# Topological Data Analysis for Brain Network Dynamics

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## Introduction

- Topological data analysis (TDA) has been applied to neuroimage data in order to discover meaningful patterns which are crucial for brain function, but there are few results on temporal brain activity using TDA [1].
- TDA method MAPPER has proven to be useful to track the temporal activity of the brain without collapsing fMRI data in time or space [2]. MAPPER graph, represents the brain dynamics in a relevant and interactive way.
- Using similar approach under different parameters and metrics, we explore magnetoencephalography (MEG) data from Human Connectome Project to reveal differences of $0$-Back (0B) and $2$-Back (2B) working memory tests. We also investigate the relation of MAPPER graph to the test performance.

## Source-level processed MEG Data

- Data: the parcellated results of the source-reconstructed Working Memory averaged event-related and time-frequency responses.
- Using $90$ normalized time series time points for $0$B and $2$B memory tests, MAPPER graphs are produced under Euclidean metric for every subject.
- The filter is the Euclidean distance between the average baseline state and all other states [3].
- Using an unconventional visualization of MAPPER graph to track $90$ time points:
  - for each test and subject, determine from the MAPPER graphs, the time points, mapper0B and mapper2B, when the state returns to the baseline,
  - compare mapper0B and mapper2B with the accuracy and the response time data.

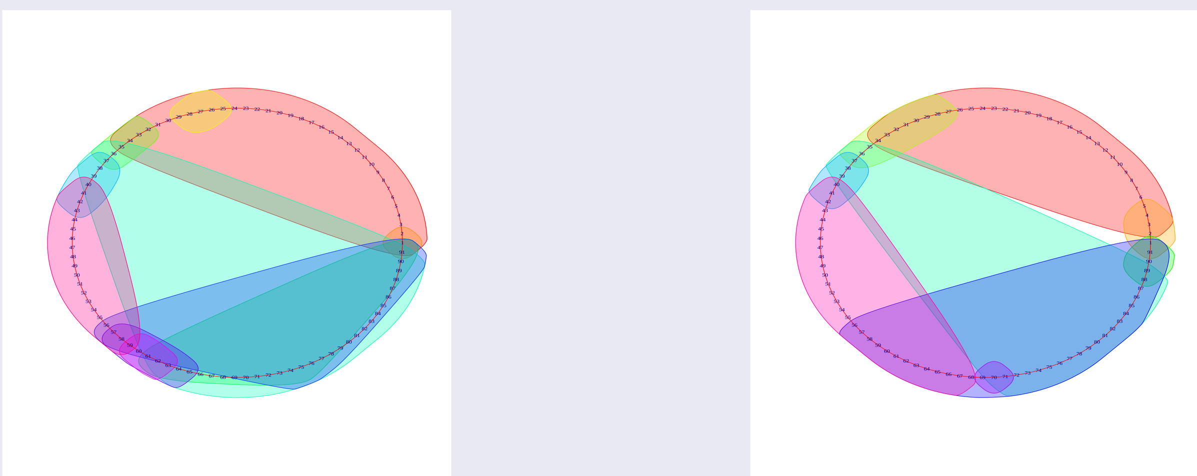


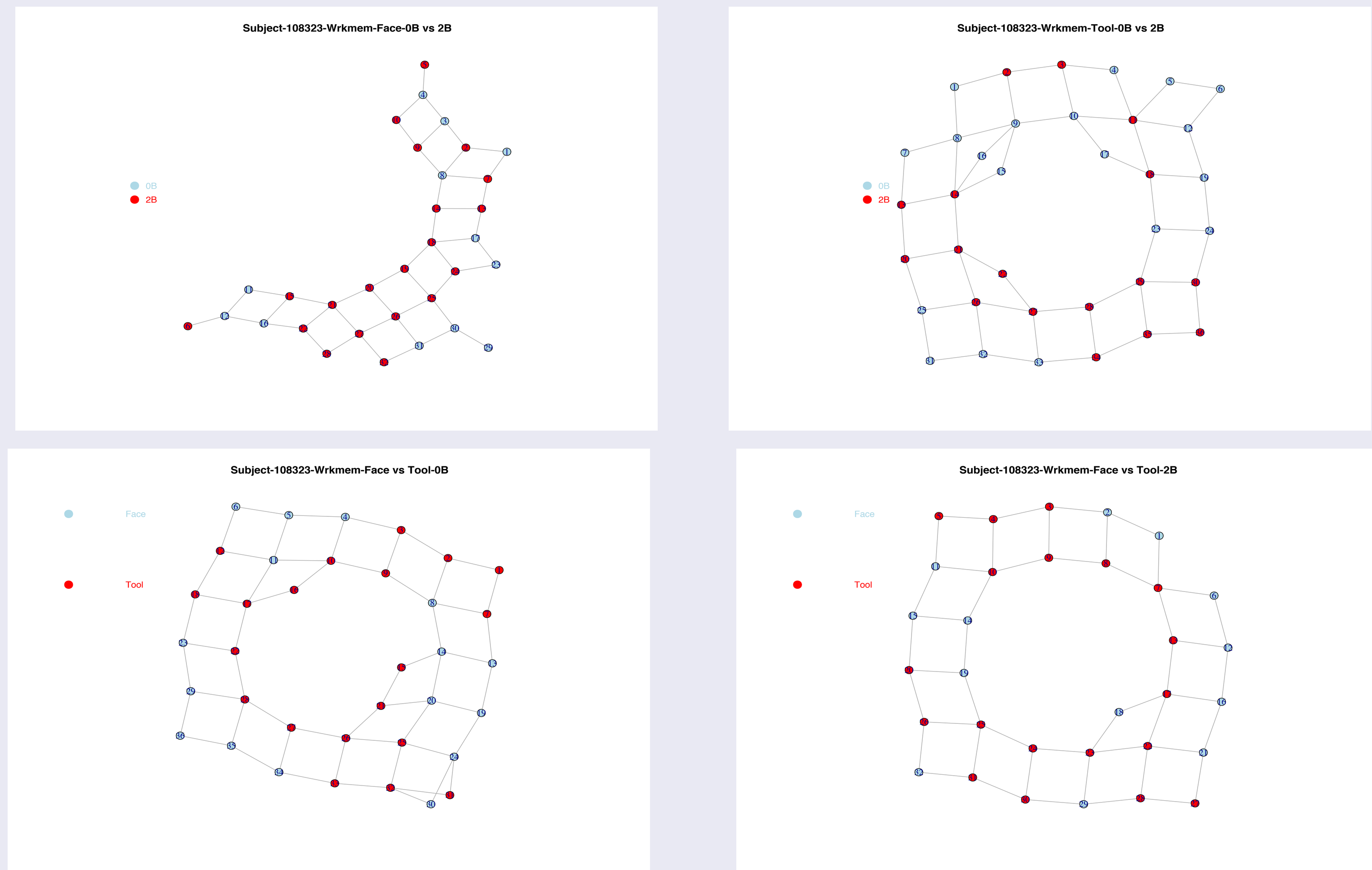
Figure: Mapper Graphs of the subject 156334, Left: 0B test, Right: 2B test

## Source-level processed MEG Results

1. No correlation between the mapper0B and the response time 0B,
2. The mapper0B and the response time 0B explain better the subjects who have high accuracy, i.e. the percentage of correctly predicting subjects who have high accuracy is
   - $75\%$ when only mapper0B is used,
   - $83.3\%$ when only response time 0B is used,
   - $91.7\%$ when both mapper0B and response time 0B are used.
3. the difference between the means of mapper data for high accuracy classes is significant.

## Preprocessed MEG Data

- Data: preprocessed Working Memory task data.
- $0$B and $2$B, $0$B Tool and $0$B Face, $2$B Tool and $2$B Face data points were amended after averaging over the trials to obtain $1280 \times 240^*$ matrices with $1280$ time points and $240$ voxels.($^*$ Number of voxels were not constant across the subjects.)
- MAPPER graph for each individual is obtained using Manhattan metric with t-SNE(Stochastic Neighborhood Estimation) filters following [2].



- The nodes in the MAPPER graph were colored according to the majority of either the image types or the test types in them.
- Several centrality measures on the Mapper graphs and their statistics are calculated.

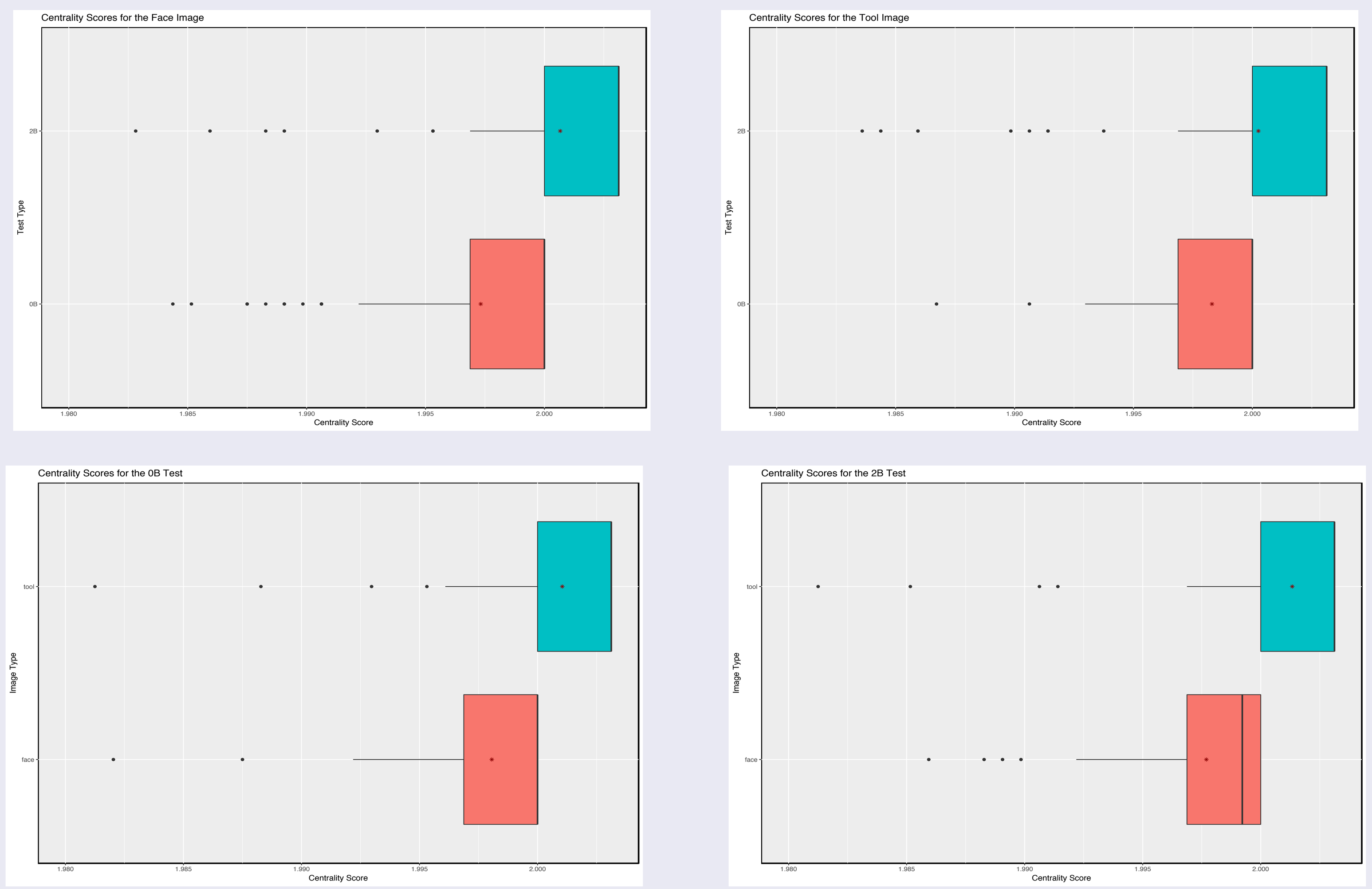


Figure: Boxplots of k-core centrality scores

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| Null Hypothesis | p-value |
|---|---|
| $\mu_{\text{face0B}} = \mu_{\text{face2B}}$ | $1.352e-08$ |
| $\mu_{\text{tool0B}} = \mu_{\text{tool2B}}$ | $5.618e-10$ |
| $\mu_{\text{face0B}} = \mu_{\text{tool0B}}$ | $2.331e-11$ |
| $\mu_{\text{face2B}} = \mu_{\text{tool2B}}$ | $3.831e-16$ |

| Null Hypothesis | p-value |
|---|---|
| $\mu_{\text{face0B}} \geq \mu_{\text{face2B}}$ | $6.758e-09$ |
| $\mu_{\text{tool0B}} \geq \mu_{\text{tool2B}}$ | $2.809e-10$ |
| $\mu_{\text{face0B}} \geq \mu_{\text{tool0B}}$ | $1.165e-11$ |
| $\mu_{\text{face2B}} \geq \mu_{\text{tool2B}}$ | $2.2e-16$ |

## Preprocessed MEG Results

- The k-core score can consistently differentiate the image type (Face - Tool) and the test type (0B - 2B).
  - In either of the tests, the Tool image points have greater mean k-core score than the Face image points,
  - For either of the image types, the 2B test points have greater mean k-core score than the 0B test points.
- Greater consistency in the whole brain functional configurations compared to cognitively less demanding tasks.

## Conclusion

- The point of return to the baseline obtained from the MAPPER graph of source-level processed MEG is positively correlated with the accuracy of the subjects.
- For preprocessed MEG data, the average coreness score suggests greater consistency in the whole brain functional configurations in cognitively more demanding tasks.
- Our result provides another evidence that TDA can provide useful information in better characterizing the dynamic nature of neural processes during working-memory tasks.

## Future Directions

Explore different graph theoretical invariants of the same data to

- find biomarkers of the task accuracy,
- differentiate tasks (Rest, Wrkmem, Story/Math, Motor).

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