Global Quantification of the Structural Brain Connectivity

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Abstract

MOTIVATION: Brain connectivity relies on a pipeline with many parameters, and the connectivity results vary depending on the decisions made in this pipeline. The field could benefit from a more robust connectivity measure.

GOAL: Finding a new structural connectivity measure that considers all possible pathways, direct and indirect, and evaluating the relationship of this measure with functional connectivity and its role in the classification of diseased and healthy populations.

Method: Global structural brain connectivity

We model brain connectivity globally as a circuit. (Chung et al., 2012, Aganj et al., 2014, Chu et al., 2017)

(a) We use a combination of differential Maxwell’s equations and Kirchhoff’s circuit laws, with diffusion tensors computed from dMRI. (Tuch et al., 2001)

(b) We compute the potentials \( \phi_i \), as depicted for 5 sources, as shown for 5 ROIs. (O’D’onnell et al., 2002)

(c) Then, potential maps are superimposed to generate voxel-wise conductance maps \( C_{ij} \), as shown for 5 voxels, or ROI-wise conductance maps \( C_{ij} \), as shown for 5 ROIs.

High conductance between two regions indicates a high degree of connectivity.

Results: structural vs. functional connectivity

While several studies have shown functional connectivity to be correlated with structural connectivity, strong functional connections have also been commonly observed between regions with no direct structural connection.

Is this variance due to the impact of indirect connections, usually not considered?

Distribution of correlations across 200 subjects of the WashU-UMN Human Connectome Project data set.

Global connectivity is more correlated with the functional connectivity than DTI Studio metrics are.

A two-tailed paired \( t \)-test between the subtraction of global and DTI SL distributions and global and GQI SL distributions revealed

Global - DTI SL \( t \)-statistic of \( t = 36.97 \) significance value of \( p = 10^{-40} \)

Global - GQI SL \( t \)-statistic of \( t = 35.24 \) significance value of \( p = 10^{-40} \)

Results: Alzheimer's disease stage prediction


- Cognitively Normal (CN): 47 subjects
- Significant Memory Concern (SMC): 56 subjects
- Early Mild Cognitive Impairment (EMCI): 34 subjects
- Late Mild Cognitive Impairment (LMCI): 49 subjects
- Alzheimer’s disease (AD): 31 subjects

Comparison of disease stages

A Wilcoxon signed-rank test between the median connectivity matrices of each disease stage showed that connectivity matrices are significantly different when comparing any two stages of the disease.

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<tr>
<th>Pair</th>
<th>p-value</th>
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<tr>
<td>CN vs SMCI</td>
<td>&lt;0.001</td>
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<tr>
<td>CN vs EMCI</td>
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<td>CN vs LMCI</td>
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<td>CN vs AD</td>
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<td>SMCI vs EMCI</td>
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Preliminary results: pairwise classification prediction accuracy of CN and AD

AdaBoost with base estimator decision tree classifier (n=20) of 5 PCA components:

- Proposed conductance method: 80.00% prediction accuracy
- GQI-3 counting tracks that cross an ROI, normalized by the median length: 68.95% prediction accuracy

Summary

Using the proposed methodology:

- one can compute structural connectivity measures that are significantly more correlated with functional connectivity than by using more standard approaches. This supports the hypothesis on the role of indirect connections in the relationship between functional and structural connectivity.
- one can better distinguish normal and Alzheimer’s disease images.