A Novel Sulcal Hierarchy Based on Manually Labelled Sulci

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Introduction:

We create a novel sulcal hierarchy based on cross-subject stability. Our hierarchy provides evidence-based organisation of sulcal reliability which corresponds with the most stable sulci in the literature and provides supplementary information on less stable sulci. We manually labelled 454 sulci across 6 subjects to quantitatively analyse sulcal stability. We used 'tedious anatomy' to generate probability maps which denote reliability of a sulcus' location[1]. These were the basis for our quantitative hierarchy of sulcal stability.

Methods:

We manually labelled 454 sulci in 6 subjects (3 male, 3 female, age 22-30, right-handed) from the HCP dataset in subject space. Each hemisphere had an average of 38 sulci. Using the tool Blender, we identified and labelled sulci according to our literature review and confirmed them with a second expert neuroanatomist. They were converted to MNI space using the MSM registration algorithm[2]. We generated probability maps of the location of each sulcus per hemisphere based on our manual labelling. These indicate the reliability and range of variability which various sulci exhibit (see Fig.1). From the probability maps, we calculate the mean probability and mass probability per sulcus. We evaluated sulcal location reliability by measuring largest common sulcus surface area.

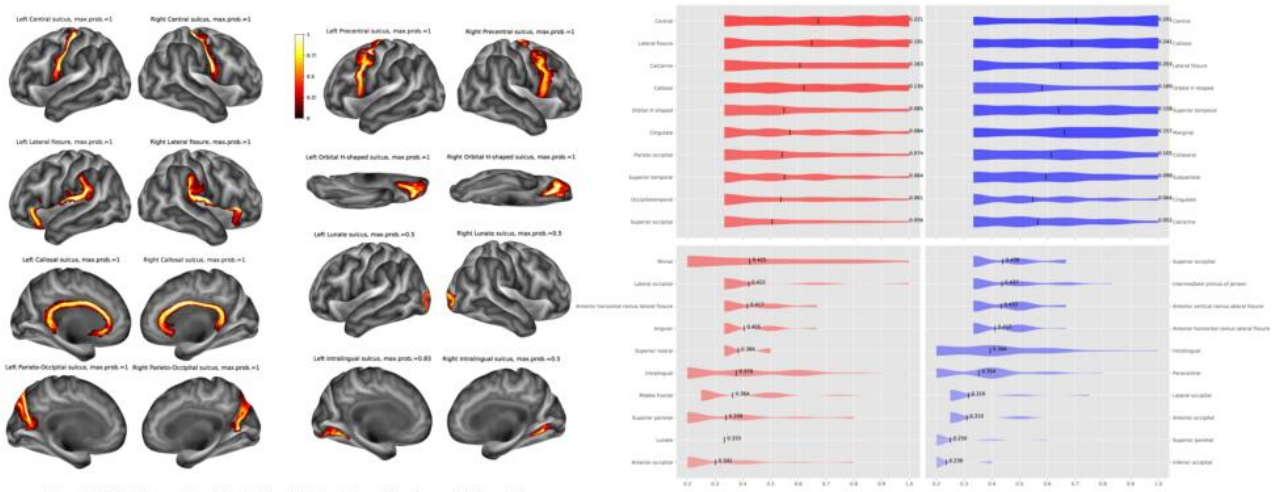

Figure 1.A: Probability maps for sulci in the left and right hemispheres. The primary sulci, Central sulcus, Lateral fissure, Callosal sulcus and Parieto-Occipital sulcus, have larger surface area with higher probability than other sulci because of their stability in shape and location on the cortex. Secondary sulci such as the Precentral sulcus and Orbital H-shaped sulcus have surface areas of both high and low probabilities. Tertiary sulci such as the Lunate sulcus and Intralingual sulcus do not have large areas of high probability because of high variability in sulcal shape and location.

Figure 1.B: The 10 most and least stable sulci of the left and right hemispheres. The 10 most stable sulci were those with the largest surface area with probability 1 shared by all hemispheres. The 10 least stable sulci are those found in at least 2 hemispheres, and with the lowest mean probabilities.

·Figure 1

Results:

The most stable sulci were the Central sulcus (0.221 LH, 0.291 RH), Lateral fissure (0.191 LH, 0.203 RH) and Callosal sulcus (0.130 LH, 0.242 RH) in both hemispheres (see Fig. 1B). The 10 most stable sulci were quantified as those which were present in all hemispheres and had the largest surface area with a probability of 1. The 10 least stable sulci were those which were present in at least two hemispheres and with the lowest mean probabilities (see Fig. 1B). We establish a hierarchy of sulcal stability from the manually labelled sulci and their probabilities (see Fig.2). 'Primary sulci' are those which exhibit stability and consistency across subjects and can be used as interlobular landmarks. 'Secondary sulci' are characterised as those which were identified in all 12 hemispheres. 'Tertiary sulci' are characterised as sulci which were not manually identified in all 12 hemispheres.

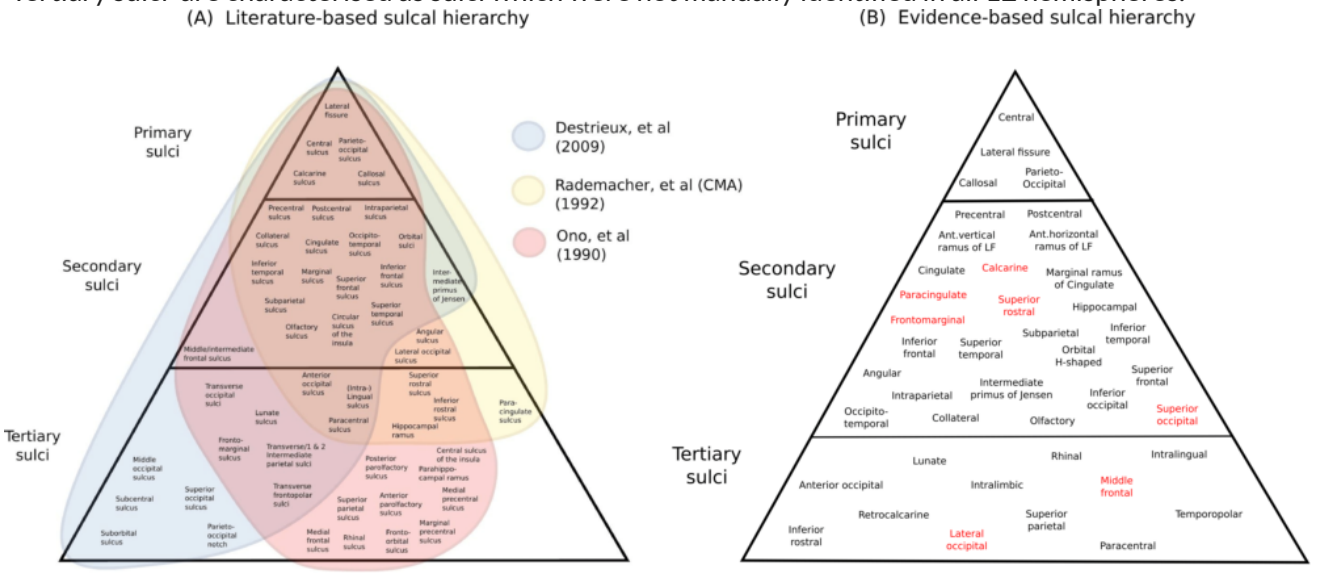

Figure 2:
Classical sulcal hierarchy (A) against our updated evidence-based sulcal hierarchy (B). The classical neuroanatomy hierarchy is based on literature of three sources. Our updated hierarchy is based on the probability maps of sulcal shape and location. The sulci in red in (B) denote those which are in different tiers than in (A).

·Figure 2

Conclusions:

The interlobular sulci are among the first to develop during foetal sulcification[3,4] and are typically the most stable landmarks for primary cortical identification[5]. We found that the primary sulci were the most stable and reliable across subjects. Notably, the interlobular Parieto-Occipital sulcus was not found to be in the top 5 most reliable sulci like the others, perhaps because of its common Y-bifurcation shape which may have increased its variability.

This underscores a limitation of purely shape- and location-based sulcal analyses. It was therefore grouped as a primary sulcus because of its characteristic position on the cortex which sustains its reliability. Other sulci had varying stability and were in agreement with the literature. Secondary sulci such as the Orbital H-shaped (0.085 LH, 0.169RH) or Superior temporal (0.064 LH, 0.158 RH), also exhibited high stability. Others, such as the Precentral (0.018 LH, 0.005 RH) or Intraparietal (0.009 LH, 0.002 RH), which are commonly studied in the literature, did not exhibit such strong stability in our probability maps (see Fig.1). As expected, tertiary sulci exhibit high variability. Our results are in congruence with other extensive anatomy studies[6,7,8].
In Fig.2 we present our novel sulcal hierarchy based on cross-subject stability. Most of the sulcal hierarchy positions are in agreement with the literature which places primary sulci as the most stable, constant and uniform, and tertiary as variable and inconsistent. Neuroimaging atlases are grounded in the use of stable sulci as reference landmarks[5]. We provide an evidence-based hierarchical atlas for cortical mapping with additional inter-individual variability.

Imaging Methods:

Anatomical MRI [2]

Informatics:

Brain Atlases

Modeling and Analysis Methods:

Image Registration and Computational Anatomy
Segmentation and Parcellation

Neuroanatomy:

Cortical Anatomy and Brain Mapping [1]

Keywords:

Other - Sulci, hierarchy

[1|2]Indicates the priority used for review

Please indicate below if your study was a "resting state" or "task-activation" study.

Resting state

Healthy subjects only or patients (note that patient studies may also involve healthy subjects):

Healthy subjects

Was any human subjects research approved by the relevant Institutional Review Board or ethics panel? NOTE: Any human subjects studies without IRB approval will be automatically rejected.

Not applicable

Was any animal research approved by the relevant IACUC or other animal research panel? NOTE: Any animal studies without IACUC approval will be automatically rejected.

Not applicable

Please indicate which methods were used in your research:

Structural MRI

For human MRI, what field strength scanner do you use?

1.5T

Provide references using author date format

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