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Comparing Fluid Registration Methods: Mapping Structural Brain Differences in the Blind

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Introduction: Sensory impairments such as blindness may induce cerebral reorganization that helps to compensate for the changes in environmental input. In particular, prior studies have found that visual cortices in early-onset blind subjects are used for other tasks, such as hearing and touch. We recently detected volumetric atrophy in the blind in posterior corpus callosum regions that connect the visual cortices [1]. Here we used Tensor-Based Morphometry (TBM) to detect corpus callosum differences between two groups composed of 15 early-blinds and 29 sighted controls (mean age: 33.6±10.1 years; 25 men/19 women). We used 4 alternative registration algorithms to assess differences in their detection power.

Methods: High-resolution T1-weighted MR images were acquired for all subjects. The corpus callosum was manually traced in the midsagittal plane using Multitracer. These 2D images were rigidly aligned (2 translations, 2 rotations) to one of the control subjects. The next steps followed the classical TBM approach: nonlinear registration, computation of the Jacobian matrices $J = \nabla u^T \nabla u$ from the deformation fields u and statistical analysis of the deformation tensors $S = \sqrt{J^T J}$. In [3], we presented a new fluid registration algorithm that allows large deformations and penalizes anisotropic changes (i.e., ones with a preferred direction locally) in a way that is consistent with the subsequent statistical analysis. This fluid algorithm is based on an elastic registration method that regularizes the matrix logarithm of S (thus ∇u) but uses ∇v instead of ∇u in the regularization equation (v is the fluid velocity, the time derivative of u) (**method 1**). This regularizer is a specific case of a statistical prior that is introduced here, in which deformation statistics (i.e., anatomical information from the dataset) are included in the mapping process. A first registration is performed using **method 1** for each group to obtain a distribution of displacement fields. From these displacements, we computed statistics (listed below) that are then introduced in the regularizer. A new registration is performed on the initial data with this new regularizer that now takes into account the statistical distribution of the data. The statistics we used included the covariance matrix of the displacement fields (**method 2**), the covariance of the deformation matrix S (**method 3**), or both (**method 4**). The squared intensity difference between images was used as a similarity term to drive images into agreement. For these four registration algorithms, the displacement field, then S and $det(S)$ were derived at each voxel for each subject. We used voxelwise Student's t-tests to compute p-value maps. As the data may not be normally distributed, we applied a voxelwise permutations test using 5000 permutations.

Results: All registration methods (**Fig. 1**) show significant volume differences between the early blind subjects and the controls in the splenium and the isthmus of the corpus callosum, as expected. The ratio maps (**Fig. 2**) reveal volume shrinkage at the corresponding locations.

Conclusions: All four registration methods were consistent with each other and had similar detection power, though the distribution of changes is more or less spread over the area of the corpus callosum, depending on the method.

References:
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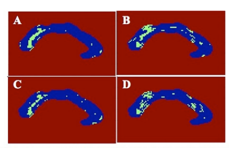

Figure 1: P-value maps computed from the different registration methods (A: method 1- B: method 2 – C: method 3 – D). Voxels with $p < 0.05$ are shown in green.

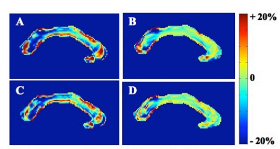

Figure 2: Corresponding ratio maps (A: method 1- B: method 2 – C: method 3 – D: method 4). Blue colors indicate volumetric deficits in the early-blind group versus controls (*-20%*) and red indicates volume excess in the early-blind group versus controls (+ *20%*).