Exploring large-scale cortical organization in chimpanzees: probing myeloarchitecture with qMRI

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Evolution of Brain Connectivity

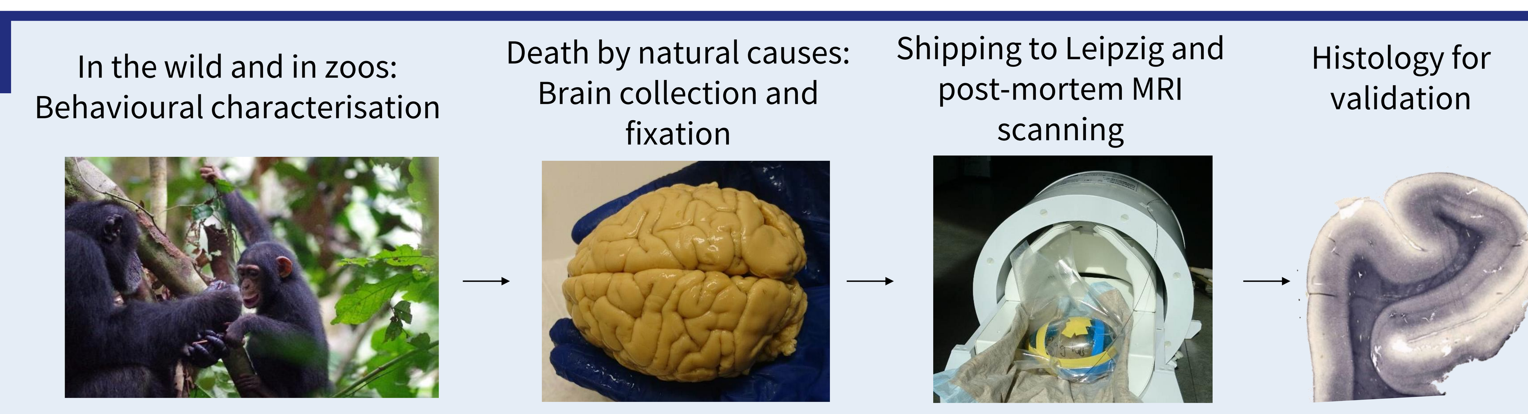
Introduction

- MRI-based comparative neuroscience provides unique insights into the evolution of the human brain [1,2].
- Large-scale principles of information processing can be uncovered by studying the spatial dimensions of cortical organisation, the so-called **cortical gradients** [3,4].
- These organisational principles are reflected in functional and structural connectivity of related cortical regions as well as in the **similarity of their microstructure** [5].
- This principle, which was initially discovered using histology, can now also be investigated through microstructural profiles obtained from **MRI at sub-mm-resolution** [6].
- To date, a complete understanding of the organization of the chimpanzee cortex, which are the closest living relatives to humans, is lacking. Ethical concerns have widely stopped *in vivo* MRI research and **existing data are sparse**.

Aims of the study

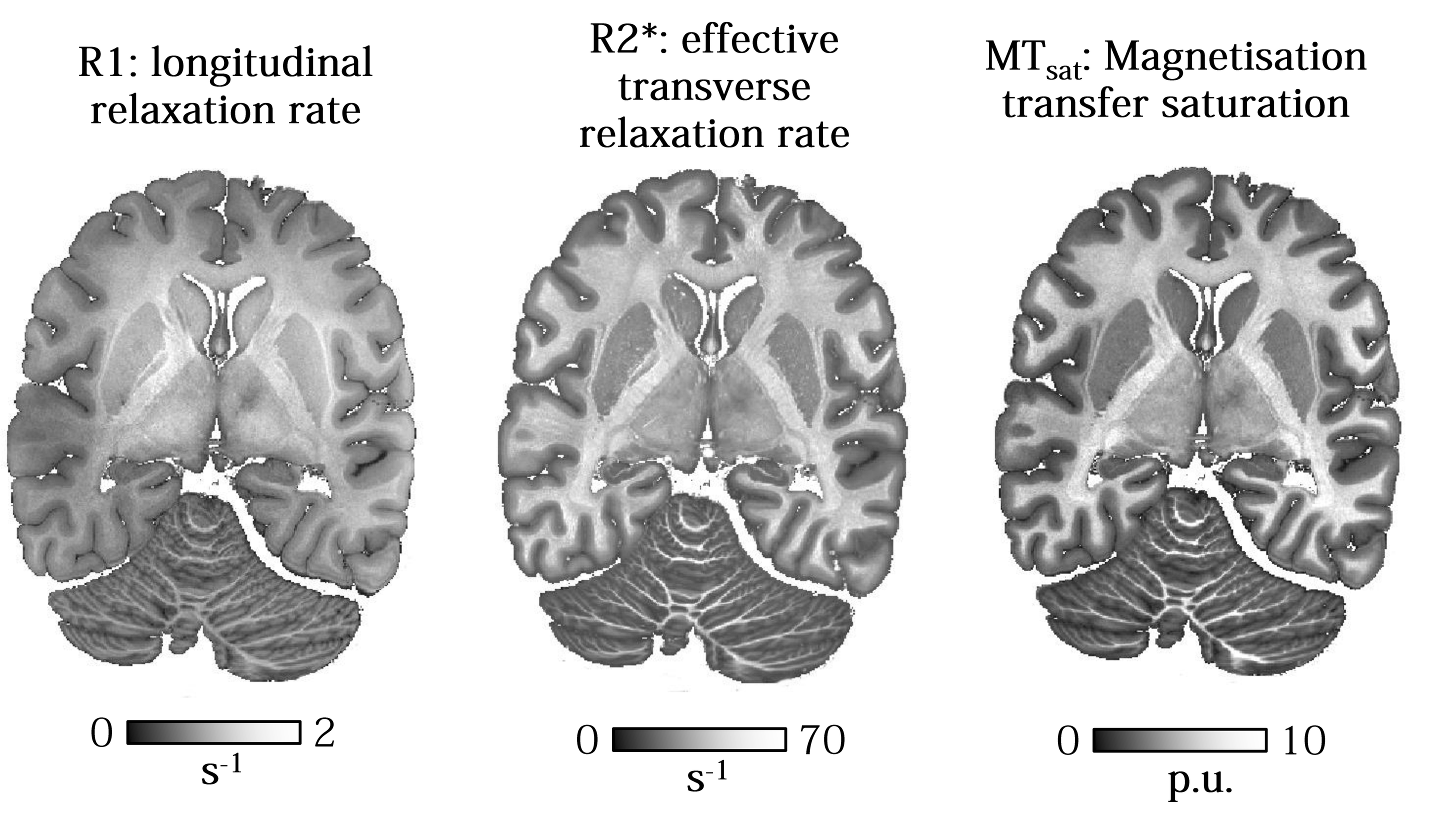
- Here, we use **post-mortem ultra-high resolution quantitative MRI** data from brains of chimpanzees, who died in the wild or in zoos from natural causes, to investigate the **large-scale cortical organisation through myeloarchitecture.**

Methods



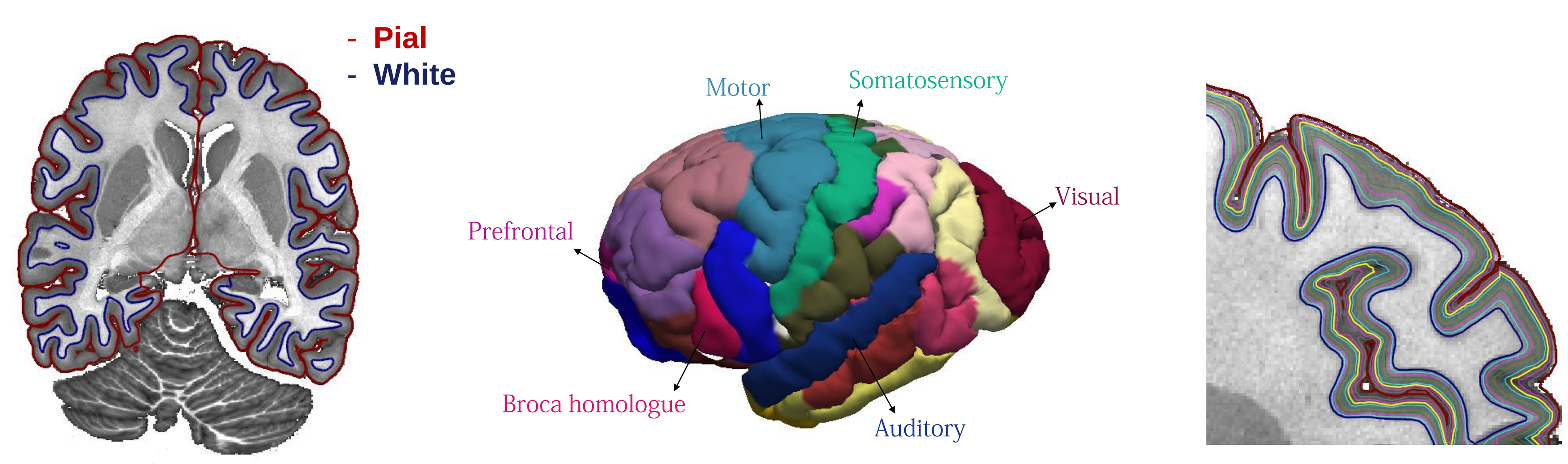
- Brains were collected and fixed in 10% PBS (phosphat buffered saline) buffered formalin at pH 7.4 between 4 and 24 hours after death.
- Here, data from **15 chimpanzee brains** (8 wild, 7 captive; age (mean±std): 26±17 years) were analysed.
- The brains were embedded in Fomblin (Solvay) and scanned in a human 7T MRI scanner (Siemens Healthineers, Erlangen, Germany).
- Multi-parameter mapping [7] was performed on the whole brains at 300µm isotropic resolution (TR = 70ms, 12 equispaced echoes, TE = 3.63-41.7ms, flip angles: 18°, 82°, MT pulse: 3kHz offset, 800°, acquisition matrix: 448 x 392 x 288) to obtain maps of various myelin-sensitive and iron-sensitive quantitative MR parameters: longitudinal relaxation rate (R1), effective transverse relaxation rate (R2*) and magnetization transfer saturation (MTsat).

Ultra-high resolution multi-parameter maps

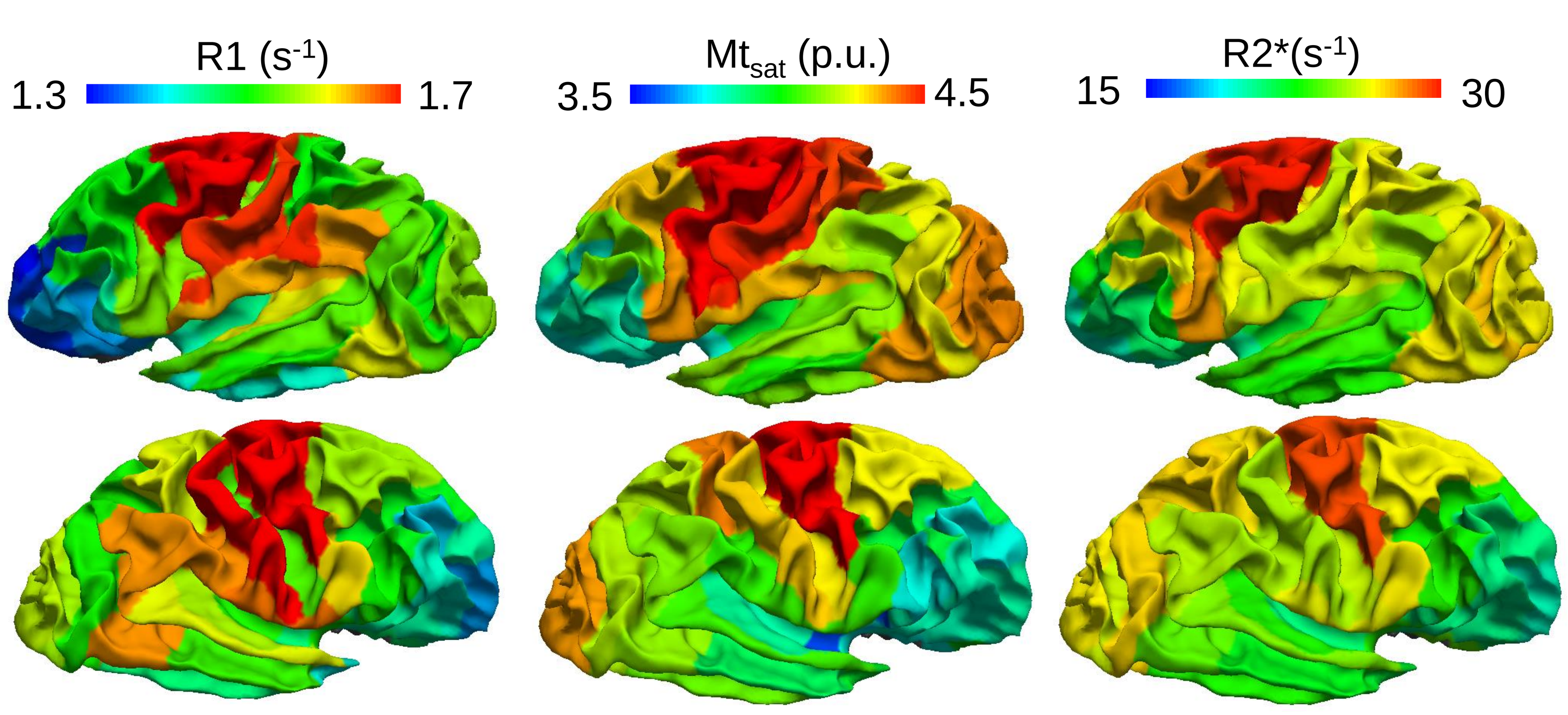


Cortical surface reconstruction

- After segmenting white matter and pial surfaces using **Freesurfer, equi-volume layering** [8] was done across 5-95% of the cortical depth in 5% steps.
- The cortex was parcellated using the Bailey-Bonin chimpanzee atlas [2], yielding 38 nodes on each hemisphere.

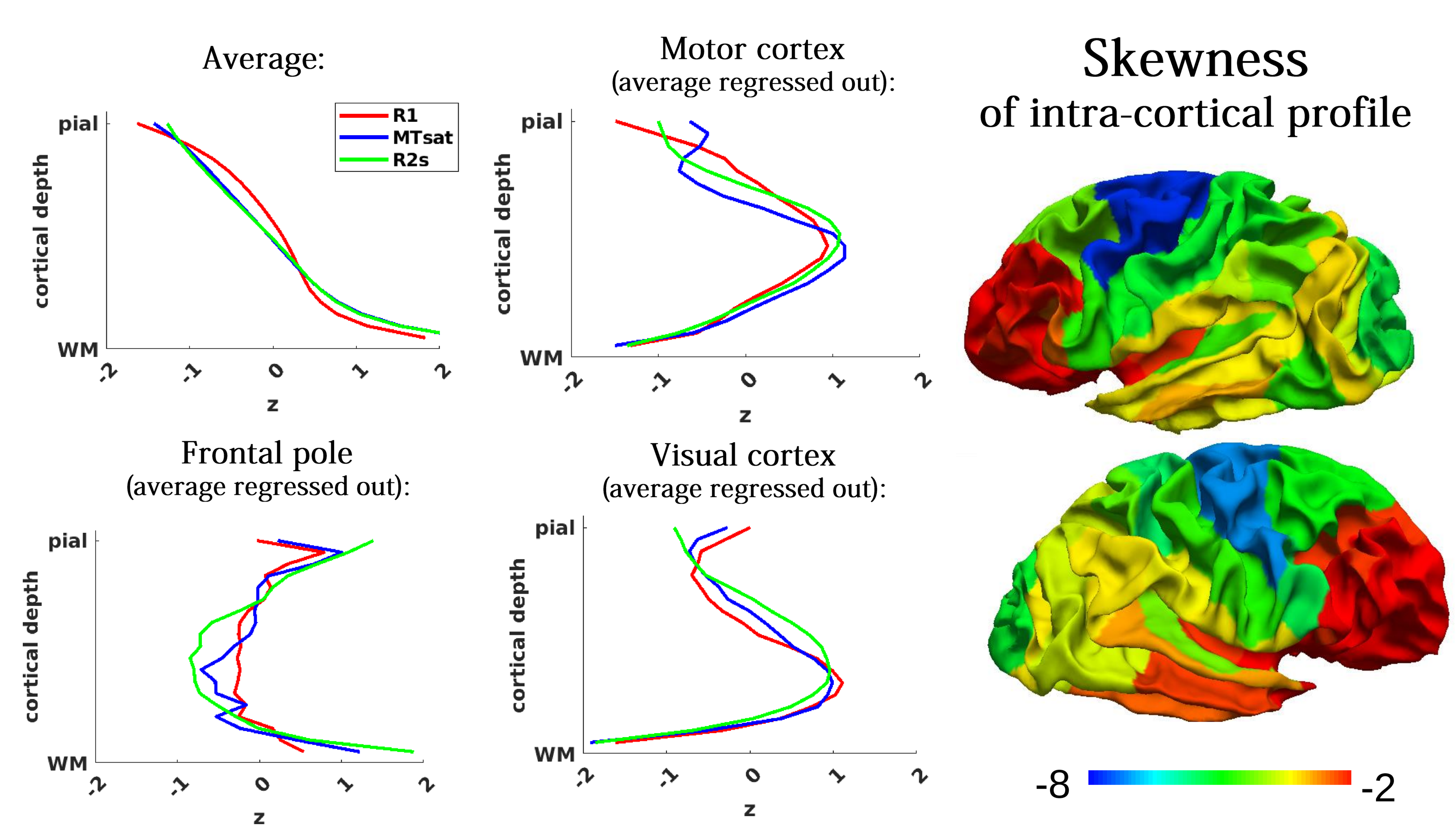


Node-specific quantitative MRI parameters



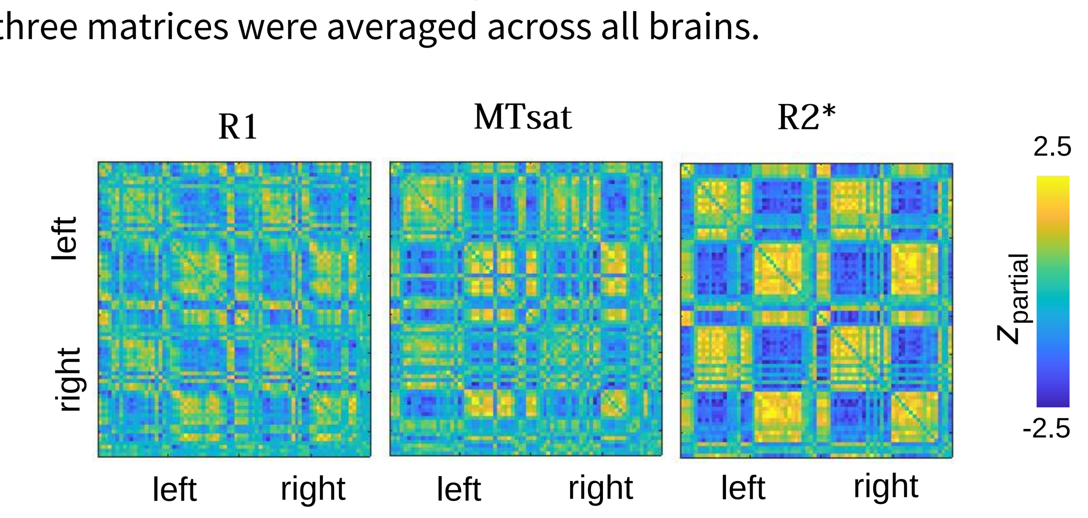
- Average parameters across cortical parcellations and across all chimpanzees are projected on the reconstructed surface of a representative chimpanzee brain.
- The parameters indicate strong cortical myelination in the motor cortex and low myelination in frontal areas.

Node-specific intracortical profiles



Microstructural profile covariance

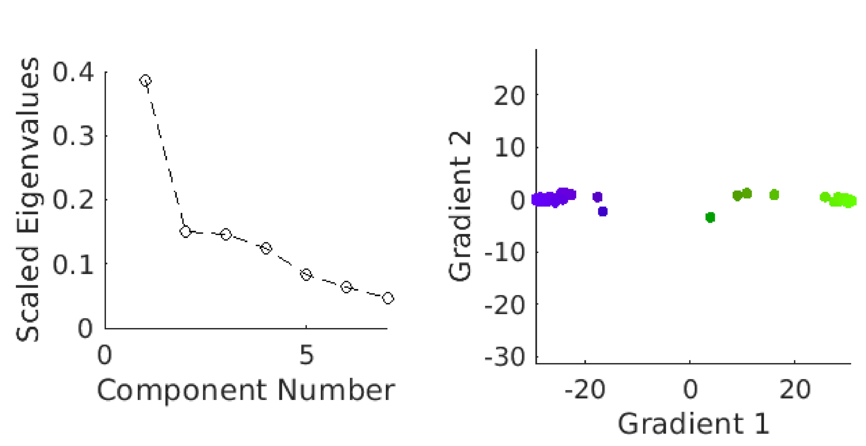
- Microstructure profile covariance (MPC) for each parameter (R1, R2* and MTsat) was calculated by **partial correlation coefficients** between the intracortical profiles of all nodes, controlling for the average profile across all nodes, followed by Fisher's z-transformation. The resulting three matrices were averaged across all brains.



- Intensity values reflect the node-to-node partial correlation coefficients between the intra-cortical profiles. Note that this correlation is not affected by the average MRI parameter value in each node.

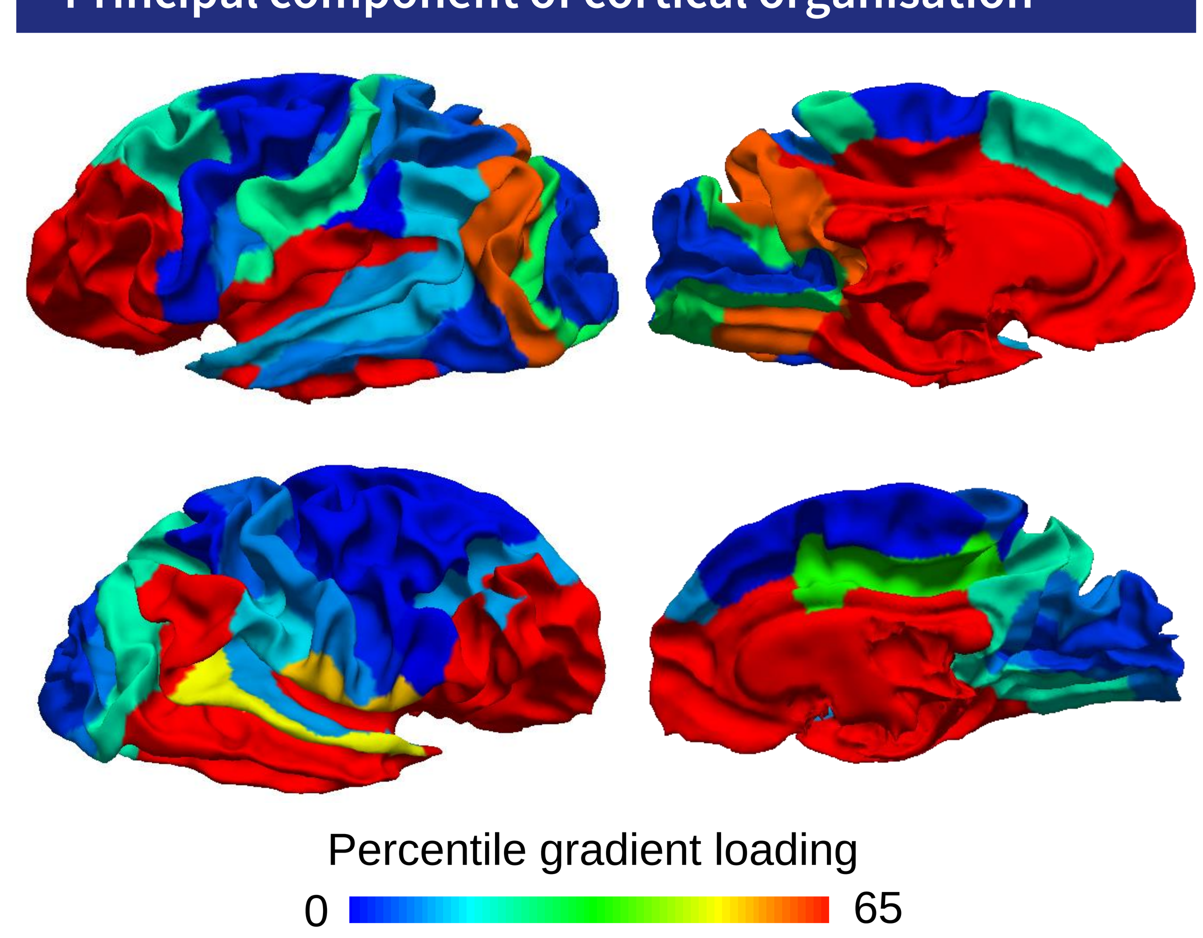
Diffusion embedding

- To identify cortical gradients, diffusion embedding was done on the averaged MPCs [9] using the software package Brainspace [10].
- The **scree plot** suggests one principal gradient.



- The principal gradient is characterized by a **unimodal pole**, including visual and motor cortex, and a **transmodal pole**, including prefrontal cortex.

Principal component of cortical organisation



Discussion

- A principle gradient of cortical organisation along a sensory-fugal axis has previously been shown in humans and macaques [3,6].
- Here, we demonstrated the presence of a comparable principle cortical gradient for the first time (to our knowledge) in chimpanzees, using ultra-high resolution whole brain post-mortem quantitative MRI data.
- Our results emphasize the feasibility of microstructural profile covariance mapping with this ethical and sustainable brain sourcing approach.
- Extending our work will allow direct comparison of cortical organisation in various non-human primate species, gaining further insight into cortical evolution.

References

[1] Friedrich, P., et al. (2021). NeuroImage, 228, 117685.
[2] Ardesch, D. J., et al. (2019). PNAS, 116(14), 7101–7106.
[3] Margulies, D. S., et al. (2016). PNAS, 113(44), 12574–12579.
[4] Mesulam, M. M. (1998). Brain, 121(6), 1013–1052.
[5] Cabezas-García, Á. M, et al. (2019). Brain Structure and Function, 224, 985–1008.
[6] Paquola, C., et al. (2019). PLoS Biology, 17(5).
[7] Weiskopf, N., et al. (2013). Frontiers in Neuroscience, 7, Article 95.
[8] Waehnert, M. D., et al. (2014). NeuroImage, 93, 210–220.
[9] Paquola, C., et al. (2019). ELife, 8, 1–23.
[10] Vos de Wael, R., et al. (2020). Communications Biology, 3(1).