Brain Hierarchical Atlas: Multi-Scale vs. Optimal Strategies in the Healthy and Pathological Brain

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Introduction (1473):

Elucidating the intricate relationship between brain structure and function is a classical --yet not fully understood-- challenge for modern neuroscience. We developed the brain hierarchical atlas (BHA) [Diez et al., 2015] adopting a systems approach using hierarchical agglomerative clustering to combine structural connectivity (SC) and functional connectivity (FC) matrices into a common atlas. Here, we present several subsequent studies using BHA with either a multi-scale strategy (MSA), combining different network resolutions, or an optimal strategy (OPS), where the number of network nodes is fixed after optimization of a given cost-function. Following MSA, we show how brain networks reorganize after traumatic brain injury in a pediatric population [Diez et al., 2017], how a combination of SC and FC can accurately predict brain aging [Bonifazi et al., 2018], the existence of intrinsic metastability dynamical patterns in the resting brain [Beim Graben et al., 2019], and aberrant developmental trajectories in the autistic brain [He et al., 2020]. In contrast, following OPS, we show a complete characterization of the progressive alterations in SC across severity stages in Alzheimer's disease [Rasero et al., 2017], a redundant role of the default mode network along lifespan [Camino-Pontes et al., 2018], small variations in dynamical FC in cerebellar networks [Fernandez-Iriondo et al., 2021], and high-order interdependencies in the aging brain [Gatica et al., 2021].

Methods (709):

SC matrices were obtained by counting the number of streamlines connecting pairs of regions. FC matrices were calculated by obtaining the Pearson correlation coefficient between pairs of region rs-fMRI time series. A hierarchical agglomerative clustering was applied to extract brain regions on different scales, used for MSA. In contrast, OPS resulted from optimization of a given cost-function. For instance, in the original work [Diez et al., 2015] OPS was obtained after maximization of the cross-modularity between SC and FC. Alternatively, an arbitrary number of regions are combined for MSA, as this allows to go from M=1 (entire brain) to M equal to the total number of available regions (here, 2514).

Results (493):

MSA-1: Network enhancement after traumatic brain injury (N=14).

MSA-2: Brain networks prediction of aging (N=155).

MSA-3: Aberrant developmental trajectory in the autistic brain (N=97).

MSA-4: Metastable resting state brain dynamics (N=30).

OPS-1: Progressive alterations of SC across severity stages in Alzheimer's Disease (N=144).

OPS-2: Redundant role of the DMN along lifespan (N=164).

OPS-3: High-order interdependencies in the aging brain (N=164).

OPS-4: Variations in dynamic FC (N=48).

Conclusions (654):

The use of the BHA guarantees four conditions simultaneously: (1) that the dynamics of voxels belonging to the same region is very similar, (2) that those voxels belonging to the same region are structurally wired by white matter streamlines, (3) when varying the level of the hierarchical tree, it provides a multi-scale brain partition, where the highest dendrogram level occurs for M = 1 (coincident with the entire brain), whereas the lowest level M = 2514 correspond to the total number of available regions, (4) the atlas with M = 20 regions is optimal based on cross-modularity, that maximizes similarity between SC and FC across different scales.

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Informatics:

Brain Atlases [2]

Modeling and Analysis Methods:

fMRI Connectivity and Network Modeling [1]Task-Independent and Resting-State Analysis

[1 |2]Indicates the priority used for review

Keywords:

Atlasing
FUNCTIONAL MRI
Neurological
Tractography