Atlas-Based Analysis of Structural Maturation in the Human Brain

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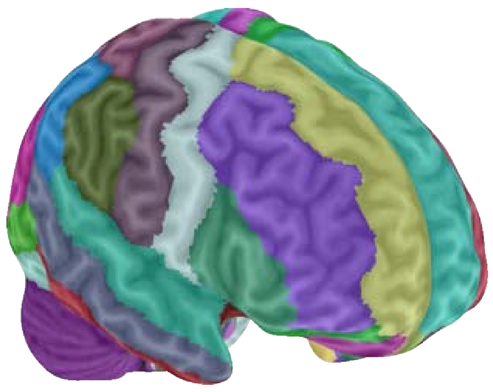
Introduction

Diffusion weighted imaging characterizes white matter properties non-invasively and allows to study the maturation of the human brain. Previous studies have reported differences between adults and children in white matter fractional anisotropy (FA) using tract-based spatial statistics which focuses on differences in the deep brain white matter (e.g. Brauer et al., 2010). We aimed to extend these findings to characterize group differences in peripheral white matter regions using a recently introduced atlas-based analysis (Faria et al., 2010) of diffusion parameters.

1



Mapping of the anatomical labeling atlas on a typical brain of the group on the brain surface. The background shows the individual FA image.

Methods

Data:

- 18 healthy participants in two age groups (9 children, 5 girls, mean age 7.0 years, SD 1.1, 9 adults, 5 female, 27.8 years, SD 2.7)
- High resolution dMRI scans acquired on a Siemens Trio scanner (1.7mm isotrop, 60 directions, b=1000s/mm^2, GRAPPA/2, AV=3).
- After motion correction and affine registration to the T1 anatomy, diffusion tensors and FA were computed.

Atlas:

Anatomical atlas (Oishi, 2009) that is shown in Figure 1 to define 130 areas in the MNI standard brain.

Processing:

Figure 2 visualizes the alignment procedure for each individual subject's data. The aim of this is to get the data from different sources into one common coordinate space without further interpolation of the FA image.
The non-linear transformation between anatomy- and diffusion-space is computed using the T2 and B0 images. The similarity of these two modalities allow us to use the monomodal non-linear registration algorithm ANTS (Avants et al., 2008).

The white-matter region was estimated in three different ways:

1. T1 segmentation using SPM's unified segmentation and registration algorithm
2. Thresholding the FA image at 0.25
3. Thresholding the FA image at 0.15

Histogram analysis showed that the FA values in some areas are approximately normally distributed, in others they are not. Therefore, we decided to compute the median of all FA values of each area for every subject rather than the mean. The medians of the area's FA values were then used to compute the group difference. Again, we cannot assume a normal distribution and applyed the non-parametric Wilcoxon-test.

2

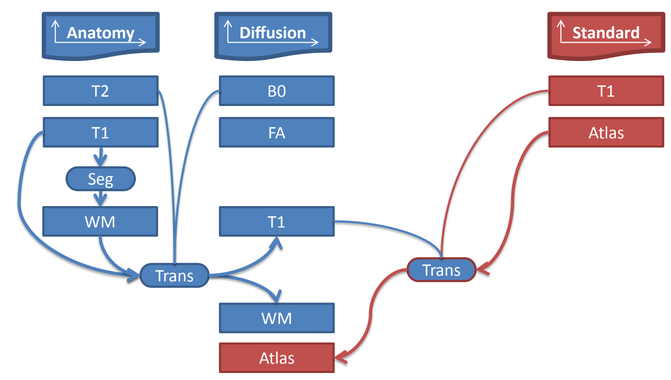
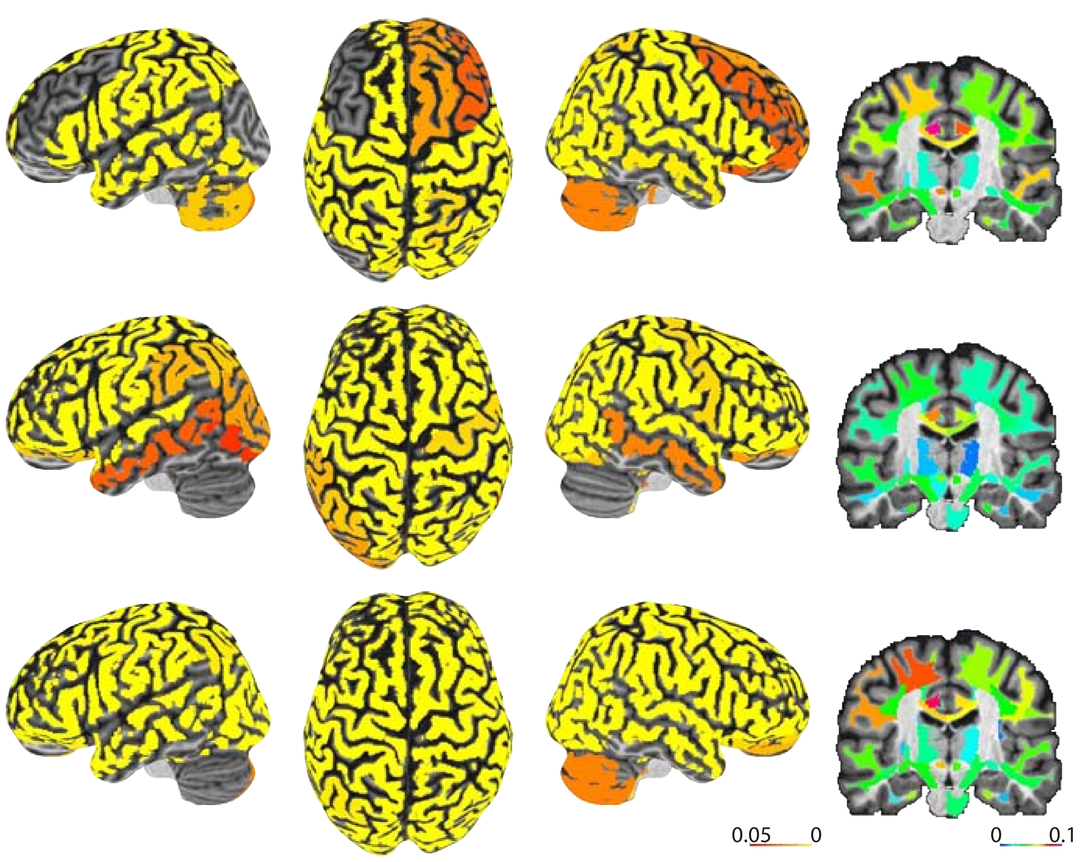


Diagram of processing pipeline to align all required images to one common coordinate-space.

Results

3



Color-coded 3D views visualize the uncorrected significance value of FA difference in the areas for the different methods to define white-matter.
The mean difference of the FA values for significant areas are shown on the right.

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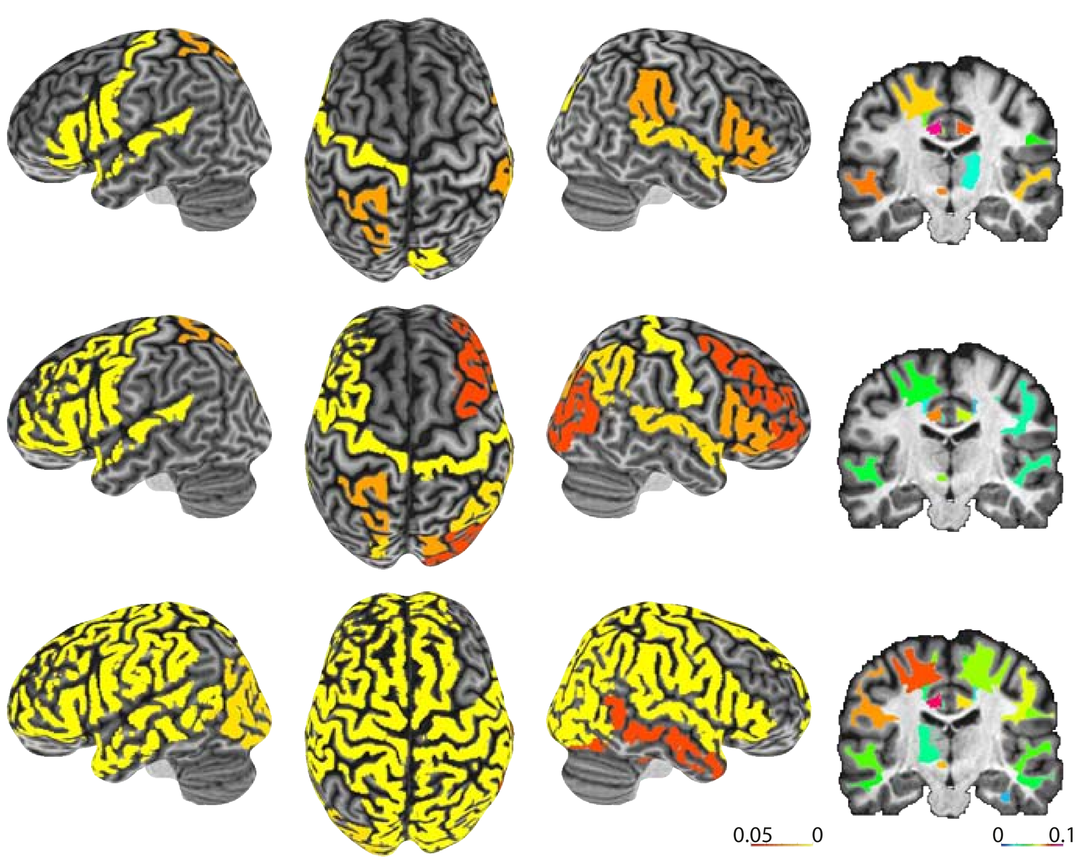
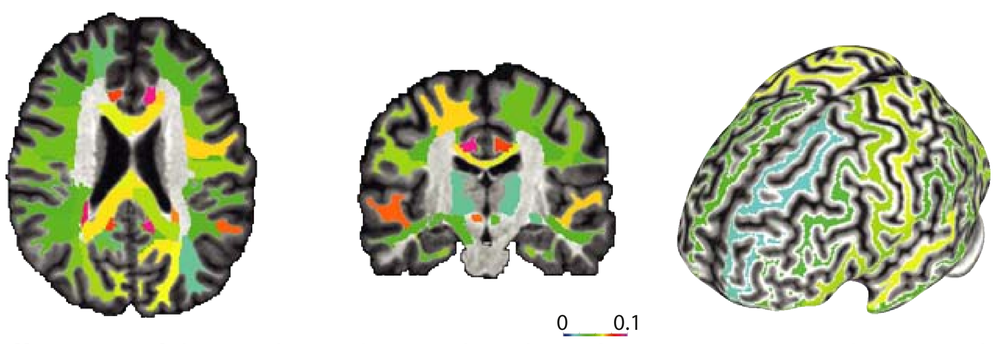


Same data but with Bonferoni correction applied. Looking at 130 independent areas reduces the number of statistically significant areas considerably.
The mean difference of the FA values for significant areas are shown on the right.

5



Mean differences of the median values with T1 based segmentation. Only areas which showed significant differences in FA values with a Student's t-test.

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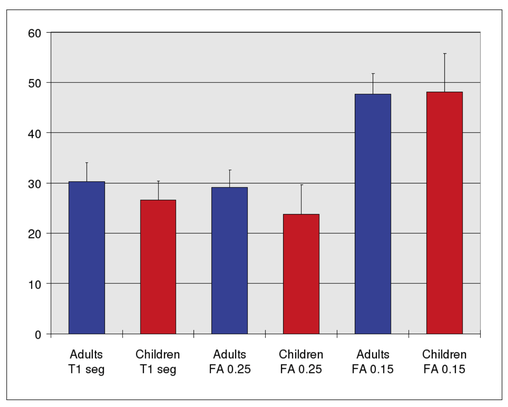

This diagram shows the mean relative volume of white-matter compared to the individual brain volume for different segmentations. T1 based segmentation and thresholding FA at 0.25 show less white-matter for children compared to adults. Thresholding FA at 0.15 considerably overestimates white-matter volume compared to T1 segmentation and includes 45% gray-matter for children and 37% for Adults.

Discussion

We found FA differences between the mature white matter of the adult brain and the immature fiber pathways of the developing brain of children. The FA differences were mainly found in the superficial areas and not in the deep white-matter.
There is a big difference in results when defining white-matter by thresholding FA at 0.15 compared to a T1 based segmentation or an FA threshold at 0.25. The comparison of relative white-matter volume with the different segmentation routines indicates that an FA threshold at 0.15 includes more gray-matter in children than in adults which biases the median FA value and consequently leads to a higher and wrong difference compared to adults.
Although only a few areas stay significant after Bonferoni correction, these areas confirm the findings and conclusions in Brauer et al., 2010.

References

Brauer et al., Cereb Cortex, 2010.
Faria et al., Neuroimage, 2010.
Oishi et al., Neuroimage, 2008.
Avants et al., Med Image Anal, 2008.

Acknowledgements

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