Reading Circuitry in the Child's Developing Brain

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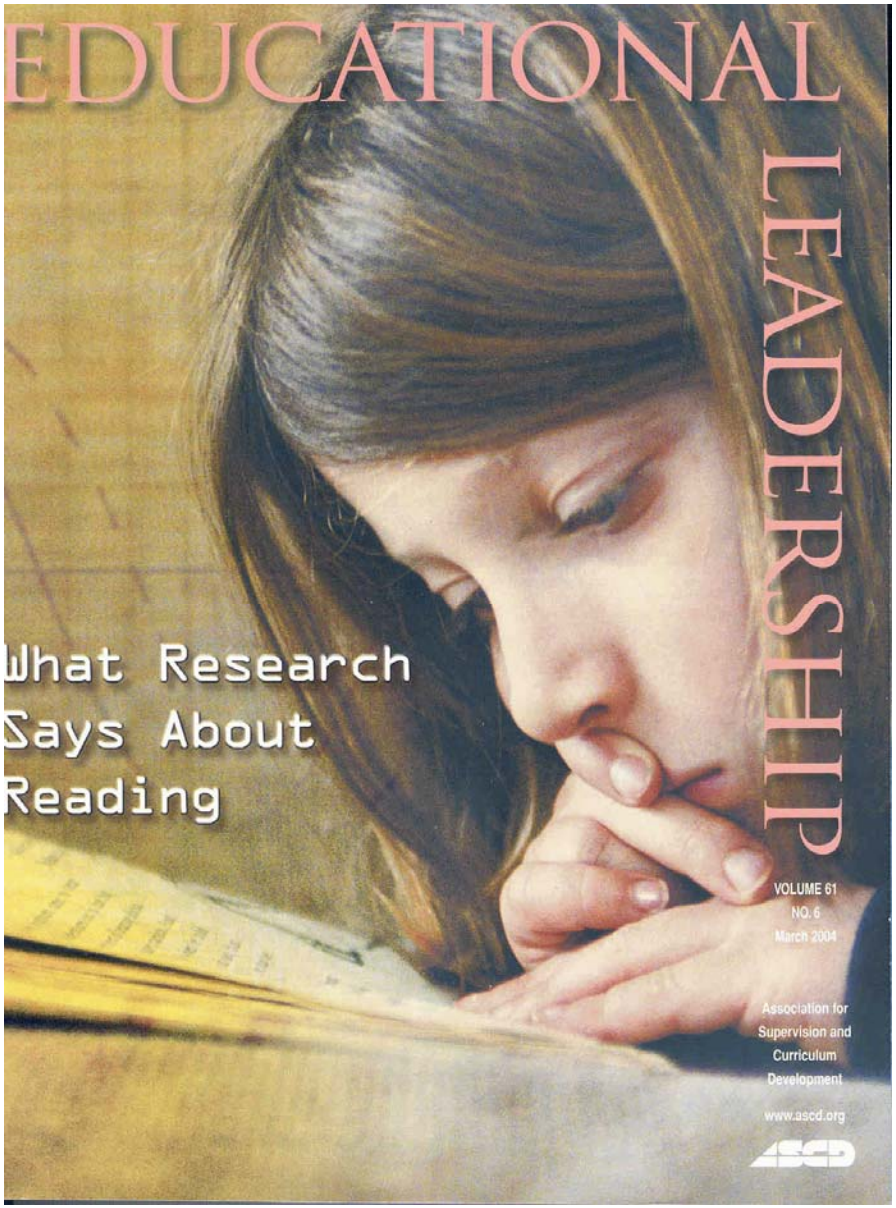

EDUCATIONAL LEADERSHIP

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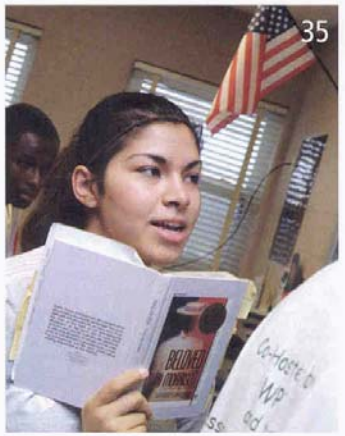
What Research Says About Reading



Consensus: Phonology and reading

"… the specification of the role of phonological processing in the earliest stages of reading acquisition is one of the more notable scientific success stories of the last decade." (Stanovich, 1991, p. 78)

"To my mind, the discovery and documentation of the importance of phonemic awareness … is the single most powerful advance in the science and pedagogy of reading this century." (Adams, 1990).

Phonemic awareness and reading

- Hearing, distinguishing and manipulating the sounds in words (also phonological awareness)
- Claimed to be the chief causal factor in early reading achievement
- Hope: If we train phonemic awareness, children will become better readers (also skills-training, decoding)

Bradley, L. & Bryant, P. (1983) Categorizing sounds and learning to read - a causal connection. *Nature,* 301, 419-421.

Example Tasks

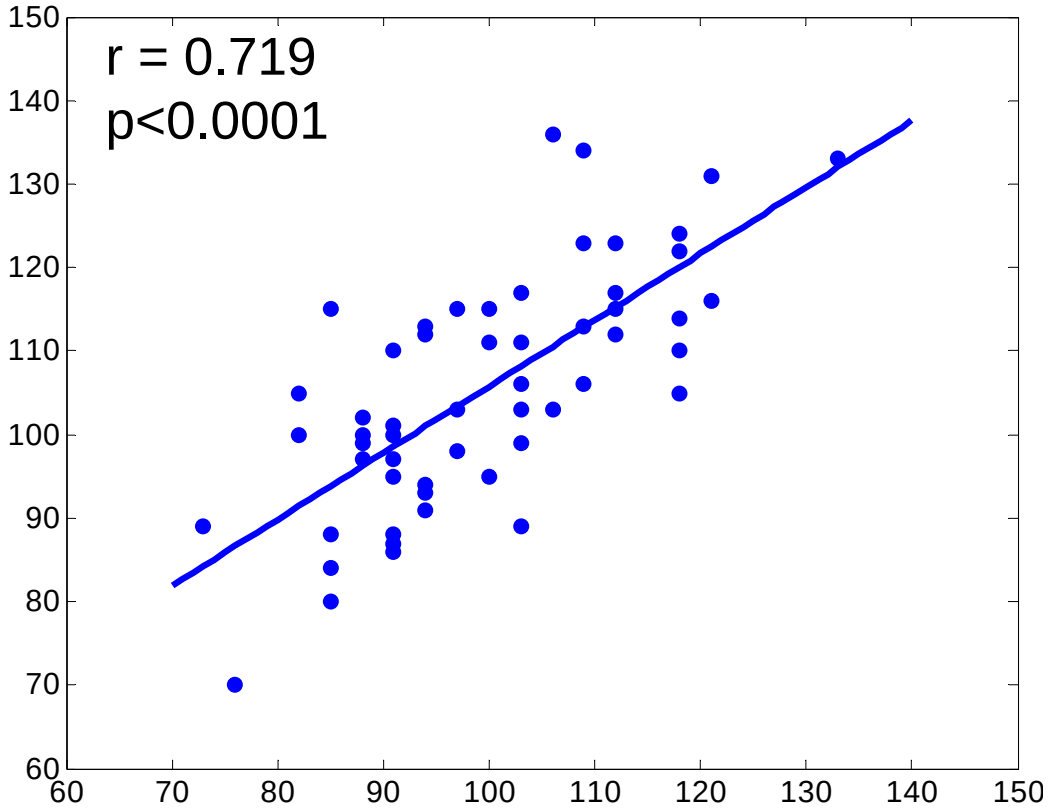
- Deletion: Remove the /r/ from rat. What do you have left?
- Add a /b/ to rat. What do you have?
- Rhyming
- Oddity: bud, bun, bus, rug
- Pronouncing pseudowords (dif, giz, dop, blif)

Word reading correlates with phonological awareness

(Ben-Shachar, Deutsch, Dougherty, Wandell)

Reading (Word ID)

read aloud: '..together,.. enough, ..'



Phonological Awareness (elision, blending)

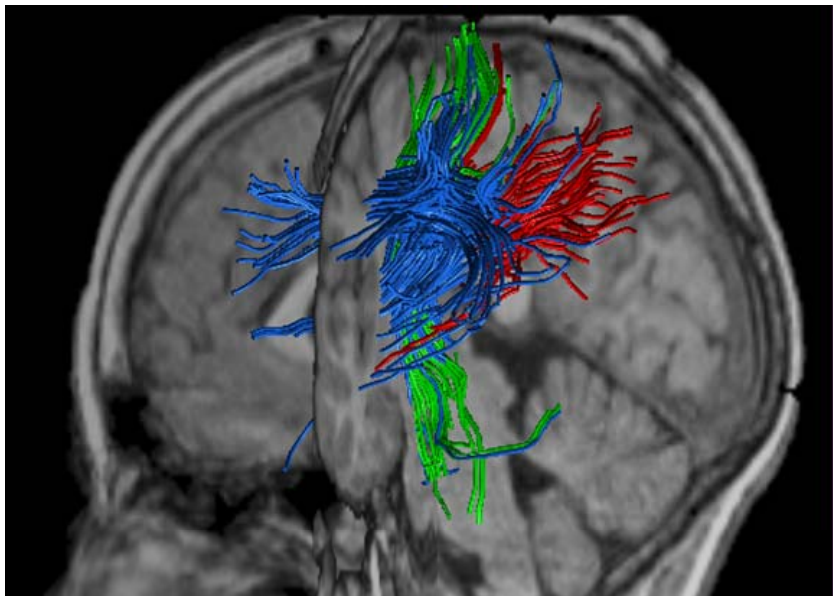
elision (strain-/r/ = stain)

blending (/t/+/oi/ = toy)

Neural Basis of Reading

- Most variance explained by social factors and general cognitive ability
- Significant variance remains...
  - What are the specific neurological factors?
- Identify biological correlates
  - Explain individual differences
  - Predict & intervene before reading failure

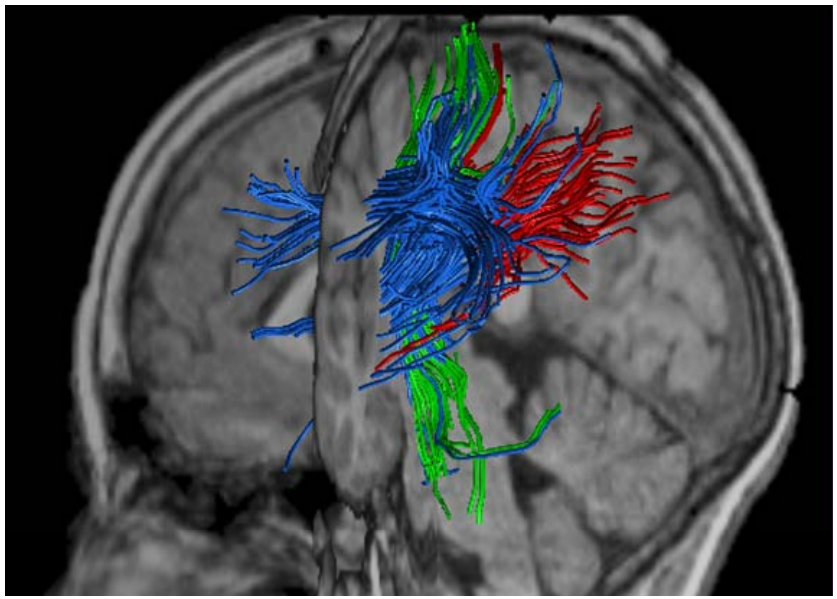
LR, 11yrs old



Specific Reading Pathways

- Magnocellular hypothesis
- Temporo-parietal junction
- OTS - fMRI
- Diffusion Tensor Imaging

LR, 11yrs old

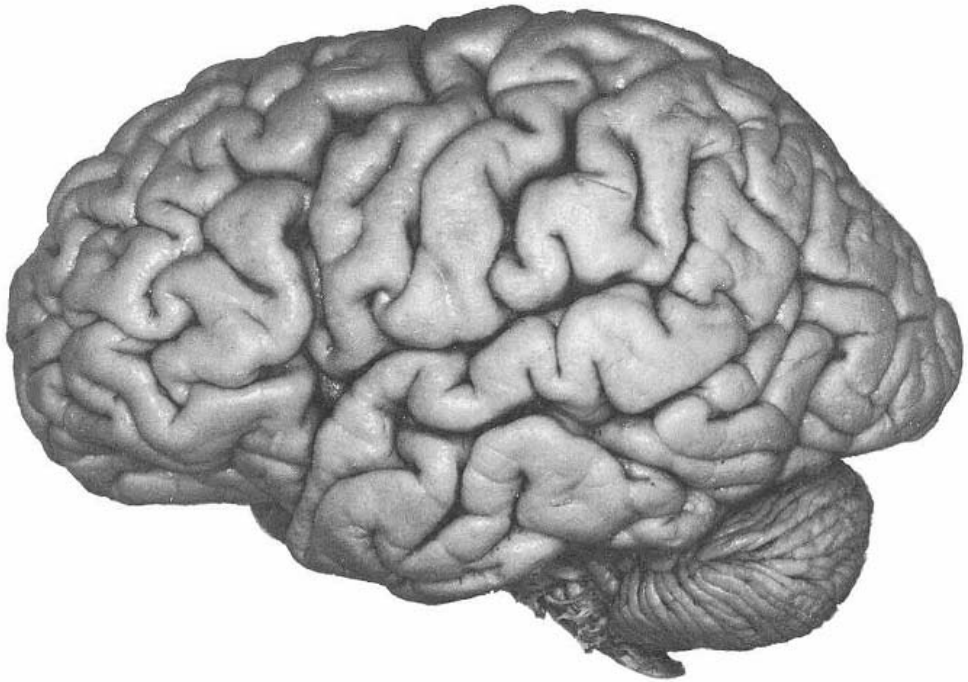


Lightness Perception
(Lotto and Purves)

The Astonishing Hypothesis

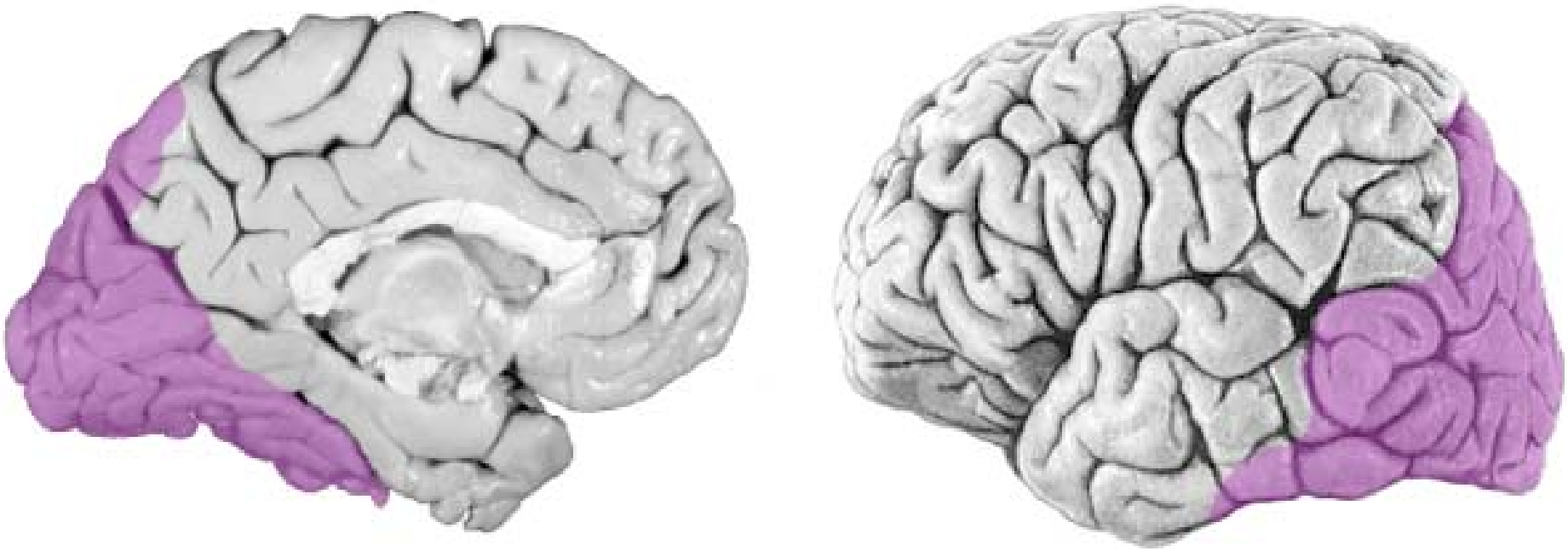
(Francis Crick; Braitenberg and Schutz, 1991)

Neurons are the computational elements
White matter connects the neurons via axons
The connection is called the synapse



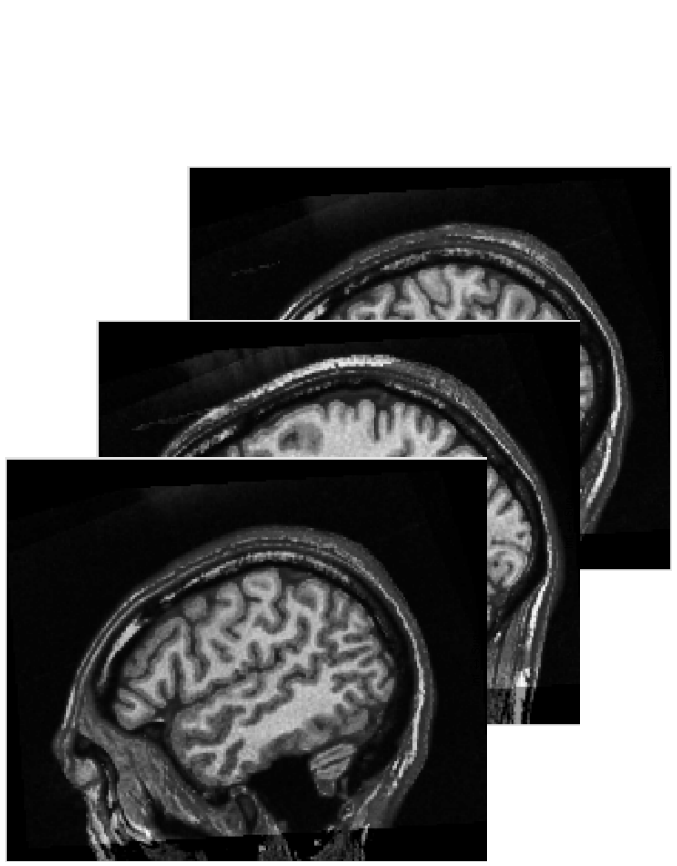
- Neurons: 10^{11}
- Synapses: 10^{14}
- Synapses/neuron 10^{3}
- Surface area of each hemisphere: 25 x 30 cm^2
- Most connections are local (10-100 um); some span many cm
- Neurons/mm^3: 10^{4}-10^{6}
- Axon length/mm^3: 3 km

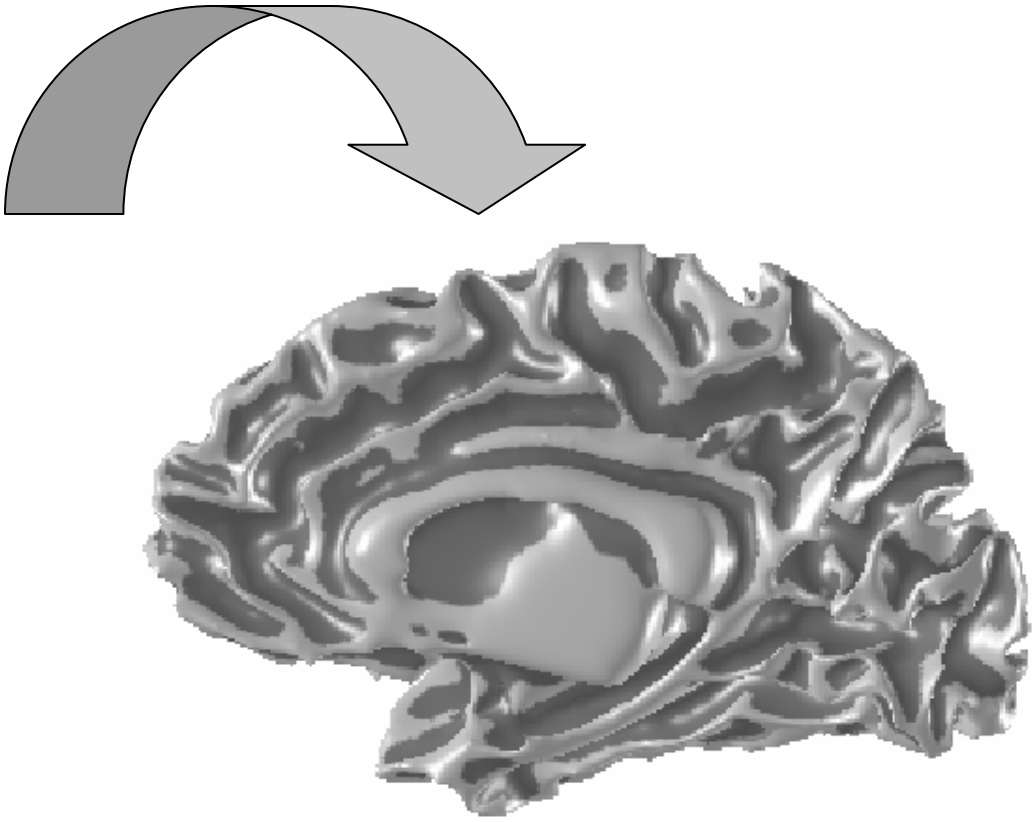
Visual cortex is about 20% of human neo-cortex



FMRI Instrumentation

Gray/white surface boundary





Brain inflation

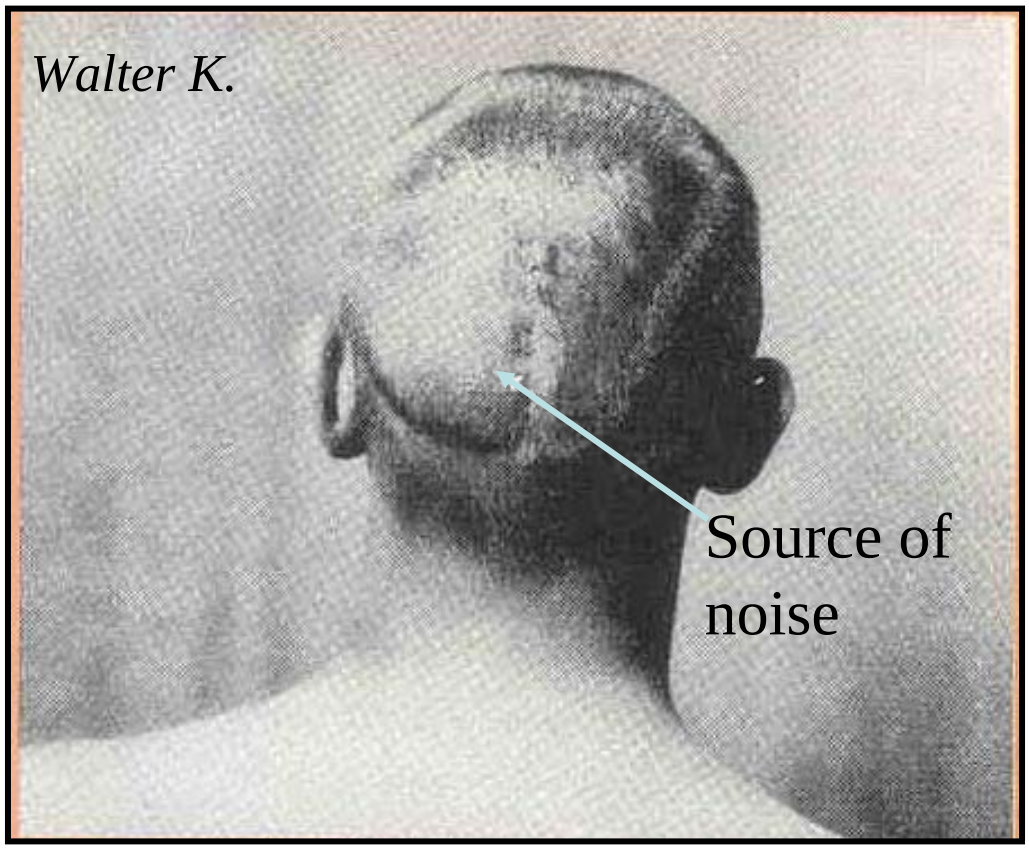
There Is An Increase In Oxygenated Blood Flow To Active Regions of Cortex

J.F. Fulton, M.D. (1928)

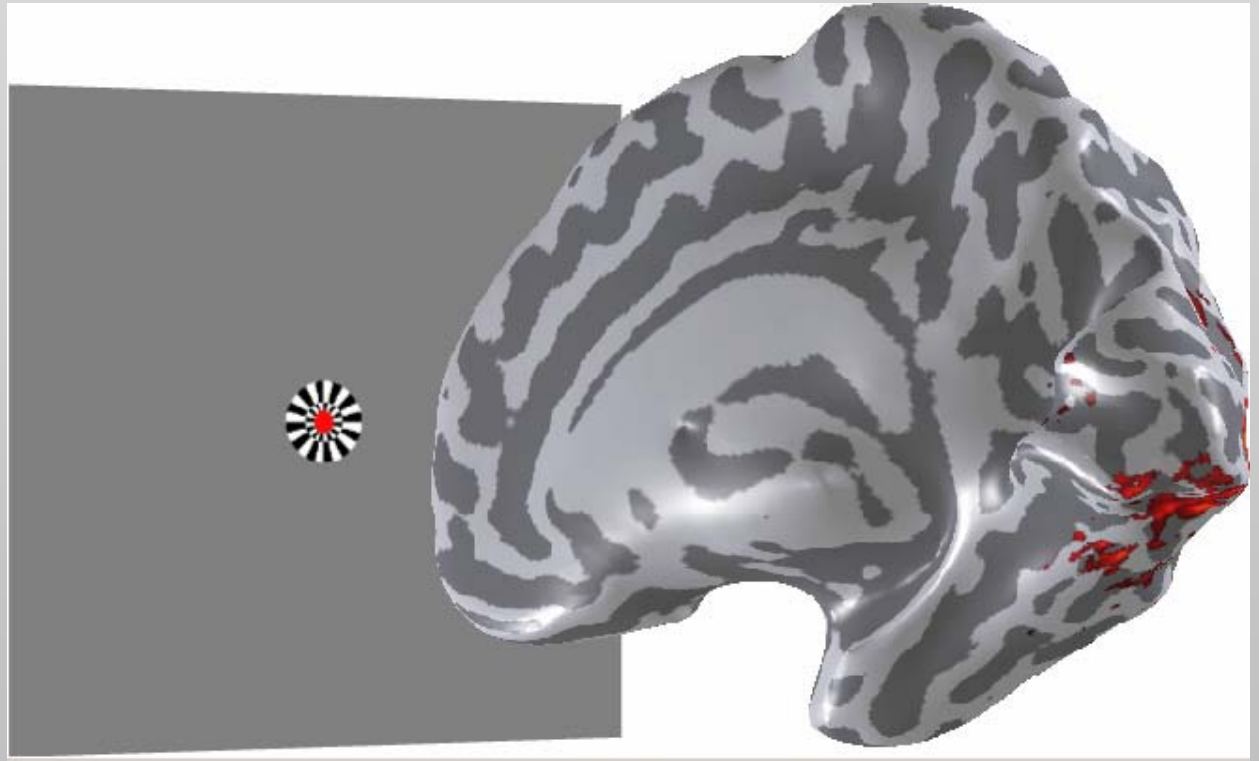
Operation

On turning down a left occipital bone flap,a large angry-looking angioma arteriale racemosum of the left occ. Lobe was disclosed which extensively involved the visual cortex. The haemorrhage occasioned by the bone flap was so excessive that the operation had to be abandoned without touching the tumour. A decompression, however, was made. The patient was discharged … with greatly improved vision.

- *Subject noted that "the noise in the back of his head increased in intensity when he was using his eyes."*
- *No increase for hearing, touch or smell*
- *Increased more when he tried harder*

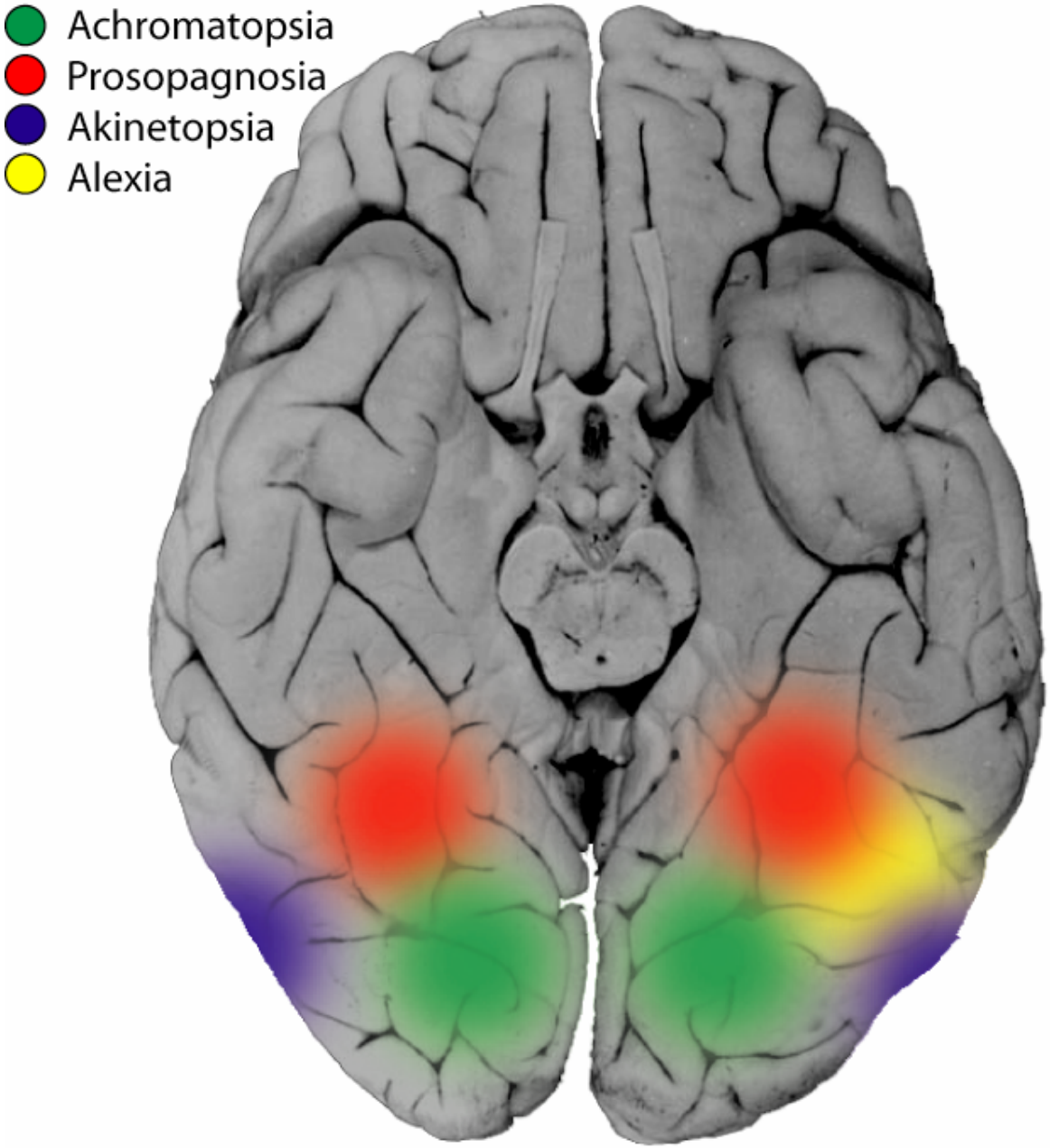


Using magnetic resonance imaging, we can measure responses in human visual cortex



eccentricity-map-encyclopedia

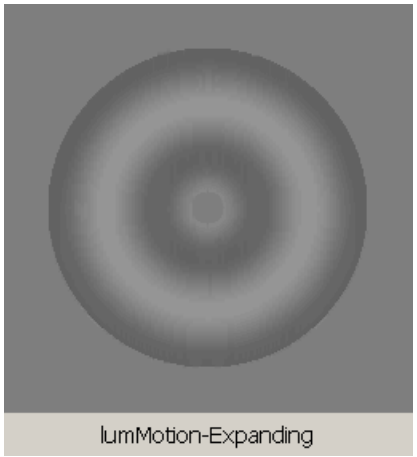
Localized cortical damage produces very specific visual dysfunctio n

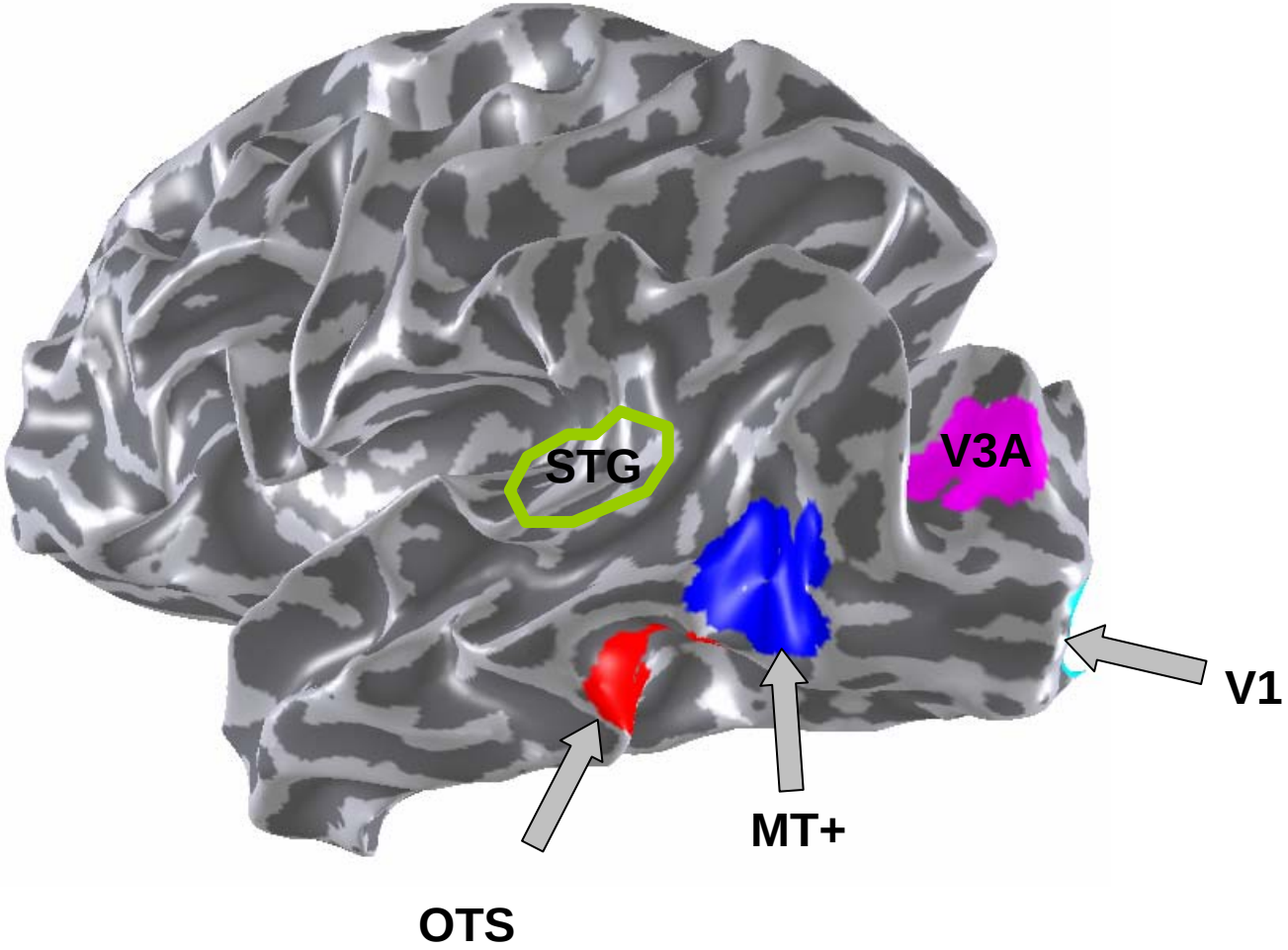


Face-blindness

prosopagnosia

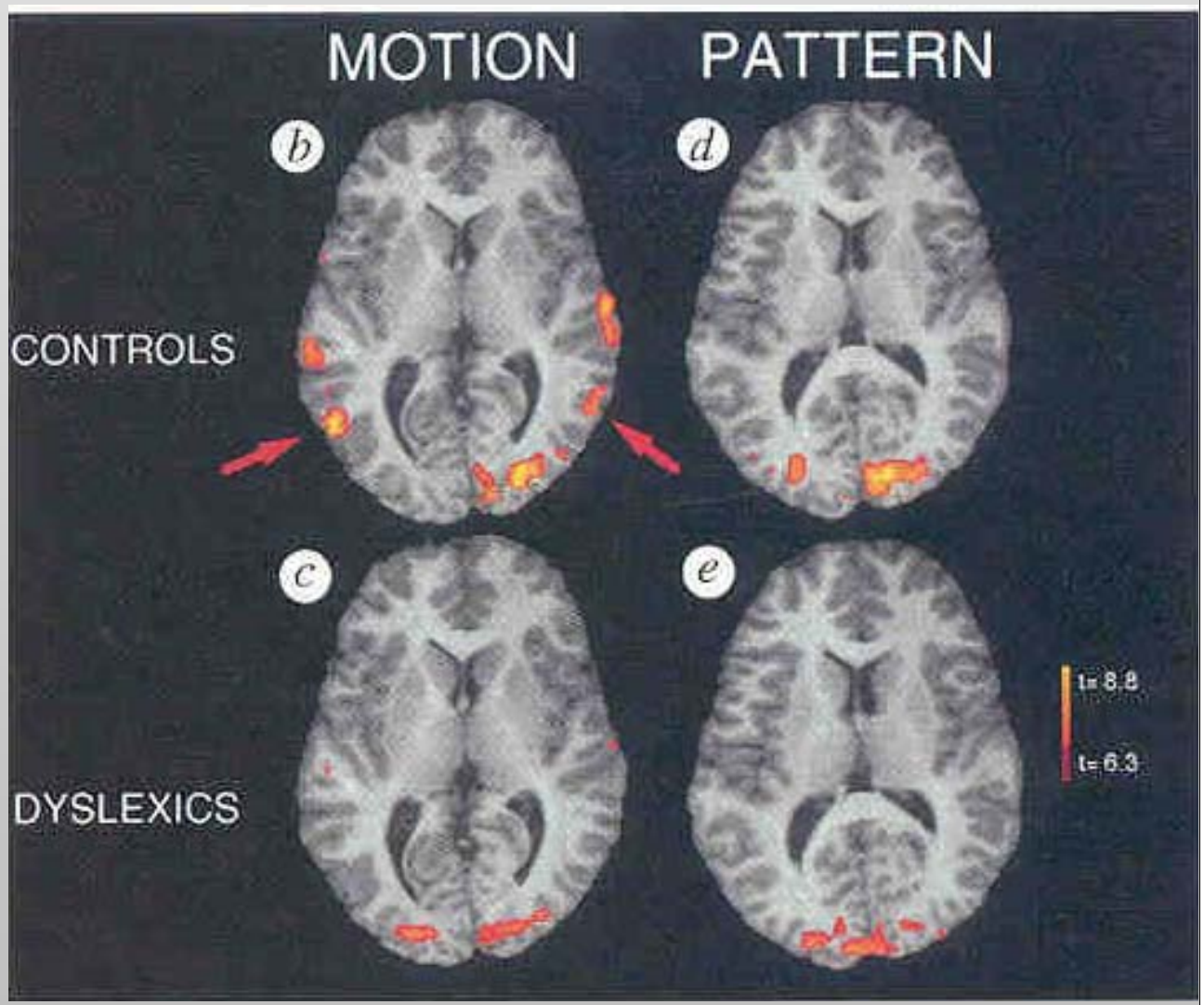
Motion responses in childrens' MT+





MT+ activation reduced in poor readers (Eden et al.)

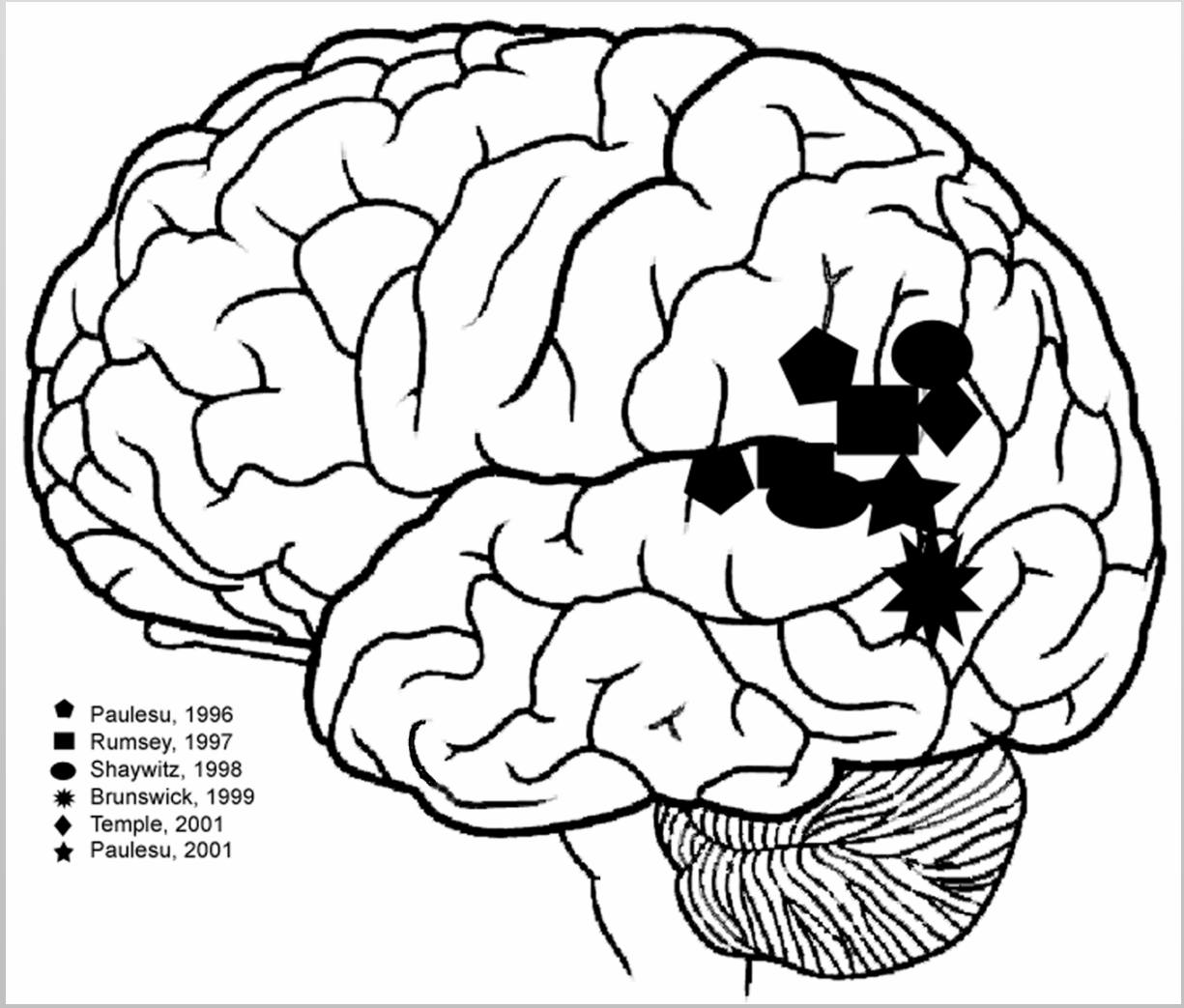
Replicated by Demb et al., Ben-Shachar et al.



Response differences during phonological tasks

Temple, 2001, CONB

Locations where dyslexics had decreased activity relative to normal readers during phonological processing.

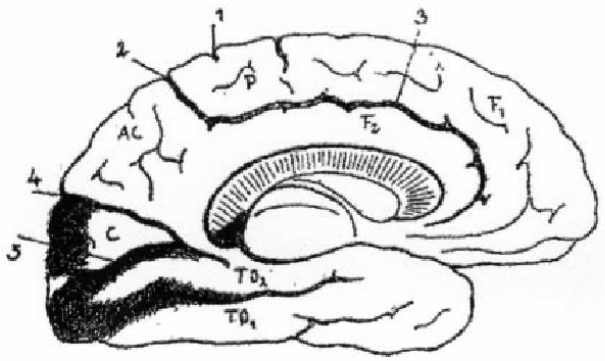


Neurology of word reading

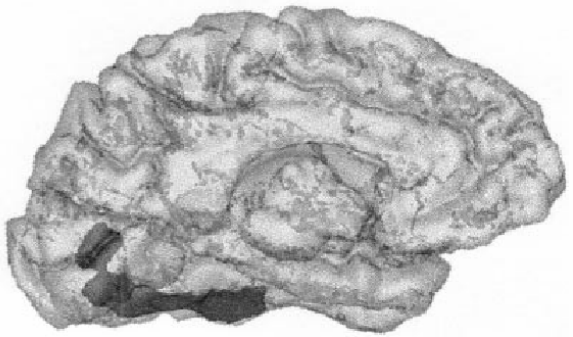
(Cohen et al, 2003; Cerebral Cortex)

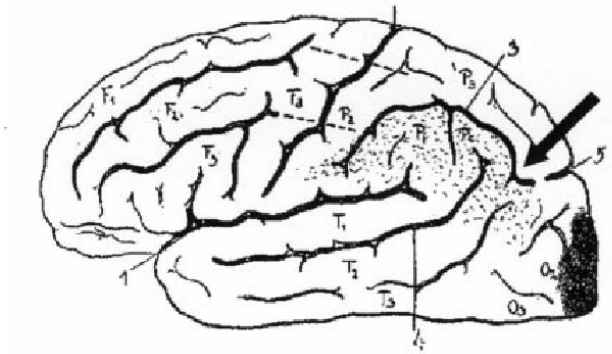
- *Dejerine described a patient with a left occipito-temporal lesion who could see, but not process letters and words*

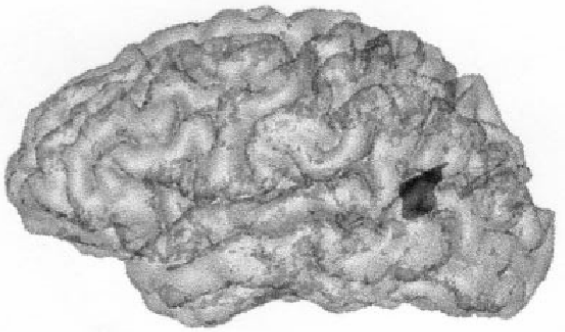
- *Callosal patients have a visual field loss of reading*



Letters vs. Checkerboards





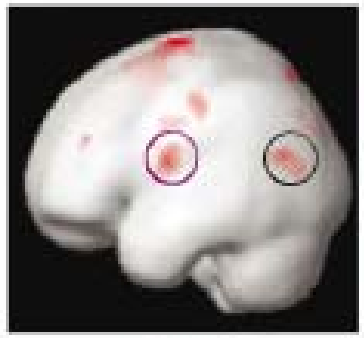


Remediation results are plagued with several weak results

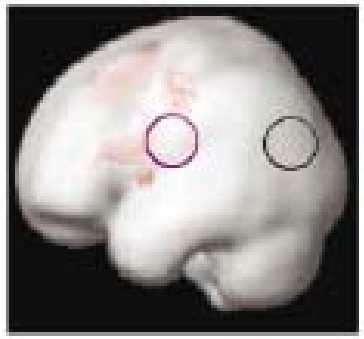
(Temple et al., PNAS, 2003; see also Shaywitz papers in PNAS and Biological Psychiatry)

Do ‘T’ and ‘D’ rhyme?
vs.
Are ‘P’ and ‘P’ the same?

Normal readers:
rhyming vs. identity



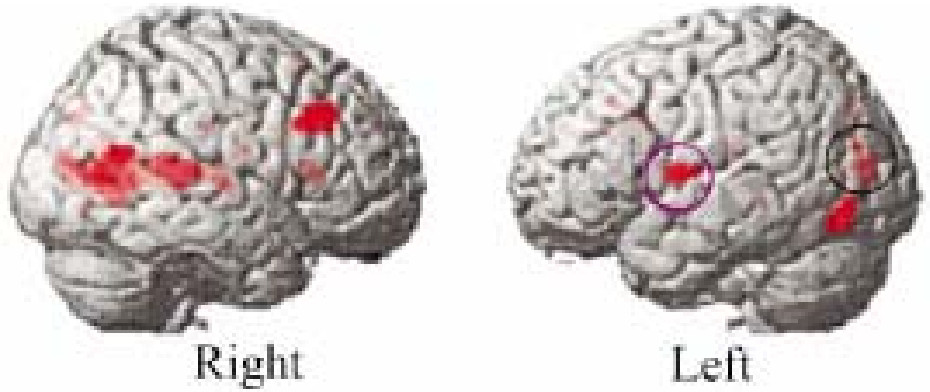
Poor readers:
rhyming vs. identity



Remediation results are plagued with several weak results

Do ‘T’ and ‘D’ rhyme?
vs.
Are ‘P’ and ‘P’ the same?

Poor readers increases after remediation



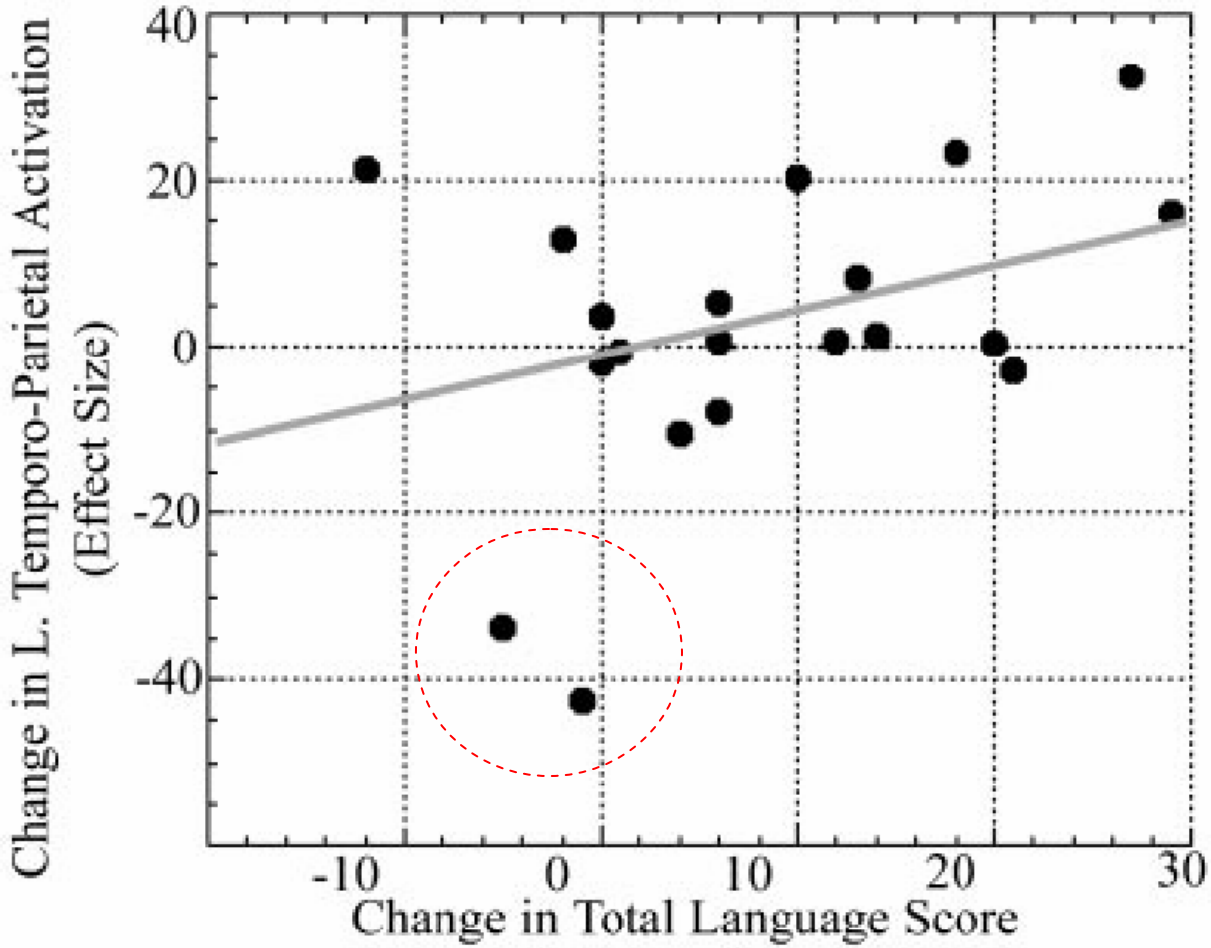
(Temple et al., PNAS, 2003; see also Shaywitz papers in PNAS and Biological Psychiatry)

Remediation results: FMRI signal size and language score

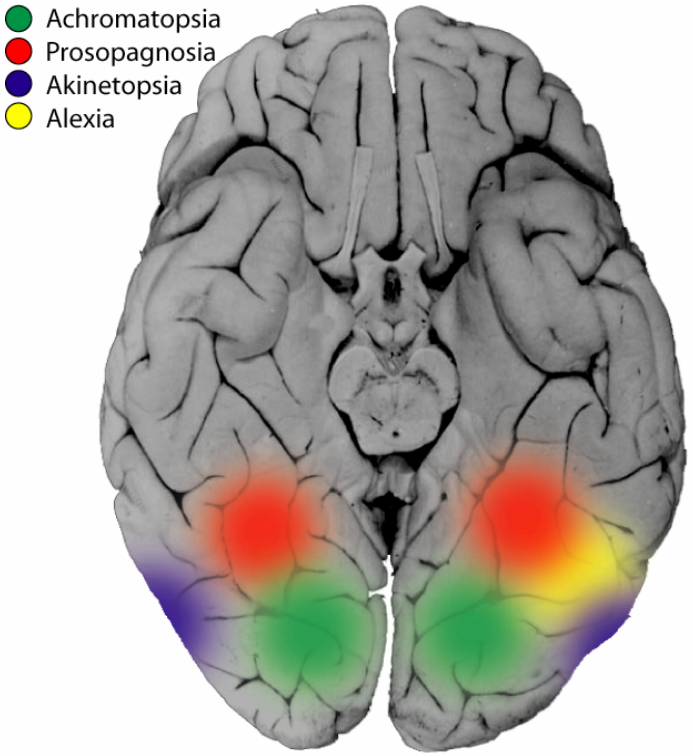
- *Removing the outliers, the correlation coefficient becomes non-significant.*

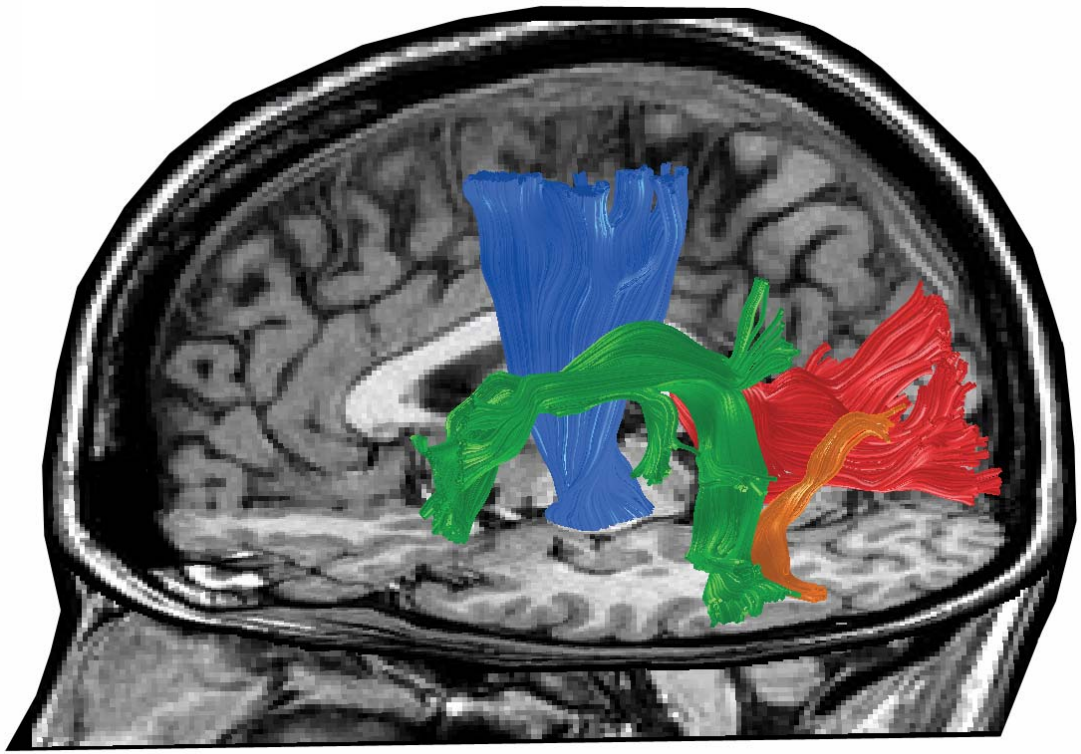
- *Removing two random points, the correlation remains significant*

Figure 2. Temple et al. (2003) PNAS

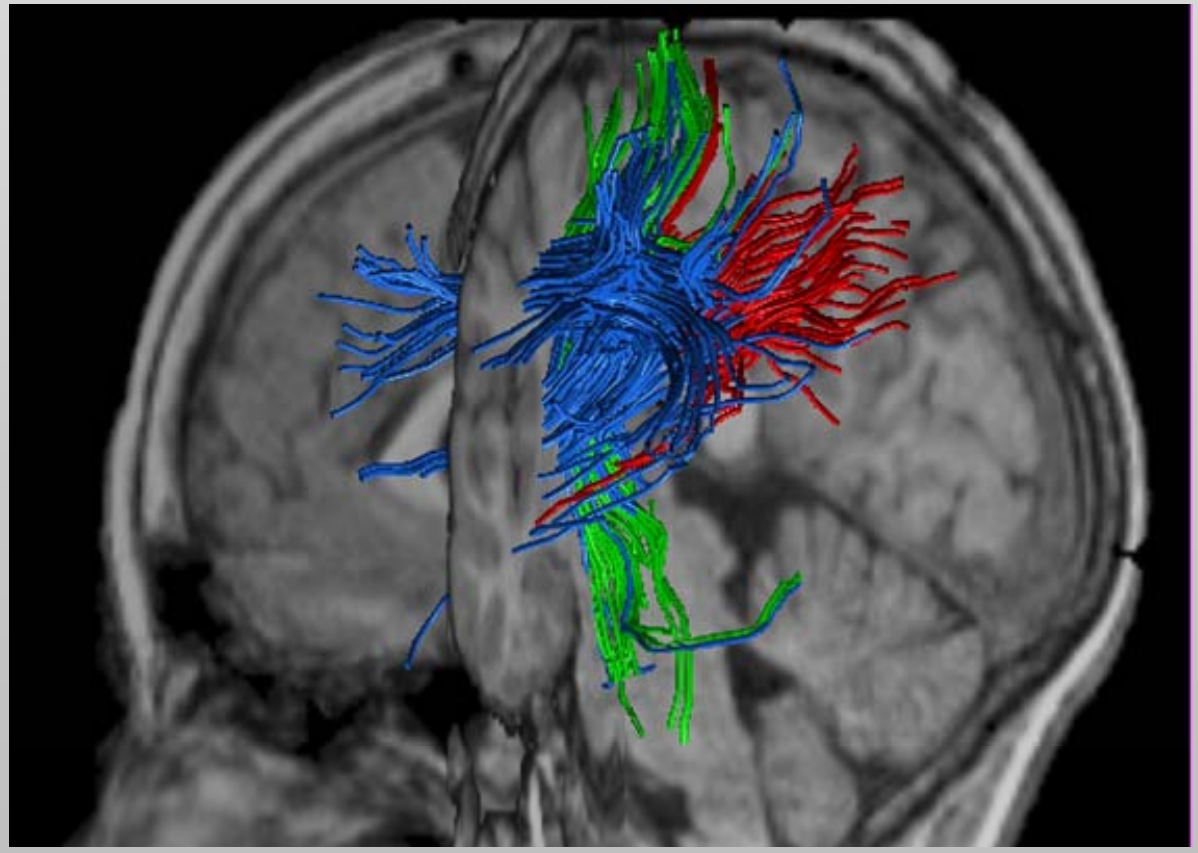


Tracking the entire network of signals

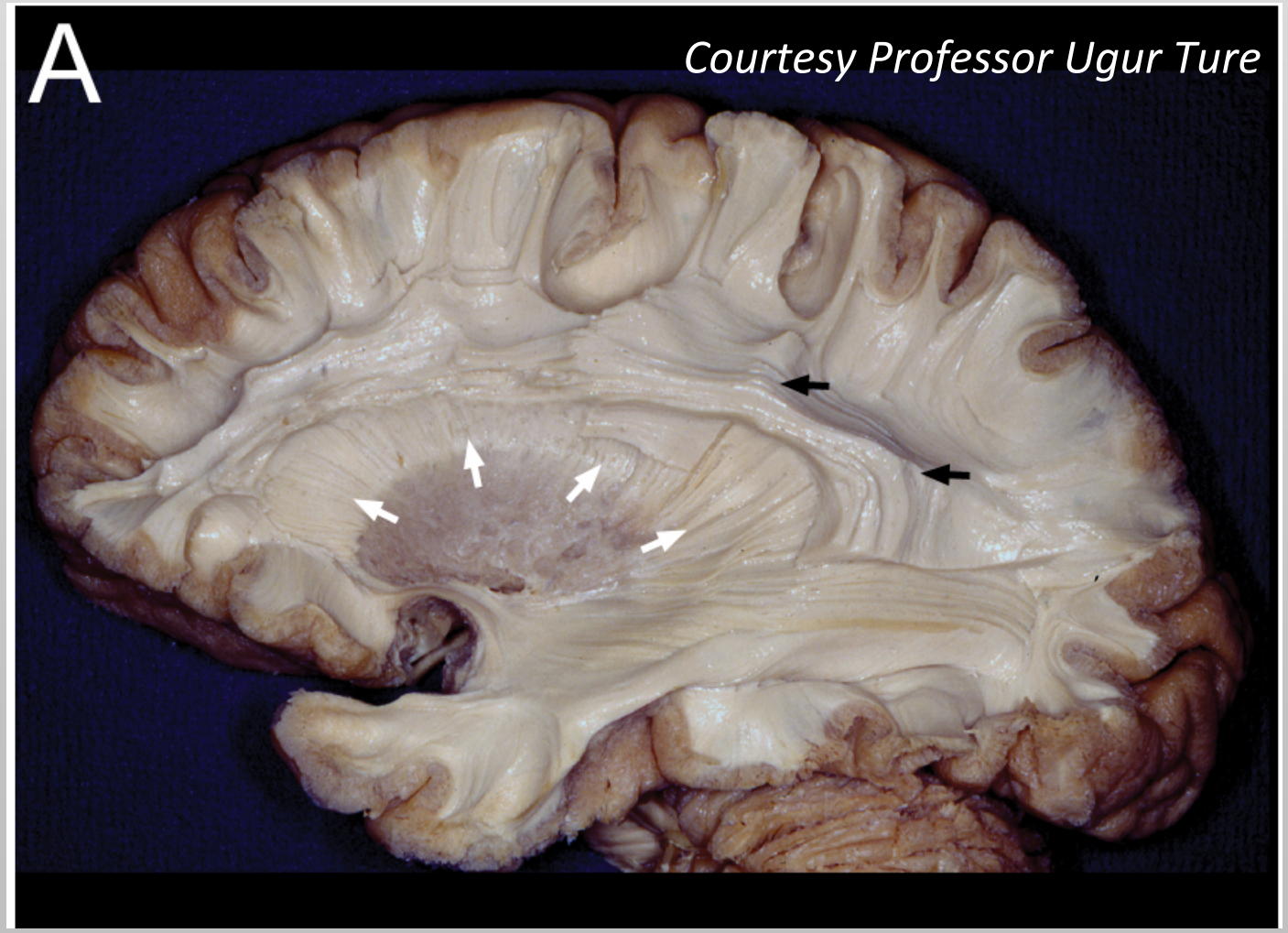




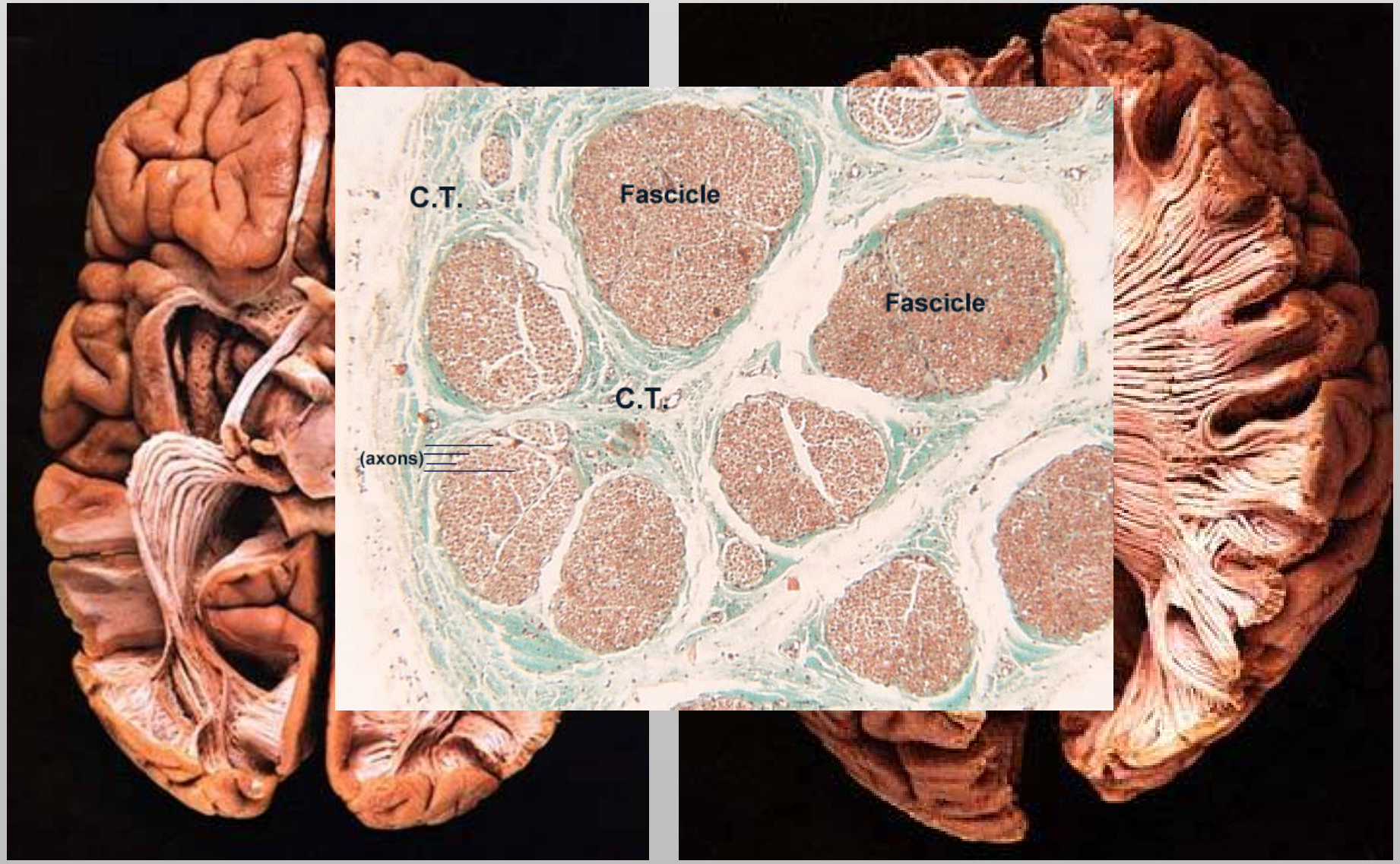
A New Structural Imaging Method: Diffusion Tensor Imaging



Human fiber tracts



Human fiber tracts

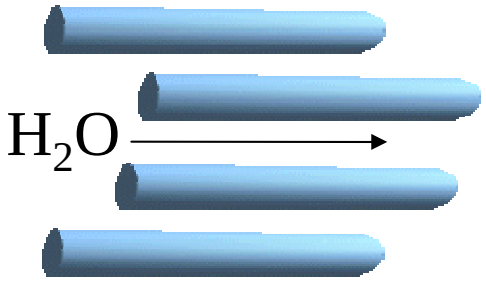


From: The Virtual Hospital (www.vh.org); TH Williams, N Gluhbegovic, JY Jew

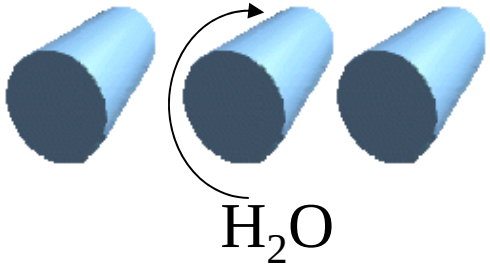
H_2O Diffusion Probes Microscopic Structures In the Brain

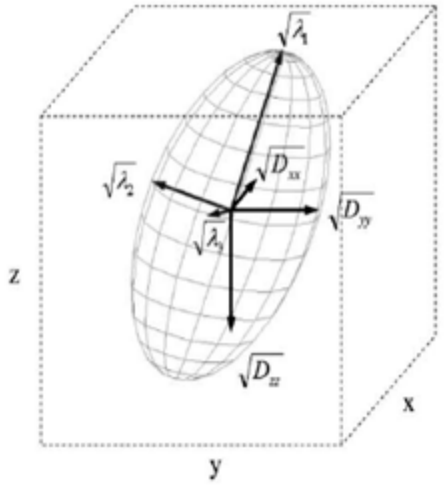
Unimpeded direction- large ADC

White matter fibres



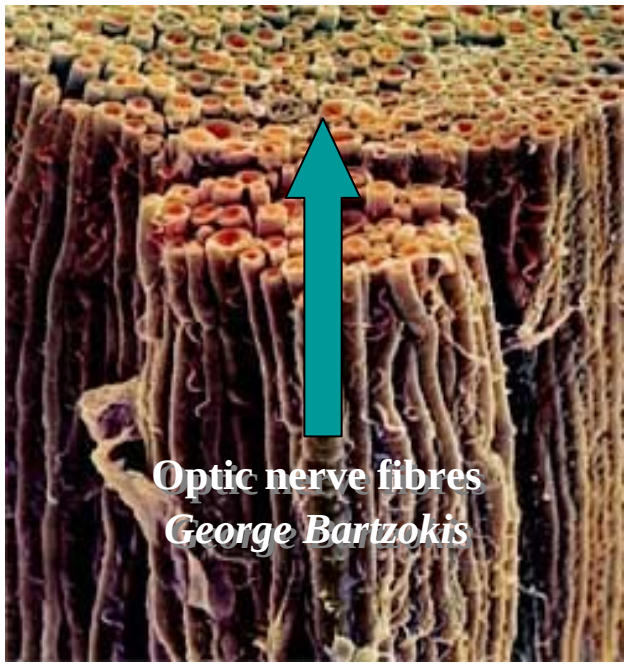
Impeded direction- smaller ADC

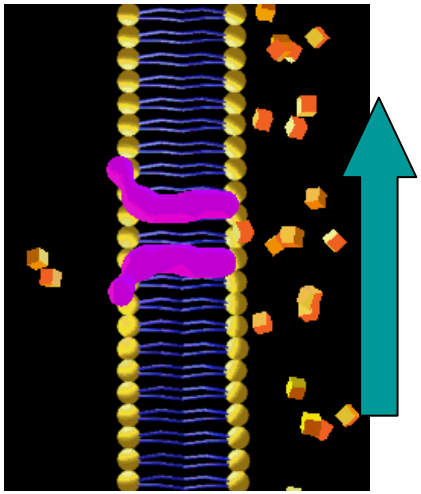




Principal axis is usually aligned with a fibre bundle; Apparent Diffusion Coefficients (ADCs) are measured in at least 6 directions

H_2O diffusion probes membrane properties in the brain

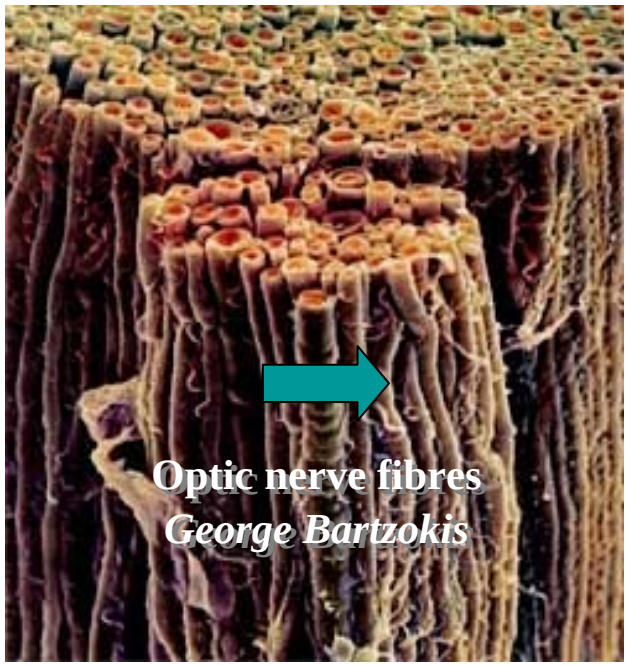


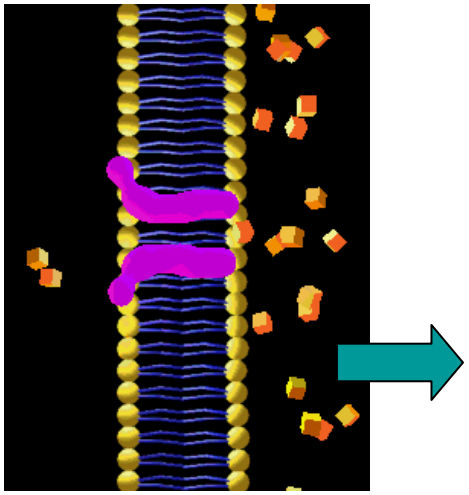


Axial diffusivity

In regions of high axial coherence, the cytoplasm within the axon limits diffusion and there is a large Apparent Diffusion Coefficient (ADC)

H_2O diffusion probes membrane properties in the brain





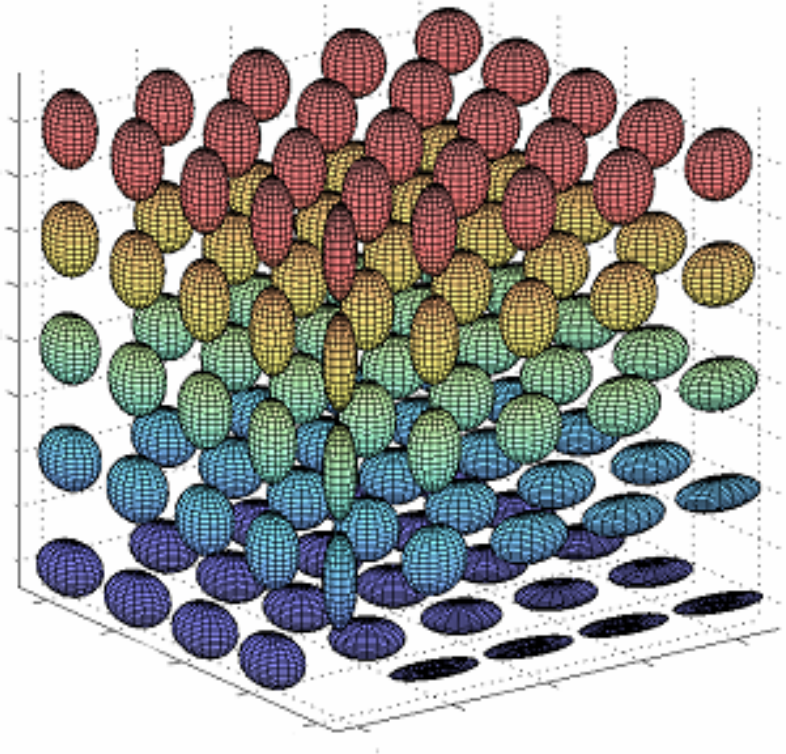
Radial diffusivity

In all other directions the bi-lipid cell membranes and myelin limit diffusion; perpendicular to the axon the ADC is smaller

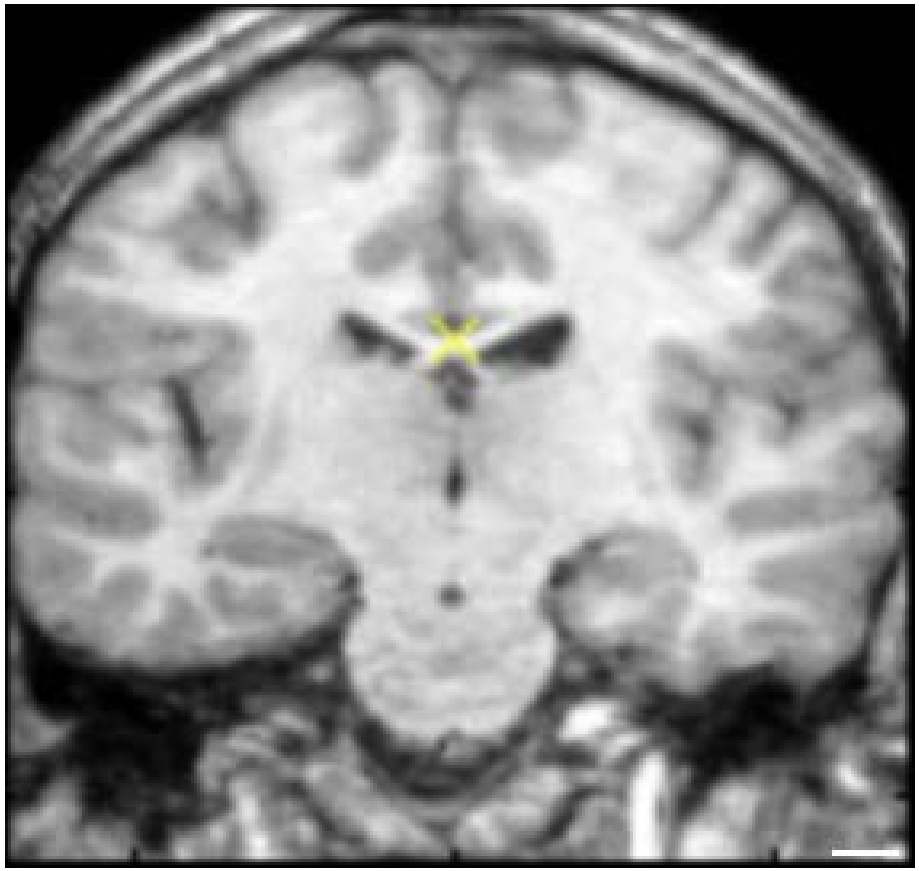
DTI Data Sets Are Volumes of Diffusion Surfaces

Conventional MR volumes are real-valued

DTI data are surfaces



DTI Reveals Differences In White Matter Structure



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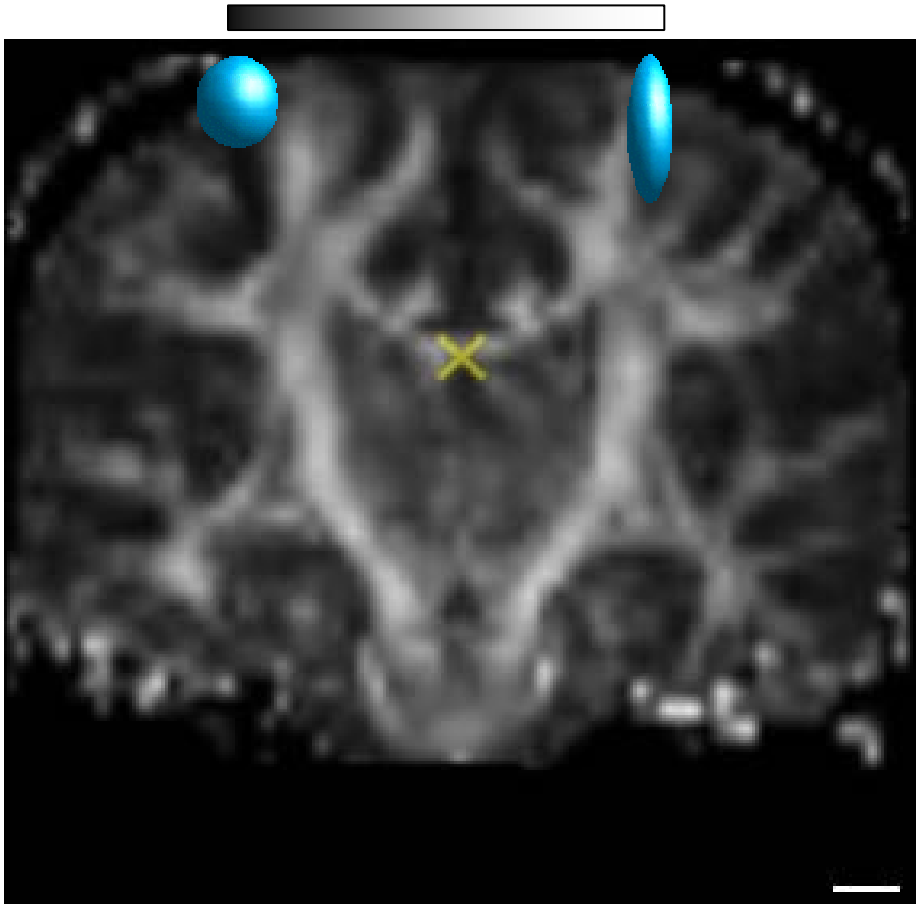
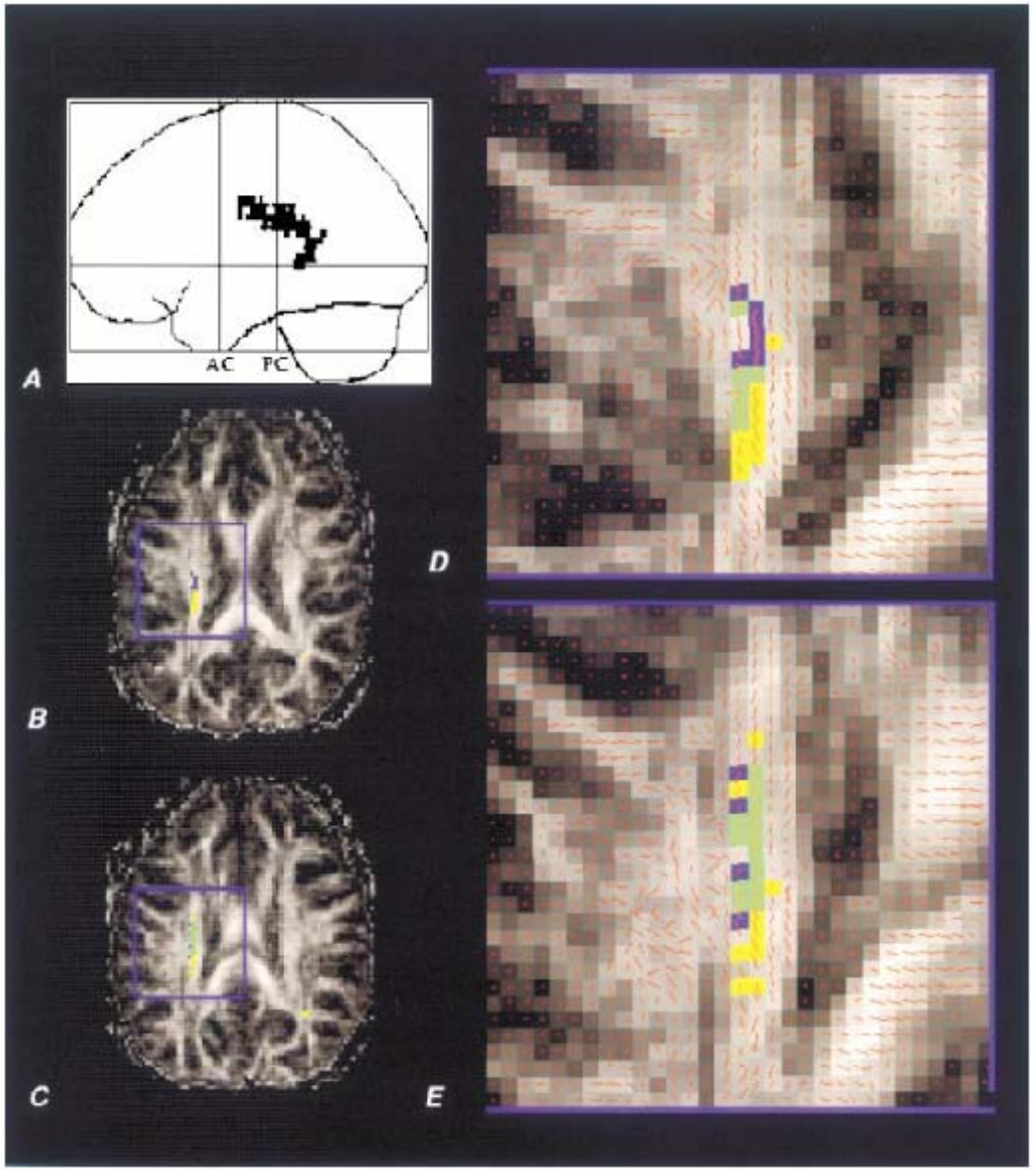


DTI: Fractional Anisotropy

In adults correlations exist between reading performance and FA

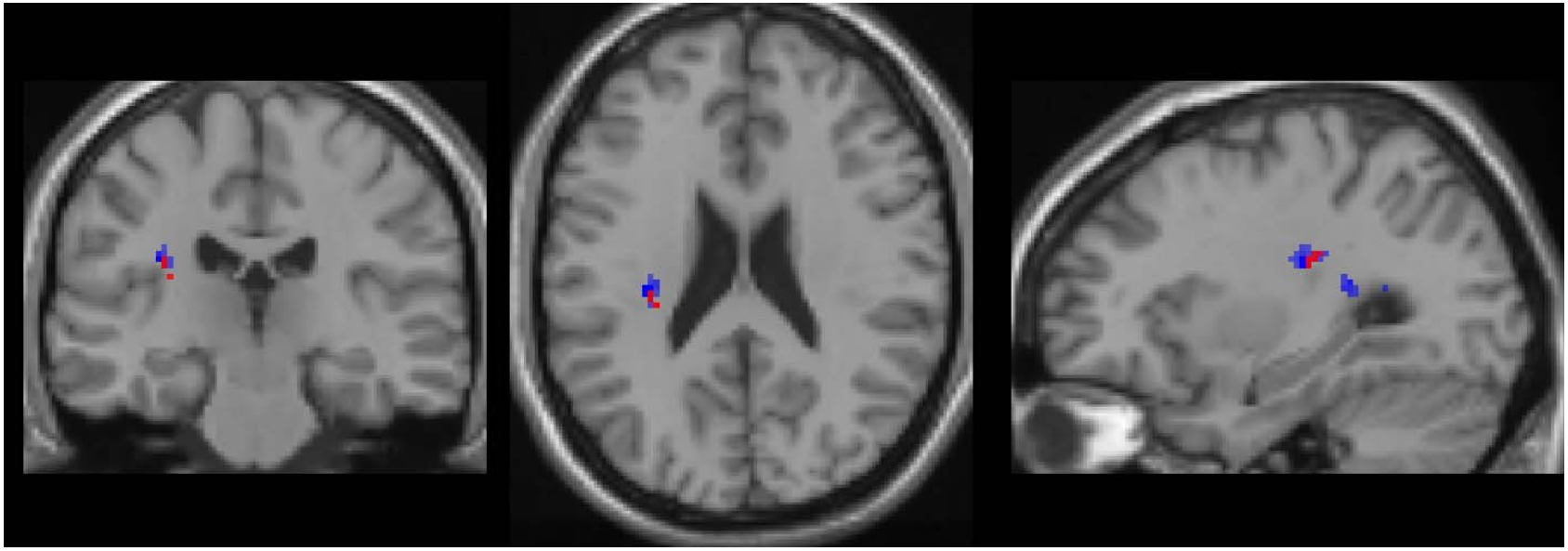
(Klingberg et al., 2000)



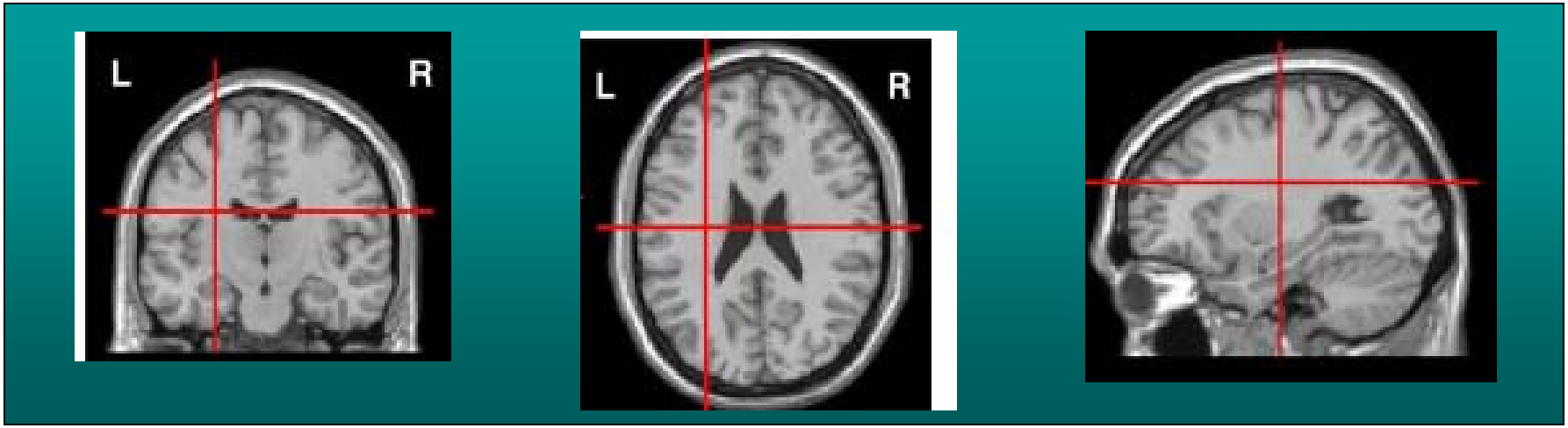
For the gray scale, lighter colors represent higher anisotropy. Green indicates voxels significant in both the between group analysis and the Word ID correlation analysis; yellow indicates voxels significant only in the between-group analysis;and blue indicates voxels significant only in the correlation analysis.

FA correlates with reading skill in children, too

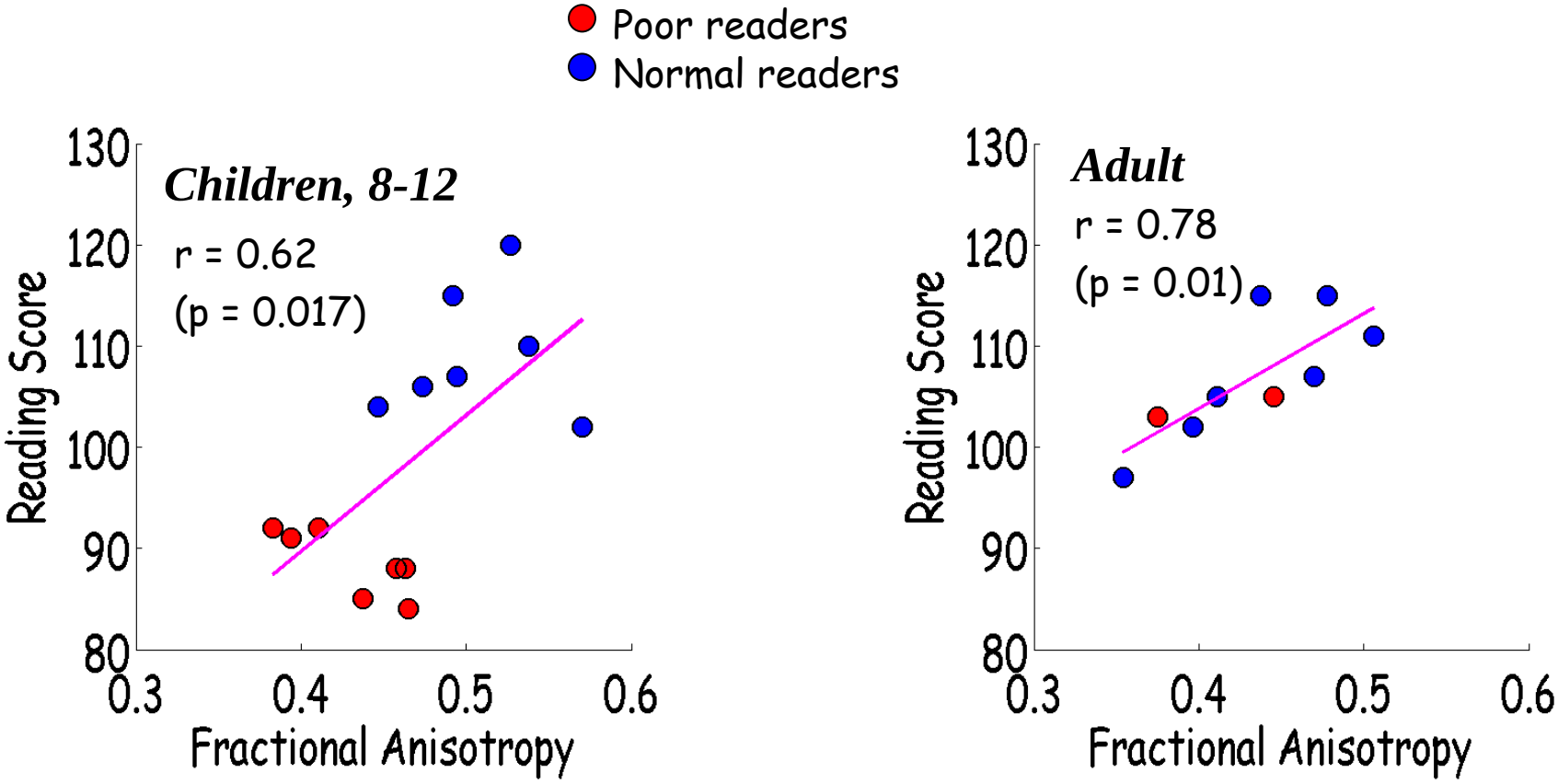
Deutsch, Dougherty, Bammer, Siok, Gabrieli, Wandell (2005)



Beaulieu C, Plewes C, Paulson LA, Roy D, Snook L, Concha L, Phillips L. (2005).

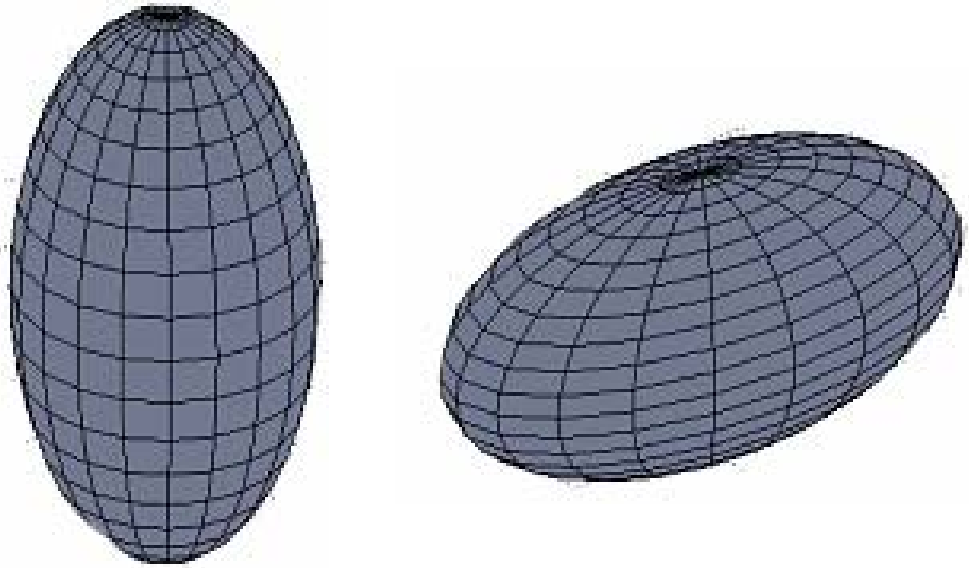


This correlation is present in children and adults



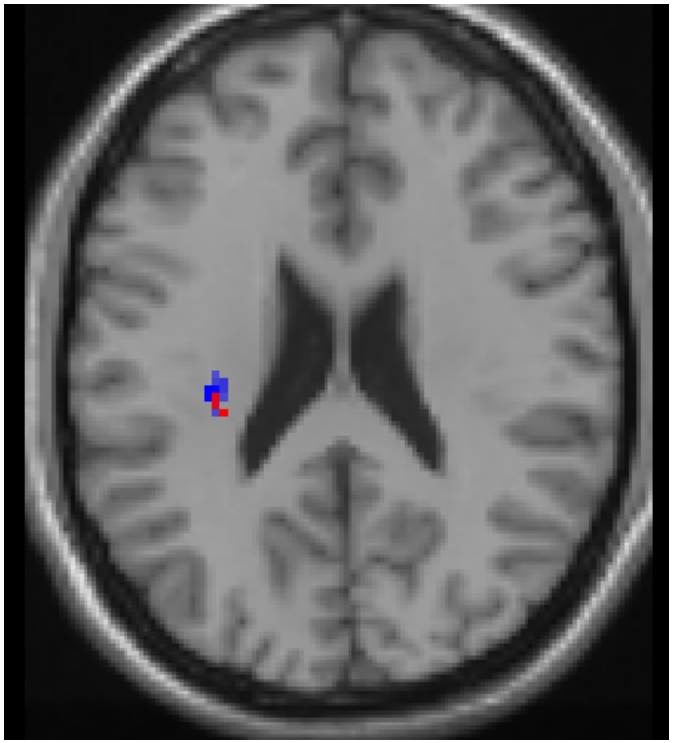
FA does not discriminate between ellipsoid orientations: What more can we learn from the principal diffusion direction?

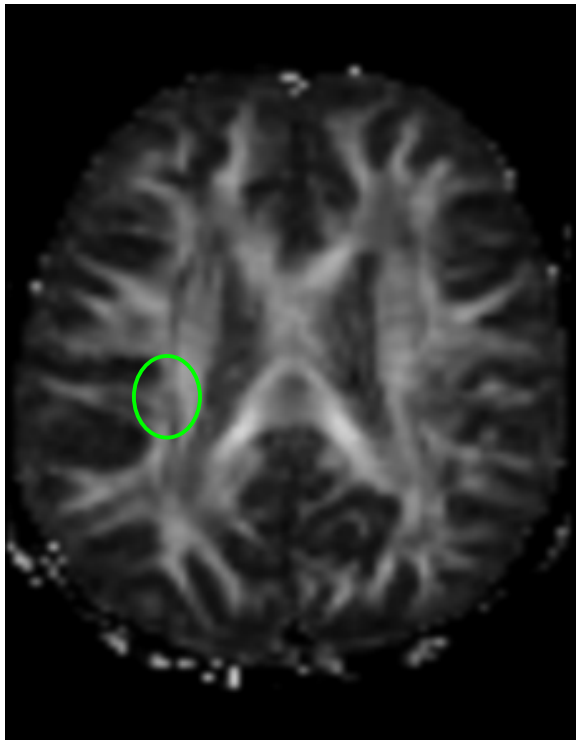
FA = 0.6
Principal diffusion directions differ

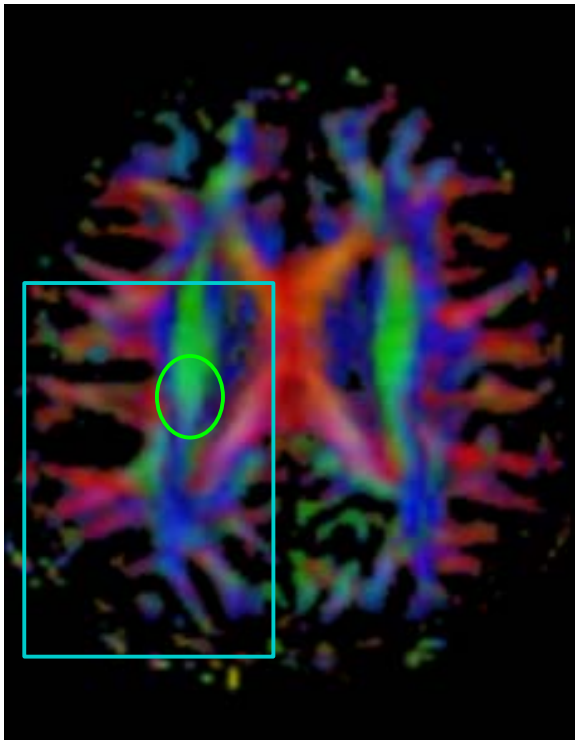


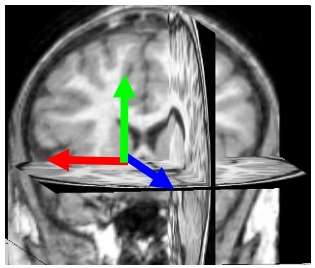
Using direction we see much more

Account for Directional Data Requires New Statistical Methods





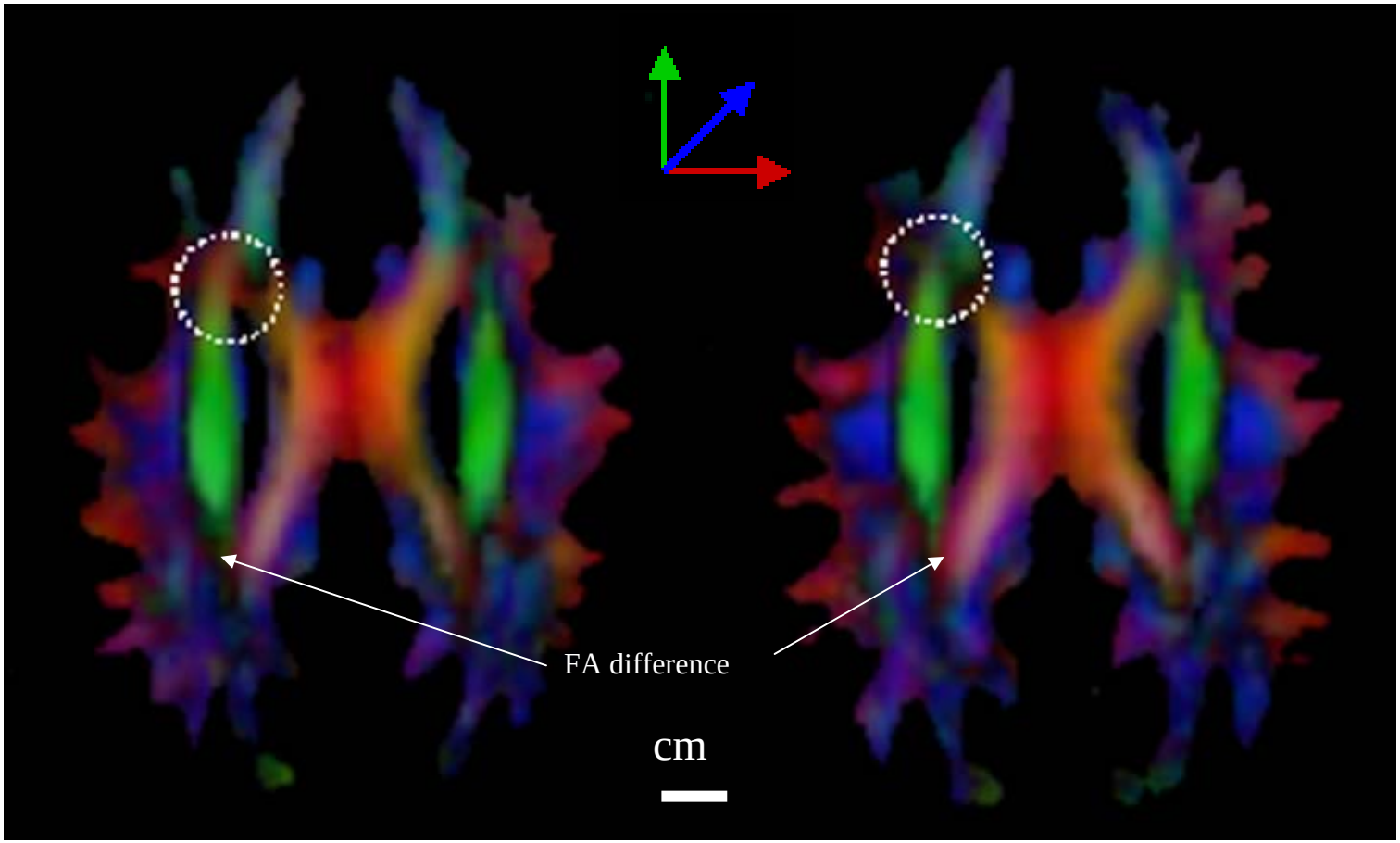




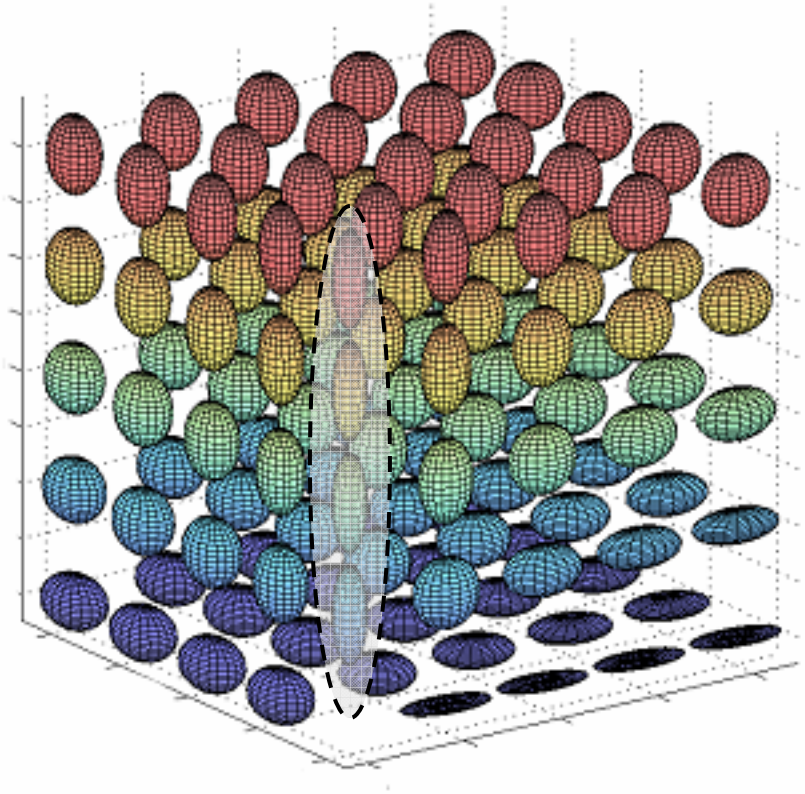
There is a directional difference in anterior cortex (N=14)

(Schwartzmann, Dougherty, Taylor, 2005, MRM)

Good Readers *Poor Readers*



Can we understand these data by analyzing fiber tracts (DTI-FT)?



Many interesting algorithm issues

– Algorithm thresholds (direction, FA)

– Confidence intervals, probabilistic reasoning

– Spatial sampling

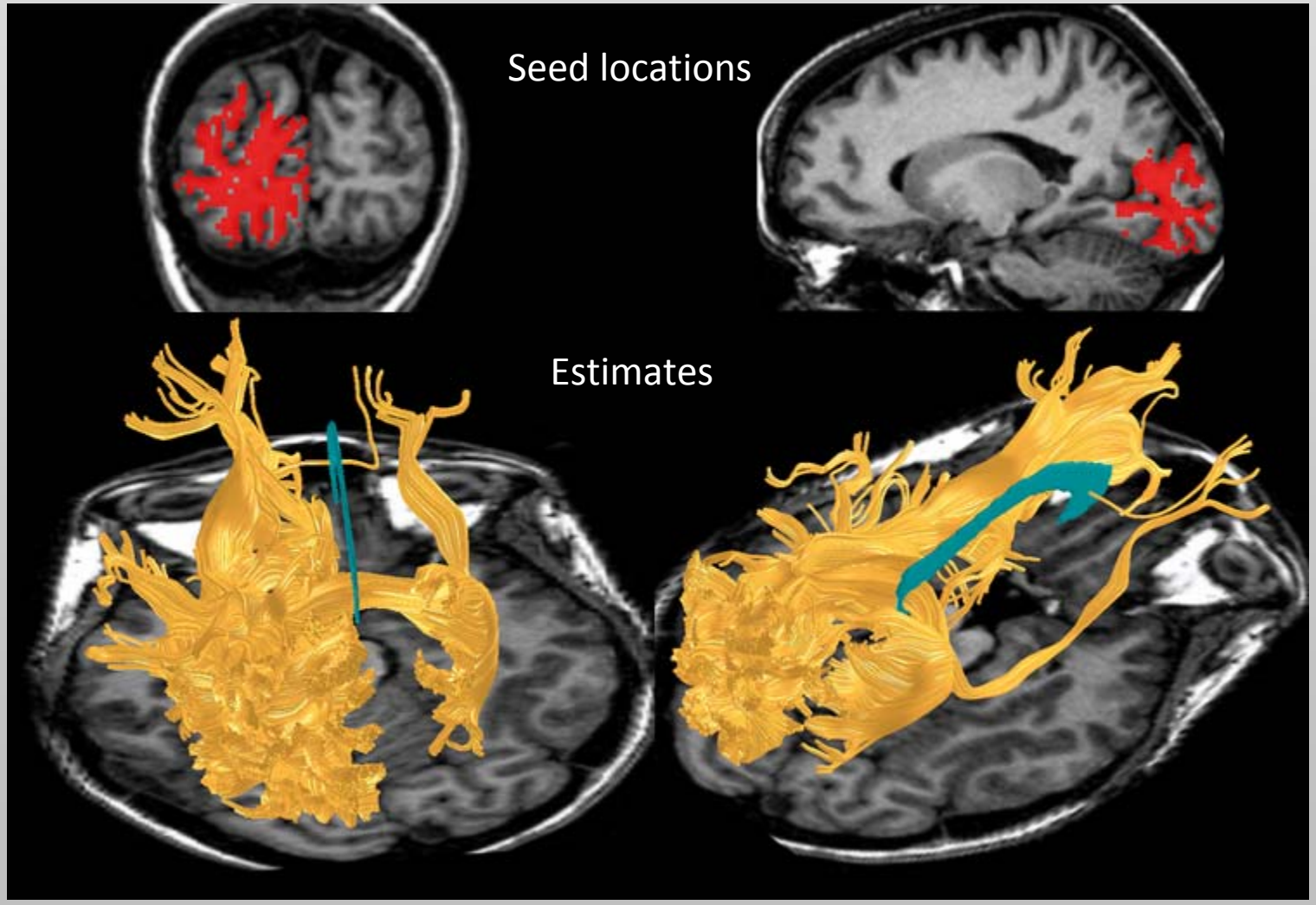
- Samples are sparse, but directions are fine
- Interpolation to intermediate positions

– Spatial co-registration between modalities (T1, fMRI) and subjects

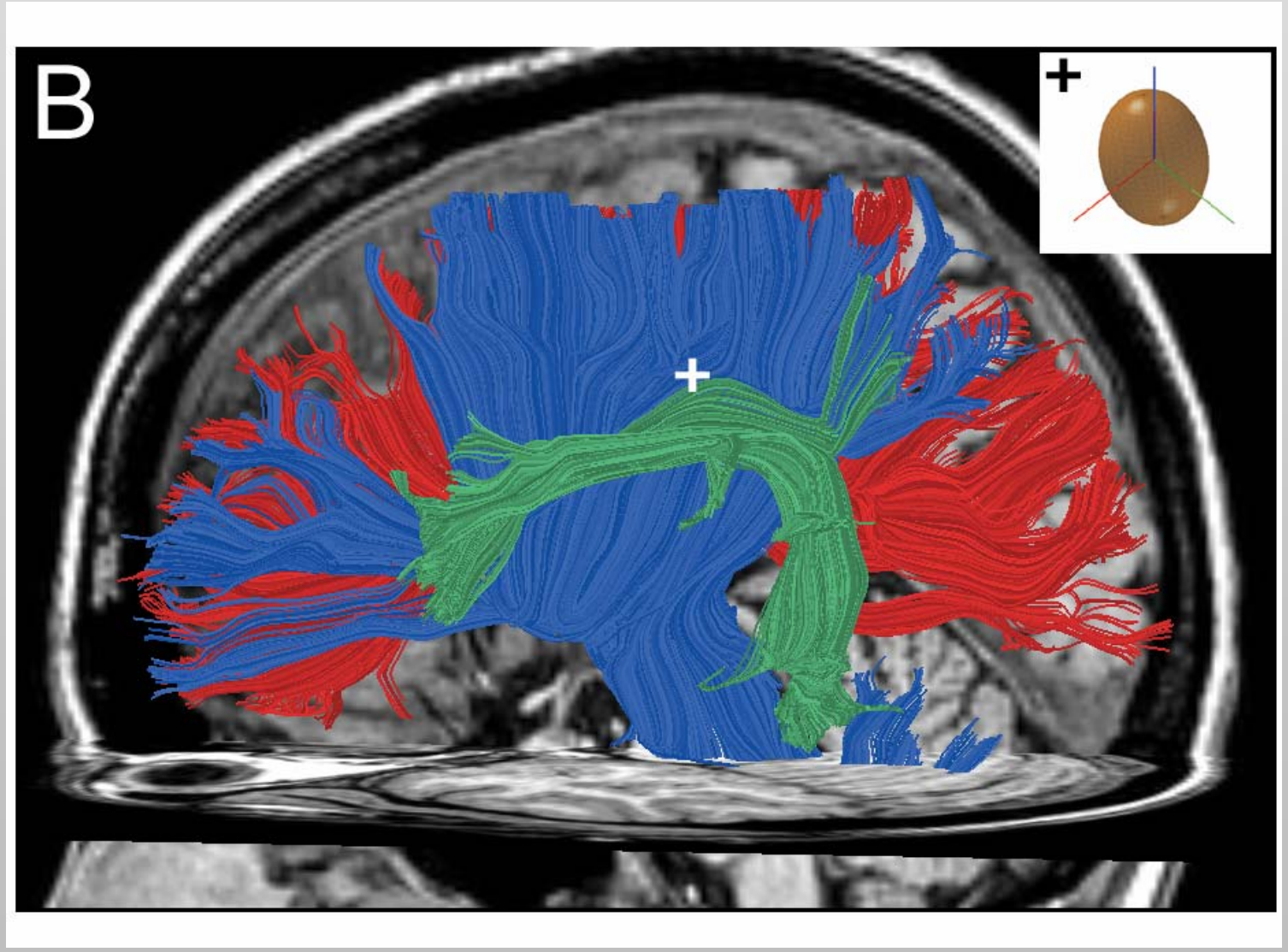
– Validation needed

Fiber tract estimates

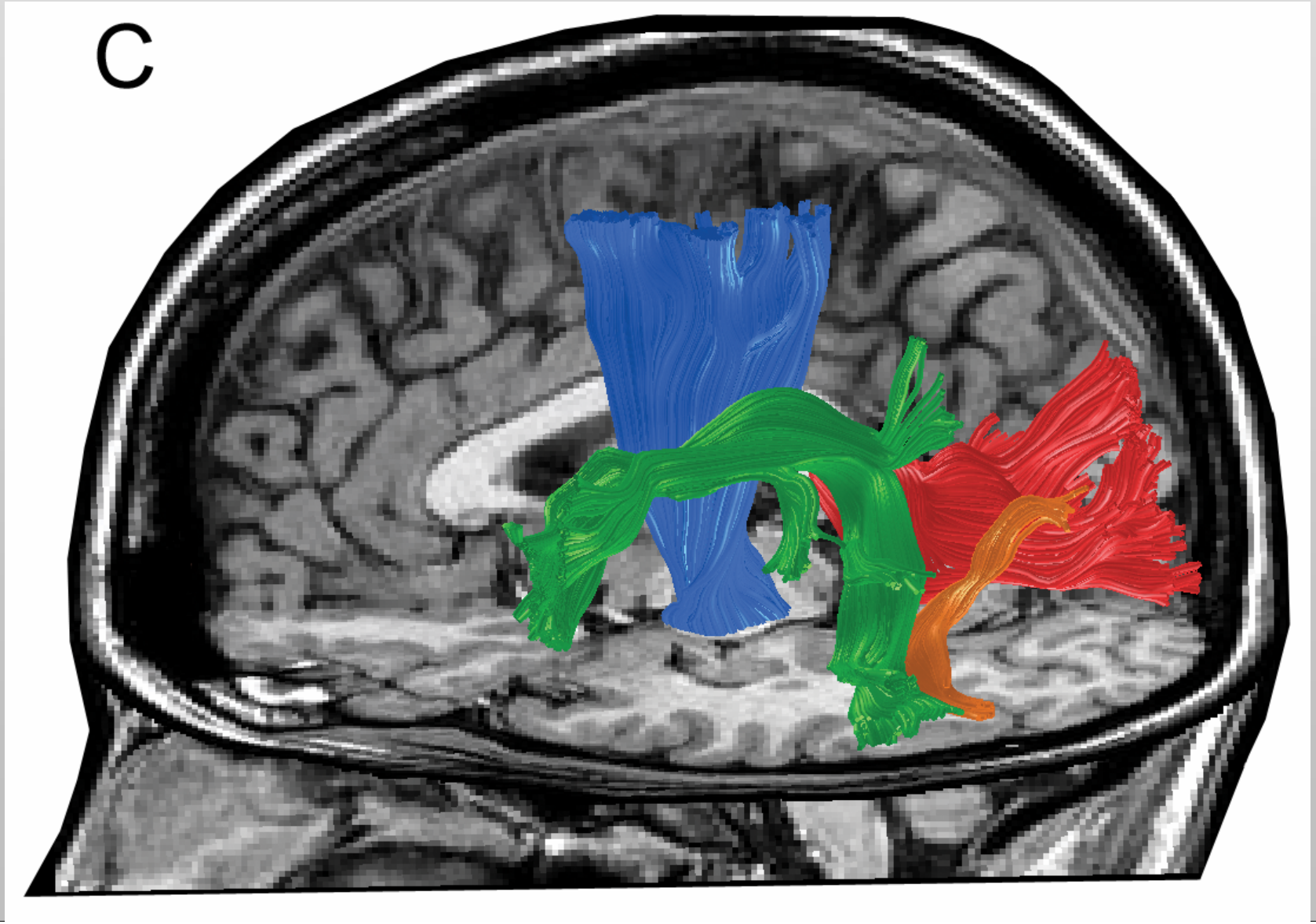
(Dougherty et al., PNAS, 2005)



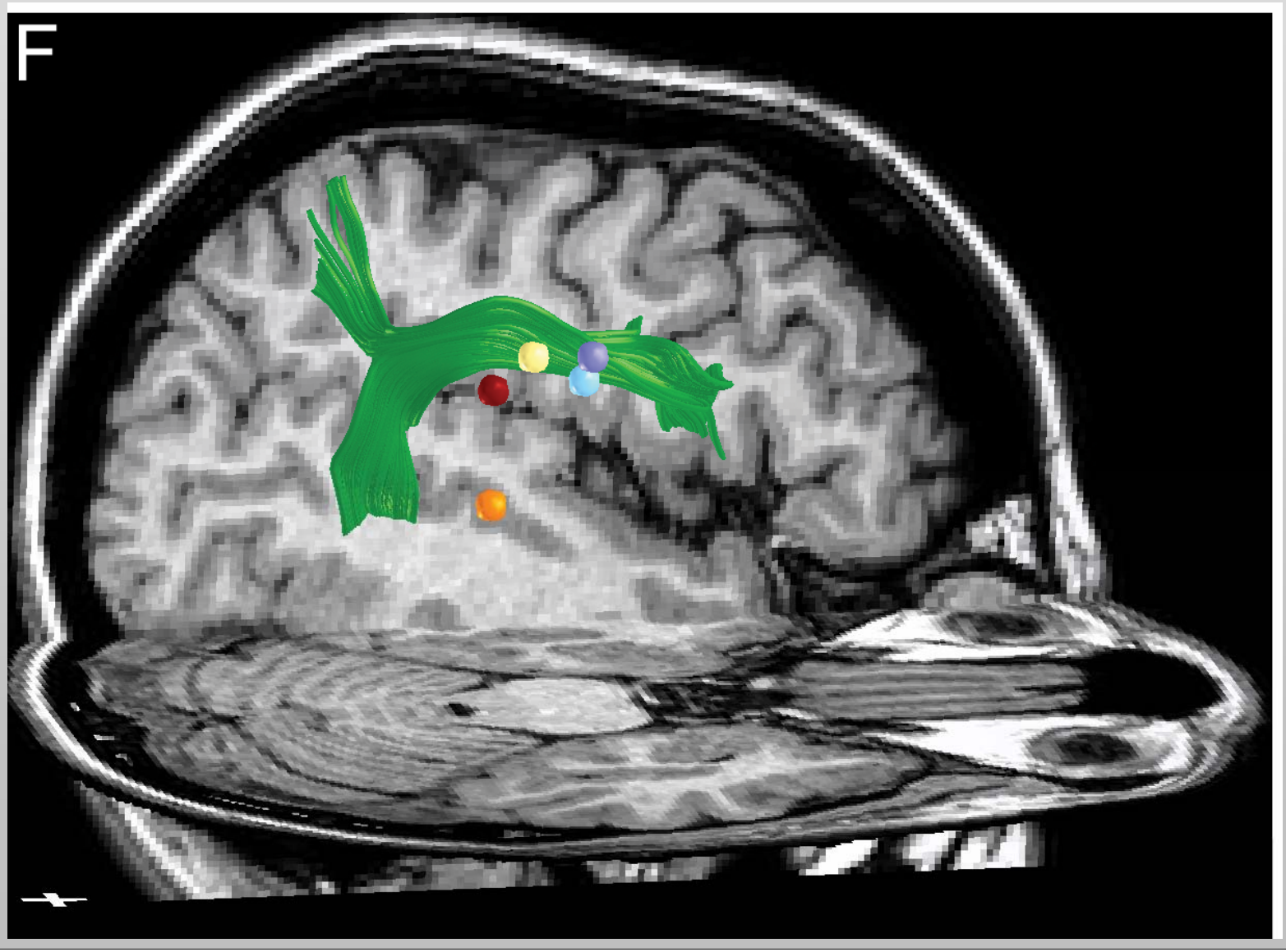
Principal reading fiber tracts



Principal reading fiber tracts

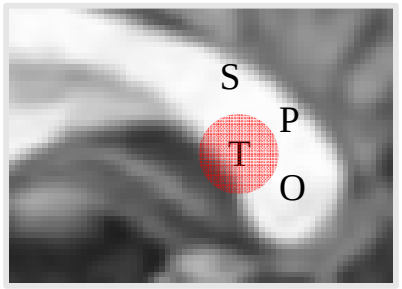


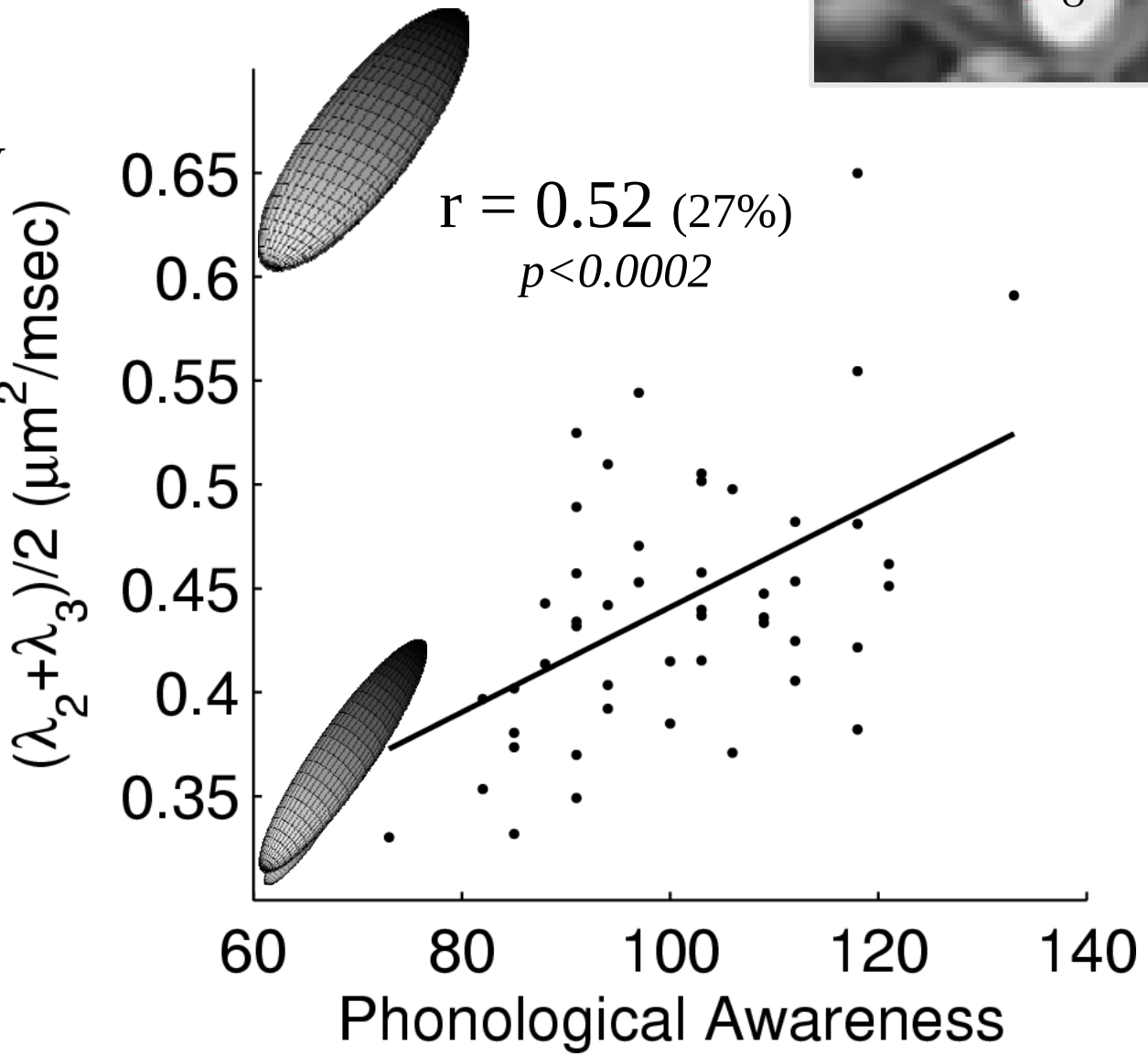
Principal reading fiber tracts and FA differences



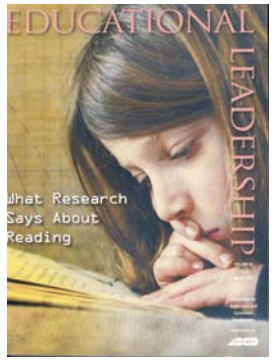
Radial diffusivity in temporal callosal projection zones correlates with phonological awareness

(Dougherty et al., in review)

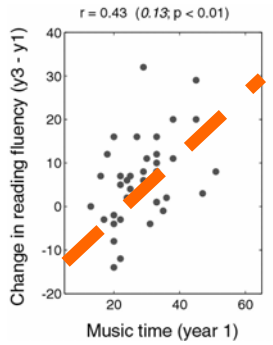


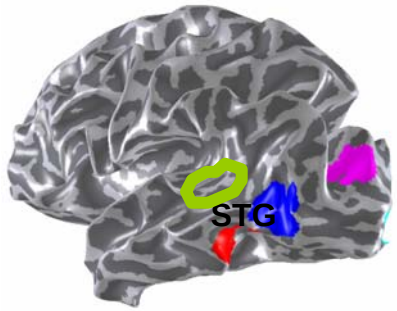


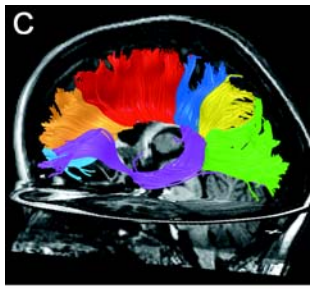
What I told you



- We are making progress on identifying key locations in the reading pathway using both functional and structural measures
- We do not have a decisive set of findings about how training influences the development and responses in these locations







What we would like to know

- Which parts of the reading pathway are enhanced by reading instruction?
  - Does specific training (e.g., phonemic awareness) influence a specific circuit? Is one training technique more or less efficient than the other? Do they combine well?
  - What physiological change result from this training? Synaptic coupling? Sprouting? Myelination and membrane changes?
- How can we improve fMRI and DTI techniques to link neuroimaging data precisely to neural changes
  - Synaptic release and sub-threshold signals, spiking activity, feed forward and backward signals mechanisms (fMRI)
  - Diffusion through myelin, cell membranes, cytoplasm (DTI)

Collaborators

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