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The Convergence of Different fMRI Analysis Streams

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Link to presentation video: https://drive.google.com/drive/folders/1srCkrJQ5ghl9N9E1Z6URIpJ3_fEHLInV?usp=sharing

Background

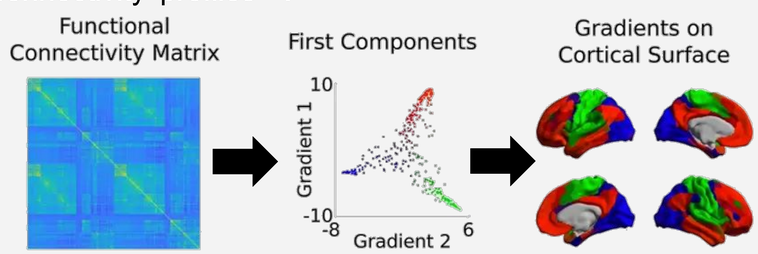
- Many of the numerous functional connectivity (FC) analysis approaches for functional magnetic resonance imaging (fMRI) are motivated by different theoretical assumptions
- There is a lack of consensus due to the missing ground truth describing the structure of whole-brain dynamics, as manifested through the blood oxygen level-dependent (BOLD) signal.

Hypothesis: A common underlying structure in the BOLD signal can drive converging results despite widely different analysis streams.

Analysis Approaches

Functional Gradients (FGs)

Theoretical Model: FGs reveal that brain regions are embedded along gradients of varying whole-brain 'connectivity' profiles[1,2].



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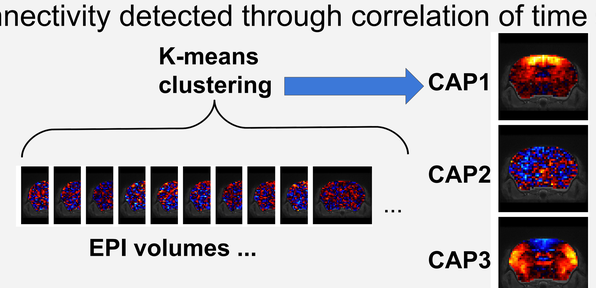
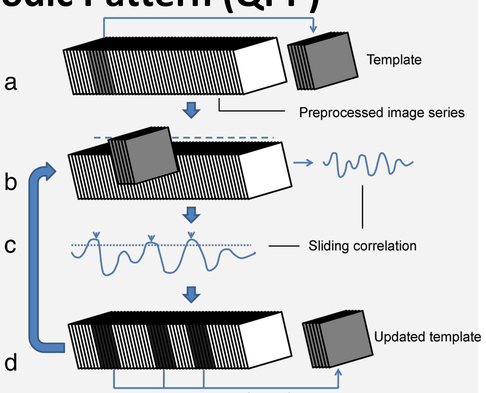
Co-activation Patterns (CAPs)

Theoretical Model: The BOLD signal is organized in spontaneous co-activation of brain areas, which underlies the connectivity detected through correlation of time series[3].



Quasi-periodic Pattern (QPP)

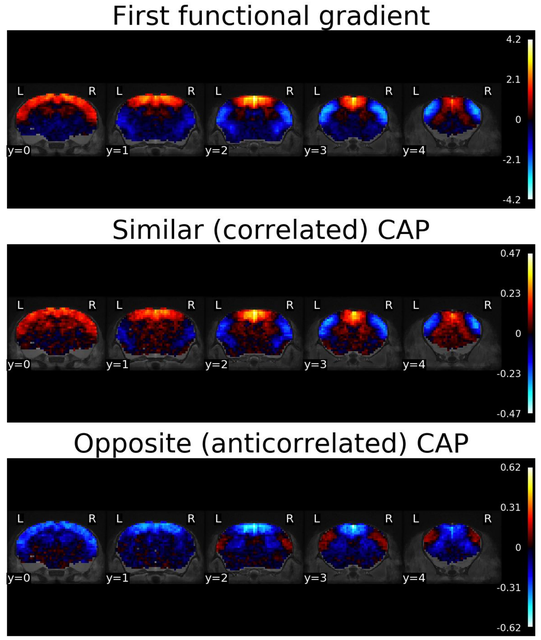
Theoretical Model: BOLD coherence is simultaneously organized across space and time, into recurrent spatiotemporal patterns[4].



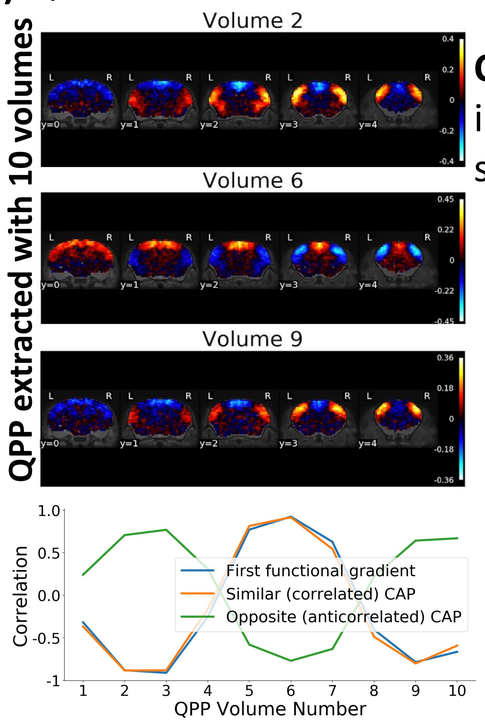
Reproduced from Majeed et al. 2011, NeuroImage

Results

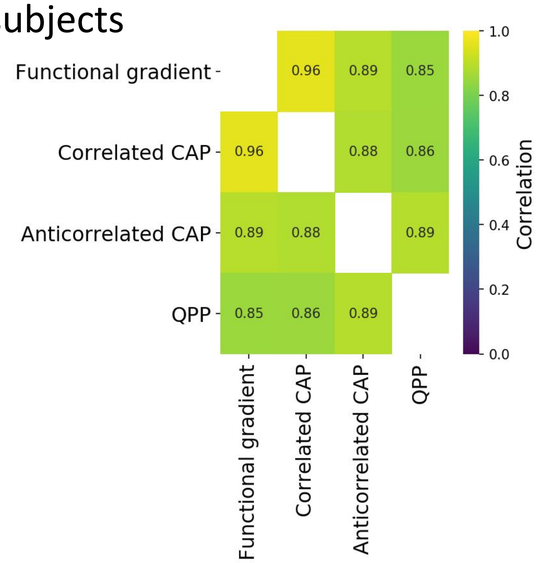
A) First FG corresponds to two anticorrelated CAPs



B) QPP reveals an an oscillation between the two CAPs

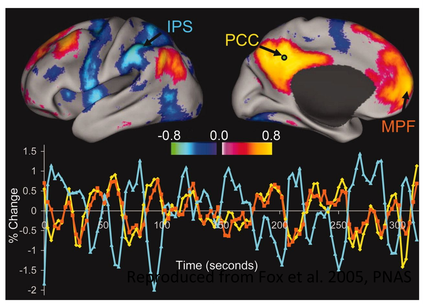


C) FC measures are inter-correlated across individual subjects



Conclusions

- identified a dominant FC pattern representing an oscillation between lateral and medial activations, consistent with previous human observations[5]



Reproduced from Fox et al. 2005, PNAS

- QPP analysis reveals patterns intrinsic to the BOLD timeseries, and the brain dynamics giving rise to the presented FG may not be best understood from a strictly 'connectomics' framework (e.g. connectivity matrix)

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Dataset: Mandino et al. 2020, bioRxiv[6]

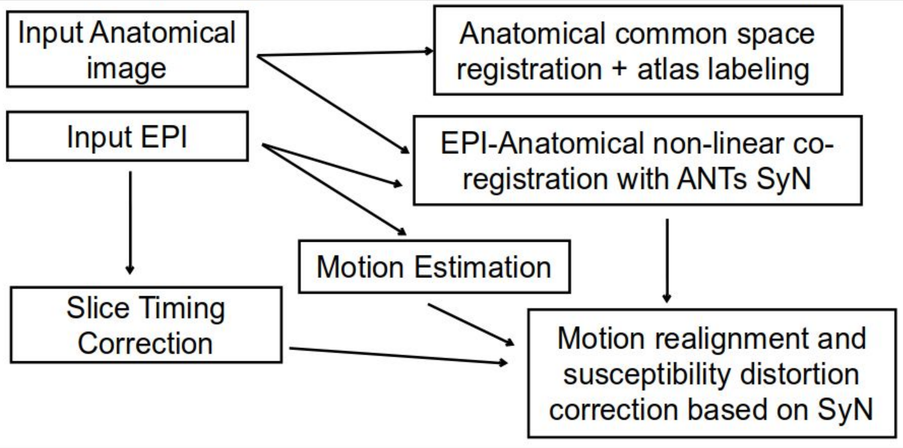
Animals: Wild type (N=10) and 3xTG (N=13) transgenic mice (Alzheimer's disease model); 3 months old

Anesthesia protocol: 0.5 % isoflurane + 0.1 mg/kg/h medetomidine; animals were mechanically ventilated

fMRI Acquisition: 11.75T Bruker scanner; Gradient echo EPI functional image (TR=1 sec, with voxel resolution 0.19x0.15 mm in-plane and 0.4 mm slice thickness, 300 volumes) and spin-echo turboRARE anatomical image.

Openneuro dataset link:
https://openneuro.org/datasets/ds001890/versions/1.0.1

Image Preprocessing with RABIES (https://github.com/CoBrALab/RABIES)



Confound regression: signal from WM/CSF/Vascular mask + 24 motion parameters + highpass filtering at 0.01Hz + smoothing kernel at 0.3mm

Result Figure Captions

Figure A)

For each subject, the pearson correlation coefficient was calculated between each voxel timeseries to derive a voxelwise FC matrix. Principal component analysis (PCA) was then conducted on the whole-sample average matrix to derive functional gradients[1]. The voxel weights of the first component are displayed across the mouse brain, and corresponds to a separation between lateral and medial cortices in their connectivity profiles. The first 5 components can be visualized at this link https://nbviewer.jupyter.org/github/Gab-D-G/sharing/blob/master/gradient_figure.ipynb. For CAP analysis[3], all EPI volumes were vectorized spatially into a voxel X time matrix, and the time series of the whole sample were concatenated. K-means clustering was applied with 15 clusters across time to cluster similar volumes. Two of the resulting cluster centroids were correlated (r = 0.96) or anticorrelated (r = -0.9) with the FG. All 15 clusters can be visualized here https://nbviewer.jupyter.org/github/Gab-D-G/sharing/blob/master/CAPs_figure.ipynb.

Figure B)

QPP analysis was run across all subjects with a window length of 10. The initial template was randomly selected as a sequence of 10 volumes among the samples. The template was then correlated across all possible volume sequences among the samples, and all sample volume sequences passing a correlation threshold of 0.01 were averaged to produce the new template. This process was repeated until the correlation between the new and previous template is above 0.99. The threshold was increase to 0.05 after the 3rd iteration. This procedure was based on previous work[4]. The three main timepoints are presented in the figure, and correspond to an oscillation between lateral activation (volume 2 and 9) and medial activation (volume 6). All 10 volumes of the QPP can be visualized at this link https://nbviewer.jupyter.org/github/Gab-D-G/sharing/blob/master/QPP_figure.ipynb, and in a video format https://drive.google.com/file/d/1A-qxKiwNjJfQWAzoHlxD3KBLT40Yfd1Z/view?usp=sharing. At the bottom of the figure are represented the correlation between each FC pattern in A), and all 10 volumes of the QPP, representing the clear oscillation between the two states of lateral and medial activations.

Figure C)

Individual scores for each FC pattern were quantified across subjects, and the matrix displayed represents the cross-individual correlation between the FC measure scores.

FG score: A linear regression was computed between the FG and each row in the subject's FC matrix, and the L2-norm of all the row weights was taken to provide the subject FG score.

CAP score: The correlation between the CAP and each volume of the subject's timeseries was computed, and the L2-norm of the resulting correlations was taken to provide the CAP score.

QPP score: The QPP template was slided and correlated across the subject's timeseries, and the L2-norm of the resulting correlations was taken to provide the QPP score.

References and Funding

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