Anisotropic similarity, a constrained affine transformation: Application to brain development analysis

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Antoine Legouhy[1], Olivier Commowick[1], François Rousseau[2] and Christian Barillot[1]

[1] Univ Rennes, CNRS, INRIA, INSERM, IRISA UMR 6074, VISAGES ERL U-1228, F-35000, Rennes, France

[2] IMT Atlantique, LaTIM U1101 INSERM, UBL, Brest, France

Introduction

Objective: quantify regional brain growth in 3 orthogonal directions by linearly registering subjects on a common basis.

Approach: introduce an affine transformation with constrained scaling directions (9 degrees of freedom).

Material and Methods

Affine transformation: $y = Lx + t$

$$L = RSU^T$$

- U is a rotation matrix that determines scaling directions
- S is an anisotropic scaling (diagonal matrix)
- R is a rotation matrix

Anisotropic similarity: affine transformation with fixed U

Block-matching registration [1][2]:

1. Matching: find homologous blocks in both images best satisfying a similarity criterion
2. Aggregation into a global transformation by minimizing the distance between the sets of blocks

For an anisotropic similarity:

Minimize: $C(R,S,t) = \sum_i \left\|y_i - (RSU^T x_i + t)\right\|^2$, U fixed

$$\boxed{\hat{t} = \bar{y} - \hat{R}\hat{S}U^T\bar{x}}$$

$$\tilde{C}(R,S) = \sum_i \|y_i' - RS\tilde{x}_i\|^2 \qquad y_i' = y_i - \bar{y},\ \tilde{x} = U^T(x_i - \bar{x})$$

$$\tilde{C}(q,S) = \sum_i \|y_i' - q * \xi_i * \bar{q}\|^2 \qquad \xi_i = S\tilde{x}_i \qquad [3]$$

Matricial quaternions: $y_i' * q = Q_{y_i'}q$ and $-q * \xi_i = -P_{\xi_i}^T q = P_{\xi_i} q$

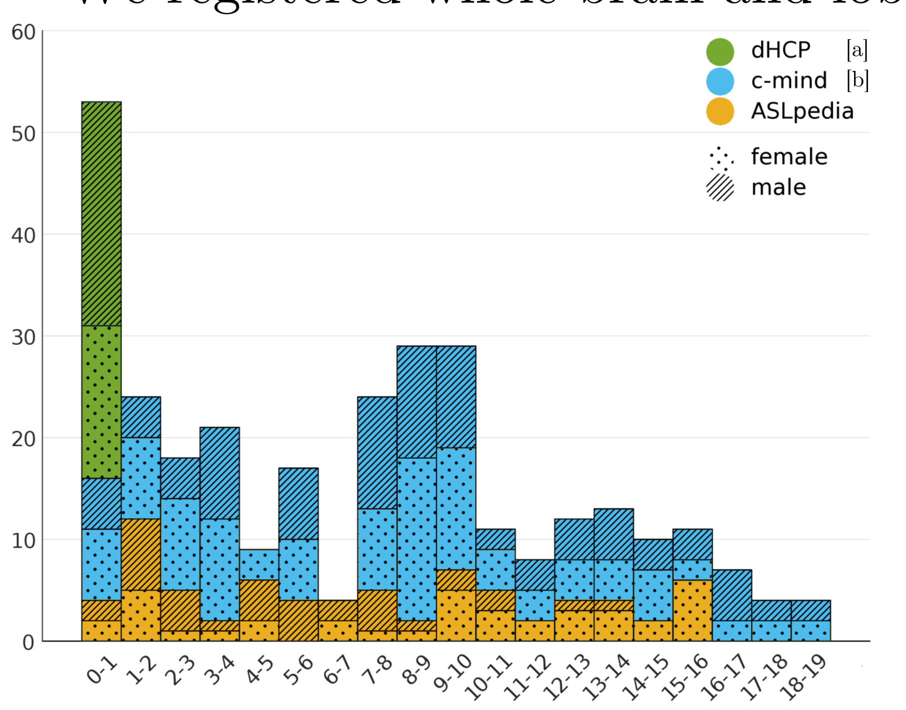
$$\tilde{C}(q,S) = -q^T\left(-\sum_i (Q_{y_i'} + P_{\xi_i})^2\right)q$$

$A_i = (Q_{y_i'} + P_{\xi_i})^2$ and $A = \sum_i A_i$.

Alternate optimization each having an anlytical solution:

- For fixed S, $\boxed{\hat{q} \text{ eigenvector with smallest eigenvalue of } A}$
- For fixed q, $\boxed{\hat{S}_{jj} = \frac{1}{\sum_i \tilde{x}_{ji}^2} q^T \left(\sum_i Q_{y_i'} \frac{\partial P_{\xi_i}}{\partial s_j}\right) q}$

We registered whole brain and lobes from 308 subjects onto an atlas based on this population using anisotropic similarity with chosen U. Then we extracted the associated scaling factors describing brain growth.



[a] Developing human connectome project (dHCP) database: http://www.developingconnectome.org

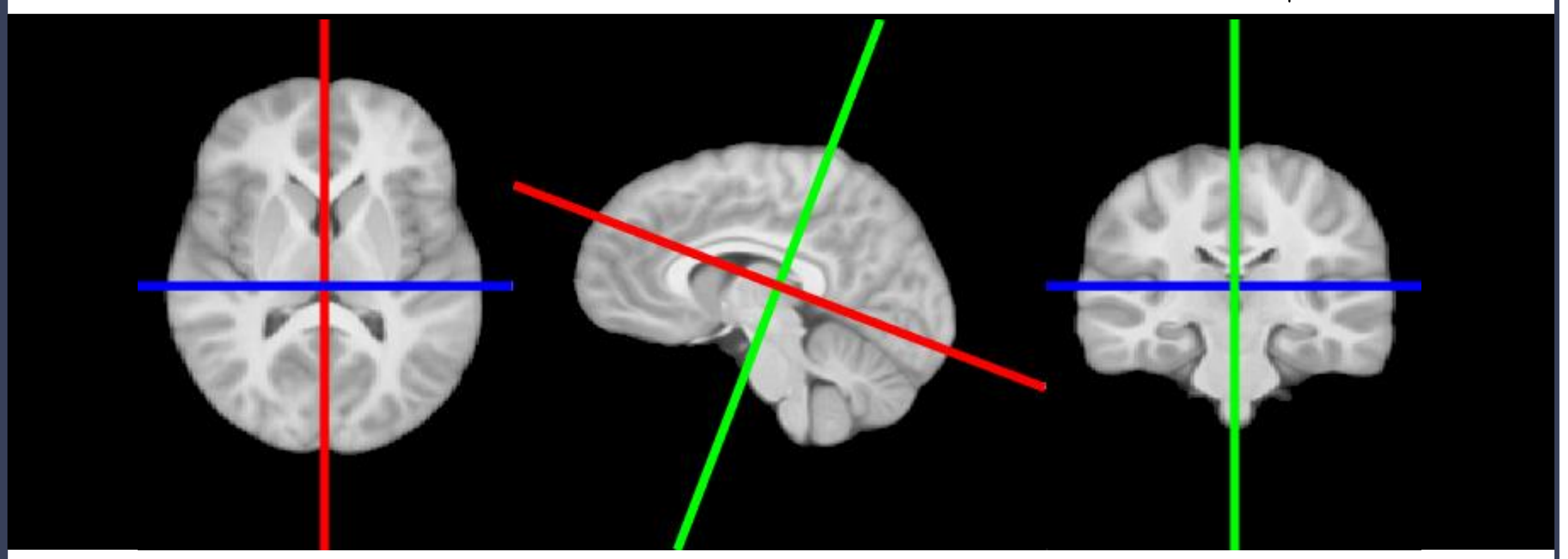
[b] C-mind database: cmind.research.cchmc.org

Results

Scaling factors along chosen directions

Black curve represents average model

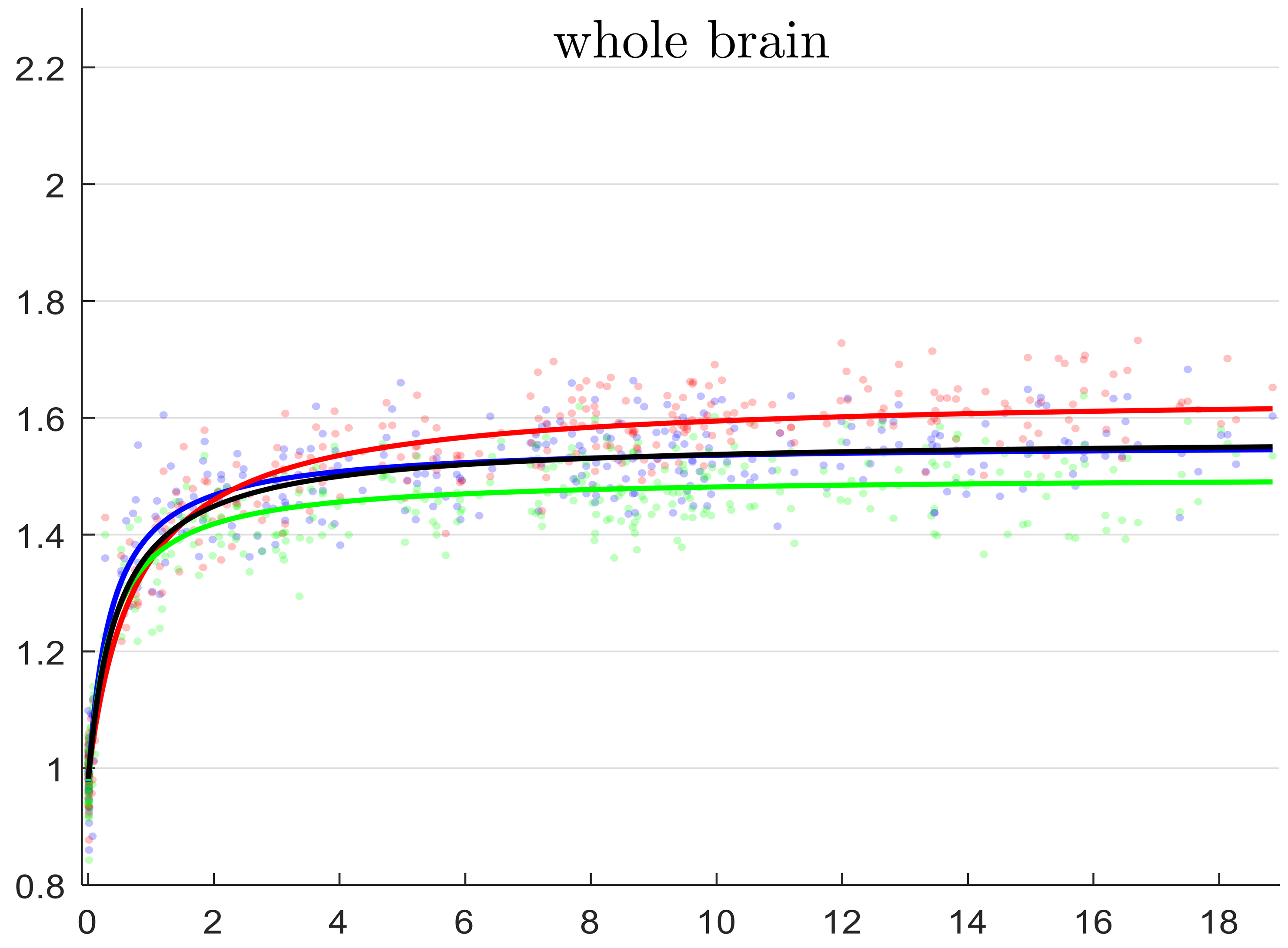
Fitted using first order rational regression: $y = \dfrac{ax+b}{x+c}$

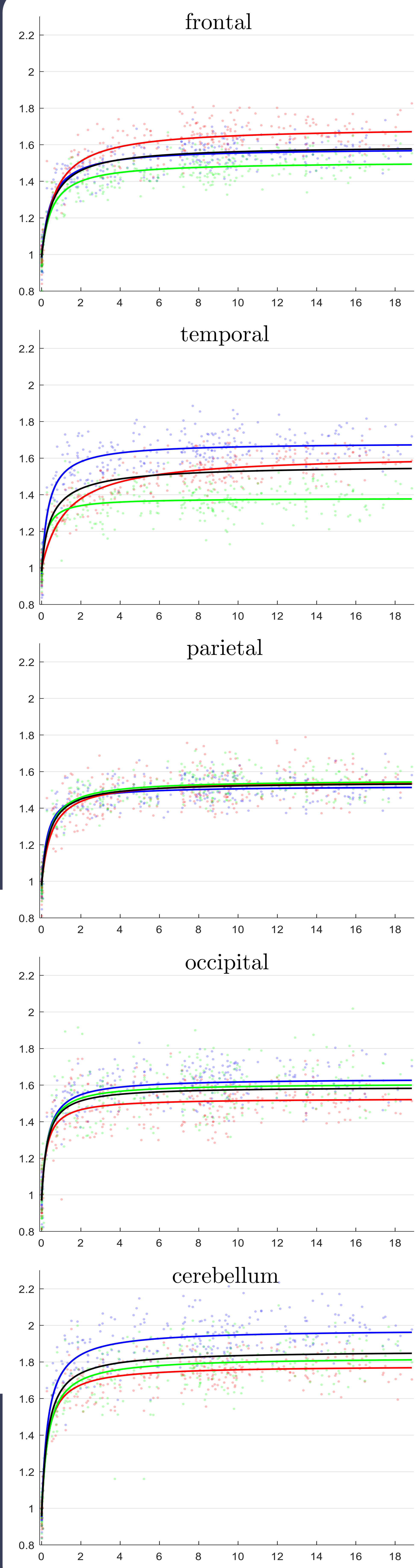


Chosen scaling directions fixed on the reference image:

1. Orthogonal to the mid-sagittal plane (blue) [4]
2. and 3. Principal directions of voxel coordinates projected on mid-sagittal plane (red and green)

Scaling factors over age in years





Conclusion

We developed a method to quantify regional brain growth in 3 orthogonal directions through anisotropic similarity registration.

An interesting continuation is to compare the results among groups of population.

[1] S. Ourselin et al, Block Matching: A General Framework to Improve Robustness of Rigid Registration of Medical Images, MICCAI 2000

[2] O. Commowick et al, Block-Matching Strategies for Rigid Registration of Multimodal Medical Images, ISBI 2012

[3] B. K. P. Horn, Closed-form solution of absolute orientation using unit quaternions J. Opt. Soc. Am, 1987

[4] S. Prima et al, Computation of the Mid-Sagittal Plane in 3D Brain Images. IEEE Transactions on Medical Imaging 2002