An Investigation Across 45 Languages and 12 Language Families : Replicating and Extending Key Findings

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Abstract

The paper *"An investigation across 45 languages and 12 language families reveals a universal language network"* examines the neural basis of language comprehension across diverse linguistic groups. By utilizing functional magnetic resonance imaging (fMRI) during naturalistic story comprehension, the study investigates the language network's functional consistency and dissociation from the Multiple Demand (MD) network. The authors provide compelling evidence for the universality of the language network, regardless of linguistic and cultural diversity, while highlighting functional specialization and hemispheric localization patterns. Key findings emphasize robust intra-network correlations within the language network and its dissociation from the MD network during language-specific tasks.

Our project builds on this work by replicating two significant figures from the study: Fig. 3c, which illustrates the localization of the language network, and Fig. 7, which presents inter-region functional correlations across hemispheres in the language and MD networks. Additionally, we extend the analysis to examine the relationship between functional integration within each network and the degree of dissociation between these networks across paradigms (story comprehension and resting state). This extended analysis provides deeper insights into the interplay of these networks during cognitive tasks, further validating and expanding the original findings.

Methods

Dataset

The dataset used in this project was derived from the study *"An investigation across 45 languages and 12 language families reveals a universal language network."* It includes both whole-brain activation maps and detailed time series data, as well as inter-region correlations and BOLD response magnitudes. The data spans multiple paradigms, such as story comprehension and resting state, and targets specific brain networks: the language network and the Multiple Demand (MD) network.

Due to the averaging of whole-brain activation maps, we were unable to replicate all figures from the original paper. Instead, our analysis focused on the more detailed data provided in the accompanying tables. Specifically, we utilized:

- **Data Table-3**: Inter-region correlations for the language and MD networks during story comprehension.
- **Data Table-4**: Inter-region correlations for the language and MD networks during the resting-state paradigm.

Replication of Figures

To replicate Fig. 3c and Fig. 7:

1. **Fig. 3c**: Focused on visualizing the localization of the language network using inter-region correlations from Data Table-3.
2. **Fig. 7**: Highlighted inter-region functional correlations across hemispheres for the language and MD networks during story comprehension.¿¿

These figures were recreated using Python-based data visualization tools.

Extended Analysis

We introduced a new analysis, resulting in **Fig. 11**, to explore the relationship between functional integration within each network and dissociation between networks across paradigms. The steps were as follows:

1. **Integration Scores**:
   - Calculated as the average intra-network correlation values for the language and MD networks.
2. **Dissociation Scores**:
   - Calculated as the average inter-network correlation values between the language and MD networks.
3. **Grouping by Paradigm**:
   - Integration and dissociation scores were calculated separately for story comprehension and resting-state paradigms and organized by language.

Visualization and Statistical Analysis

To visualize the results:

- A scatter plot (Fig. 11) was generated with:
  - **X-axis**: Integration scores (within-network correlations).
  - **Y-axis**: Dissociation scores (cross-network correlations).

For statistical analysis:

1. **Pearson's Correlation**:
   - Assessed the relationship between integration and dissociation scores.
2. **Linear Regression**:

- Quantified the strength and direction of this relationship.

Results

Replication of Figures

1. **Fig. 3c – Language Network Localization**:
   - **Original Paper:** This figure demonstrated the localization of the language network across participants, focusing on the robust intra-network correlations during the story comprehension paradigm. It highlighted the functional specialization of the language network, predominantly in the left hemisphere.
   - **Our Results:** Our replication closely matched the original findings when examining the correlation matrices for both the story comprehension and resting-state paradigms. These results reaffirm the localization of the language network and its hemispheric specialization, with robust intra-network correlations observed, particularly in the left hemisphere. However, inconsistencies were observed in the average correlation voxel values. While the exact cause of these discrepancies remains unclear, potential explanations include differences in the preprocessed data we used, variations in stated methodologies, or ambiguities in the methodological steps (which we followed step by step). Interestingly, when we ran the analysis without applying the Fisher transform, which the original paper stated was used, our results aligned more closely with theirs, though still not perfectly. Despite these differences, our findings support the same conclusions as the original paper regarding the robustness and specialization of the language network.
2. **Fig. 7 – Inter-Region Functional Correlations**:
   - **Original Paper:** Fig. 7 presented inter-region correlations within the left and right hemispheres for both the language and MD networks during story comprehension. The figure emphasized the functional segregation of these networks, with the language network showing higher within-network correlations compared to the MD network.
   - **Our Results:** Our replication closely matched the original findings in Fig. 7, demonstrating robust intra-network correlations for the language network and comparatively weaker correlations for the MD network. The patterns and overall conclusions were consistent with the original study, with only minor differences in correlation magnitudes. These differences were not significant and do not affect the validation of the functional segregation and distinct intra-network connectivity of the language network.

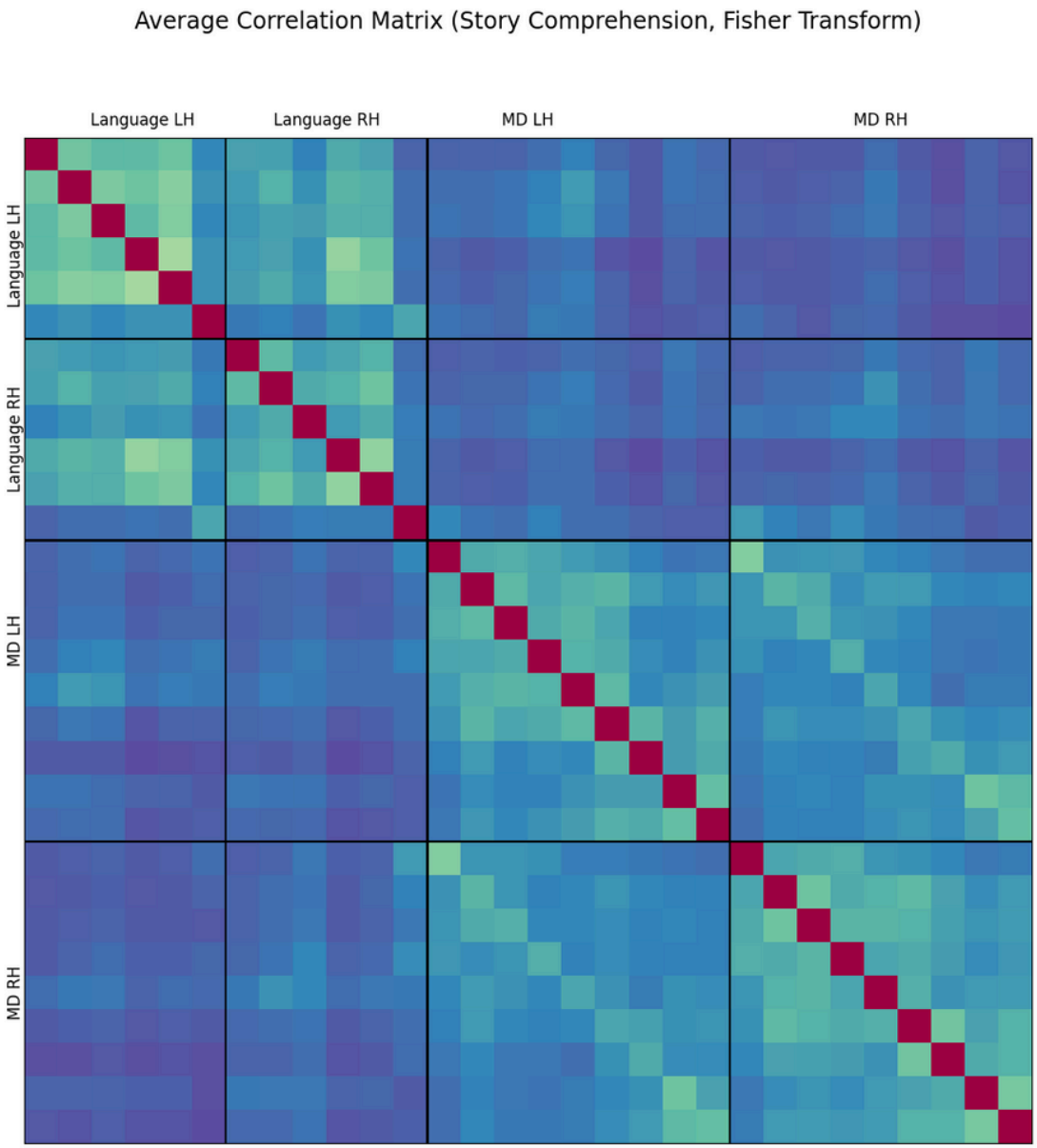
Extended Analysis – Fig. 11

- **Integration and Dissociation**:
  - **Our New Analysis**: Fig. 11 explored the relationship between functional integration (within-network correlations) and dissociation (cross-network correlations) across paradigms. A negative correlation was observed, particularly during the story comprehension paradigm, indicating that stronger network integration is associated with greater network dissociation.
  - This finding complements the original paper's emphasis on the functional independence of the language network and provides new insights into the interplay between the language and MD networks.

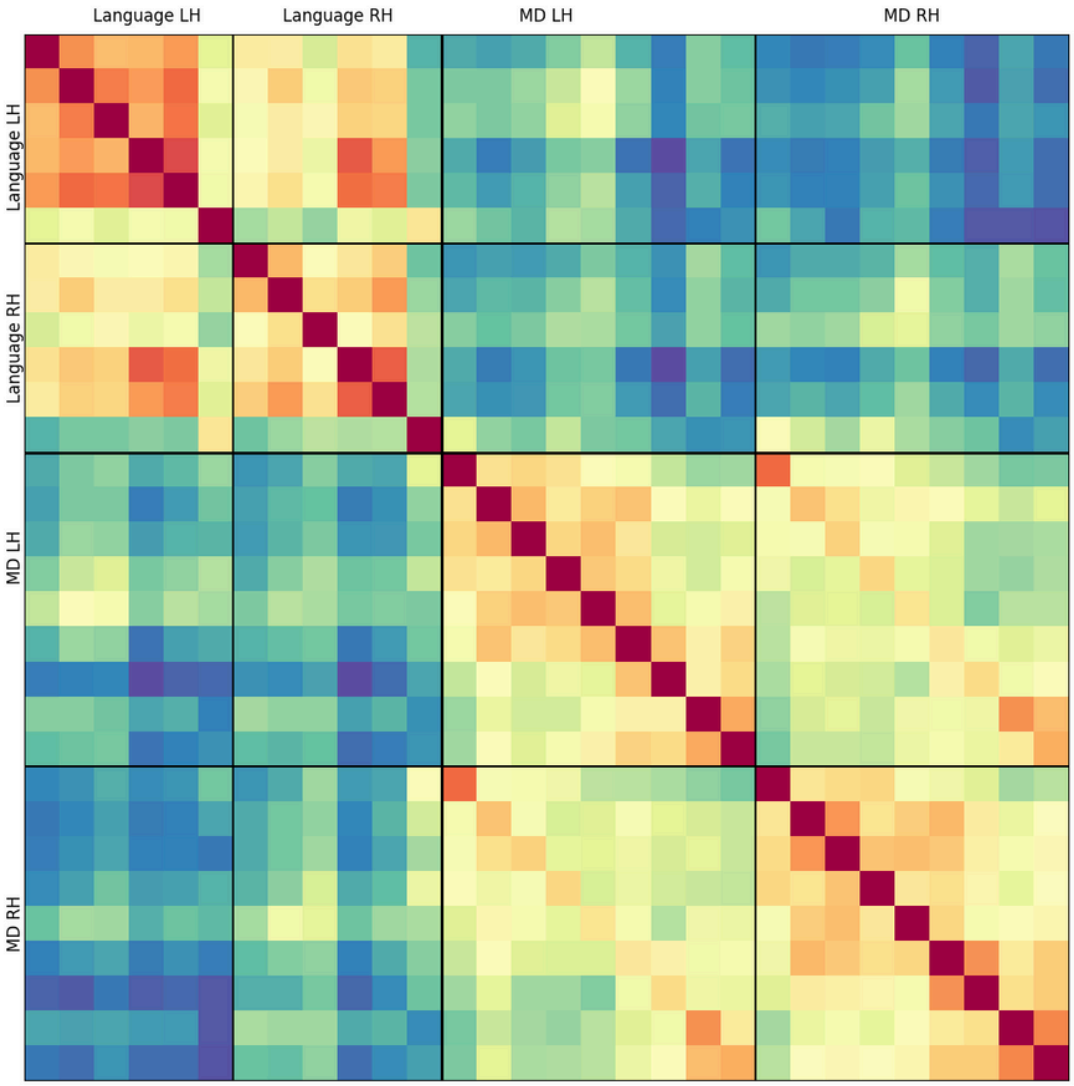
Replication of figures

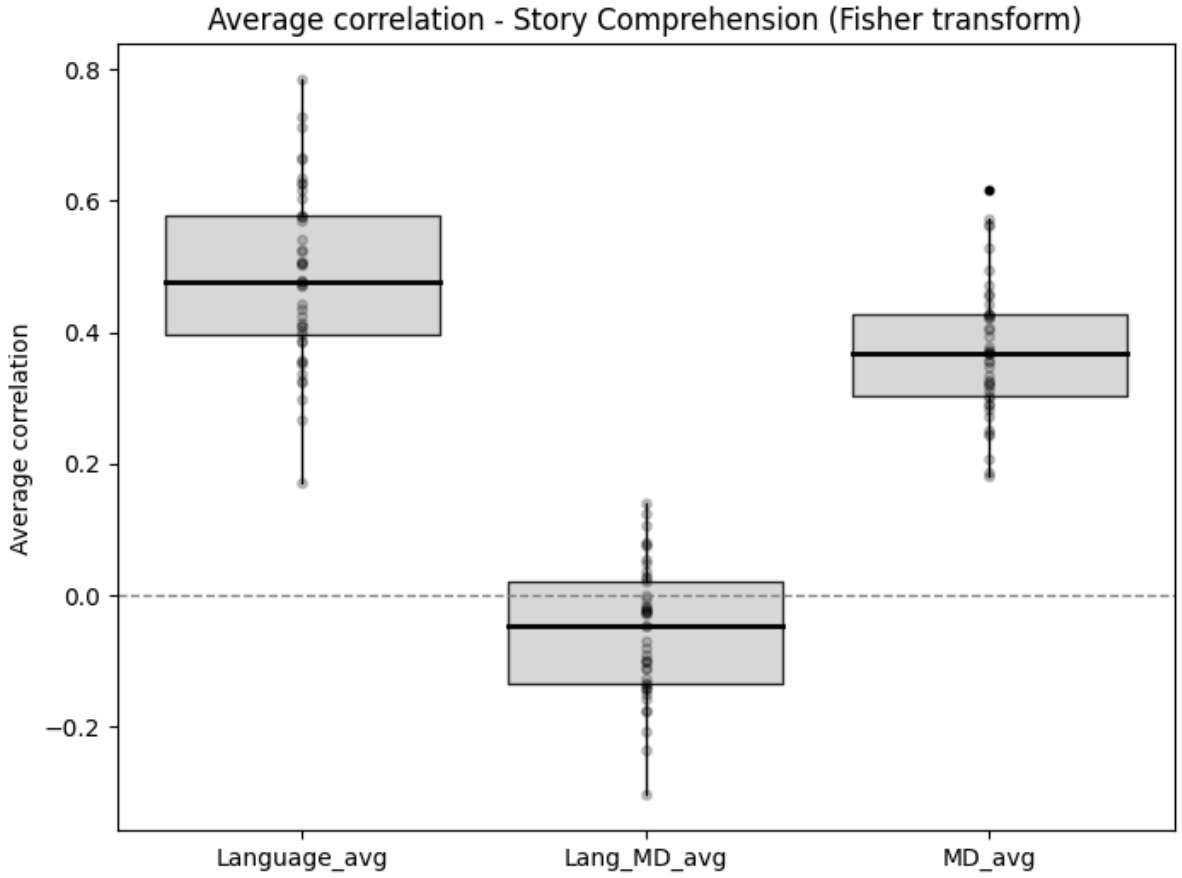
Fig. 3 C

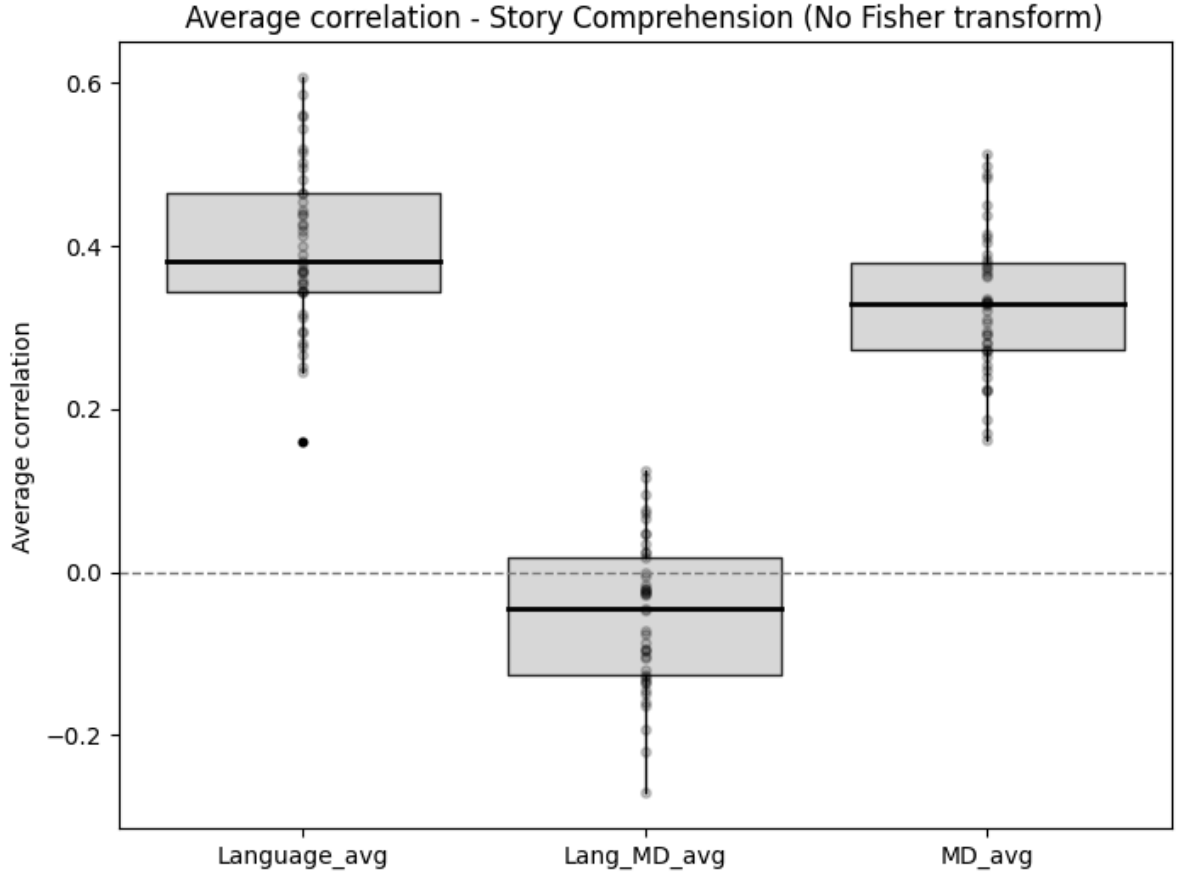
i. Story comprehension



Average Correlation Matrix (Story Comprehension, No Fisher Transform)

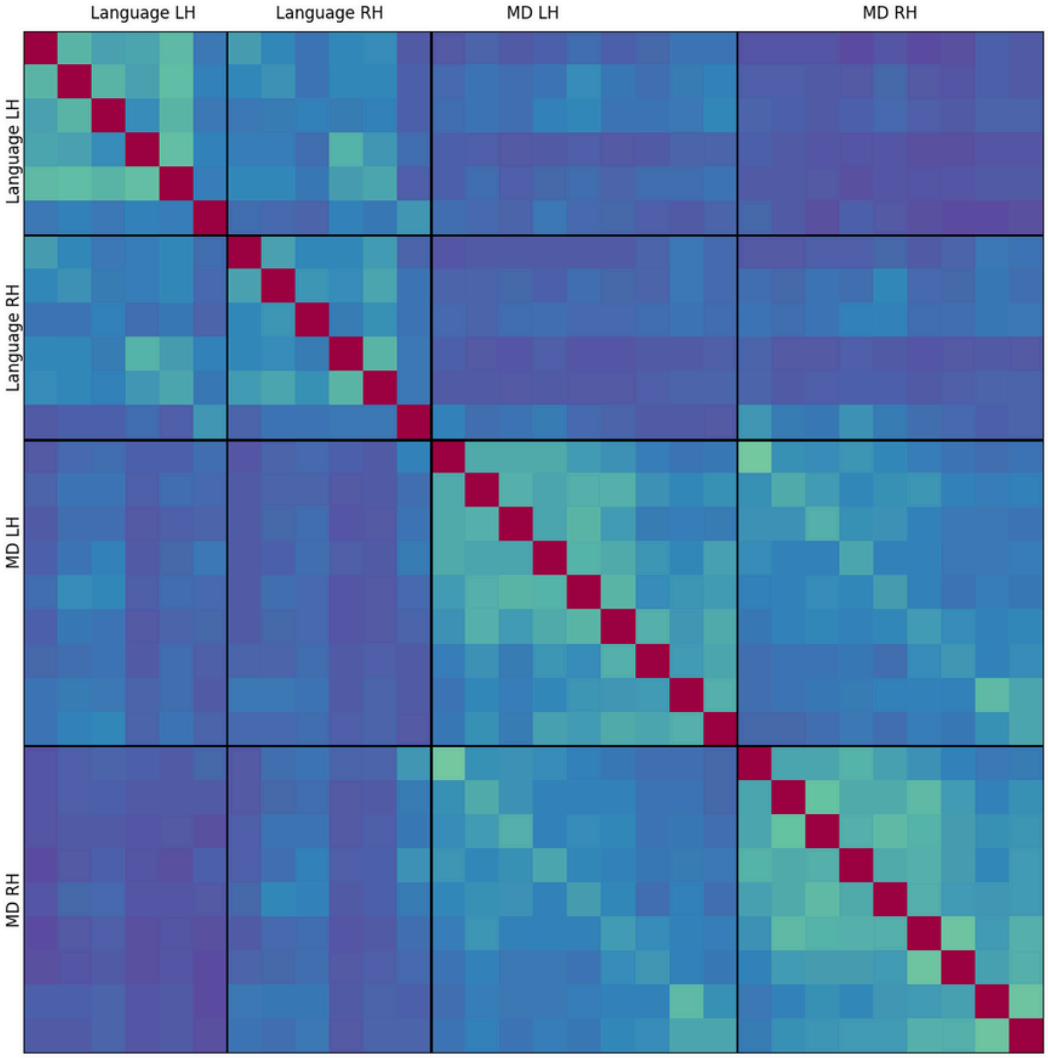




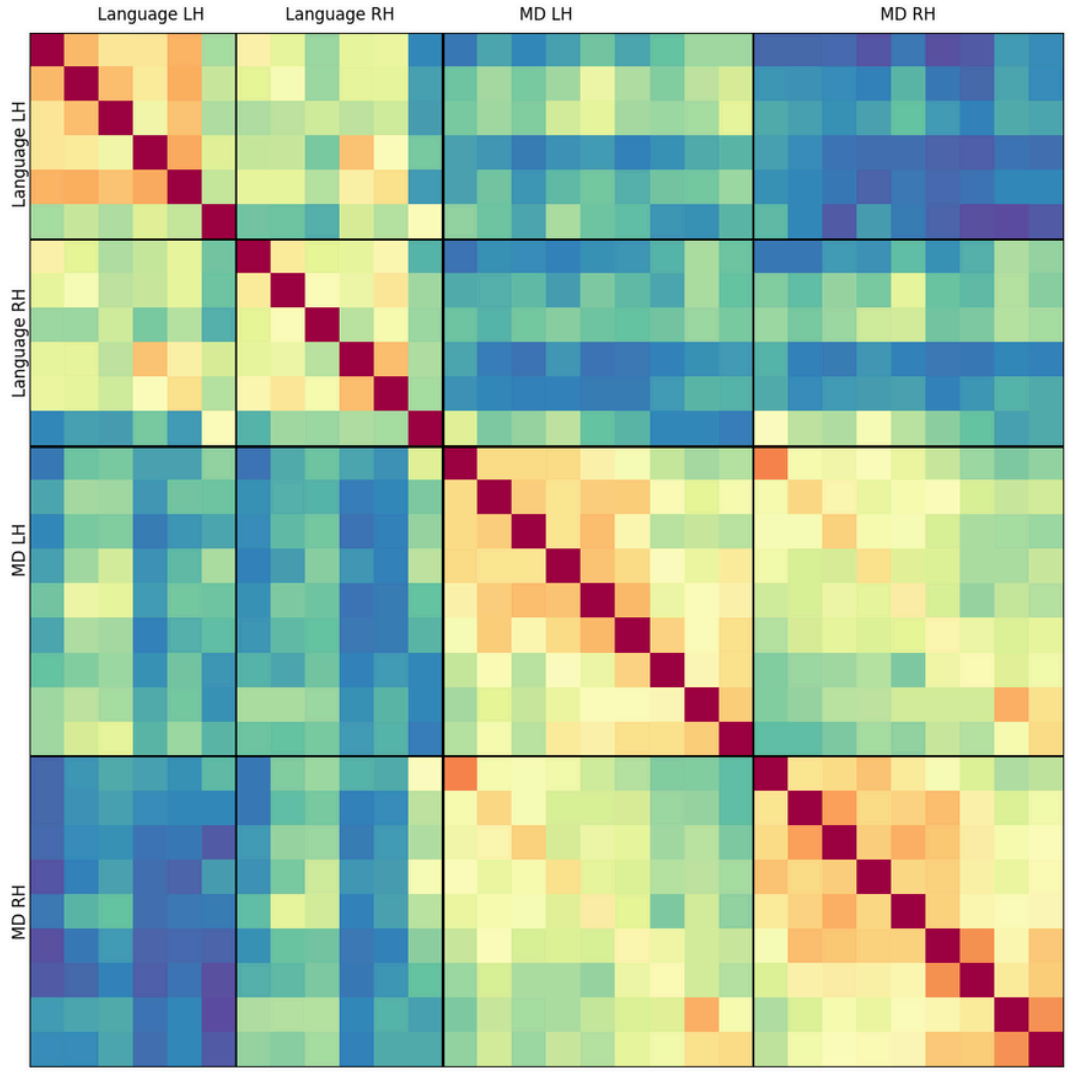


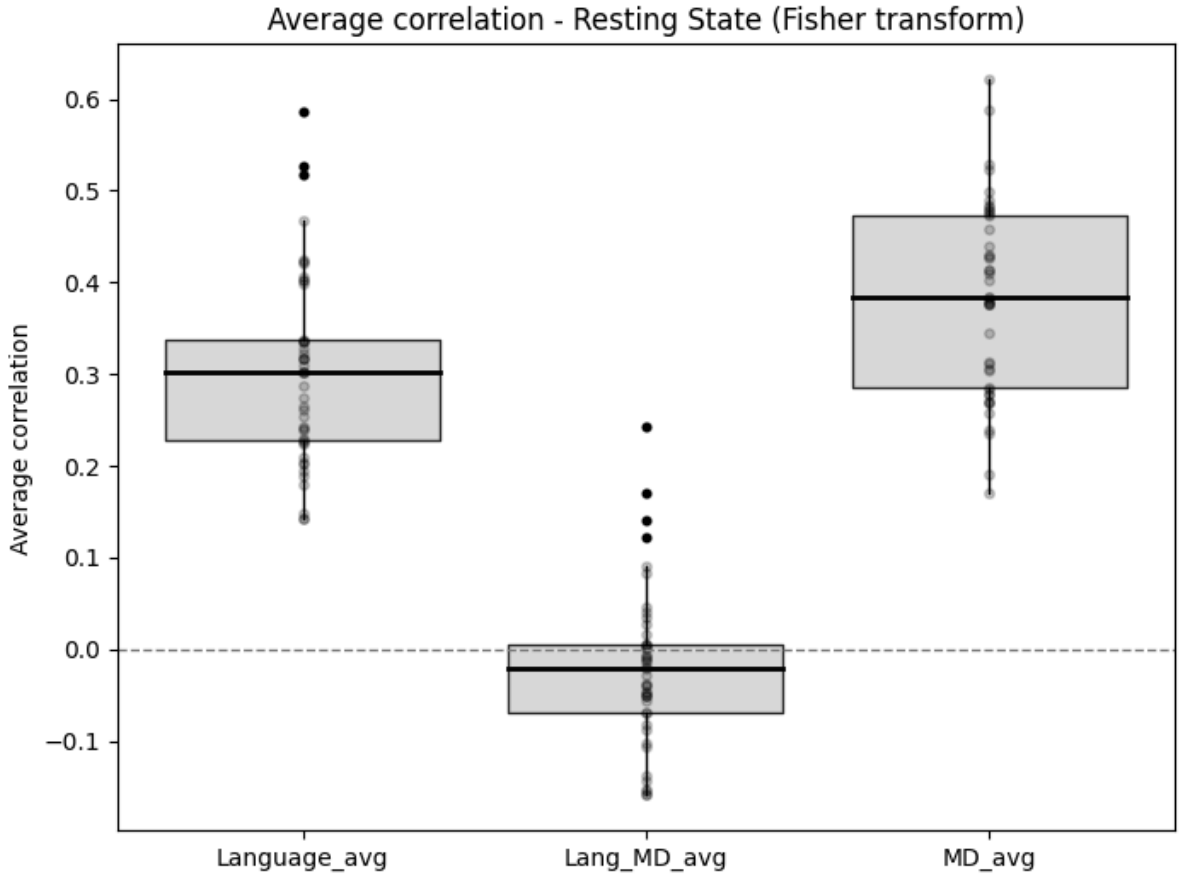
ii. Resting state

Average Correlation Matrix (Resting State, Fisher Transform)



Average Correlation Matrix (Resting State, No Fisher Transform)




Average correlation - Resting State (Fisher transform)
Average correlation
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
Language_avg
Lang_MD_avg
MD_avg

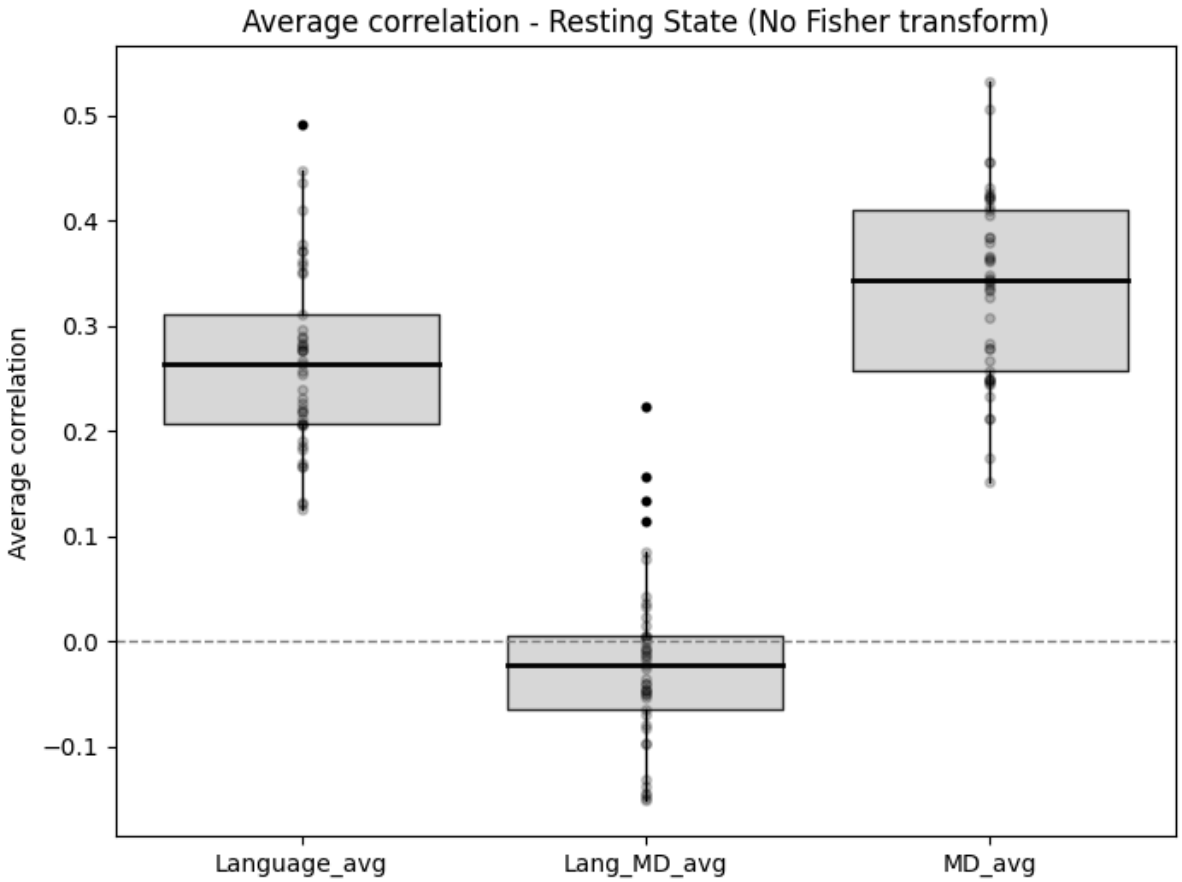

Average correlation - Resting State (No Fisher transform)
Average correlation
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
Language_avg
Lang_MD_avg
MD_avg

Fig. 7

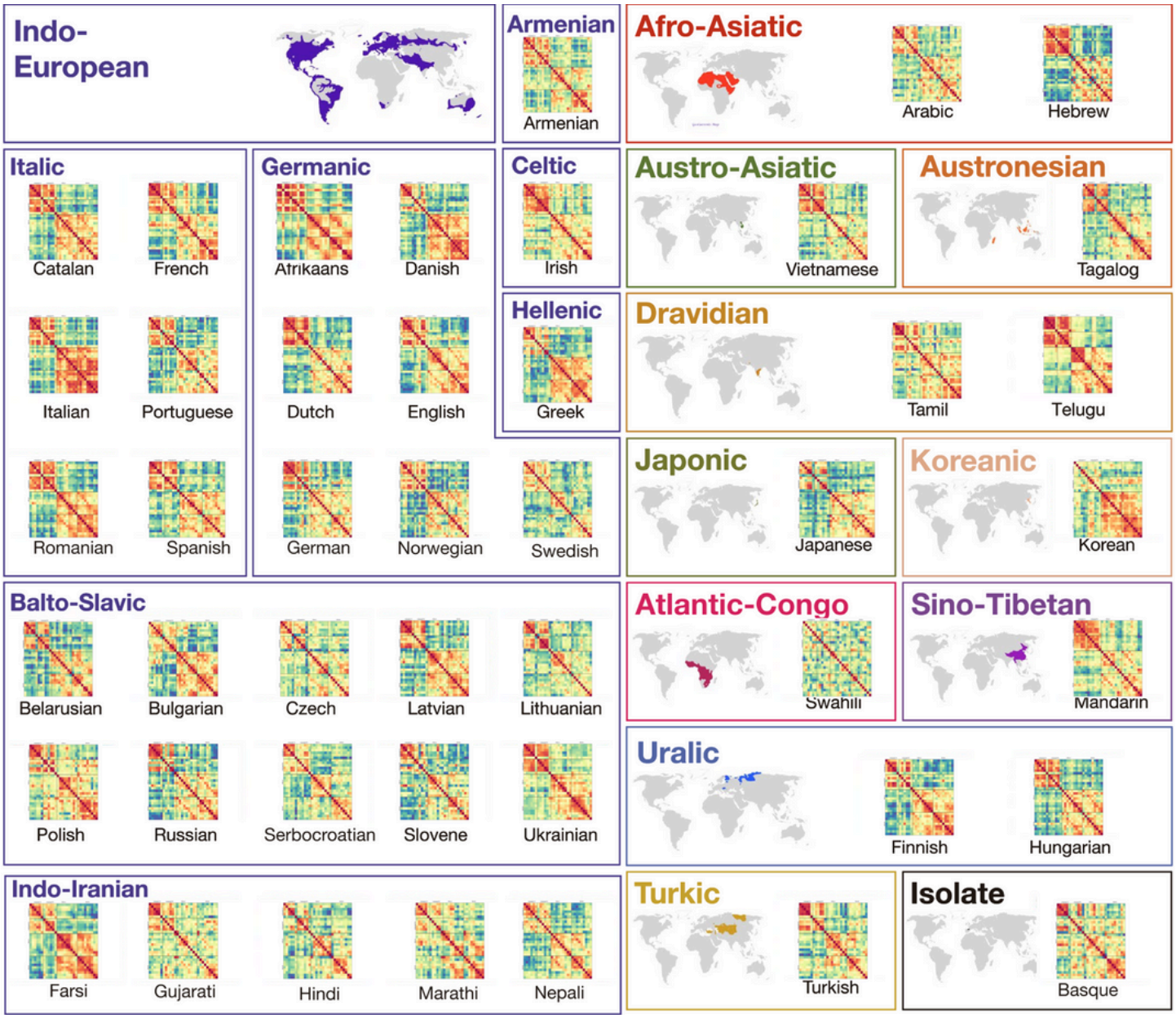
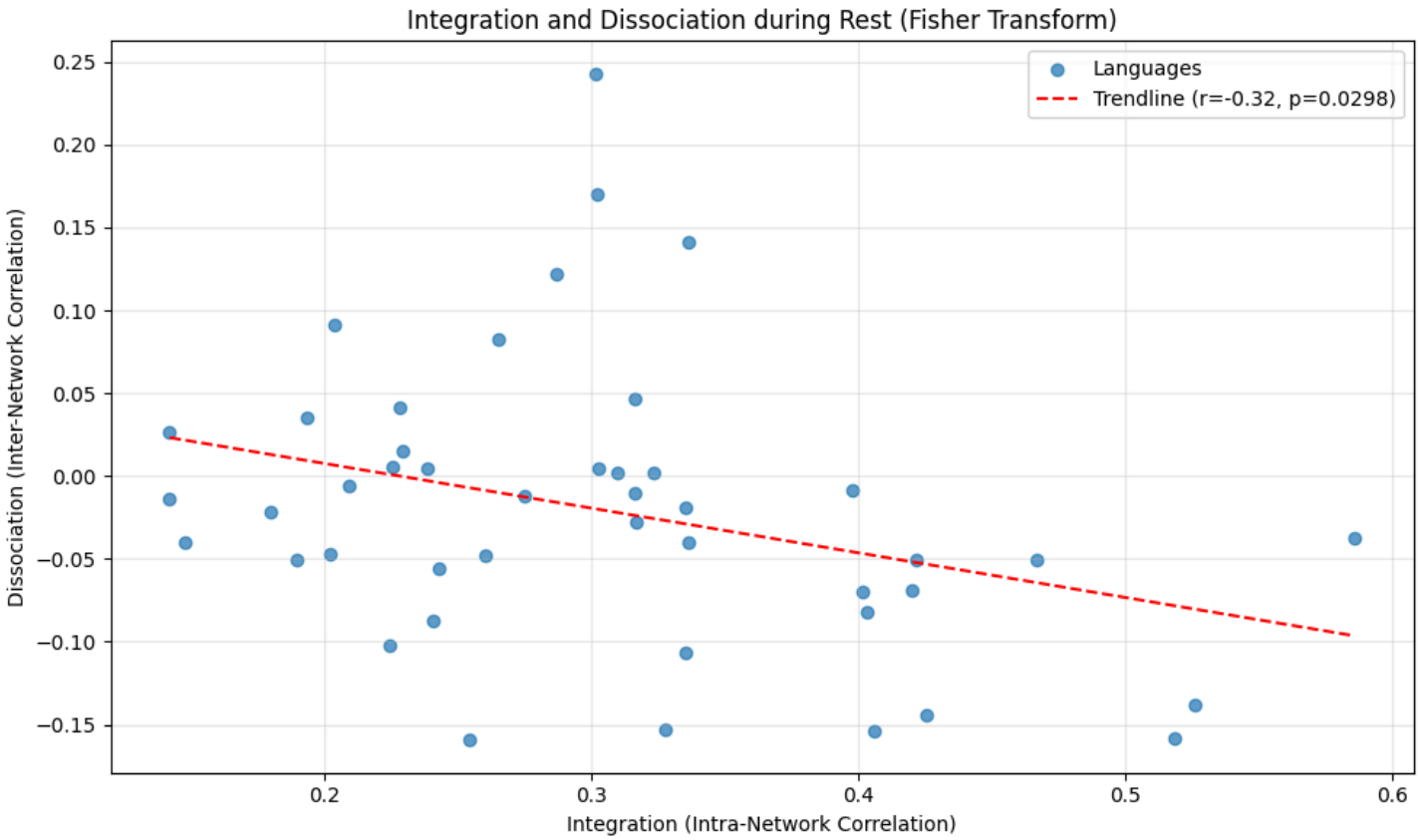
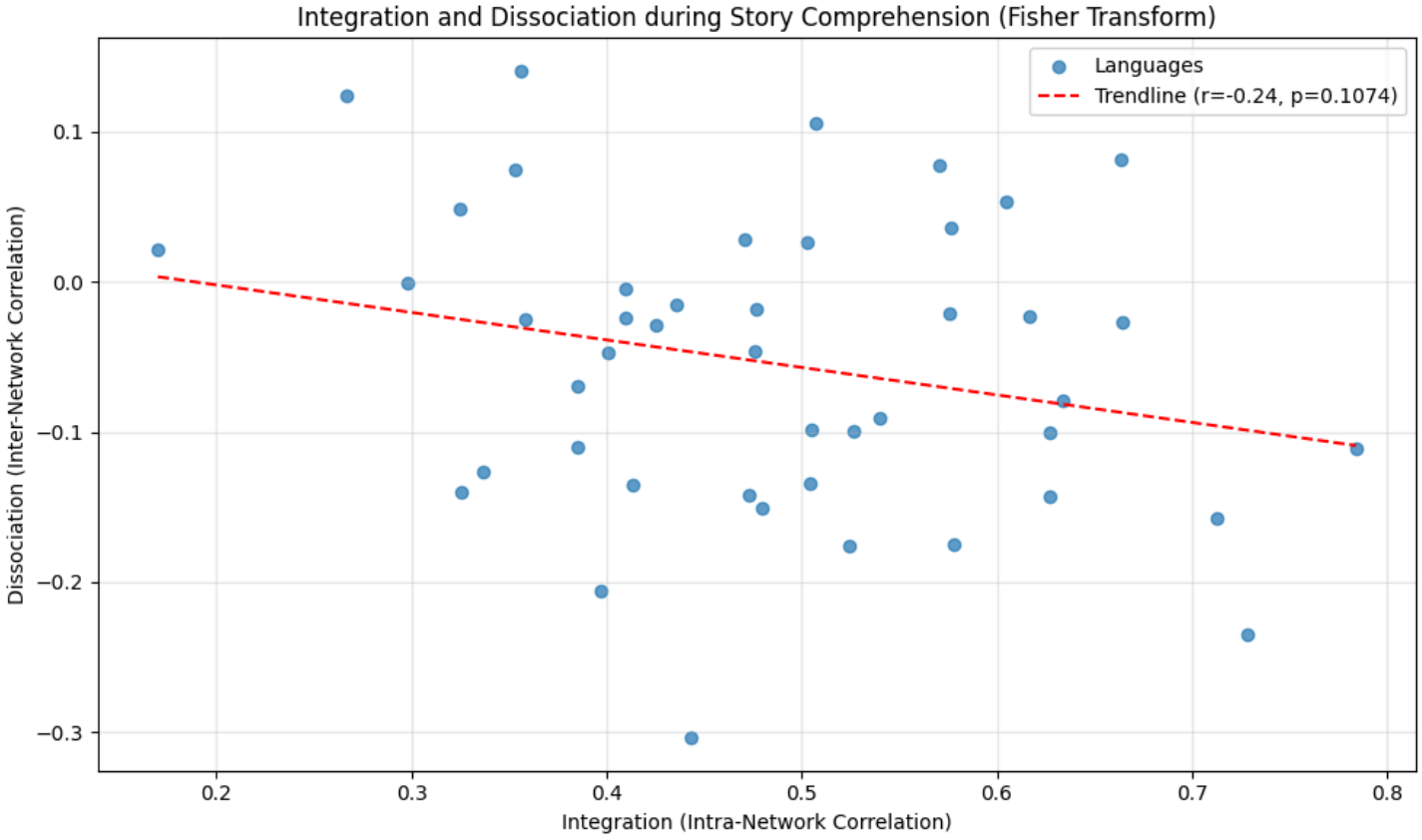


Fig. 11

i. Resting state



ii. Story comprehension



Discussion

Comparison to Original Findings

- **Fig. 3c and Fig. 7**:

  Our replicated figures mostly matched the original results, confirming key patterns of localization and functional connectivity within the language network. Specifically:

  - **Fig. 3C:** The correlation matrices for both story comprehension and resting-state paradigms closely aligned with the original findings, demonstrating robust intra-network correlations and consistent hemispheric asymmetry. However, average correlation values were slightly lower than reported in the original paper, likely due to variations in preprocessing pipelines or metodology.
  - **Fig. 7:** The replicated inter-region functional correlations for the language and MD networks during story comprehension were consistent with the original study. Minor differences in correlation magnitudes were observed but were not significant, validating the functional segregation and distinct intra-network connectivity of the language network.
- **Extended Analysis – Fig. 11**:
  - The observed relationship between integration and dissociation aligns with the original study's focus on functional specialization within the language network. However, our findings add a dynamic dimension by examining how these relationships vary across paradigms.

Limitations

While we successfully replicated some aspects of Figs. 3C and 7, we were unable to fully recreate all of the original figures. Specific limitations include:

- The use of preprocessed data, rather than unaveraged activation maps, may have introduced variability and affected the replication of average correlation values.
- Certain dataset components and methodological details were unavailable, restricting our analysis to inter-region correlation data provided in the study's data tables.

Future Directions

- Leveraging unaveraged activation maps in future studies could allow for more detailed replications and analyses of additional figures.

Investigating individual variability and expanding the analysis to other paradigms or cognitive states could further explore the interplay between the language and MD networks.