Threshold PCA Denoising Outperforms MP-PCA in Correlation Tensor Imaging of Human Brain Microstructure at 3T

Manu Raghavan[a], Lisa Novello[b], Rafael Neto Henriques[c], Noam Shemesh[c], Andrada Ianuş[d], Thorsten Feiweier[e], Domenico Zacà[f], Jorge Jovicich[a]

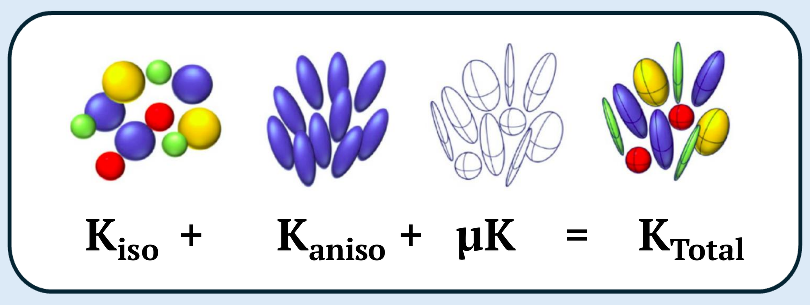
[a]CIMeC, University of Trento, Trento, Italy, [b]Fondazione Bruno Kessler, Trento, Italy, [c]Champalimaud Foundation, Lisbon, Portugal, [d]King's College London, London, UK, [e]Siemens Healthineers AG, Erlangen, Germany, [f]Siemens Healthcare, Milan, Italy

Ministero dell'Università e della Ricerca

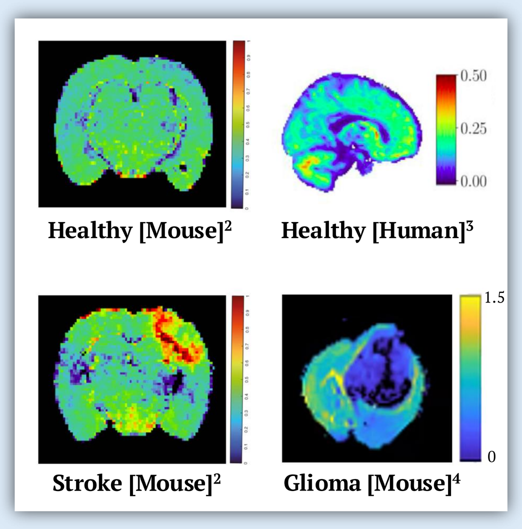
Italiadomani — PIANO NAZIONALE DI RIPRESA E RESILIENZA

Finanziato dall'Unione europea NextGenerationEU

INTRODUCTION



- **Correlation Tensor Imaging (CTI)**[1] (**K**: Kurtosis, non-Gaussian diffusion)
- Is micro kurtosis (μK) relevant in healthy tissue? **YES!**[1,2,3]
- Is micro kurtosis (μK) relevant in pathological tissue? **YES!**[3,4]
- Human CTI[2] ~ so far 50min
  → Limited clinical feasibility → **Acceleration** is critical
- Acceleration → SNR losses → **Denoising is critical**



- **This work compares 3 denoising pipelines on human CTI data at 3T:**
  - *P1: No Denoising (Reference)*
  - *P2: Marčenko-Pastur PCA* ***(MP-PCA)***[5]
  - *P3: Threshold PCA* ***(TPCA)***[6]

METHODS

- **Population & MRI Acquisition:**
  - CTI data of 8 healthy young volunteers, 3T MRI[3]
- **Preprocessing and CTI:**
  - ***Denoising:*** *P1 (None), P2 (MP-PCA), P3 (TPCA)*
  - *Gibb's ringing (MRtrix3)*
  - *Geometric distortions and eddy currents (FSL),*
  - *Signal drift*[7] *, Bias field (MRtrix3)*
- **Statistical Analysis:**
  - ***Denoising Performance:***
    - *Mean Values of CTI metrics*
    - *Within-ROI variability of CTI metrics*
    - *% CTI fit fails (biologically implausible)*
  - ***Pipeline Effects:*** *Friedman → Wilcoxon's + FDR correction*

RESULTS

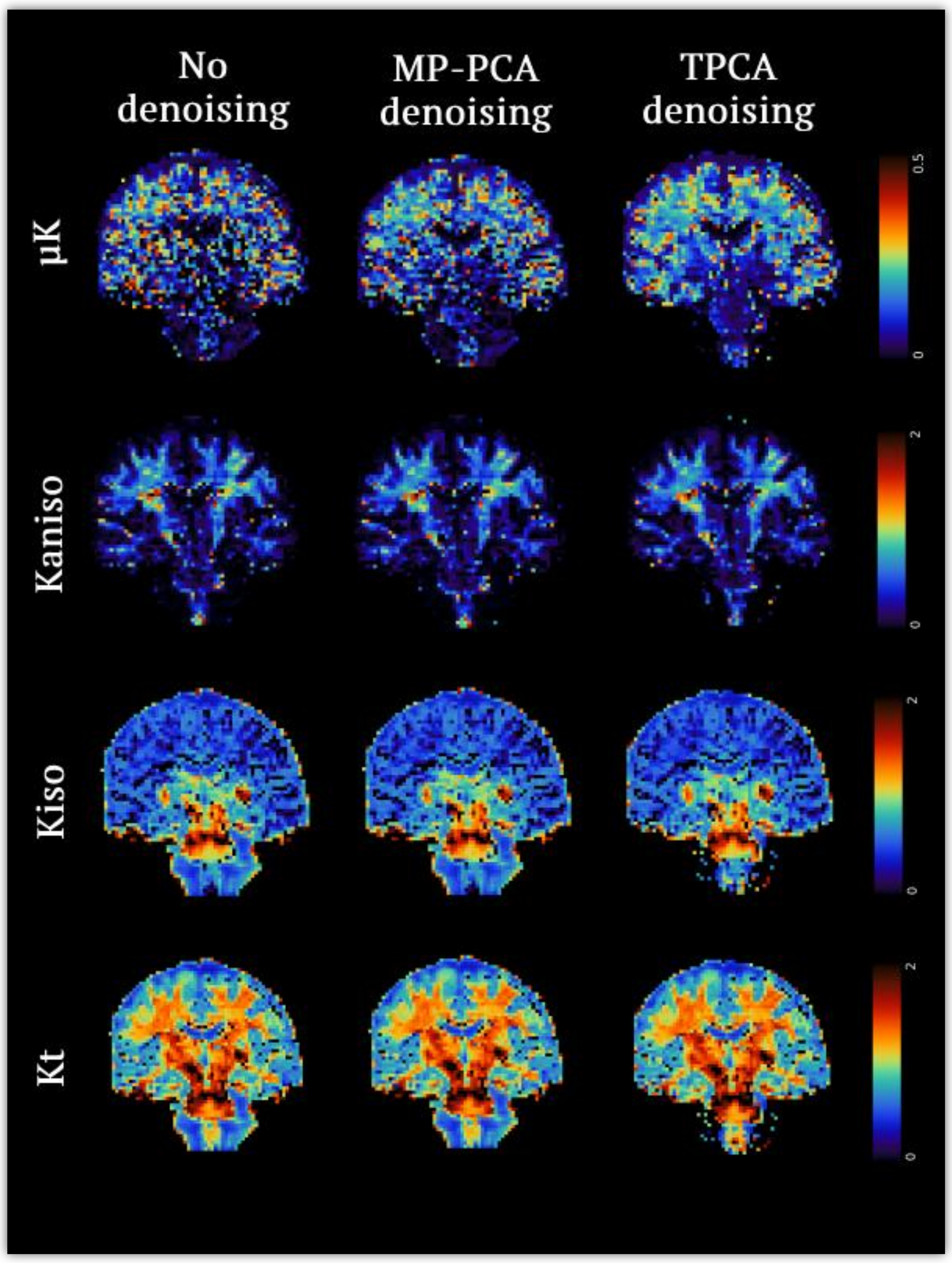


Figure 1. Single subject CTI derived maps of microkurtosis (μK), anisotropic kurtosis (Kaniso), isotropic kurtosis (Kiso), and total kurtosis (Kt) across denoising pipelines.

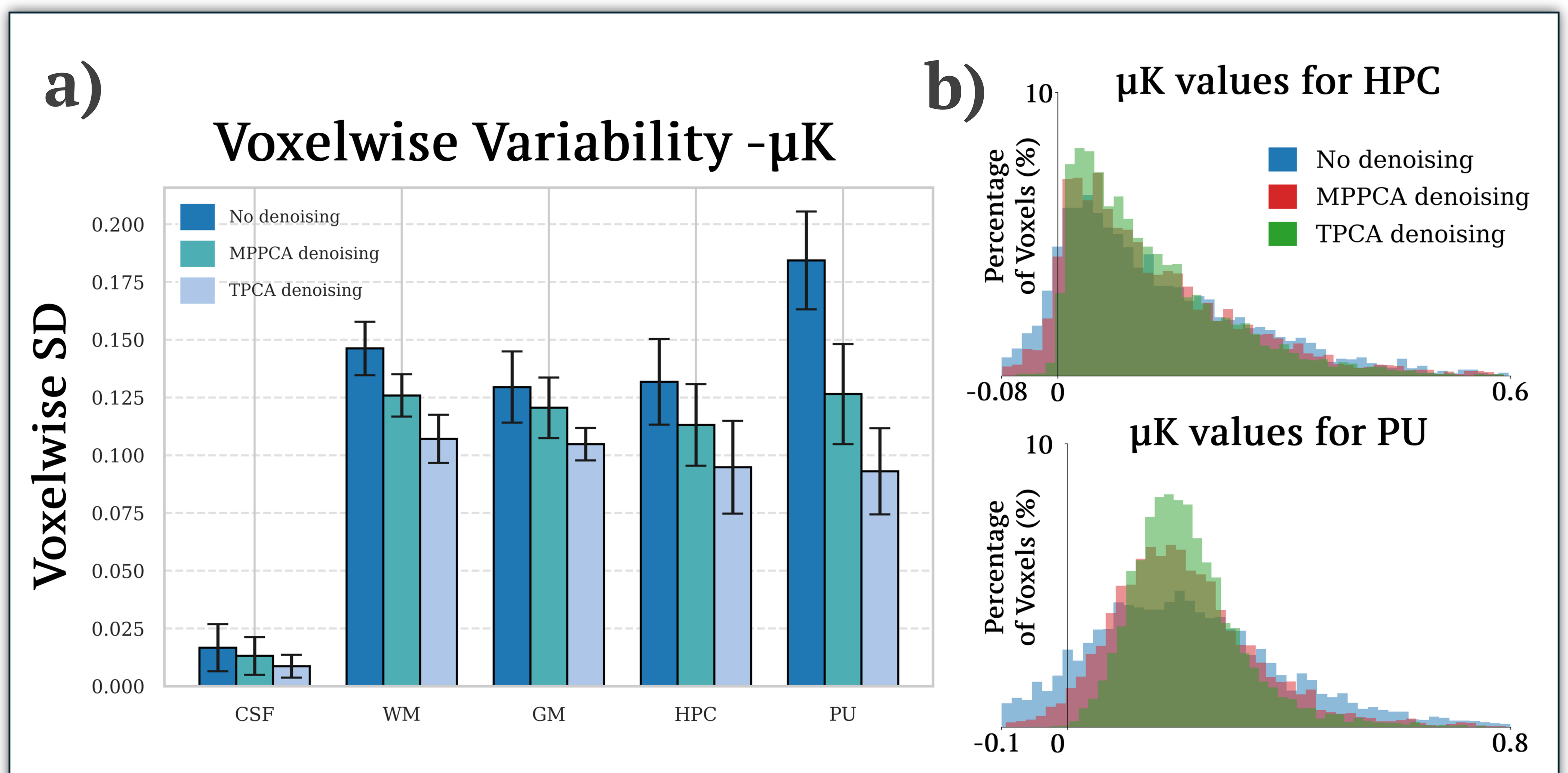


Figure 2. Denoising reduces μK variability. (a) μK variability drop (P1 > P2 > P3) across regions. (b) μK distributions in HPC (top) and PU (bottom).

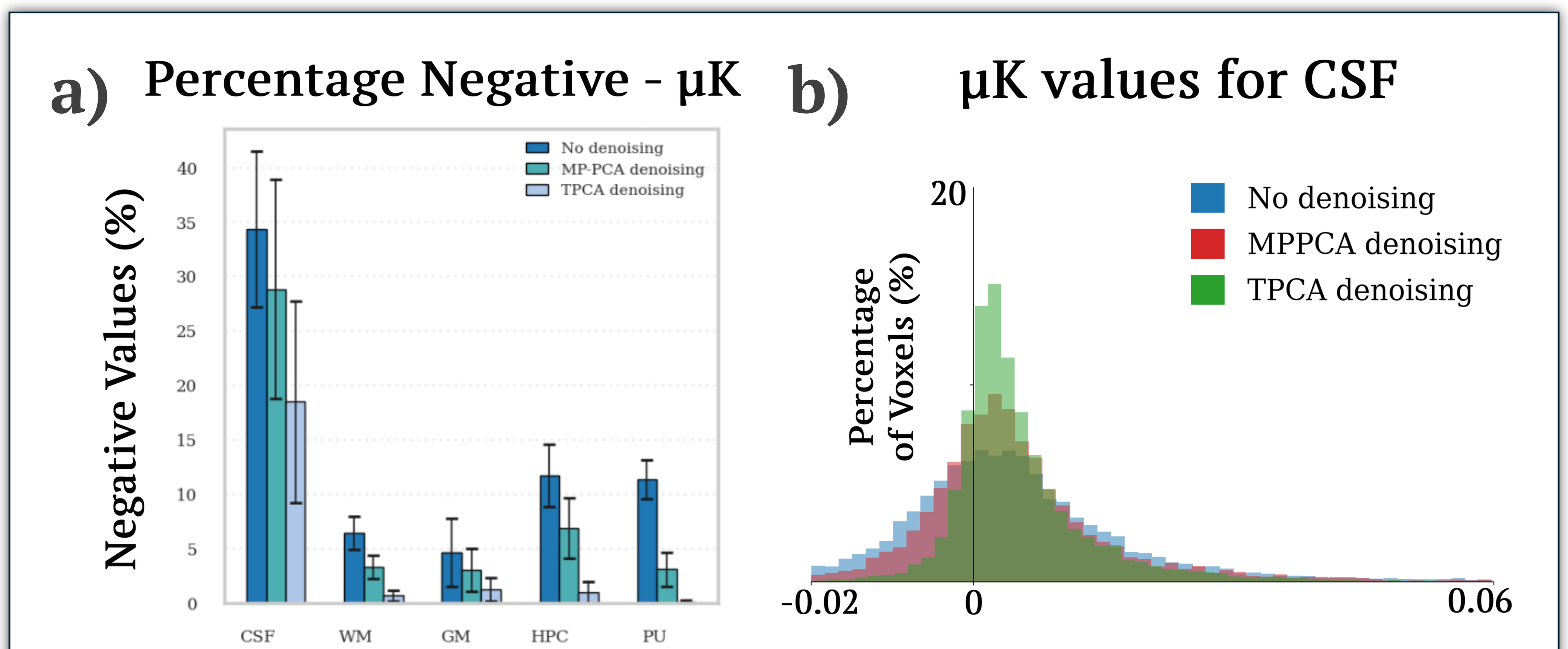


Figure 3. Denoising reduces % negative μK fits. (a) P1 > P2 > P3 across regions. (b) CSF μK distribution.

DISCUSSION

- **PCA denoising does not affect mean CTI ROI values**
- **But, both PCA methods reduce CTI variability within ROIs, especially in μK:**
  - *Lower voxelwise standard deviation ($p < 0.01$)*
  - *Lower biologically implausible fits ($p < 0.01$)*
- **TPCA outperforms MP-PCA (WM & GM regions)**
- CSF: Strongest difference in % negatives between the P1, P2 and P3

CONCLUSION

- **Denoising Performance:**
  - ***P3 (TPCA) > P2 (MP-PCA) > P1 (No Denoising)***
  - ***Correcting for spatial autocorrelations (TPCA) improves CTI accuracy***
- **Strongest Improvement:**
  - *CTI Metric: μK, Brain Regions: CSF, Hippocampus, Putamen*
- **Future Directions:**
  - *Add Rician bias correction*
  - *Acquisition of CTI data with an accelerated (~12m) protocol*
  - *Test-retest reproducibility of current results*

SCAN ME

References: 1. Henriques RN, Jespersen SN, Shemesh N (2020) Correlation tensor magnetic resonance imaging. NeuroImage 211:116605. 2. Alves R, Henriques RN, Kerkelä L, Chavarrías C, Jespersen SN, Shemesh N (2022) Correlation Tensor MRI deciphers underlying kurtosis sources in stroke. NeuroImage 247:118833. 3. Novello L, Henriques RN, Ianuş A, Feiweier T, Shemesh N, Jovicich J (2022) In vivo Correlation Tensor MRI reveals microscopic kurtosis in the human brain on a clinical 3T scanner. NeuroImage 254:119137. 4. Henriques, R.N., Simões, R.V., Monteiro, S., Ianuş, A., Carvalho, T., Jespersen, S.N., Shemesh N., 2023. Correlation Tensor Imaging Enhances Histological Differences Between Mouse Glioblastoma Subtypes. 2023 ISMRM & ISMRT Annual Meeting (Toronto, CA) 5. Veraart J, Novikov DS, Christiaens D, Ades-aron B, Sijbers J, Fieremans E (2016) Denoising of diffusion MRI using random matrix theory. NeuroImage 142:394–406. 6. Henriques RN, Ianuş A, Novello L, Jovicich J, Jespersen SN, Shemesh N (2023) Efficient PCA denoising of spatially correlated redundant MRI data. Imaging Neuroscience 1:1–26. 7. Vos SB, Tax CMW, Luijten PR, Ourselin S, Leemans A, Froeling M (2017) The importance of correcting for signal drift in diffusion MRI. Magnetic Resonance in Med 77:285–299.