Contribution ID: **35**

Type: **Poster**

Regional cytoarchitecture tracks cortical network homogeneity and heterogeneity

Wednesday 26 October 2022 17:00 (1 hour)

INTRODUCTION:
Defining the functional units of the human cortex is a key goal of neuroscience. For decades, significant efforts have been made to derive functionally meaningful parcellations based on a broad range of neuroanatomical and neuroimaging features 1. More recently, studies have derived low-dimensional, continuous representations of cortical organization (also referred to as gradients) using cortex-wide decompositions of functional, microstructural, and structural connectivity features. Reconciling arealization and gradient mapping frameworks, the current work profiled functional, microstructural, and structural gradient features within a recently proposed probabilistic atlas of cortical cytoarchitecture1. We then assessed inter-regional heterogeneity and homogeneity of multimodal features, to quantify the uniqueness and redundancy of gradient fingerprints across cytoarchitecturally-defined cortical areas.
METHODS:
We studied Magnetic Resonance Imaging (MRI) data of 50 unrelated healthy adults (age: 29.82±5.73 years, 21 females) from the open-access MICA-MICs dataset 2. Participants underwent high resolution T1-weighted MRI, resting-state functional MRI (rs-fMRI), myelin-sensitive quantitative T1 (qT1), and diffusion MRI. Following processing through micapipe (http://micapipe.readthedocs.io) 3, we estimated vertex-wise gradients for each imaging modality using nonlinear dimensionality reduction techniques, retaining the first five gradients explaining the most variance in the input data 4. Each vertex could thus be represented by a unique gradient profile, composed of 15 gradient values (three modalities x five gradients). We then used Julich-Brain 1, a 3D probabilistic atlas of the human brain, to assign cortical vertices to cytoarchitecturally-defined regions. To explore the homogeneity of cortical areas, we estimated the cosine similarity of parcel-wise gradient profiles and examined these similarity patterns in a model of the primate cortical hierarchy 5. We then performed hierarchical clustering on this cosine similarity matrix to further examine patterns of homogeneity. To explore the heterogeneity of cortical areas, we generated a distance index by calculating the cosine distance between gradient profiles of different areas. Spin-tests were performed to determine which areas showed significantly higher heterogeneity than others.
RESULTS
Vertex-wise gradients of multimodal neuroimaging data were calculated and showed different trajectories across the cortex (Fig1.A). Combining the probabilistic atlas of cortical cytoarchitecture and our 15 multimodal gradients, we constructed gradient profiles for each cortical region (Fig1.B). We found higher homogeneity in paralimbic regions and lower homogeneity in idiotypic i.e., sensory and motor cortices. Discretizing these patterns of homogeneity using hierarchical clustering revealed four clusters, indicating high homogeneity within each cluster and high heterogeneity between the four clusters (Fig1.C). As for regional heterogeneity, visual and primary sensorimotor cortices showed highest values ($p<0.05$, FDR correction), while paralimbic network showed minimal heterogeneity (Fig1.D).
CONCLUSION:
Combining cytoarchitecture and multimodal MRI, we explored patterns of functional, microstructural, and structural homogeneity and heterogeneity of human cortical areas. Our findings point to a sensory-paralimbic differentiation of cortex-wide gradient fingerprints, with sensory/motor regions being more heterogenous compared to less distinctive paralimbic cortices. By reconciling local and global cortical features, our work may provide new insights into the neuroanatomical basis of specialized and integrative cortical function.

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Session Classification: Poster Session