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Network vs ROI Perspectives: Brain Connectivity Analysis using Complex Principal Component Analysis

Puneet Kumar[1*], Alakhsimar Singh[2*], Xiaobai Li[1,3], Shella Keilholz[4], Eric H. Schumacher[5] (*denotes Equal Contribution)
[1]University of Oulu, Finland [2]NIT Jalandhar, India [3]Zhejiang University, China [4]Emory University, USA [5]Georgia Inst. of Tech., USA

BACKGROUND

- This work implements Complex Principal Component Analysis (CPCA) [1] to analyse the brain connectivity at network and brain Region of Interest (ROI) levels.
- Unlike standard correlation-based connectivity (i.e., time-averaged ROI-to-ROI correlations over the scan), CPCA examines the relationships of networks in the primary spatiotemporal pattern.
- CPCA largely reproduces traditional Quasi-Periodic Patterns (QPP)-like activity [2] and handles tasks of various lengths, while QPP struggles with shorter tasks.
- Network-level and ROI-level observations are presented for Human Connectome Project (HCP) dataset comprising four 15-min rest scans (TR = 0.72 s) and seven tasks (1 h total) [3].
- Focus centers on the Task-Positive Network (TPN) defined as the Dorsal Attention Network (DAN) plus Fronto-Parietal Network (FPN) and the Default Mode Network (DMN).
- Major contributions of this study include CPCA implementation and dual (network & ROI-level) connectivity analysis. The code is available at www.github.com/MIntelligence-Group/DBCATS.

METHODS

- Overview of the proposed method is shown in Fig. 1.

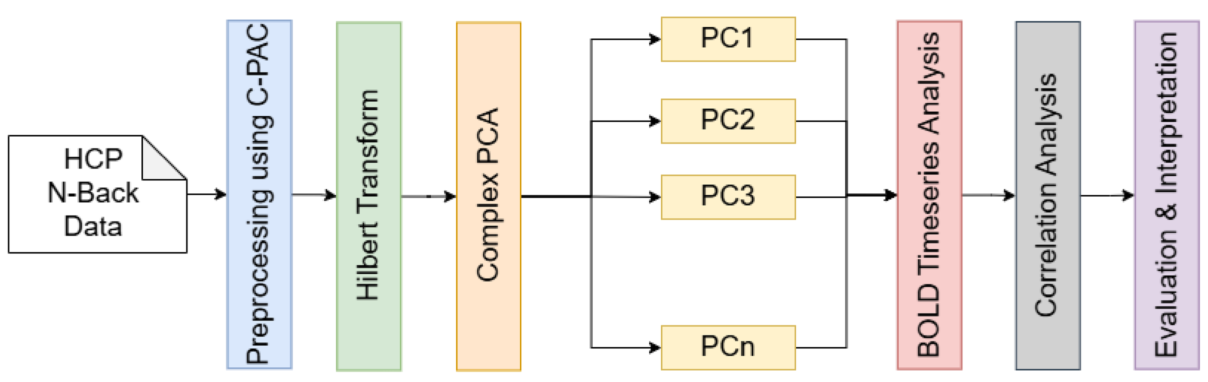

Fig. 1 CPCA pipeline: C-PAC preprocessing, Hilbert transform, complex PCA, BOLD time series and connectivity analysis.

- Data is preprocessed using the Configurable Pipeline for the Analysis of Connectomes (C-PAC) [4], including motion & slice-timing correction, normalization to MNI space and band-pass filtering (0.01–0.1 Hz)
- The Analysis focused on the working memory (0-back/2-back) task with 405 frames per run. Each run comprised eight 42.5 s task blocks (10 trials of 2.5 s), four 15 s fixation blocks, and 2 s stimuli followed by a 500 ms ITI.
- DMN (36 ROIs), DAN (33 ROIs), and FPN (30 ROIs) are defined using the 7-network parcellation [5]
- CPCA is adapted for fMRI via Hilbert transform to introduce a 90° phase shift, capturing instantaneous amplitude & phase
- Seven principal components (PCs) are extracted to reconstruct dominant spatiotemporal patterns.

RESULTS

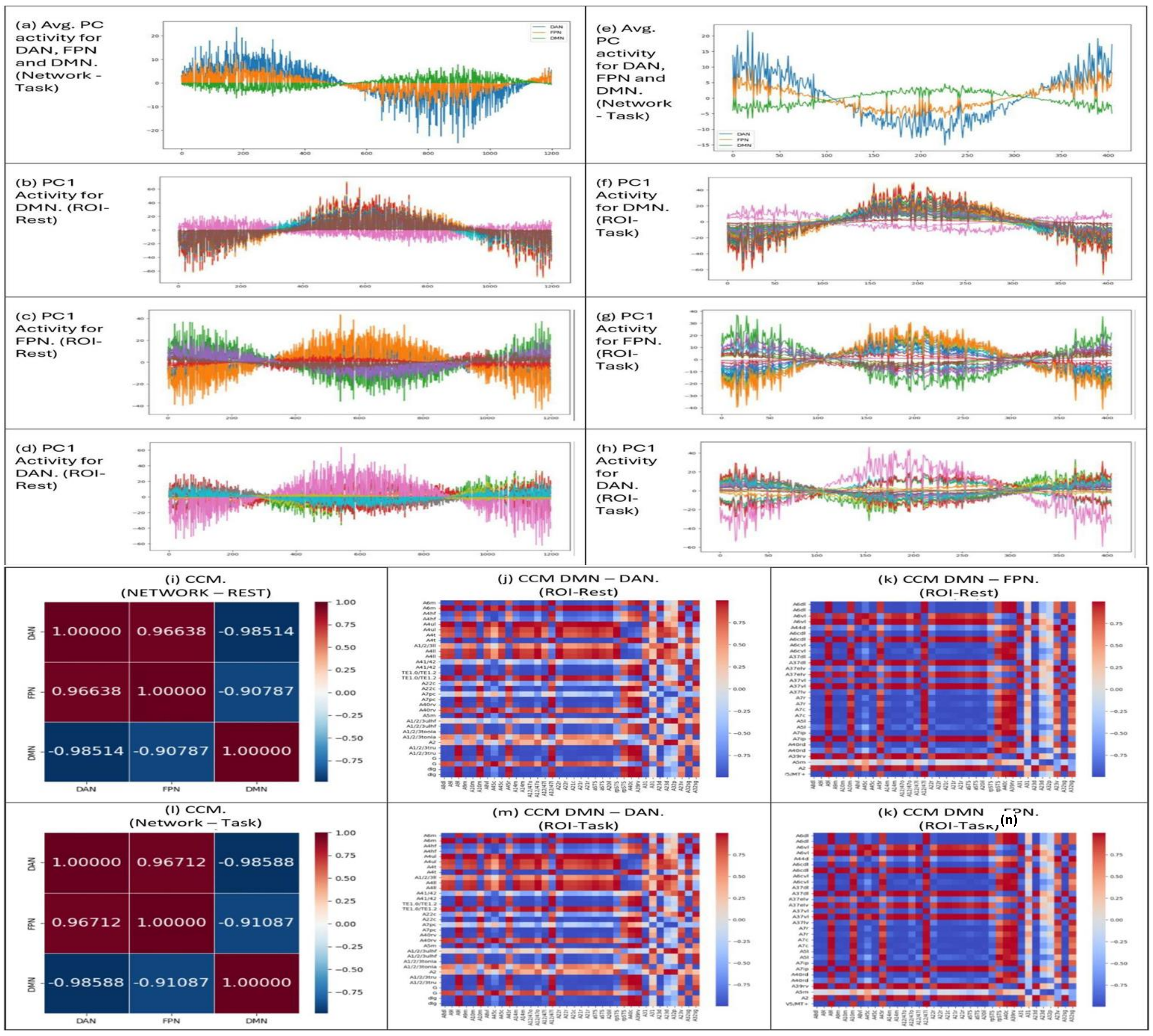

Fig. 2 Network-level and ROI-level BOLD PC1 time series and connectivity: network- and ROI-level activity for DMN, DAN, FPN in rest (a–d) and task (e–h); network Correlation Connectivity matrices (CCMs) (i,j); ROI CCMs DMN–DAN (k,l) and DMN–FPN (m,n).

- Fig. 2(a) and 2(e) depict Blood Oxygenation Level Dependent (BOLD) activation at the global network level for rest and task states.
- Fig. 2(i) shows a –0.99 correlation between the DMN and DAN, and Fig. 2(l) shows a –0.91 correlation between the DMN and FPN, both reflecting very strong inverse relationships.
- Fig. 2(b–d) depicts local ROI-level BOLD activation (from both left and right hemispheres) during rest, and Fig. 2(f–h) during task.
- In the rest state, FPN shows 440 positive and 618 negative correlations with DMN, and DAN shows 531 and 629 at the ROI-level.
- For the task state, FPN has 439 positive and 620 negative correlations with DMN, and DAN has 532 and 629.
- Comparing Fig. 2(k–n) indicates slightly shifted connectivity patterns from rest to task, reflecting changes in DMN, DAN, and FPN signals.

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DISCUSSION

- At the network level, DMN shows anticorrelation with both DAN (–0.99) and FPN (–0.91), as per Fig. 2(i,j).
- At the ROI level, 44% (1972) of DMN-TPN pairs are positively correlated, while 56% (2496) are negatively correlated, indicating local differences.
- Correlations become more negative from rest to task, though changes are modest.
- Fig. 2(k–n) shows these changes, highlighting how brain connections adapt at the ROI level and exhibit task-dependent shifts.
- This work's novelty is to adapt CPCA as a potential brain connectivity analysis method at network and ROI level, comparing rest and task.
- Future works will extend the approach to other datasets featuring tasks of varying durations and benchmarking against QPP and Co-activation Pattern (CAP) analyses.
- Linking CPCA-derived connectivity shifts to task performance or individual differences could uncover functional significance.
- Correlation metrics alone may miss higher-order relationships; future work could explore mutual information or graph-theoretic measures.

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