Imaging for Neuroscience

Homework – Group 1

The goal of this homework is to investigate the relationship between brain states of two different groups of individuals as defined by dynamic functional connectivity obtained from resting state functional MRI data.

DATASET

Dataset included:

old = folder containing data of 10 old healthy controls
young = folder containing data of 10 young healthy controls

For both old and young controls, each subfolder contains:

preproc_rs_fMRI.nii.gz = preprocessed fMRI data (2x2x2 mm^3, TR=1 s, 400 volumes) mapped into the MNI152 symmetric atlas
brain_mask.nii.gz = individual fMRI brain mask mapped into the MNI152 symmetric atlas

Data also included:

Schaefer_segmentation.nii.gz = Schaefer segmentation (100 parcels - 7 RSNs) of the MNI152 symmetric atlas
Schaefer2018_100Parcels_7Networks_order.txt = file containing the labels of the parcels. For example, parcel 1 (7Networks_LH_Vis_1) is referring to a parcel of the Visual Network (RSN) of the Left Hemisphere
labels.mat = vector with the labels of the parcels
MNI_WM_mask.nii.gz = white matter mask of the MNI152 symmetric atlas

ANALYSIS TO BE PERFORMED

1) For each healthy control (HC) extract the average fMRI signals for each parcel of the atlas:
    a. Exclude voxels outside the individual mask
    b. Exclude voxels within the white matter mask

2) For each HC, compute the (static) functional connectivity (FC) using all the acquired volumes. After applying the Fisher's z-transform to the computed FC (zFC), generate two figures (one figure for the young HC group and one for the old HC group) with each figure reporting the 10 zFCs of the group (include the labels of the parcels).

3) For each HC, compute the dynamic functional connectivity using a sliding windows approach, with a window length of 30 time points, shifting the window with a sliding step equal to 2 TR, and computing the functional connectivity (FC) matrix corresponding to each time window.

4) For each FC, obtained in each window, apply the z-Fisher transform

5) Characterization of the old population:
   a. Pack in a matrix the values of the upper triangular part from **all** the computed FC matrices (for each window) of **all** the **old** HCs. Perform a clustering analysis using the hierarchical method and the Euclidean distance in order to identify different functional states. Test a number of clusters from 2 to 10 and, using the silhouette approach, identify the optimal number of clusters (**K_Old**). NB: the silhouette approach often returns 2 as the optimal number of clusters; consider a local optimum when choosing **K_Old**.
   b. Compute the fractional occupancy (i.e., the number of windows assigned to one mode divided by the total number of windows) for each old HC
   c. For each state, by considering the centroid of the state (i.e., the centroids of each of the K_Old cluster),
      i. Reduce the density of the matrix by setting to 1 the top 25% highest positive values and to 0 the remaining values. After this operation, you will obtain a sparse matrix for each of the K_Old centroids. Save the K_Old matrices in a 3D matrix called A_Old (expected size: n parcels x n parcels x K_Old)
      ii. For each of the K_Old matrices in A_Old, calculate the Laplacian matrix, defined as:

$$L_{ij} \begin{cases} k_i \ if \ i = j \\ -1 \ \ if \ i \neq j \ and \ there \ is \ an \ edge \ between \ i \ and \ j \\ 0 \ \ otherwise \end{cases}$$

      with $k_i = \sum_j A\_Old_{ij}$
      iii. For each Laplacian matrix, calculate the principal eigenvector, i.e. the eigenvector corresponding to the eigenvalue of lowest magnitude (NB: exclude 0 eigenvalues). After this step, you should obtain one Gradient vector for each Laplacian matrix. Save the gradients in a matrix named Gradient_Old

6) Characterization of the young population: repeat points a-c for the young population

7) Comparison between young and old:
      i. Is K_Old equal to K_Young?
      ii. Generate the matrix Dist_All (expected size (K_old+K_Young)x (K_old+K_Young)) by performing the Spearman's Correlation between all the computed Gradients (both Old and Young)
      iii. Which is the state of the old population that least resembles the youth states? Provide a metric to quantify this decision.

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Submit your homework in the **elearning page** of the course in the ***Homeworks* section**.
The submission MUST be **completed by June 12th, 2024.**
You are required to do the homework **in English** (report, codes etc.).

You will be required to submit a **.zip folder** named **Group<Number>.zip** containing:

1) a copy of your own commented code(s);
2) a brief and complete presentation in power point/pdf of the performed analysis (methods, problems and issues, results, discussions, …). Mandatory maximum 10 slides (excluding the title slide). The first slide should report the list of students who contributed to the homework;
3) in case the homework requires performing the tissue segmentation, please provide the resulting nifti files.

Only one submission is required (only one participant for each group must submit the homework solution).