Deconfounding Subcortical Signals in fMRI by Modeling Region-Specific Cerebrospinal Fluid Noise

NeuroPRISM LAB

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HIGHLIGHTS

- A novel, spatially targeted cerebrospinal fluid (CSF) artifact correction approach was applied to 7T fMRI data.
- Time-series of CSF voxels displayed significant spatial variation across the brain.
- This localized, region-specific, approach increased sensitivity in both resting-state and task fMRI.

MOTIVATION

Capturing reliable signals from **subcortical structures** is challenging due to their small size and low SNR[1,2]. These challenges are further exacerbated by **physiological noise** arising from adjacent CSF.

Conventional CSF correction—optimized for the cortex—often utilizes a global approach, which may fail to account for the **spatial heterogeneity** of CSF-related noise.

RESEARCH QUESTION

Does **region-specific** CSF correction improve **sensitivity** and **precision** of subcortical signals?

SCANNING PARAMETERS

Subjects:
- Resting-state fMRI (N = 83)
- Task-fMRI (N = 43)

fMRI Acquisition:
- Ultra high-resolution 7T fMRI
- TR = 2.34 seconds
- Voxel size = 1.1mm isotropic
- Pre-processed with fMRI prep[5]

Subcortical Seeds (N=16):
- Harvard-Oxford Subcortical Atlas[3]
- Brainstem Navigator Atlas[4]
- Subject-Specific PAG[6]

Resting-State:
- Scan length: 3 runs (~11 min per run)

Visual Avoidance Task:
- Stimuli: IAPS images
- Presentation: 3-sec duration
- Contrast: negative images > baseline

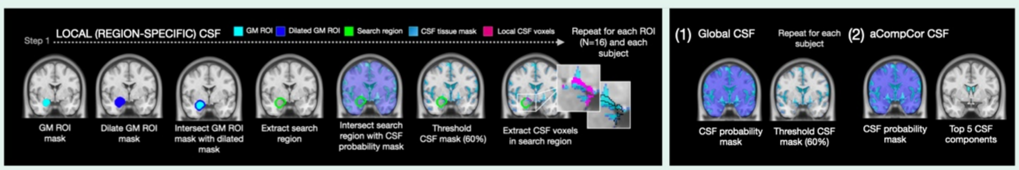

Fig 1. Cerebrospinal fluid correction methods. Shown are the proposed local CSF correction (*left*) and the two global approaches: (*middle*) averaging signal across all CSF voxels exceeding threshold, and (*right*), aCompCor, a principle component-based method using signals from the entire CSF mask.

LOCAL CORRECTION:
MODELS CSF NOISE ADJACENT TO EACH INDIVIDUAL ROI

vs.

GLOBAL CORRECTION:
COMBINES CSF SIGNALS FROM DISTINCT REGIONS & APPLIES A UNIFORM CORRECTION TO ALL ROIS

SPATIAL DISTRIBUTION OF CSF

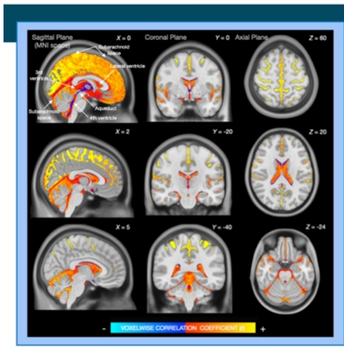

Fig 2. Voxel-wise correlation between individual CSF voxels and the weighted global CSF time-series.

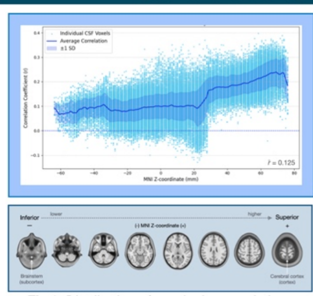

Fig 3. Distribution of voxel-wise correlations between CSF voxels and the global CSF signal (*see Fig. 2*)

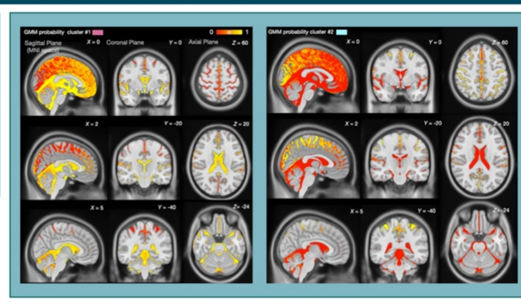

Fig 4. Unsupervised clustering (GMM) of CSF voxel-wise correlations (*see Fig. 2*). The two distributions observed in Figure 3 motivated a two-cluster model.

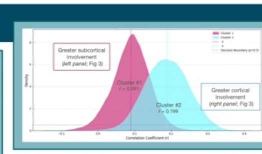

Fig 4. Kernel density estimation of GMM-derived probability clusters from the CSF voxel-wise correlations (*see Fig. 3*)

CSF voxels show **distinct temporal variability** that follows clear **anatomical gradients**

HOW CSF CORRECTION STRATEGIES INFLUENCE RESULTS

FUNCTIONAL CONNECTIVITY

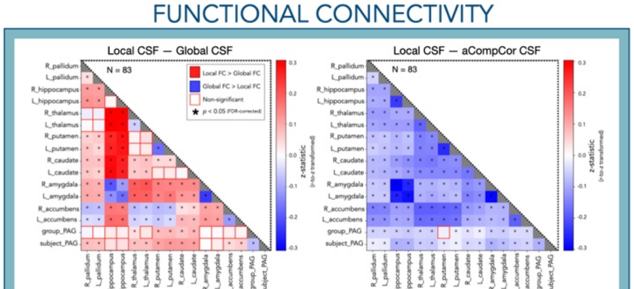

Fig 5. Functional connectivity differences between local CSF and global correction methods.

TASK-BASED ACTIVATION

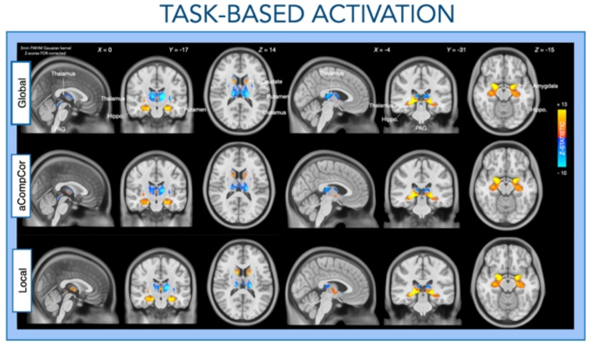

Fig 6. Group-level fMRI activation/deactivation maps for the contrast: negative images > baseline. Maps are displayed at $p < .05$ (FDR-corrected) on the MNI2009c template.

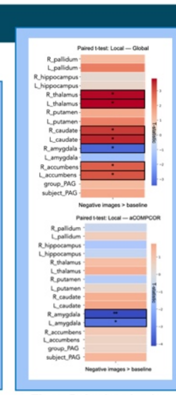

Fig 7. Paired activation t-tests (*see Fig 6*)

Local CSF correction yields **more positive subcortical activations** during an emotion task (FDR-corrected, $\alpha < 0.05$, $p < 0.05$)

CONCLUSION

Localized CSF correction improves sensitivity to subcortical signals, highlighting the importance of spatially-informed noise removal.

These strategies enhance fMRI **data quality**, **reliability**, and **statistical power**.

RESOURCES

Scan here for our **open source python package**

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Open to opportunities

References

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