WE 300

Comparison of Principal Diffusion Directions Using Directional Statistics

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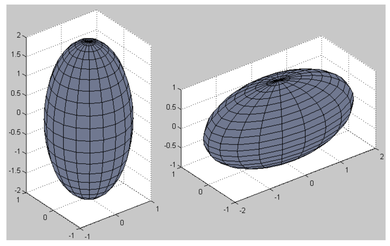
PURPOSE

To establish a formal methodology of group comparisons for DTI direction maps.

BACKGROUND

- Diffusion Tensor (DT) data: 3x3 matrix at each voxel
- Traditional imaging stats designed for scalars
- Previous DTI group studies use only scalar measures (e.g. FA)
- Fractional Anisotropy (FA), trace and coherence index – commonly analyzed scalars derived from DT – ignore 3D orientation



FA = 0.6 FA = 0.6

- Principal Diffusion Direction – principal eigenvector of DT-estimates tangent to white matter neural fibers
- Statistical methods needed for analyzing vectors and tensors in imaging data
- FA differences have been observed between good and poor readers (Deutsch, in press)

DTI METHODS

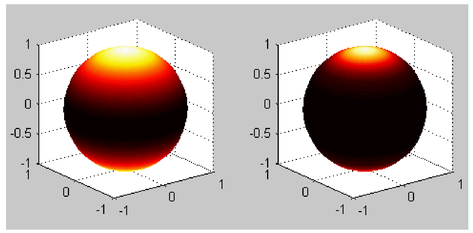
- Diffusion-weighted single-shot SE EPI sequence; b = 0 and ~800 s/mm^2 (Bammer 2002); 4 repeats averaged; 2x2x3mm voxels
- 12 child subjects: 6 normal readers and 6 dyslexic.
- DT maps spatially normalized to the MNI EPI template by applying parameters computed from b=0 (T2-weighted) images and spline-based tensor interpolation (Pajevic 2002)
- Group differences were restricted to the intersection of white matter regions common to all the normalized brains

STATISTICAL METHODS

Bipolar Watson Distribution:

- Models directions $\pm x_i$ with undefined sign
- Parameter κ controls the concentration of the density around the mean μ

$$f(\pm \boldsymbol{x}) = C \exp\left(\kappa \left(\mu^T \boldsymbol{x}\right)^2\right) = C \exp\left(\kappa \cos^2\theta\right)$$



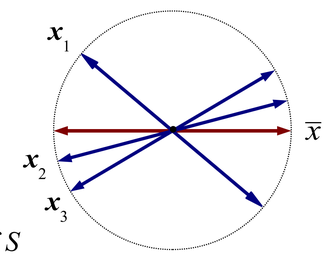
$\kappa = 1$ $\kappa = 5$

How to compute mean direction:

- Scatter (covariance) matrix S:

$$S = \frac{1}{n}\sum_{i=1}^{N} \boldsymbol{x}_i \boldsymbol{x}_i^T = \frac{1}{n}\mathbf{X}\cdot\mathbf{X}^T$$

- *Mean*: $\overline{x}$ = principal eigenvector of S
- *Dispersion*: $s = 1 - \gamma$, γ = max. eigenvalue of S

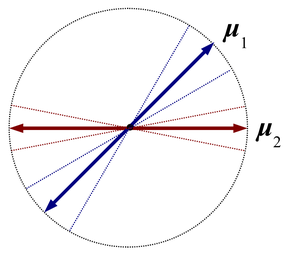


How to test mean directions:

- Two samples of sizes N_1 and N_2, dispersions s_1 and s_2
- Combined sample $N = N_1 + N_2$, dispersion s
- Test statistic for H_0: $\mu_1 = \mu_2$. Test statistic:

$$T = \frac{\left(N s - N_1 s_1 - N_2 s_2\right)/(p-1)}{\left(N_1 s_1 + N_2 s_2\right)/(n-2)(p-1)}$$

where $p = 3$ is the dimension of the space

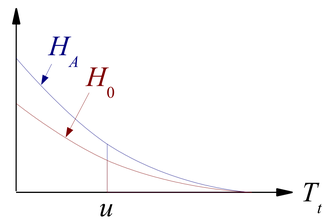


➡ Under H_0: $\mu_1 = \mu_2$, for large κ, $T \sim F_{(p-1),(n-2)(p-1)}$

False Discovery Rate (FDR):

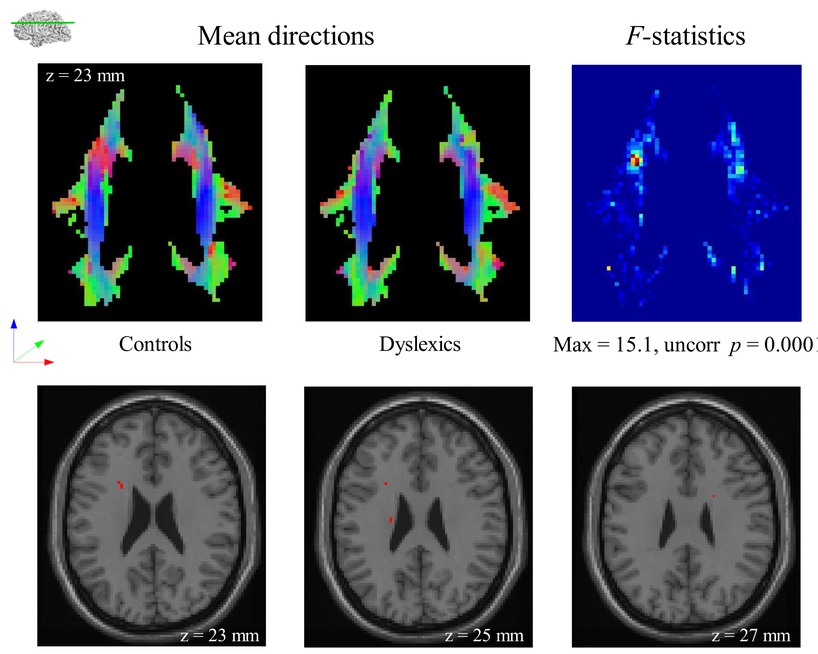
- Region of interest M
- Threshold test statistic T at level u

$$\hat{FDR} = \frac{P_{H_0}\left\{T_t \geq u | t \in M\right\}}{\hat{P}\left\{T_t \geq u | t \in M\right\}}$$



RESULTS

- No group differences in FA were found at FDR = 0.2
- Group differences in mean direction were found, at FDR = 0.2, at the anterior confluence of the corona radiata and the frontal callosal projections, in both hemispheres.



CONCLUSIONS

- DTI principal directions provide insight into differences in anatomical structure between groups that may be invisible to FA
- A methodology for such comparison is available by means of the Watson model and false discovery rate theory
- In dyslexic children, the corona radiata extends more anteriorly than in controls – may relate to gross white matter differences between good and poor readers (e.g., Robichon 1998)

REFERENCES

- Bammer et al. (2002). Diffusion tensor imaging using single-shot sense-epi. *Mag Res in Med, 48: 128-36.*
- Deutsch et al. (in press). Correlations Between White Matter Microstructure and Reading Performance in Children. *Cortex*
- Genovese et al. (2002). Thresholding of Statistical Maps in Functional Neuroimaging Using the False Discovery Rate. *NeuroImage 15:870-878*
- Mardia and Jupp (2000). Directional statistics. *John Wiley & Sons Ltd., England*
- Pajevic et al. (2002). A continuous tensor field approximation of discrete DT-MRI data for extracting microstructural and architectural features of tissue. *J Mag Res, 154: 85-100.*
- Robichon and Habib (1998). Abnormal callosal morphology in male adult dyslexics: relationships to handedness and phonological abilities. *Brain Lang. 62(1):127-46.*

Acknowledgments

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