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ENCODING NEUROANATOMICAL INFORMATION USING WEIGHTED SPHERICAL HARMONIC REPRESENTATION

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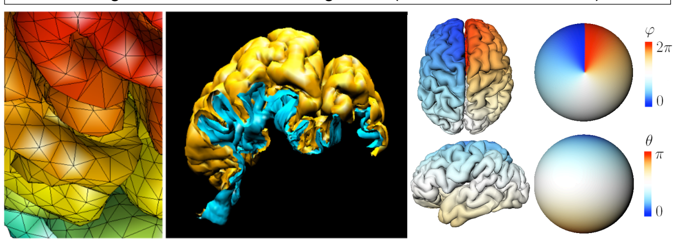
1. Introduction

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.

2. Magnetic Resonance Images

Three Tesla T1-weighted magnetic resonance images (MRI) were acquired for 16 autistic and 12 normal subjects. MRI were spatially normalized and tissue types were classified based a supervised artificial neural network classifier. Afterwards, a triangular mesh for each cortical surface was generated by deforming a mesh to fit the proper boundary in a segmented volume using a deformable surface algorithm (MacDonald *et al.*, 2000).



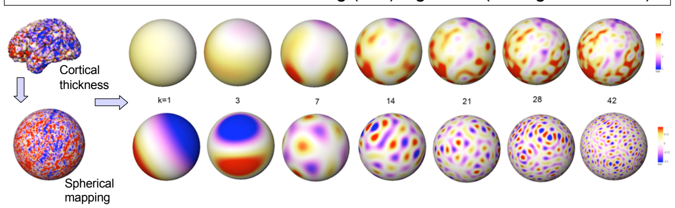
Left: Triangle mesh representation of a cortical surface. **Middle:** Parts of both outer (yellow) and inner (blue) cortical surfaces. The deformable surface algorithm (MacDonald et al., 2001) was used to establish the mapping from a cortical surface to a unit sphere. **Right:** Deformable surface algorithm (MacDonald et al., 2001) was used to establish the mapping from a cortical surface to a unit sphere.

3. Weighted-SPHARM Represenation

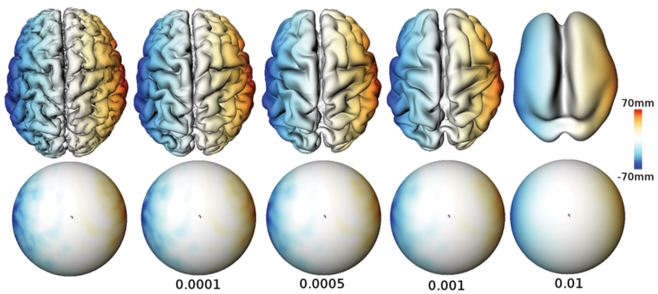
The Weighted-SPHARM represents the surface coordinates and a function defined on the surface as

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

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).



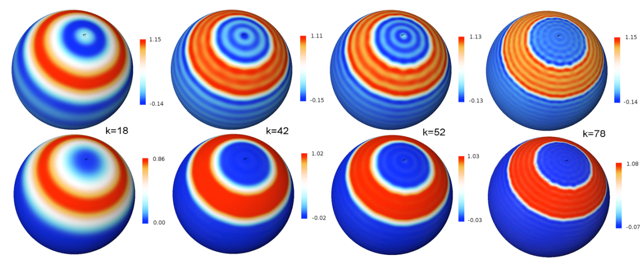
Top: Weighted-SPHARM up to degree *k* showing the smooth pattern of cortical thickness.
Bottom: Weighted-SPHARM within degree *k* showing spatial resolution.



Weighted-SPHARM of a cortical surface at different bandwidths. 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.

4. 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.

5. Surface Registration

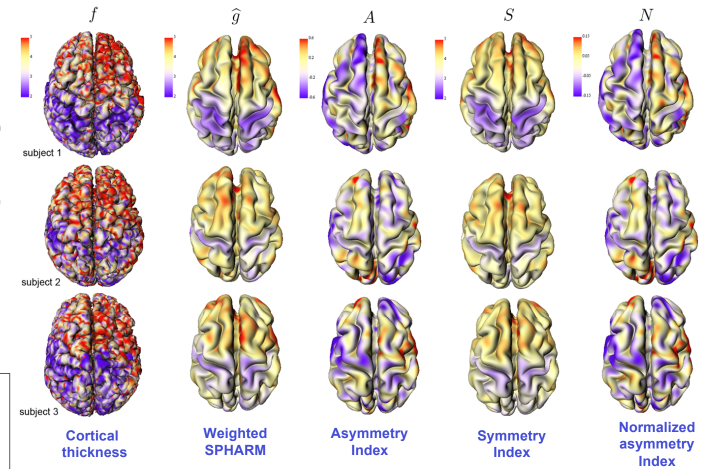
The surface registration between subjects was established using the SPHARM-correspondence (Chung et al., 2007). It can be shown that the optimal displacement between two weighted-SPHARM representation is simply obtained by subtracting the two representations. Then the hemispheric correspondence is obtained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

6. Asymmetry index

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

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

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

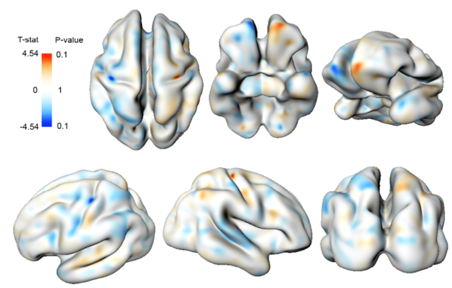


7. Random Field Theory

The normalized asymmetry index was used in the group comparison between autistic and control subjects. The *t*-statistic and the corresponding corrected P-value maps were constructed by thresholding the maxima of a *t* random field $T(\theta,\varphi)$:

$$P\Big[\sup_{(\theta,\varphi)\in S^2}T(\theta,\varphi)>h\Big]\approx\sum_{d=0}^{2}R_d(S^2)\mu_d(h)$$

where R_d are the *d*-dimensional Resels and μ_d are the *d*-dimensional Euler characteristic densities (Worsley et al., 1996). The thresholded P-value map is used to localize the regions of abnormal asymmetry pattern.



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 (red) regions show less (more) gray matter in the left hemisphere compared to the right hemisphere. The central sulci and the prefrontal cortex showed abnormal cortical asymmetry pattern in autistic subjects (corrected P-value < 0.1).

References

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