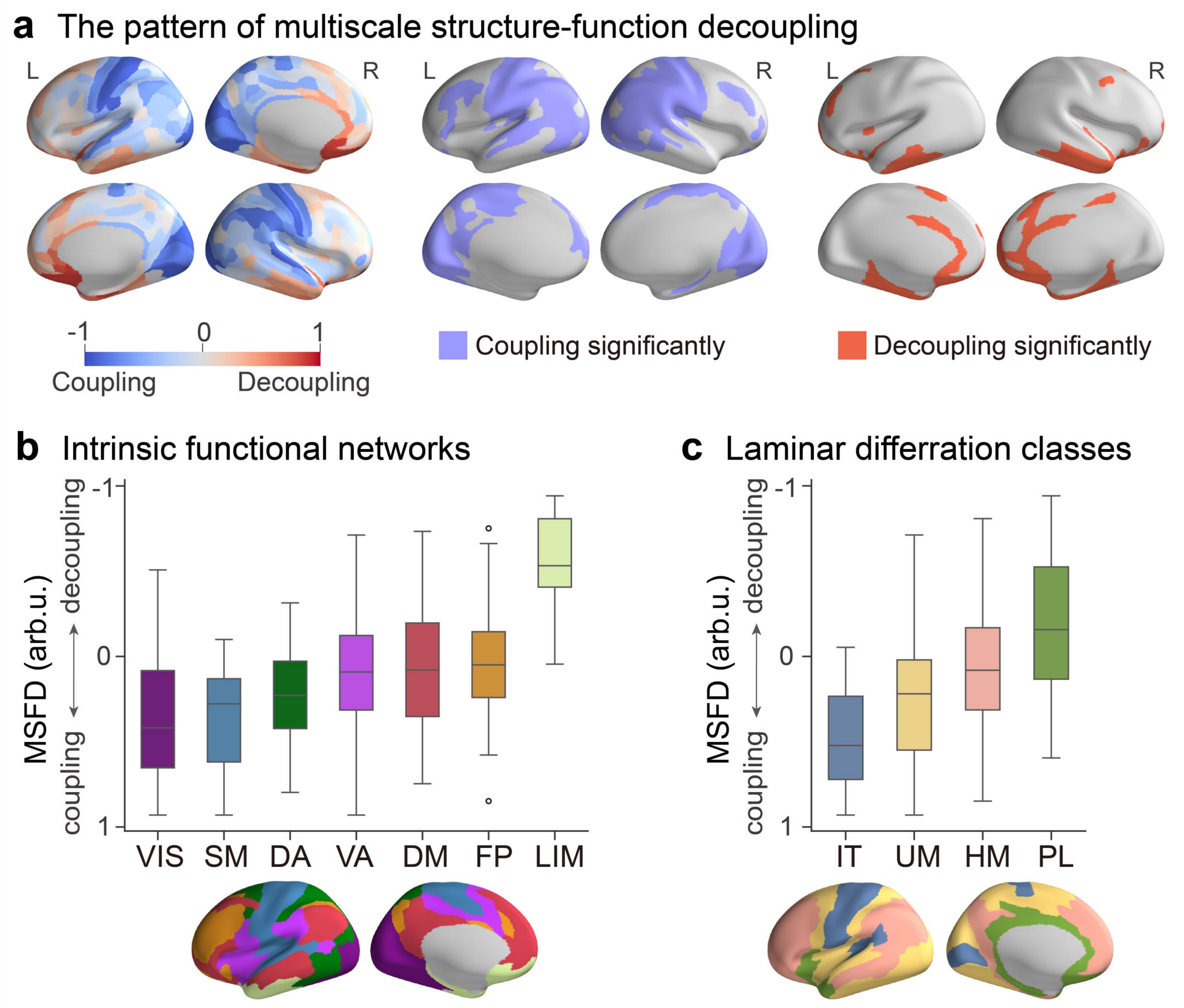

Fig. 3 The spatial pattern of the MSFD. (a) The statistically significant areas were grouped into coupling and decoupling patterns. The MSFD values within each of intrinsic functional networks **(b)** and laminar differentiation classes **(c)** are presented as box plots.

The MSFD follows microstructure and macroscale hierarchies

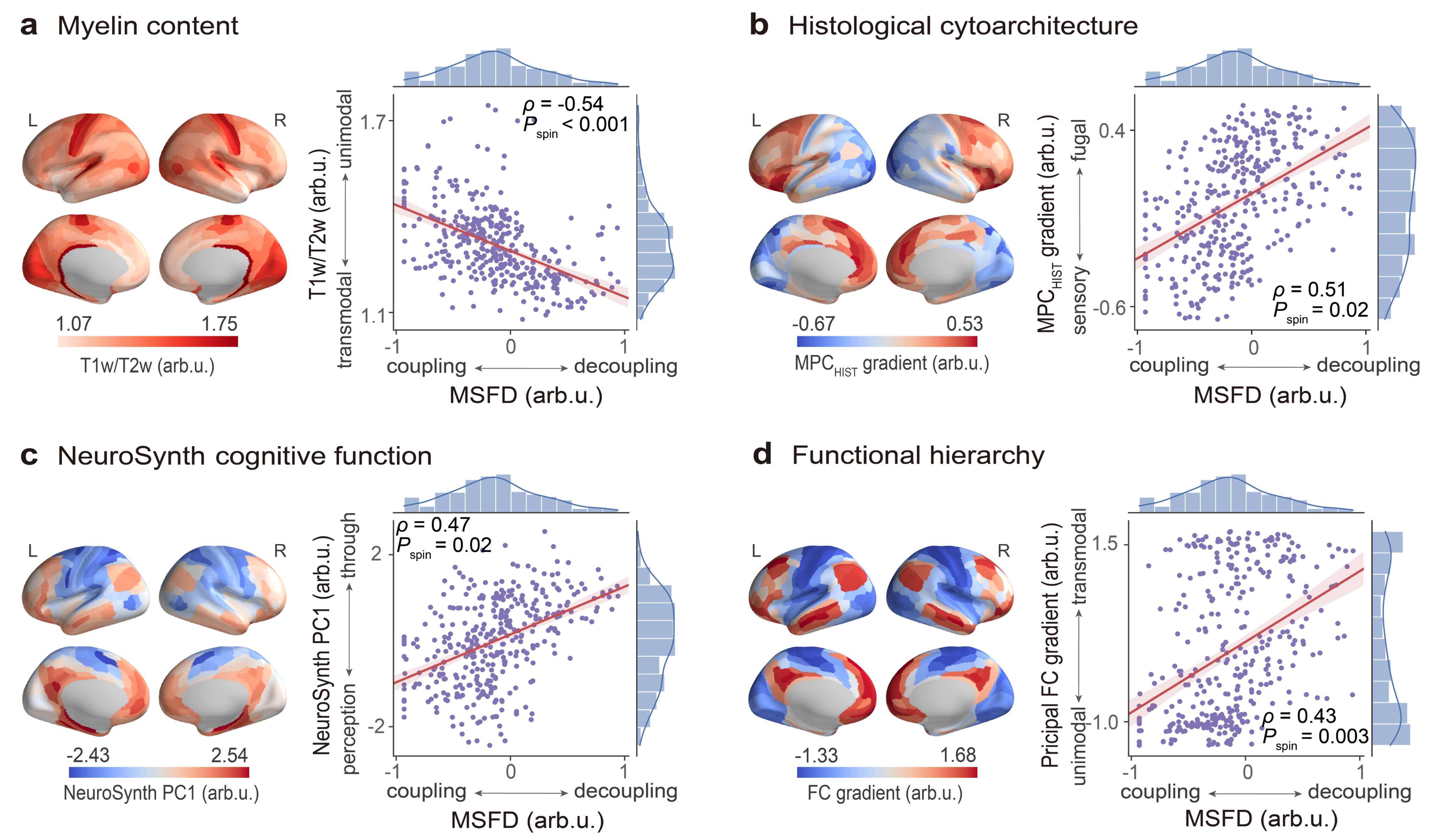

Fig. 4 Relation to microscale and macroscale hierarchies. Regional MSFD correlated with the myelin content **(a)**, the principal histological cytoarchitecture gradient **(b)**, the first principal component of NeuroSynth meta-analytic decodings **(c)**, and the principal functional connectivity gradient **(d)**.

Conclusion

- Multiscale connectome eigenmodes provide a more compact representation of spontaneous and task-evoked cortical activity, outperforming eigenmodes derived from any single connectome.
- Multiscale structure-function relationship was gradually decoupled from the sensorimotor to transmodal cortices, reflecting microstructure and macroscale functional hierarchies.
- These findings highlight that the multiscale cortical wiring diagram serves as a powerful anatomical scaffold in shaping macroscale intrinsic human brain function.

References

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