# Introduction to MRI Modalities and their Uses in Exposure Research

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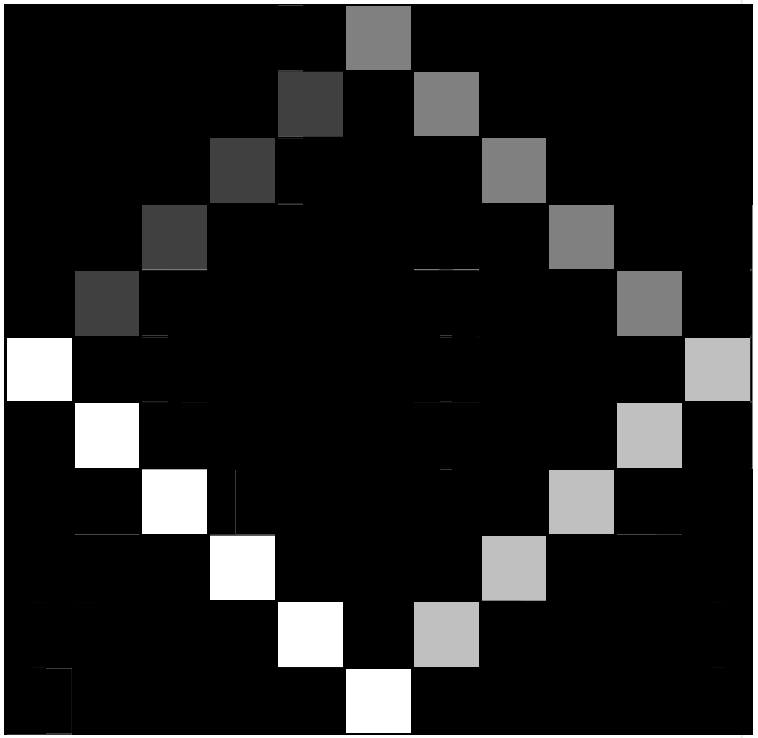
# Construction of an Image

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 2 | 0 | 4 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 |
| 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 |
| 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 |
| 0 | 0 | 0 | 8 | 0 | 0 | 0 | 6 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 8 | 0 | 6 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 |



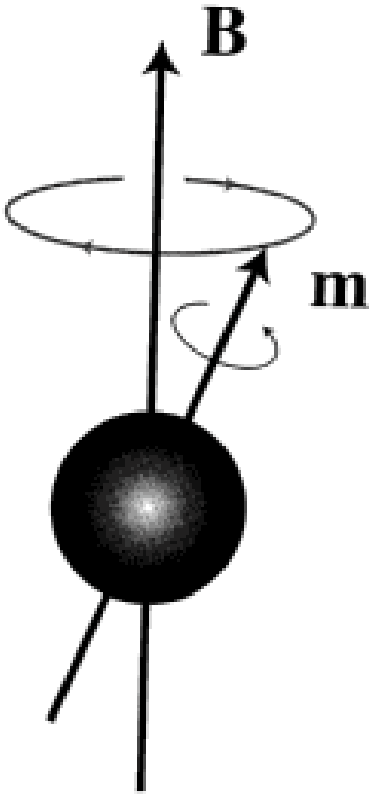
**Numerical measure in each pixel**

**Gray scale representation in each pixel**

"Pixel" = picture element, corresponding to a "Voxel" = volume element of tissue imaged

# PRECESSION OF HYDROGEN NUCLEUS IN AN EXTERNAL MAGNETIC FIELD

Protons (hydrogen nuclei) are components of most of the important molecules in the brain: water and nearly all organic compounds



# ANATOMICAL IMAGING

**Measures Volumes & Shapes**

At the surface of a brain structure:

- strictly speaking, indentations & protrusions
- more intuitively, "local volumes" at the surface

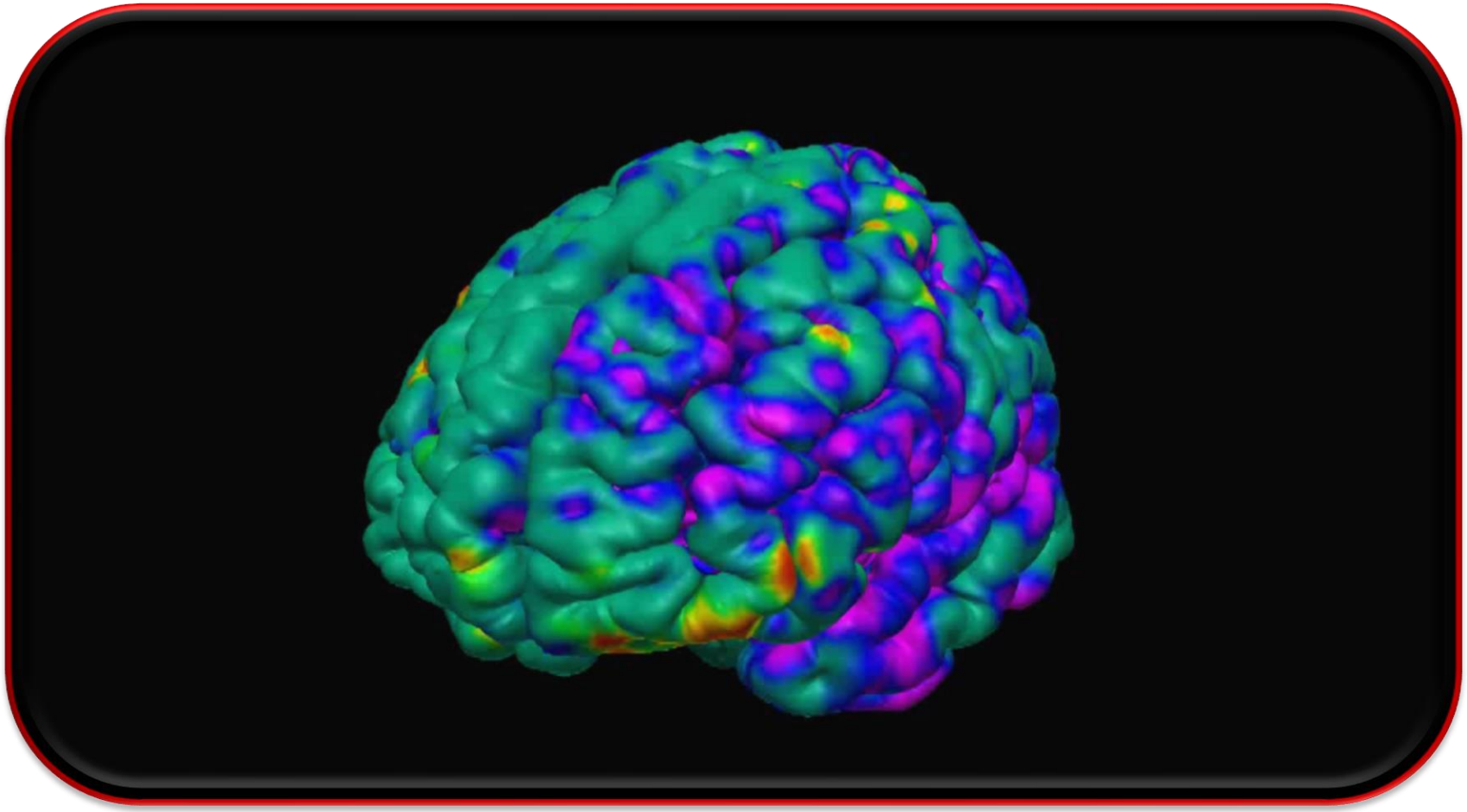
Columbia Center For Children's Environmental Health

Mailman School of Public Health
Columbia University

Correlation of Prenatal PAH Exposure with Local Volumes at Age 7

# 7 Year Old Children Exposed Prenatally to PAH

**Peterson et al, *JAMA Psychiatry*, 2015**



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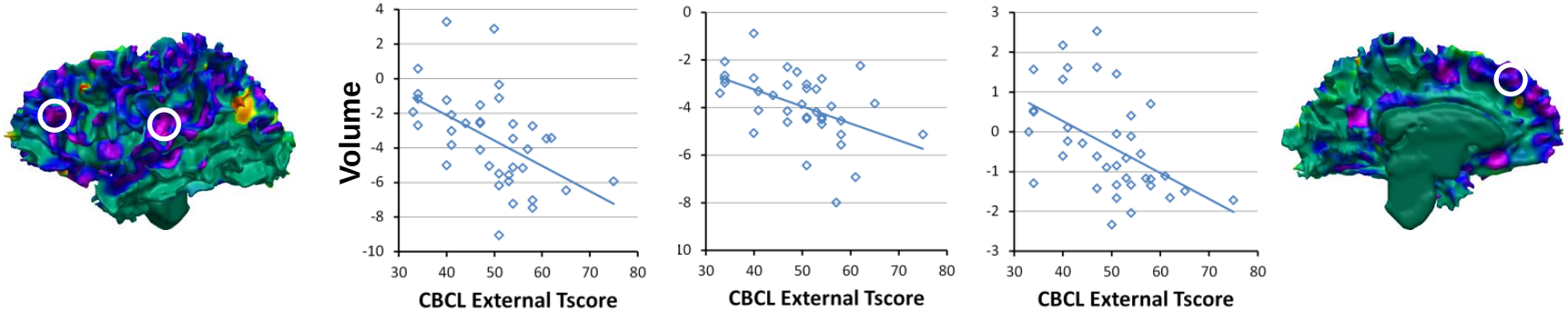
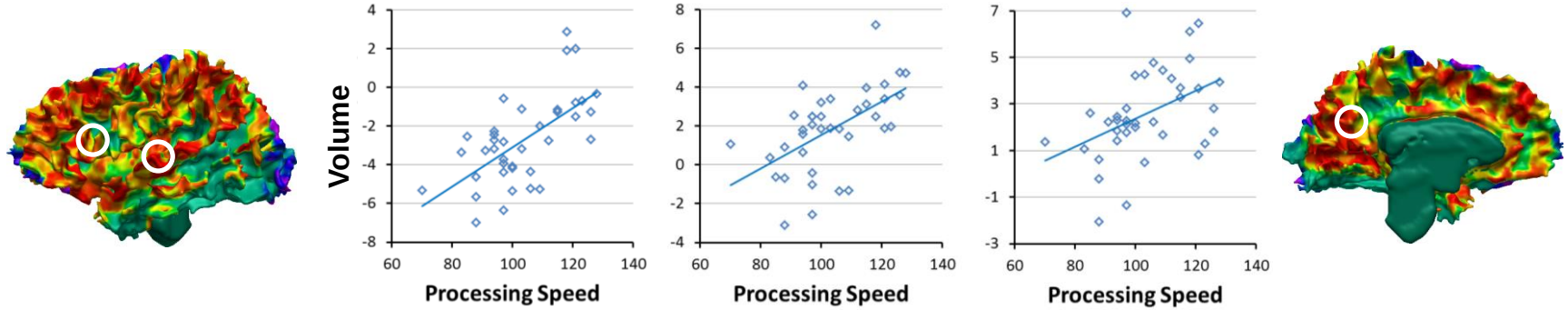
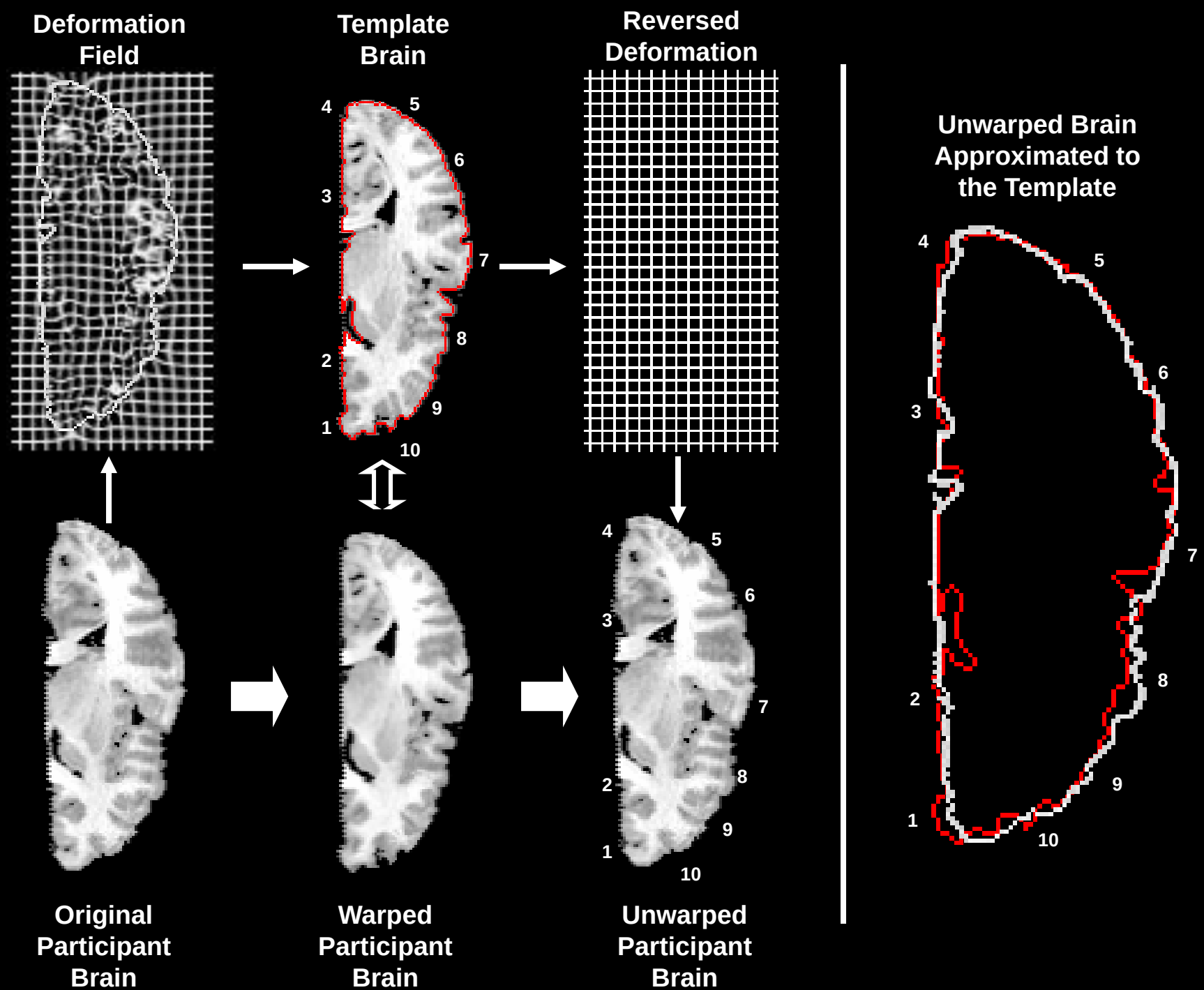
# White Matter Abnormalities Associate with Behavioral and Cognitive Problems

## ADHD, Aggression, & Rule-Breaking Symptoms




## Cognitive Processing Speed




Deformation Field
Template Brain
Reversed Deformation
Unwarped Brain Approximated to the Template
1
2
3
4
5
6
7
8
9
10
Original Participant Brain
Warped Participant Brain
Unwarped Participant Brain

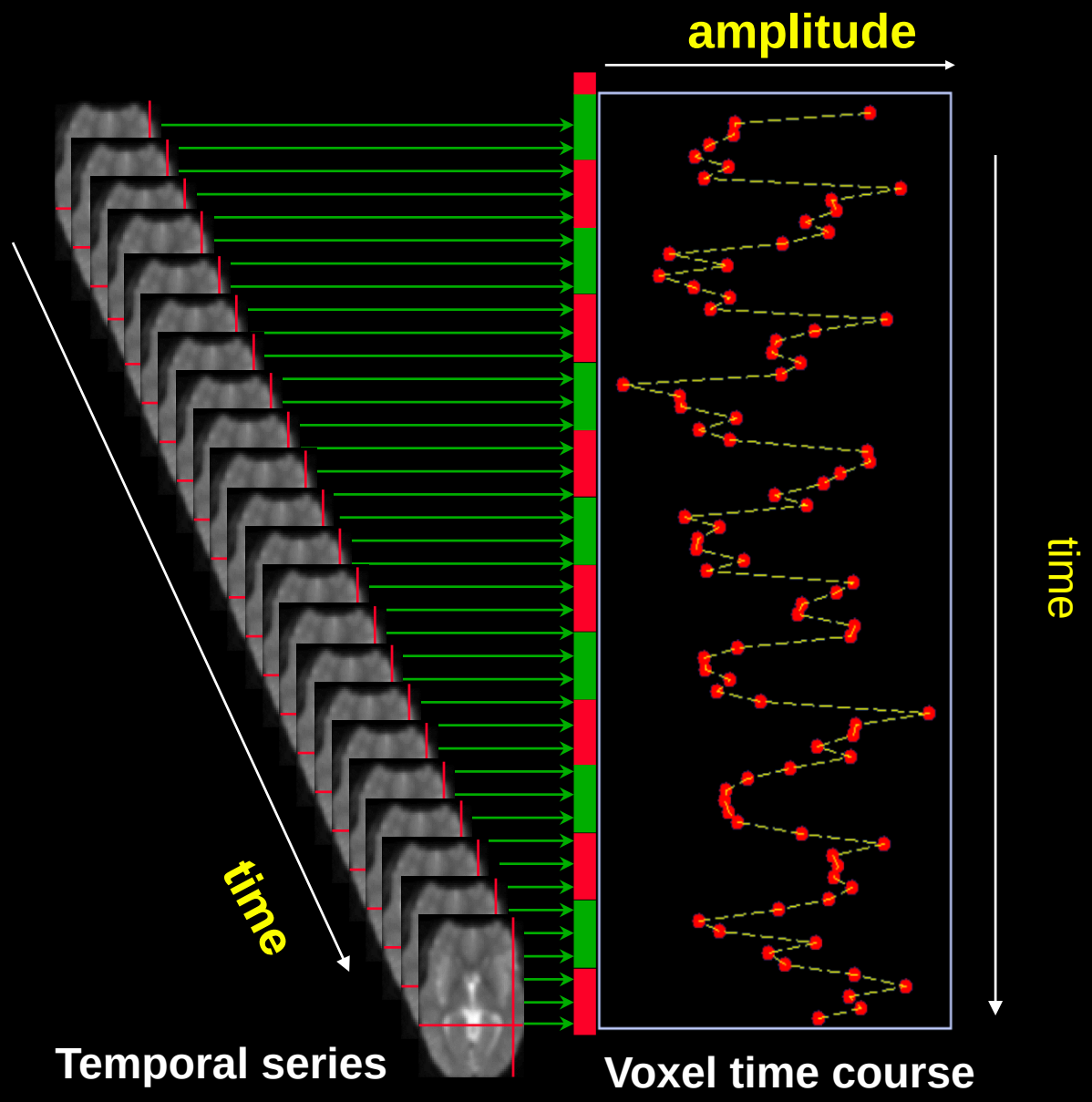
# FUNCTIONAL MRI

## Measures Deoxyhemoglobin Changes

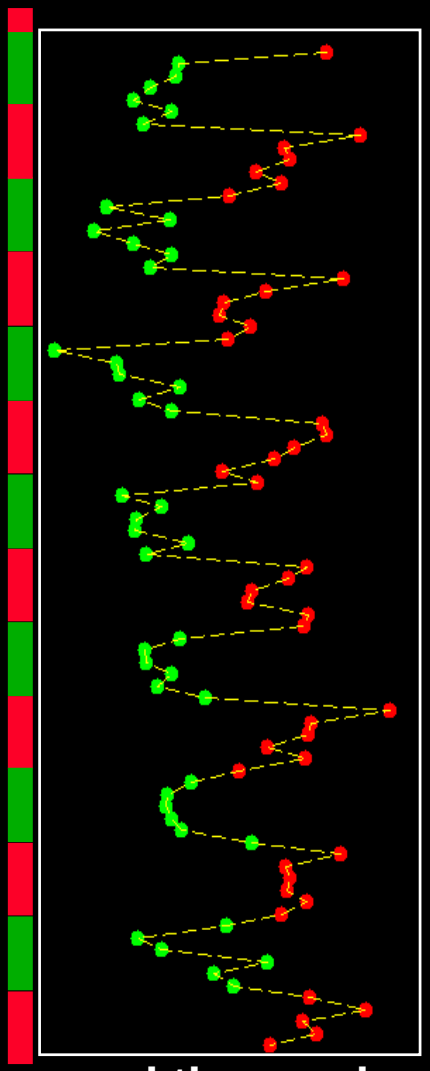
- "Blood Oxygen Level Dependent" MRI signal
- an indirect (and very distant) index of neural activity

# THE BASIC THEORETICAL CONSTRUCT FOR TASK-BASED FMRI: SUBTRACTION PARADIGMS

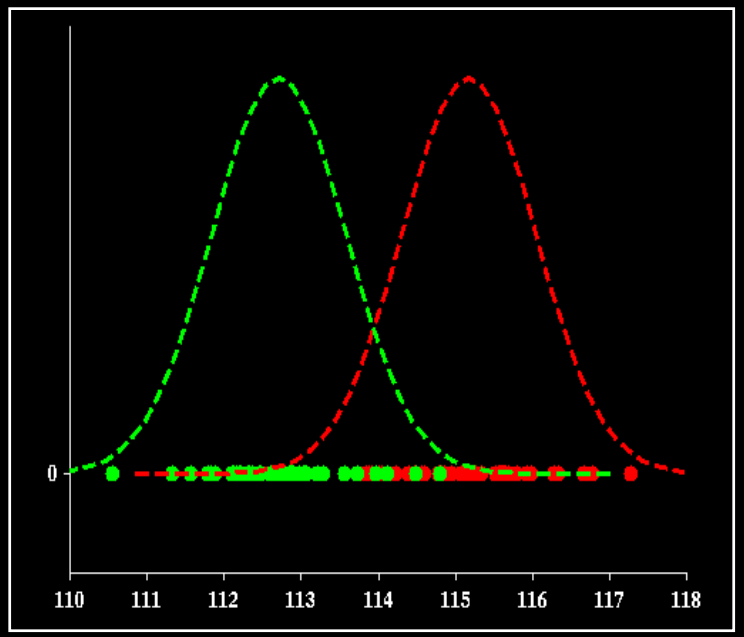
# One voxel = One Statistical Test



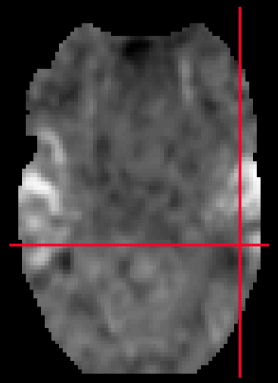
# e.g. two-sample *t*-test



voxel time series




$$t = \frac{\overline{Y_{1\bullet}} - \overline{Y_{0\bullet}}}{\sqrt{\hat{\sigma}^2\left(\frac{1}{n_1} + \frac{1}{n_0}\right)}}$$

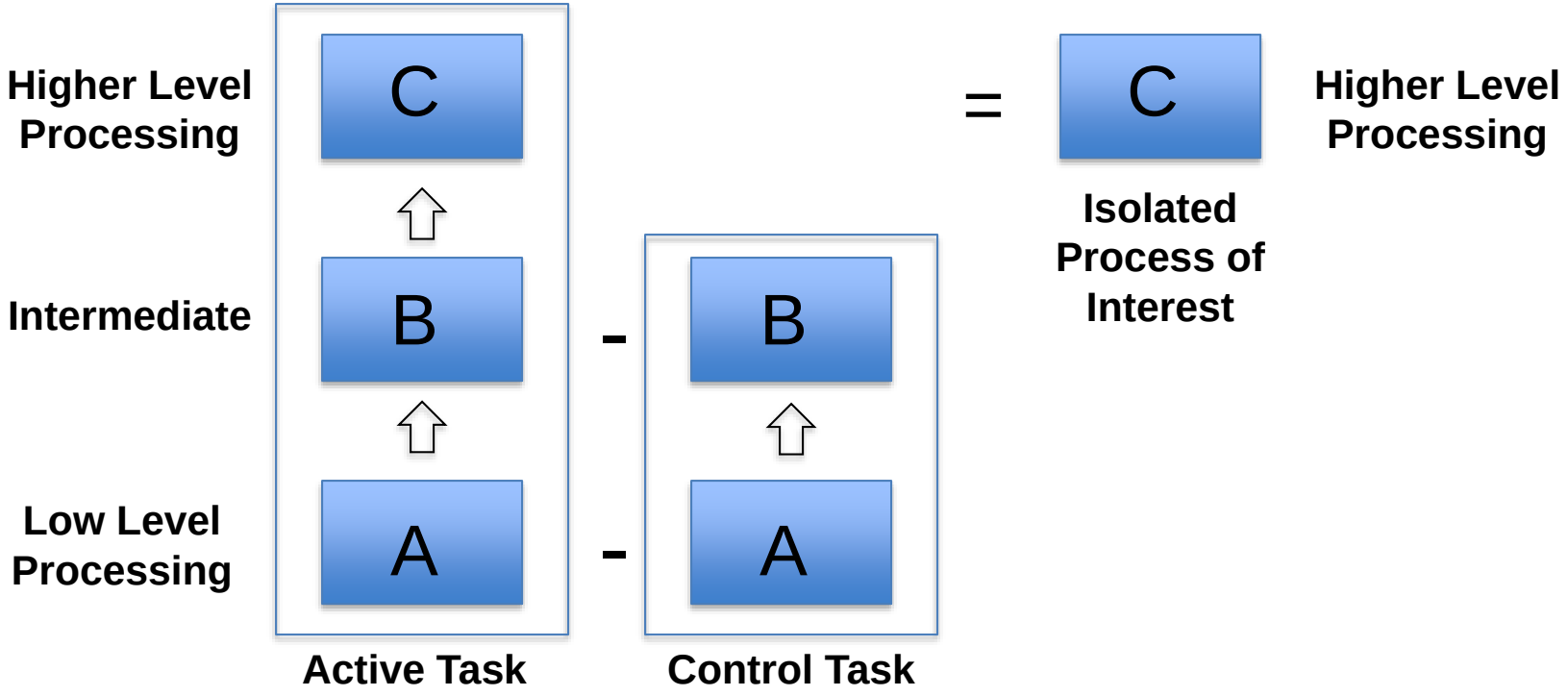


***t*-statistic image**
**SPM{*t*}**
***compares size of effect to error variance***

# SUBTRACTION ASSUMPTIONS

1) Processing in the brain is serial
2) Occurs within linearly additive modules

Highly suspect, but experimentally robust



# Task-Based fMRI Example

## The Simon Task

**Congruent**

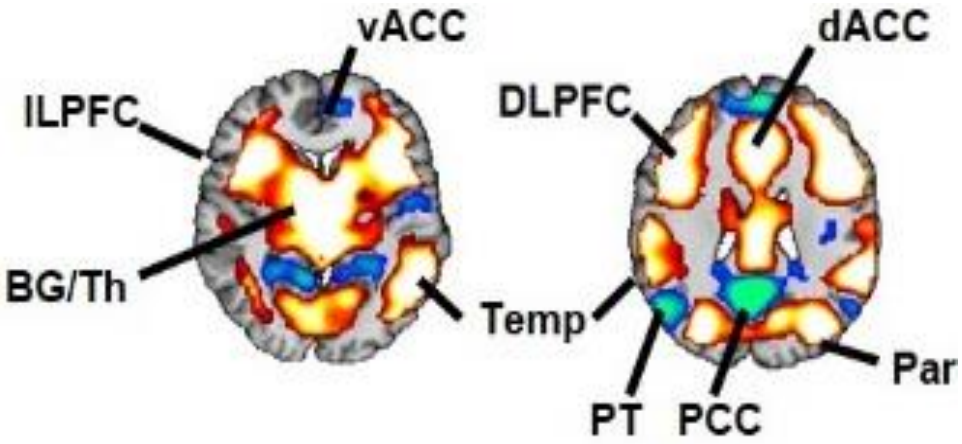
<  >

**Incongruent**

>  <

(Respond to Direction of Arrow)

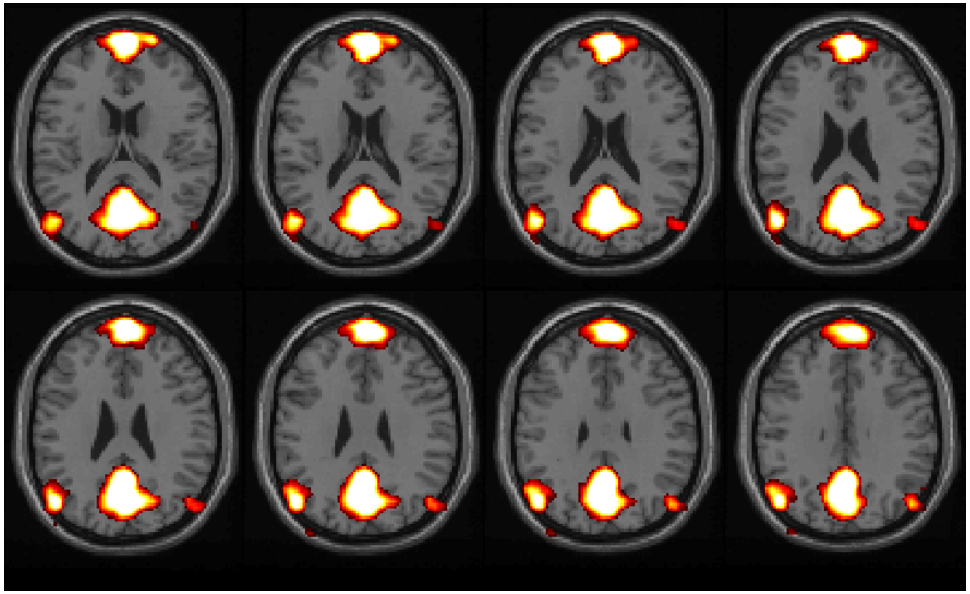
To inhibit the more automatic response and instead execute the less automatic one requires self-regulatory control



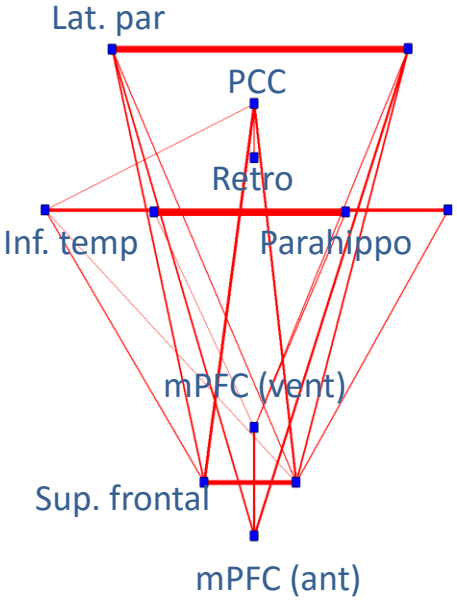
# Resting-State fMRI (functional connectivity)

**Default-Mode Activity**

(Mind-Wandering & Self-Awareness)

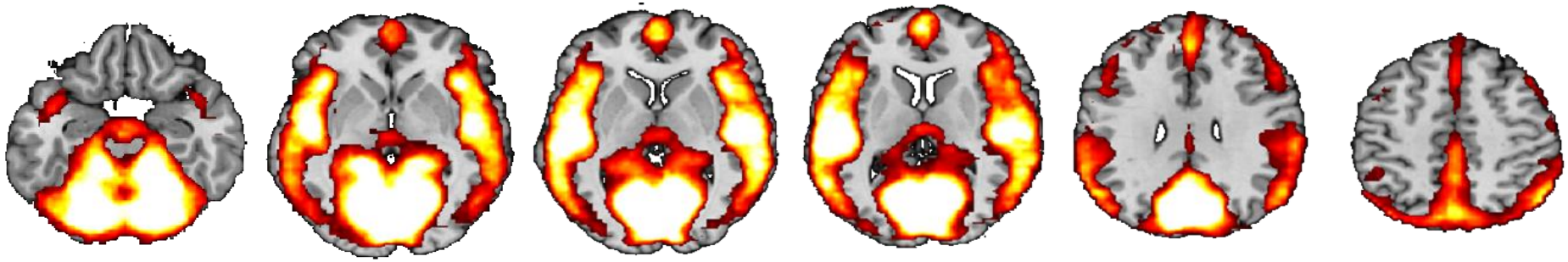


Network-Based Connectivity



# Perfusion fMRI (Arterial Spin Labeling)

Resting Regional Blood Flow



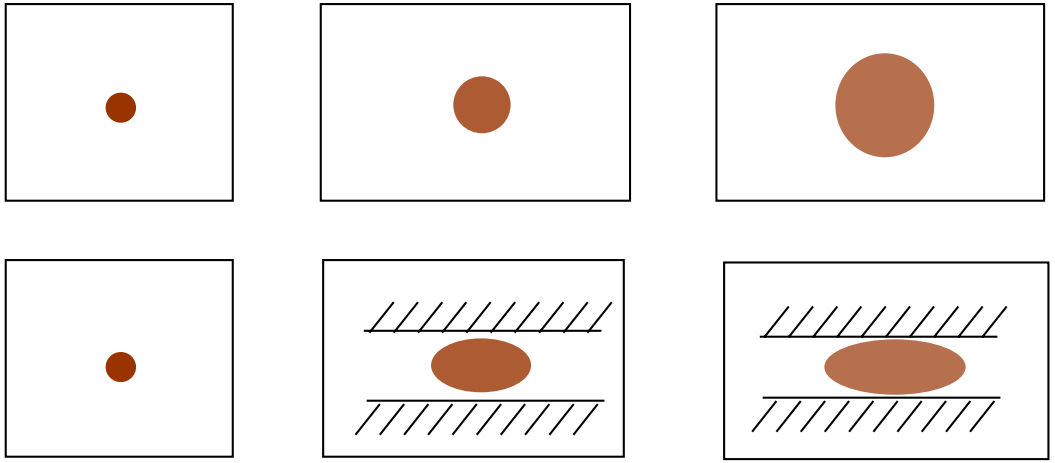
# DIFFUSION TENSOR IMAGING (DTI)

**Measures the Preferential Direction and Rate of Diffusion of Water in the Brain**

- Diffusion that is spatially preferential is termed "anisotropic"

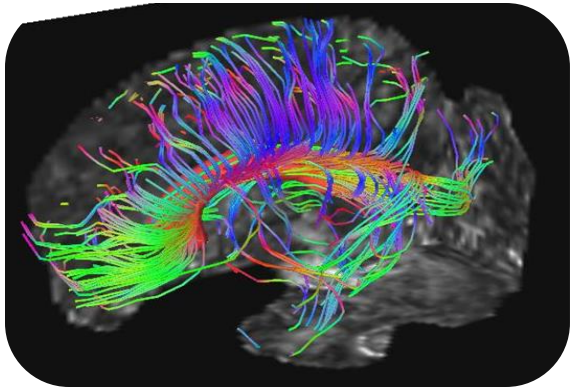
# Diffusion Tensor Imaging

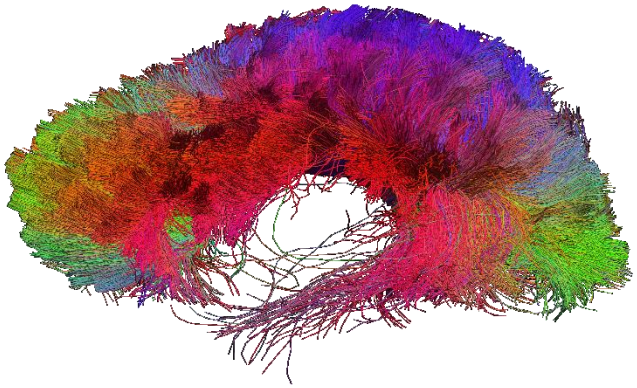
## Diffusion: incoherent molecular motion induced by thermal energy (Brownian motion)



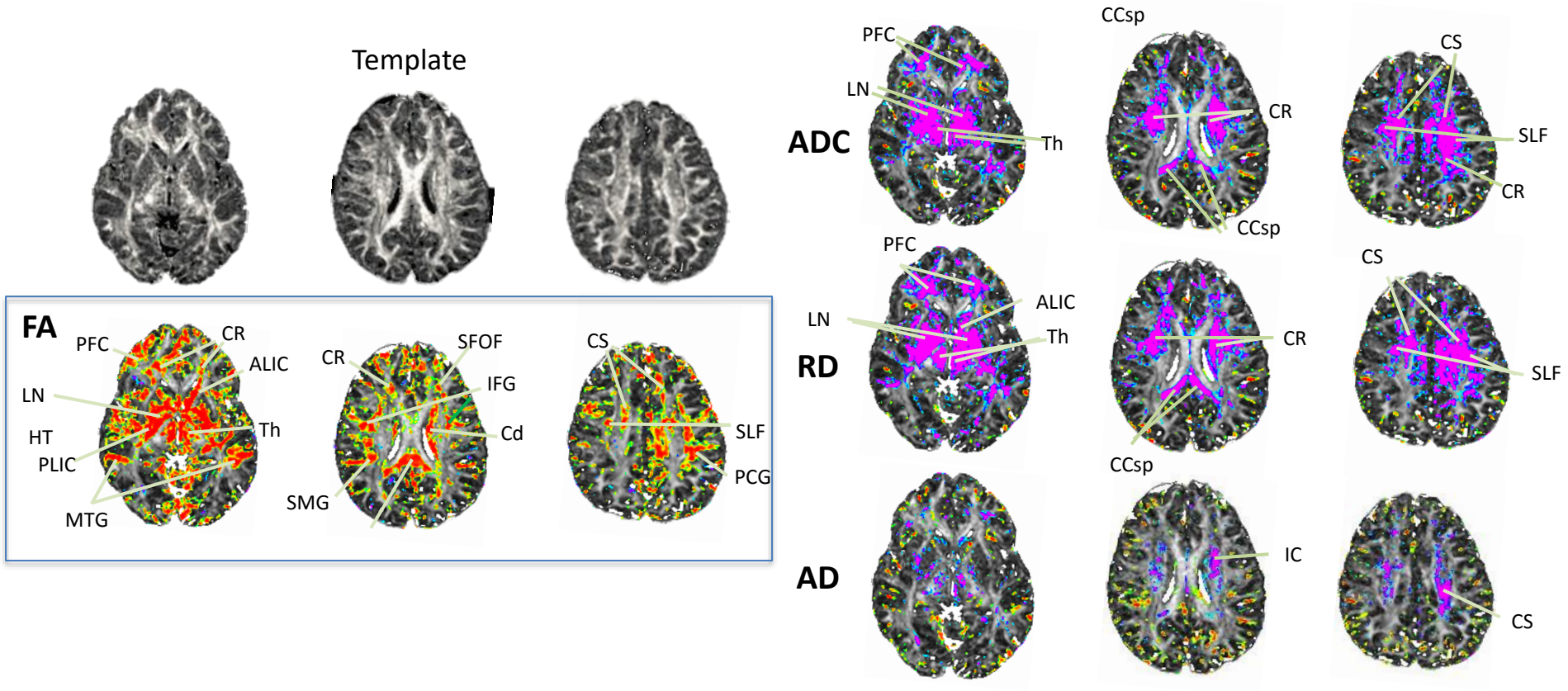
Unrestricted diffusion

Restricted Diffusion





# Correlation of DTI Measures with Age
# Ages 9-12 years (mean 10.85)
# N=234



# MAGNETIC RESONANCE SPECTROSCOPY (MRS)

**Measures the Concentrations of Certain Chemical Compounds that are "Visible" to the MRI Scanner**

# MRS Capabilities

- Can quantify concentration of nuclei that have a net nuclear spin (present only in nuclei having odd-numbered protons or neutrons)

- Includes $^{1}H$, $^{13}C$, $^{19}F$, $^{23}Na$, $^{31}P$, and Lithium

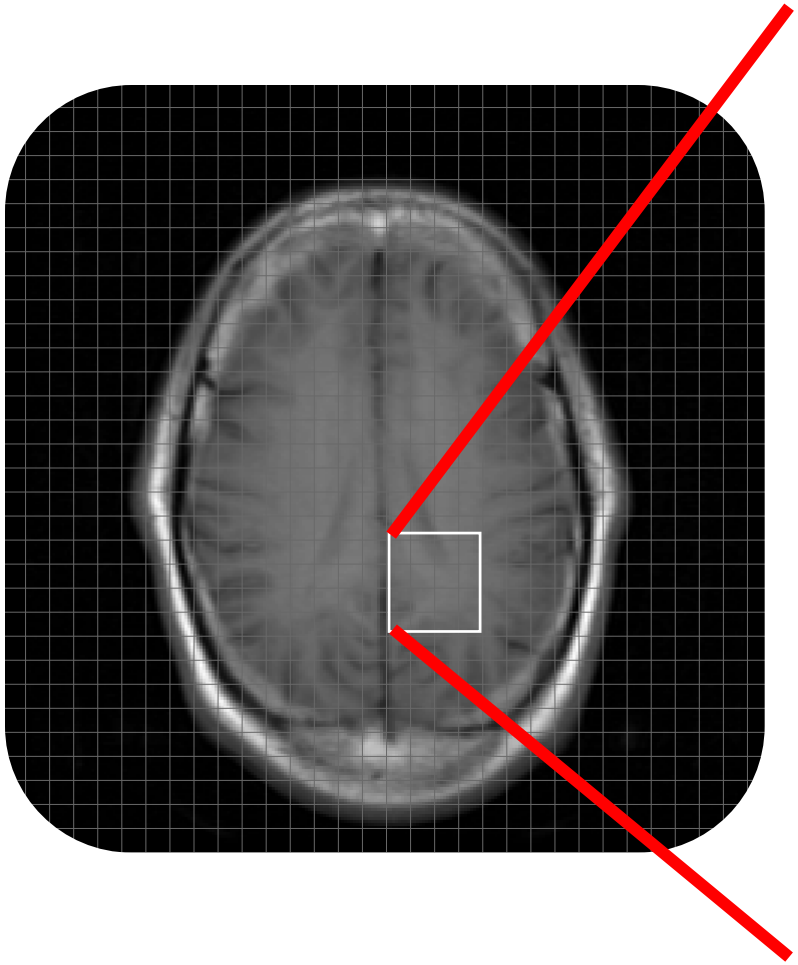
# MRS Principles

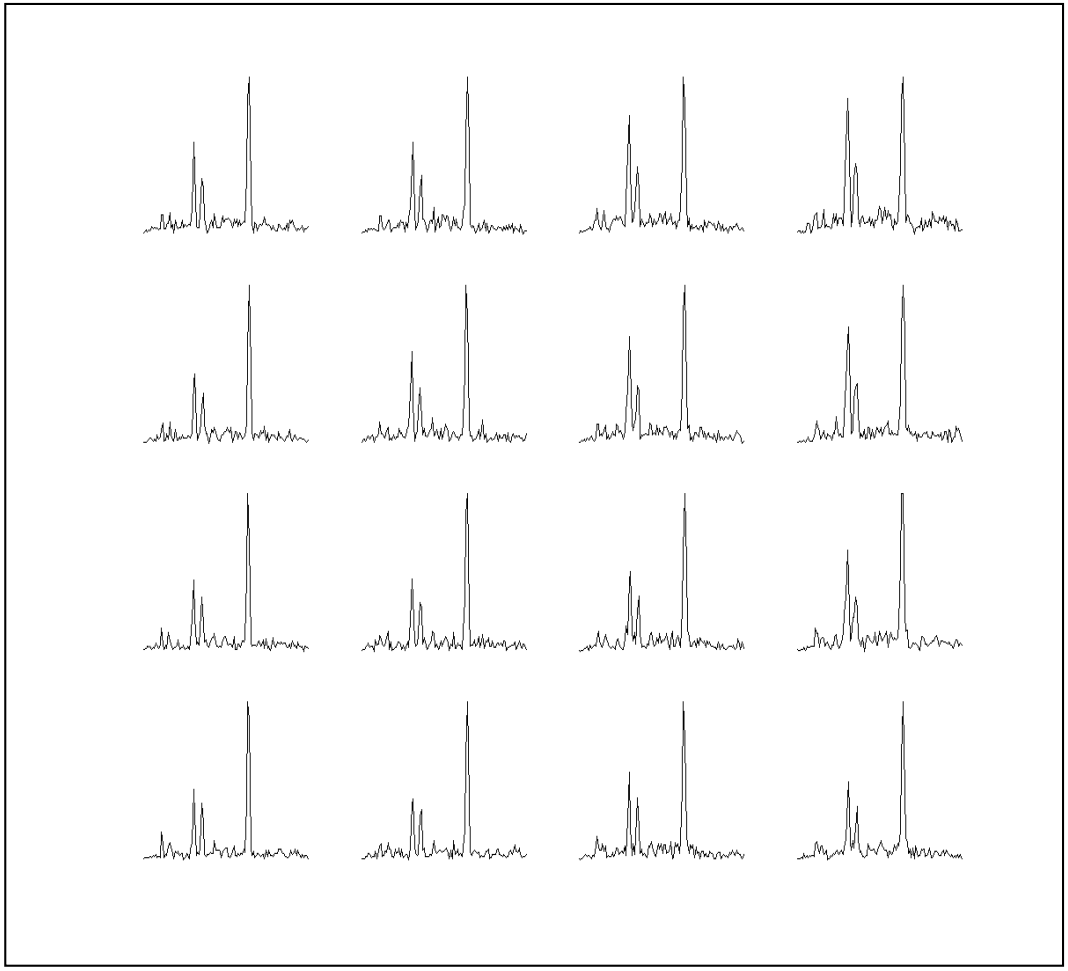
- When nuclei relax, the radio signal they emit is determined by their physical environment
  - The frequency of the signal is altered slightly, producing a ``chemical shift'' fingerprint
  - The shift is characteristic of the specific molecules to which the nuclei belong
- Areas under specific spectral peaks measure metabolite concentrations

# Examples of Proton MRS Metabolites

- NAA: density of healthy neurons, energy metabolite
- Choline: marker of membrane turnover
- Creatine: energy substrate
- Lactate
- Combined glutamate + glutamine ("Glx"), GABA

# MR Spectroscopic Imaging

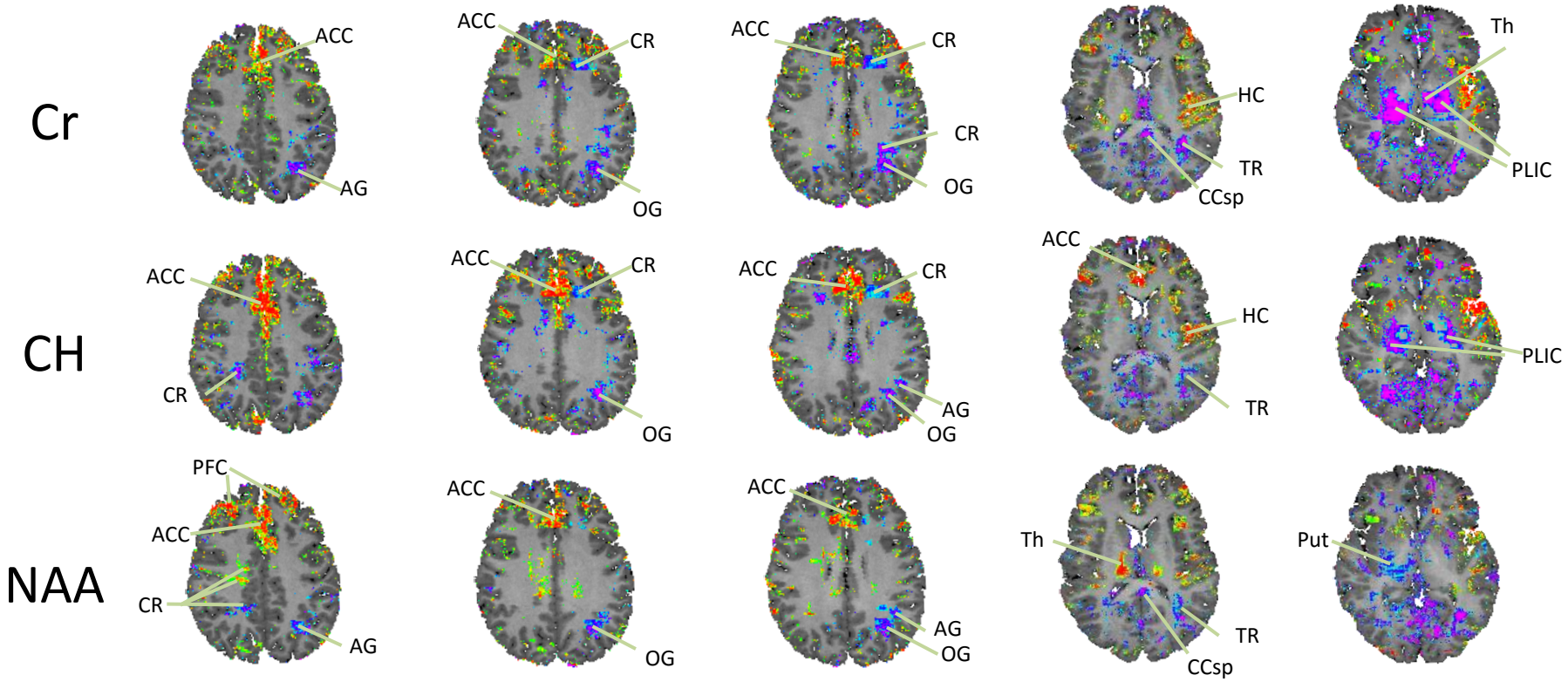




Spectra in 1 x 1 x 1 cm Volumes

The largest peak is NAA, an index of density of healthy neurons

# Correlation of MRS Metabolite Concentrations with Age
# Ages 9-12 years (mean 10.85)
# N=234



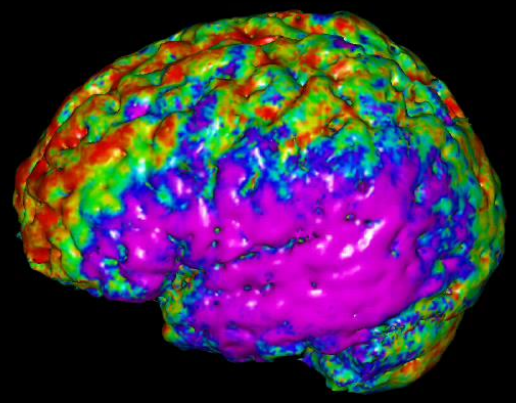
# Integrated Multi-Modal MRI

- Anatomical MRI
- fMRI
- Perfusion
- DTI
- MRS

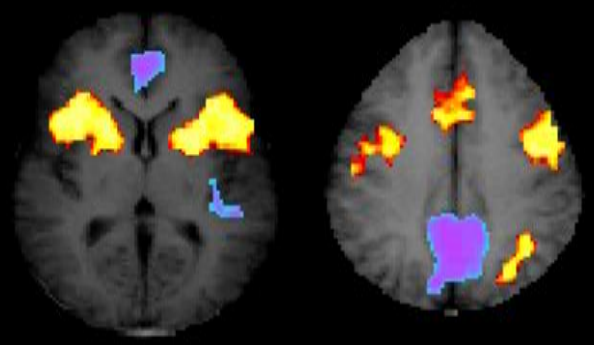
All bundled into a single, multivariate and multidimensional, Graphic User Interface

Think: the blind man and the elephant

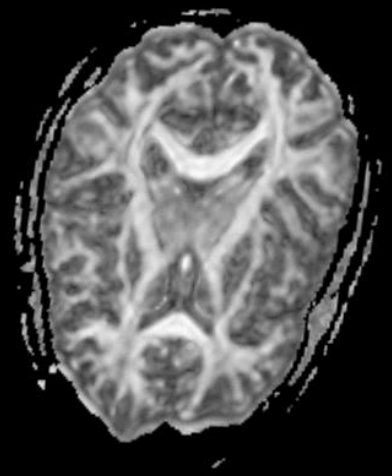
Anatomical MRI



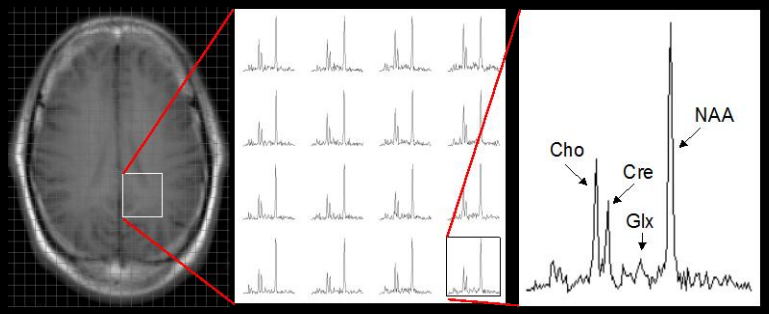
FMRI



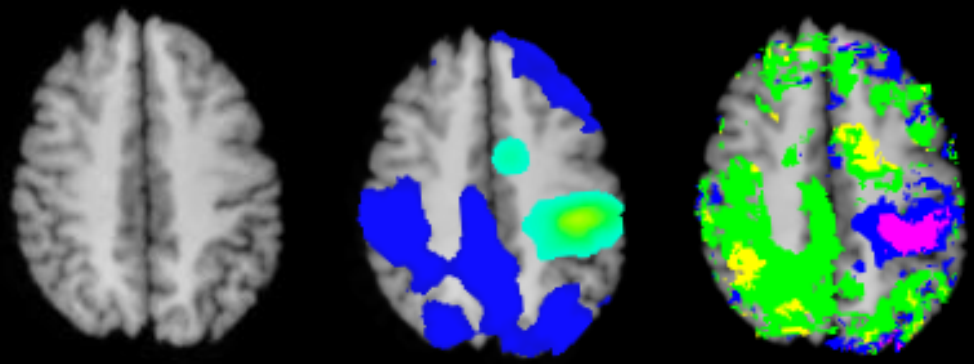
DTI



MR Spectroscopy




Multimodal Imaging



Anatomical

Functional

Correlation of Neuronal Density with Functional Activation

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# Absolutely Essential Friends & Collaborators

**Ricky Perera, Ph.D.**
**Columbia University**

**Virginia Rauh, Ph.D.**
**Columbia University**

**Ravi Bansal, Ph.D.**
**CHLA & USC**