Diffusion Tensor Imaging and Reading Development

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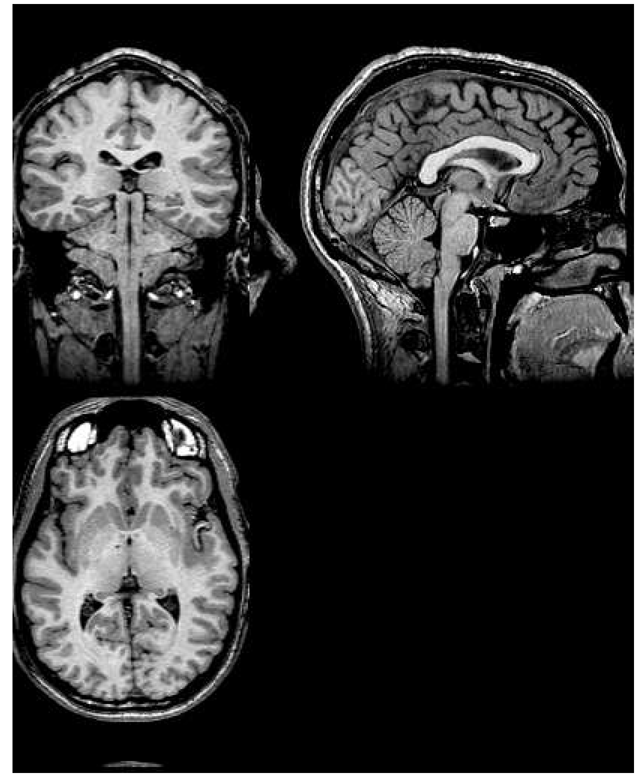
Reading and Anatomy

Every brain is different...

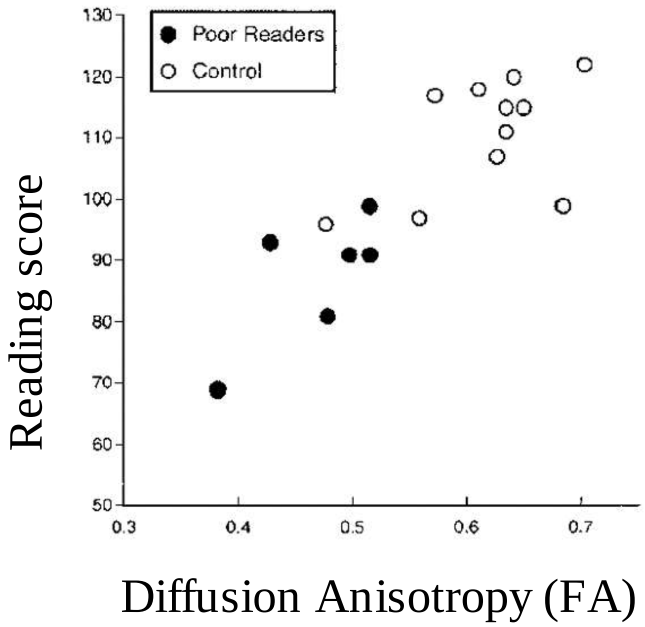


Not all brains optimized for highly proficient reading?

Background

- Diffusion of water through a temporo-parietal white matter region is correlated with reading skill in adults

(Klingberg et al., Neuron, 2000)



Two Outstanding Questions

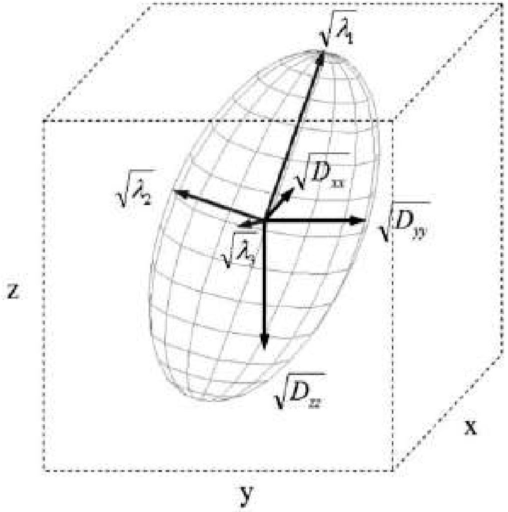
- Cause or result of reading?
  - Measure children before reading experience differs
- Lesion or displacement?
  - Measure tract positions
  - Measure diffusion along major tracts

Diffusing Water Probes Microscopic Tissue Structure

- Tissue structures affect diffusion
- MR diffusion measure (DTI) hints at microscopic structure within voxel
- Diffusion through white matter probes:
  - density of axons
  - degree of myelination
  - average fiber diameter
  - directional similarity of axons

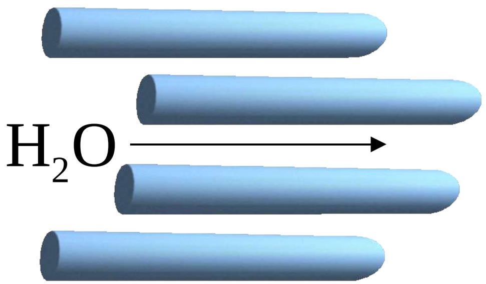
Diffusion in the Brain

Apparent Diffusion Coefficient (ADC) is measured in 6 directions

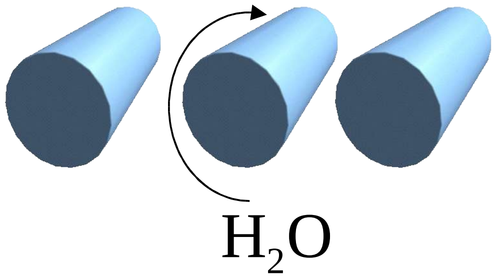


Unimpeded direction- large ADC

White matter fibers

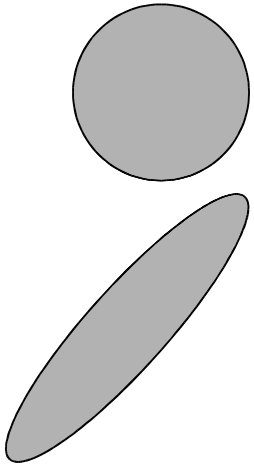


Impeded direction- smaller ADC

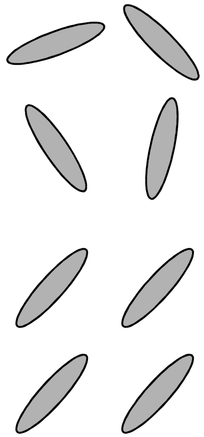


DTI- Scalar Indices

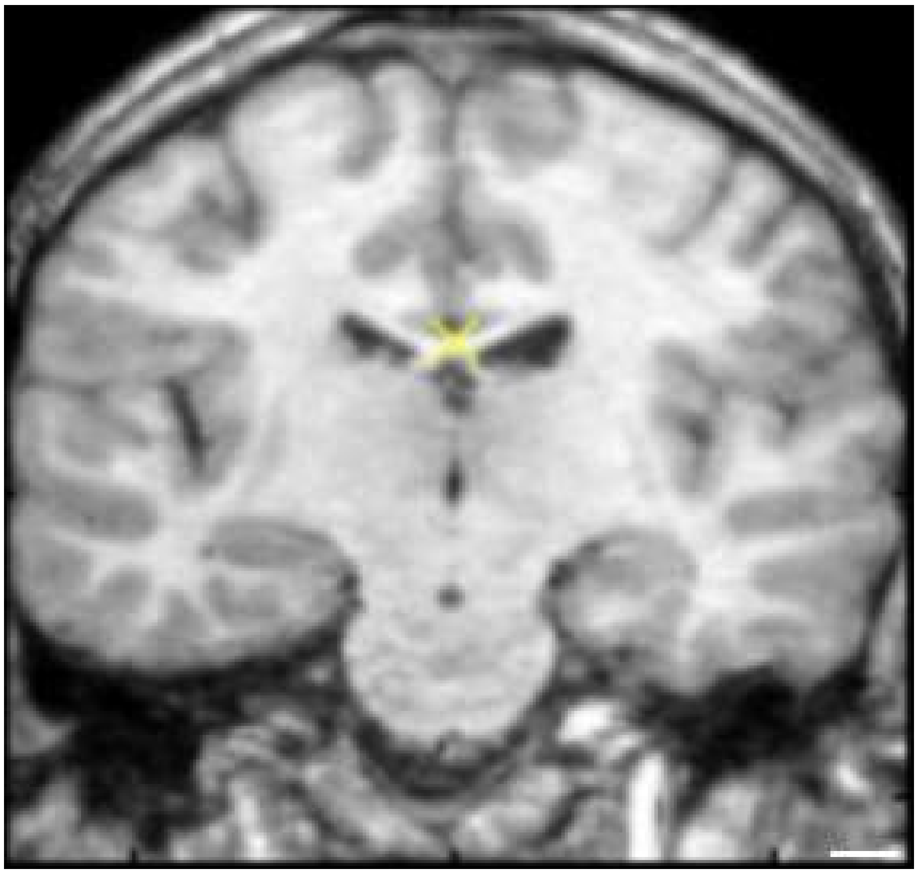
- Fractional Anisotropy
  - Normalized variance of elipsoid axis magnitudes (Basser & Pierpaoli, 1996)
  - FA=0 for sphere, FA=1 for tube



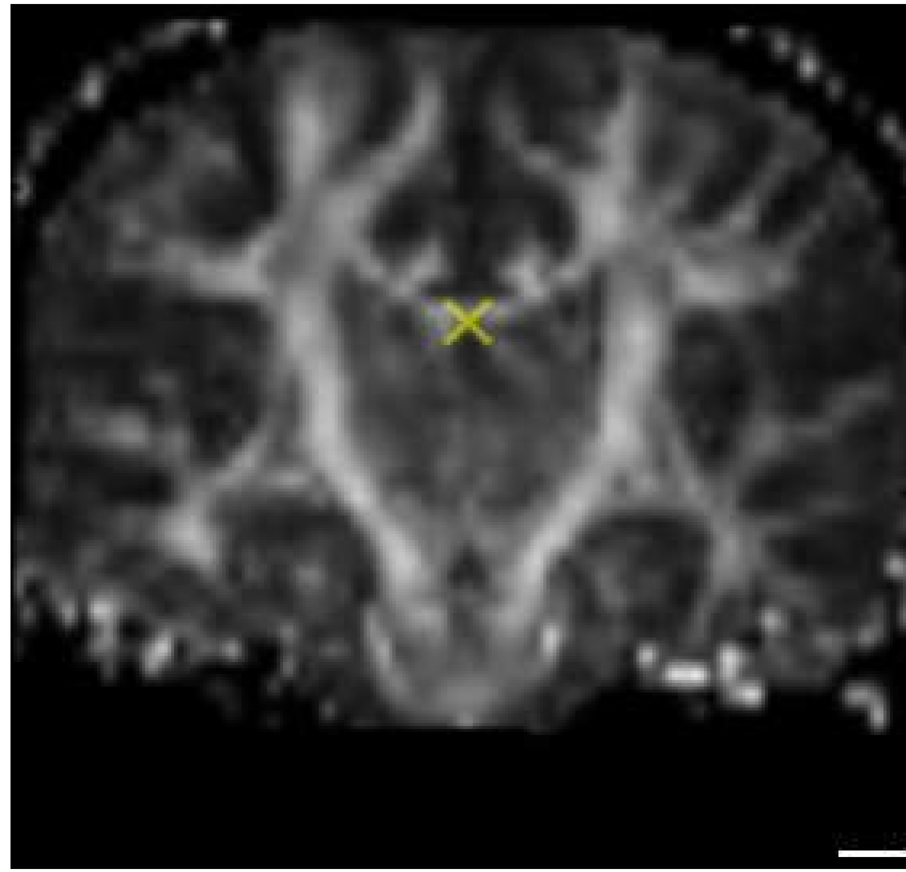
- Coherence Index
  - Variance in principal direction measured across array of voxels
  - Random: CI=0, aligned: CI=1



DTI: White Matter Structure



T1



Fractional Anisotropy

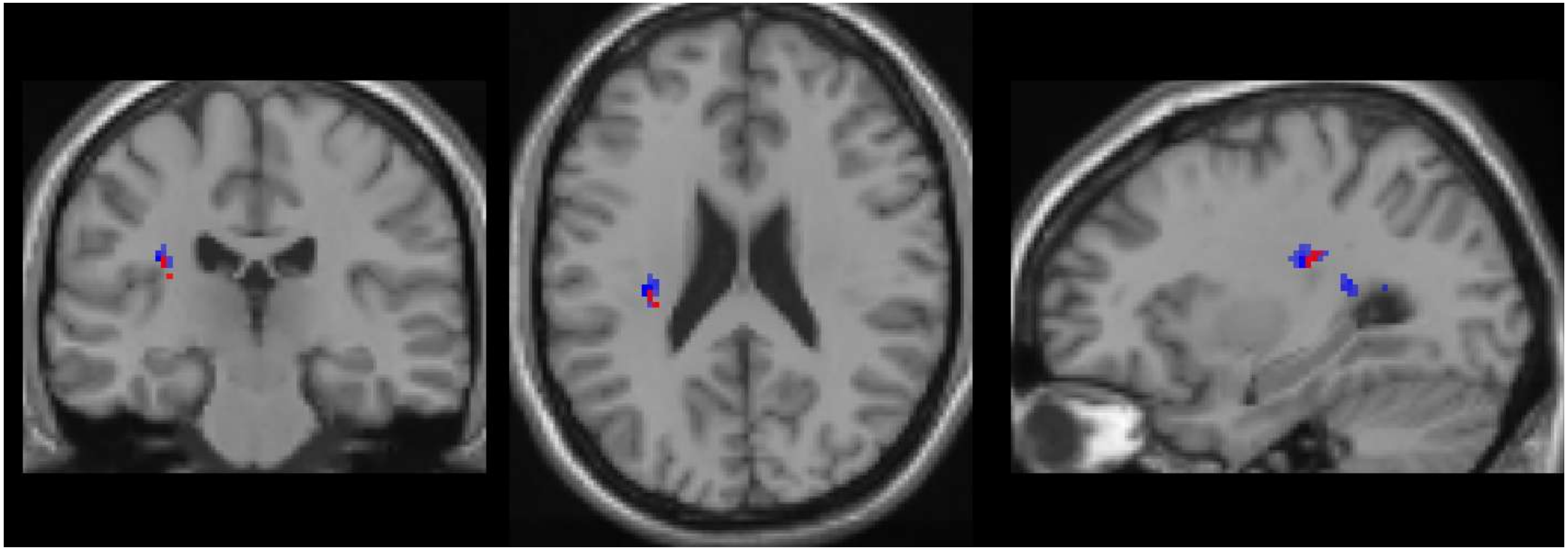
Behavioral Measures of Reading

- Normal readers vs. Poor readers
- Groups Matched on:
  - Nonverbal IQ
  - SES, handedness, sex
- Differed on:
  - Reading (W-J letter-word id & word attack, Passage comp., reading fluency)
  - Rapid naming
  - Phonological processing (CTOPP)

Data Analysis

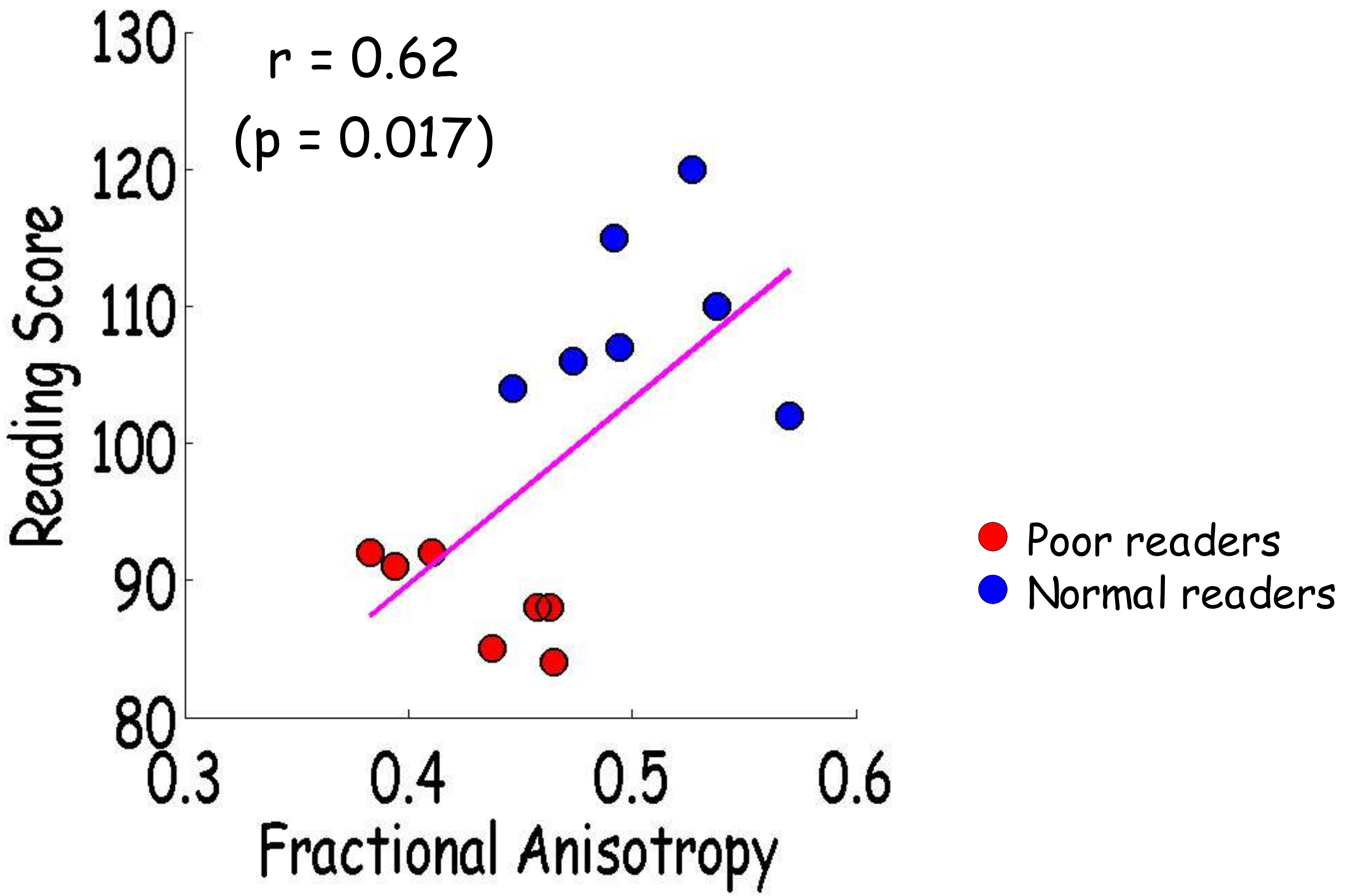
- Spatially normalize FA & CI images
  - Normalize inplane to MNI EPI template
  - Apply params to FA & CI
- Search in volume of interest
- Map significant regions back to unnormalized brains
- Analyze diffusion direction maps

FA & CI Correlated with Reading Skill in Children



Deutsch, Dougherty, Bammer, Siok, Gabrieli, Wandell (in press). Cortex.

Reading & FA in Children



Two Outstanding Questions

- Cause or result of reading?
  - Difference present in children- cause
- Lesion or displacement?
  - Measure tract positions
  - Measure diffusion along major tracts

Lower FA & CI Could Mean…

- Microstructure ("lesion")
  - Less myelination
  - Lower fiber density
  - More disorganized fibers
- Macrostructure ("displacement")
  - Displaced fiber-bundle paths
    - Known anatomical differences related to reading: sulcal patterns, corpus callosum…

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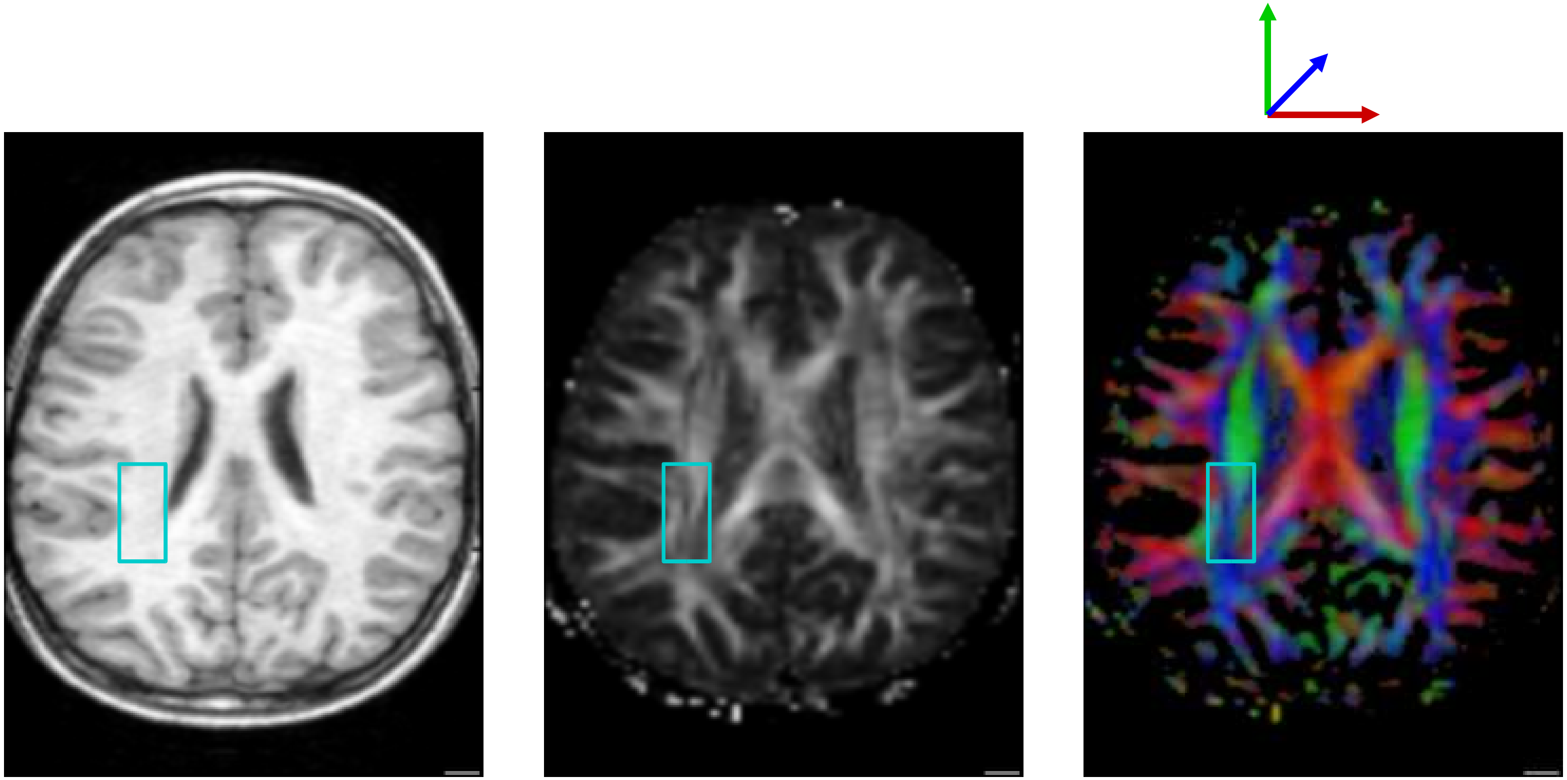
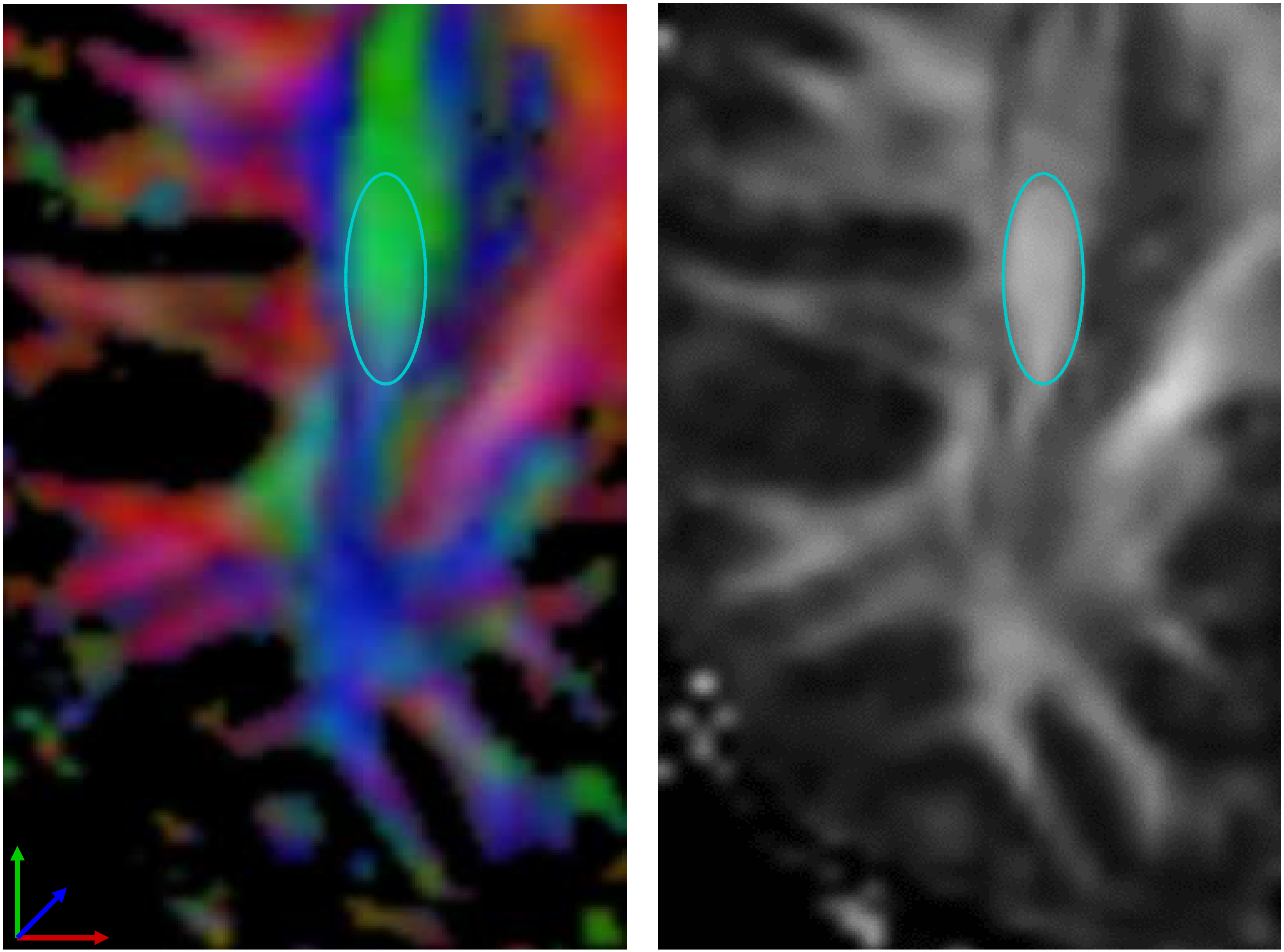
Lesion or Displacement?



H1: Intra-pathway Lesion



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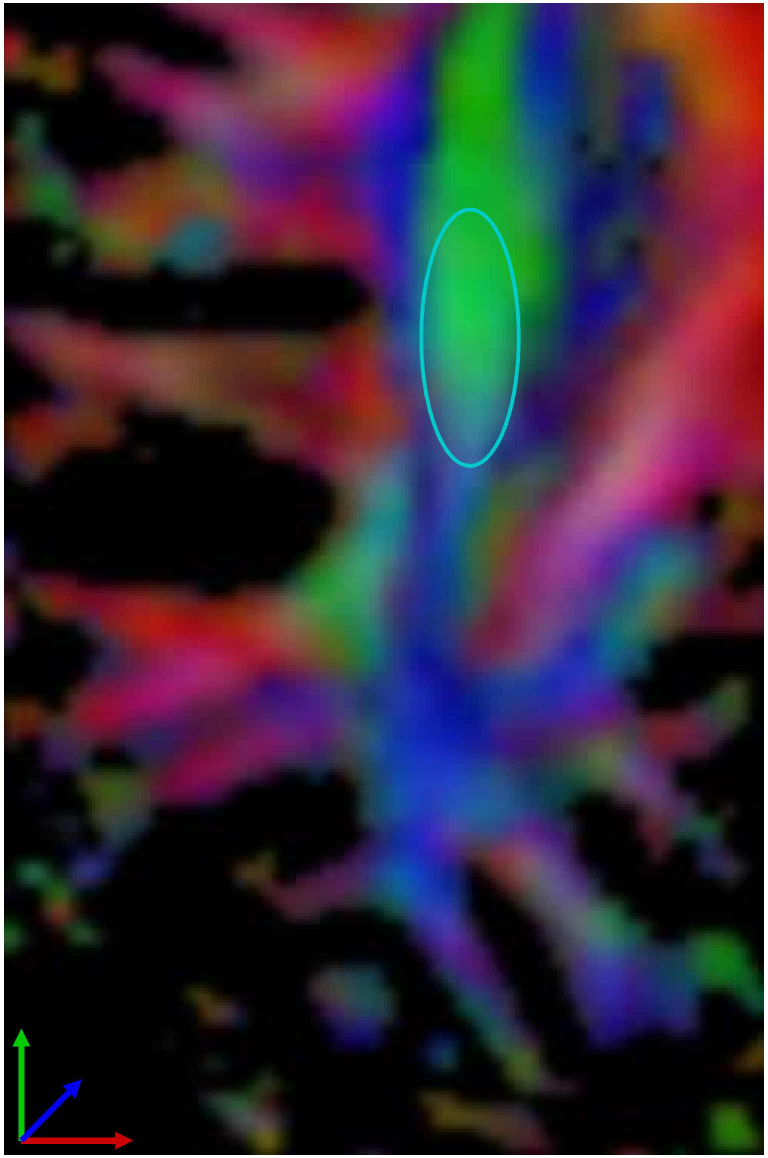
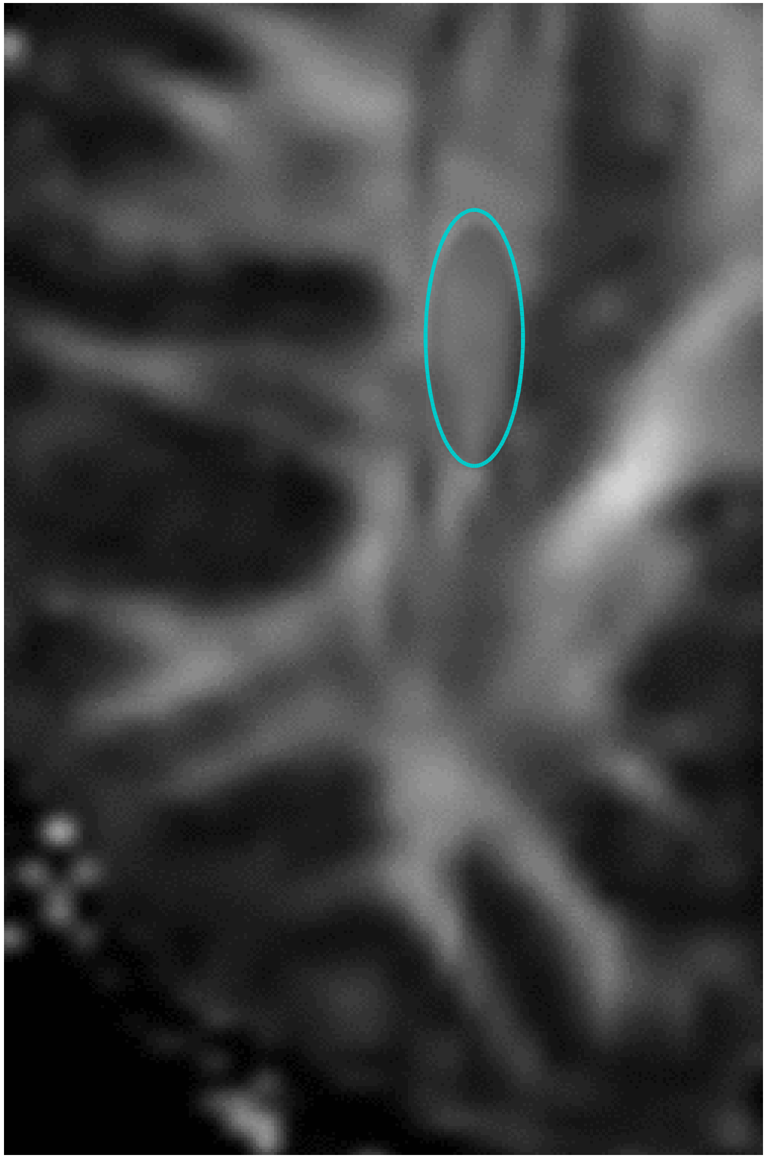
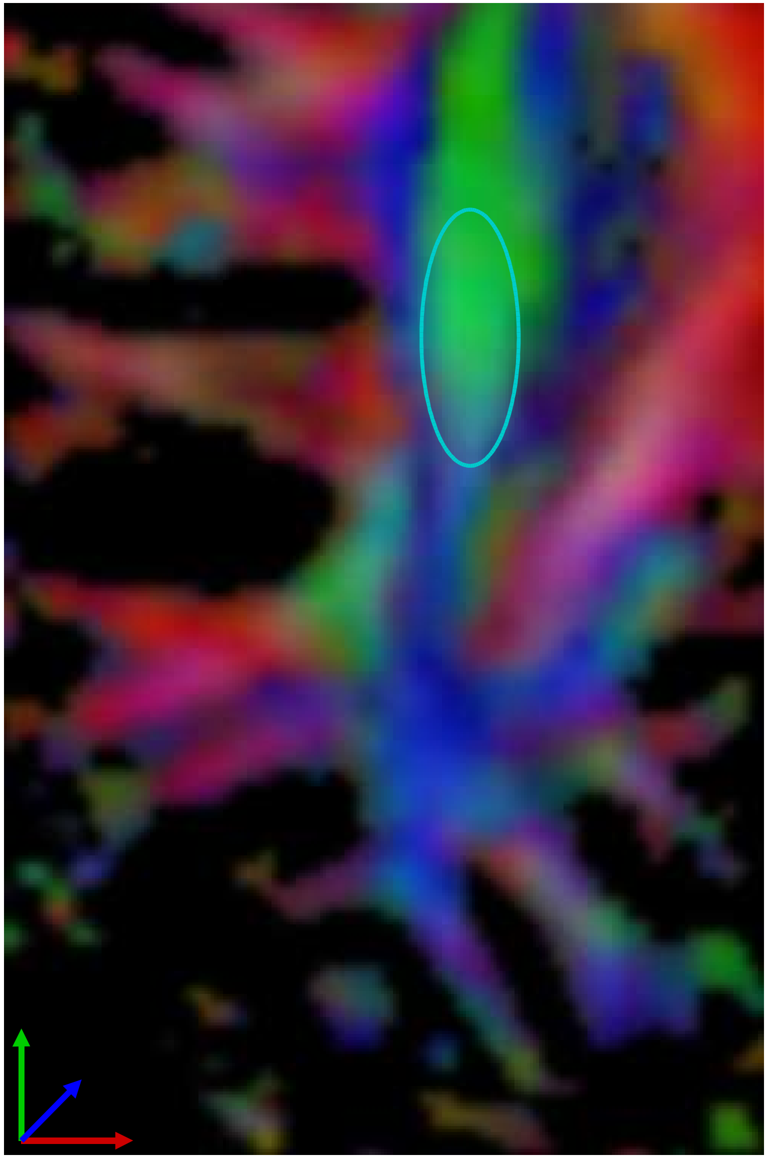
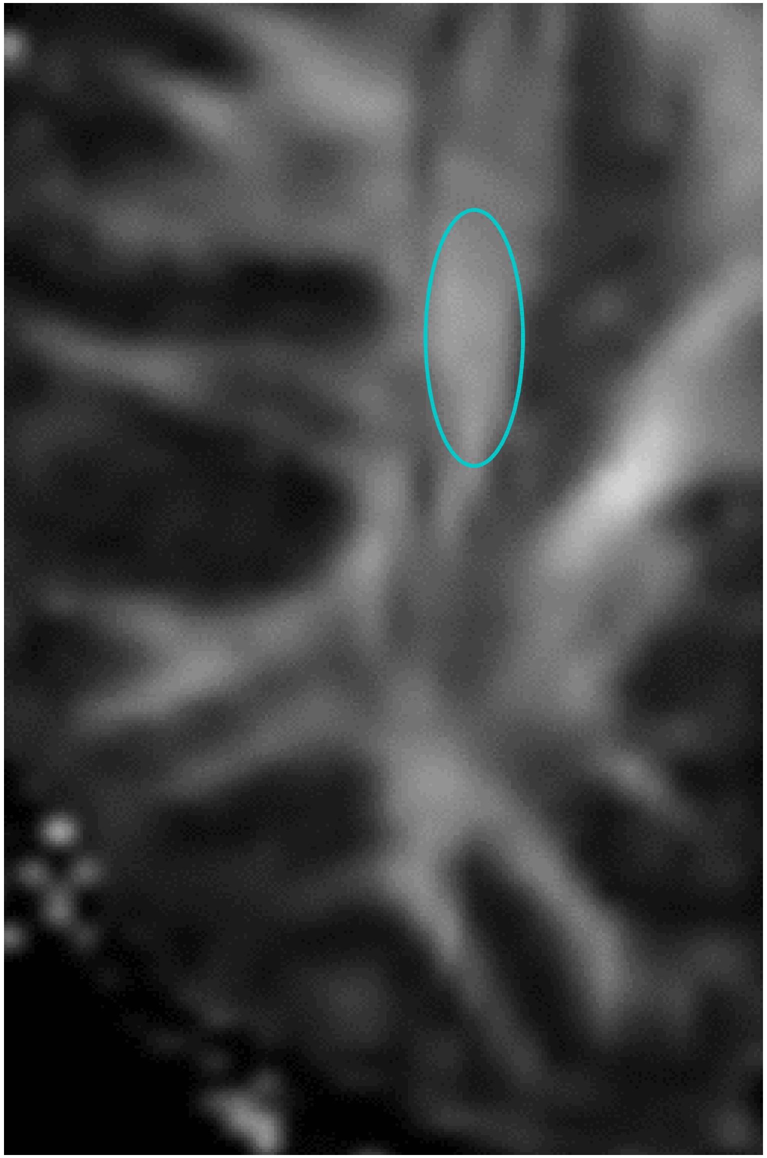




H2: Pathway Displacement





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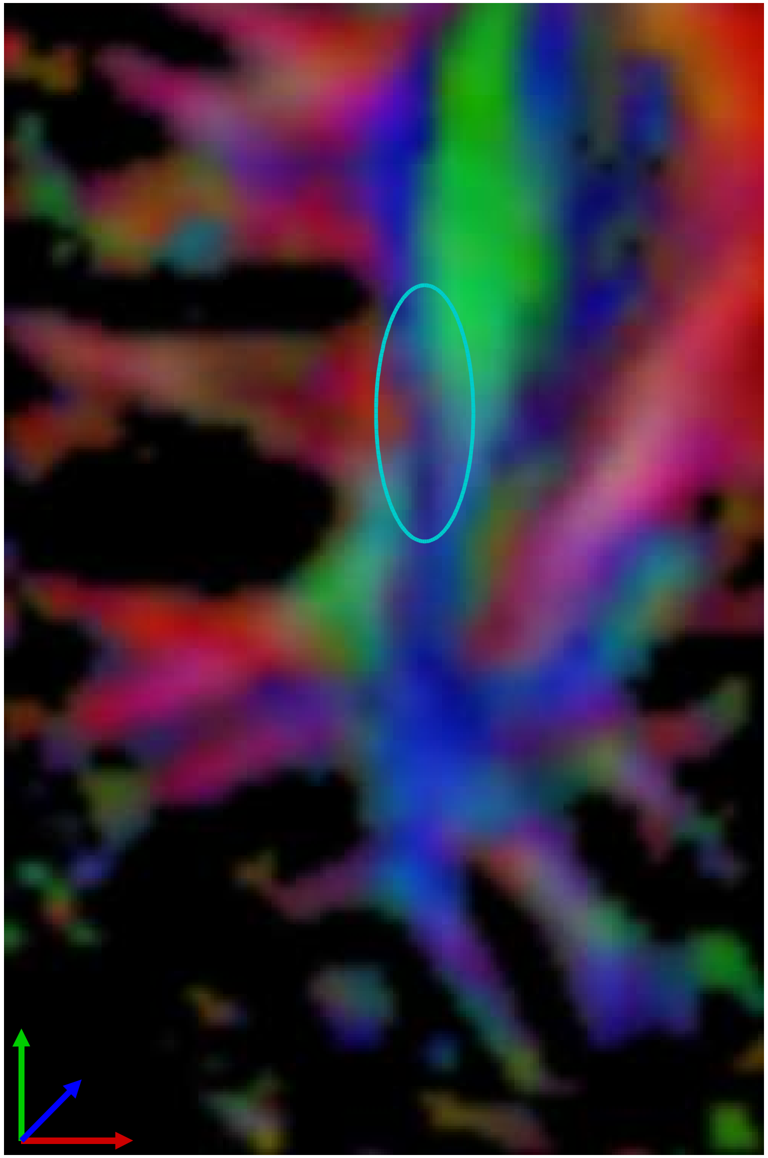
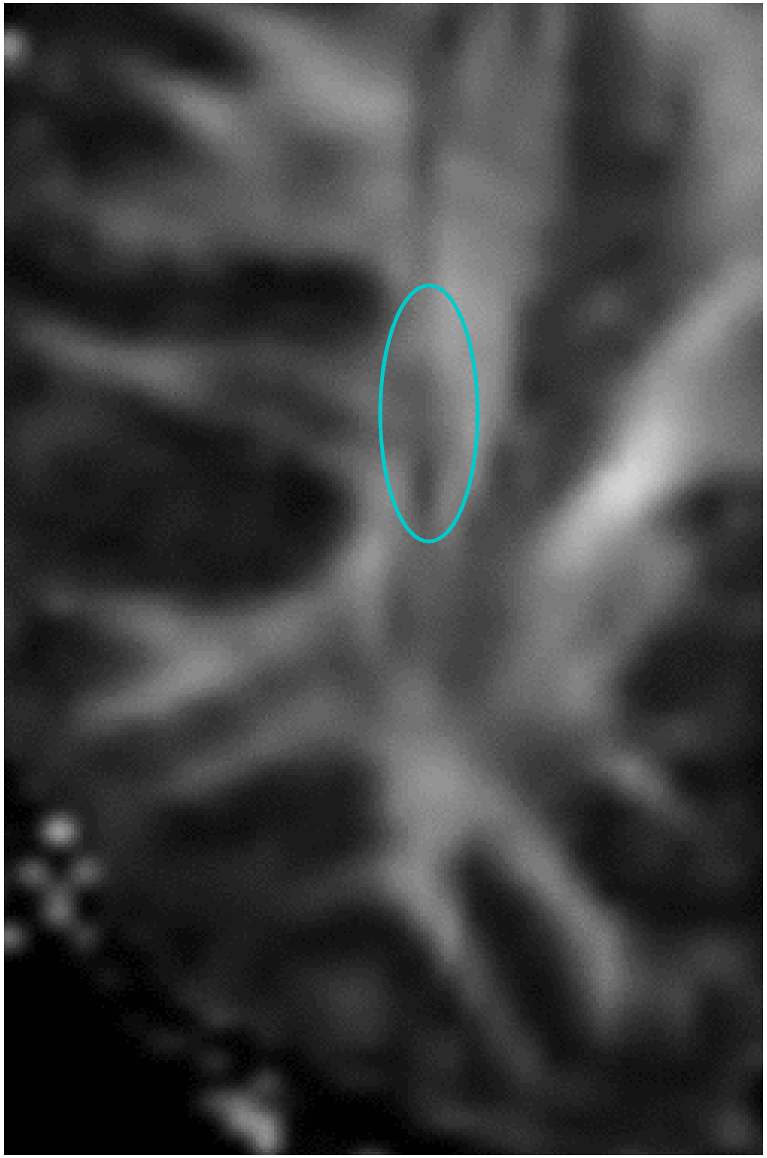
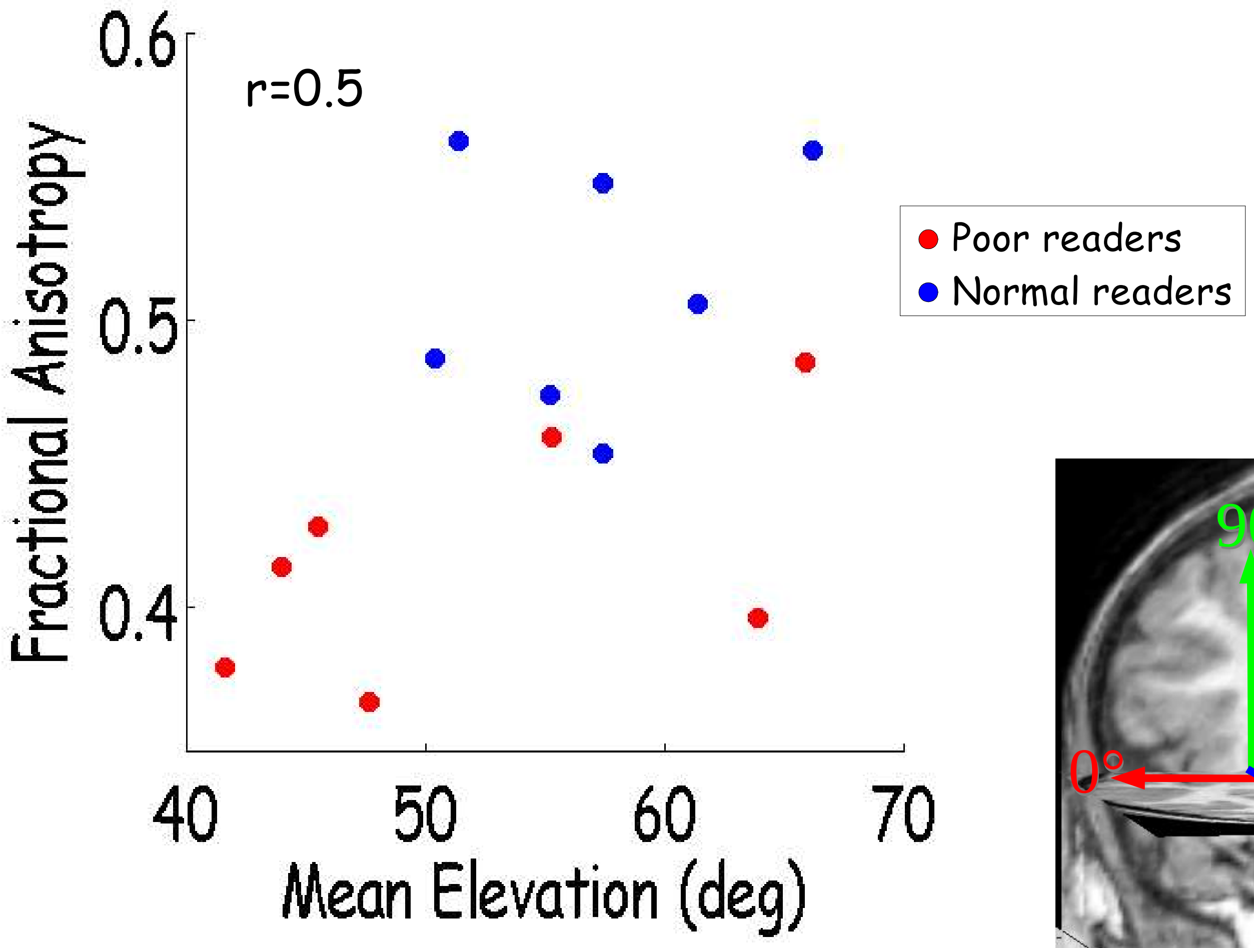
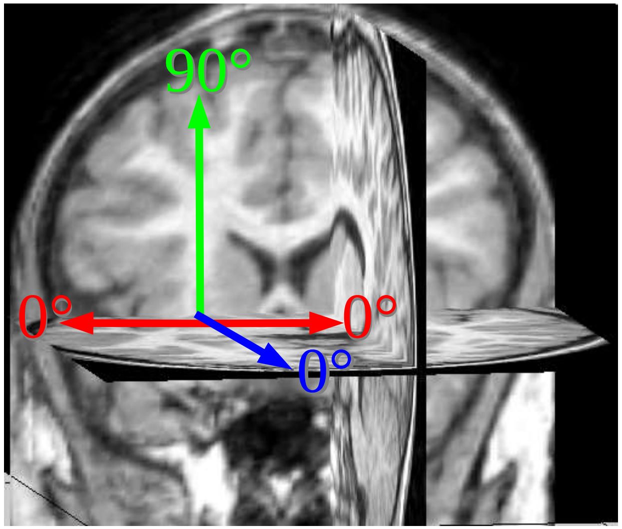




Principal Diffusion Direction is Related to FA



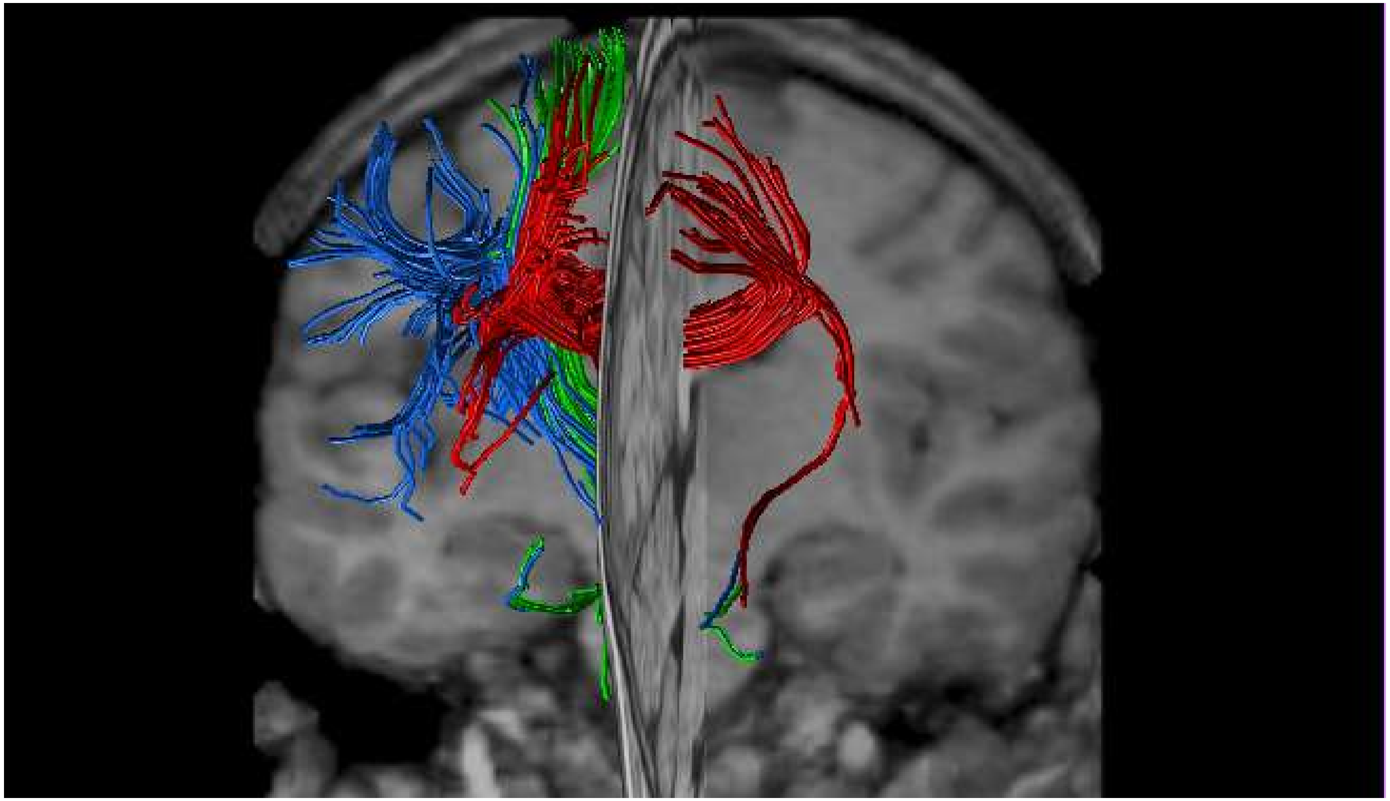


Elevation: angle from ac-pc plane

Two Outstanding Questions

- Cause or result of reading?
  - Difference present in children- cause
- Lesion or displacement?
  - Tract positions differ
  - FA & CI along major tracts do not differ
  - displacement

Tracing Virtual Fibers



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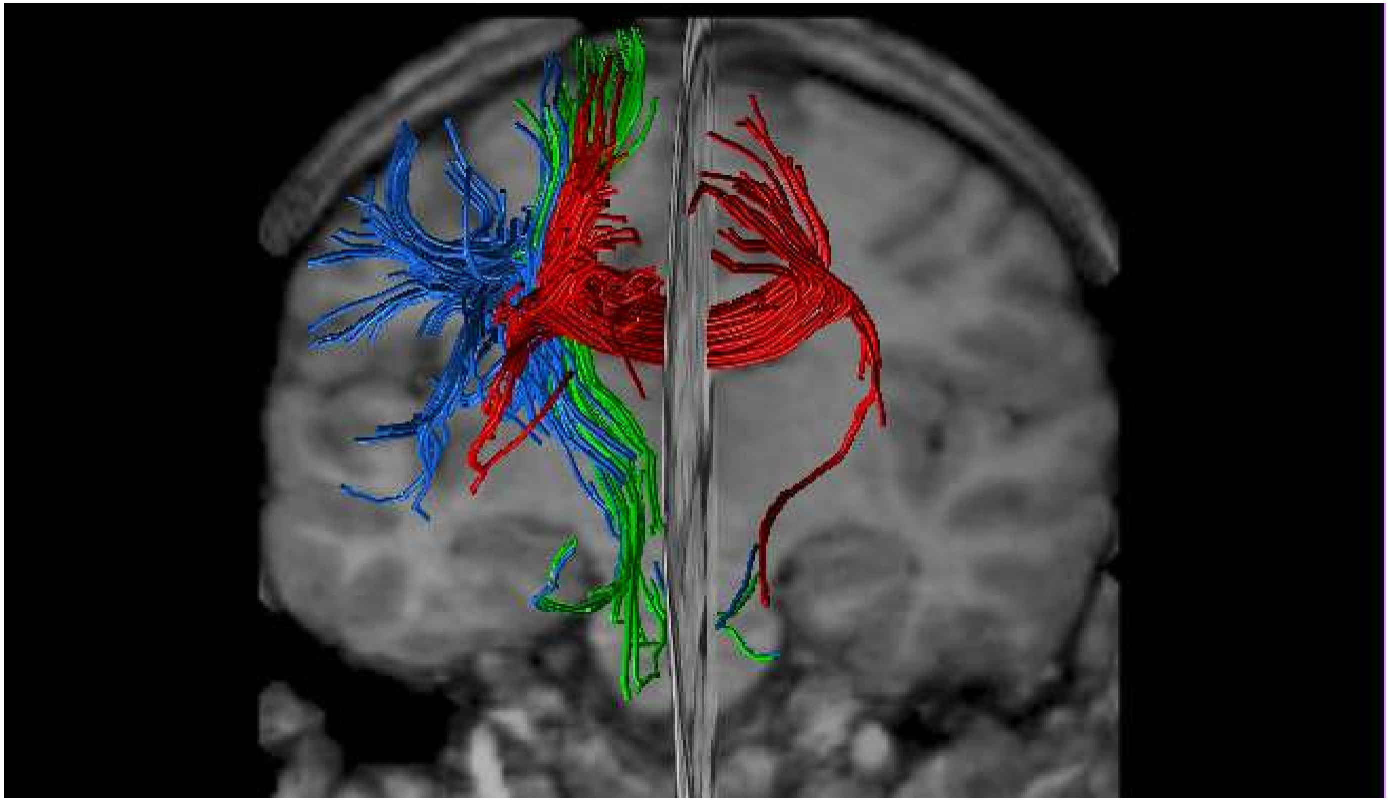

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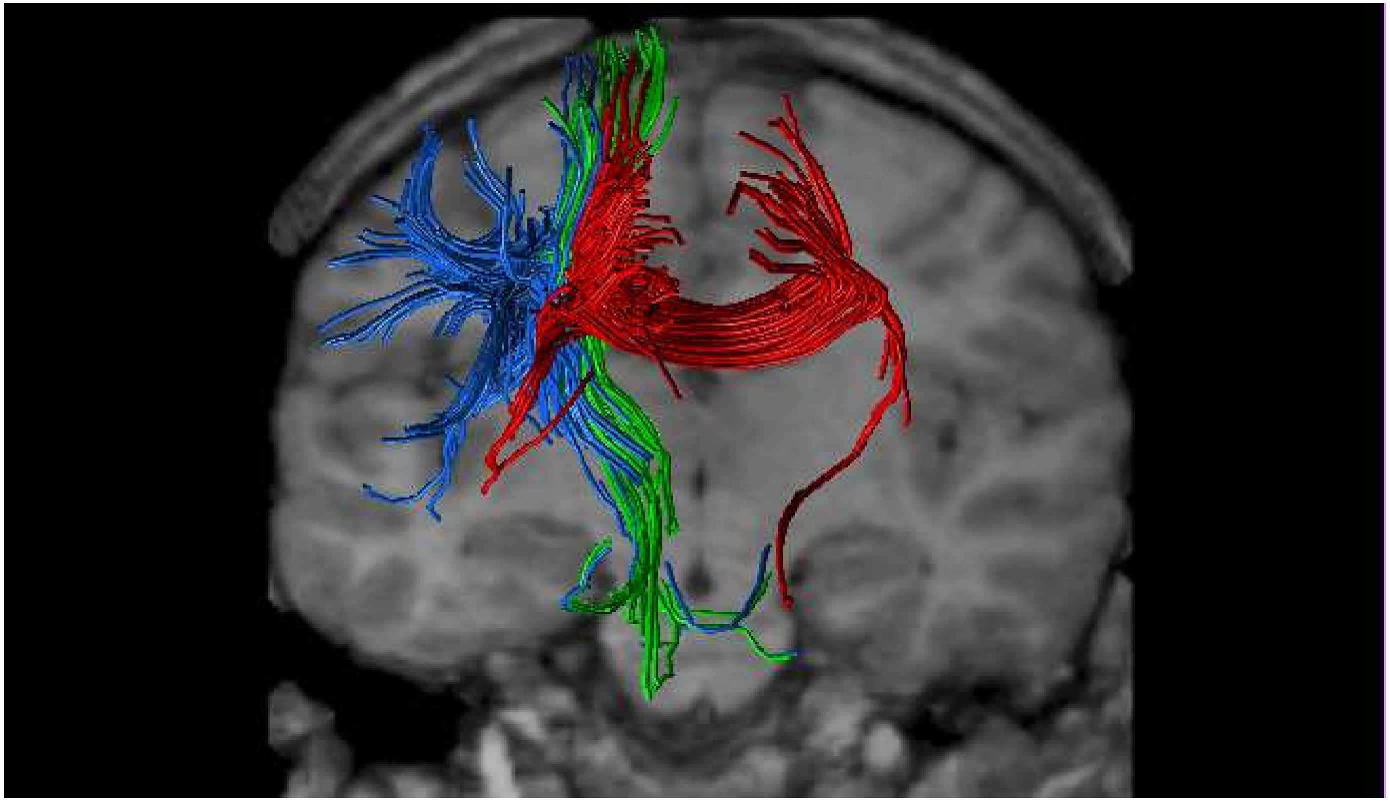

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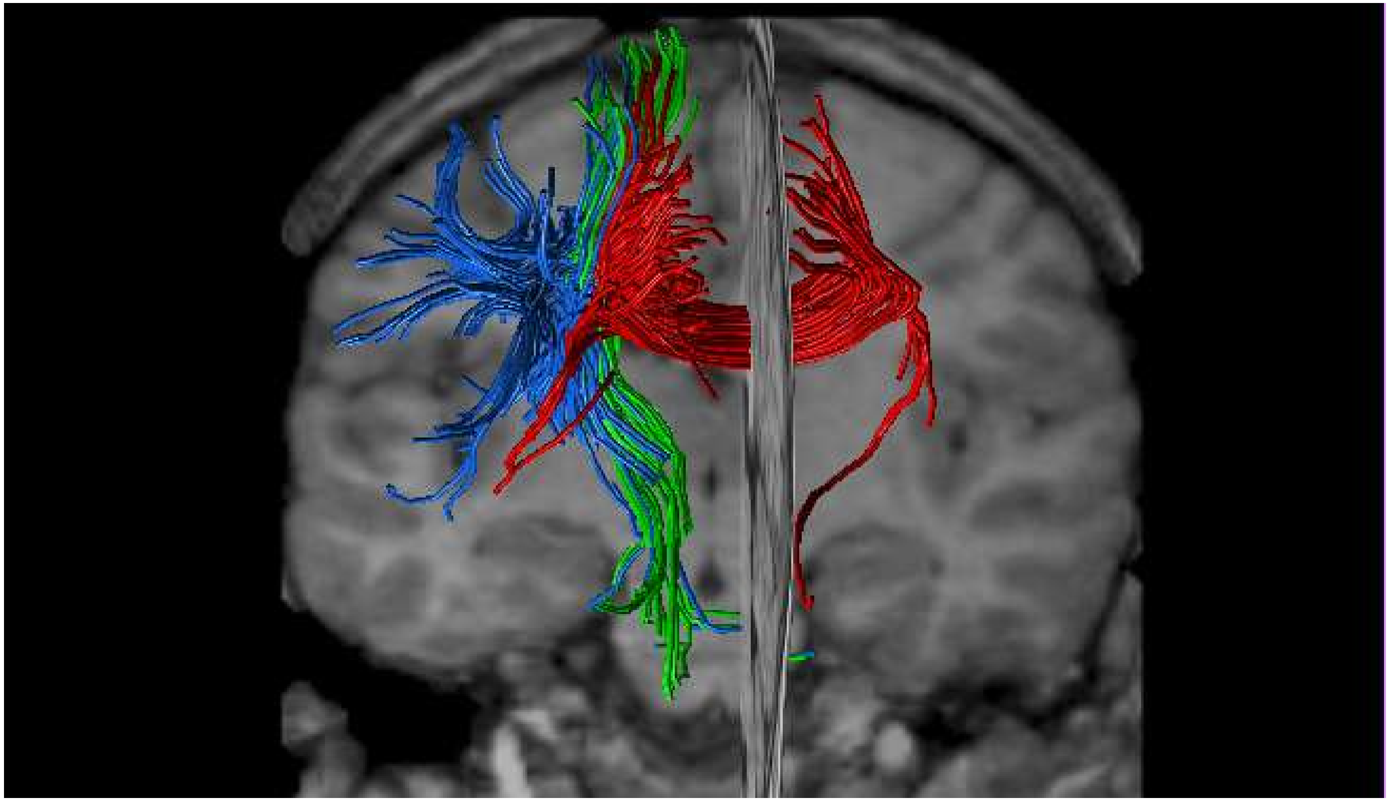

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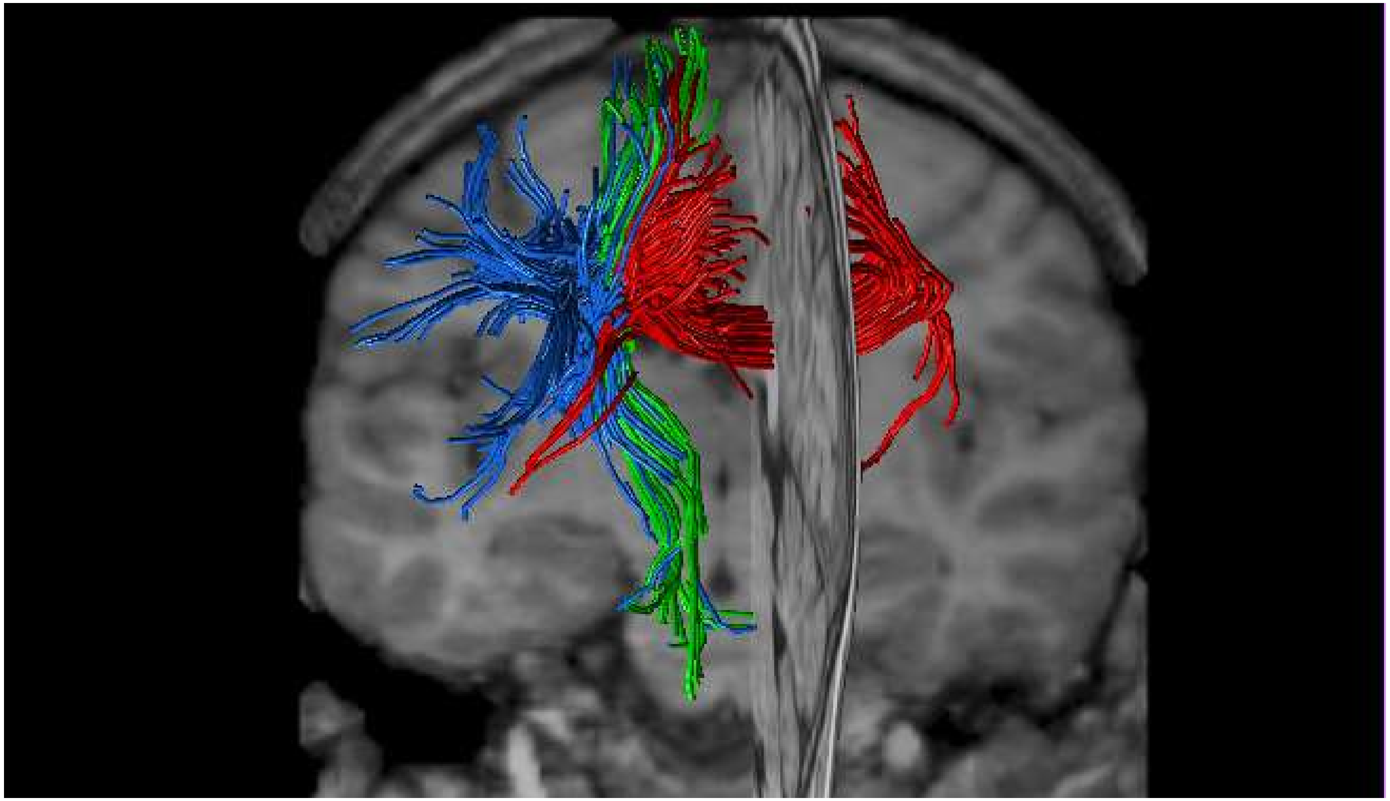

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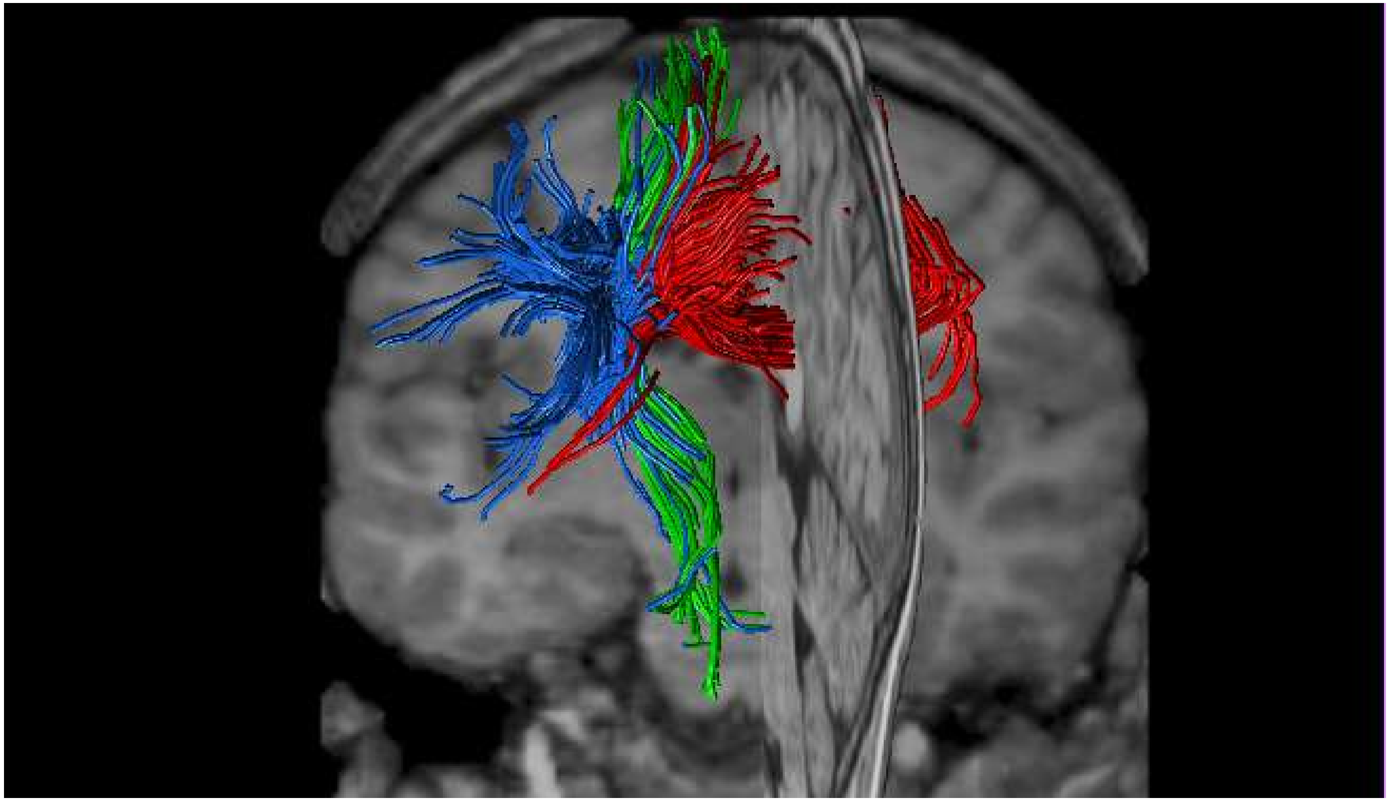

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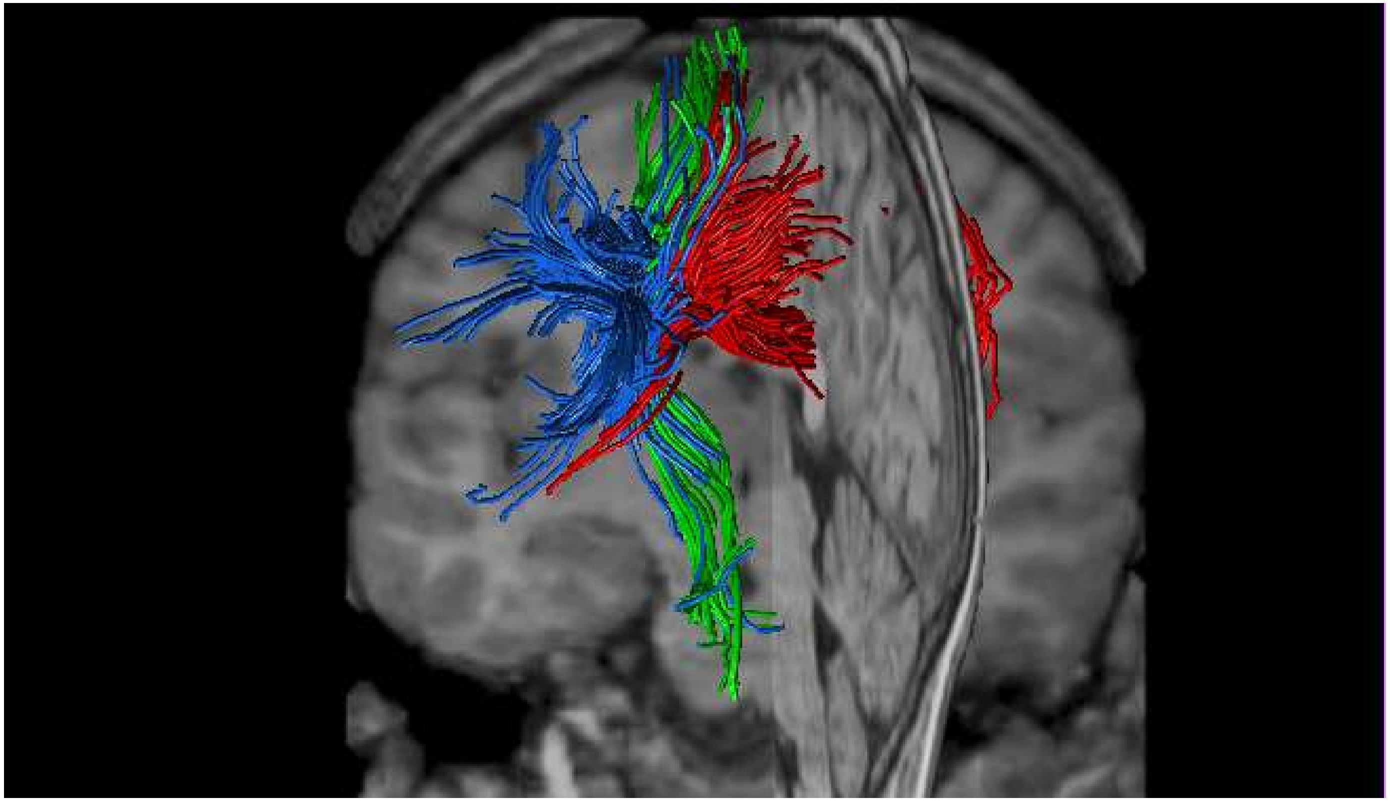

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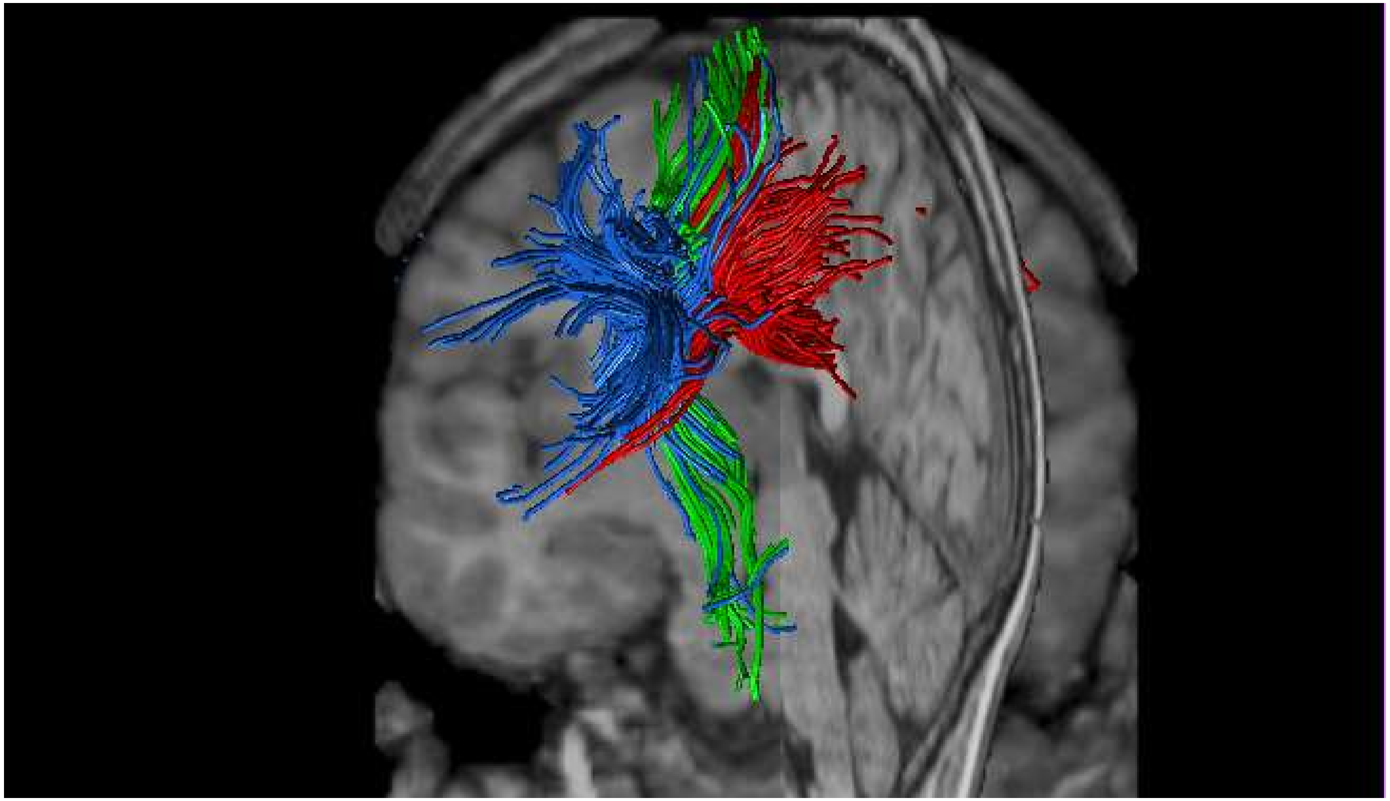

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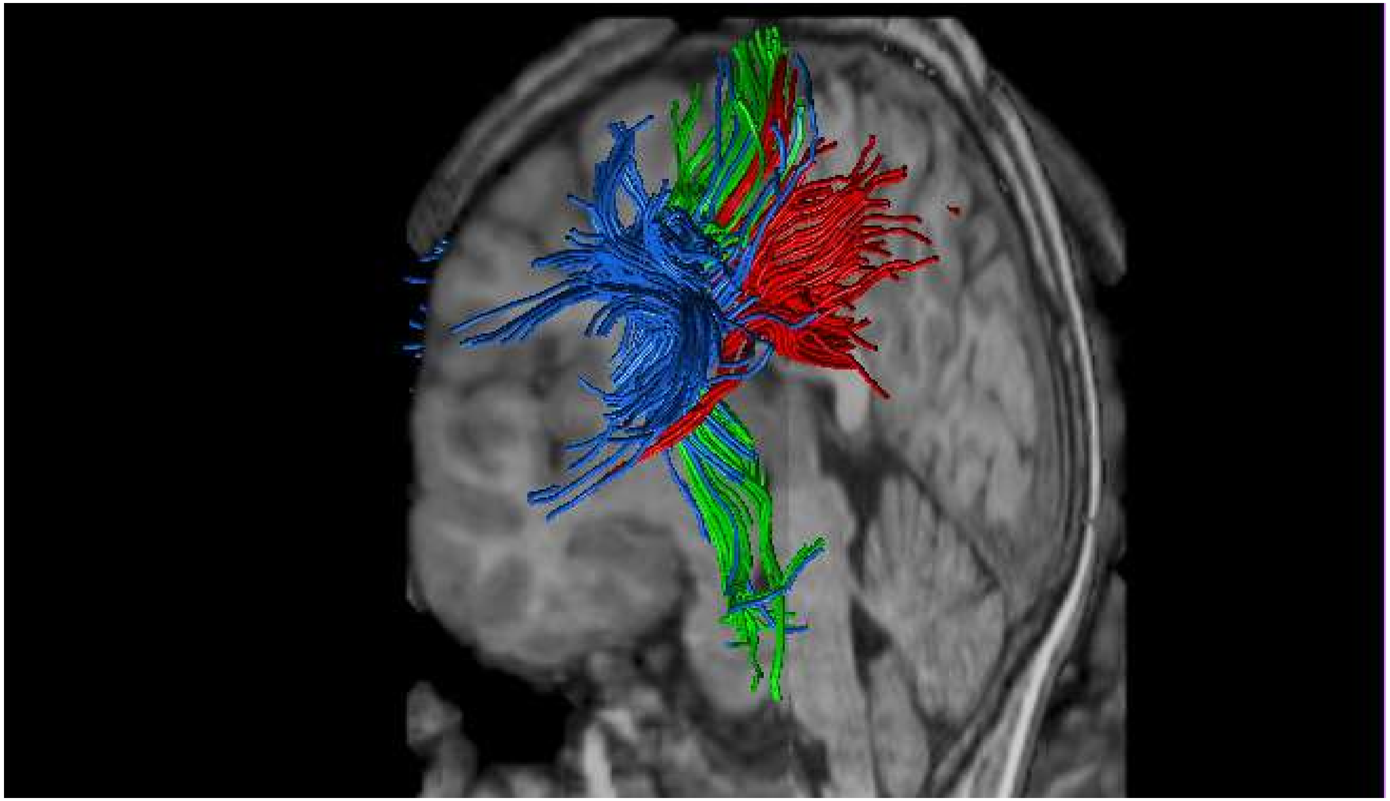

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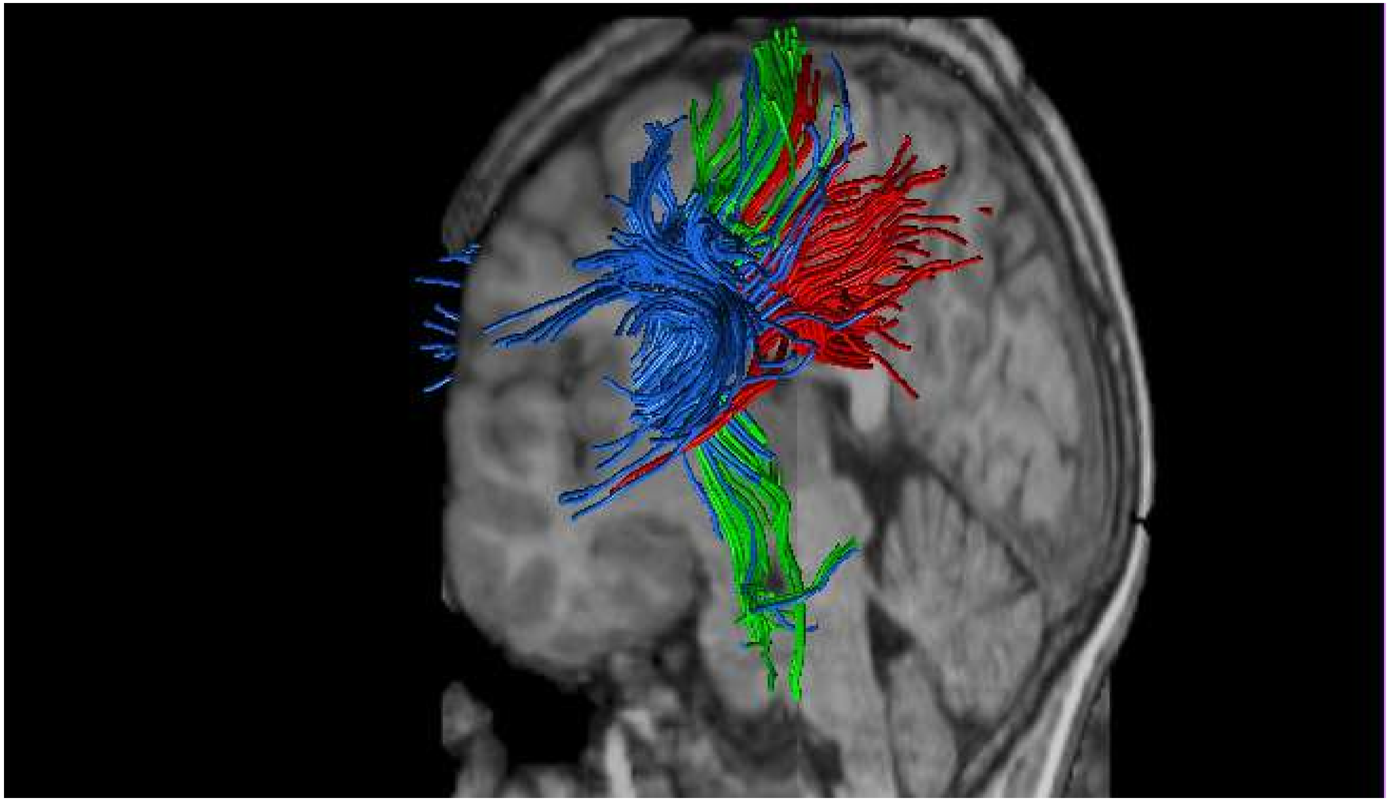

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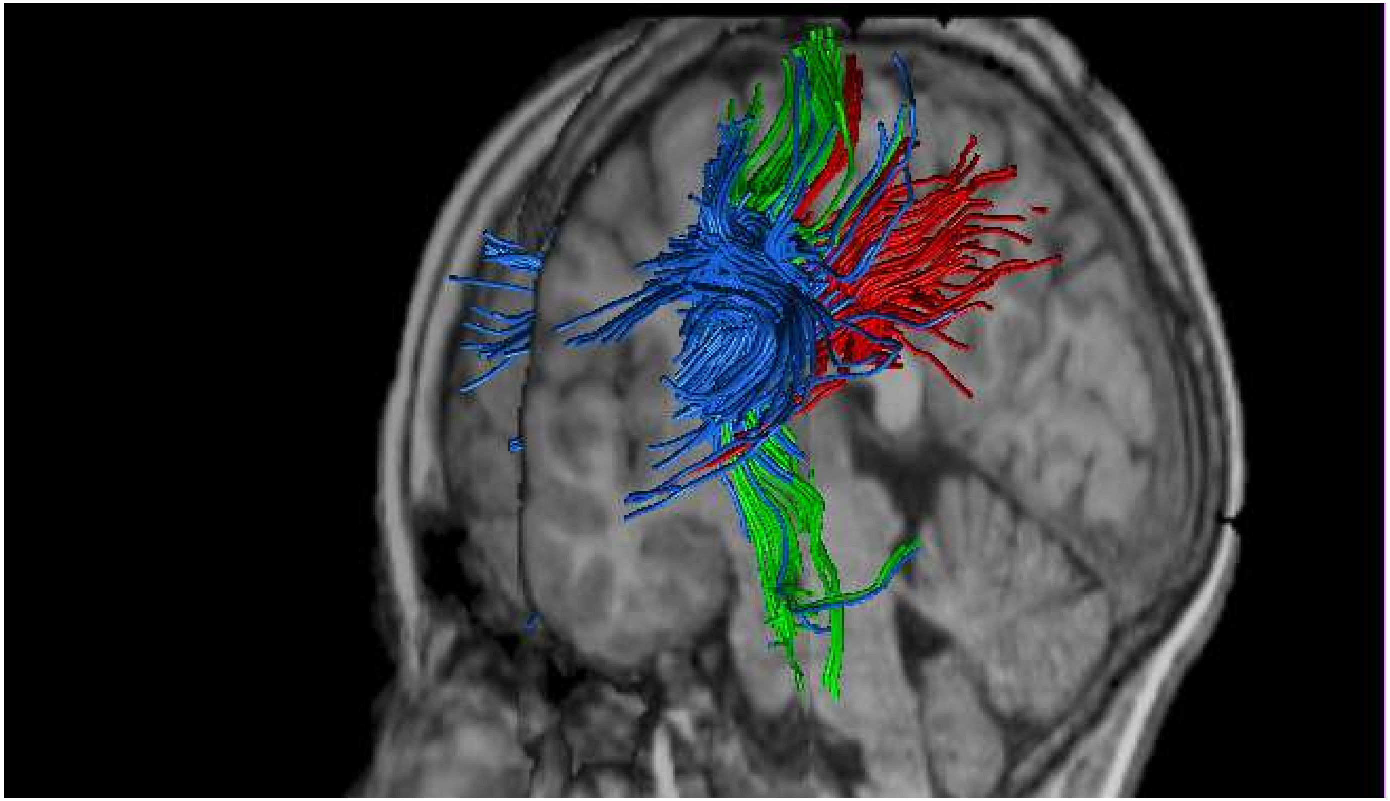

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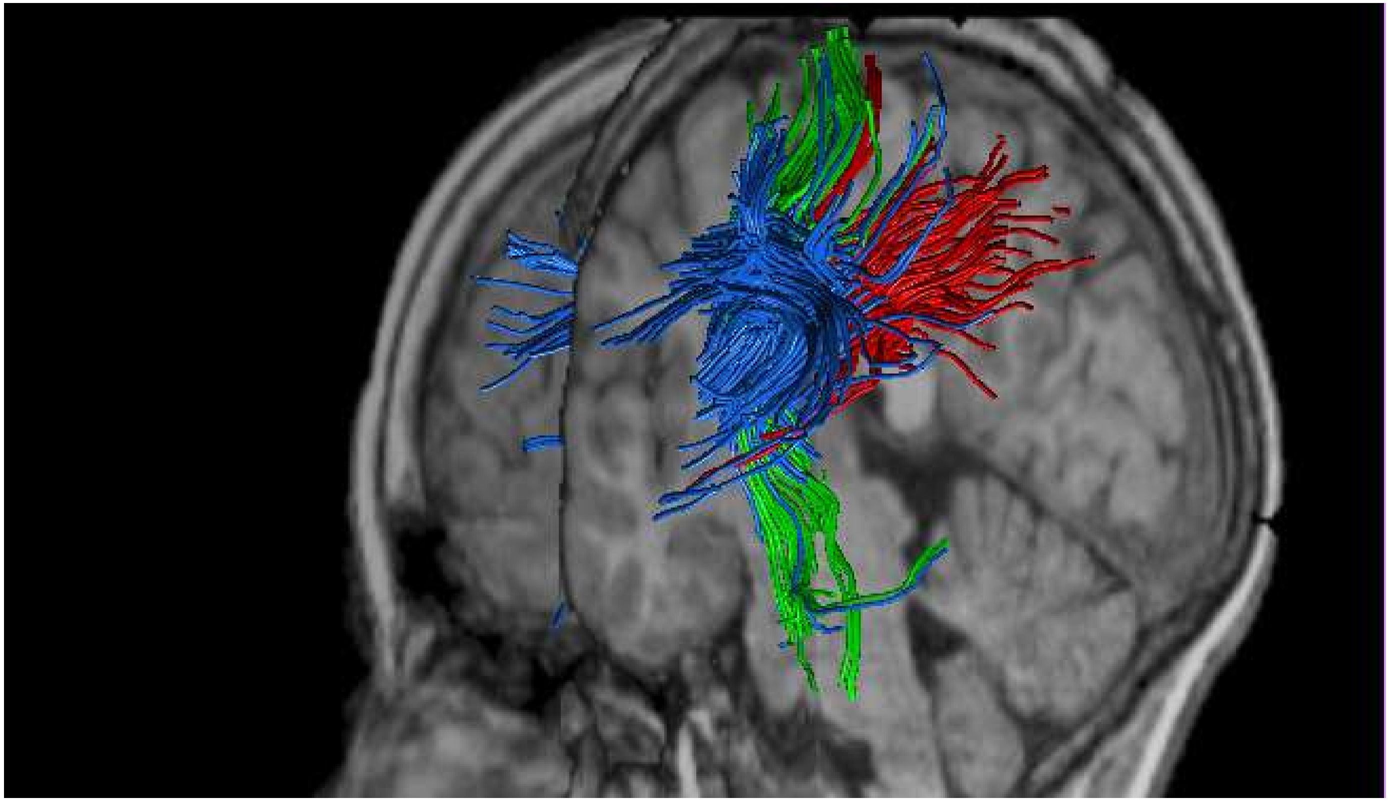

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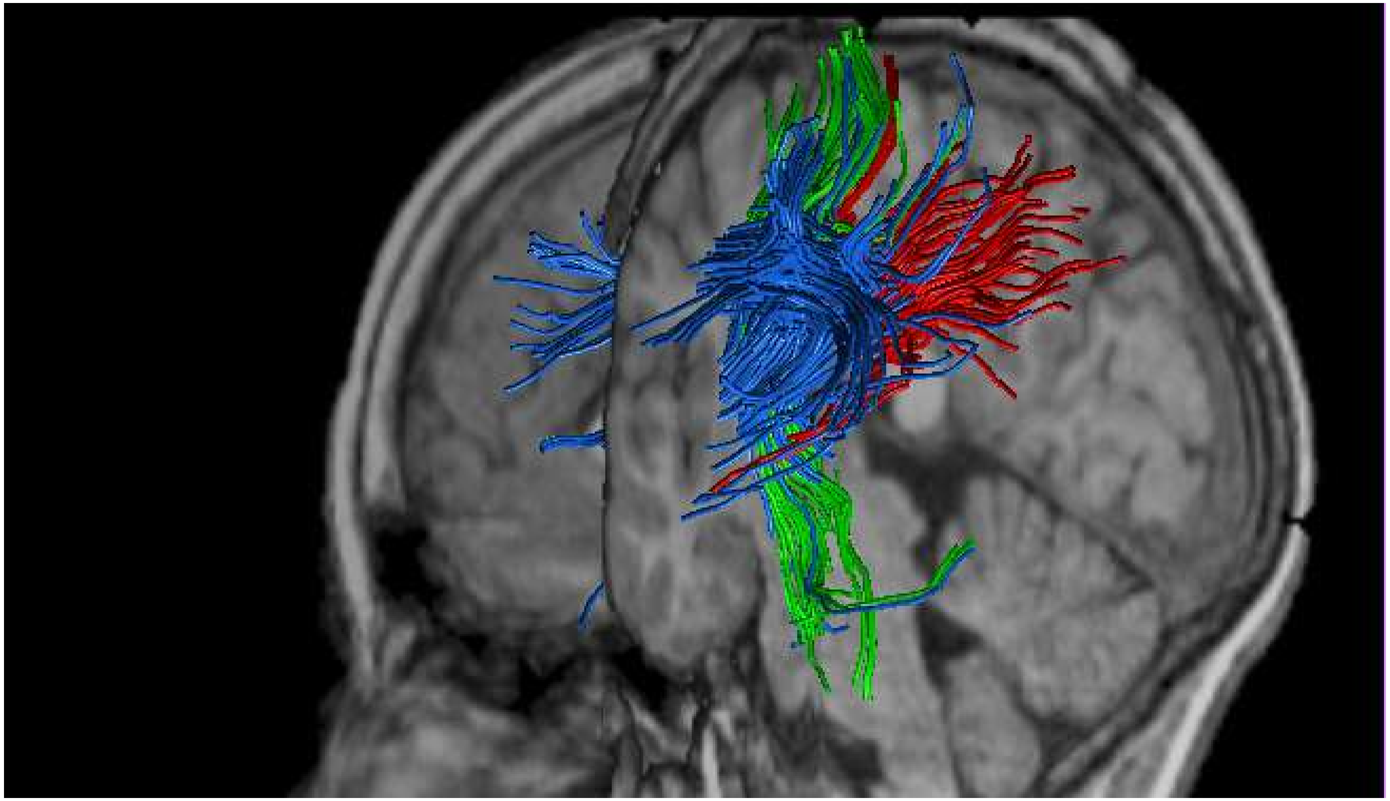

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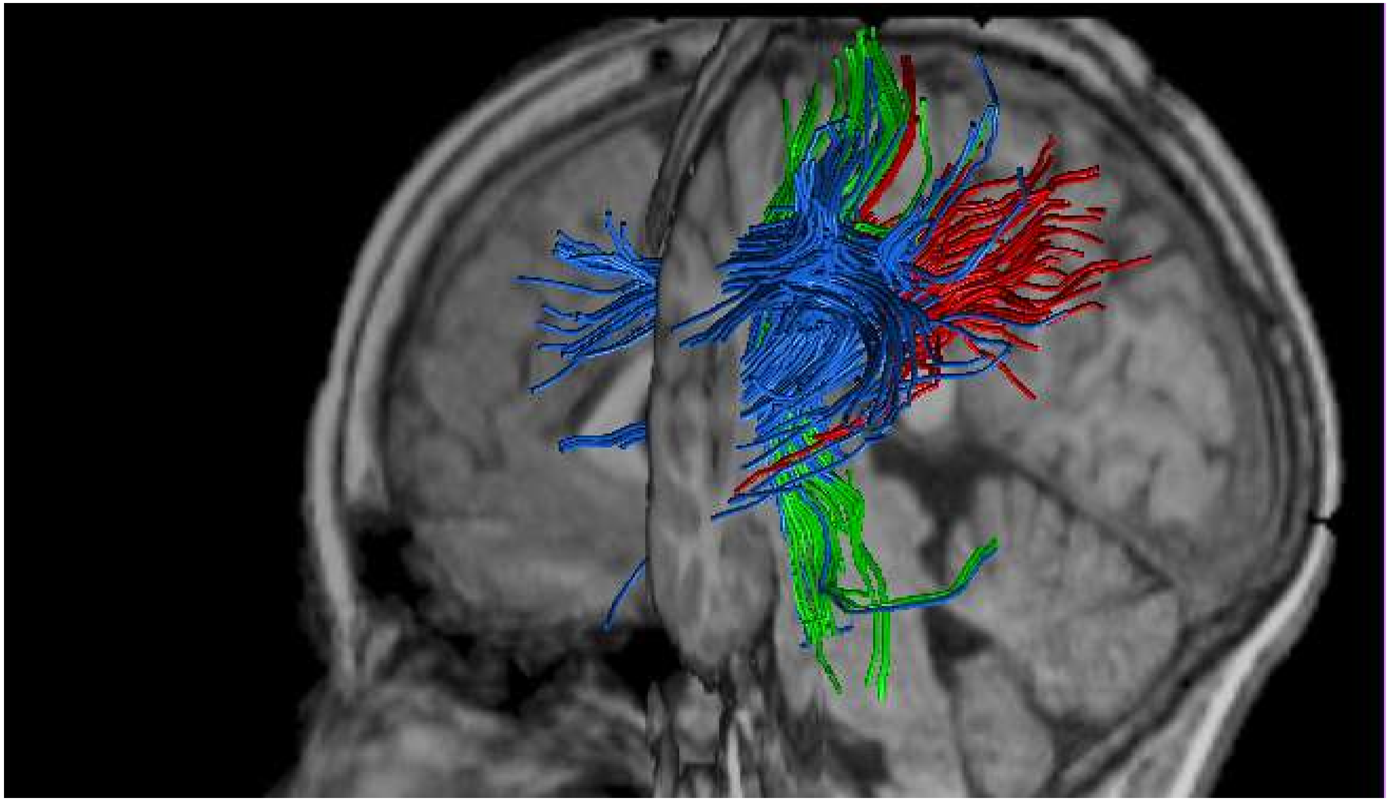

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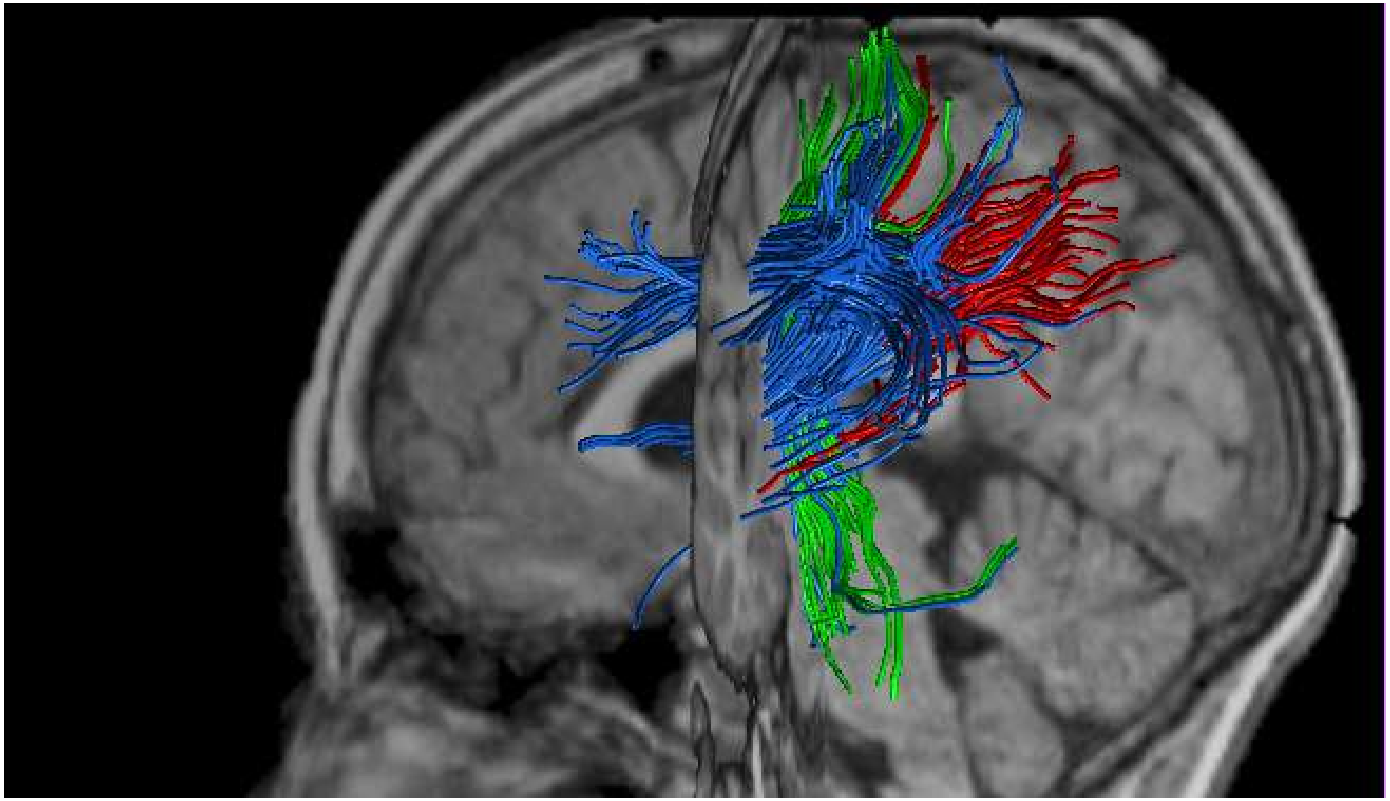

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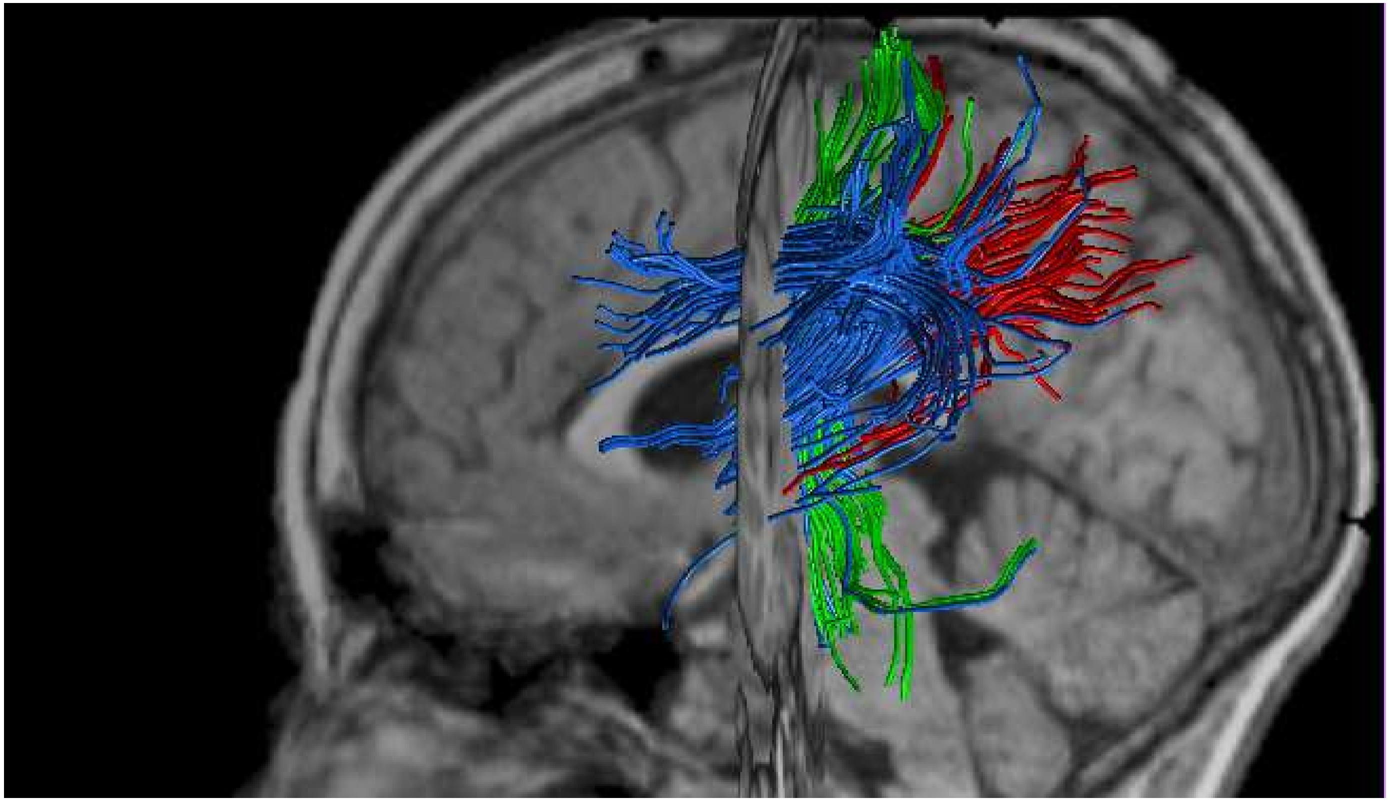

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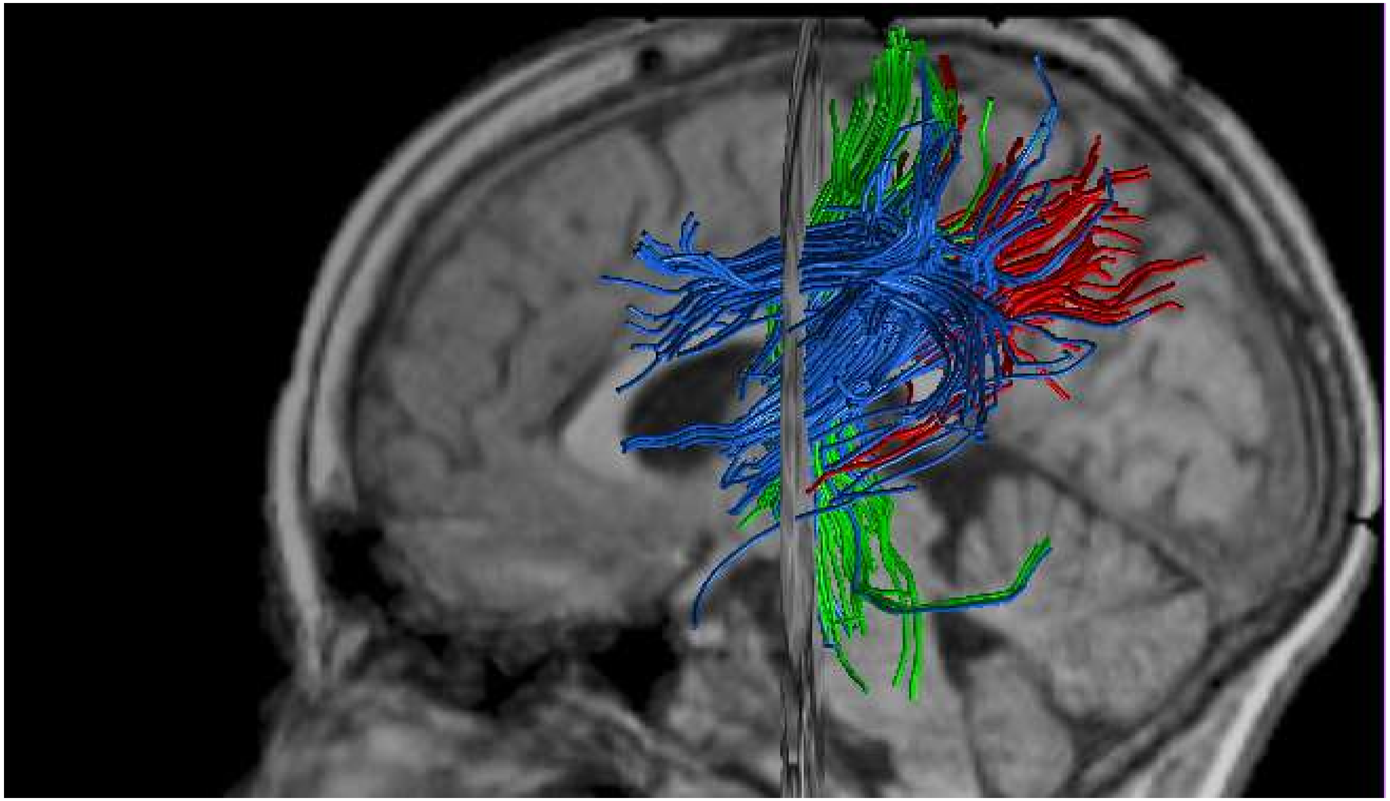

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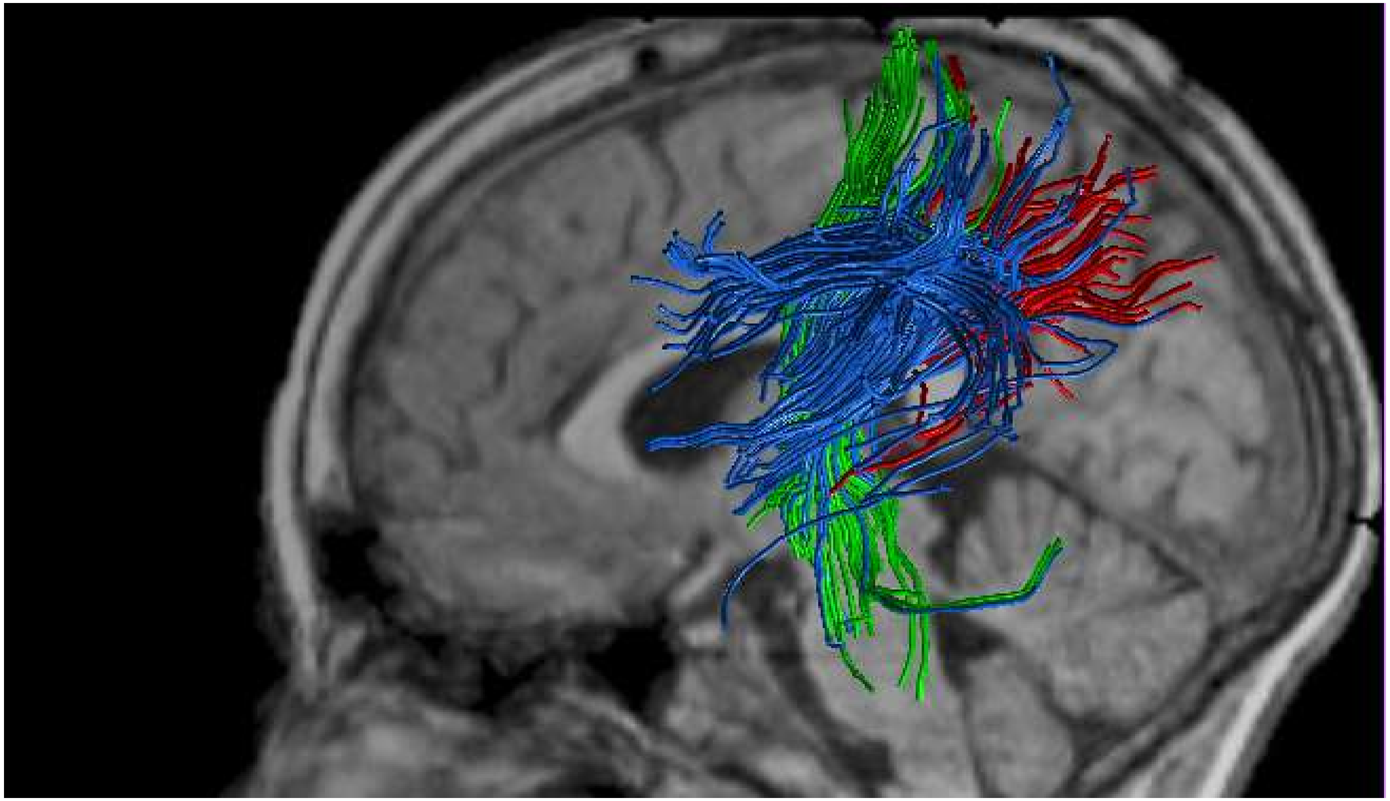

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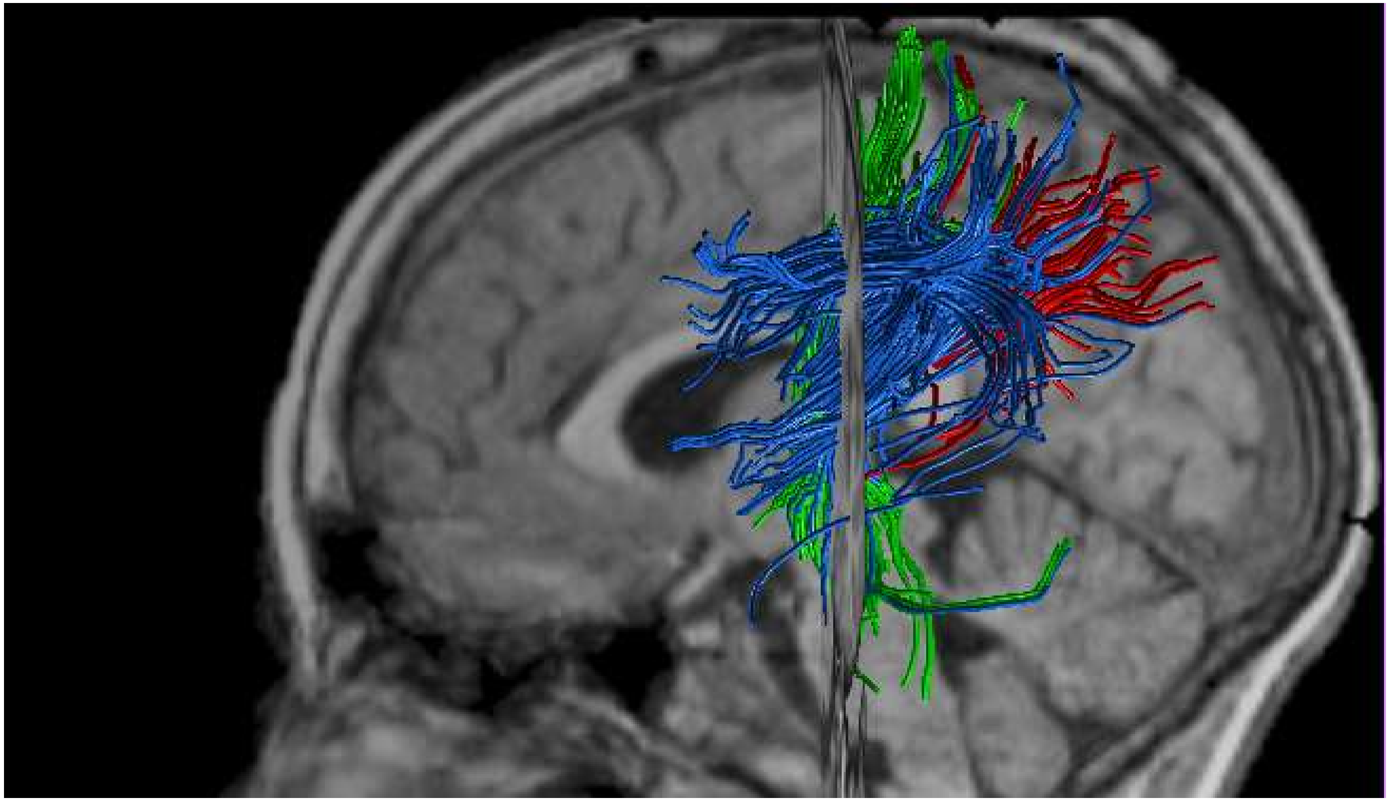

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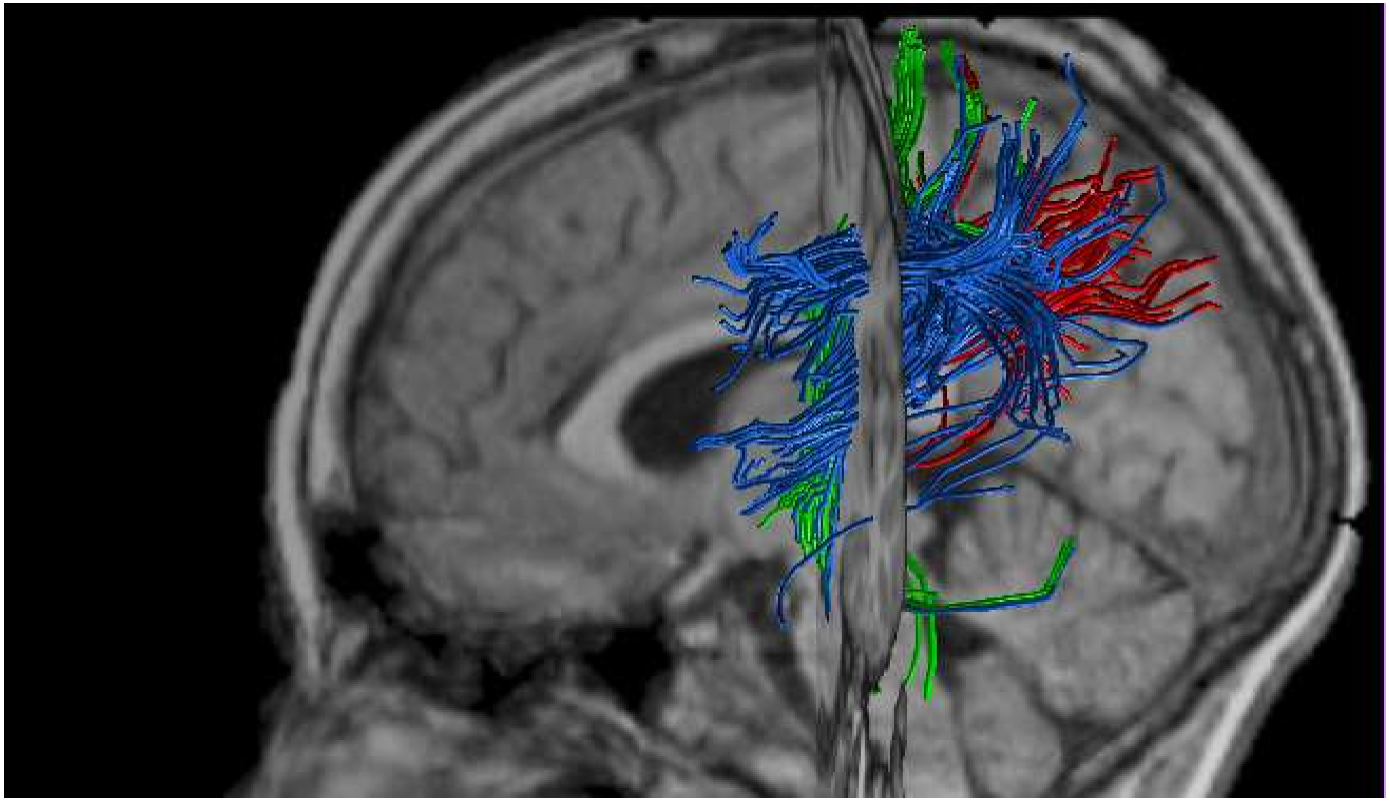

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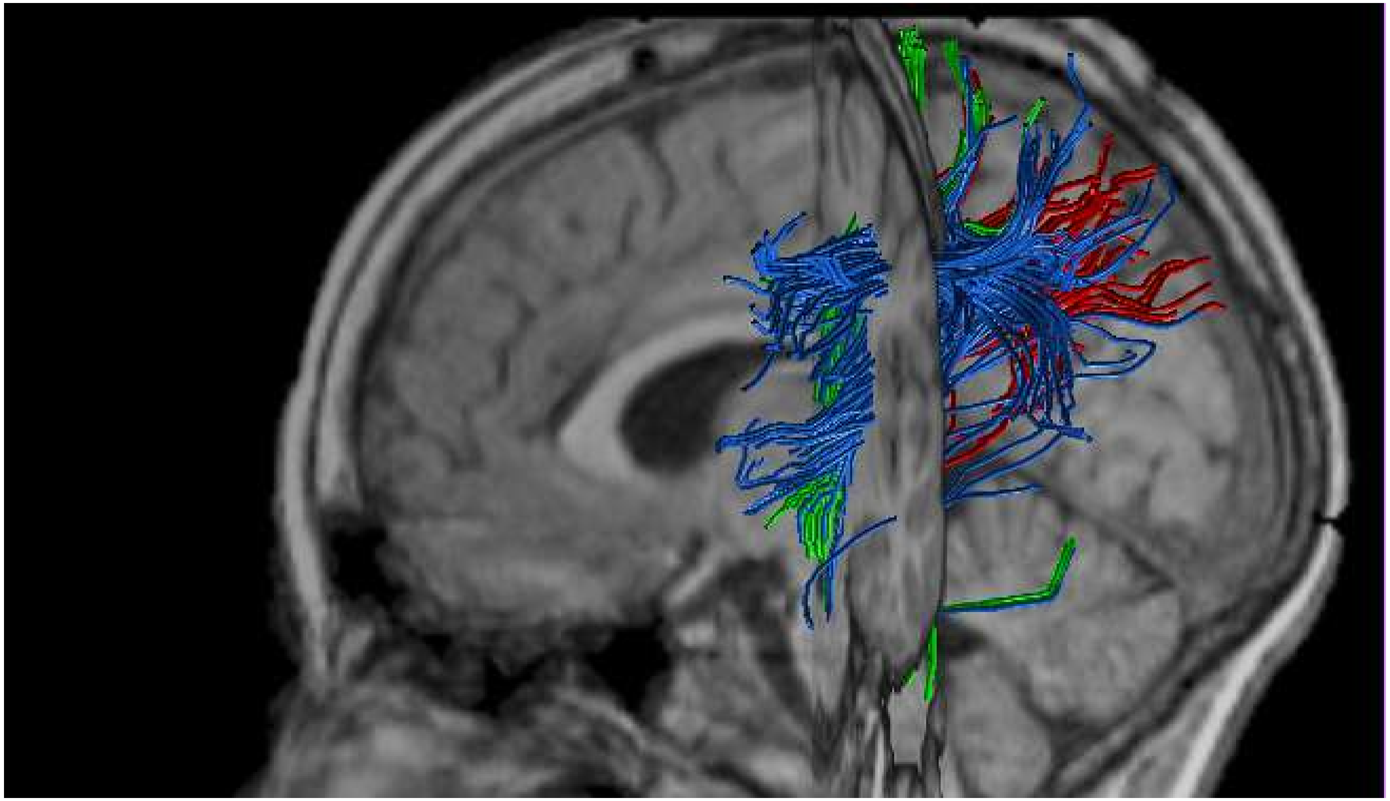

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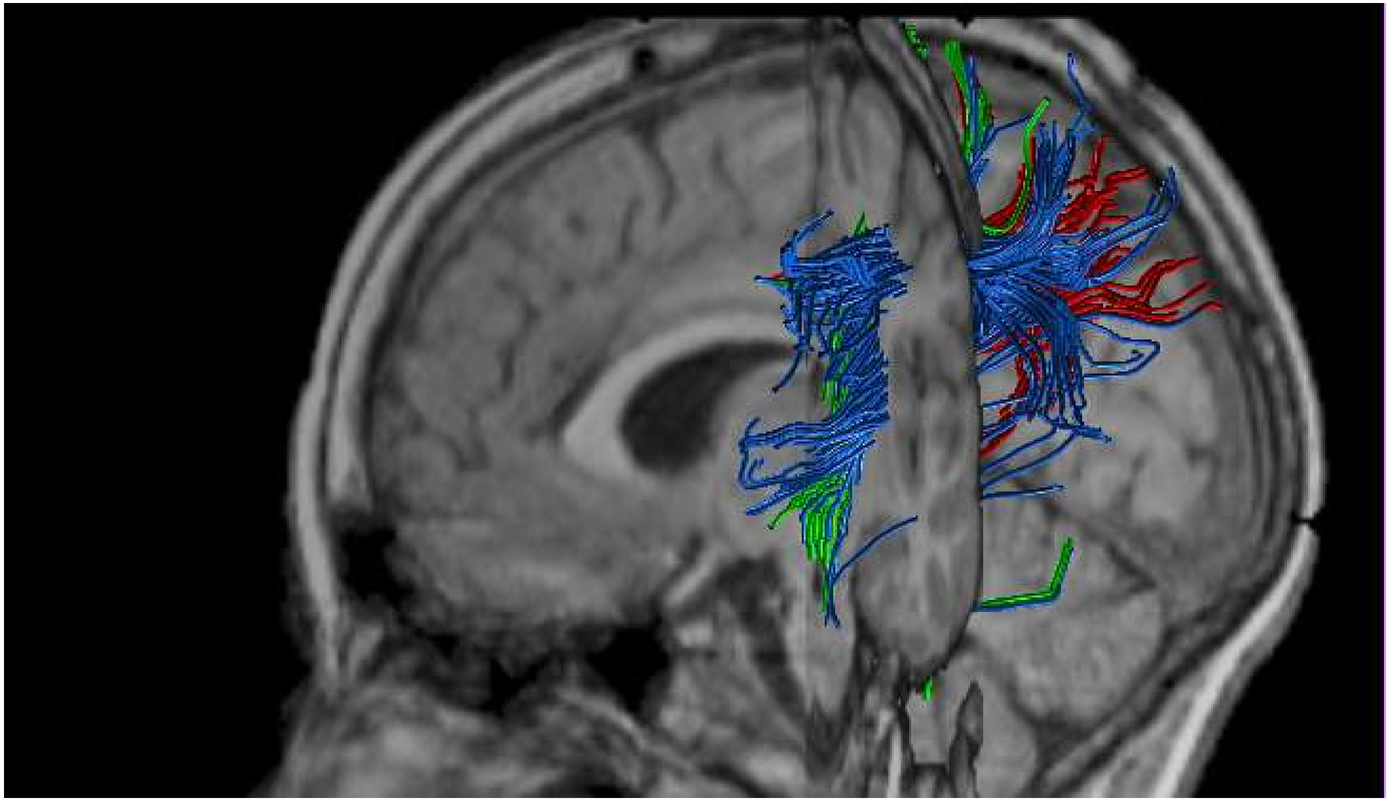

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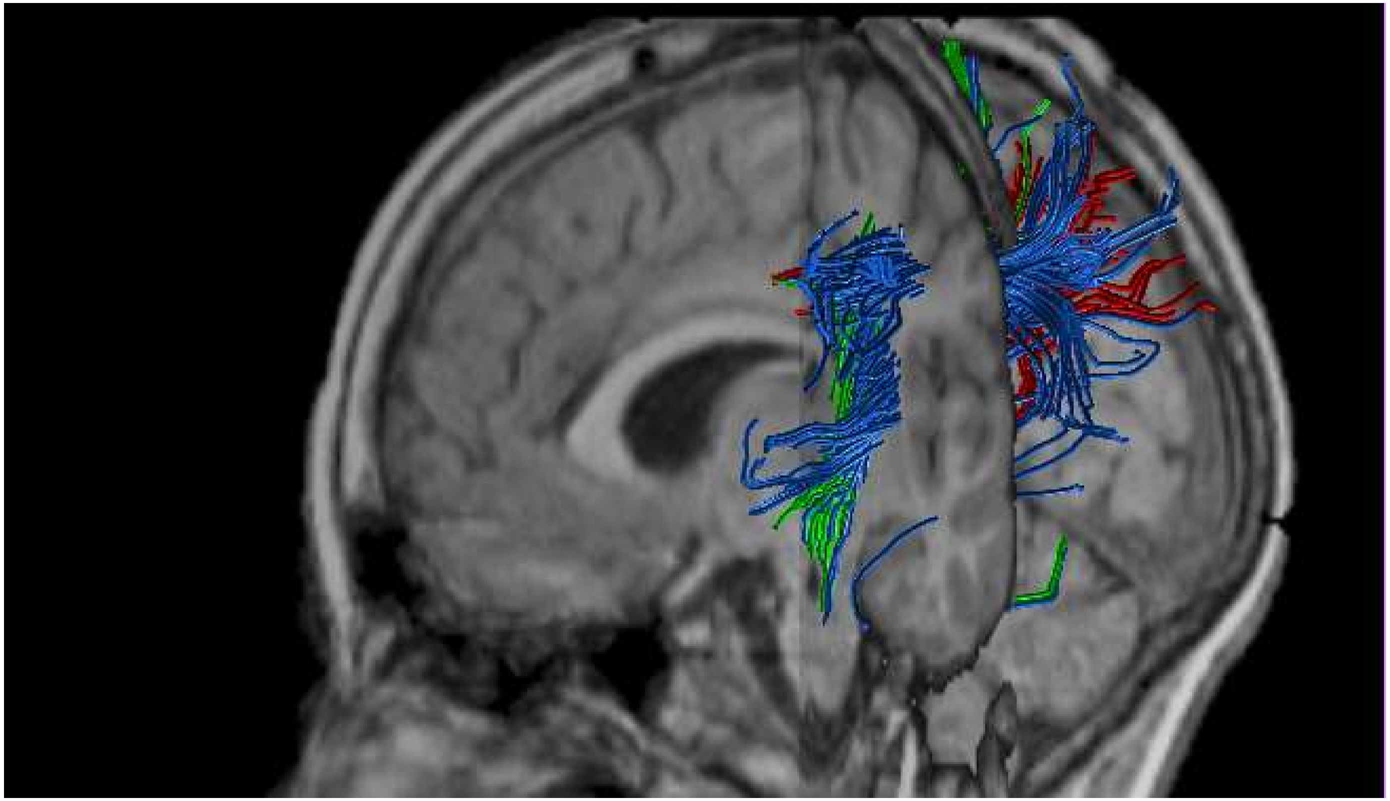


Conclusions

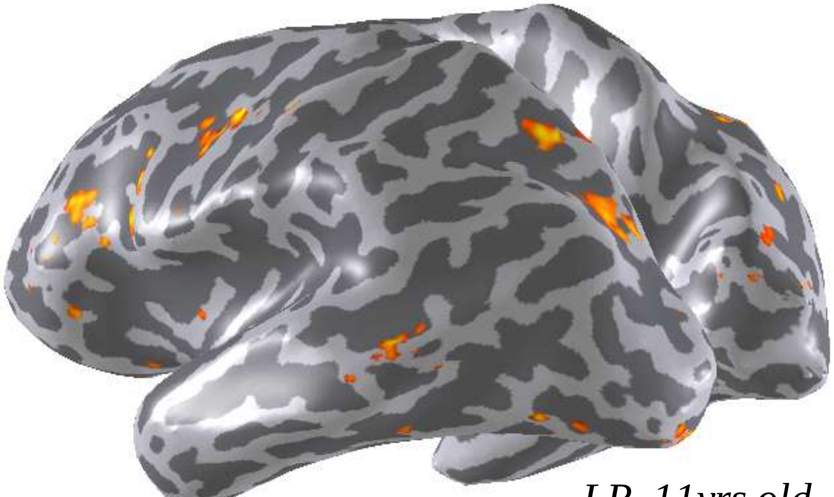
- White matter differences between good and poor readers are present in children- important for reading
- Differences likely due to differing organization of neural pathways rather than tissue microstructure
  - Involving: Superior Longitudinal Fasiculus, Corona Radiata and perhaps posterior Corpus Callosum

Thank You!

- Gayle Deutsch- SIRL & Neurology
- Roland Bammer- Radiology
- Mark Eckert- Psychiatry
- Wai Ting Siok- Psychology
- John Gabrieli- Psychology
- Brian Wandell- SIRL & Psychology

Ongoing & Future Efforts

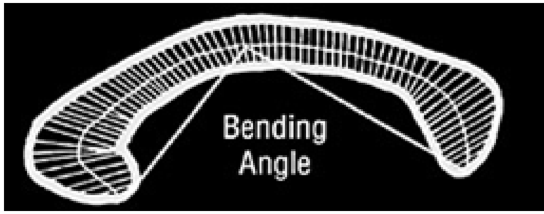
- Combine DTI & fMRI
- T1 anatomical measurements
- Tractography Validation
- Longitudinal Study of Reading development

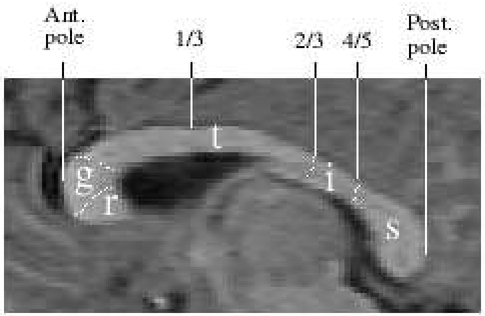


LR, 11yrs old

Reading and Lateriazation

- Corpus callosum differences
  - Poor readers have:
    - smaller bending angle (Robichon & Habib, 1998)
    - Larger isthmus & splenium (Rumsey et. al. 1996)
- Laterialization?
- Intra-hemispheric connections?





splenium
isthmus
truncus
genu
rostrum

DTI: How it works

- Bipolar gradient pulse ("diffusion-weighting")
  - Pulse pair has no net effect on stationary spins
    - Second pulse undoes first
  - Spins moving along gradient are not rephased by second pulse and end up phase-shifted
    - Phase-shift $\propto$ distance moved during time T