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Comparison of the motor-hand area morphology in Great Apes

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INTRODUCTION

The neocortical folding pattern is related to functional architecture in primary areas [1, 2].

The folding pattern is globally conserved within species, and partially shared inter species. For example, within the central sulcus, the motor-hand area (or hand-knob) has been described as a common anatomical feature in primates [3] (see Fig 1).

Given the importance of the hand in primate evolution, here we examined the morphological variability of the hand-knob in chimpanzee, gorilla and human.

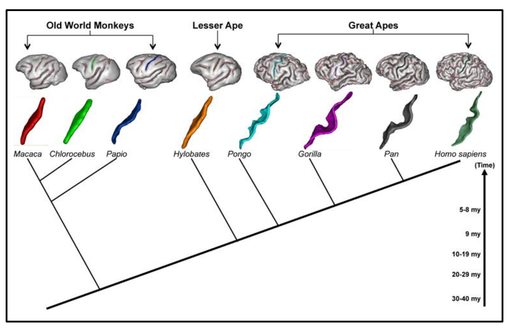

Fig 1: From Hopkins et al, 2014 [3]: 3D brain cortex reconstructions and extracted central sulci from representative primate species in the study along a phylogenetic timeline.

COHORT

30 chimpanzees

Whole-brain in vivo anatomical scans were acquired in 30 captive chimpanzees (Pan troglodytes) in a 3-tesla MRI scanner. All subjects are part of the National Chimpanzee Brain Resource (www.chimpanzeebrain.org).

18 gorillas (post-mortem)

Whole-brain anatomical scans were acquired in 18 post-mortem specimens of gorilla brains (Gorilla gorilla) in a 7-tesla MRI scanner.

All scans were performed under the guidelines of the US Department of Health and Humans Services

30 humans

Human brain data used in the preparation of this work were obtained from the MGH-USC Human Connectome Project (HCP) database (https://ida.loni.usc.edu/login.jsp)

We used thirty T1-weighted images.

METHODS

1. Extraction of central sulci

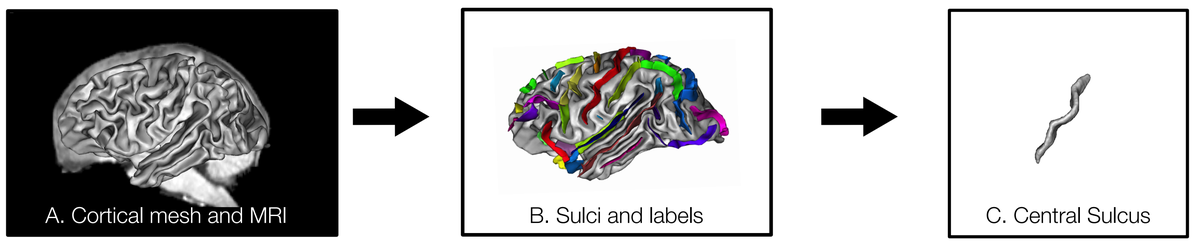

Fig 2 : A. Cortical segmentation (WM surface) from brain MR image (Morphologist 2012 pipeline [4]). B. Sulci extraction and manual labelisation of the chimpanzee brain based on the human nomenclature used in Morphologist (Perrot 2011 [7]). The gorillas labeling was automatically performed using the CNN-based segmentation for sulci automatic labeling of Brainvisa (Borne et al., 2020 [8]) with a training phase on the chimpanzee labeling. C. Selection of the central sulci.

2. Brains affinely normalized to Talairach space.

3. Right sulci flipped to allow left/right comparison.

4. Pairwise shape similarity matrices computed after rigid alignment (from Sun et al., 2012 [5])

A pairwise similarity matrix records shape similarity for each pair of sulci. The similarity between two sulci is coded by the average quadratic distance between their 3D representations after alignment (Sun et al., 2009 [9]). Alignment is achieved by the Iterative Closest Point (ICP) algorithm (Besl and McKay, 1992 [10]). This efficient algorithm iteratively aligns one sulcus relative to another through successive rotations and translations. The iterations are driven by minimization of the average distance between shifted and target sulci. For each pair of sulci, the ICP algorithm is applied twice before and after sulcal role switches. The smallest residual distance across the two alignments is used as a similarity measure.

5. Isomap to project high dimensional space spanned by the sulci to one single dimension

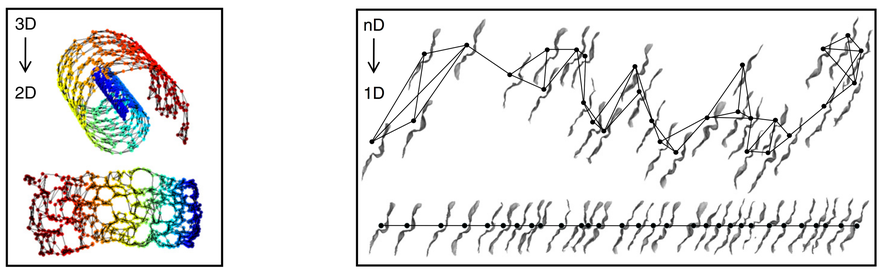

Fig 3 : From Sun et al., 2012 [5]: Manifold learning using Isomap. (left) An application of the Isomap algorithm: a set of points living in a Swiss roll is unrolled from 3D space to 2D space. The nearest neighbor graph approximating the Swiss roll manifold is visualized through black links. The shortest paths in this graph are used to approximate geodesic distances in the manifold. (right) The dimension of the manifold spanned by the central sulci is much higher and unknown. However, the same approach is used to map this manifold to a one dimensional axis in order to obtain an approximation of its organization.

6. All sulci rigidly aligned to the sulcus with the minimum average distance to the set.

7. Moving local average shapes computed at regular coordinates.

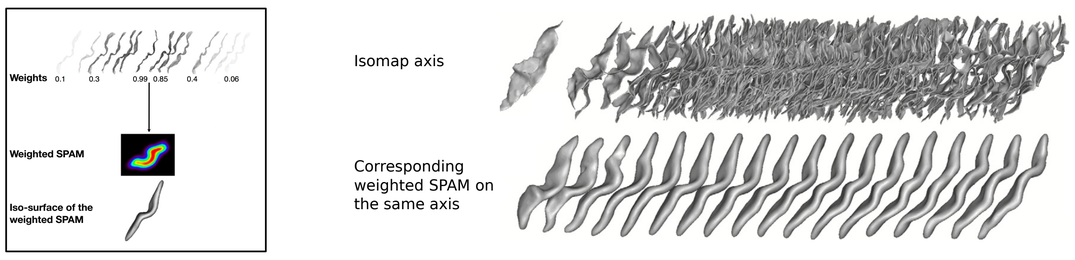

Fig 4 : From Sun et al., 2012 [5]: Computing local average shapes using weighted SPAM

RESULTS

We performed three experiments comparing :
A. Chimpanzees and Humans B. Chimpanzees, Gorillas and Humans C. Chimpanzees and Gorillas

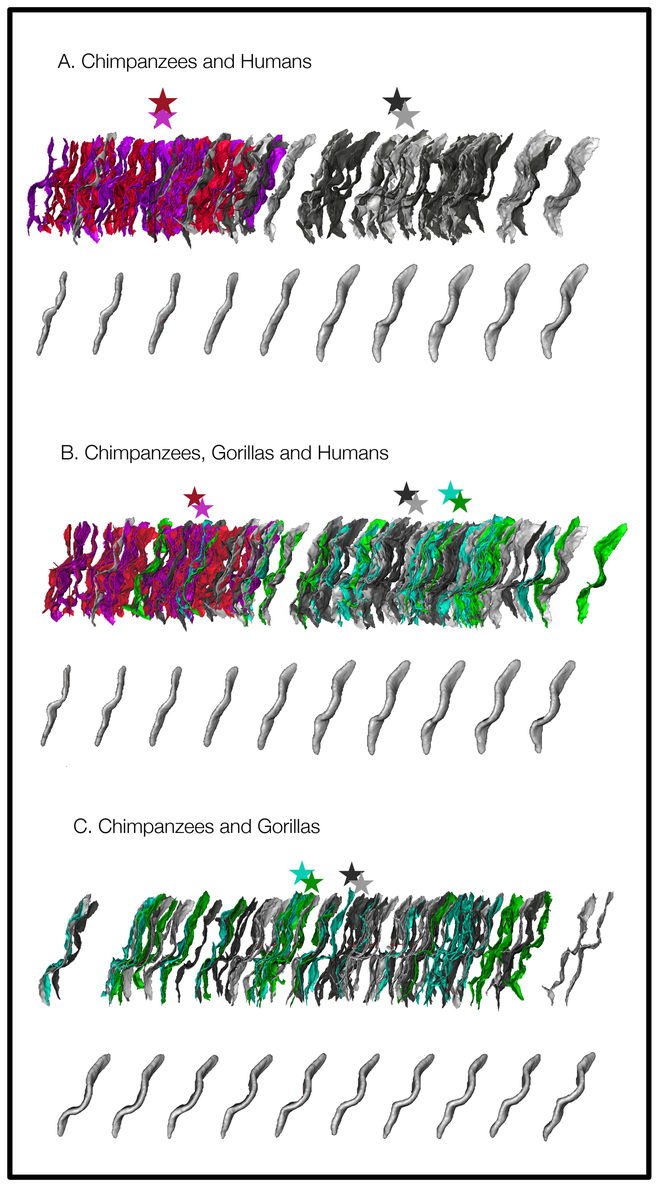

Fig 5: A, B, C: Sulci distributed on the Isomap axis (top) and corresponding moving average (bottom) for the three experiments. Stars correspond to the median of each group.
Color: Chimpanzee sulci: Left: grey; Right: black; Human sulci: Left=red, Right=magenta; Gorilla sulci: Left=green, Right=cyan.

A. Chimpanzees and Humans

The isomap clearly separates the shapes of human sulci from those of chimpanzee.

It seems to describe a shape variation ranging from a close knob configuration (for chimpanzees) to an open knob configuration (for humans), coinciding with a change in direction of sulci extremities.

There is no asymmetry between right and left distributions within each species.

B. Chimpanzee, Gorillas, and Humans

The isomap also separates the shape of the human sulci from those of chimpanzee and gorilla together.

The shape variability described on this isomap is similar to the one of the isomap in the chimpanzee/ human experiment (Pearson; chimp (r= 0.95); humans (r= 0.97)).

There is still no asymmetry between right and left distributions.

C. Chimpanzees and Gorillas

The isomap does not separate the two species (p=0.33) and we did not observe asymmetry between right and left distributions: chimp (p=0.20), gorilla (p=0.55).

This last isomap does not describe exactly the same shape feature as the previous isomap but it is correlated (chimp (r=0.58), gorilla (r=0.61)). It seems to correspond closely to the shape variability found previously in humans [5, 6] ranging from a single to a double (S/D) knob configuration.

Note that in these previous experiments performed with more human subjects, this S/D knob shape feature was asymmetrical, especially in right-handed people [5].

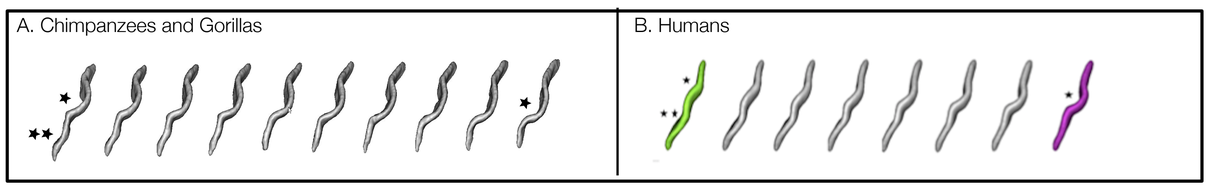

Fig 6: A. Moving average on the isomap axis for the Chimpanzee and Gorillas experiment.
B. Sun et al., Brain Struct. And Function, 2016: Moving average on the isomap axis in an experiment with humans only.
Stars indicate the knobs. The isomap axis for the Chimpanzee and Gorilla seems to correspond to the shape variability in humans, ranging from a single to double knob.

CONCLUSION

- Chimpanzee and Gorillas : very similar central sulcus shape

- Humans only and Chimpanzee+Gorillas :The shape feature of the S/D knob captures the greatest variance

- However humans vs the other two great apes: another characteristic appears, more important than the S/D knob, which clearly differentiates humans from the other two great apes.

- This characteristic seems more related to the overall shape of the central sulcus : a less simple shape for humans ? or singularities in its sulcus extremities ?

Next steps:

In order to verify if the asymmetry on the S/D knob isomap is specific to humans, the experiment on chimpanzee and gorillas has to be reproduced with a larger number of subjects.

A better normalization of the sulci size has also to be performed: the central sulcus taking up relatively more space in the brains of chimpanzees and gorillas, it appears longer than that of humans in our isomaps

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