

# NEUROIMAGING

(...at the NIH)

Peter A. Bandettini, Ph.D.

Functional MRI Facility  
Unit on Functional Imaging Methods  
Laboratory of Brain and Cognition

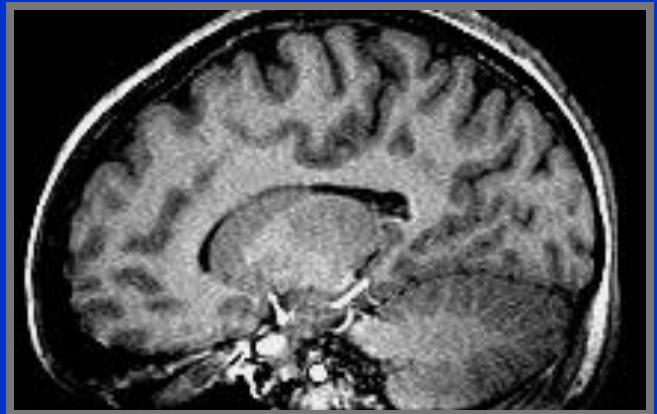


# Two Types of Neuroimaging

- Structural/Anatomical Imaging
- Functional Imaging

# Structural Brain Imaging

- Reveals the anatomy of the brain and the physical structure of brain pathology.
- Primarily associated with Computerized Axial Tomography (CAT or CT) and Magnetic Resonance Imaging (MRI).



- Structural/Anatomical Imaging
  - X-ray
  - Computerized Tomography (CT)
  - Magnetic Resonance Imaging (MRI)
    - Angiography
    - Venography
    - Perfusion
    - Diffusion Tensor Imaging

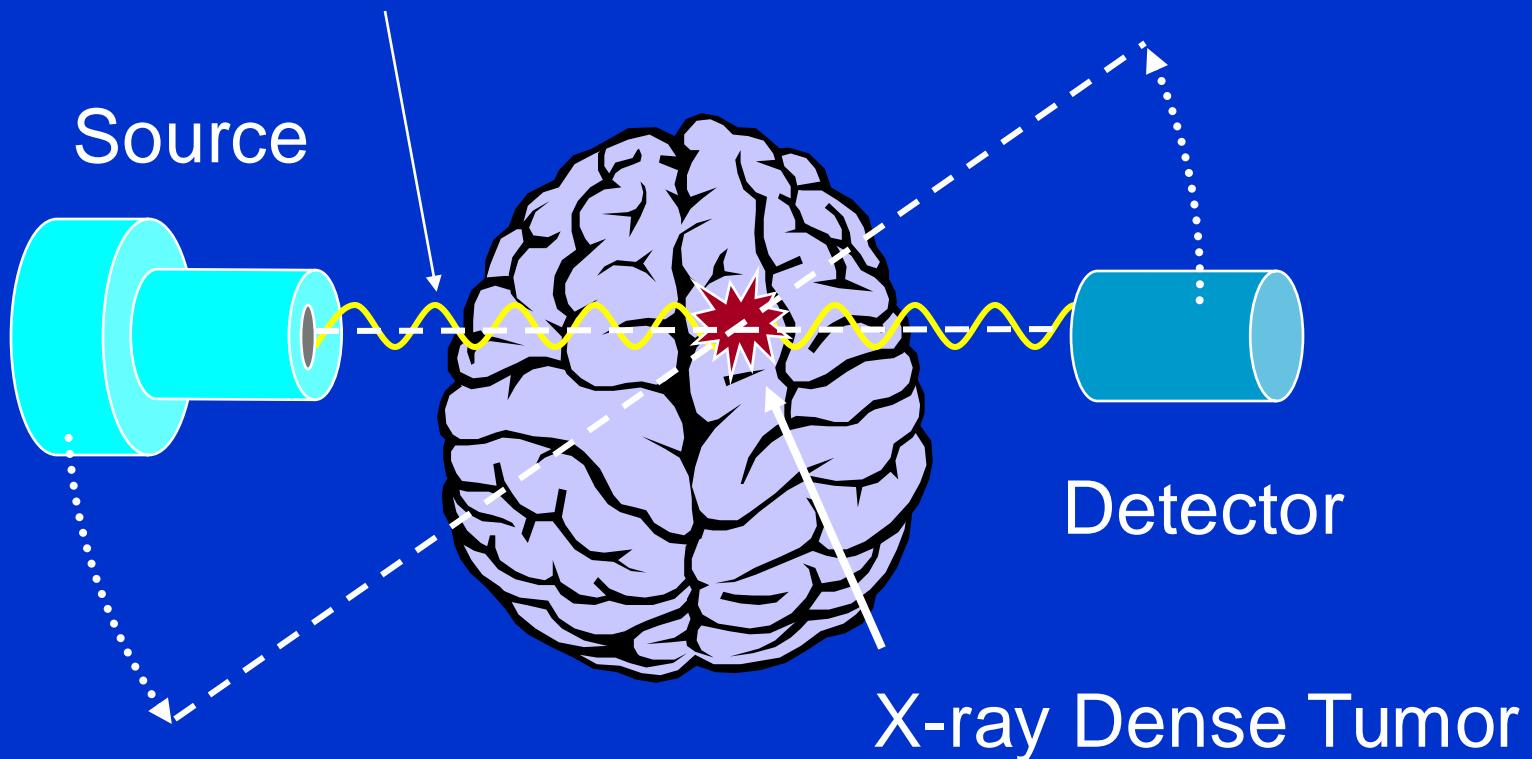
# •Functional Imaging

- Xenon Computerized Tomography (Xe CT)
- Positron Emission Tomography (PET)
- Single Photon Computed Tomography (SPECT)
- Functional MRI (fMRI)
- Electroencephalography (EEG)
- Magnetoencphalography (MEG)
- Transcranial Magnetic Stimulation (TMS)

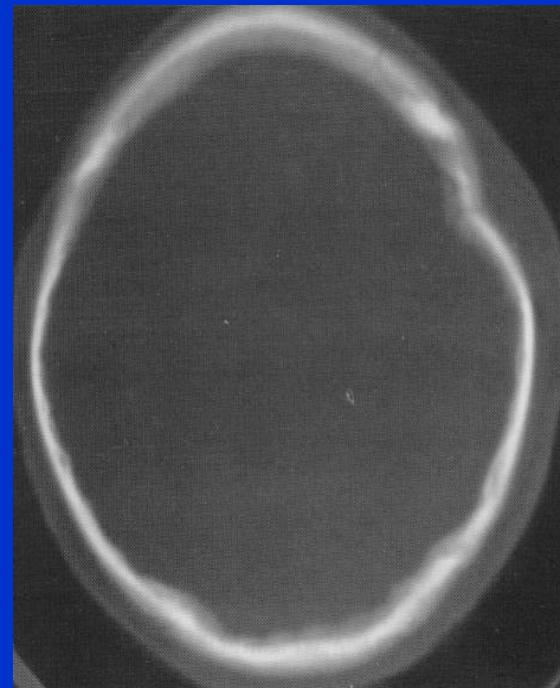
# Computerized Tomography (CT)

Creation of images in slices or sections.

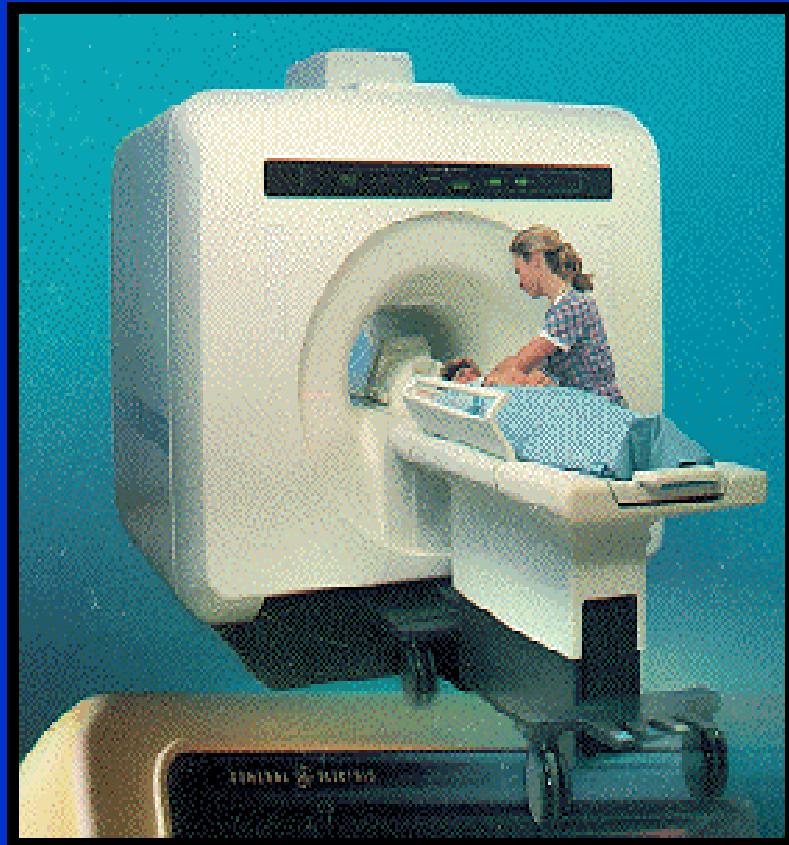
Narrow X-ray beam



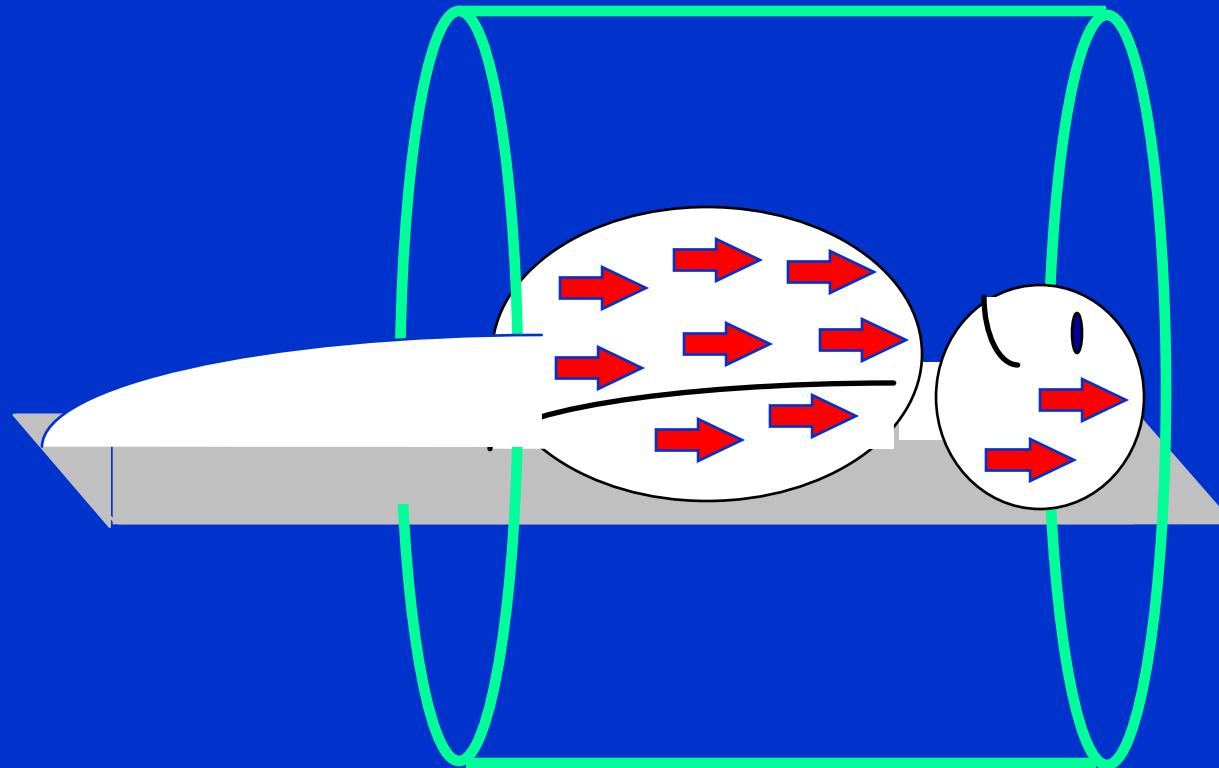
# CT Images



# Magnetic Resonance Imaging

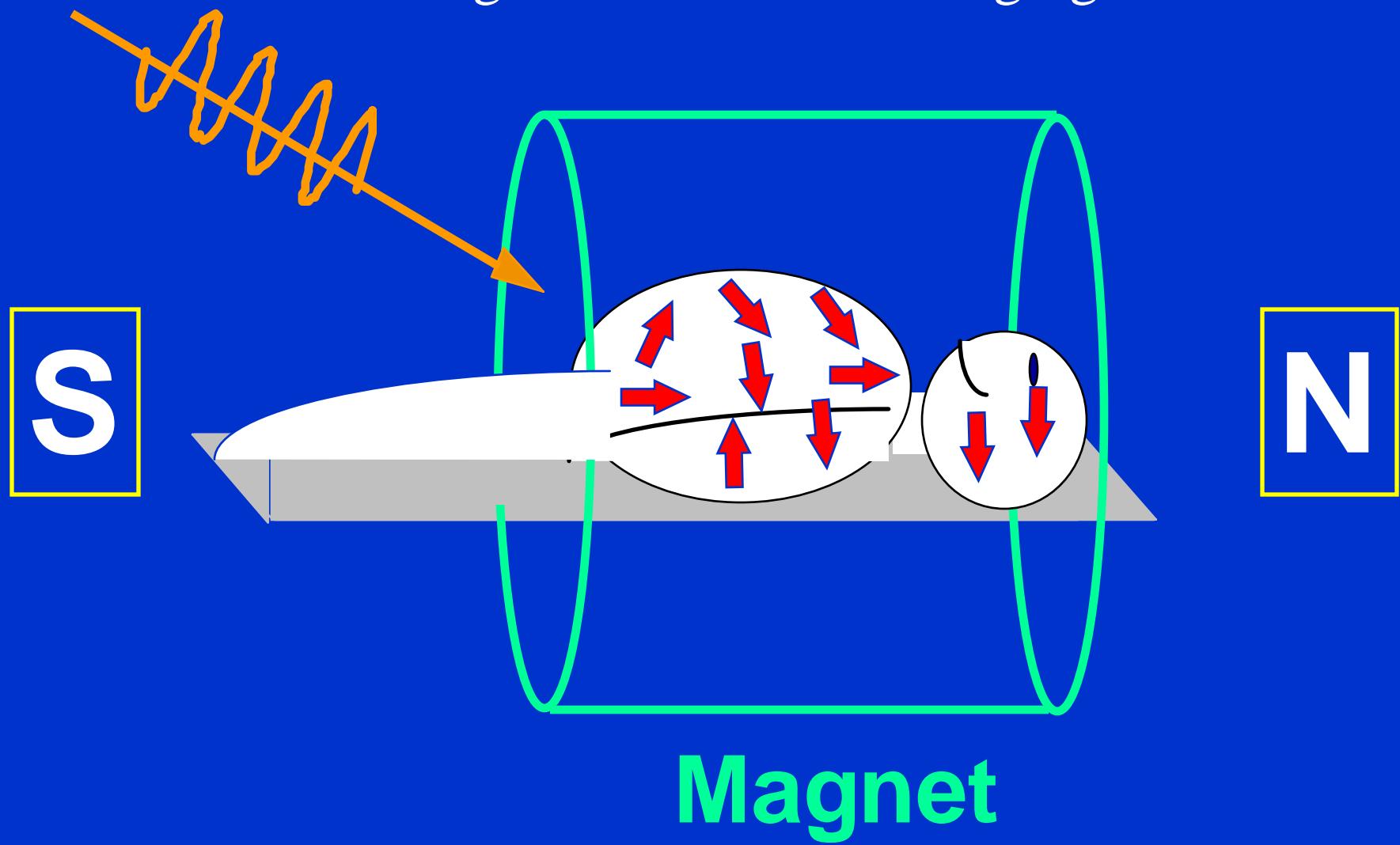


# Magnetic Resonance Imaging

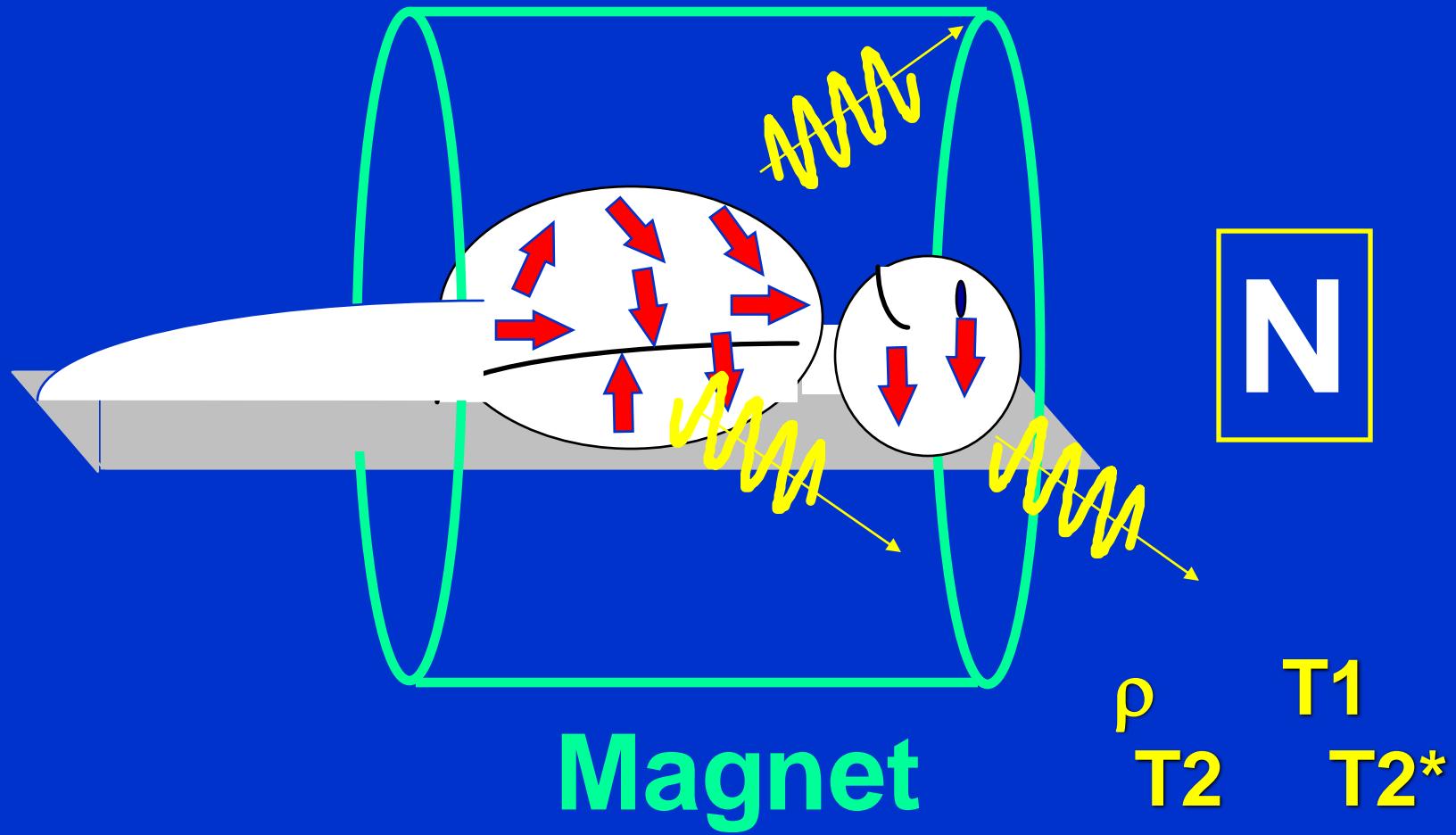


Magnet

# Magnetic Resonance Imaging

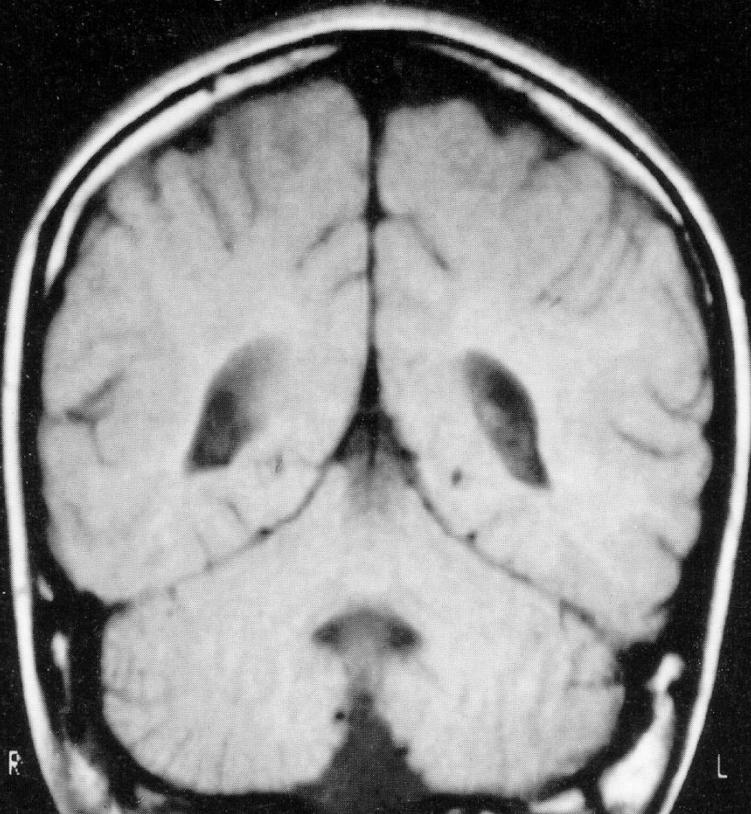


# Magnetic Resonance Imaging



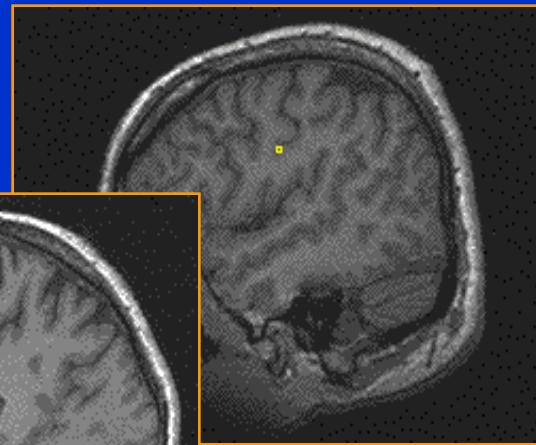
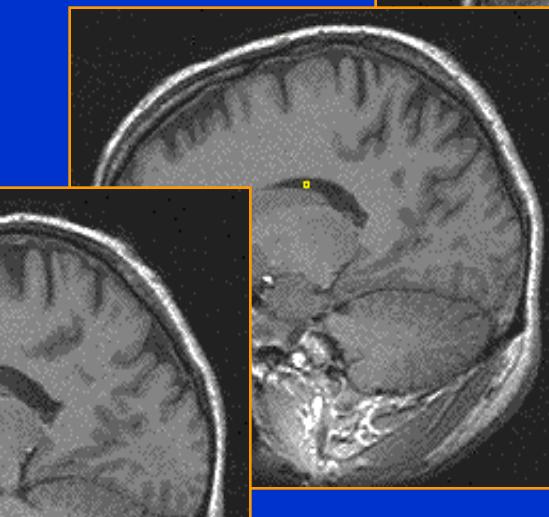
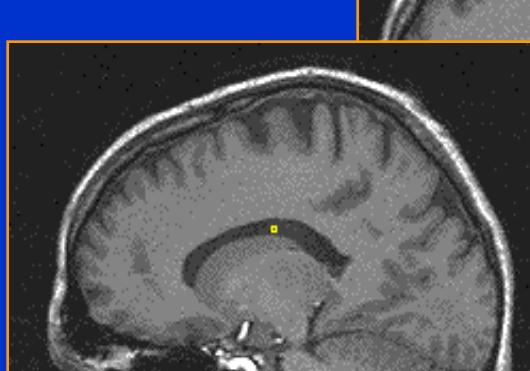
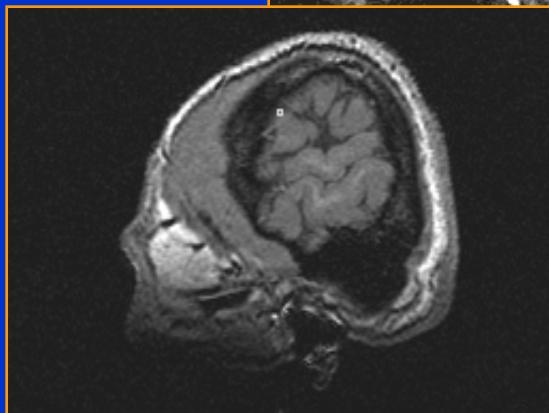
# MRI Images with Different Contrast Weighting

T1 Weighted

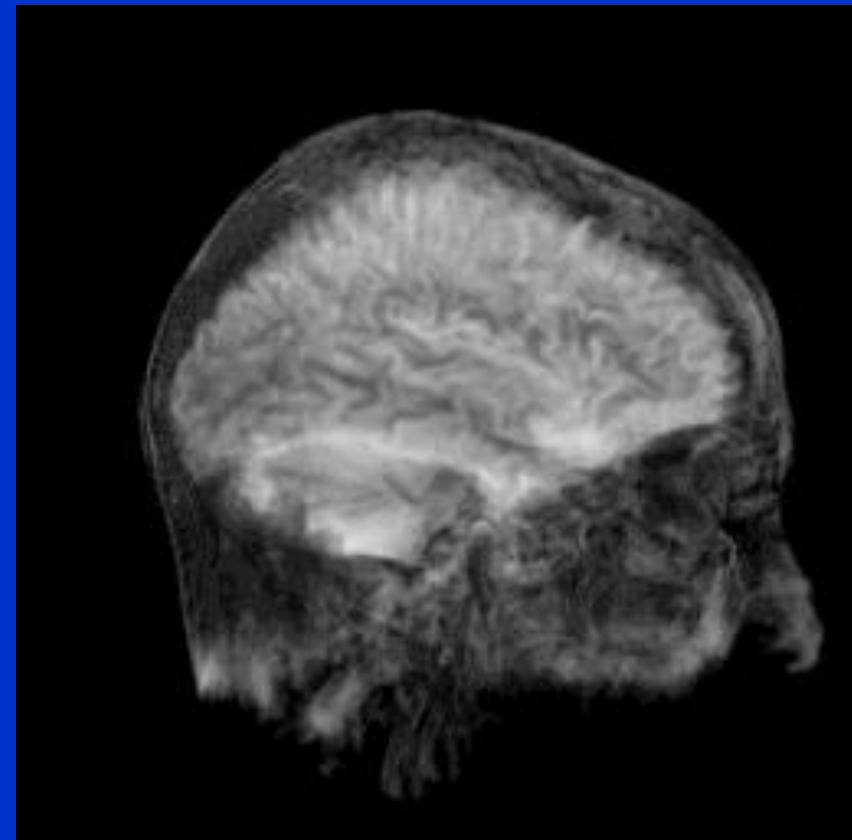
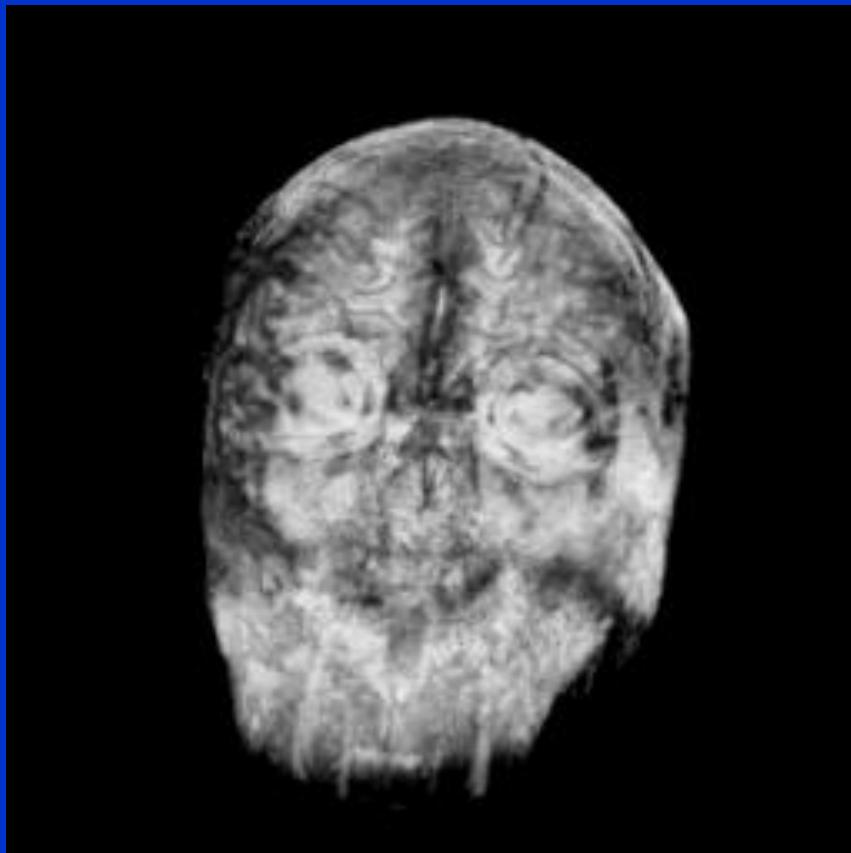


T2 Weighted



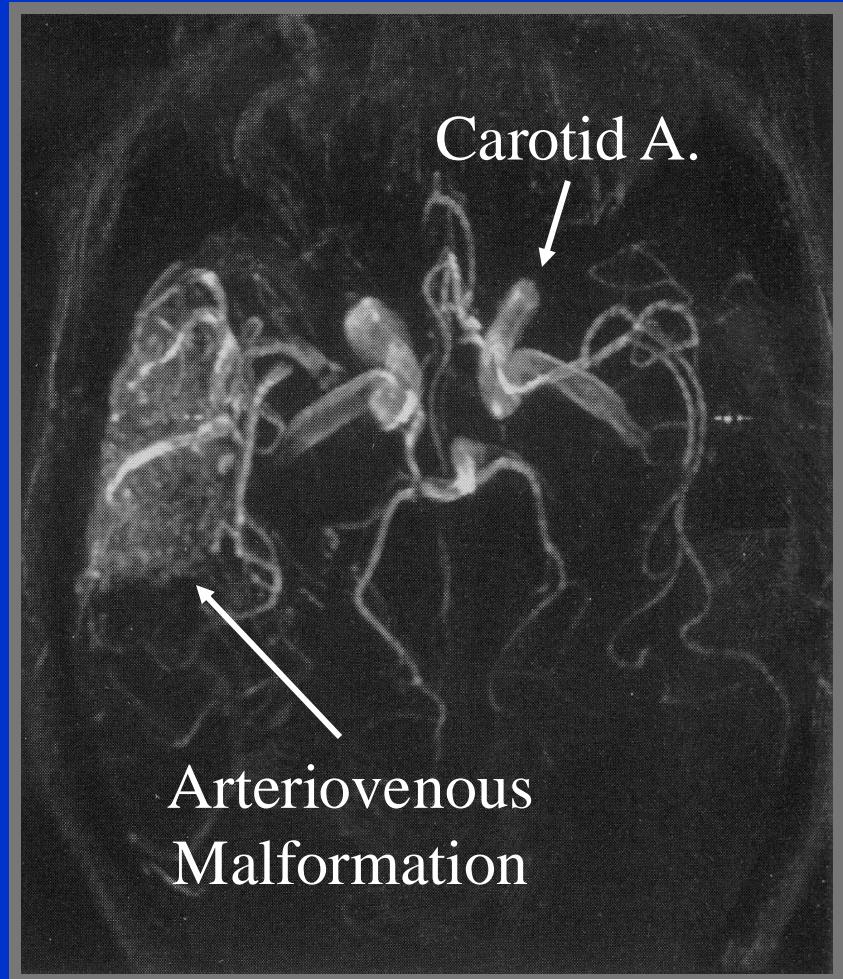
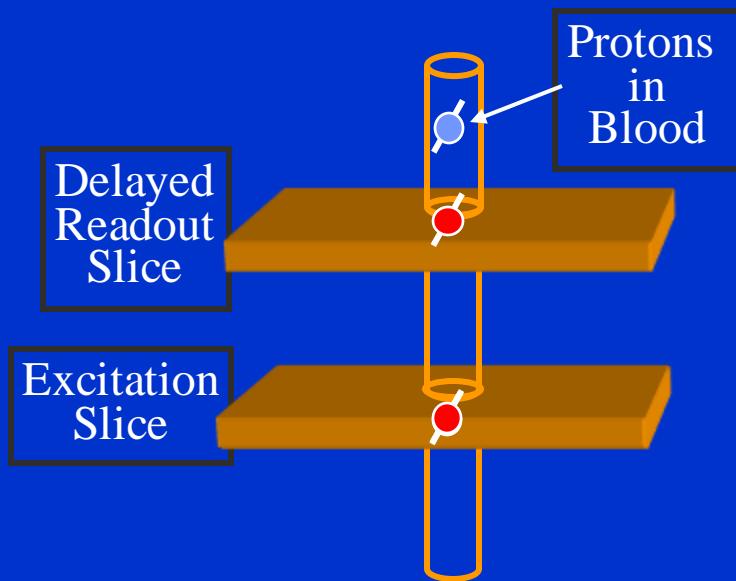


# 3D Rendered MRI

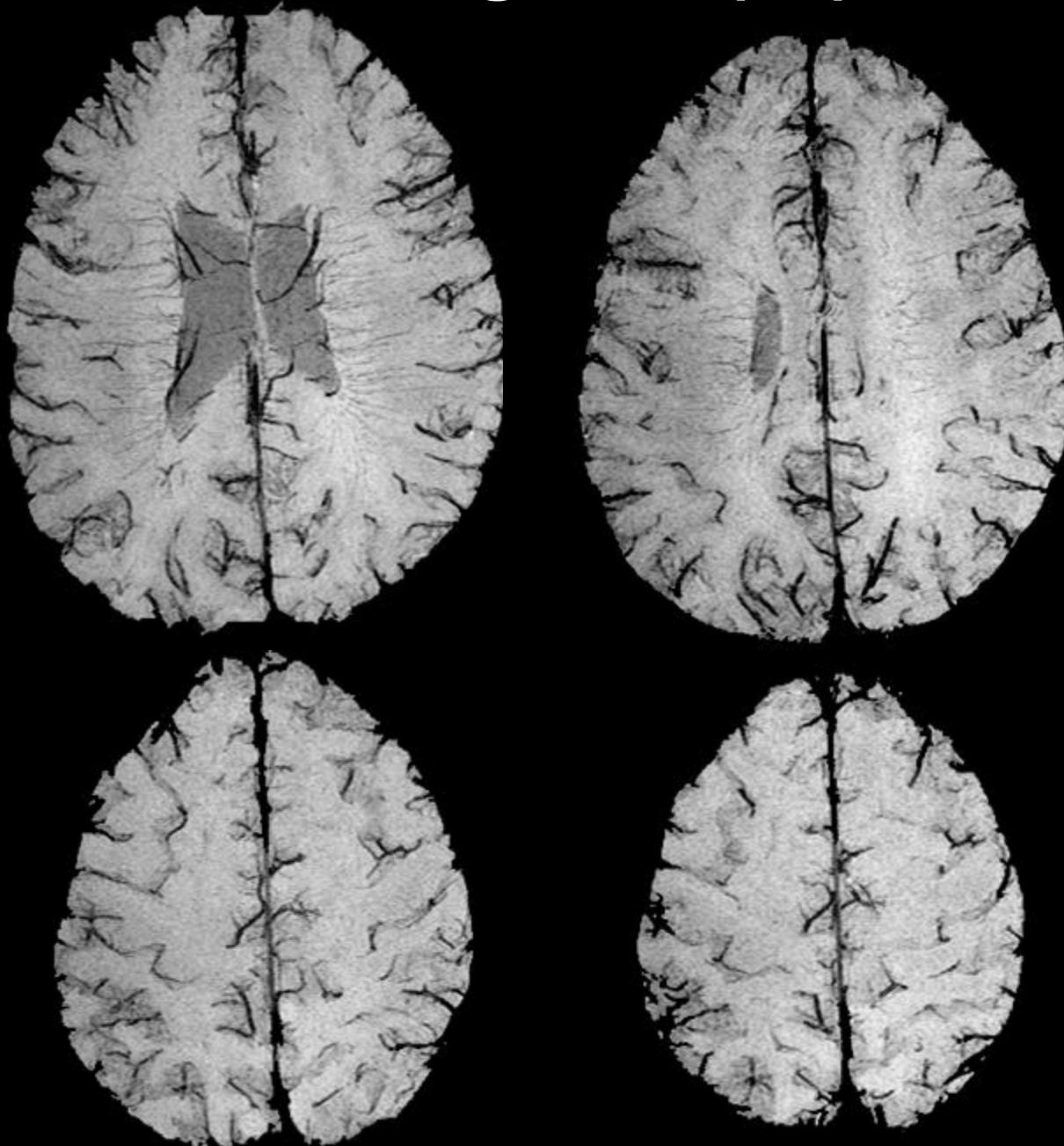


# MR Angiography Shows Blood Vessel Structure

- Blood vessel structure can be visualized by injection of MR tracers or by “spin tagging” techniques.



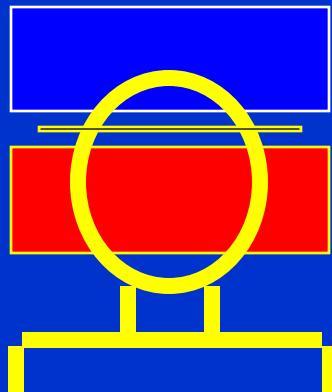
# Venograms (3T)



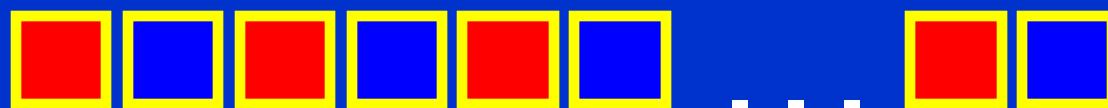
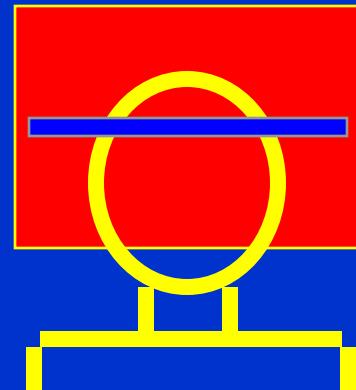


# Perfusion / Flow Imaging

EPISTAR

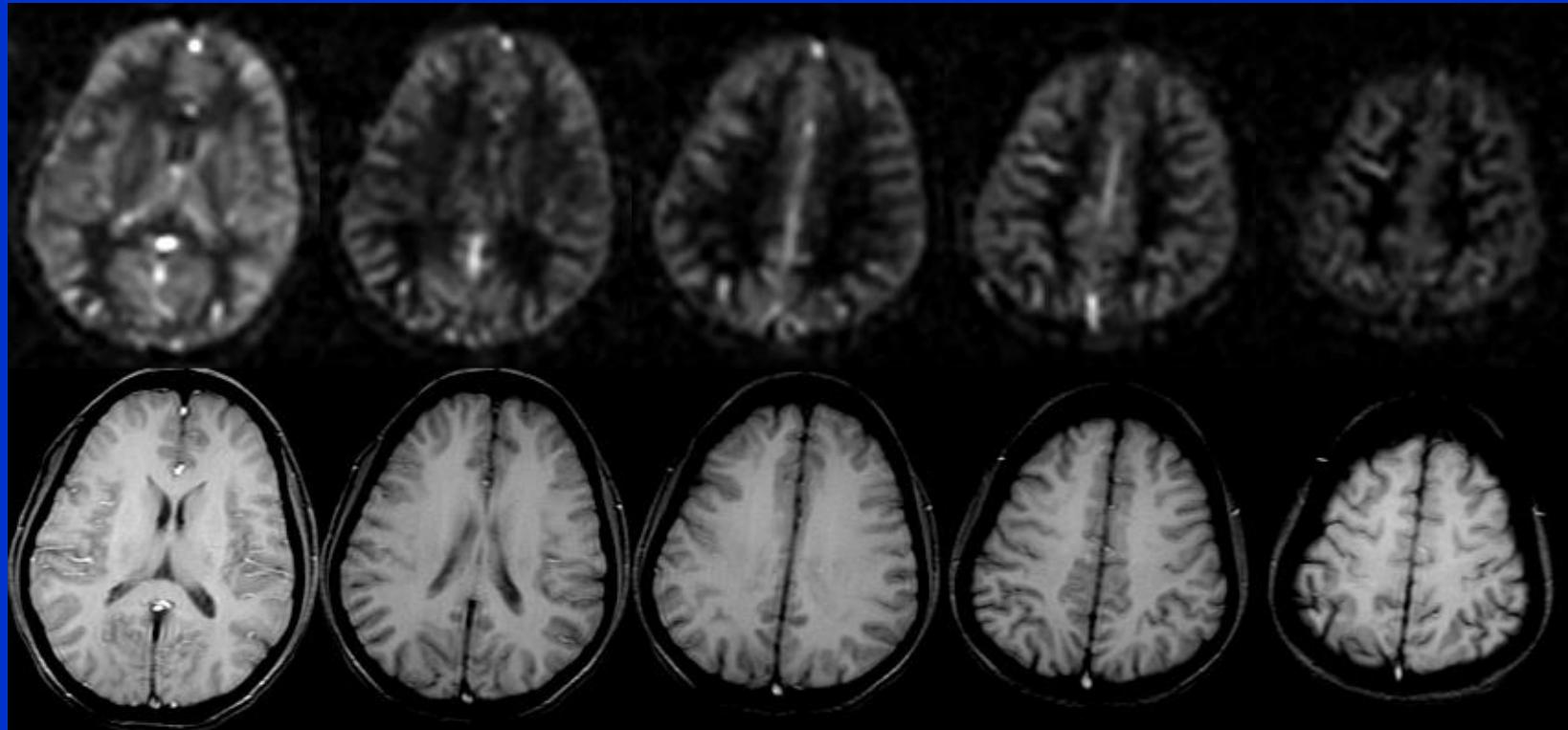


FAIR

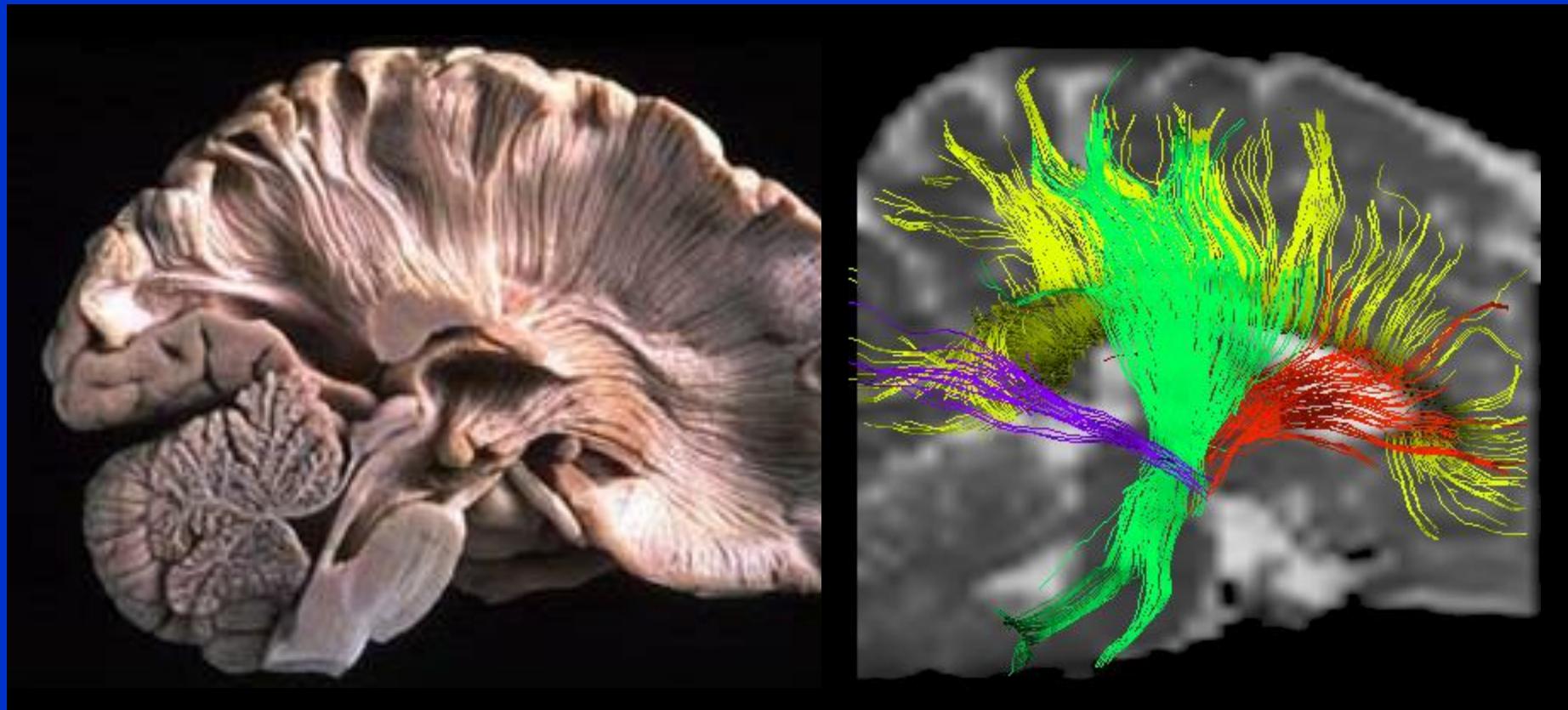


Perfusion  
Time Series

# Perfusion Imaging with MRI

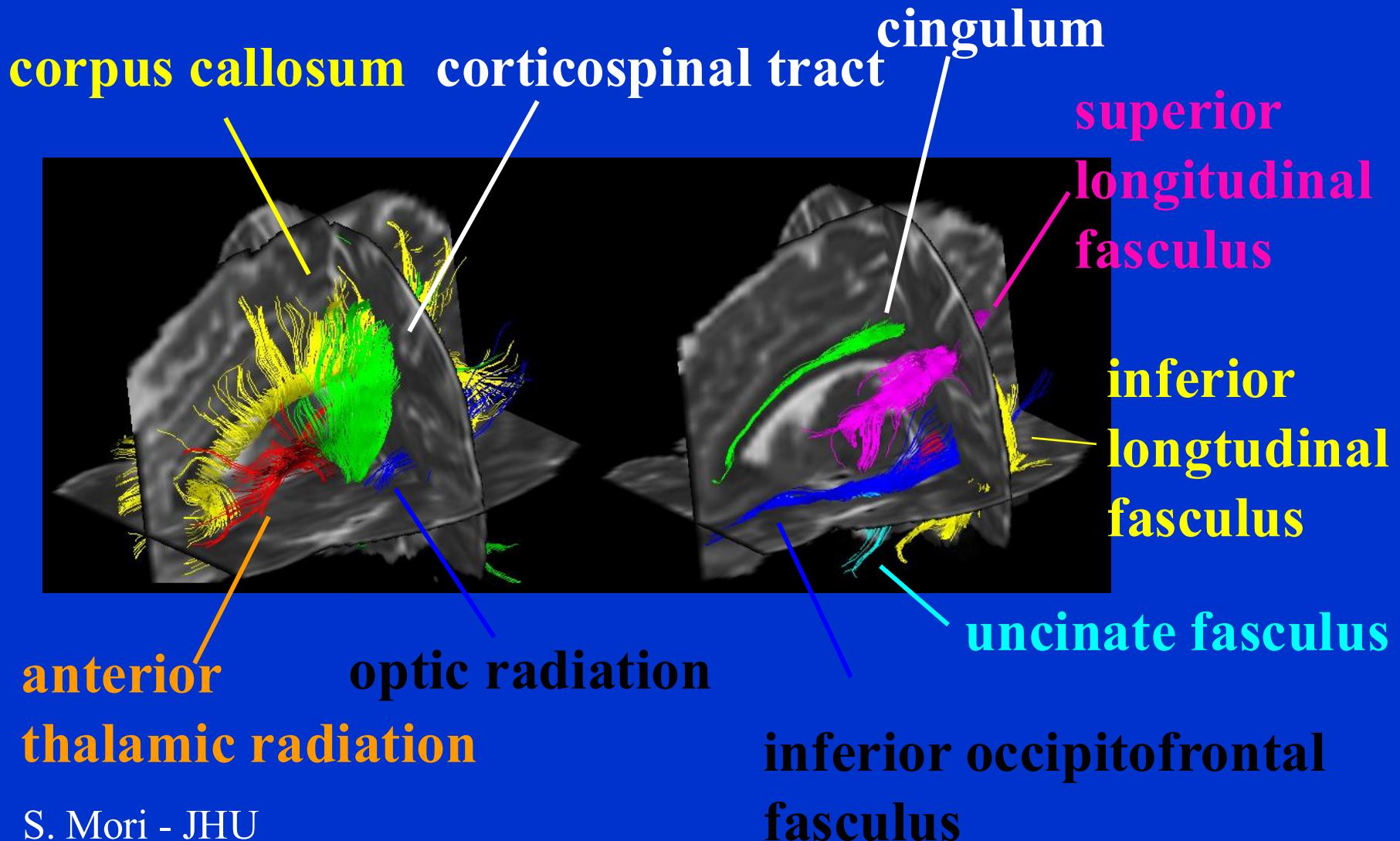


# Diffusion Tensor Imaging



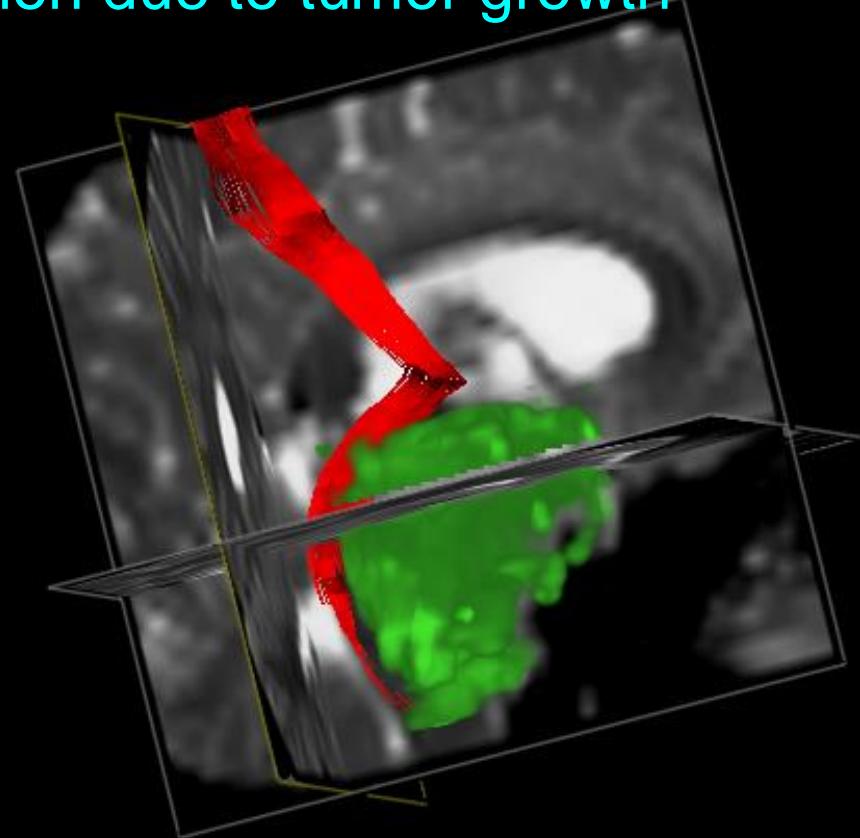
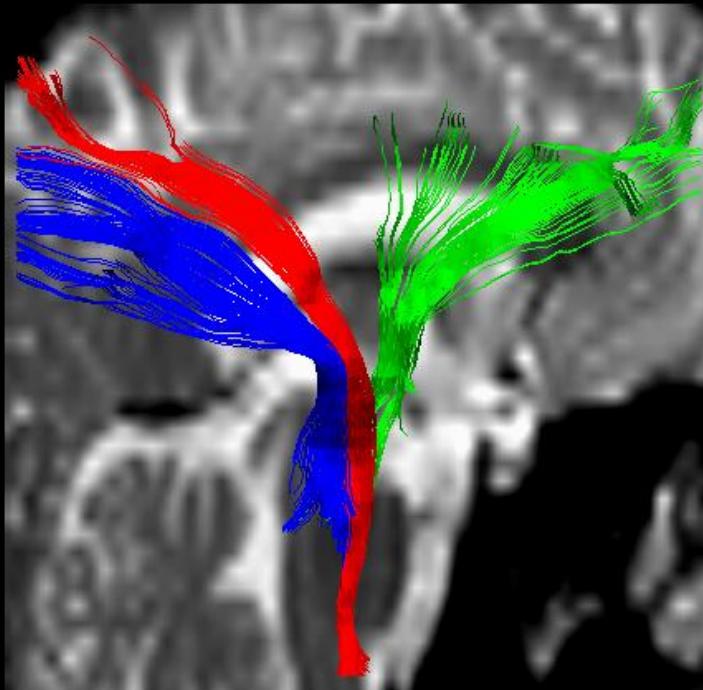
S. Mori - JHU

# Diffusion Tensor Imaging

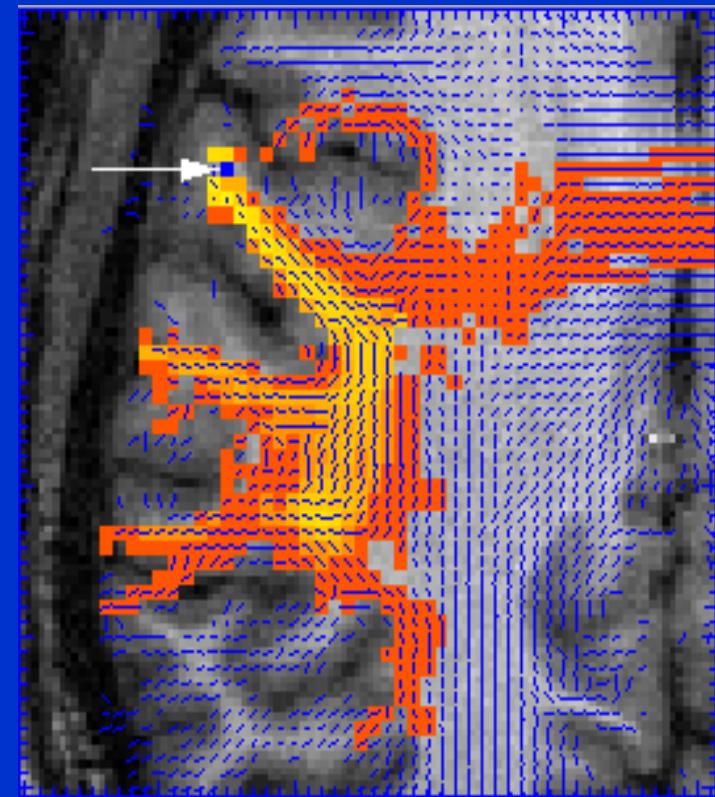
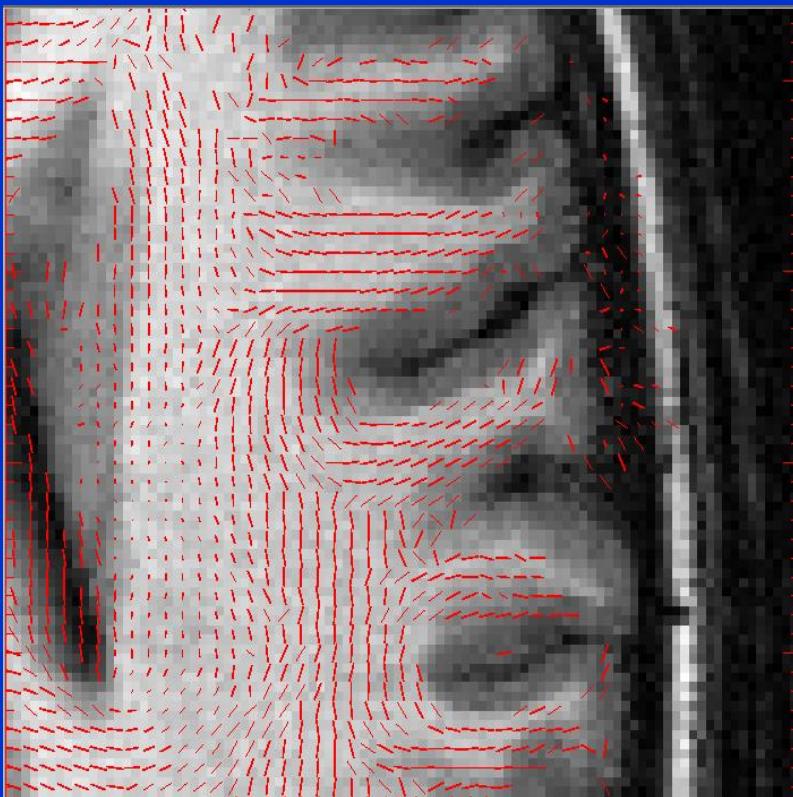


# Anatomical guidance with DTI:

Example: Anatomical deformation due to tumor growth

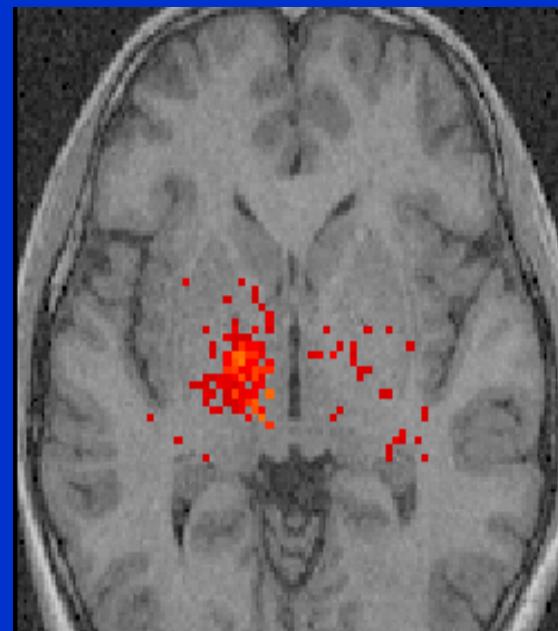
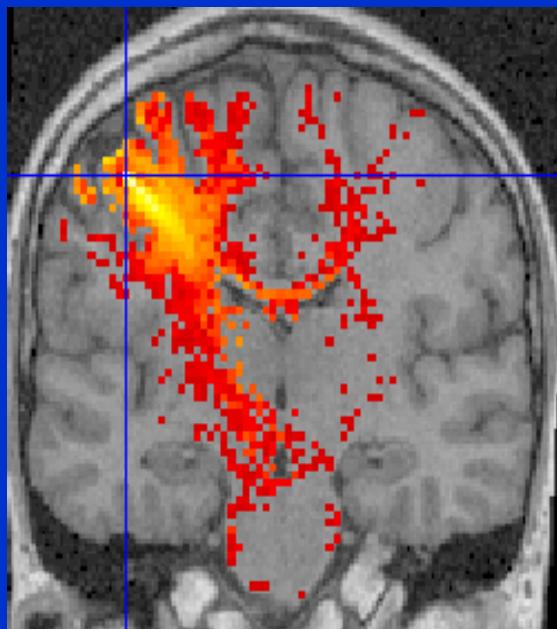


# DTI Connectivity



Koch and Norris, Max Planck, Leipzig

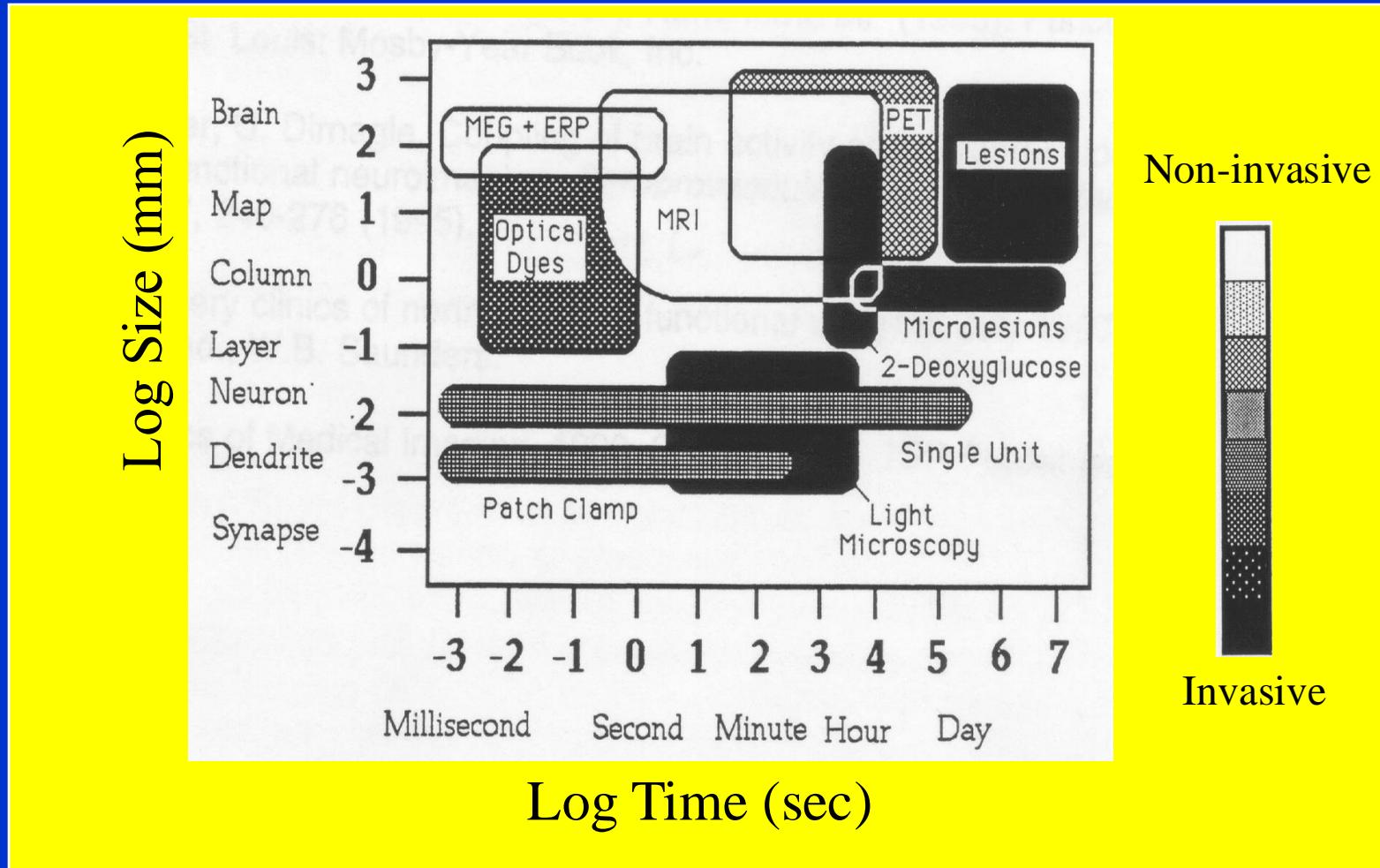
# DTI Connectivity



# Functional Imaging

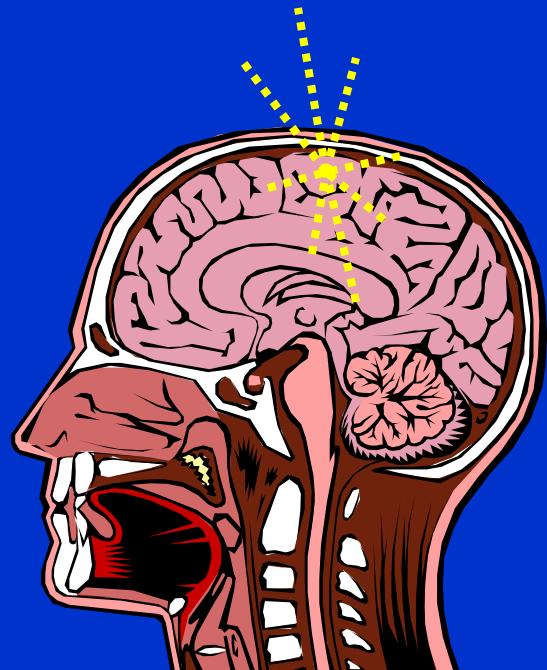
- Unlike structural imaging, functional imaging provides pictures of brain physiology or chemistry.
- By targeting factors that are related to brain activity (eg. blood flow and oxygenation), images of brain activation can be obtained.
- Functional imaging has been used for pre-surgical mapping of function and, eventually, may replace or augment more traditional tests.
- Functional imaging is now a major new research paradigm in neuroscience.

# Functional Neuroimaging Techniques

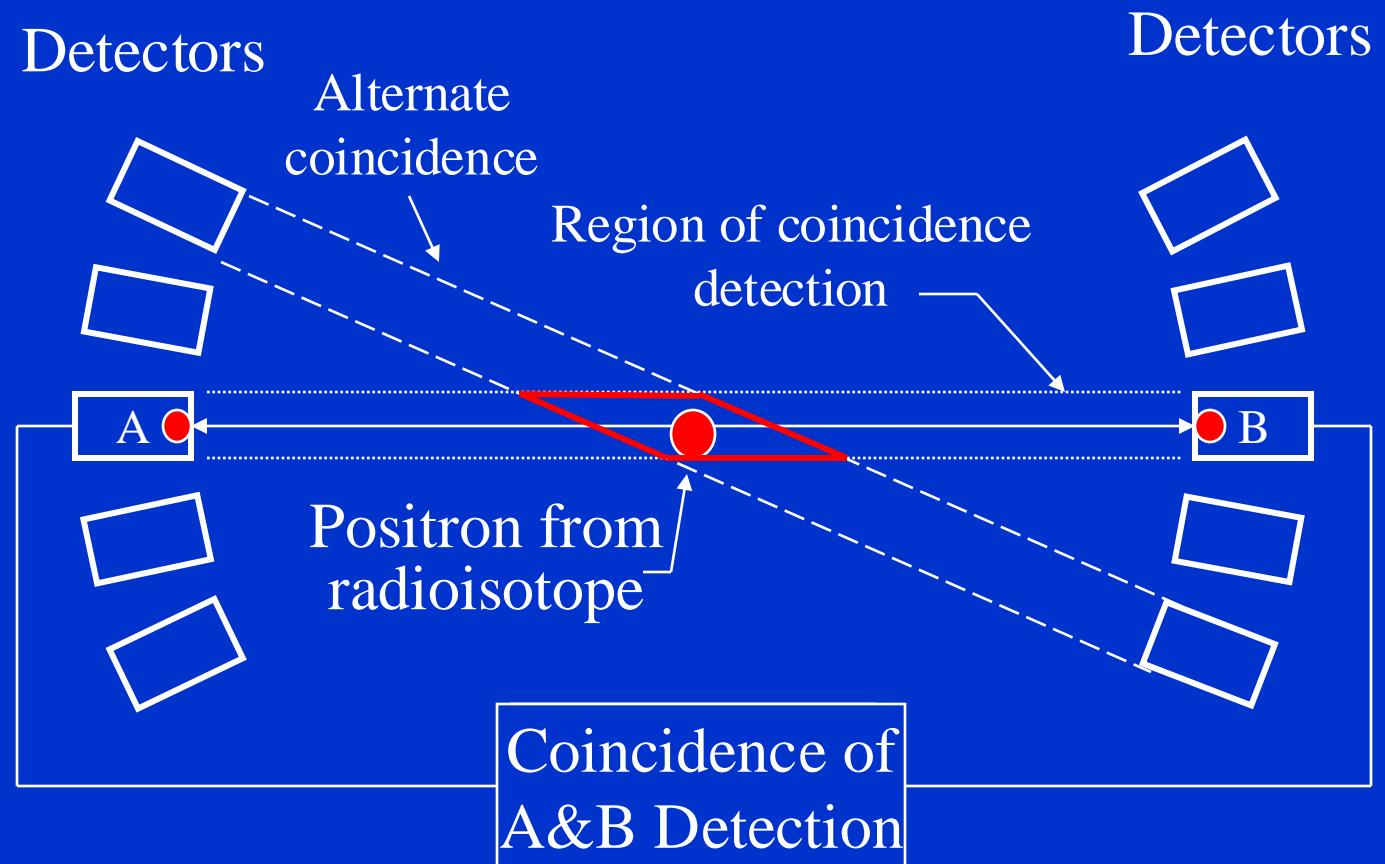


# Positron Emission Tomography (PET)

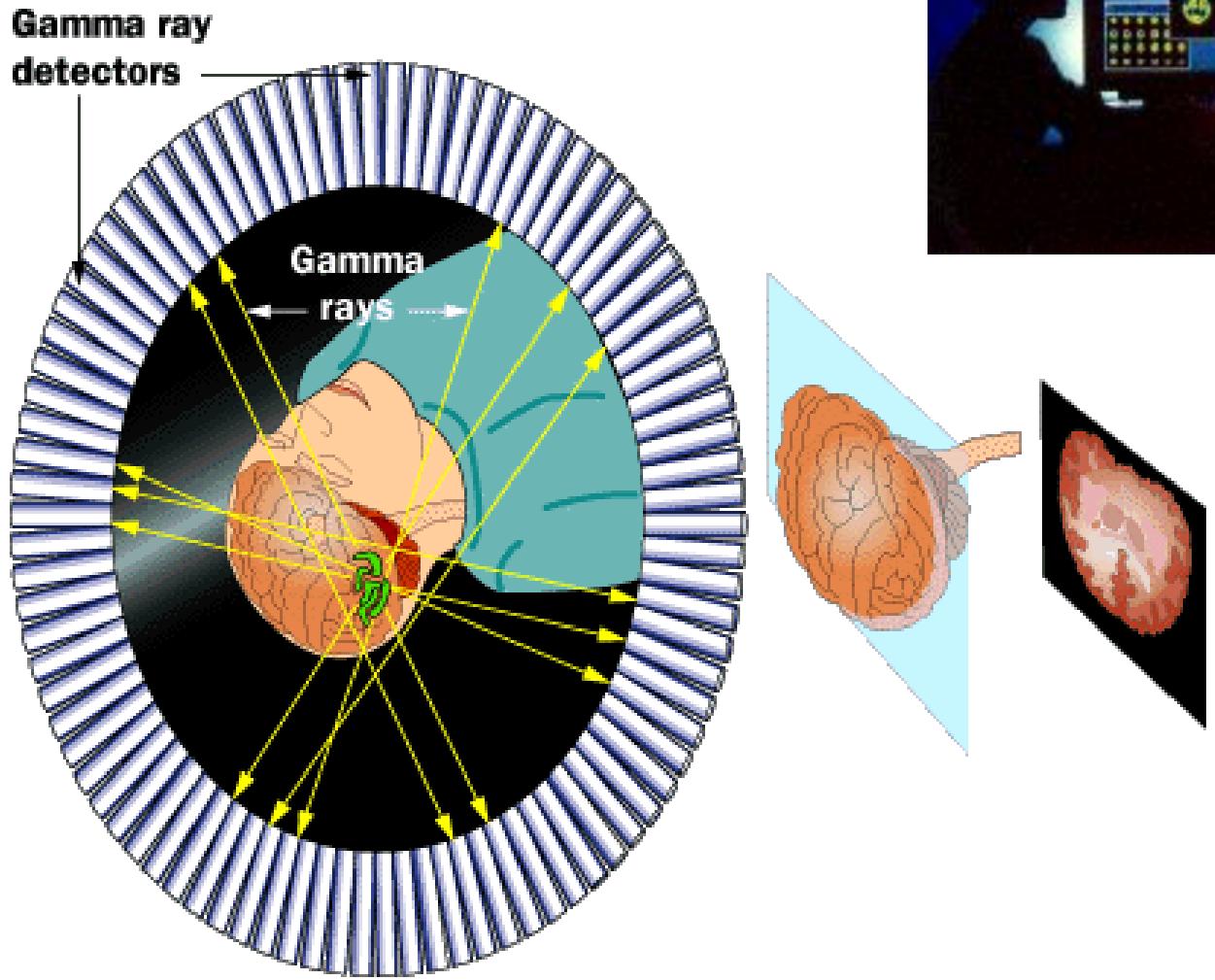
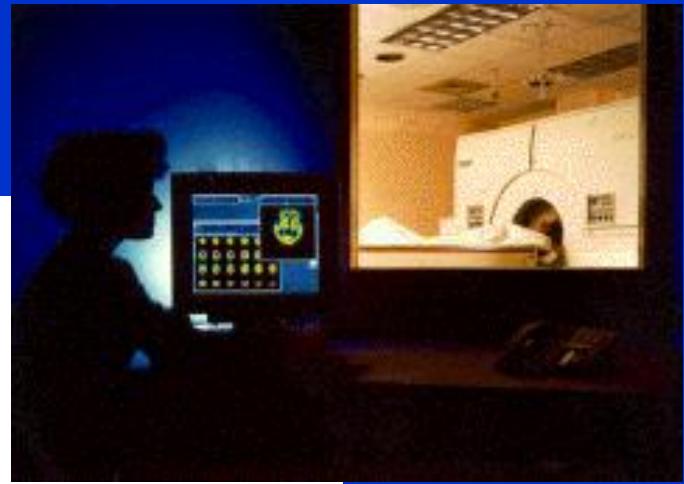
- Positron emission tomography (PET) is a technique for studying functional processes *in vivo* by measuring the concentrations of positron-emitting radioisotopes within the subject.
- PET is primarily used to study biochemical and physiological processes within living organs with 3-dimensional spatial resolution.



# PET mechanism



# Positron Emission Tomography

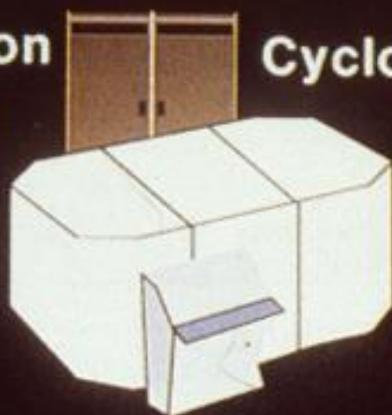




# Imaging of neuroreceptors by PET

Isotope production

[ $^{11}\text{C}$   $^{18}\text{F}$   $^{13}\text{N}$   $^{15}\text{O}$ ]



Cyclotron

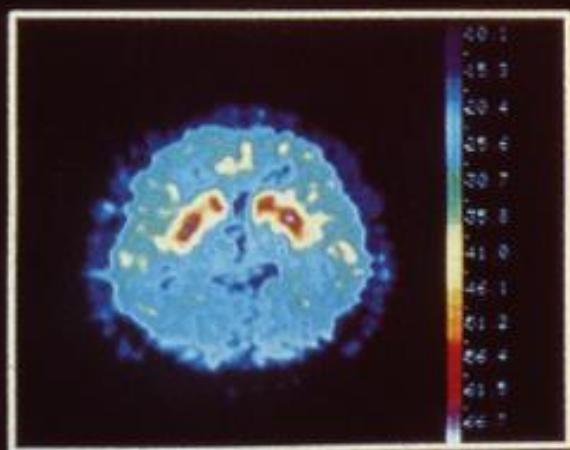
$^{11}\text{CO}_2$

Radio chemistry

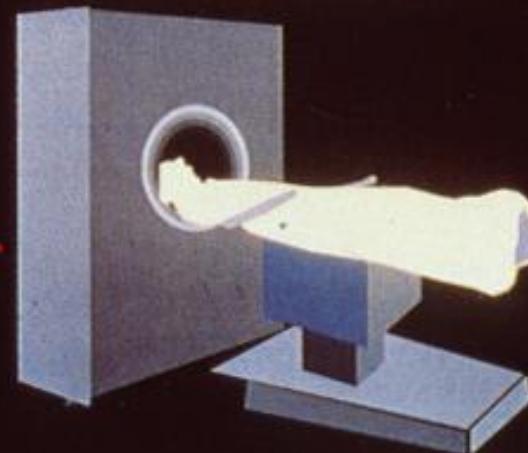
Precursor



Image of  
ligand distribution  
in brain

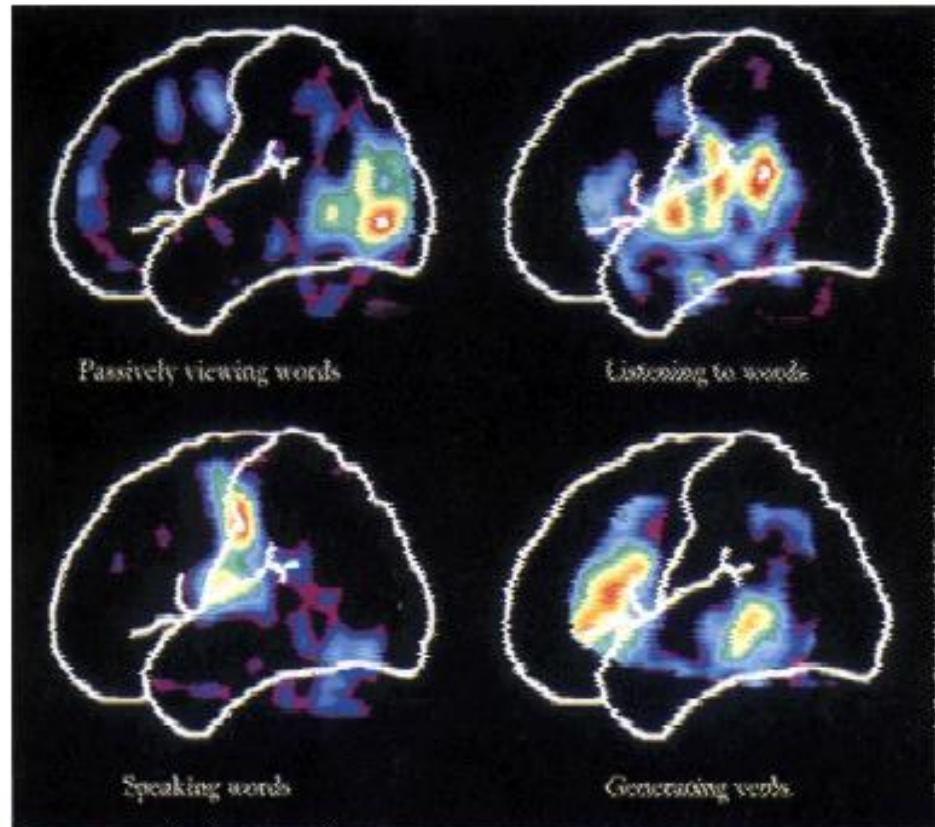
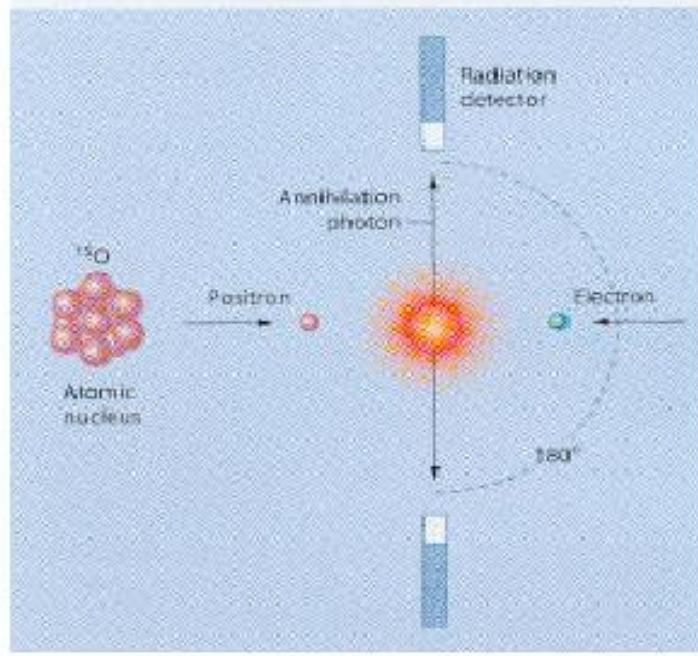


Positron camera

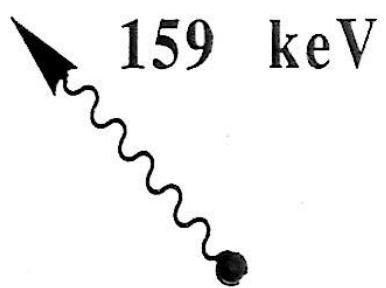


$^{11}\text{C}$ -ligand



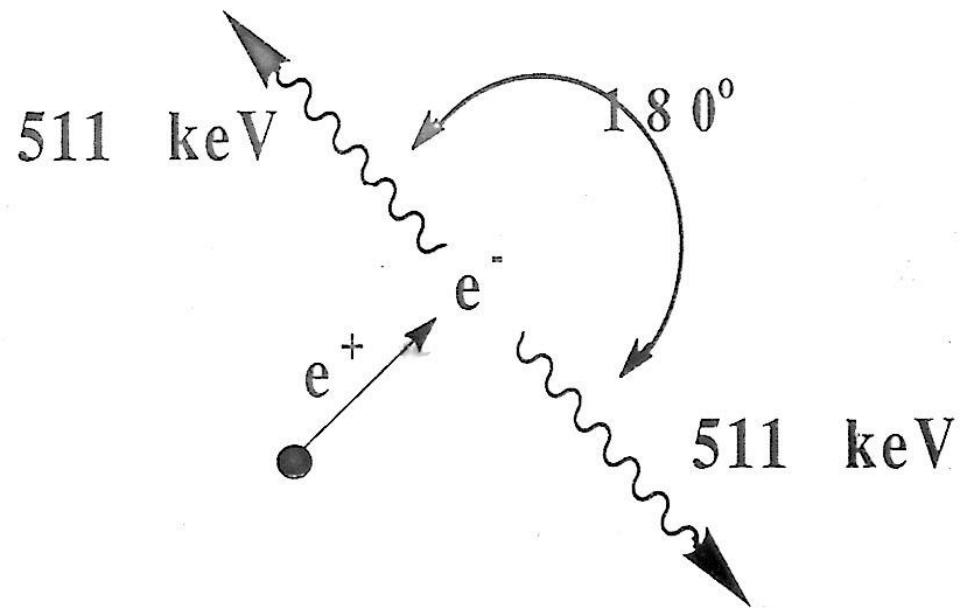


# SPECT



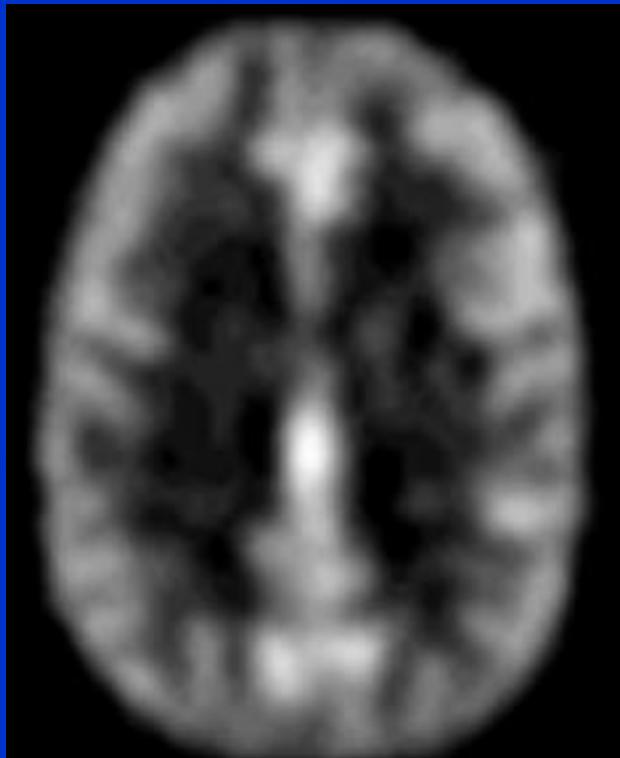
Single Photon  
Source  $^{123}\text{I}$

# PET

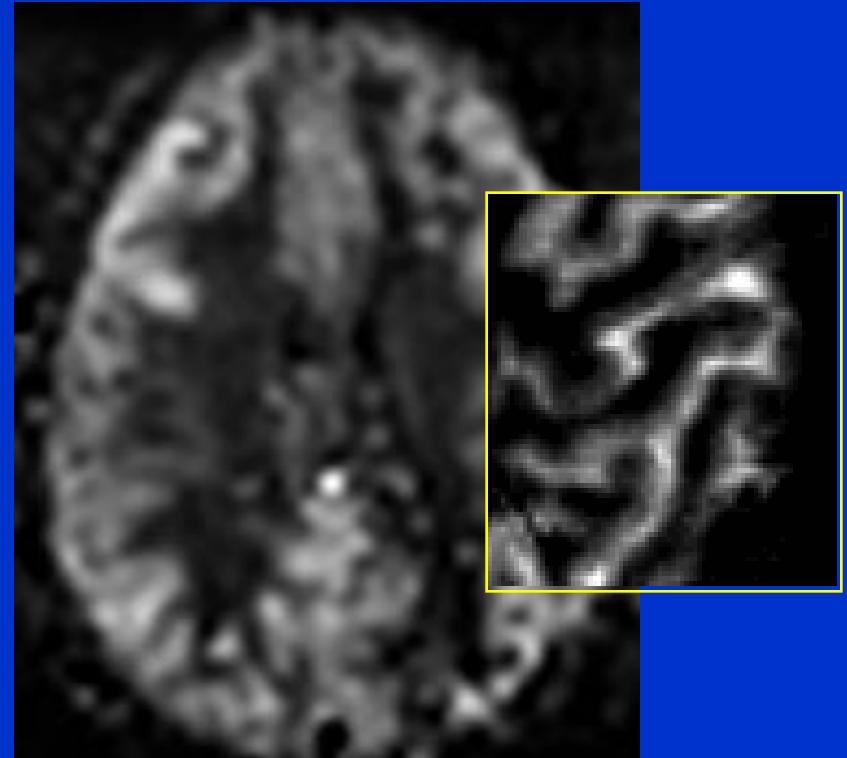


Positron Source

# Comparison with Positron Emission Tomography

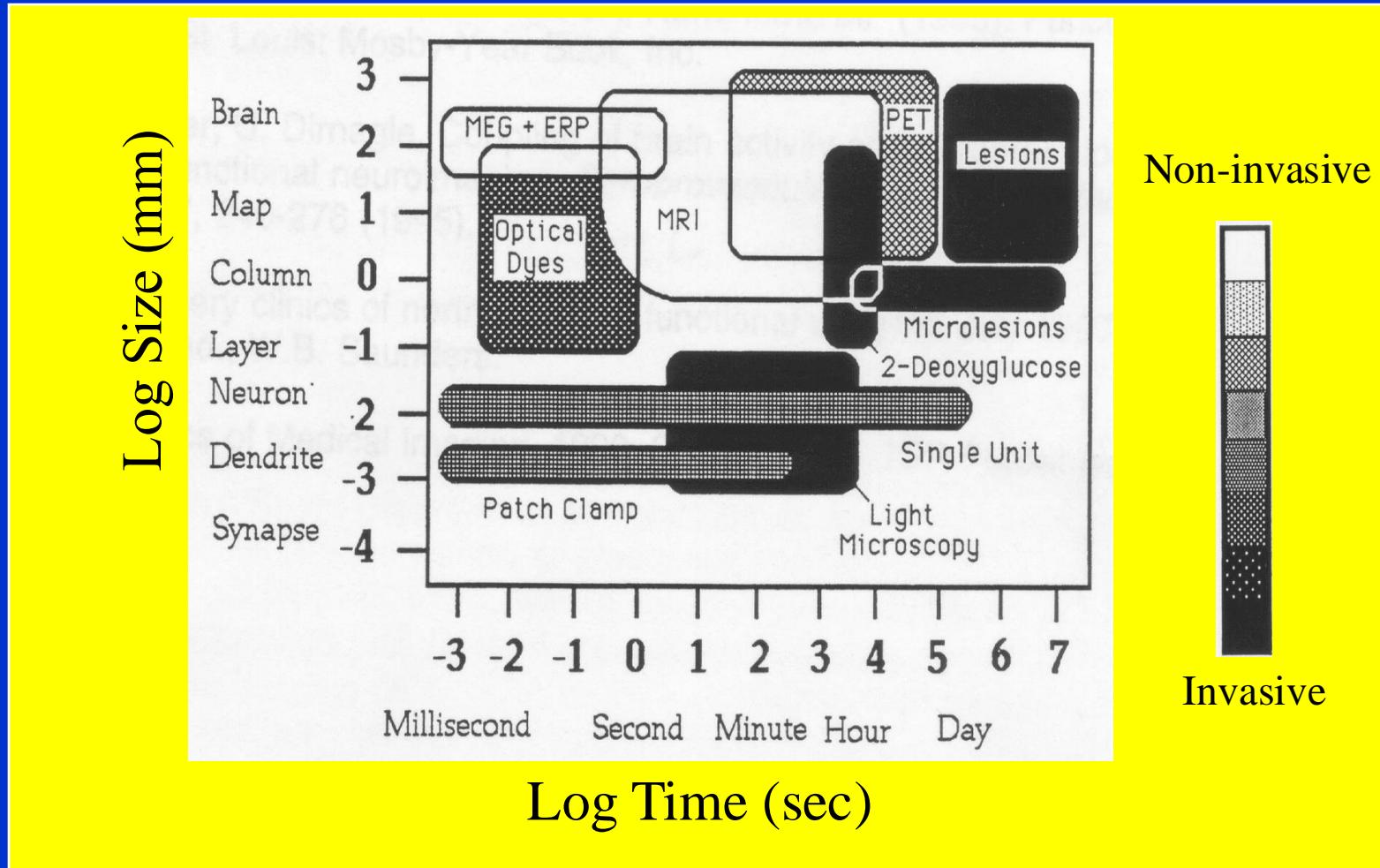


PET:  $\text{H}_2^{15}\text{O}$



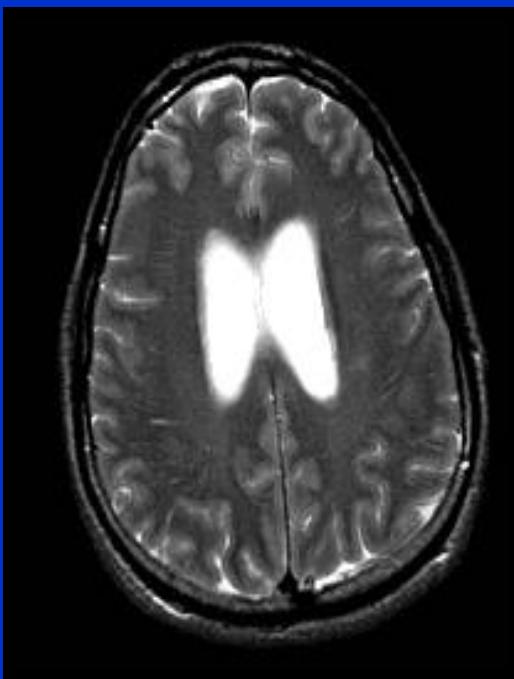
MRI: ASL

# Functional Neuroimaging Techniques

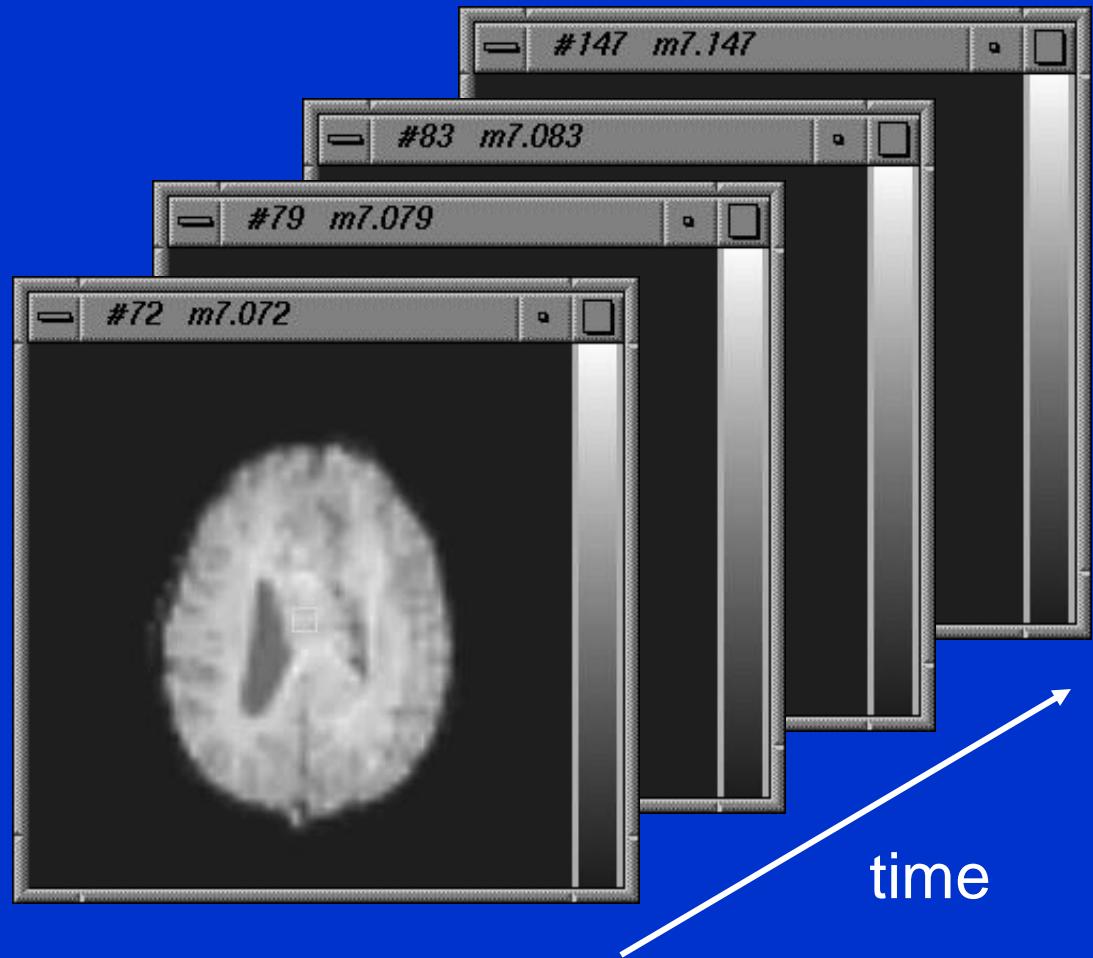


# Contrast in Functional MRI

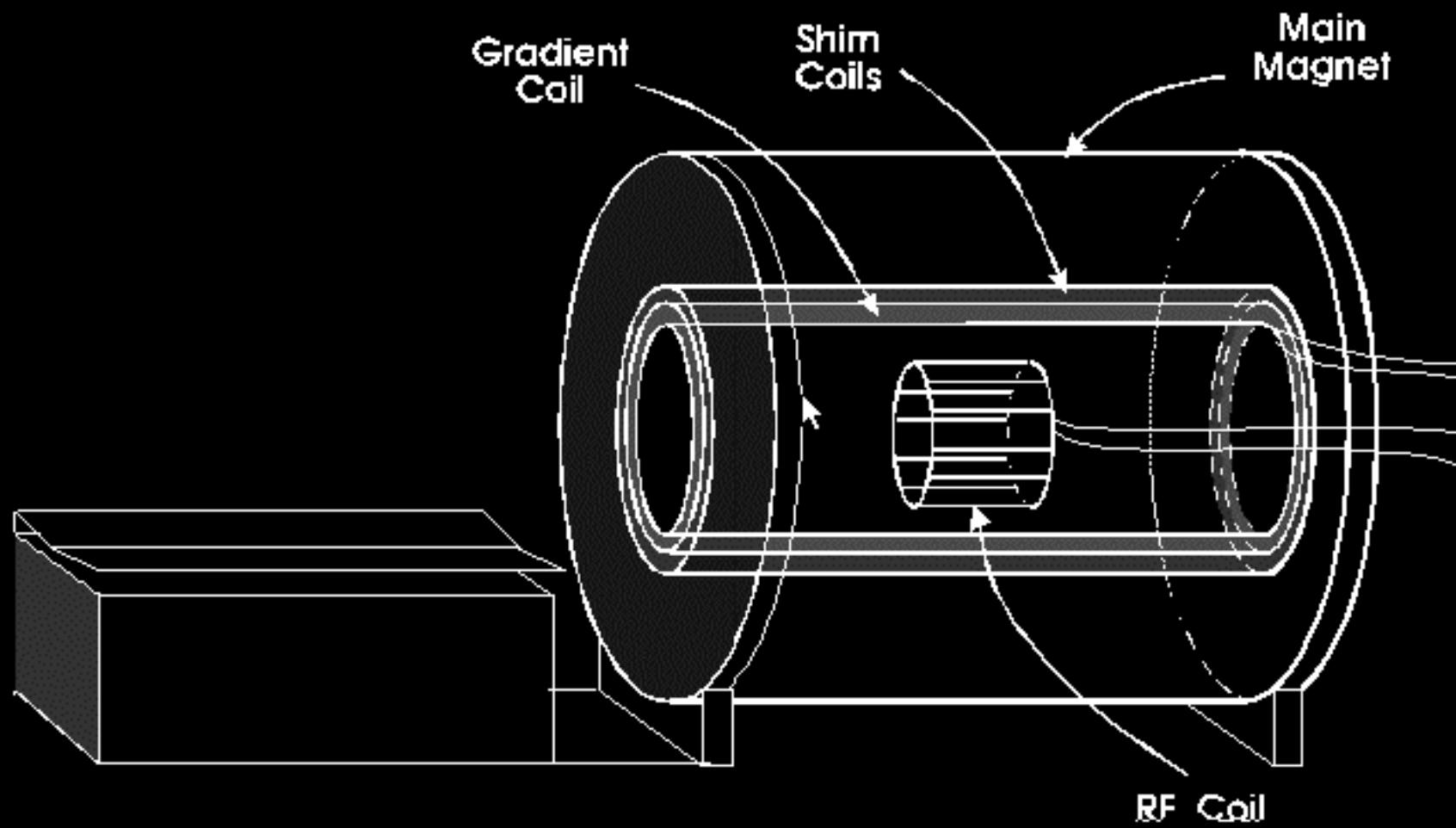
- Blood Volume
- **BOLD** (Blood Oxygenation Level Dependent Contrast)
- Perfusion
- CMRO<sub>2</sub>



Anatomic



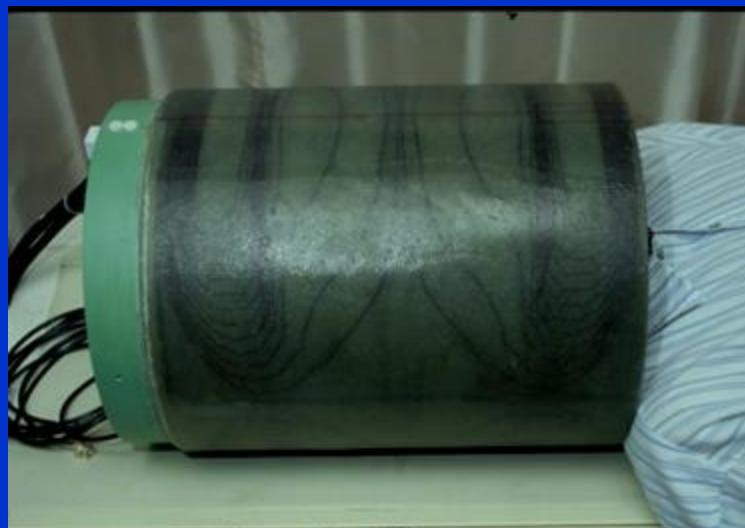
Functional



**1991-1992**



**1992-1999**



# General Electric 3 Tesla Scanner





# MRI Instrumentation

Computer  
Graphics



Video Image  
Source

Baseline Task

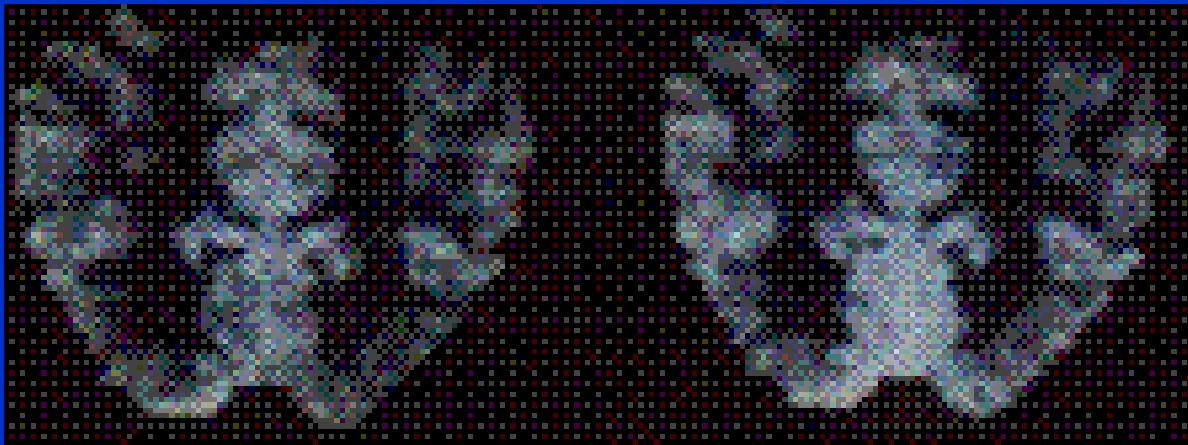
Experimental Task



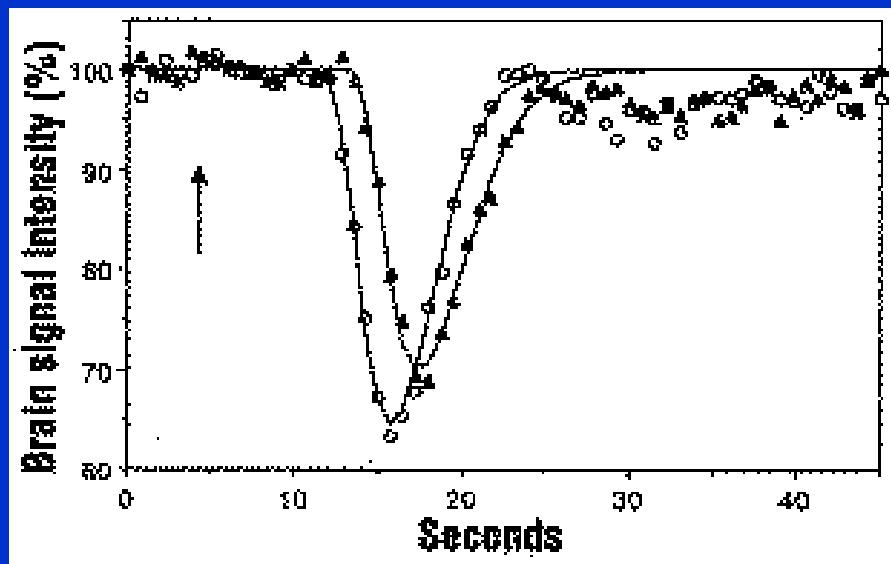
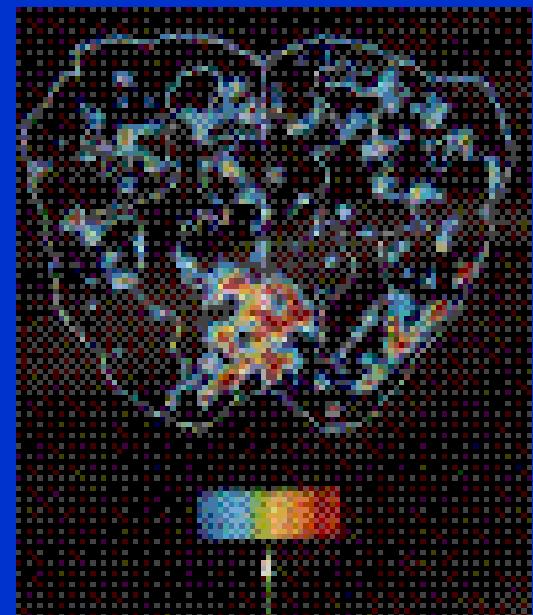


# Blood Volume Changes with Brain Activation

**Resting**



**Active**

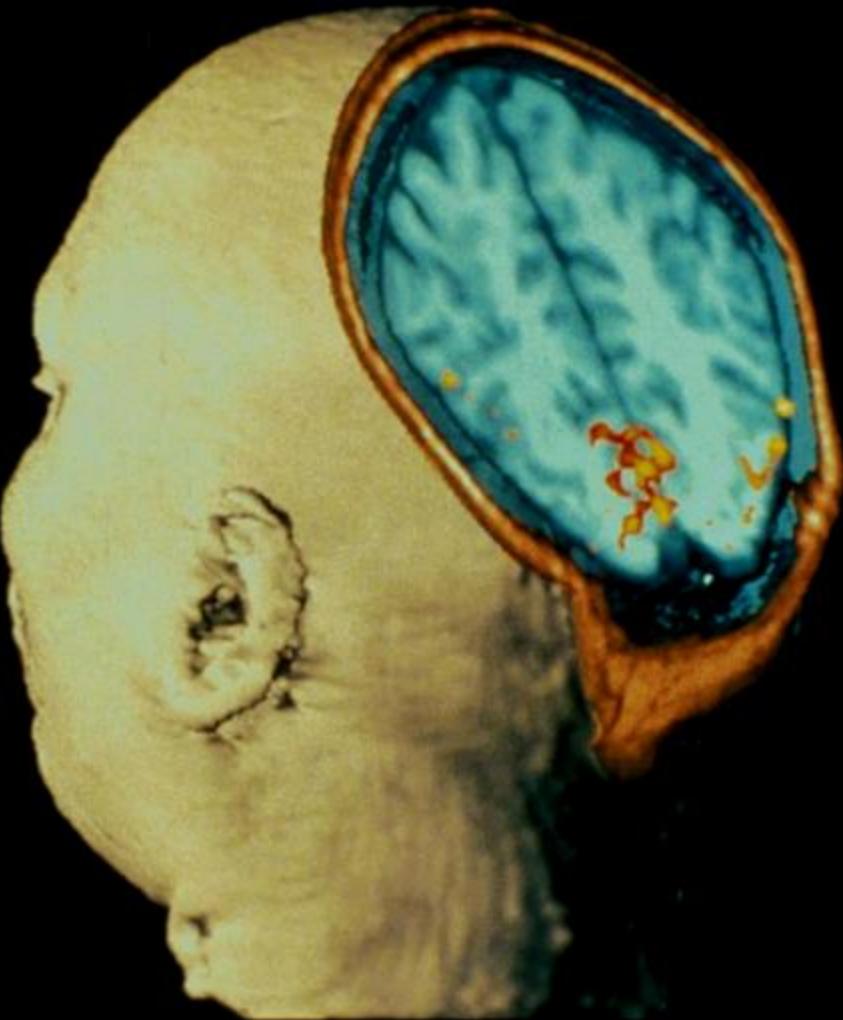


# Photic Stimulation

MRI Image showing  
activation of the  
Visual Cortex

From Belliveau, et al.  
Science Nov 1991

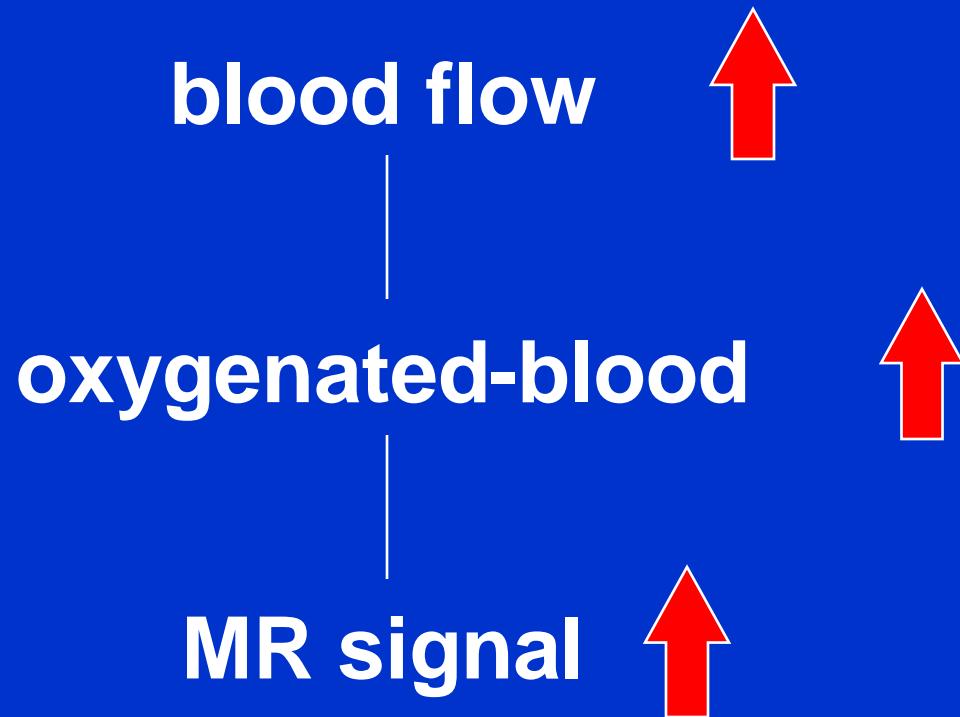
MSC - perfusion



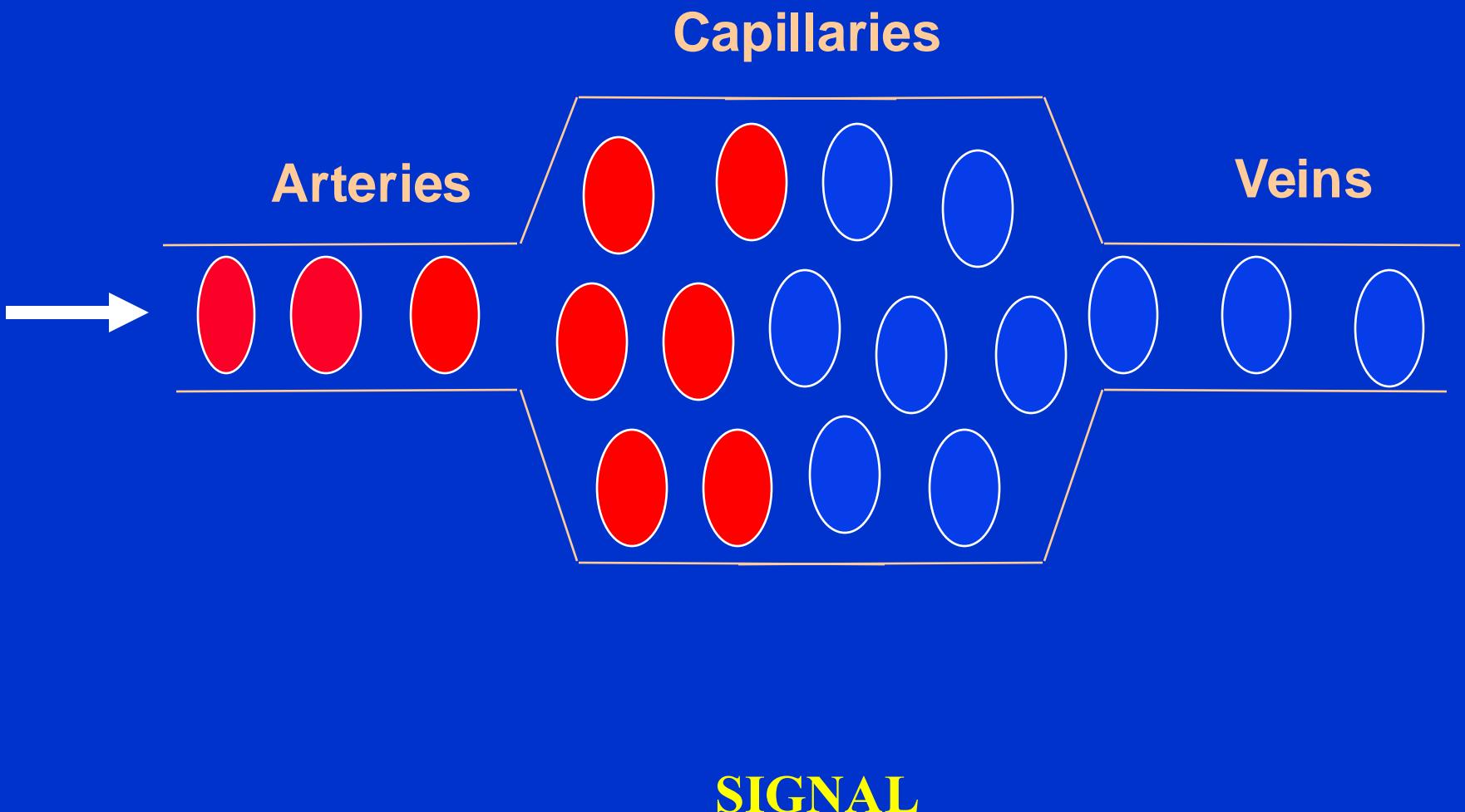
# BOLD

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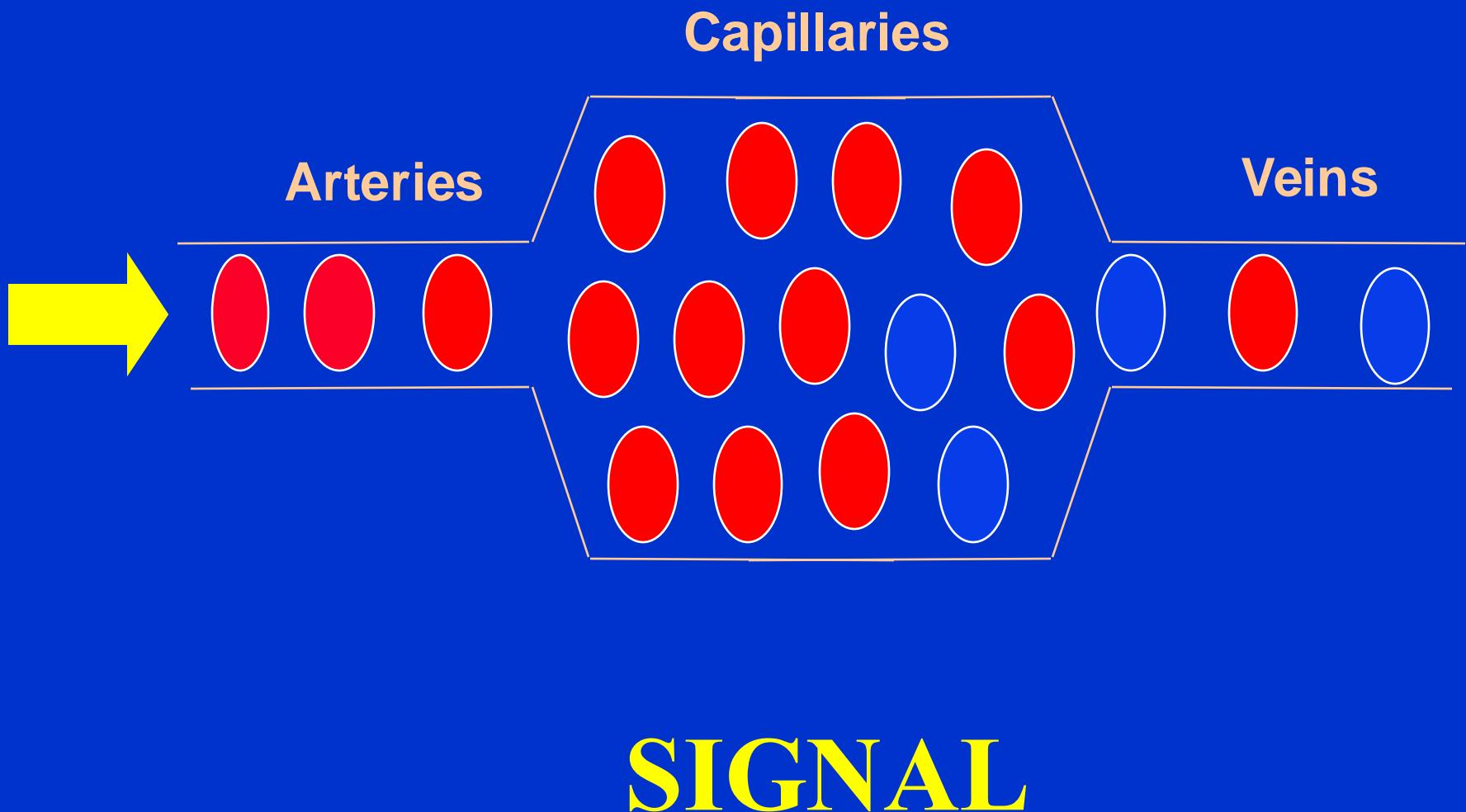
(**blood** oxygenation level dependence)



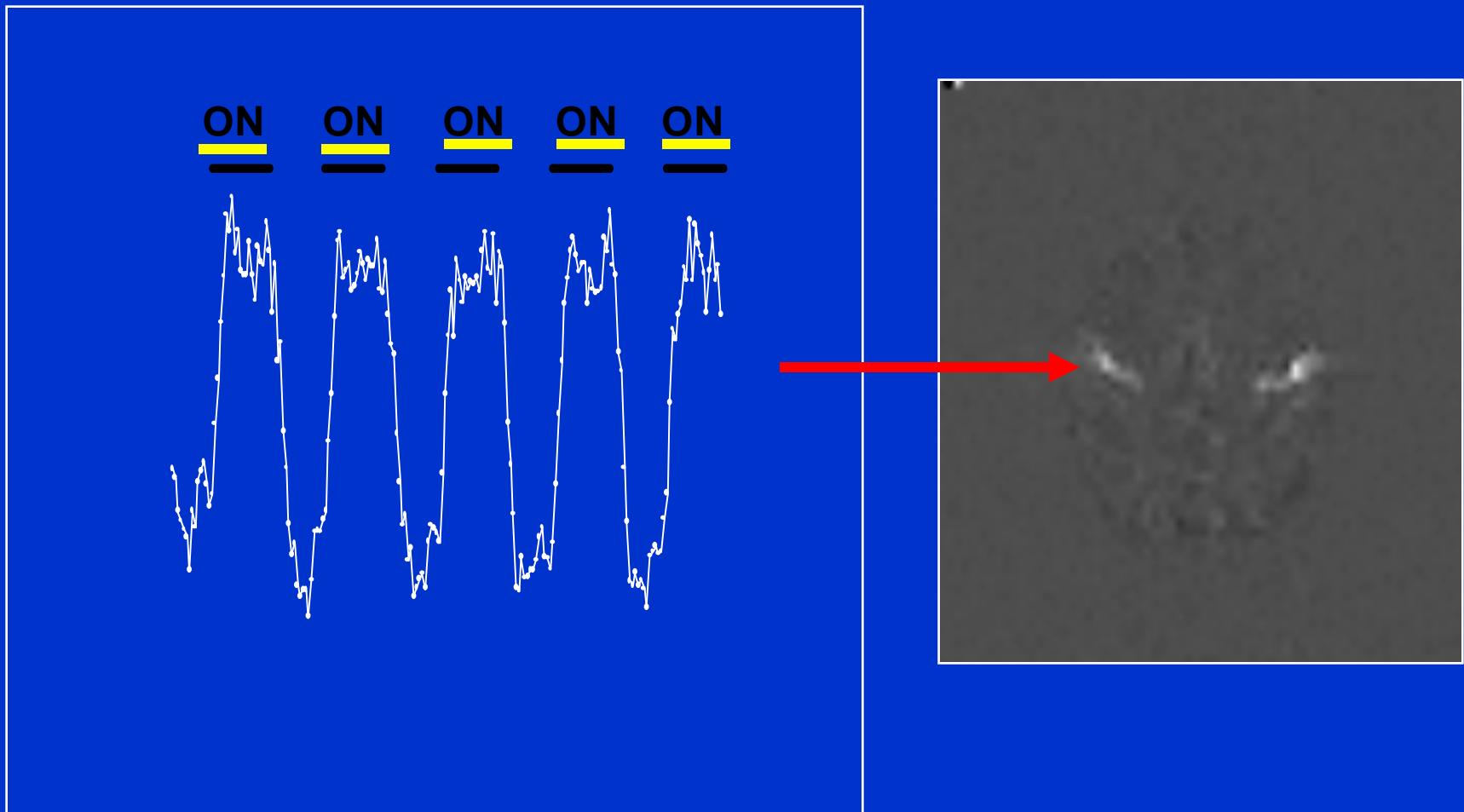
# **BOLD:** Resting Perfusion



# **BOLD:** Activated Perfusion

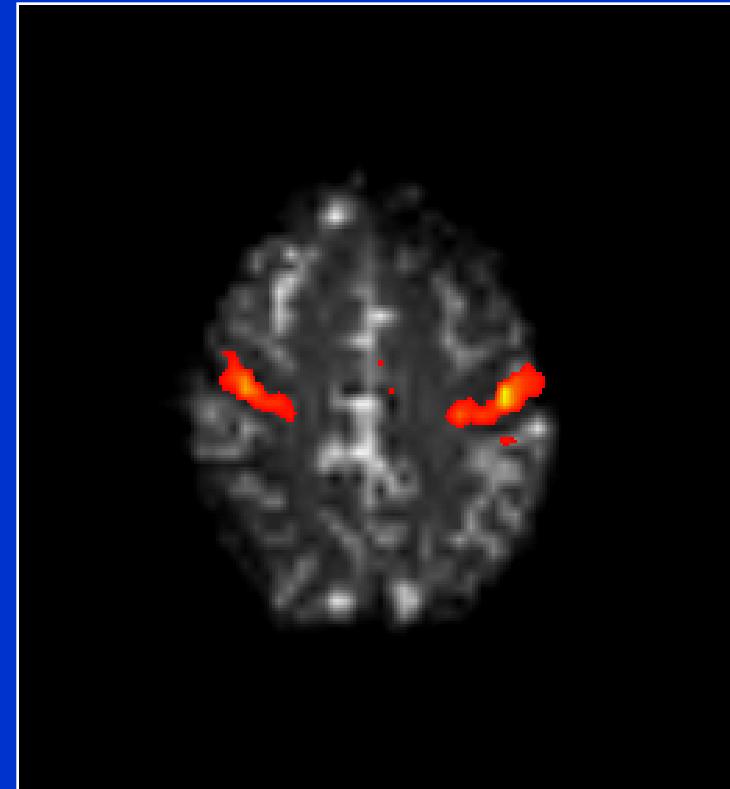


# BOLD: Motor Cortex Activation





Cross Correlation Image

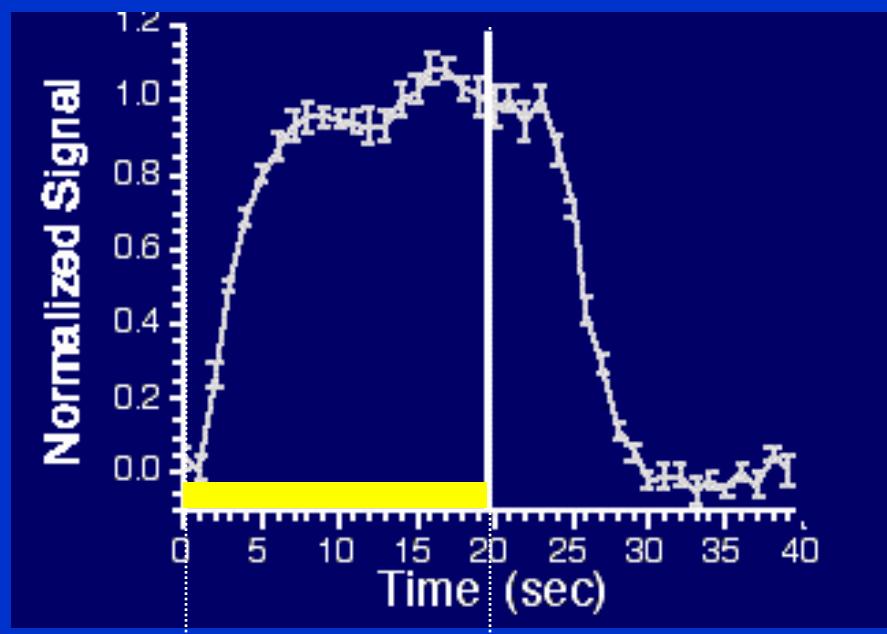


Cross Correlation Image  
Anatomical Image

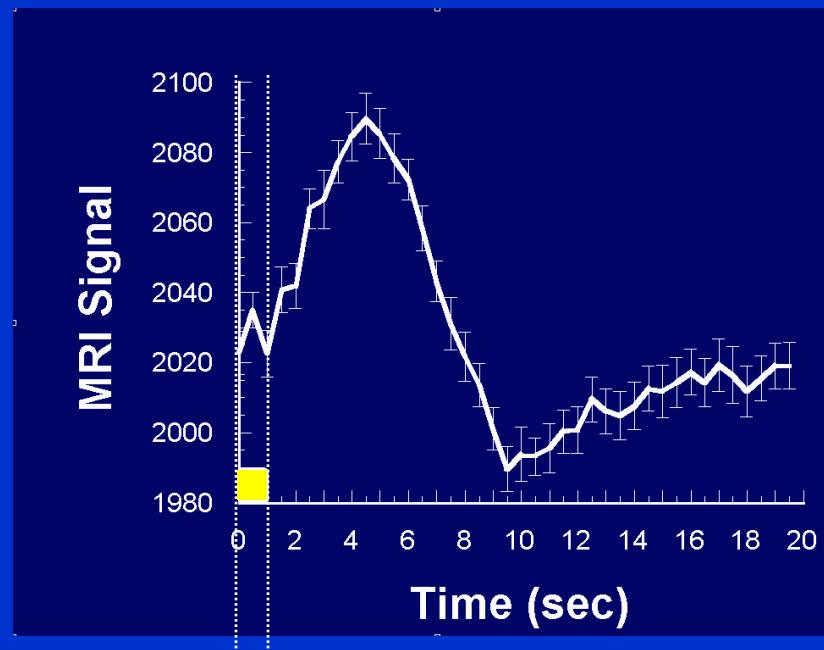


# The BOLD Signal

Blood Oxygenation Level Dependent (BOLD) signal changes



*task*

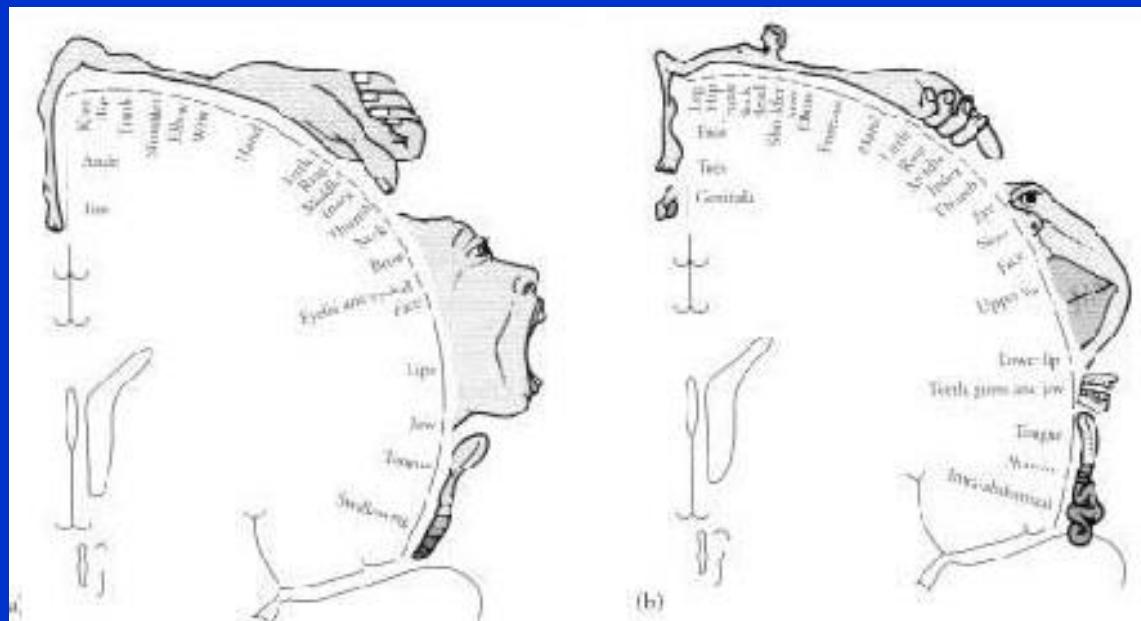
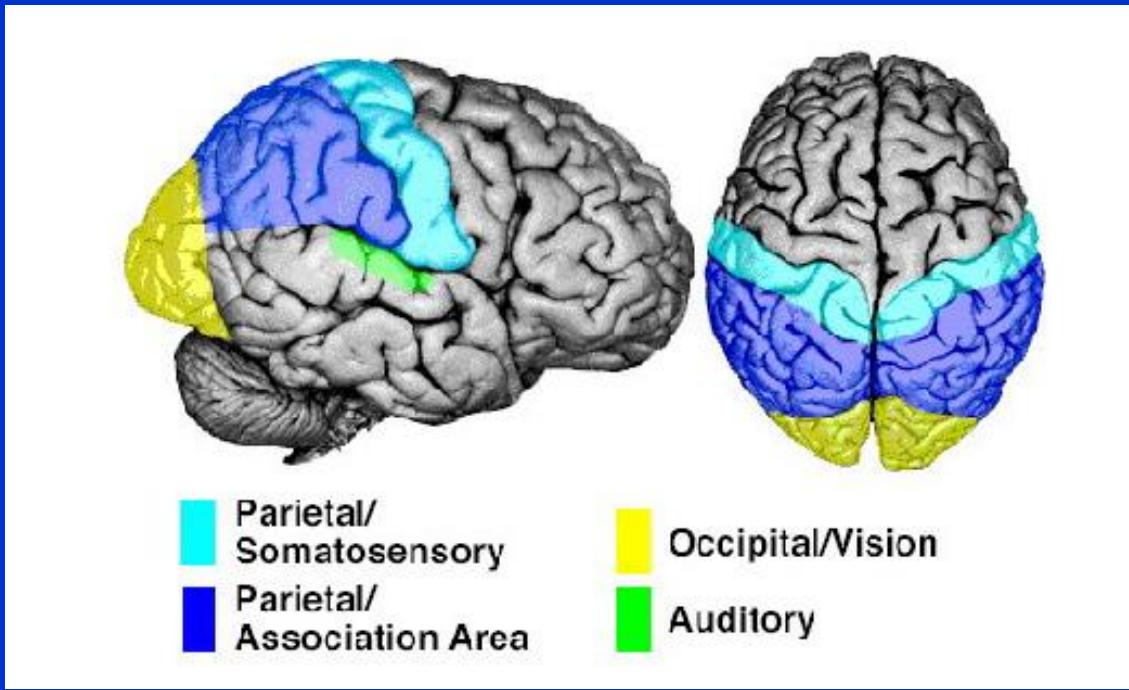


*task*

# Alternating Left and Right Finger Tapping

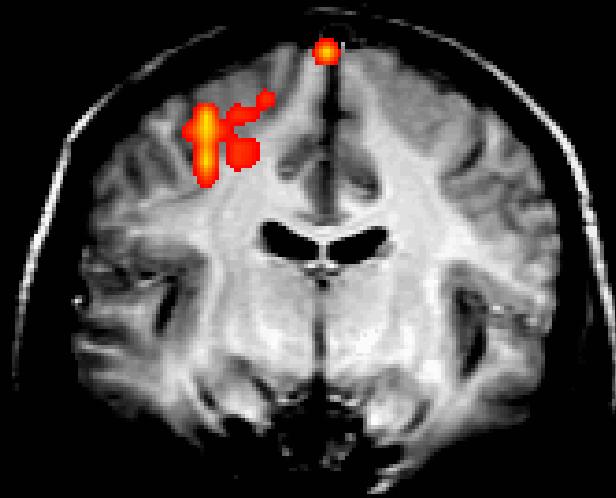


~ 1992

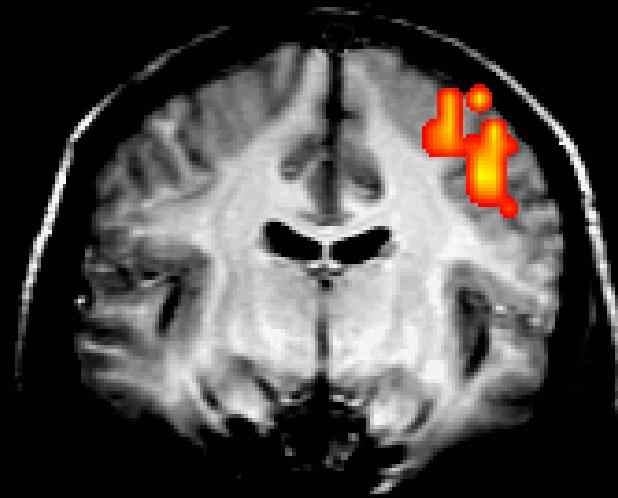


# Finger Movement

Left

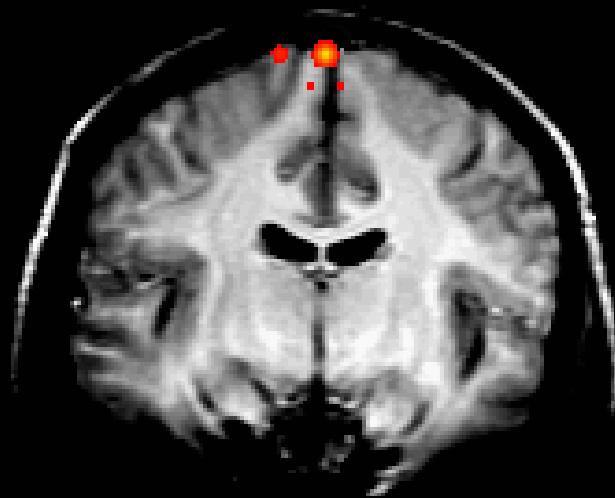


Right

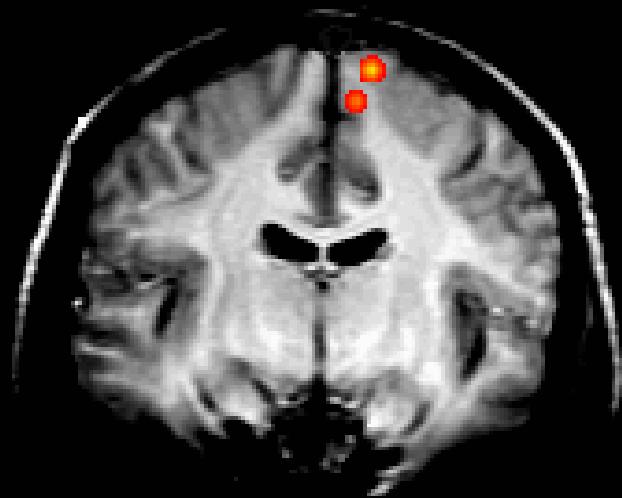


# Toe Movement

Left



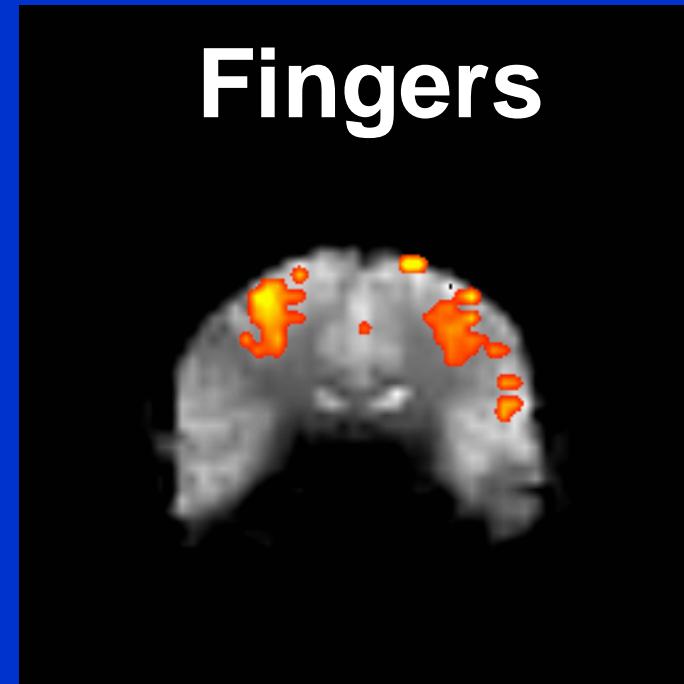
Right



**Wrist**

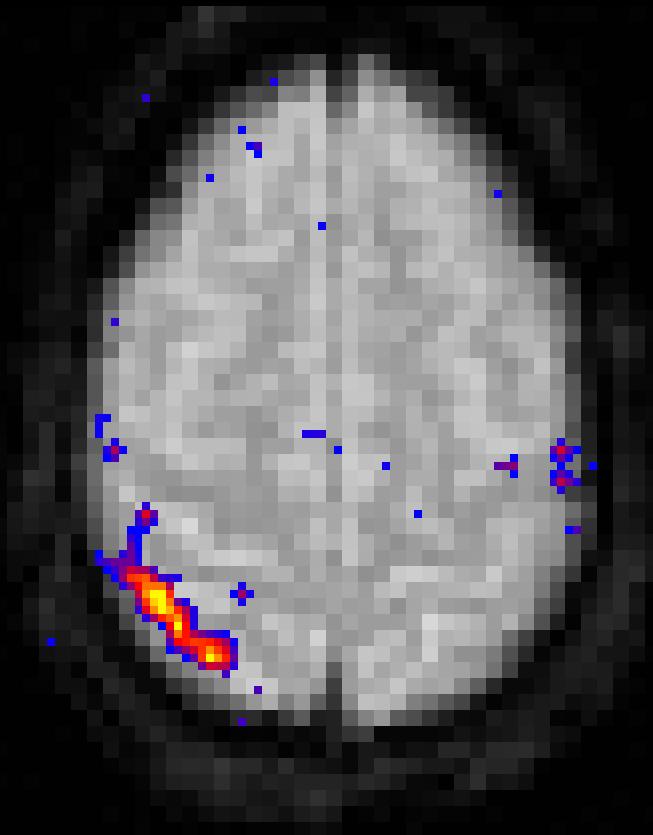
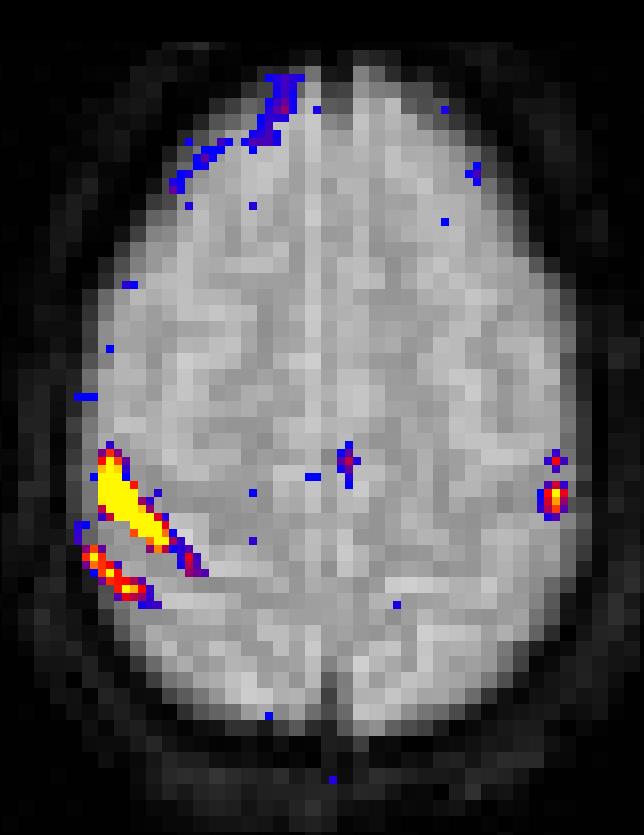


**Fingers**

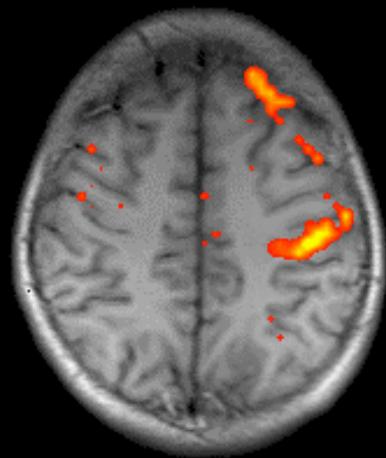


# Finger Movement

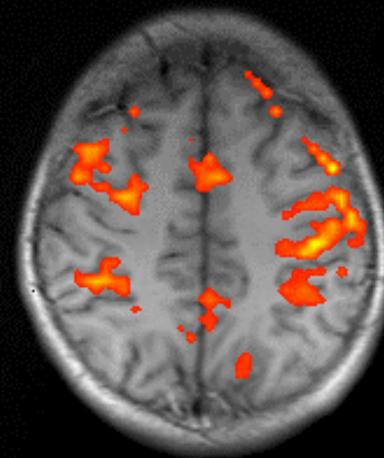
# Tactile Stimulation



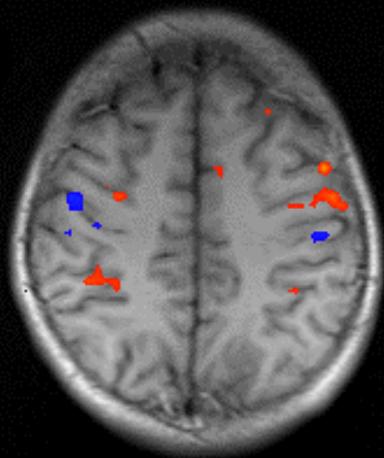
Simple Right



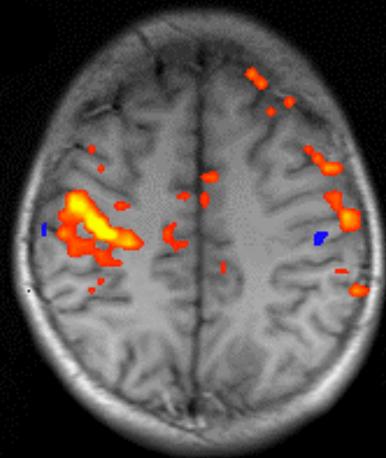
Complex Right



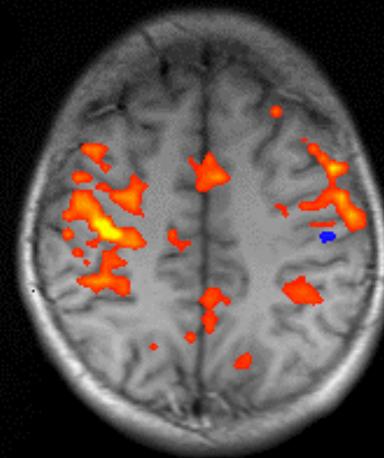
Imagined  
Complex Right



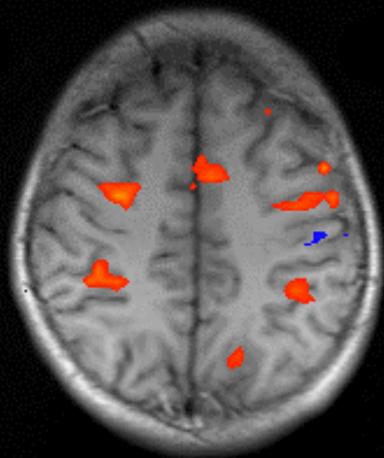
Simple Left



Complex Left



Imagined  
Complex Left



*Left*

## Simple Finger Movement on the Left Hand

1

2

3

4

5

6

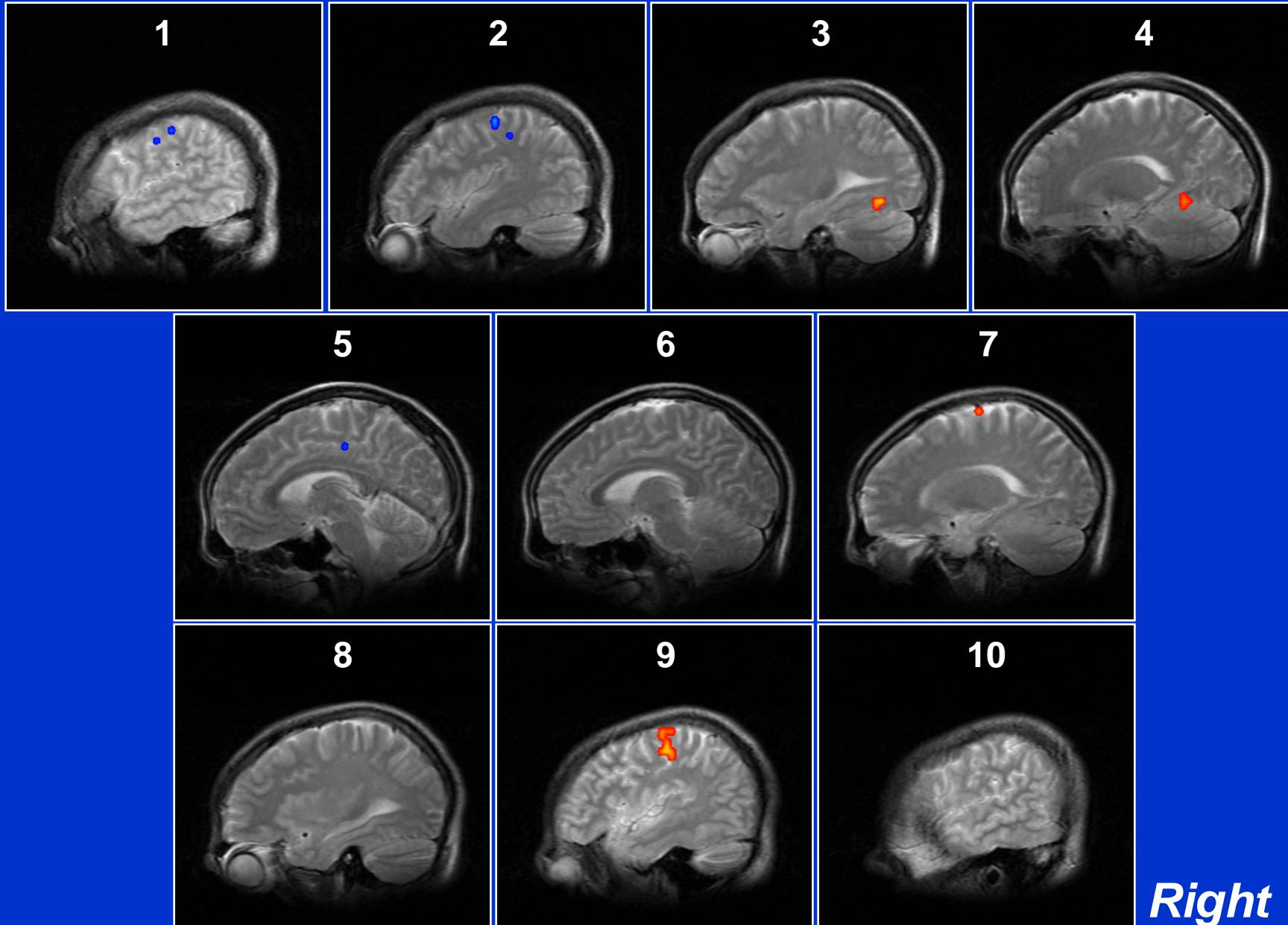
7

8

9

10

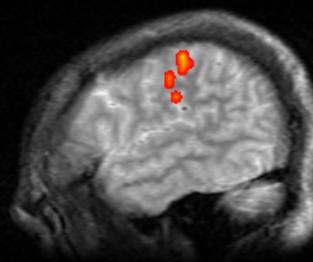
*Right*



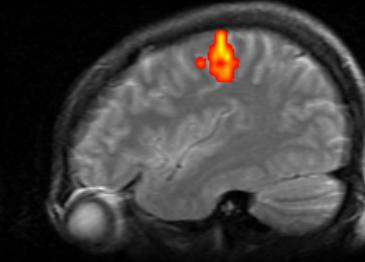
*Left*

## Simple Finger Movement on the Right Hand

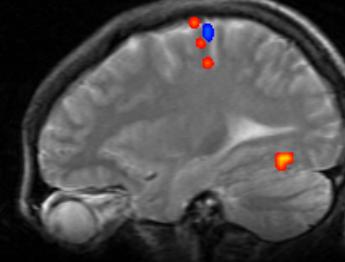
1



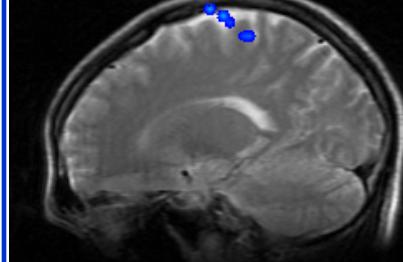
2



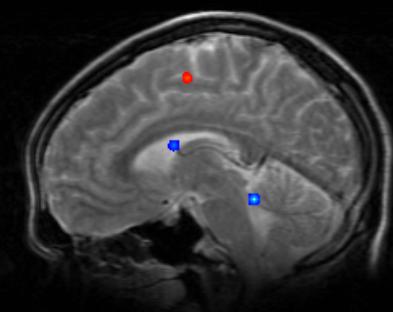
3



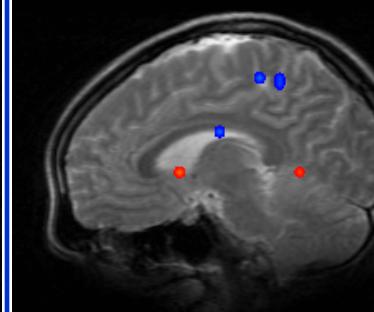
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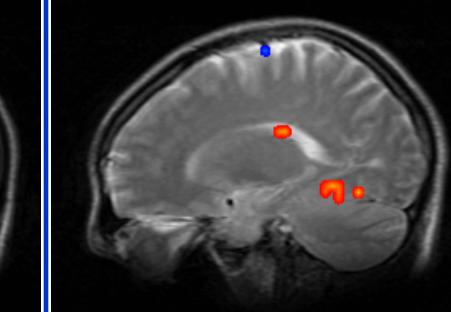
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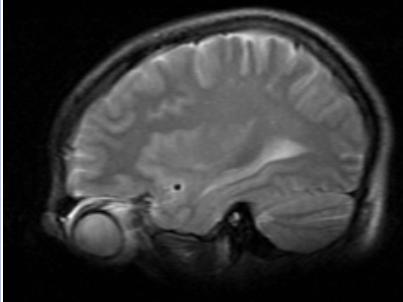
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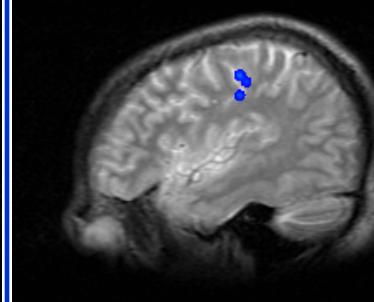
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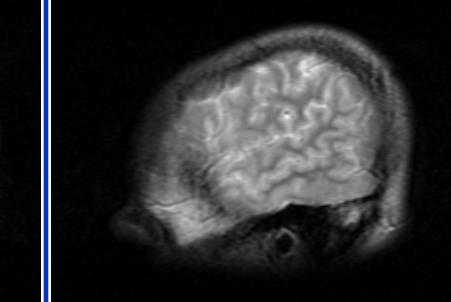
8



9



10



*Right*

*Left*

## Complex Finger Movement on the Right Hand

1

2

3

4

5

6

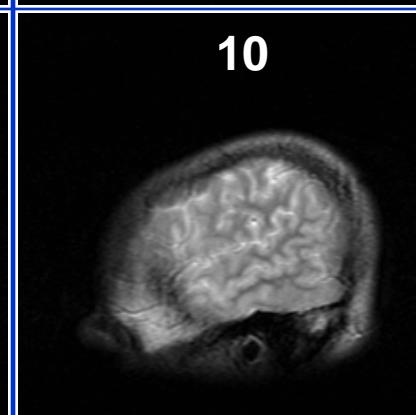
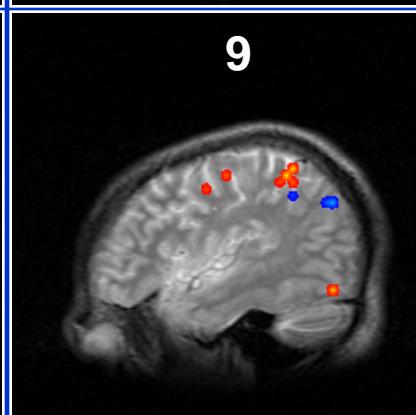
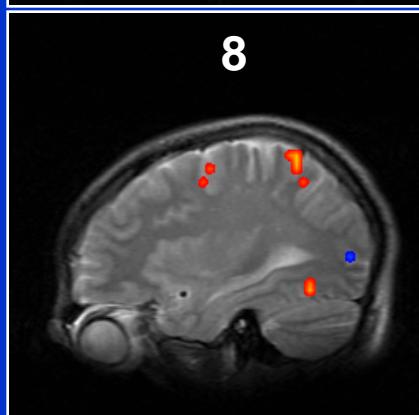
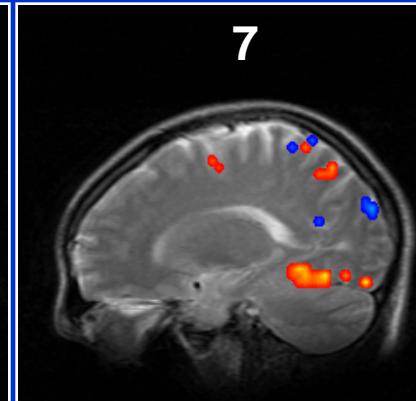
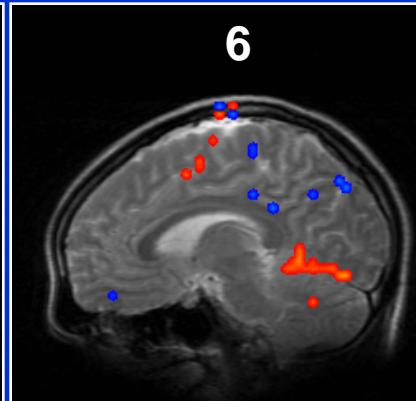
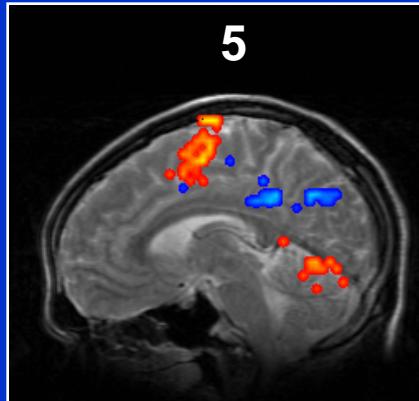
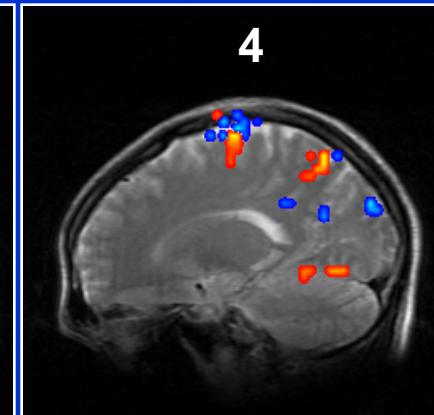
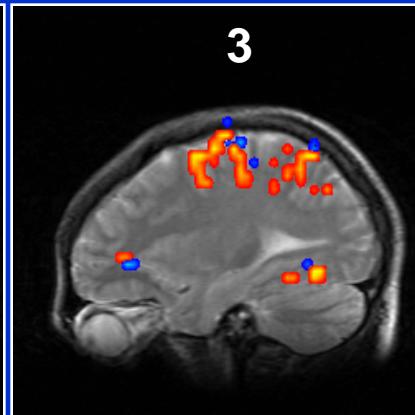
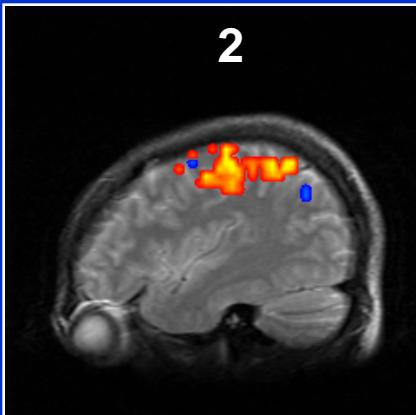
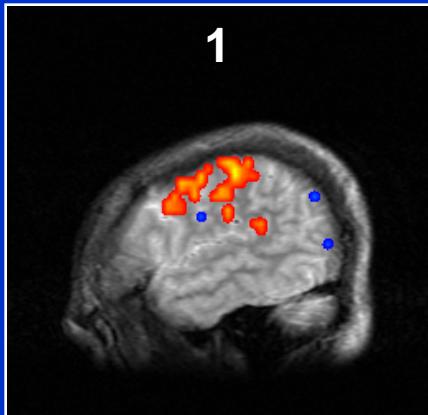
7

8

9

10

*Right*



*Left*

## Complex Finger Movement on the Left Hand

1

2

3

4

5

6

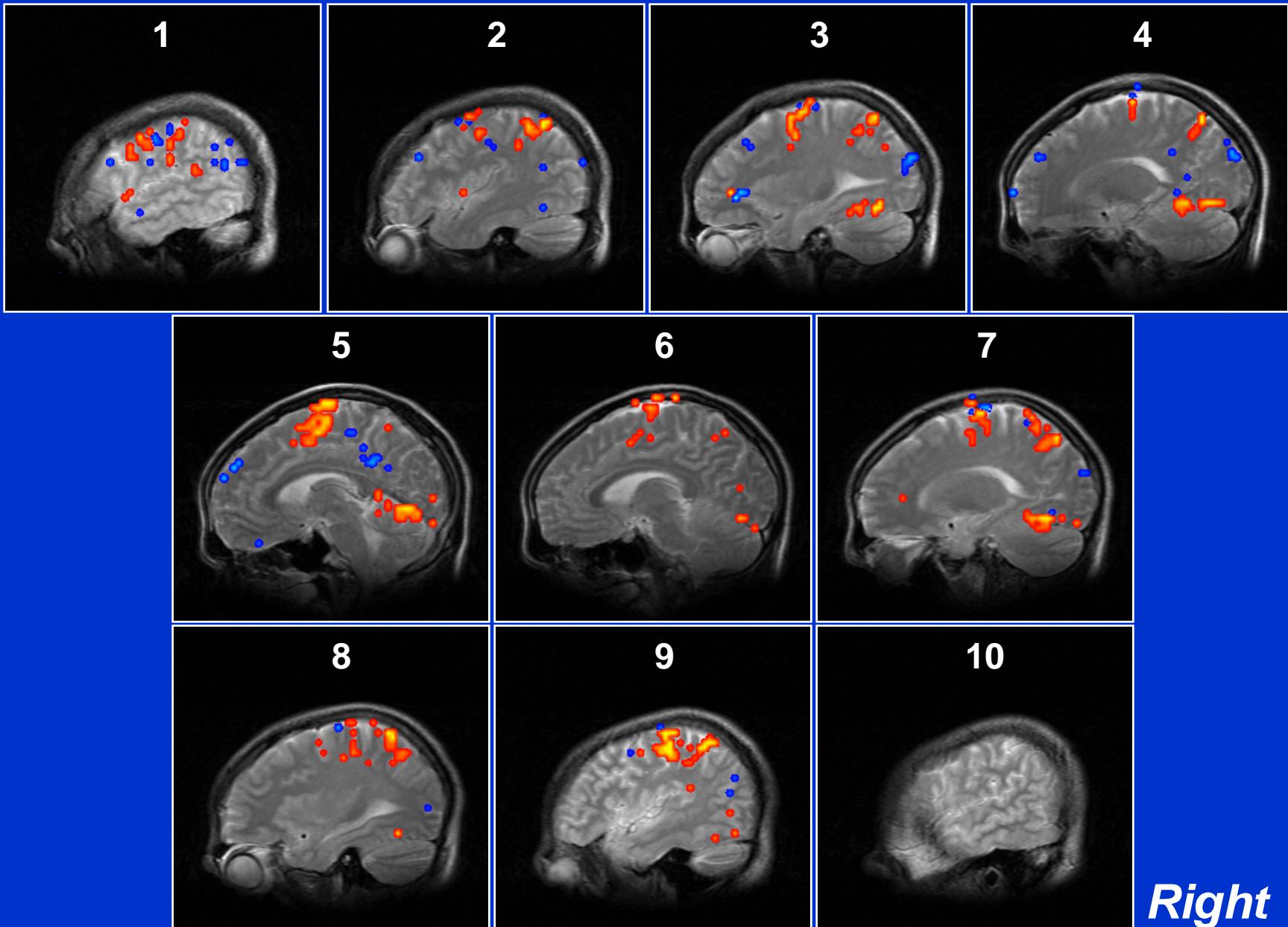
7

8

9

10

*Right*



*Left*

## Imagined Complex Finger Movement on the Left Hand

1

2

3

4

5

6

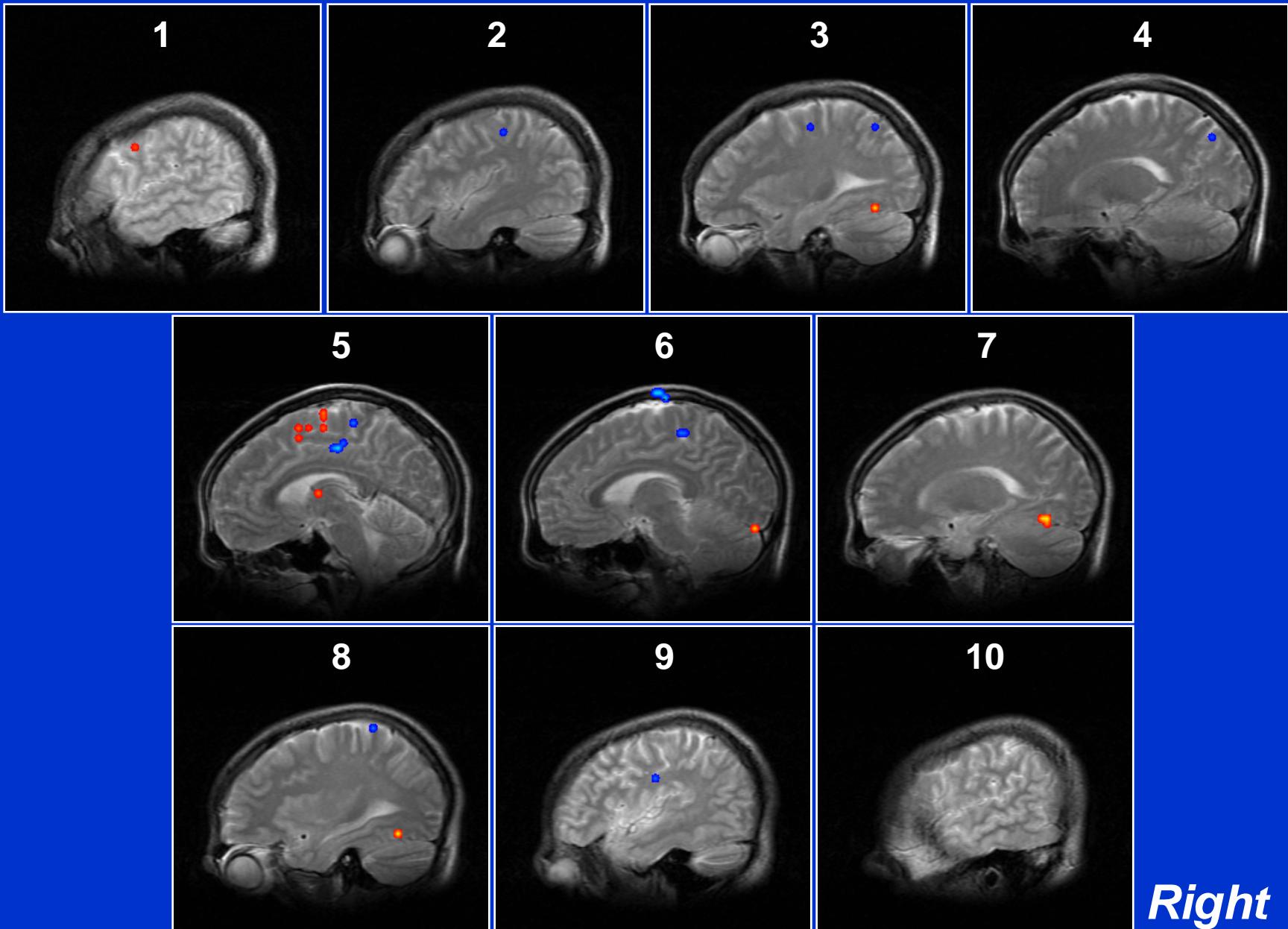
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8

9

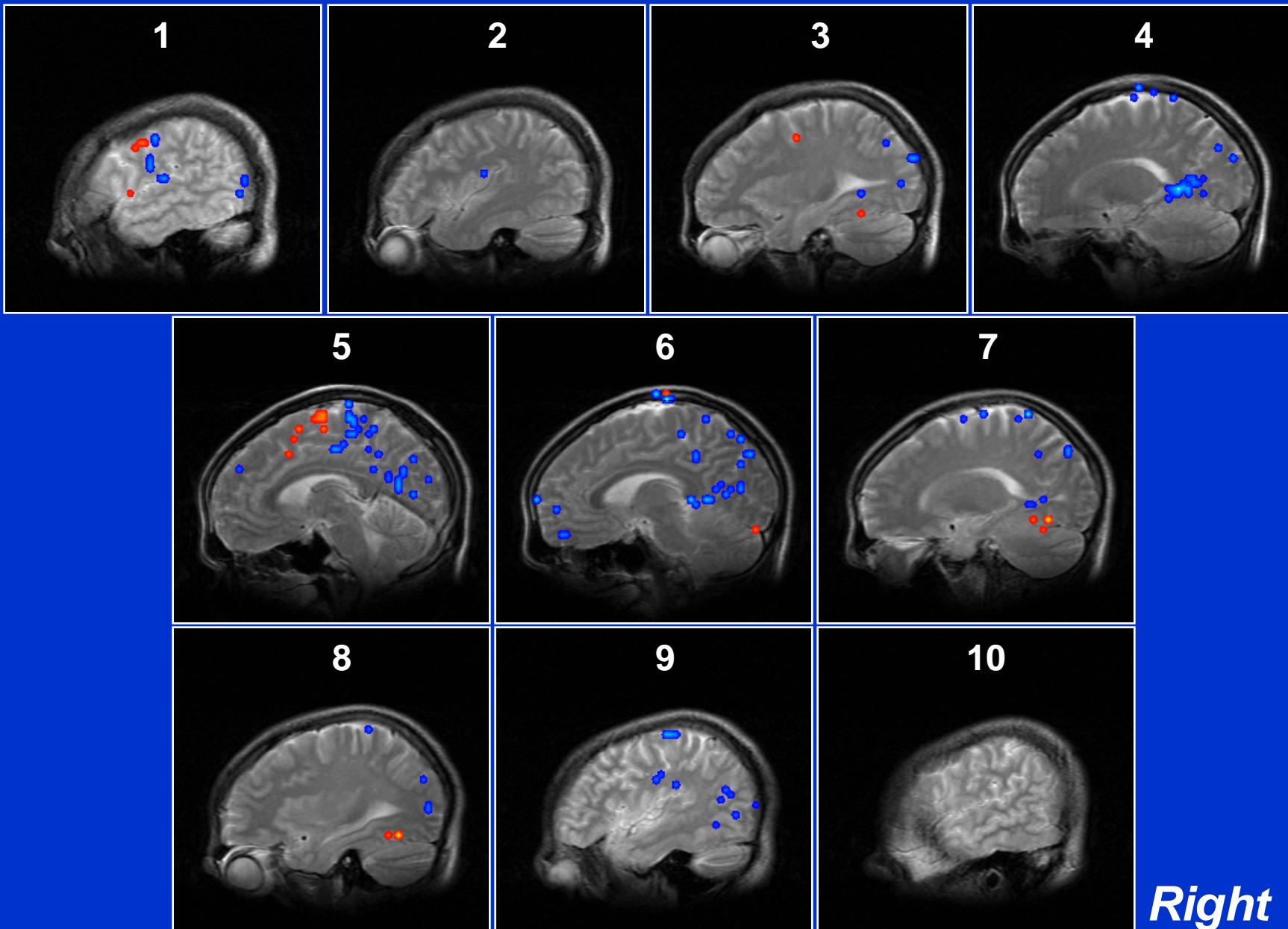
10

*Right*



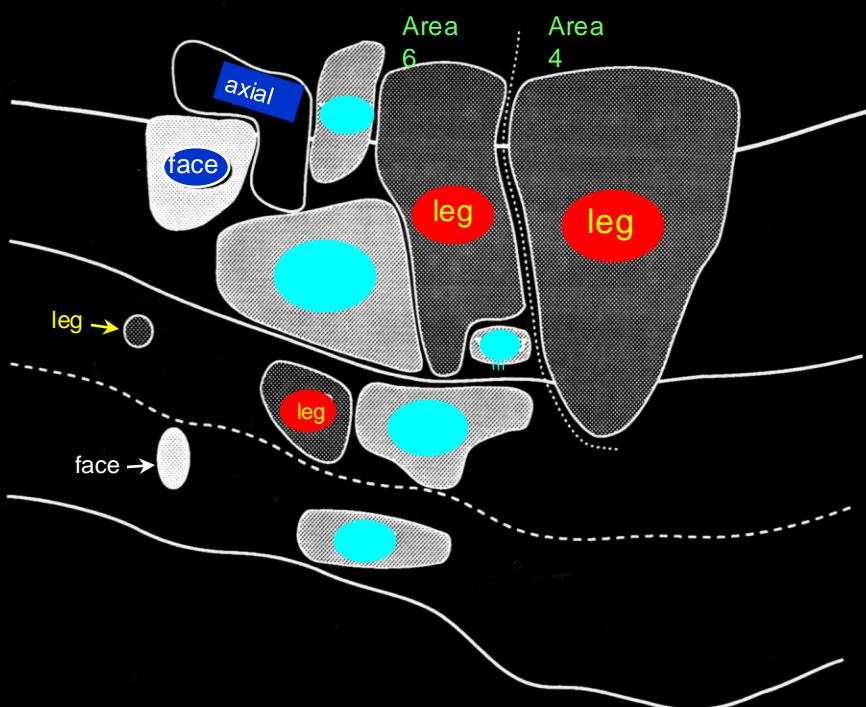
*Left*

## Imagined Complex Finger Movement on the Right Hand

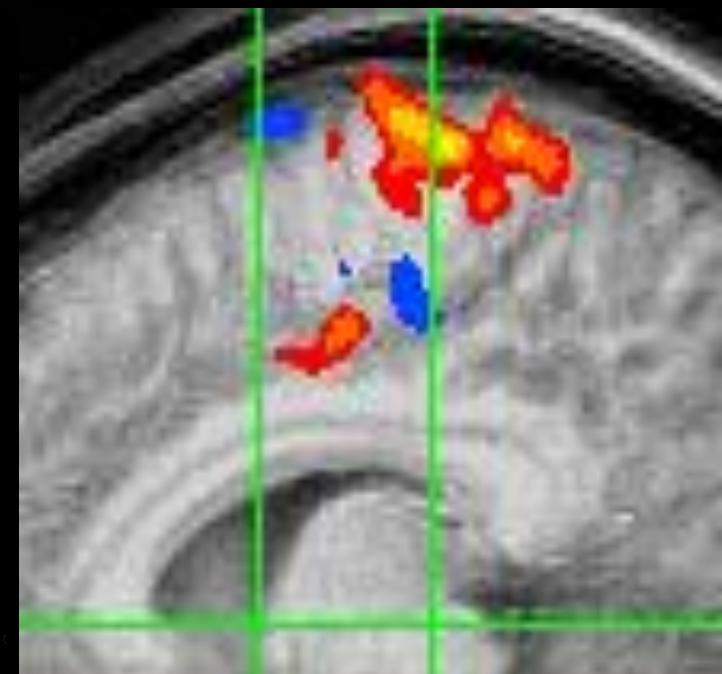


*Right*

# FMRI of Leg Motor Topography - Medial Wall



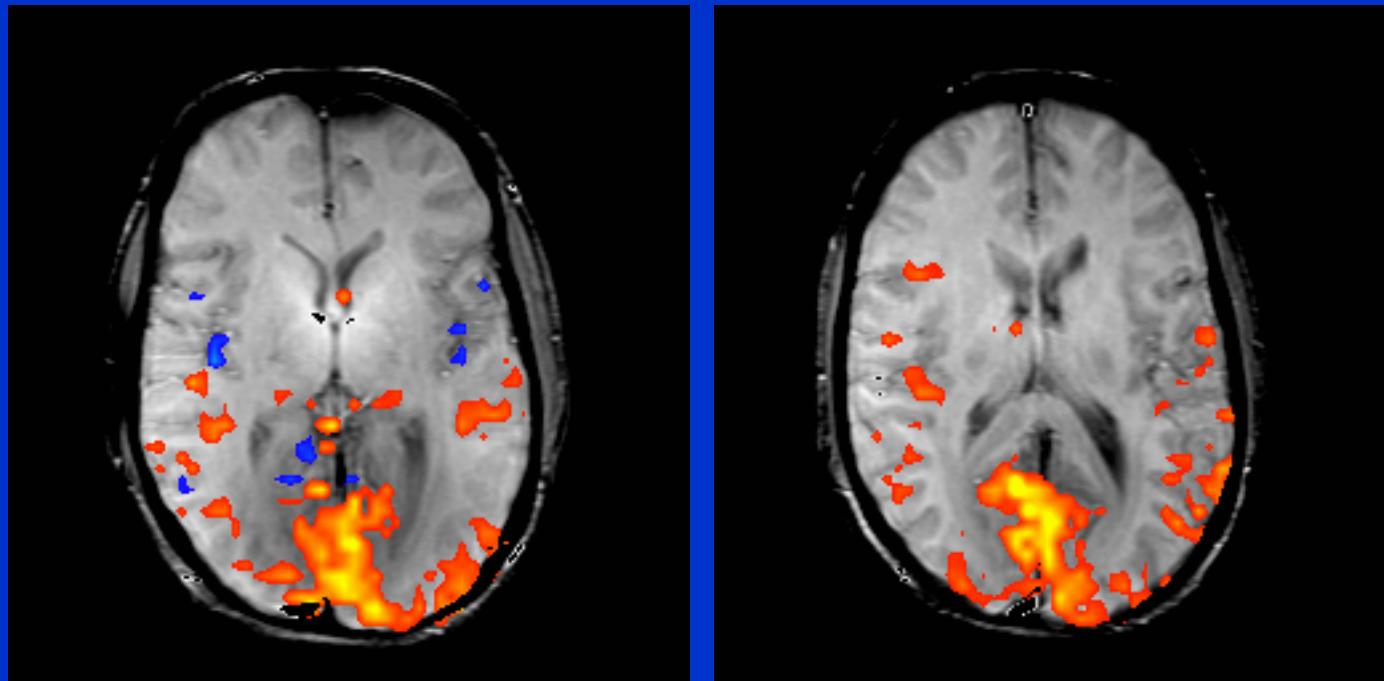
*Macaque*



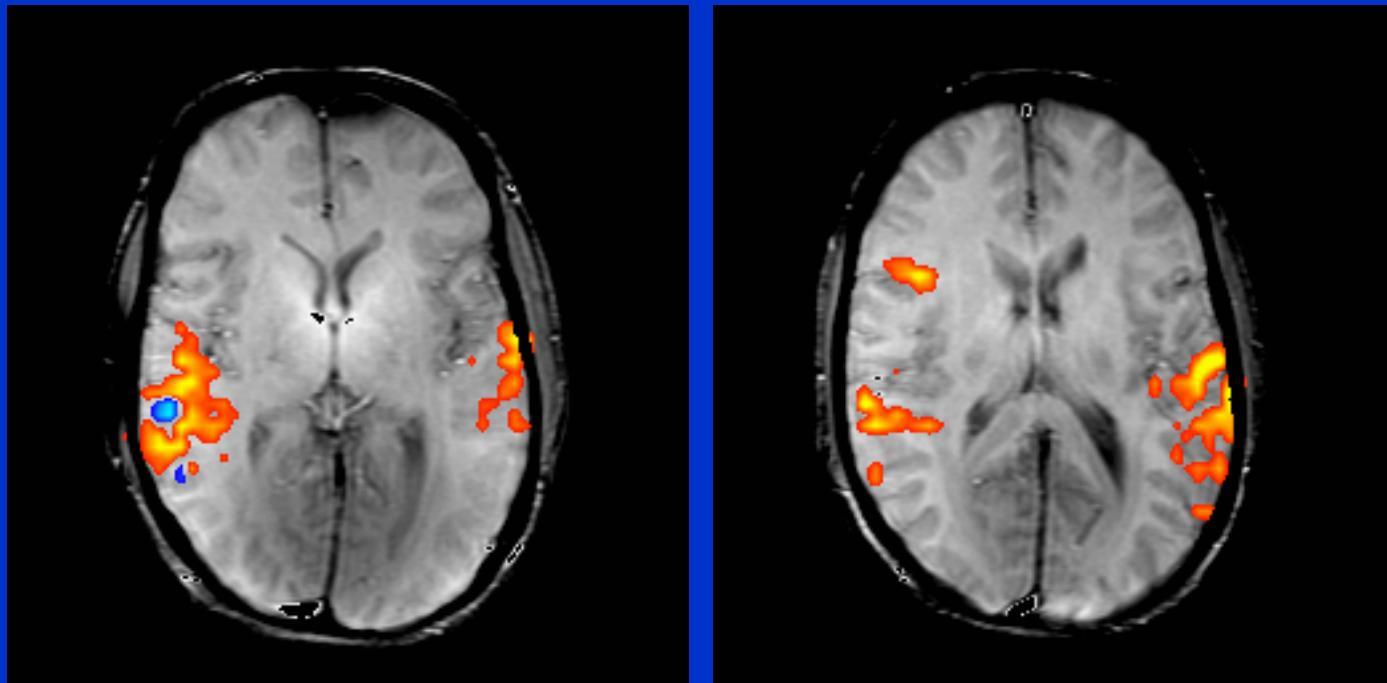
*Human*

Thanks to S. Rao

# Reading

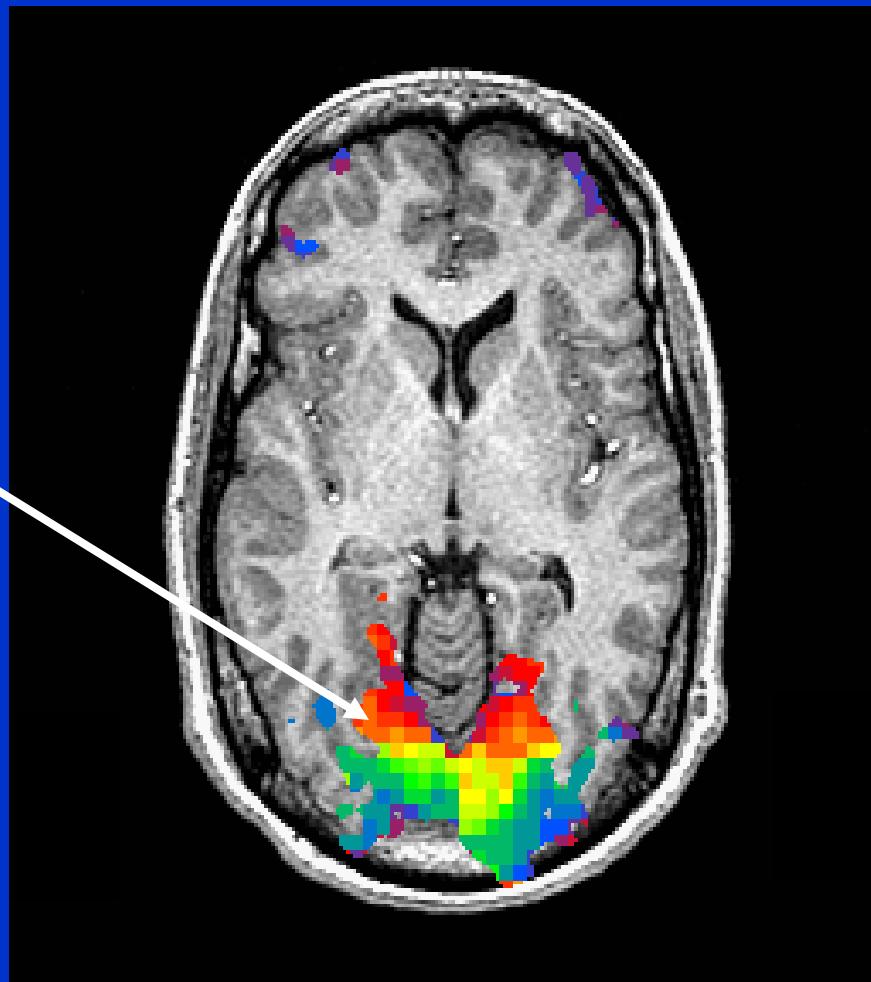


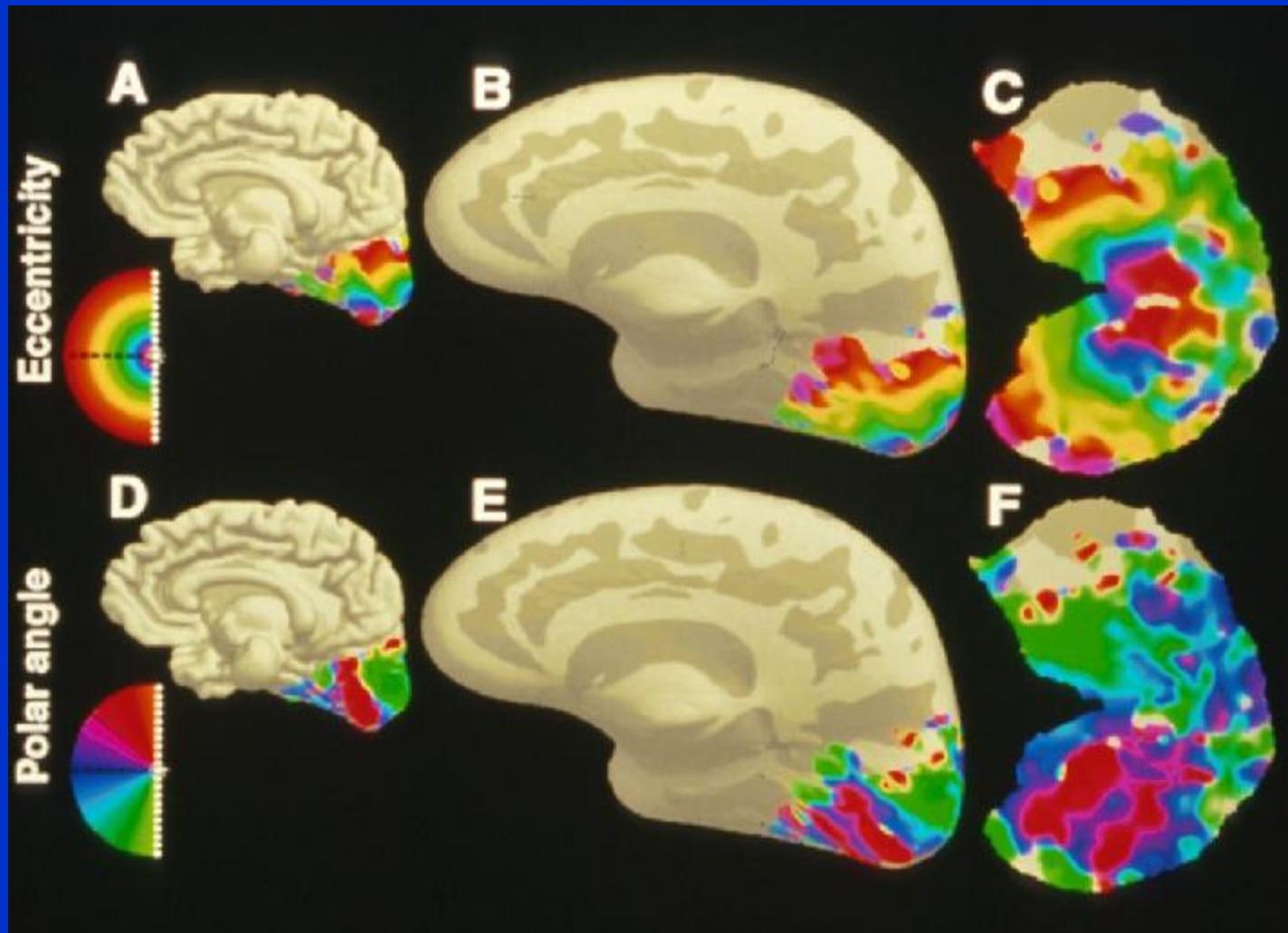
# Listening to Spoken Words



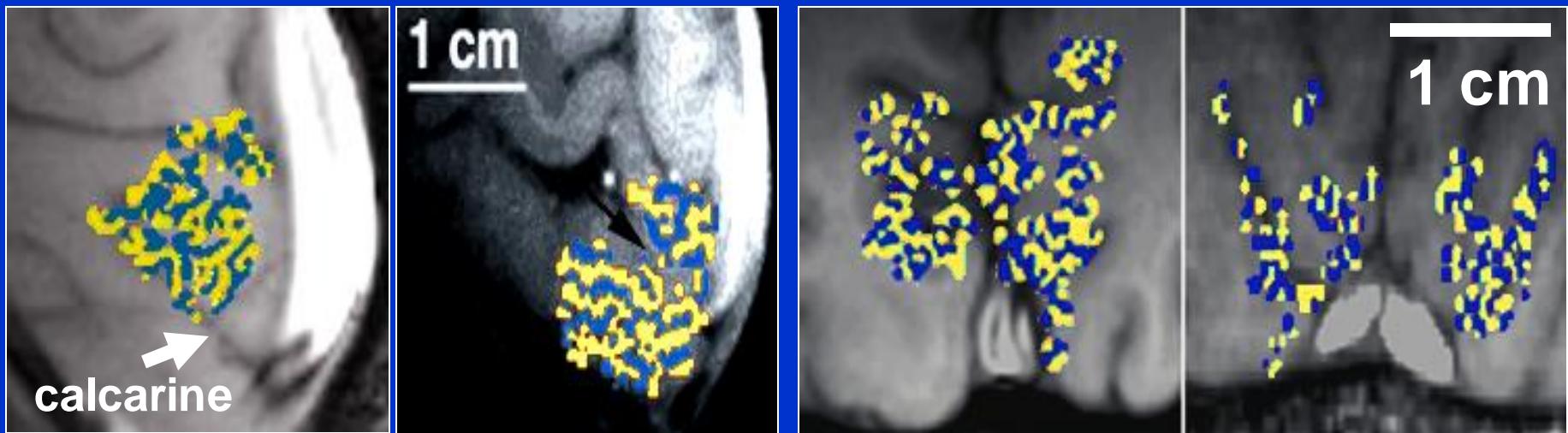
# fMRI Mapping of Visual Cortex

Functional Activation  
(Color codes visual field eccentricity)





# ODC Maps using fMRI



- Identical in size, orientation, and appearance to those obtained by optical imaging<sup>1</sup> and histology<sup>3,4</sup>.

Menon et al.

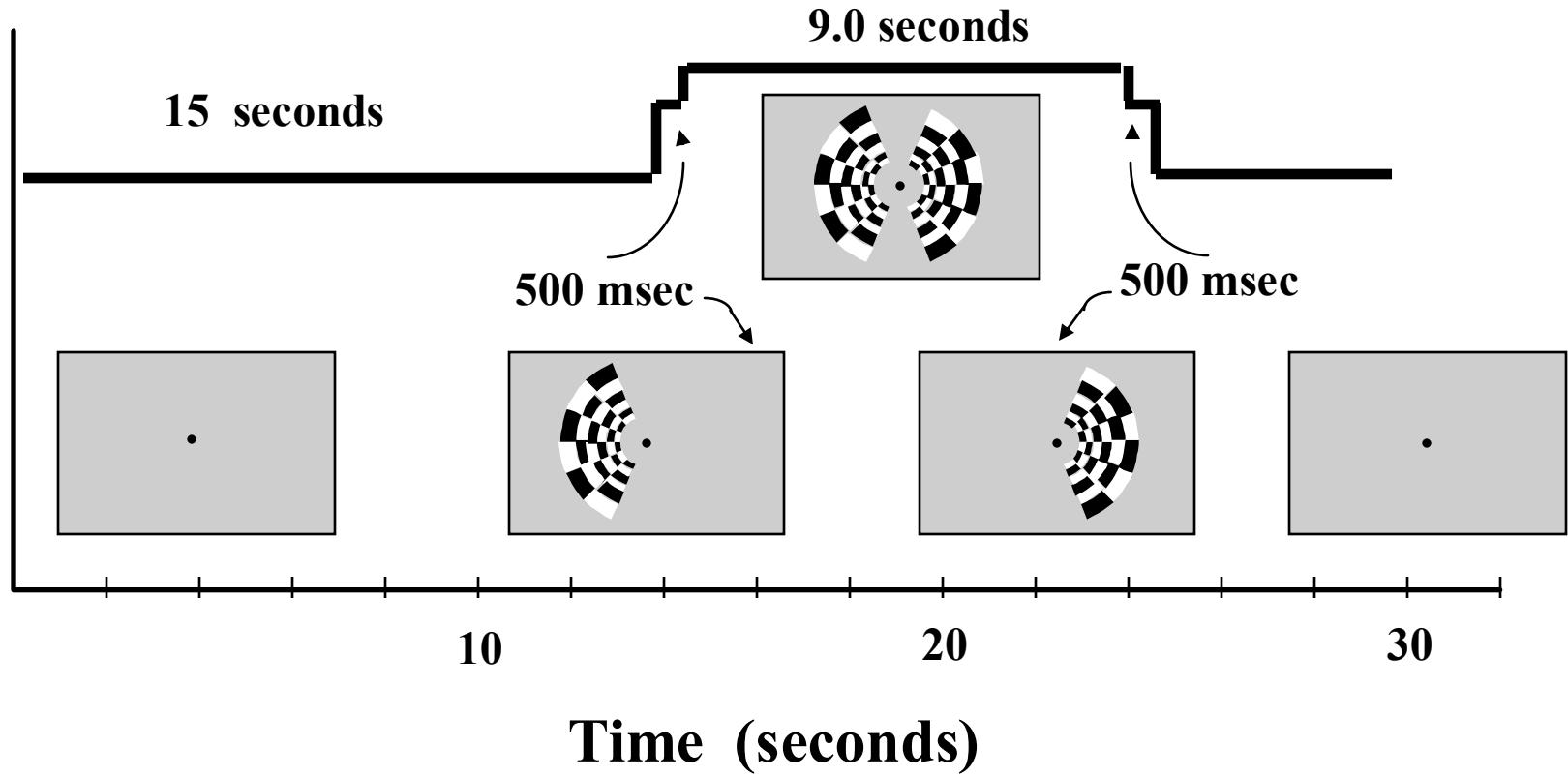
<sup>1</sup>Malonek D, Grinvald A. *Science* 272, 551-4 (1996).

<sup>3</sup>Horton JC, Hocking DR. *J Neurosci* 16, 7228-39 (1996).

<sup>4</sup>Horton JC, et al. *Arch Ophthalmol* 108, 1025-31 (1990).

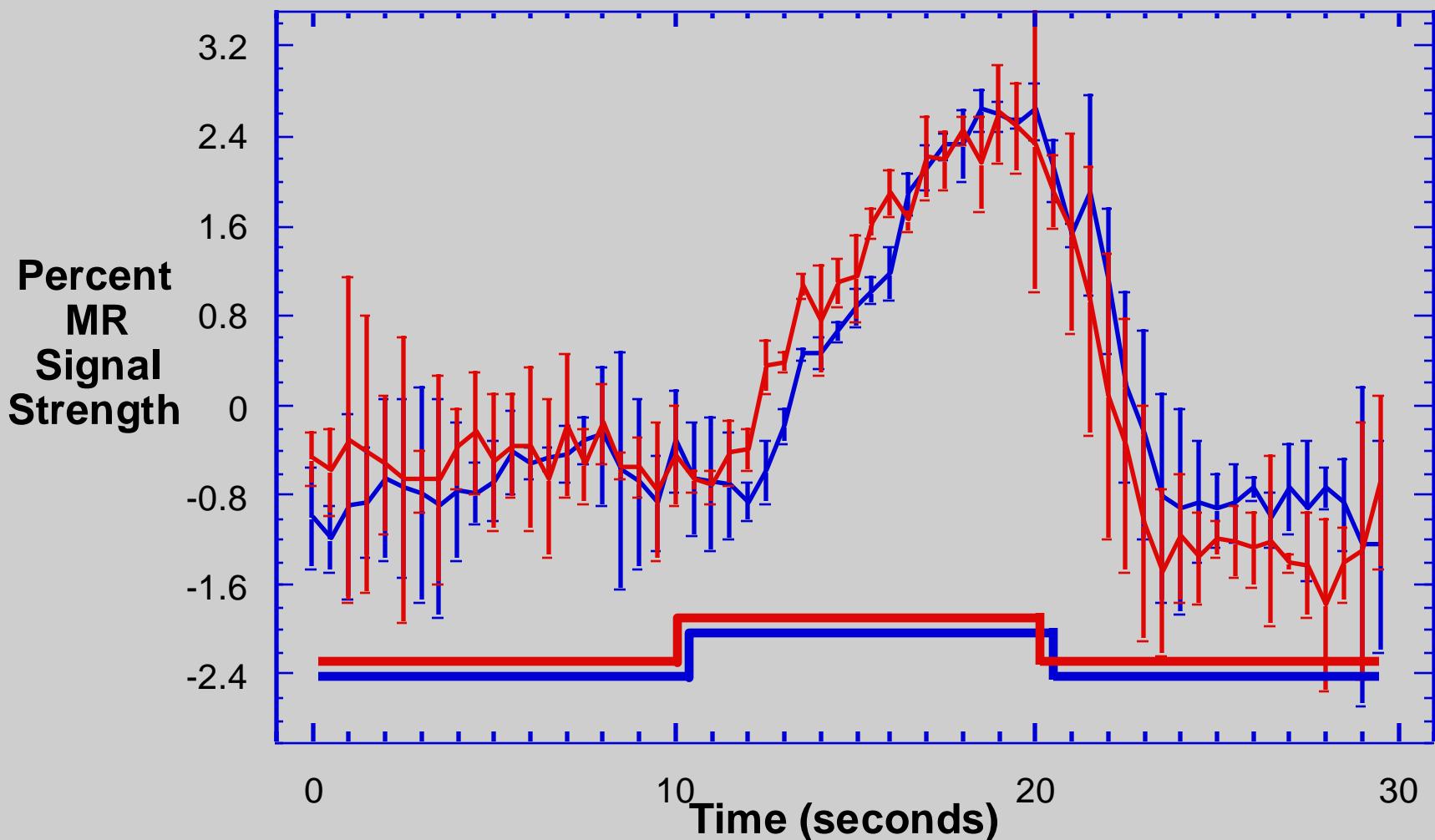
# Regions of Interest Used for Hemi-Field Experiment

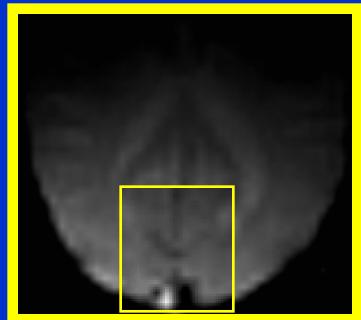




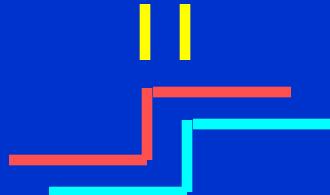
# Hemi-field with 500 msec asynchrony

Average of 6 runs    Standard Deviations Shown

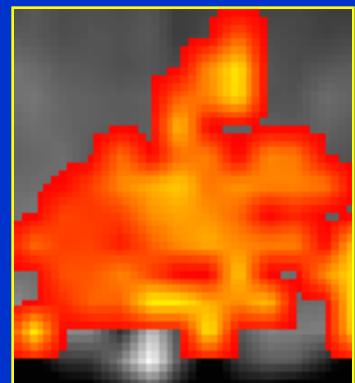




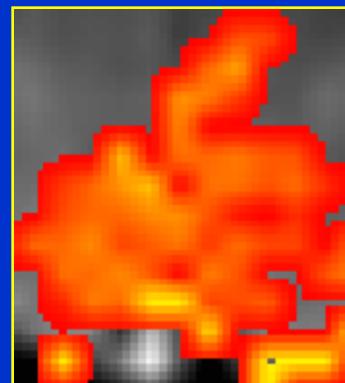
**500 ms**



+ 2.5 s



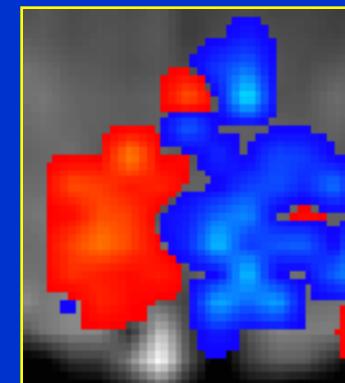
0 s



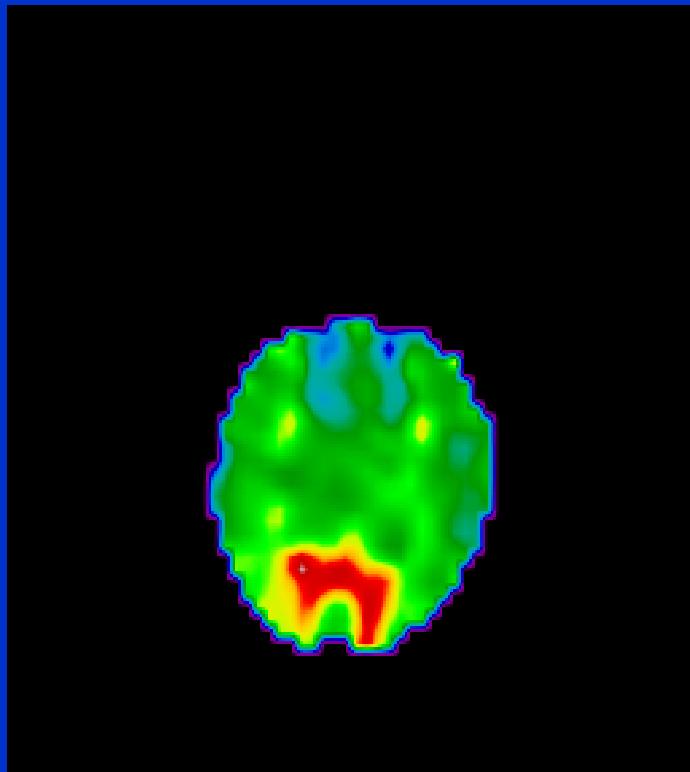
- 2.5 s

# Right Hemifield

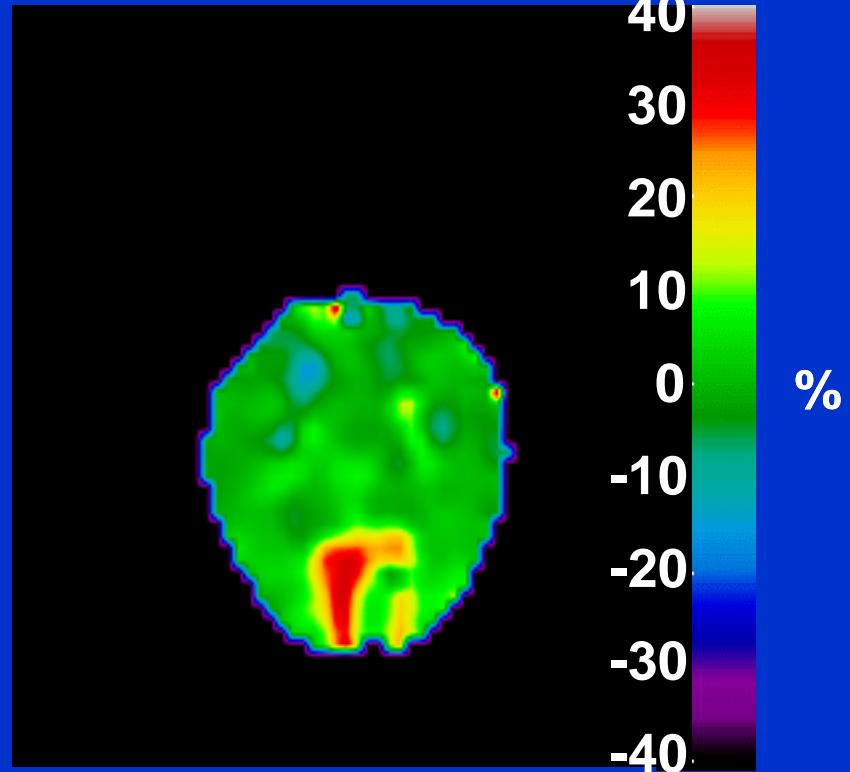
# **Left Hemifield**



# Computed CMRO<sub>2</sub> changes

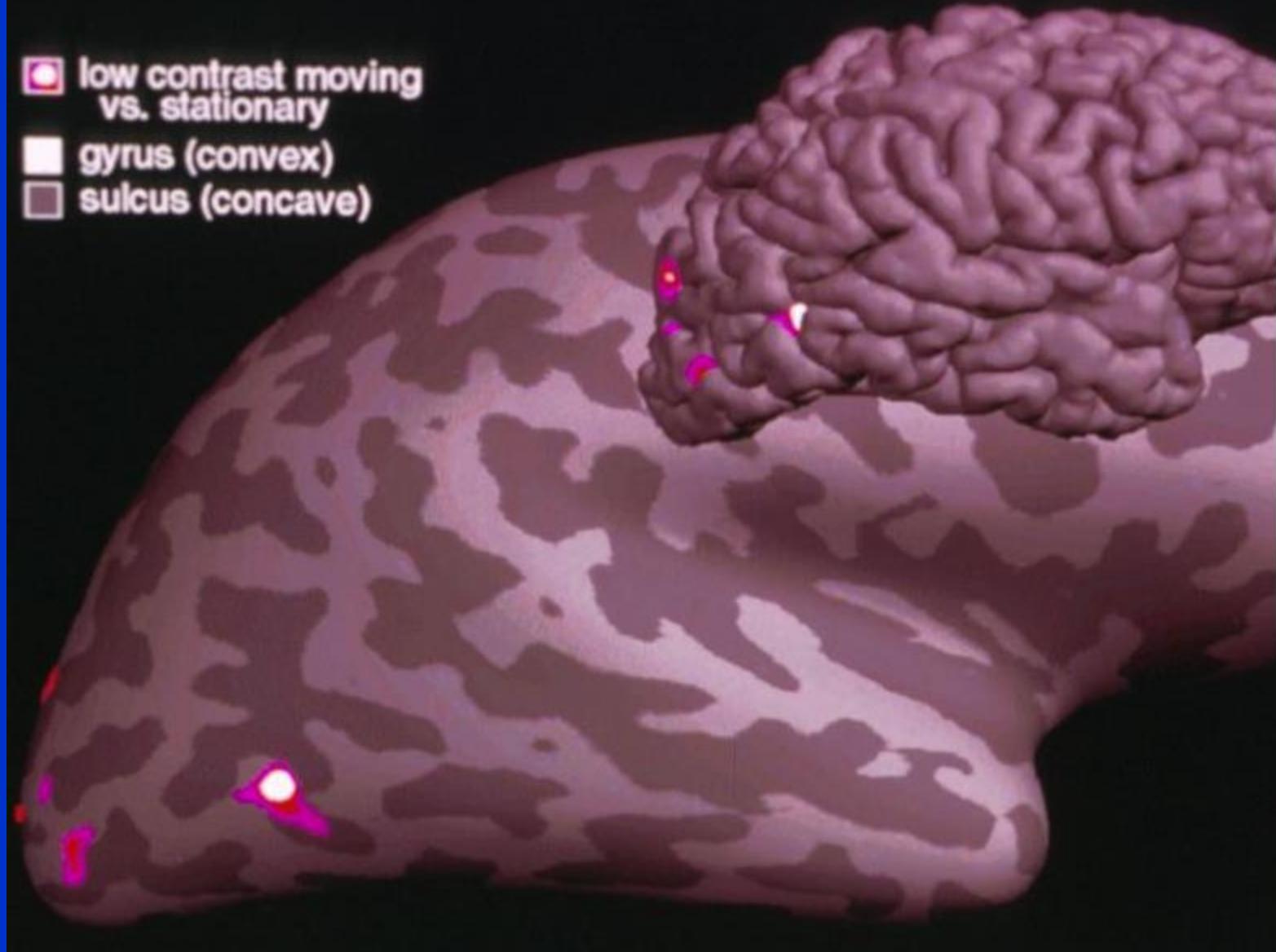


Subject 1

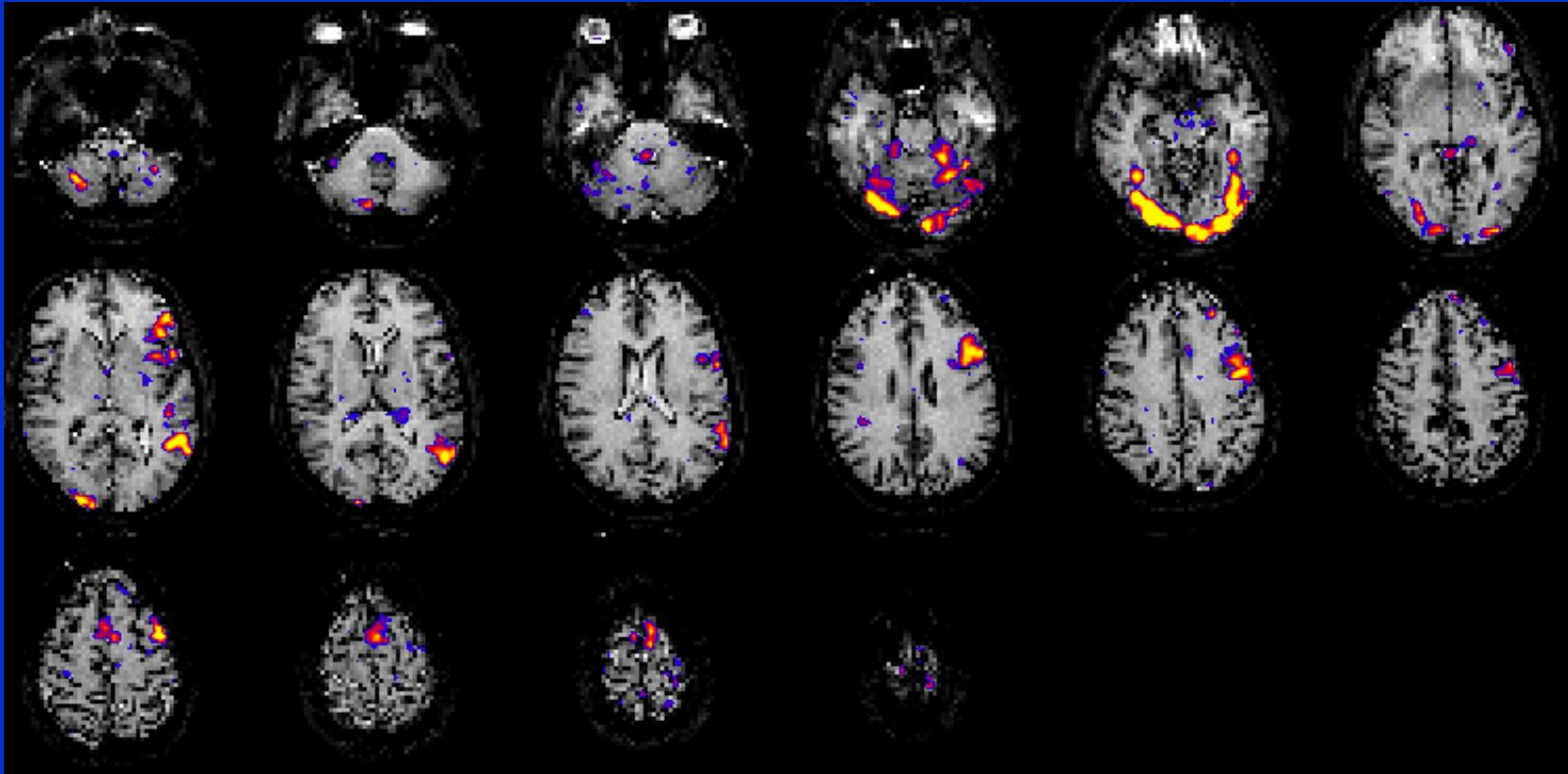


Subject 2

- low contrast moving vs. stationary
- gyrus (convex)
- sulcus (concave)



# Word stem completion



# A Primary Challenge:

**...to make progressively more precise inferences using fMRI without making too many assumptions about non-neuronal physiologic factors.**



**Anatomy**



**BOLD**



**Perfusion**



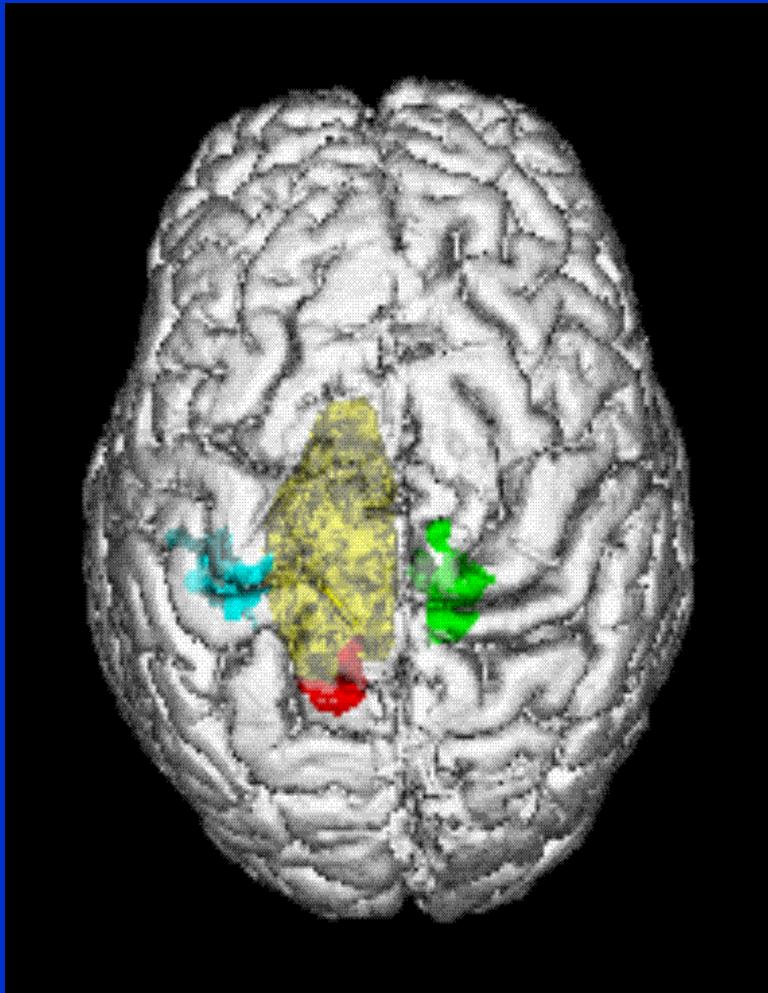
# Presurgical Mapping

Left Foot

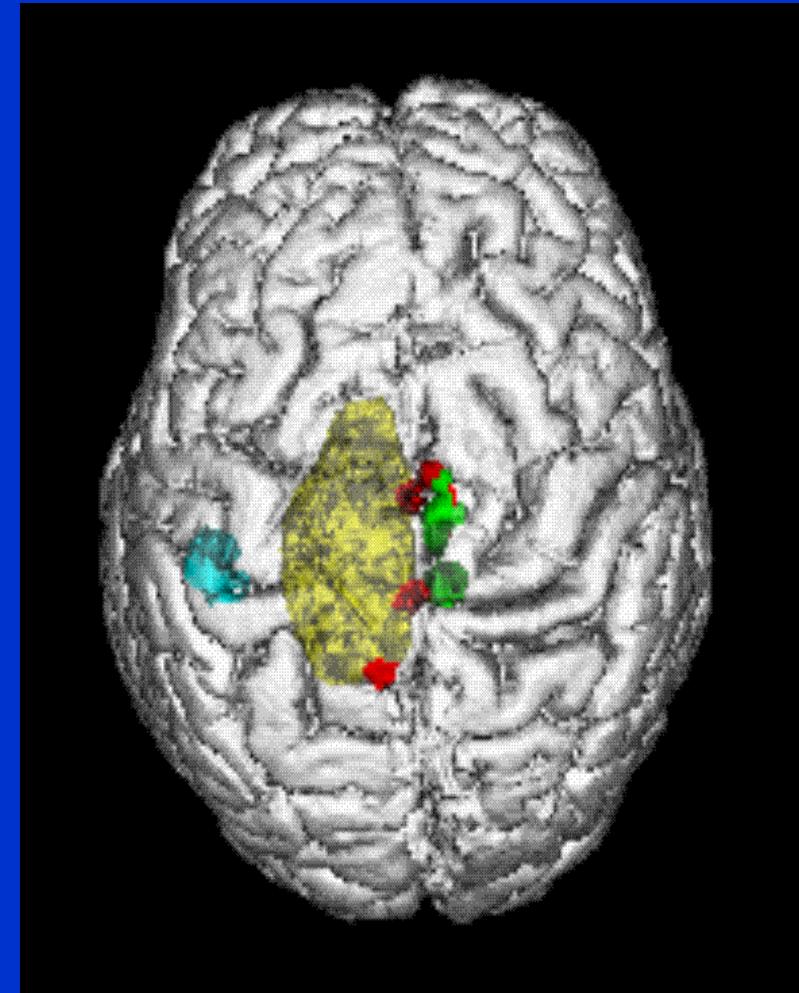
Tumor

Right Foot

Right Hand

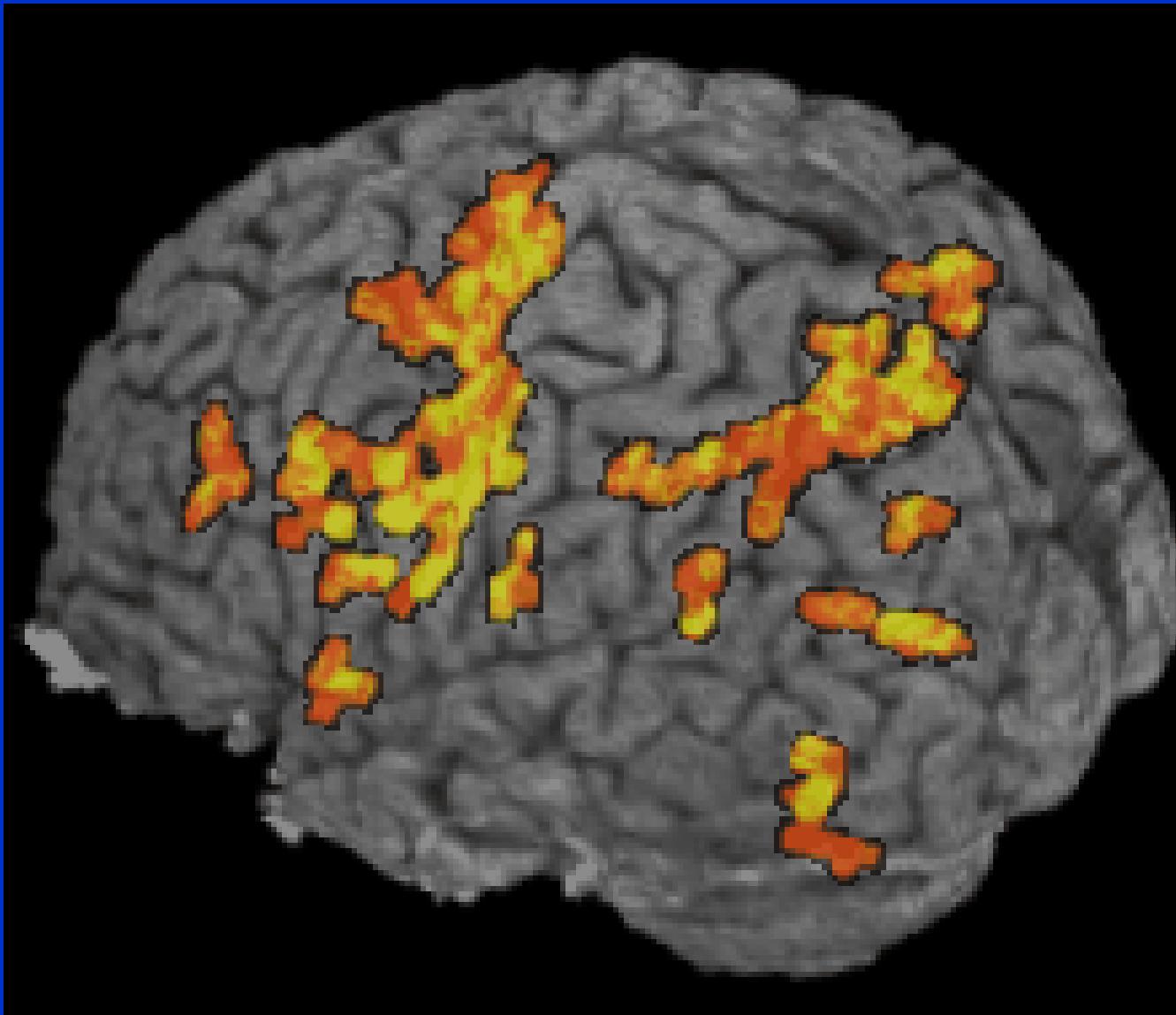


fMRI



O-15 PET

# End of Acquisition



< 1 s to render

Blocked trials:  
20 s on/20 s off  
8 blocks

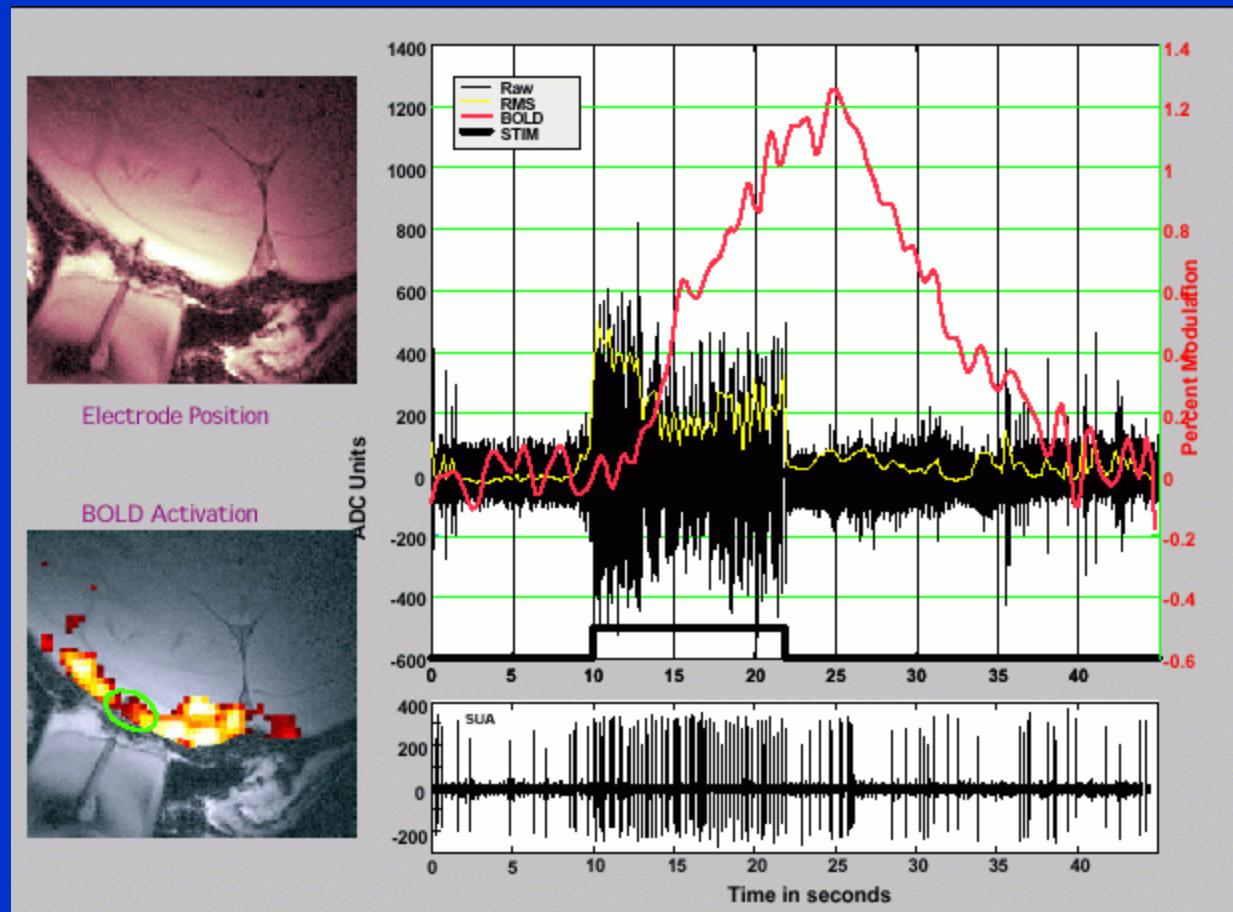
Blocks: 12345678

Color shows  
through brain

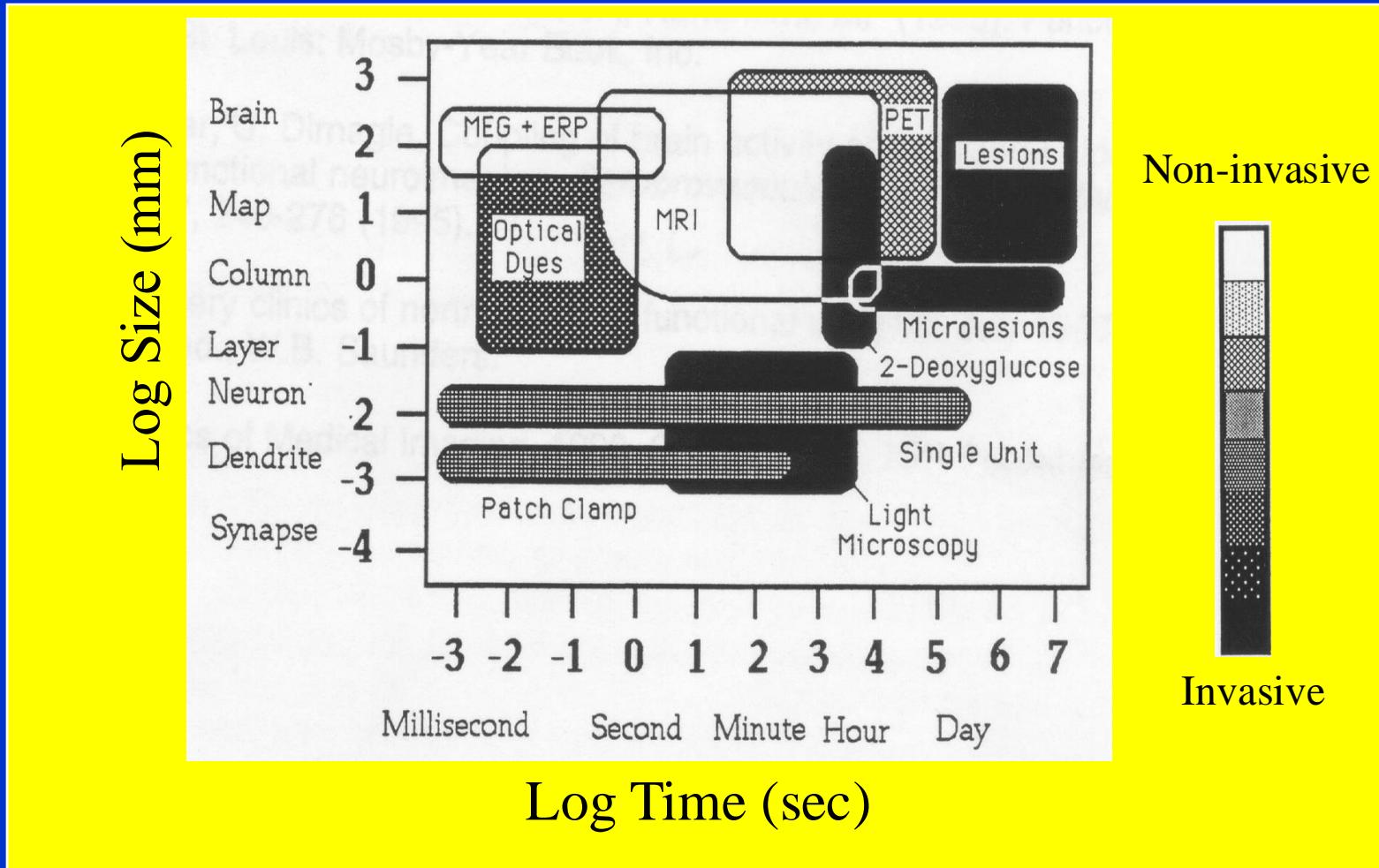
Correlation > 0.45



# Combined Electrophysiological Measurement and fMRI



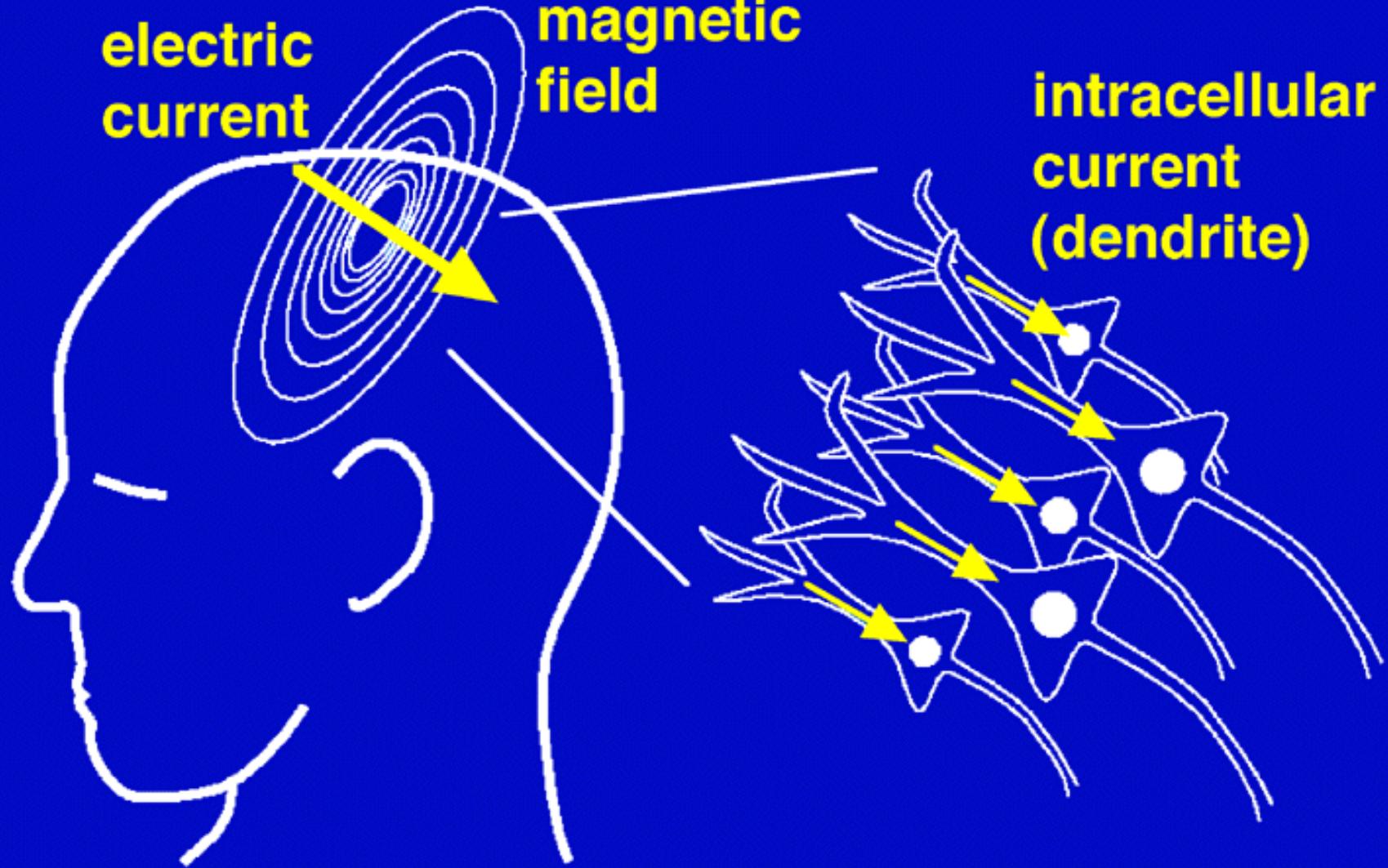
# Functional Neuroimaging Techniques



**electric  
current**

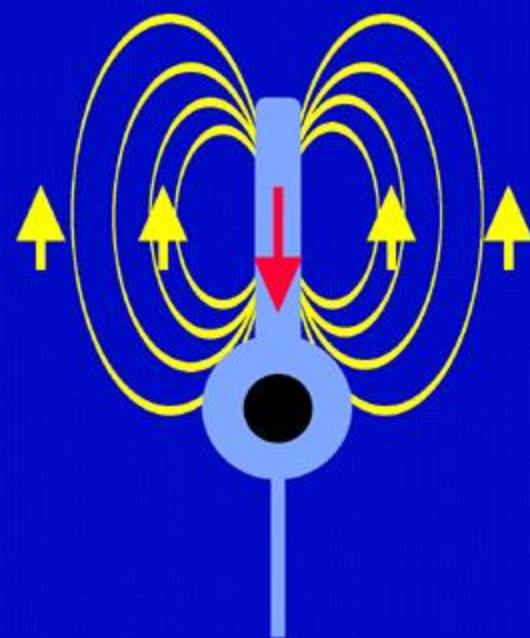
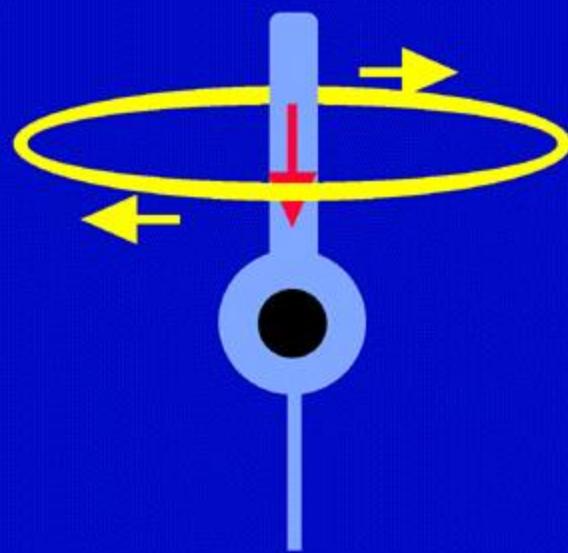
**magnetic  
field**

**intracellular  
current  
(dendrite)**

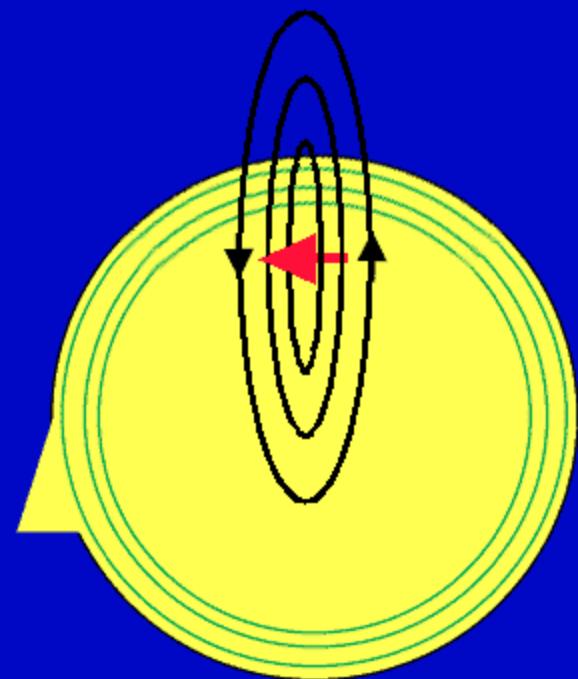


**MEG:**  
intracellular  
current

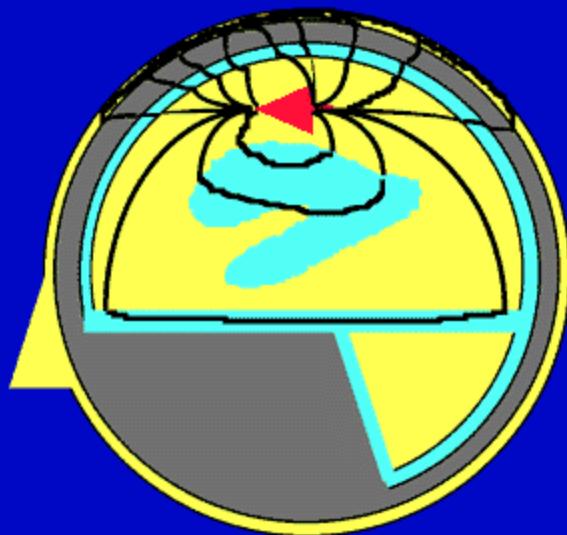
**EEG:**  
extracellular  
current

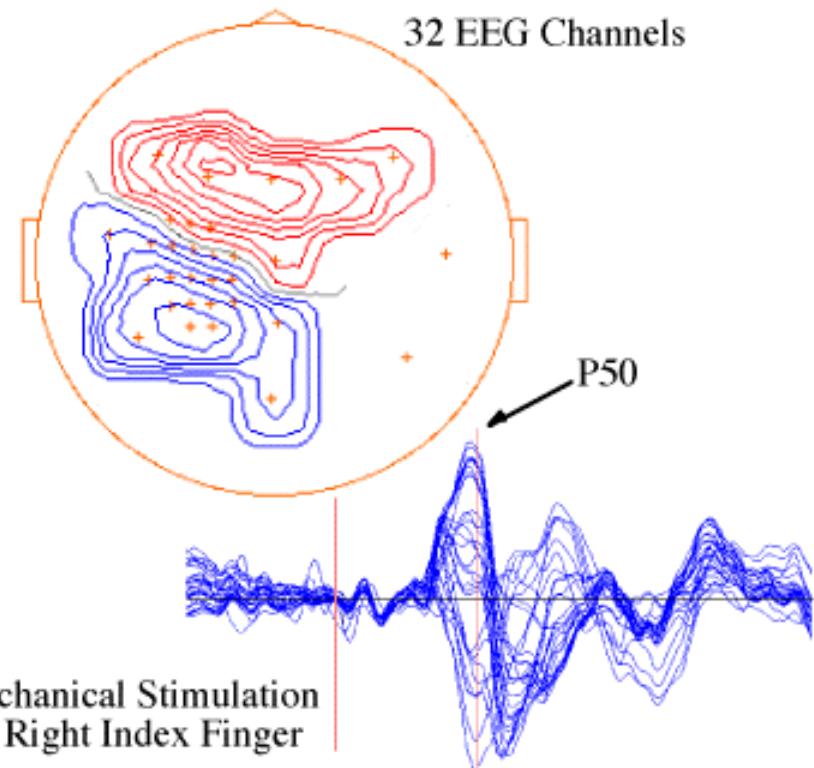
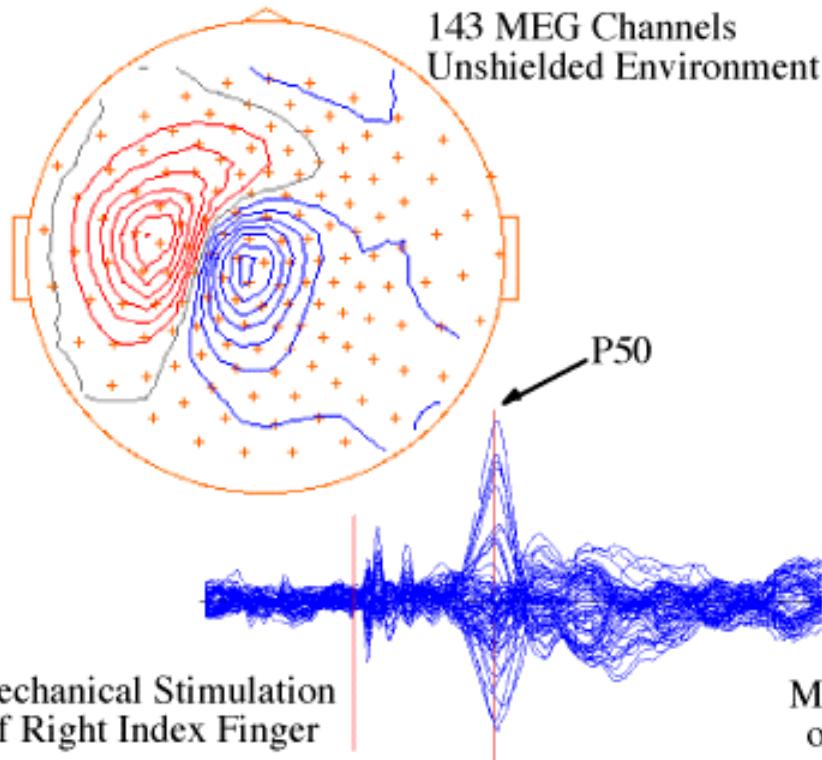


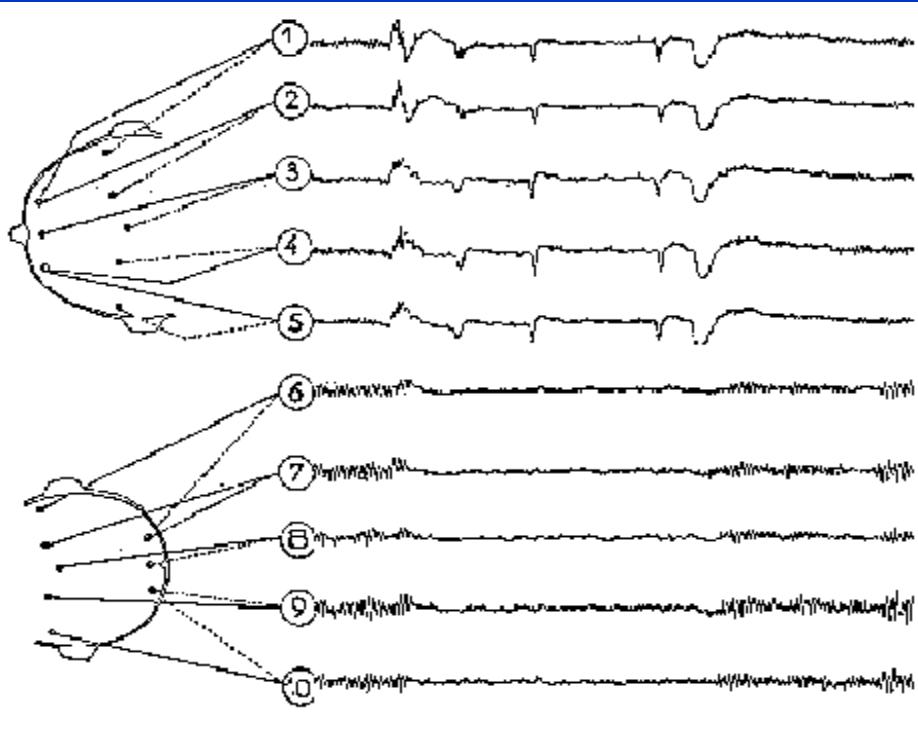
**MEG**



**EEG**



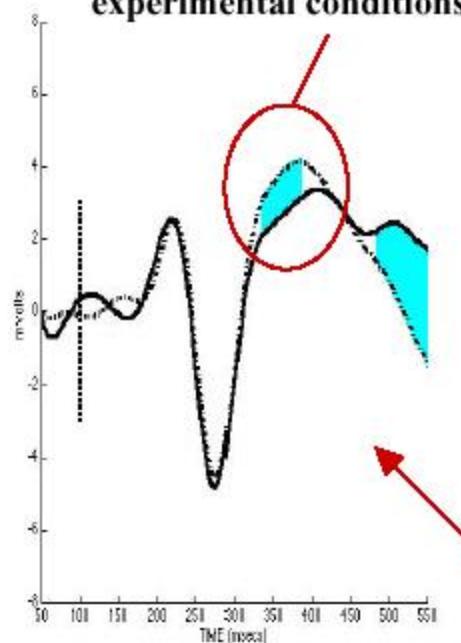




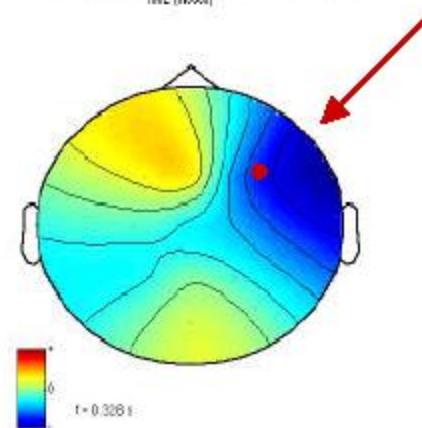
## Electroencephalography (EEG) recording



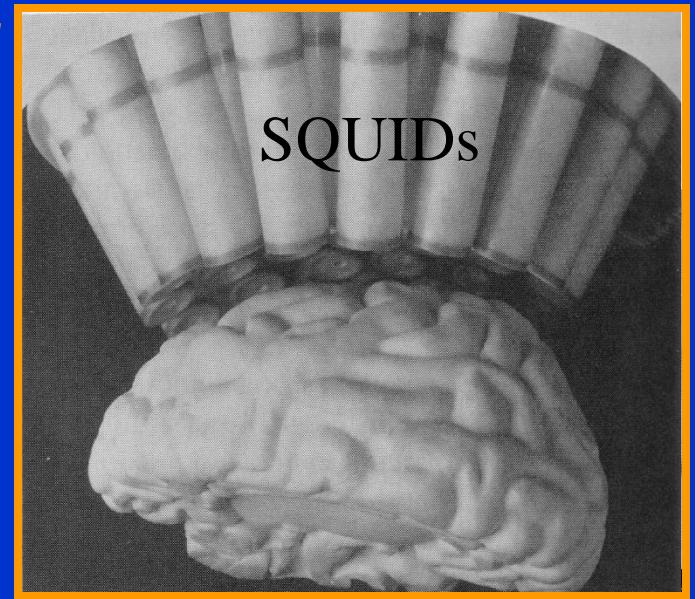
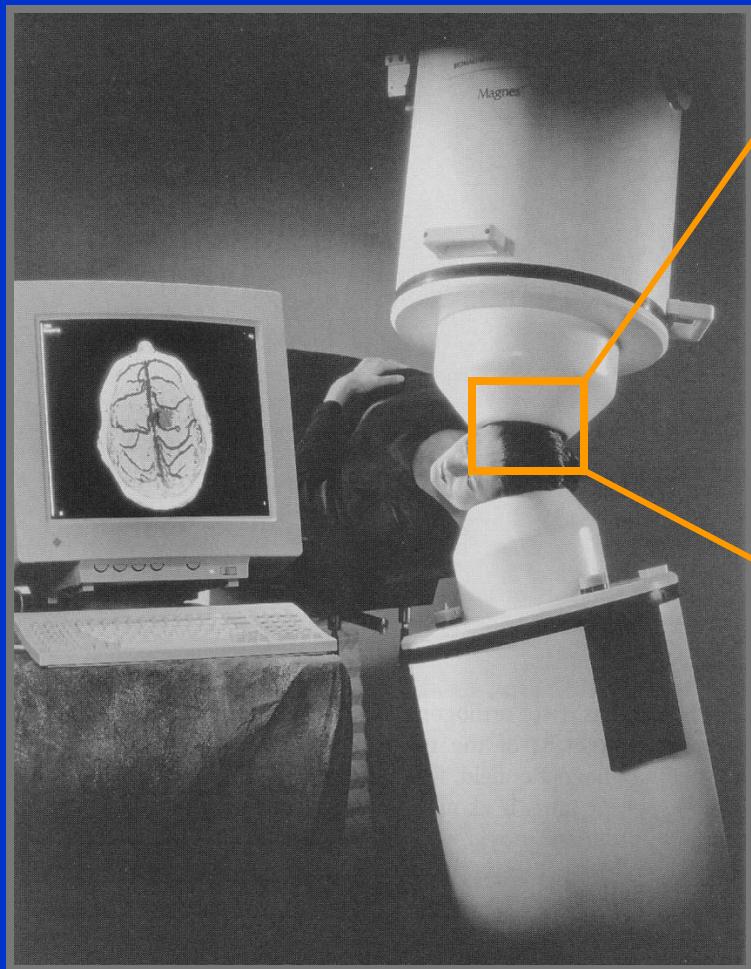
Statistical (T test) between two experimental conditions



F4



# Magnetoencephalography (MEG)

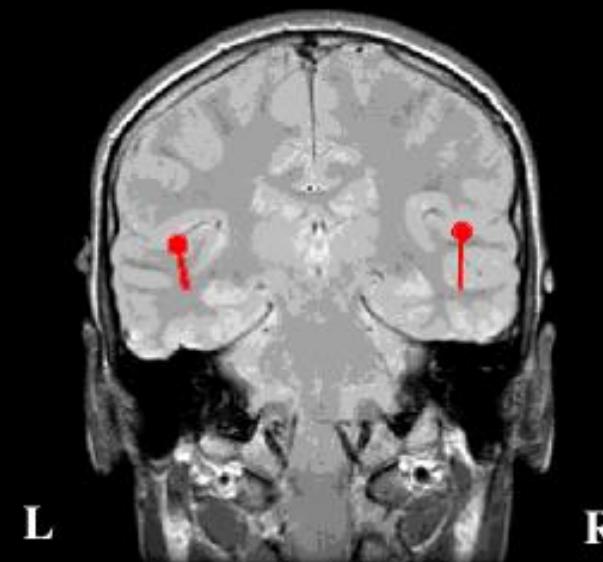
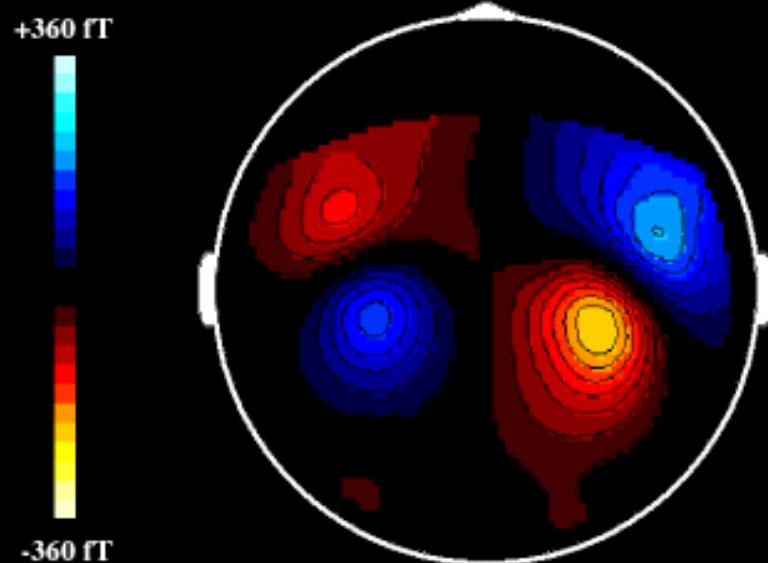
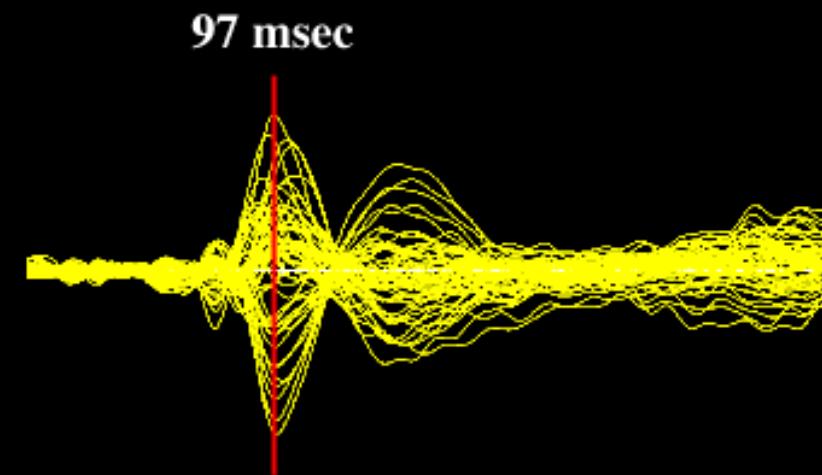
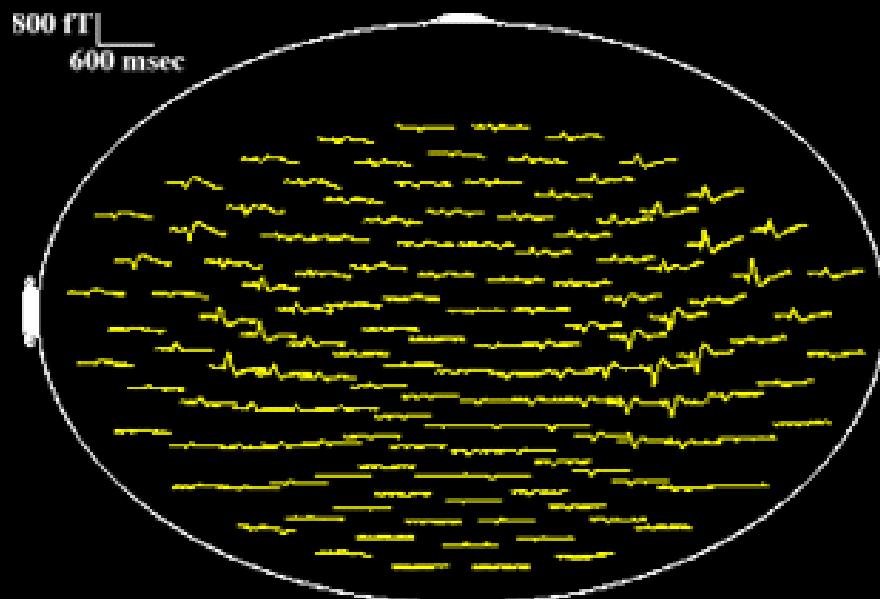


SQUID:  
Superconducting Quantum  
Interference Device

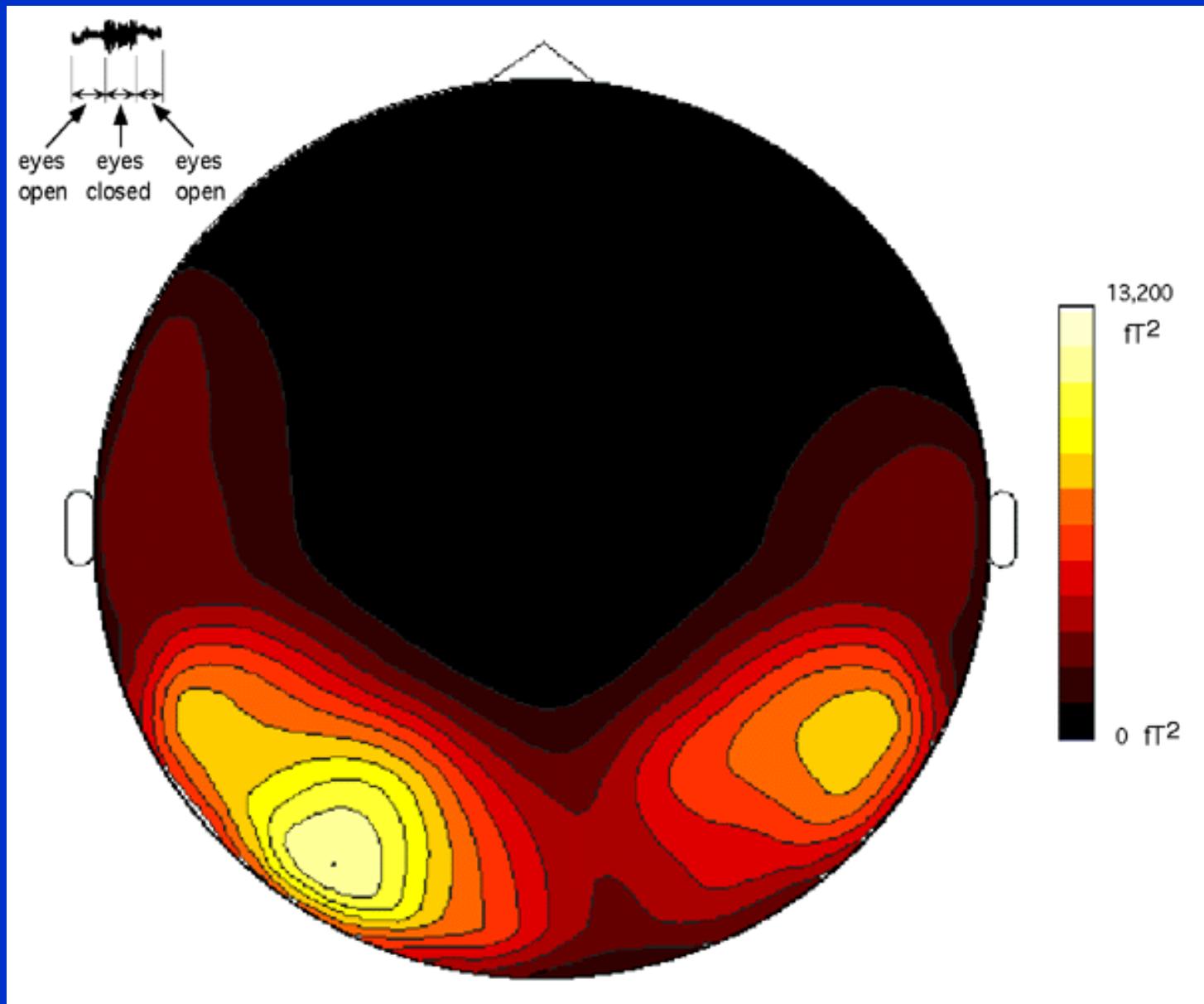


Combined MEG and EEG

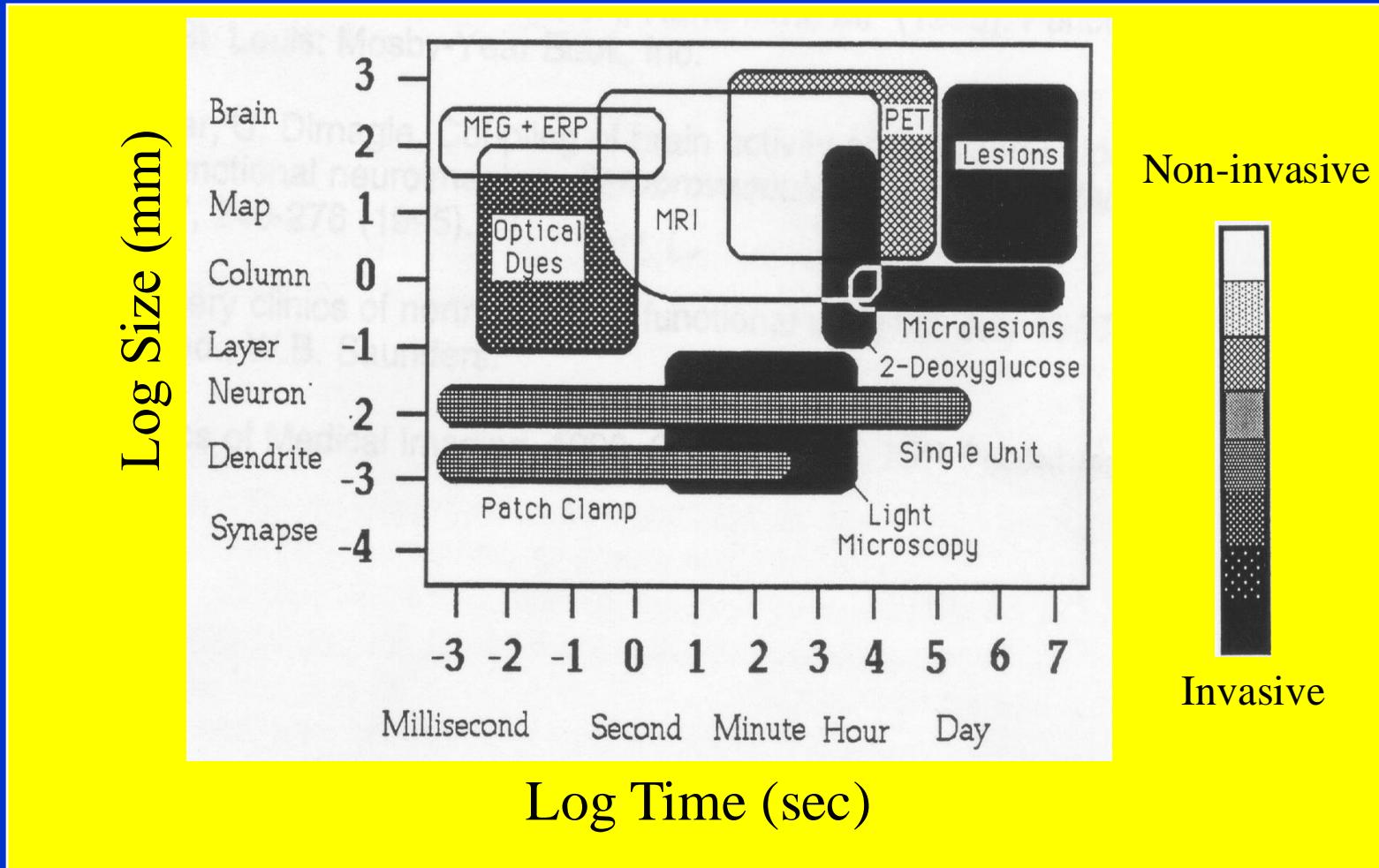
# MEG Mapping



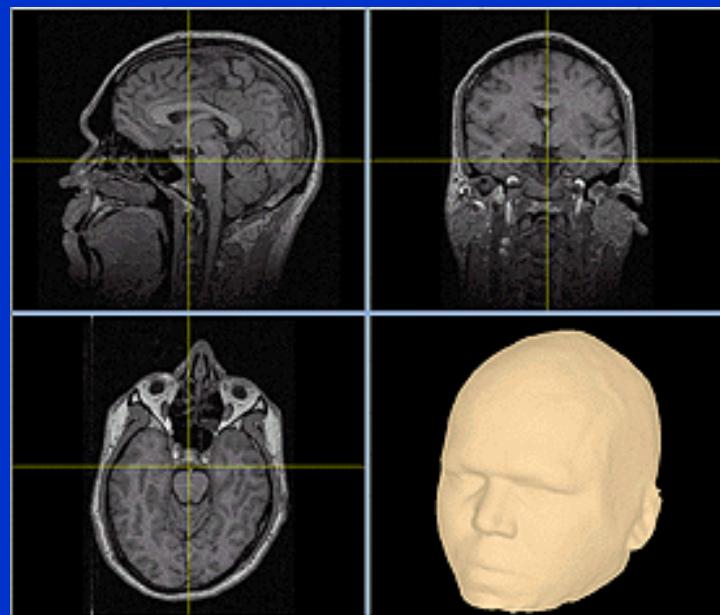
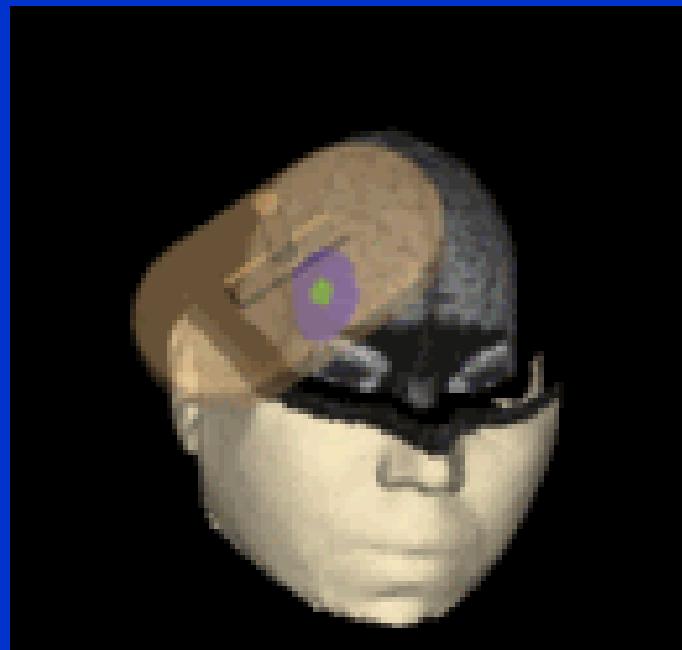
# Alpha Wave Activity Mapped with MEG



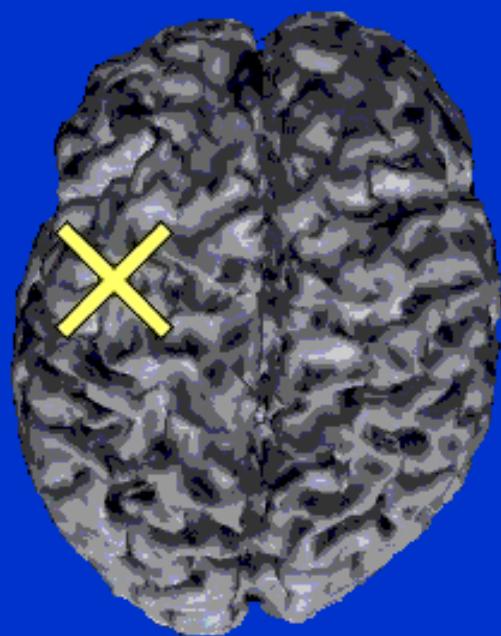
# Functional Neuroimaging Techniques



# Transcranial Magnetic Stimulation



# Transcranial Magnetic Stimulation (TMS)



# Acknowledgements

Ted Deyoe, Medical College of Wisconsin  
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Eric Wong, University of California, San Diego  
Ravi Menon, University of Western Ontario  
Nikos Logothetis, Max Plank Institute, Germany

# FIM Unit & FMRI Core Facility

<b>Director:</b>	<b>Graduate Student:</b>	<b>Summer Students:</b>
<b>Peter Bandettini</b>	<b>Natalia Petridou</b>	<b>Hannah Chang</b>
<b>Staff Scientists:</b>	<b>Post-Back. IRTA Students:</b>	<b>Courtney Kemps</b>
<b>Sean Marrett</b>	<b>Elisa Kapler</b>	<b>Douglass Ruff</b>
<b>Jerzy Bodurka</b>	<b>August Tuan</b>	<b>Carla Wettig</b>
<b>Frank Ye</b>	<b>Dan Kelley</b>	<b>Kang-Xing Jin</b>
<b>Wen-Ming Luh</b>	<b>Visiting Fellows:</b>	<b>Program Assistant:</b>
<b>Computer Specialist:</b>	<b>Sergio Casciaro</b>	<b>Kay Kuhns</b>
<b>Adam Thomas</b>	<b>Marta Maierov</b>	<b>Scanning Technologists:</b>
<b>Post Docs:</b>	<b>Guosheng Ding</b>	<b>Karen Bove-Bettis</b>
<b>Rasmus Birn</b>	<b>Clinical Fellow:</b>	<b>Paula Rowser</b>
<b>Hauke Heekeren</b>	<b>James Patterson</b>	
<b>David Knight</b>	<b>Psychologist:</b>	
<b>Patrick Bellgowan</b>	<b>Julie Frost</b>	
<b>Ziad Saad</b>		