Unified Cortical Asymmetry Analysis in Autism via Weighted-SPHARM

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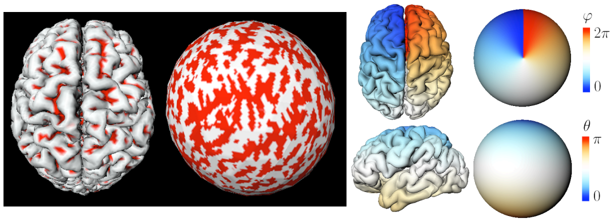
1. Introduction

We present a new framework for cortical asymmetry analysis using the weighted spherical harmonic (SPHARM) representation (Chung et al., 2007). The weighted-SPHARM represents cortical surface coordinates as a weighted linear combination of spherical harmonics. This new representation can be used to establish the hemispheric correspondence and register cortical surfaces to a template automatically without any image flipping. The methodology is used in characterizing abnormal cortical asymmetry in high functioning autistic subjects.



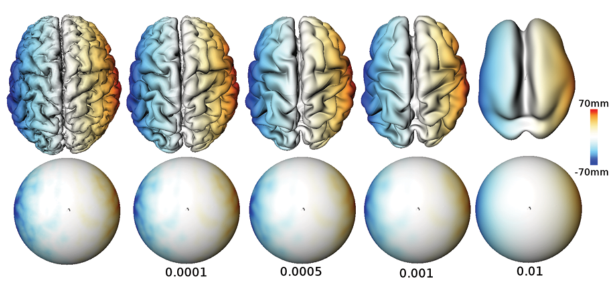
Left: Deformable surface algorithm (MacDonald et al., 2001) was used to establish the mapping from a cortical surface to a unit sphere. **Right:** Spherical coordinates projected onto a cortical surface.

2. Weighted-SPHARM

The Weighted-SPHARM represents the surface coordinates and a function defined on the surface as

$$g(\theta,\varphi) = \sum_{l=0}^{k} \sum_{m=-l}^{l} e^{-l(l+1)t} \langle f, Y_{lm} \rangle Y(\theta,\varphi),$$

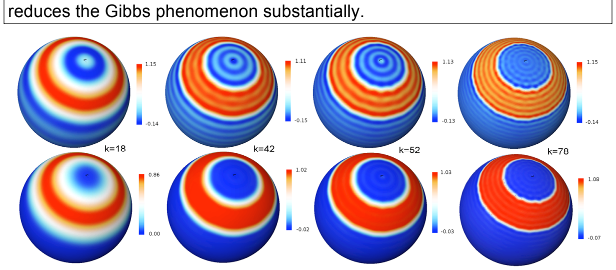
where Y_{lm} is the spherical harmonic of degree l and order m. The bandwidth t controls the amount of smoothing. The SPHARM coefficients $\langle f, Y_{lm} \rangle$ are estimated via the iterative residual fitting (IRF) algorithm (Chung et al., 2007).



Weighted-SPHARM representation of cortex at different scales (t = 0.0001,0005, 0.001, 0.01). The color scale represents the x-coordinate values. The first column is the original surface and the corresponding x-coordinate values projected on the unit sphere.

3. Gibbs Phenomenon

The traditional SPHARM representation (Gerig et al., 2001) suffers from the Gibbs phenomenon (ringing artifacts), which is usually associated with the discrete or rapidly changing measurements. The weighted-SPHARM reduces the Gibbs phenomenon substantially.



Top: The traditional SPHARM representation applied to a step function (1 in the circular band 1/8 < θ < 1/4 and 0 otherwise) at different degree. The SPHARM shows the severe ringing artifacts. **Bottom:** The weighted-SPHARM shows the reduced ringing artifacts.

References

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•MacDonald, J.D. et al., Automated 3D Extraction of Inner and Outer Surfaces of Cerebral Cortex from MRI, *NeuroImage.* **12**:340-356, 2000.

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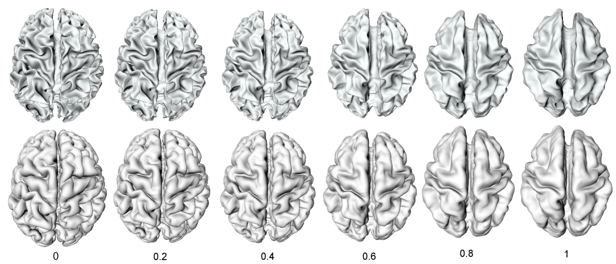
4. Hemispheric Correspondence

The surface registration between subjects was established using the SPHARM-correspondence (Chung et al., 2007). It can be shown that the optimal displacement between two weighted-SPHARM representation is simply obtained by subtracting the two representations. Then the hemispheric correspondence is obtained by registering $g(\theta,\varphi)$ to its mirror reflection $g(\theta, 2\pi-\varphi)$.



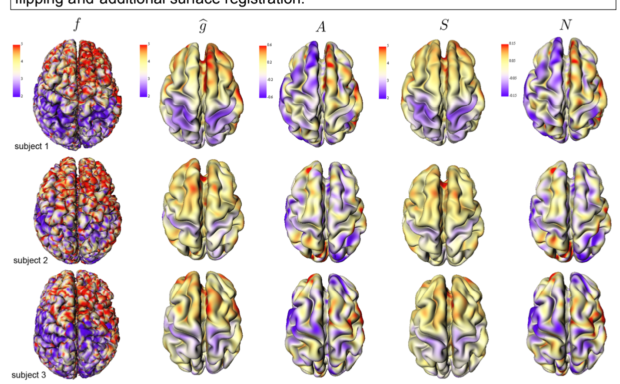
The trajectory of surface registration from a single subject (=0) to the average surface template (=1). **Top:** Inner surfaces. **Bottom:** Outer surfaces.

5. Asymmetry index

Based on the SPHARM-correspondence principle, the normalized asymmetry index of type (L-R)/(L+R) is given as

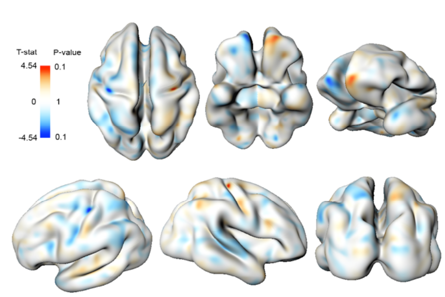
$$N(\theta,\varphi) = \frac{\sum_{l=1}^{k} \sum_{m=-l}^{-1} e^{-1(l+1)\sigma} \langle f, Y_{lm} \rangle Y_{lm}(\theta,\varphi)}{\sum_{l=0}^{k} \sum_{m=0}^{l} e^{-l(l+1)\sigma} \langle f, Y_{lm} \rangle Y_{lm}(\theta,\varphi)}.$$

Once we have the weighted-SPHARM representation of cortical thickness, an asymmetry analysis on cortex can be performed without physically performing image flipping and additional surface registration.



6. Results

The normalized asymmetry index was used in the group comparison between autistic and control subjects. The T-statistic map and the corresponding corrected P-value maps were constructed and used to localize the regions of abnormal asymmetry pattern. The central sulci and the prefrontal cortex showed abnormal cortical asymmetry pattern in autistic subjects (P-value < 0.1).



The final result of the two sample T-test showing the focalized regions of abnormal asymmetry pattern. The P-value map is corrected for the multiple comparisons. Blue regions show less gray matter in the left hemisphere.