NEUROIMAGING

(…at the NIH)

Peter A. Bandettini, Ph.D.
bandettini@nih.gov
Functional MRI Facility
Unit on Functional Imaging Methods
Laboratory of Brain and Cognition

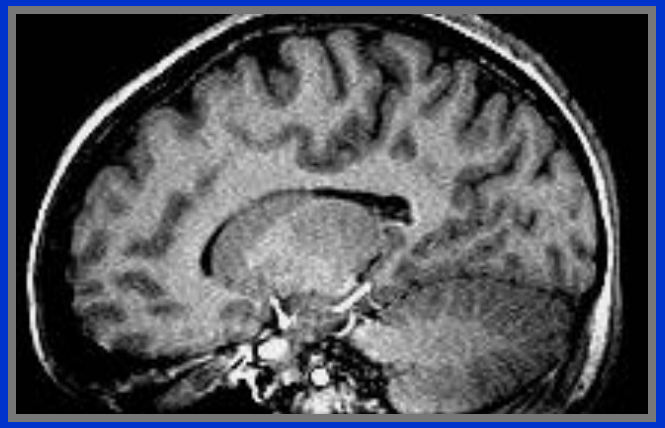
NIMH
National Institute
of Mental Health

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.

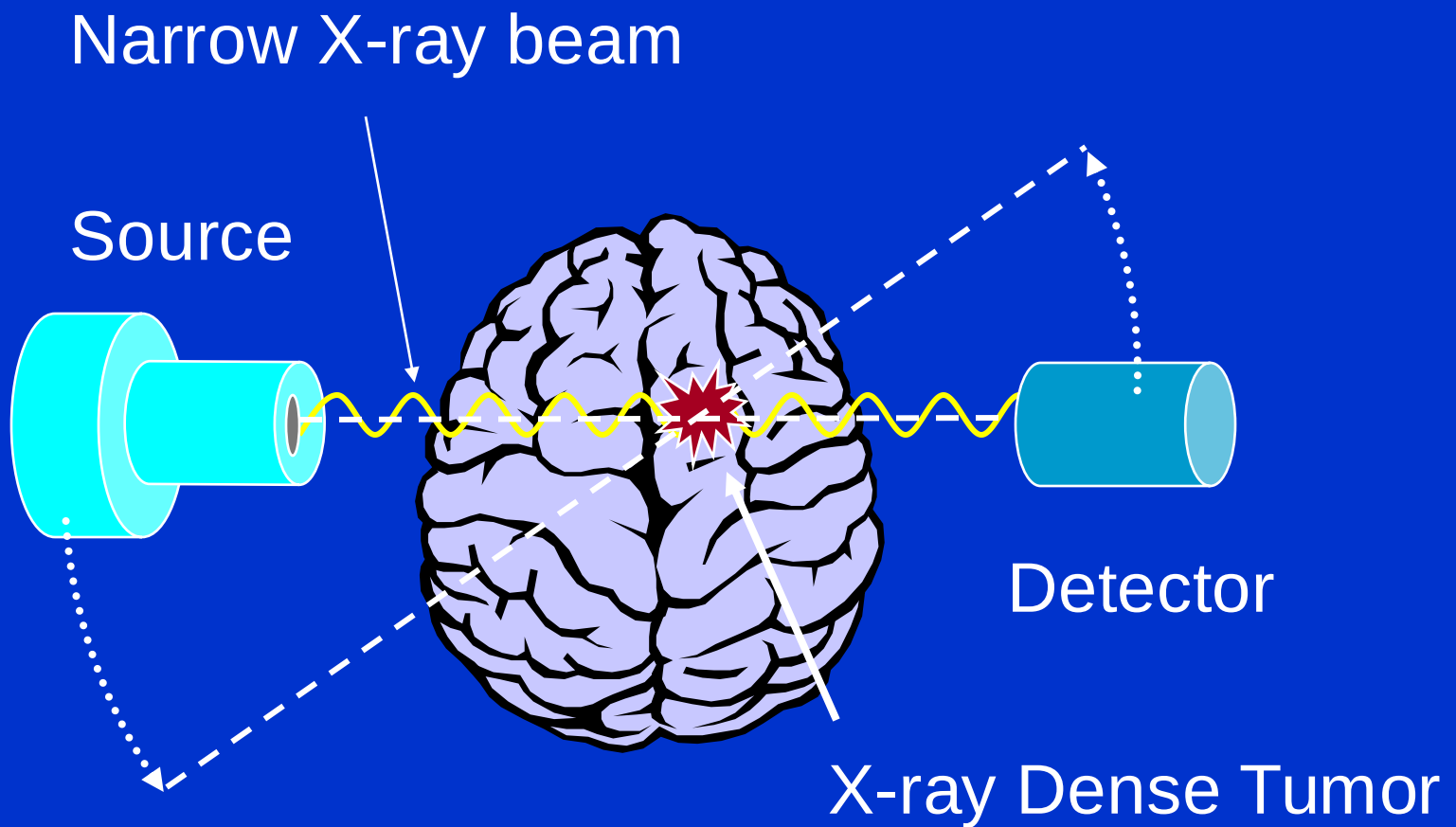


- Primarily associated with Computerized Axial Tomography (CAT or CT) and Magnetic Resonance Imaging (MRI).

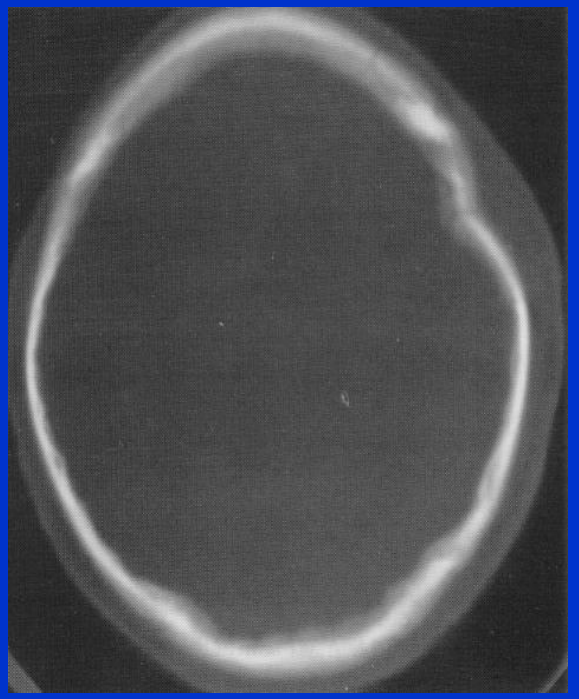
- Structural/Anatomical Imaging
  - X-ray
  - Computerized Tomography (CT)
  - Magnetic Resonance Imaging (MRI)
    - Angiography
    - Venography
    - Perfusion
    - Diffusion Tensor Imaging

Computerized Tomography (CT)

Creation of images in slices or sections.

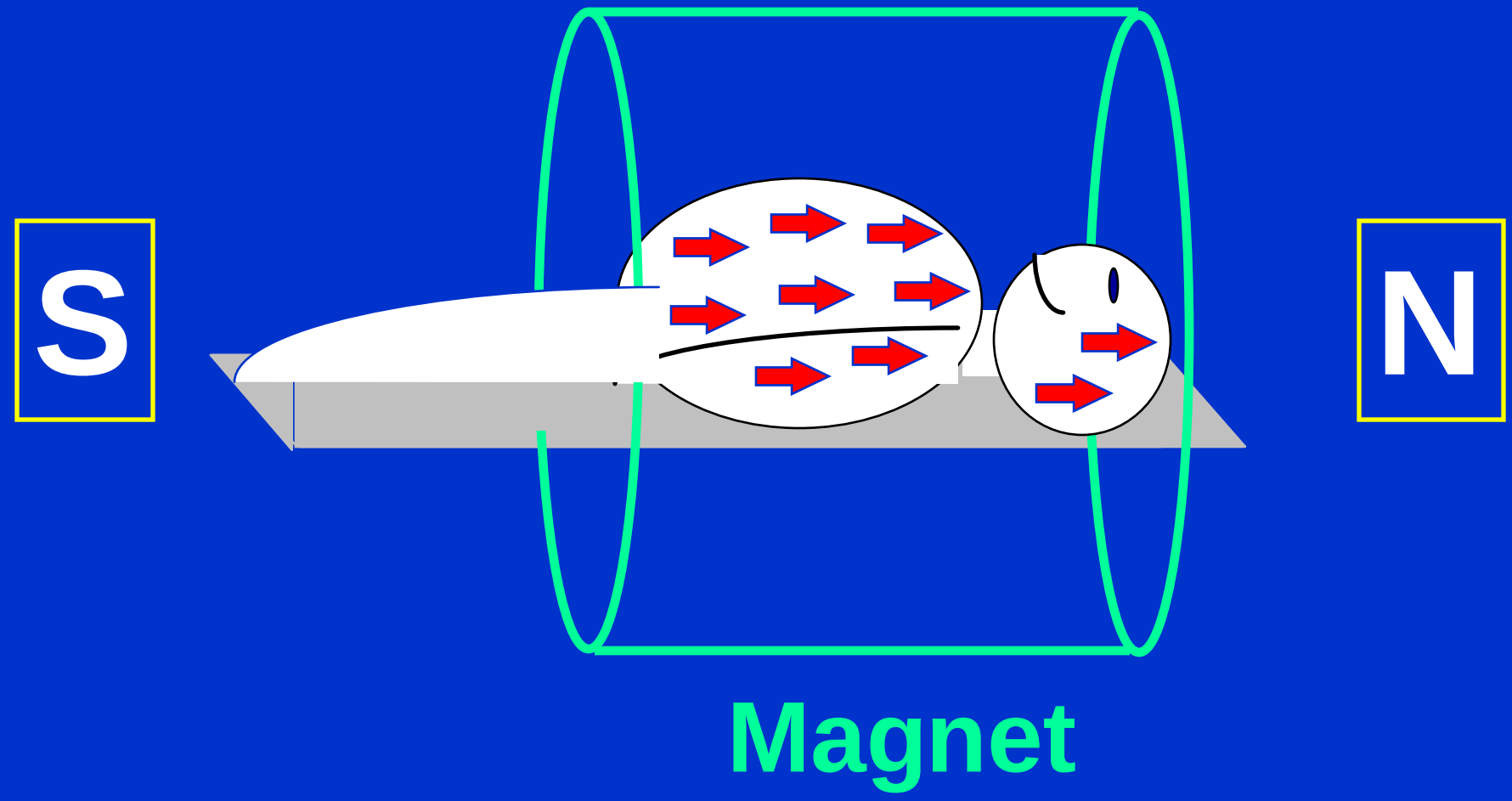


CT Images

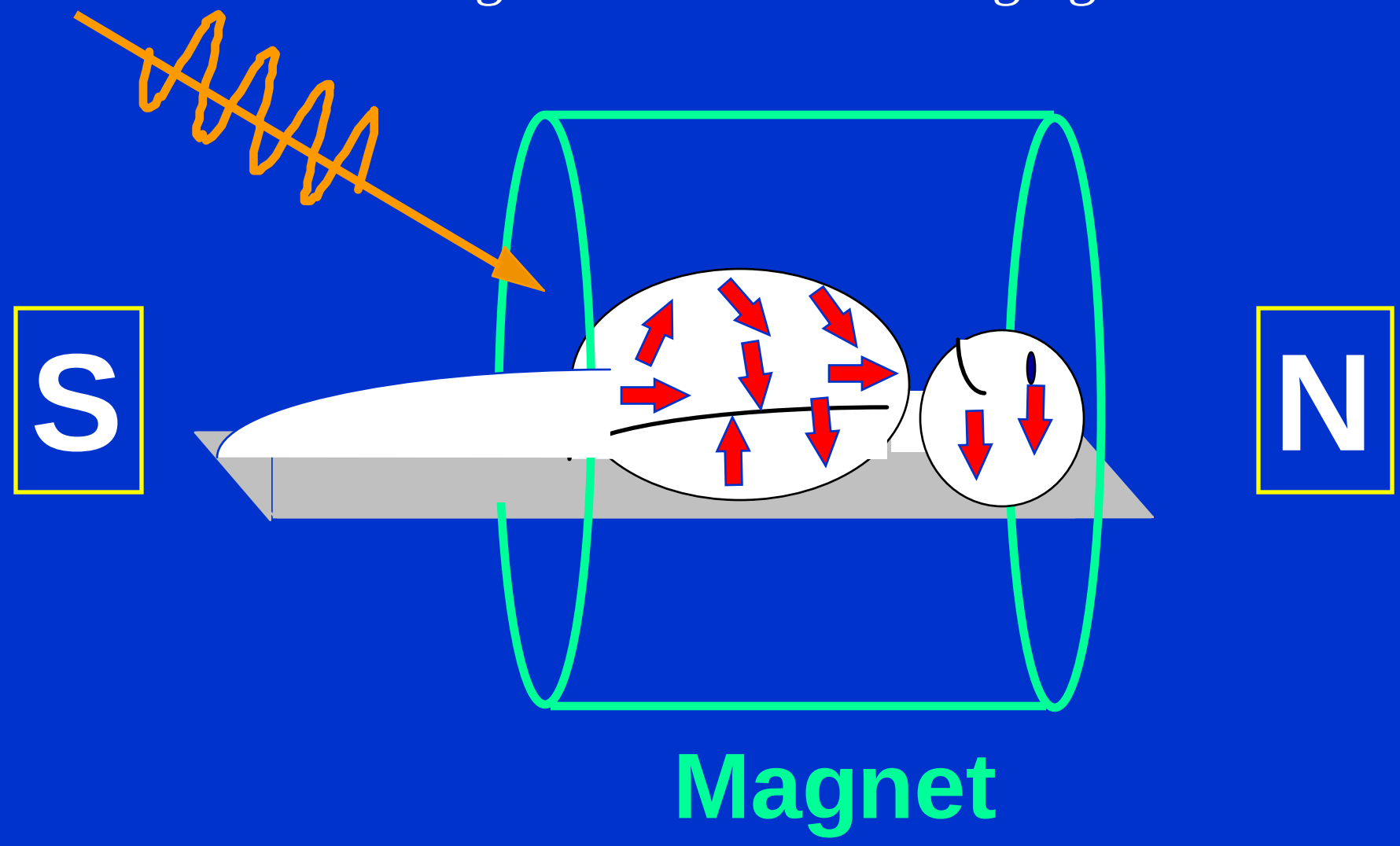


Magnetic Resonance Imaging

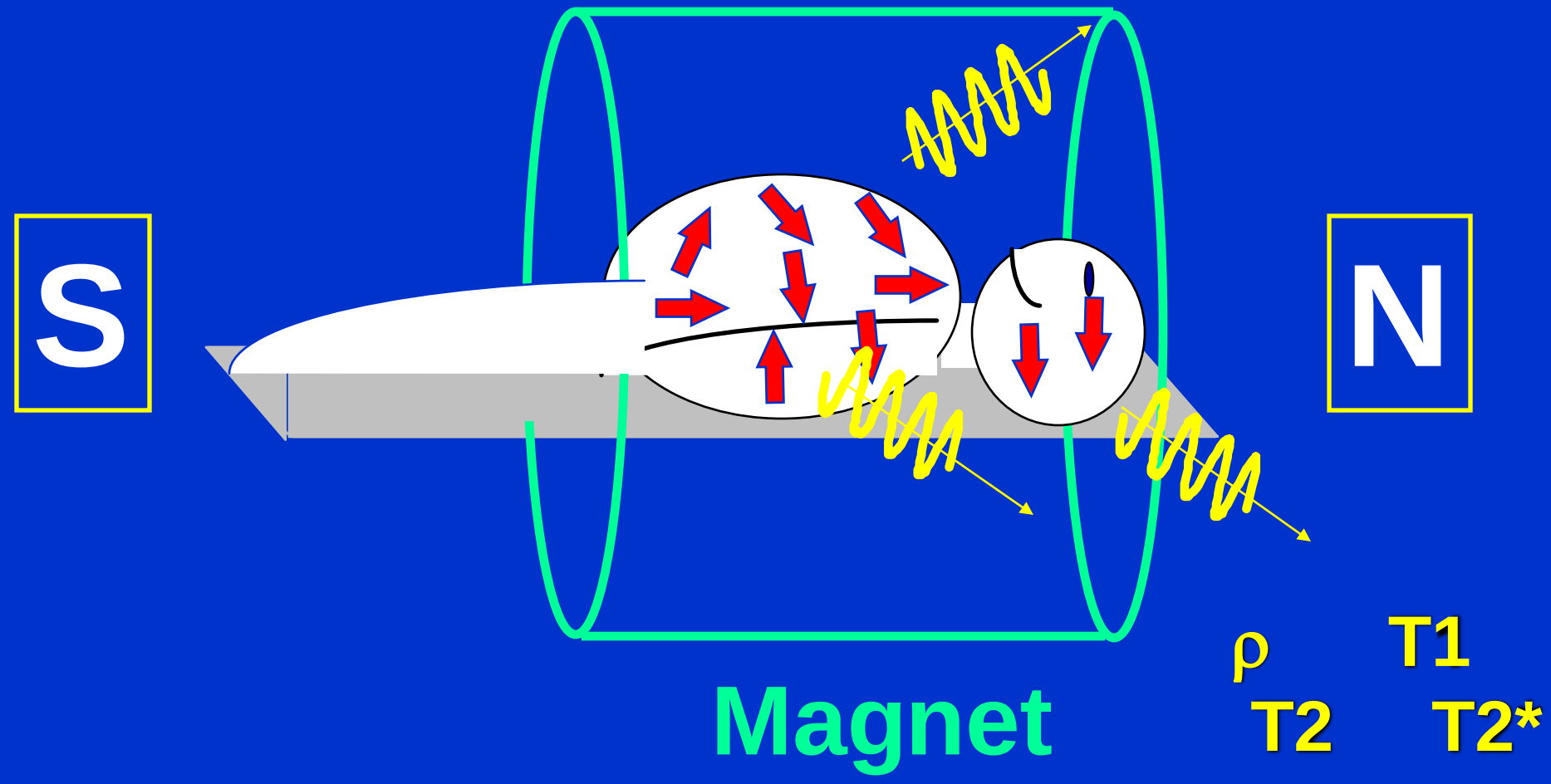
Magnetic Resonance Imaging



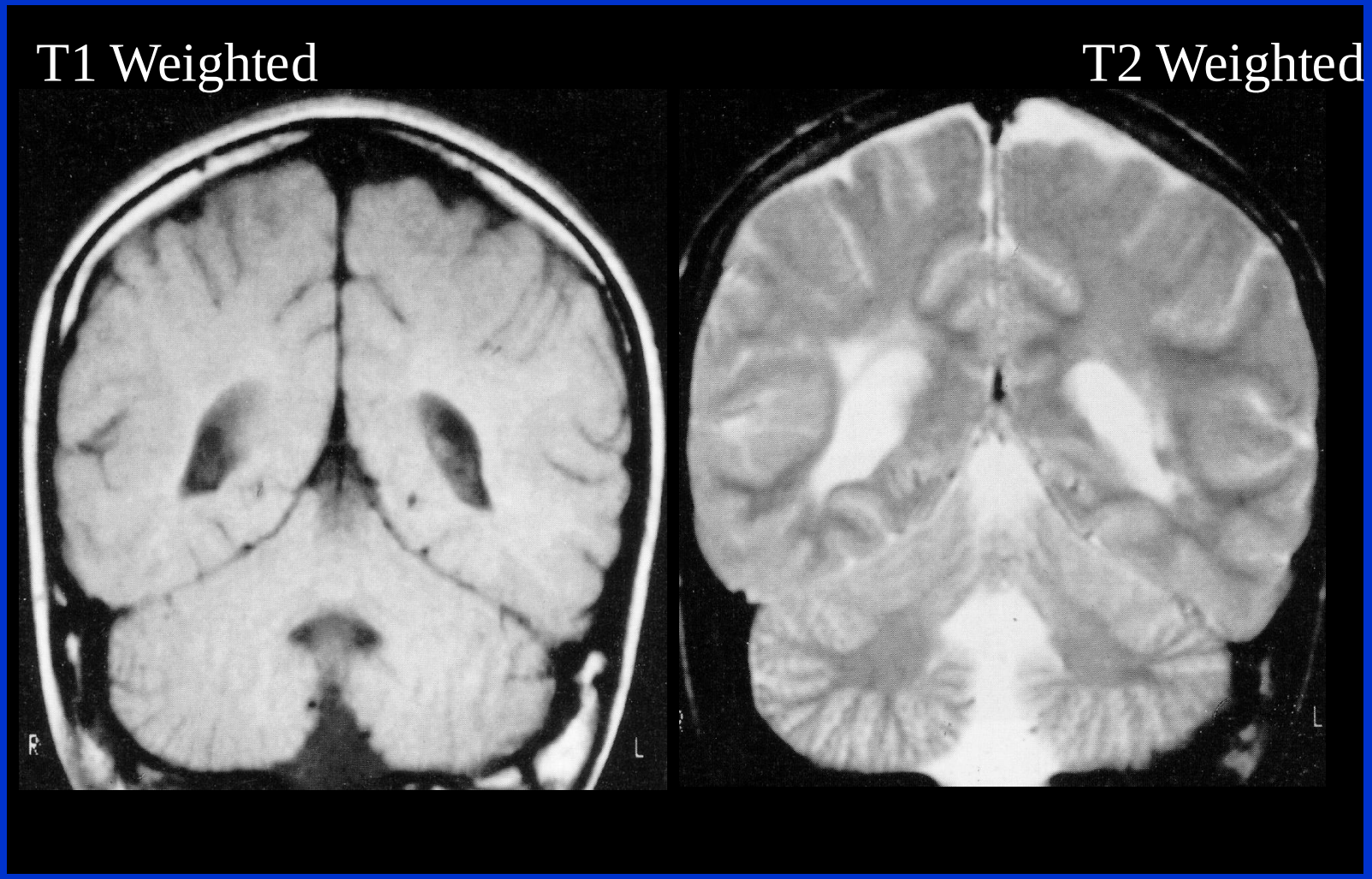
Magnetic Resonance Imaging



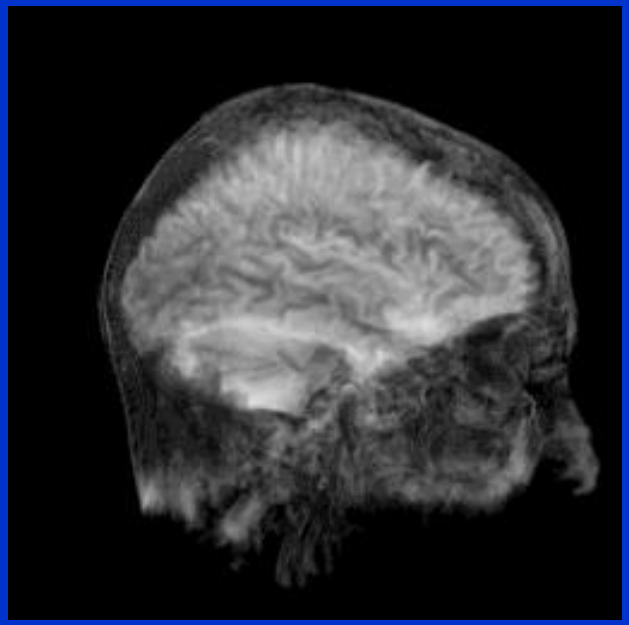
Magnetic Resonance Imaging

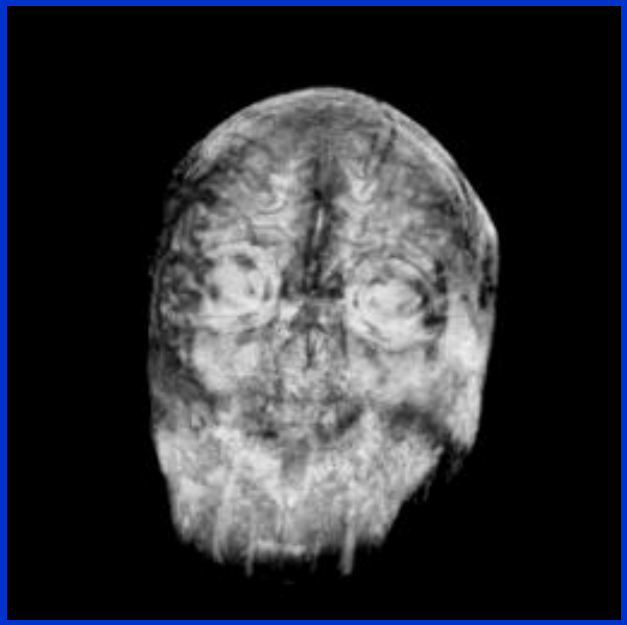


MRI Images with Different Contrast Weighting

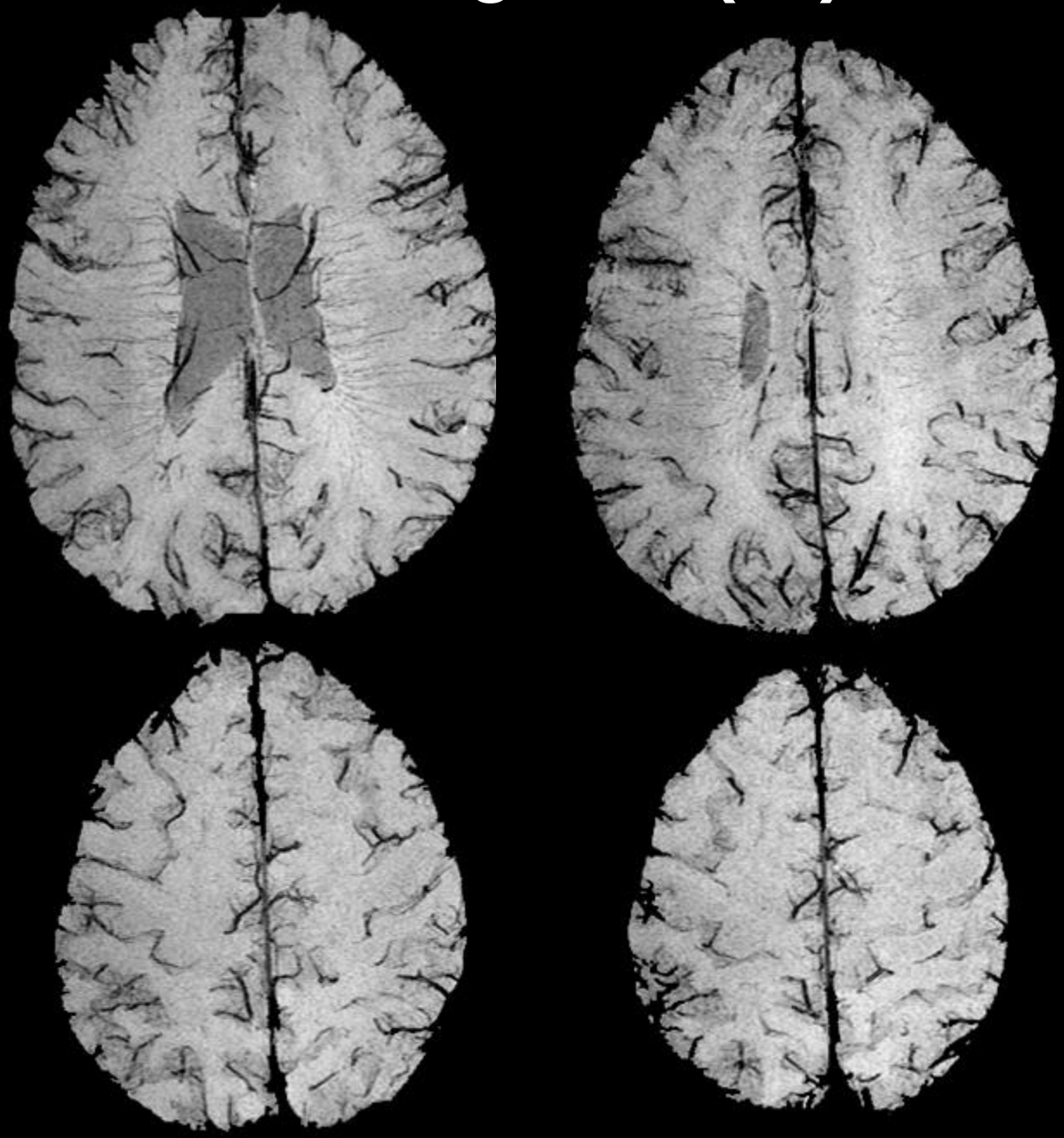


3D Rendering

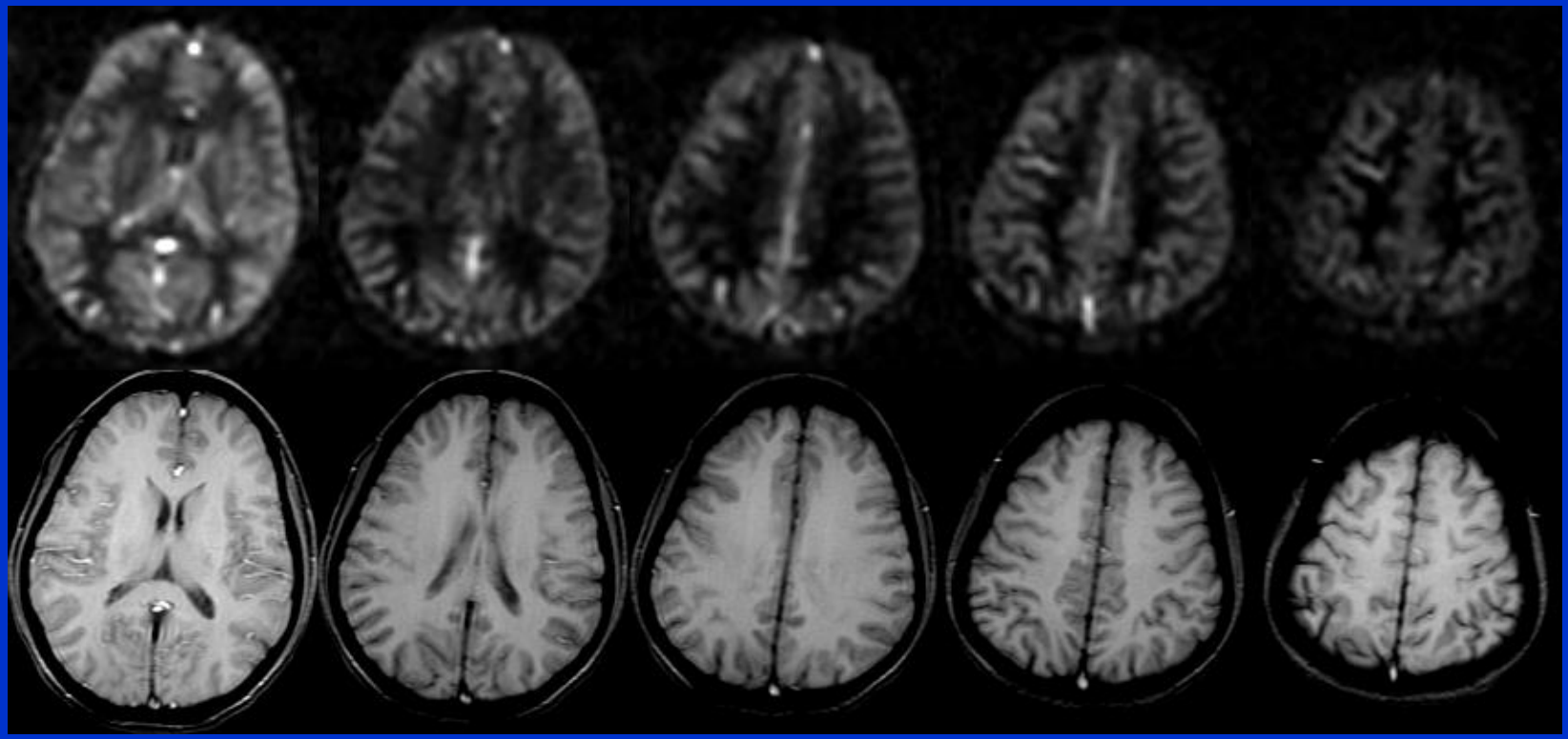




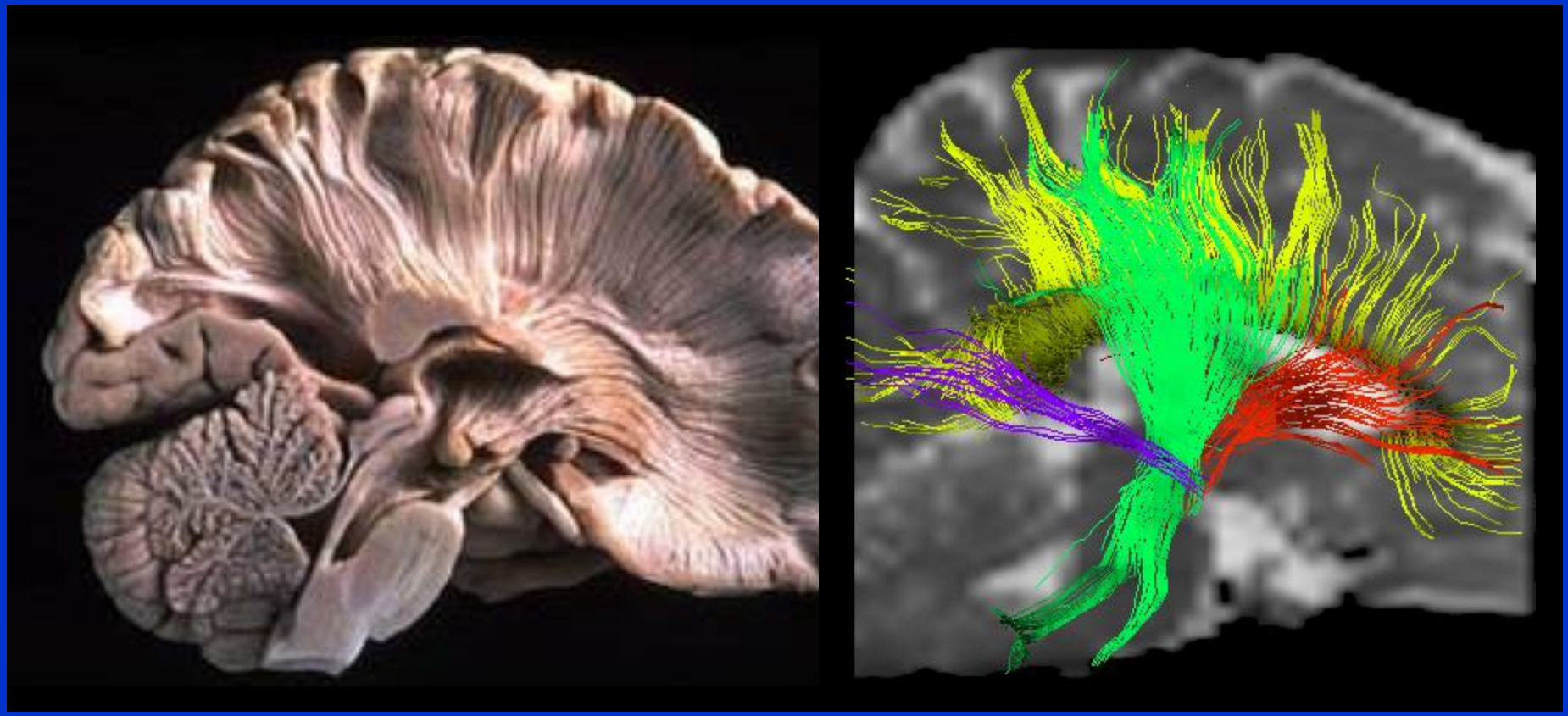
Venograms (3T)



Perfusion Imaging with MRI

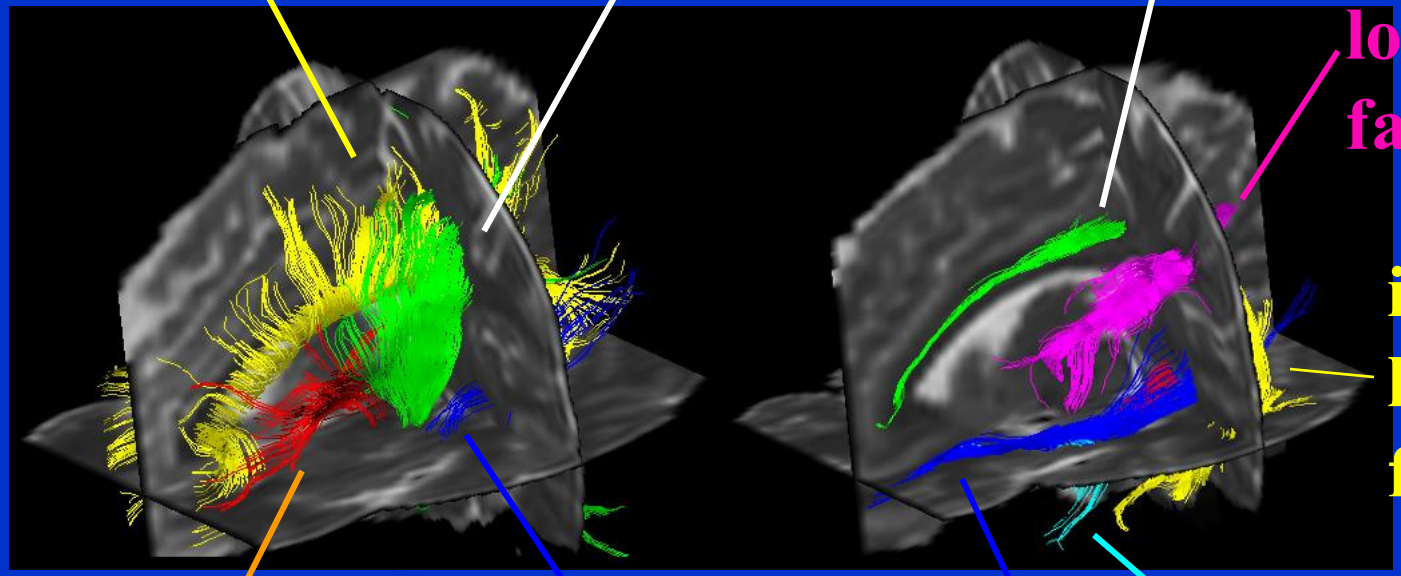


Diffusion Tensor Imaging



S. Mori - JHU

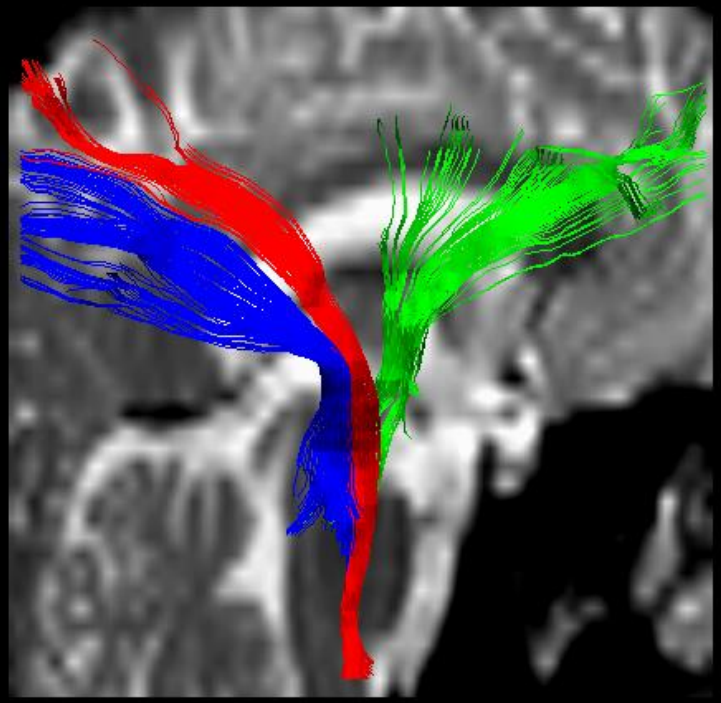
Diffusion Tensor Imaging

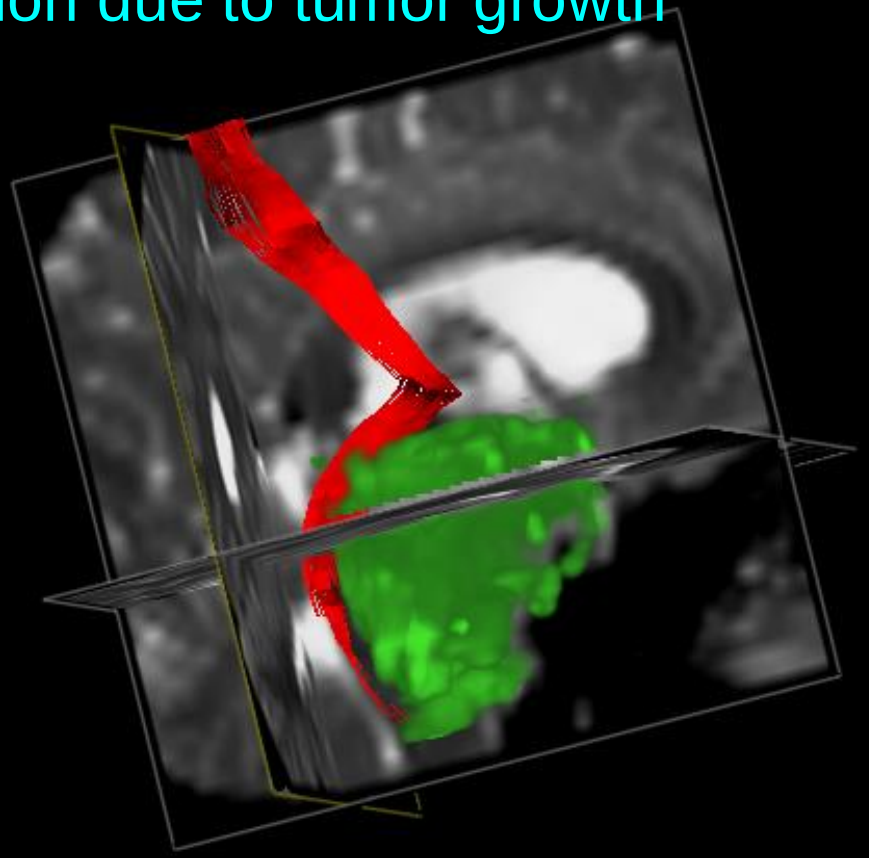


S. Mori - JHU

Anatomical guidance with DTI:

Example: Anatomical deformation due to tumor growth





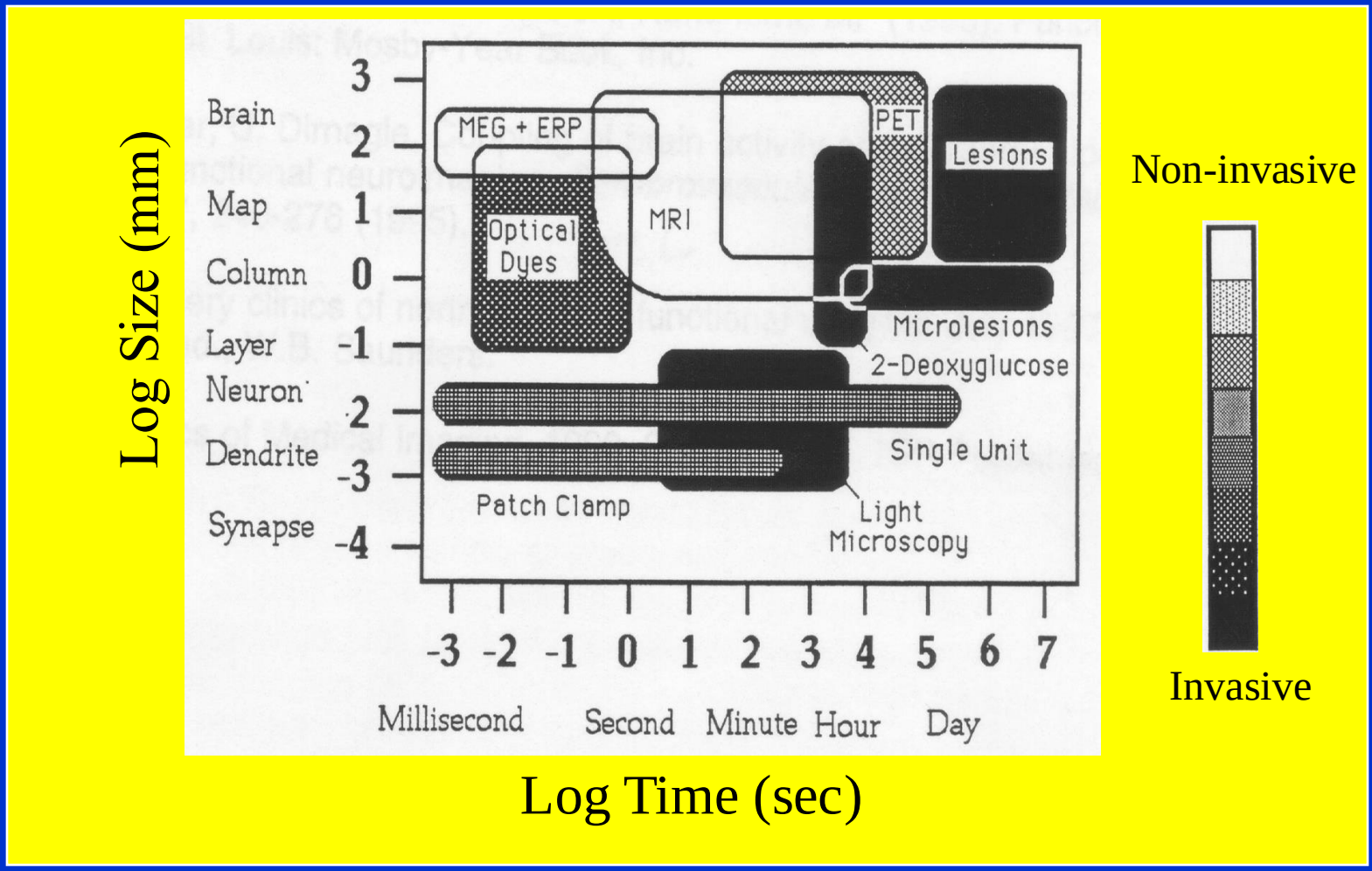
S. Mori - JHU

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.

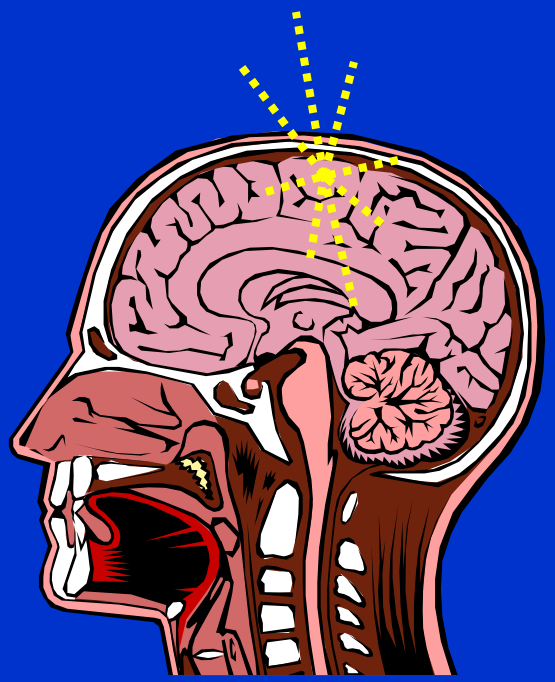
- Functional Imaging
  - –Xenon Computerized Tomography (Xe CT)
  - –Positron Emission Tomography (PET)
  - –Single Photon Computed Tomography (SPECT)
  - –Functional MRI (fMRI)
  - –Electroencephalography (EEG)
  - –Magnetoencphalography (MEG)
  - –Transcranial Magnetic Stimulation (TMS)

Functional Neuroimaging Techniques

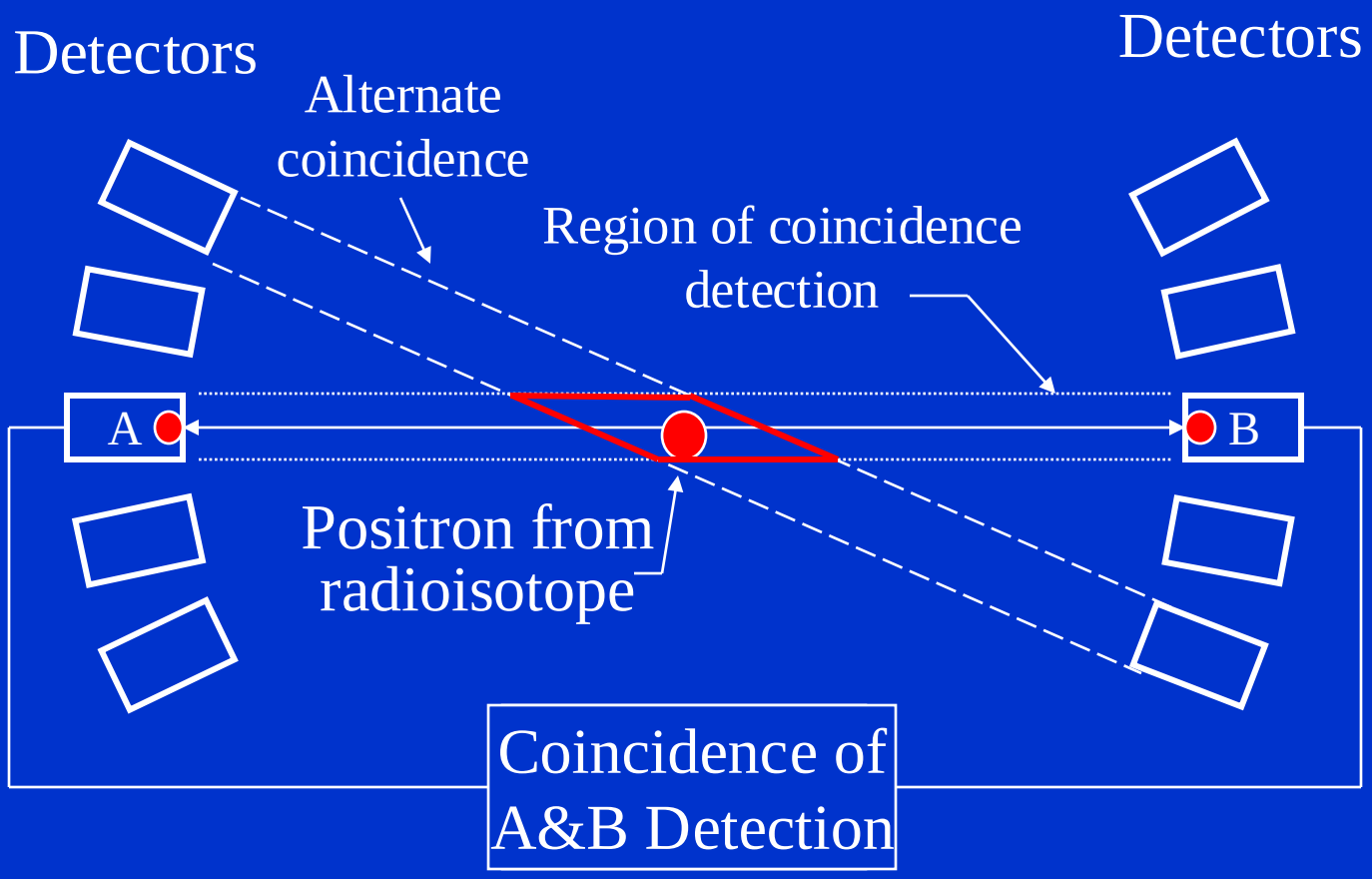


Positron Emission Tomography (PET)

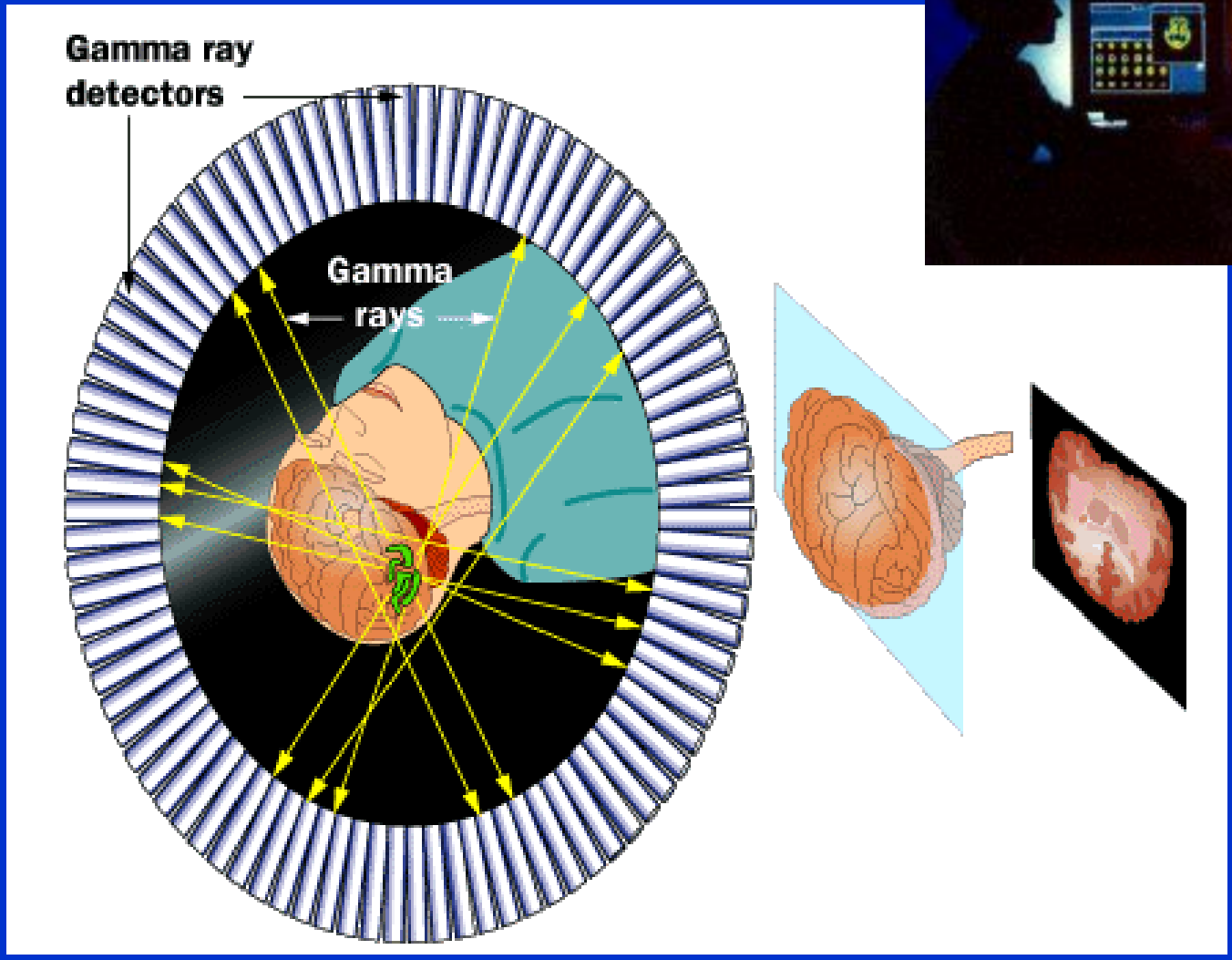
- Positron emission tomography (PET) is a technique for studying functional processes *in vivo* by measuring the concentrations of positron-emitting radioisotopes within the subject.
- PET is primarily used to study biochemical and physiological processes within living organs with 3-dimensional spatial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

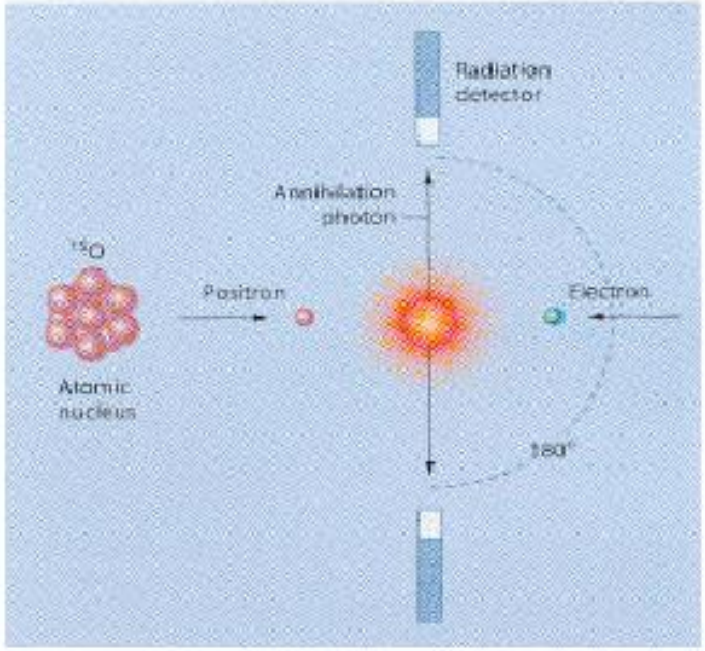


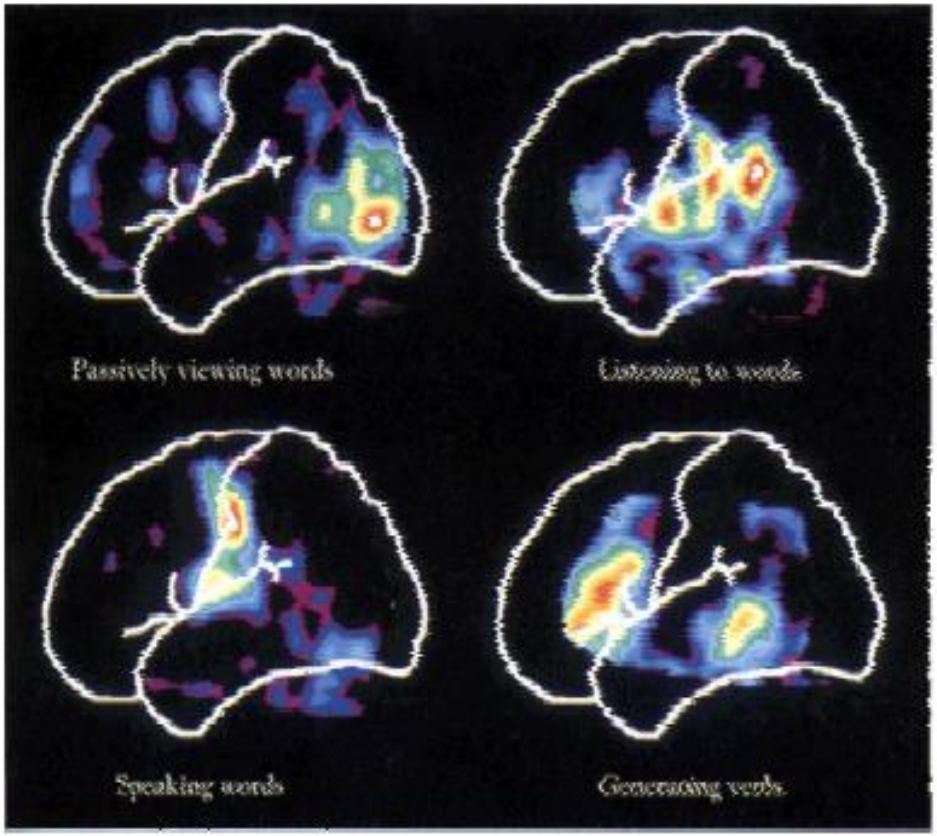
PET mechanism



Positron Emission Tomography

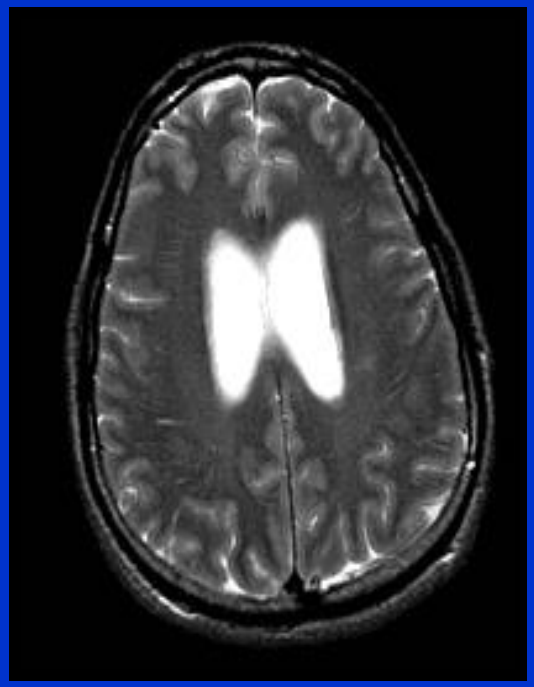


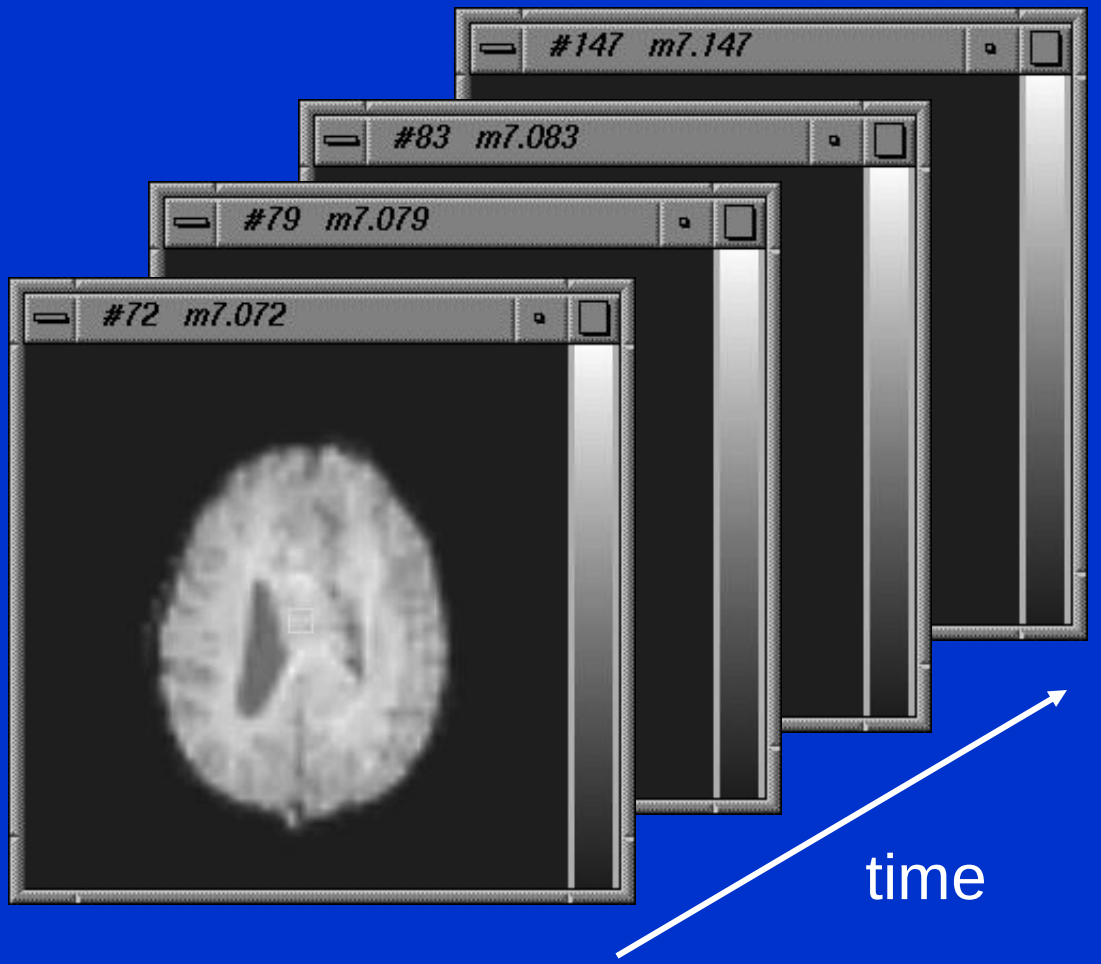

Radiation detector
Annihilation photon
^{15}O
Positron
Electron
Atomic nucleus
180°


Passively viewing words
Listening to words
Speaking words
Generating verbs

Contrast in Functional MRI

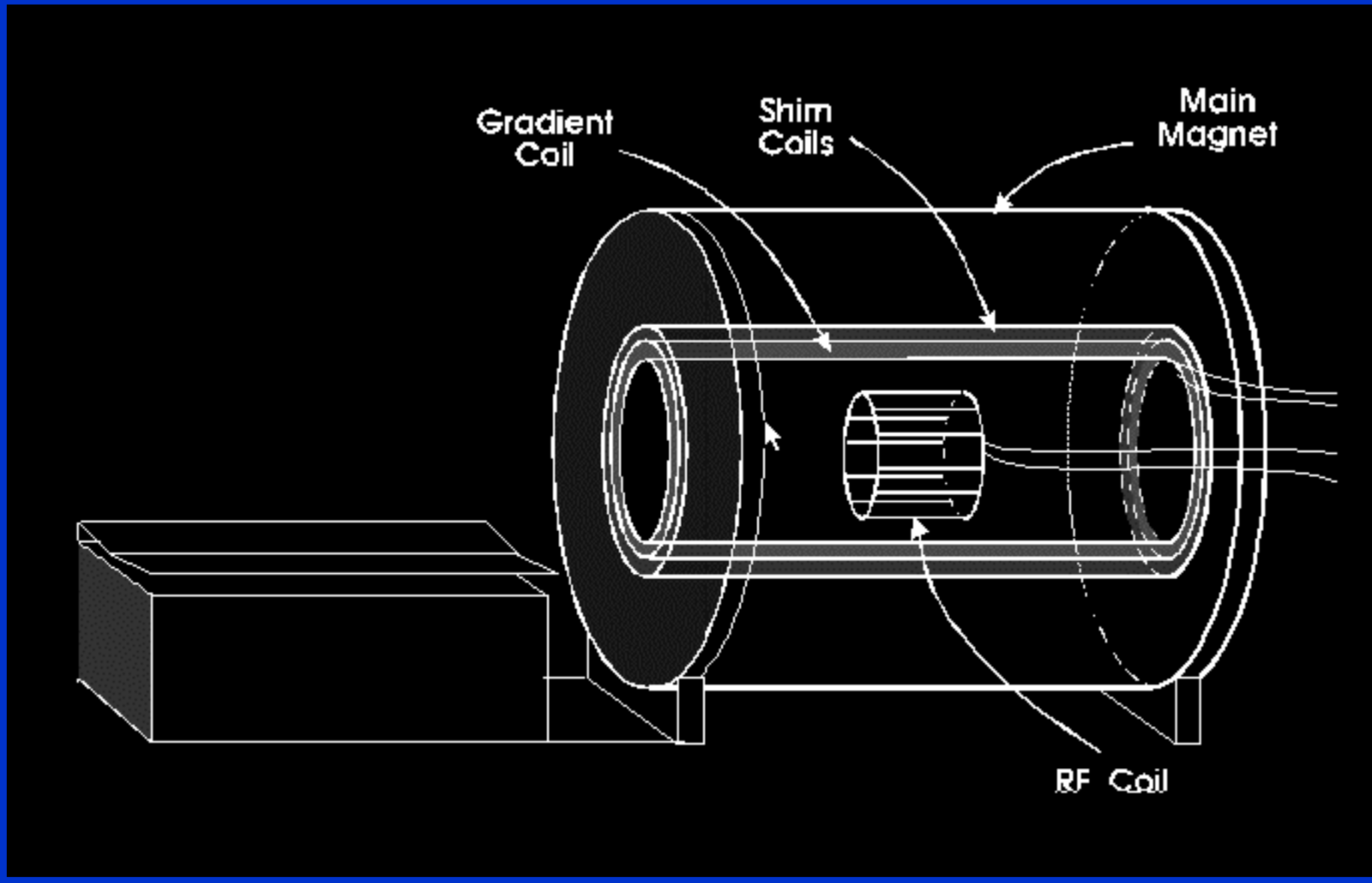
- Blood Volume
- Blood Oxyenation
- Perfusion
- Metabolism



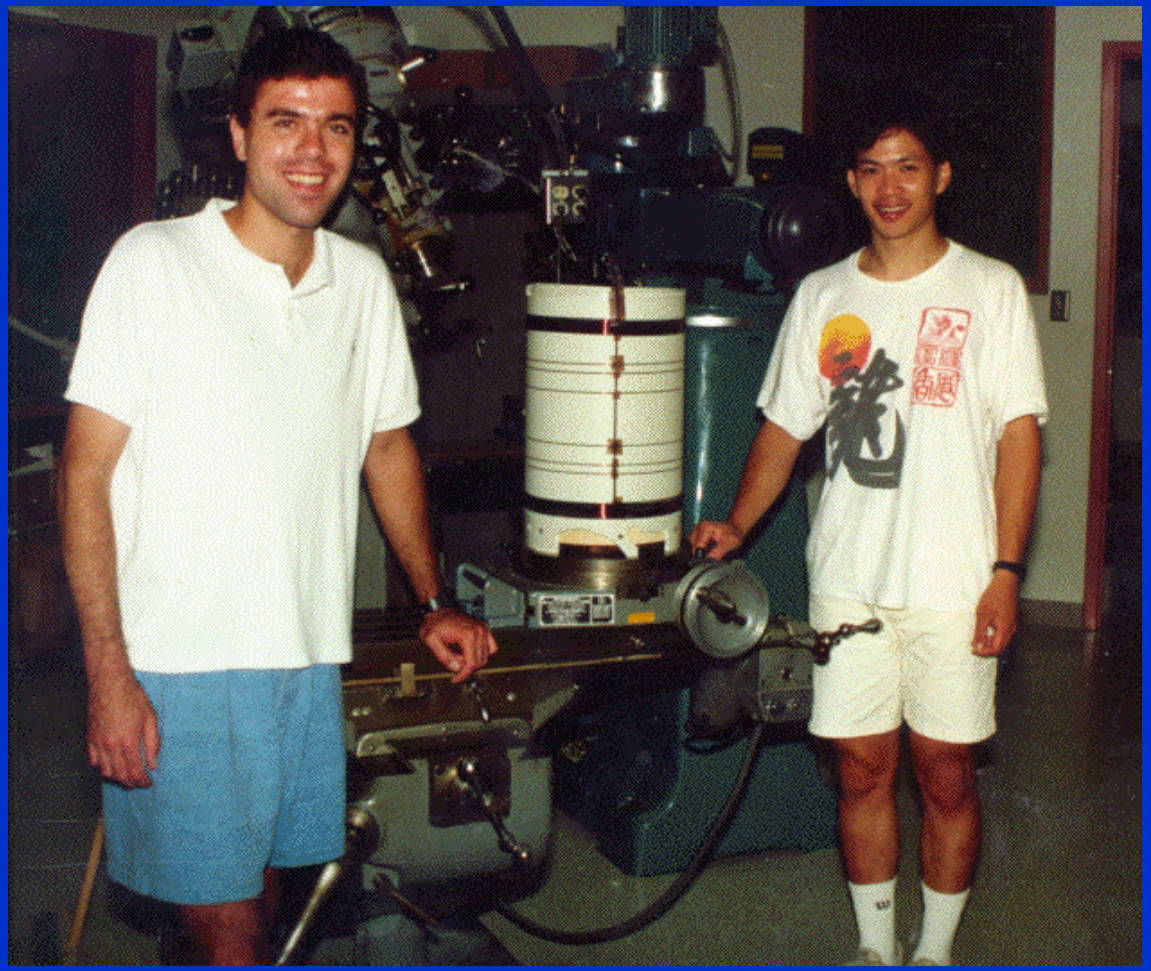


Anatomic

Functional


Gradient Coil
Shim Coils
Main Magnet
RF Coil

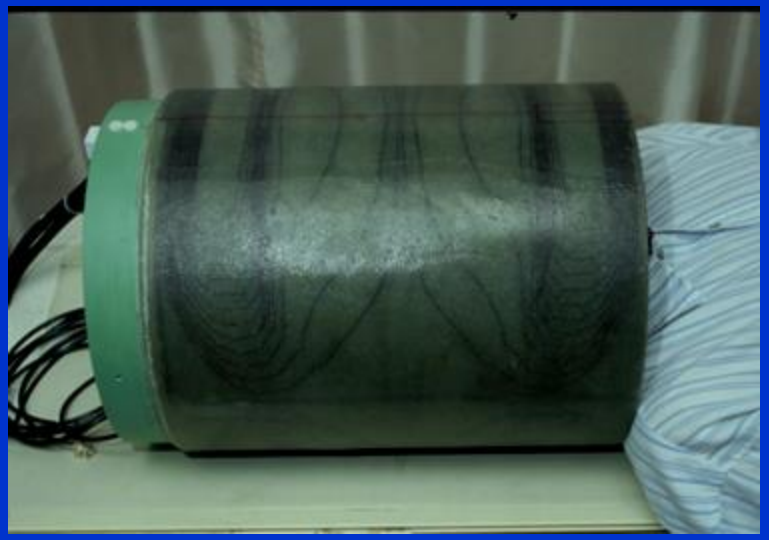
Local gradients solved the problem



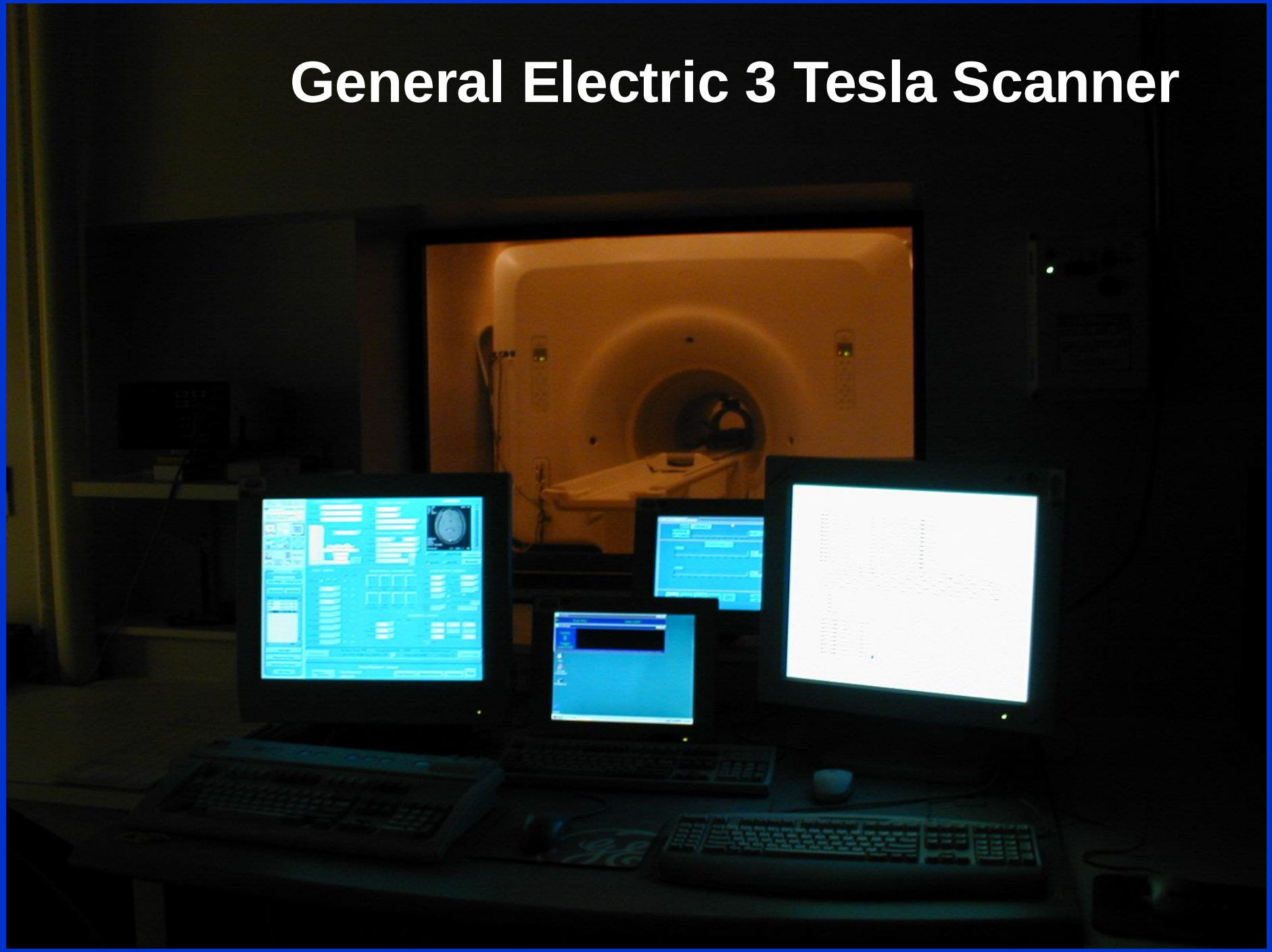
August, 1991

1991-1992

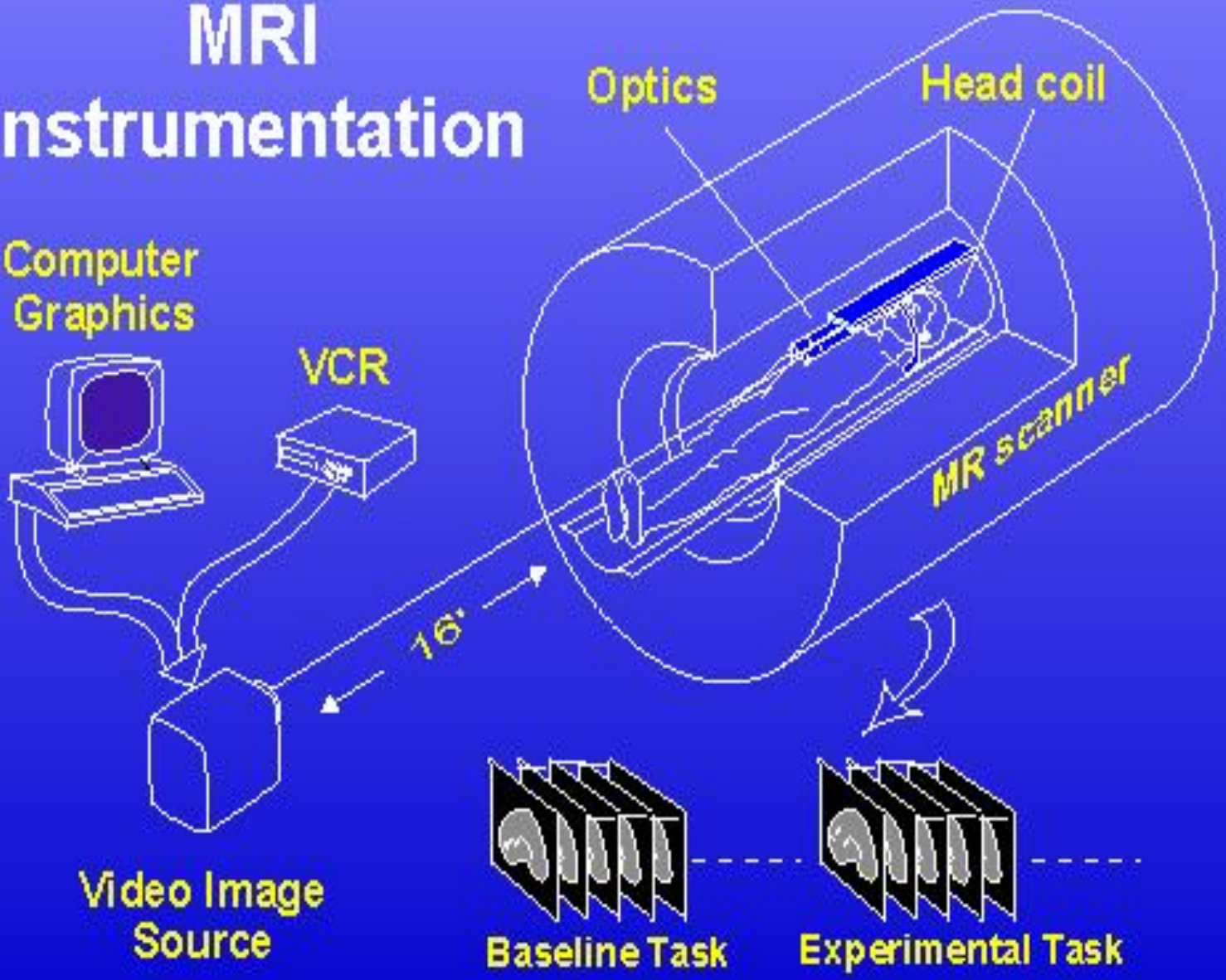
1992-1999



General Electric 3 Tesla Scanner

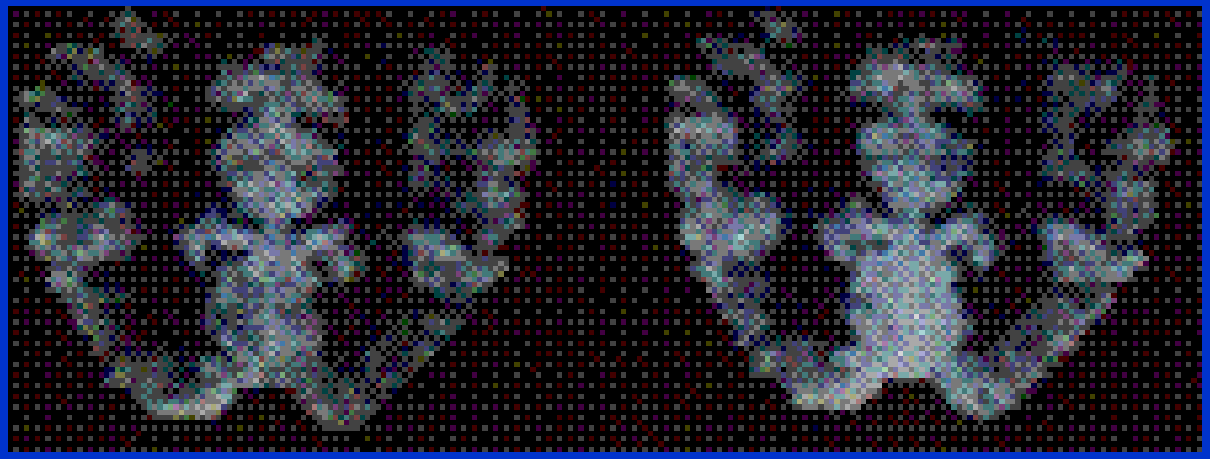


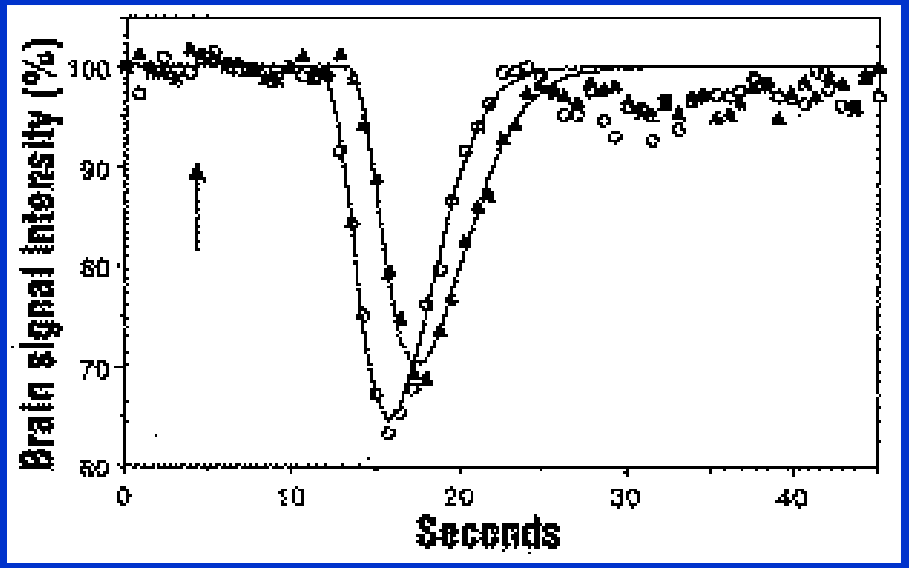
MRI Instrumentation

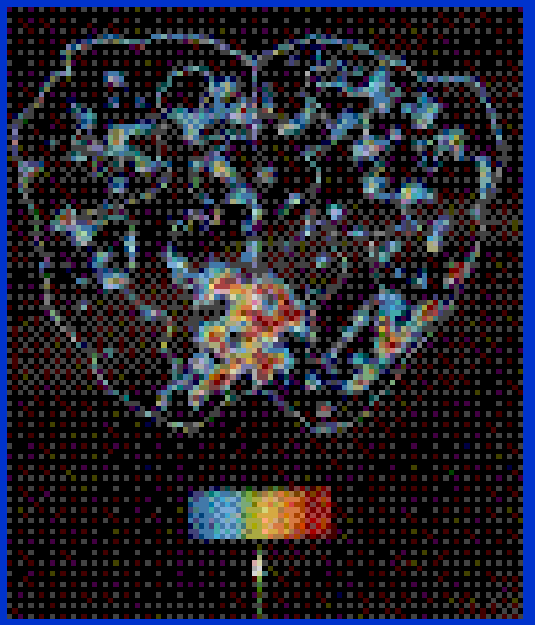


Blood Volume Changes with Brain Activation

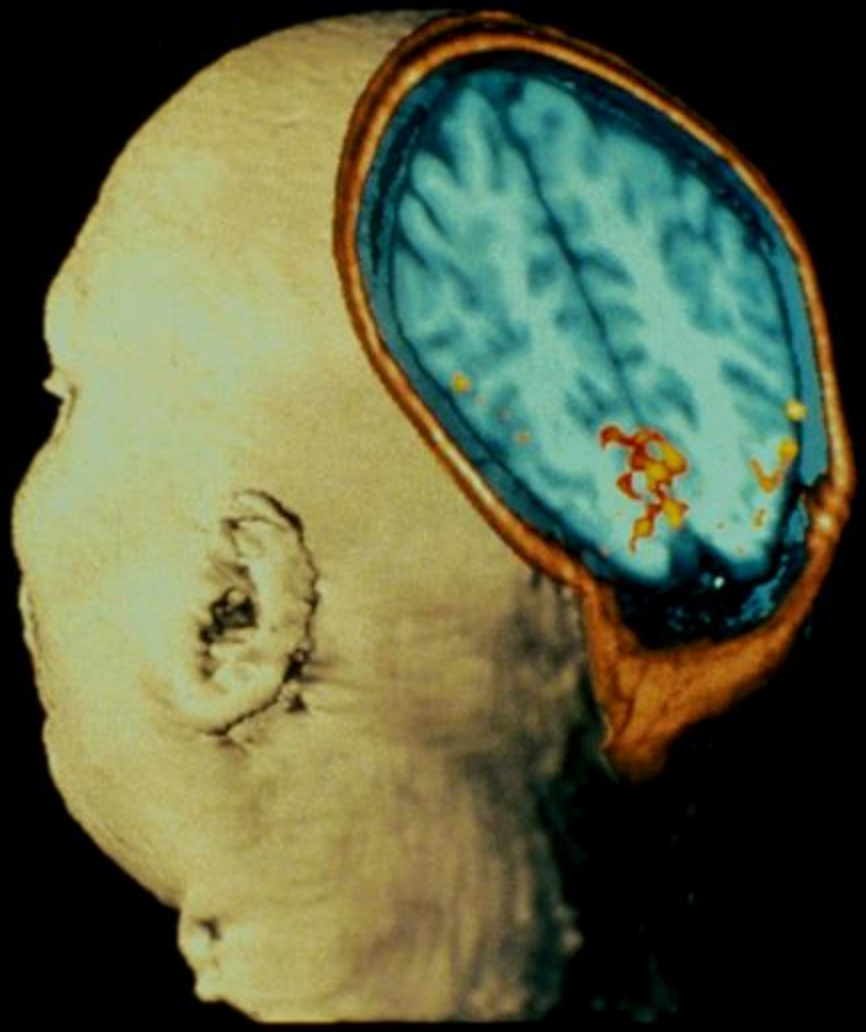
Resting **Active**







Photic Stimulation



MRI Image showing activation of the Visual Cortex

From Belliveau, et al. Science Nov 1991

BOLD Contrast in the Detection of Neuronal Activity

Cerebral Tissue Activation

↓

Local Vasodilation

↓

Increase in Cerebral Blood Flow and Volume → Oxygen Delivery Exceeds Metabolic Need

↓

Increase in Capillary and Venous Blood Oxygenation

↓

Decrease in Deoxy-hemoglobin

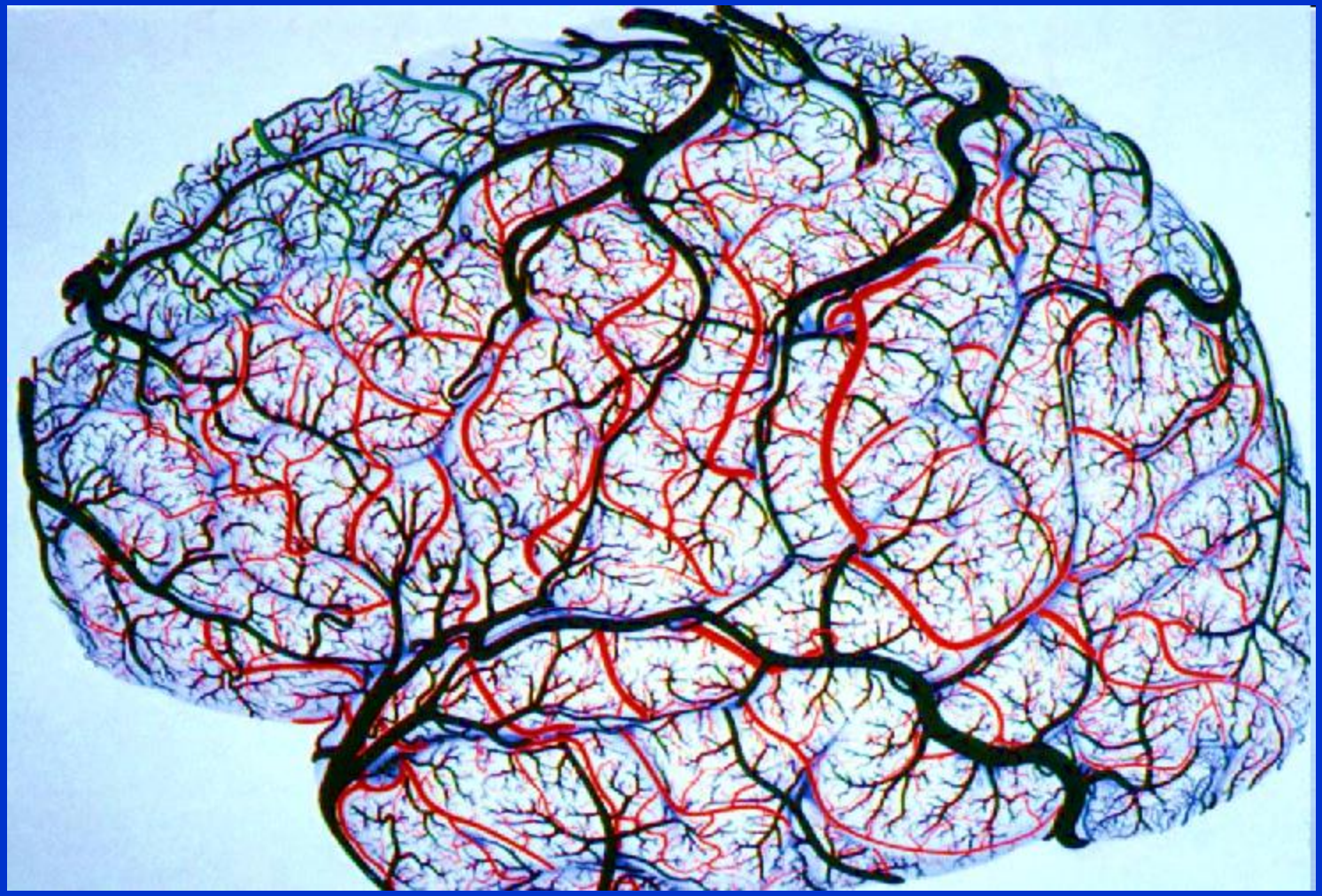
Deoxy-hemoglobin: paramagnetic
Oxy-hemoglobin: diamagnetic

↓

Decrease in susceptibility-related intravoxel dephasing → Increase in T2 and T2*

↓

Local Signal Increase in T2 and T2* - weighted sequences



BOLD

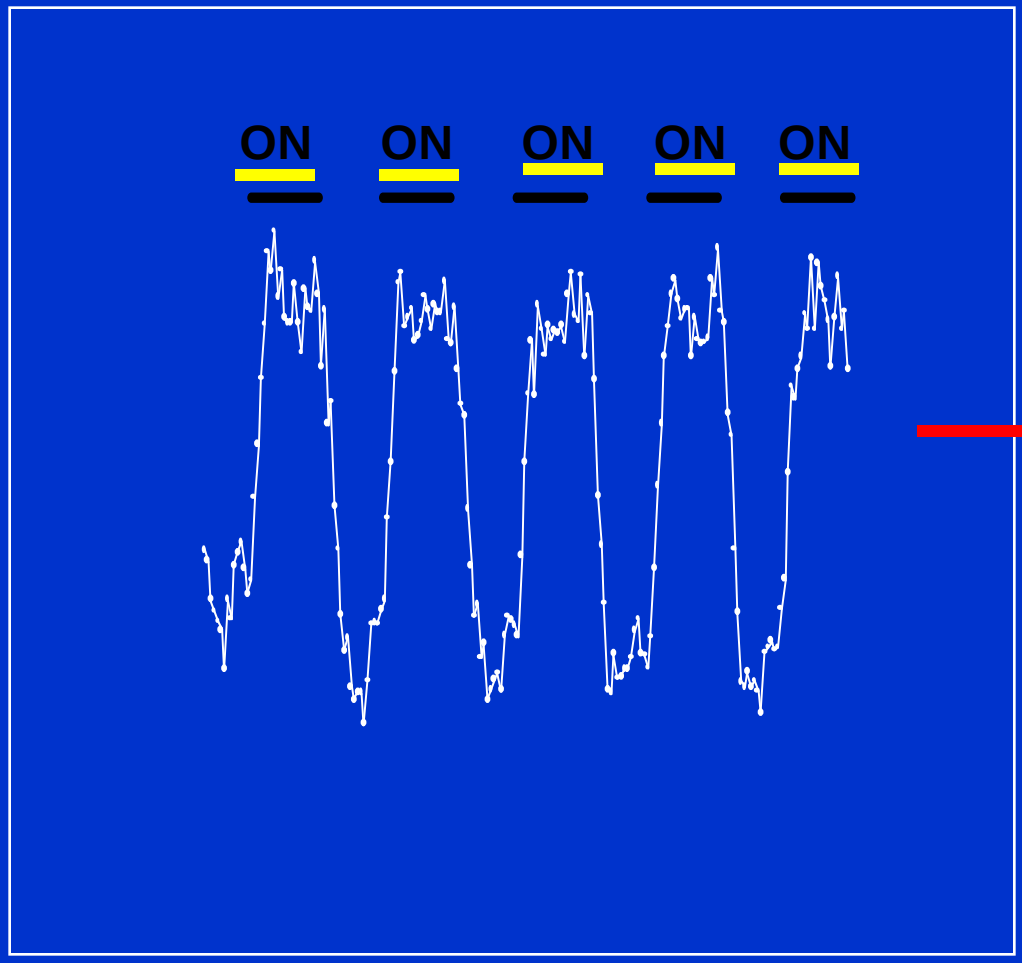
(blood oxygenation level dependence)

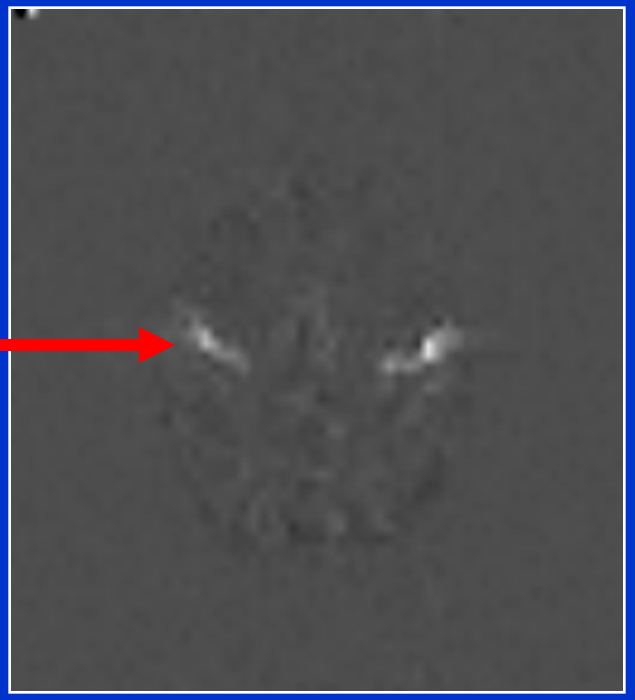
blood flow

oxygenated-blood

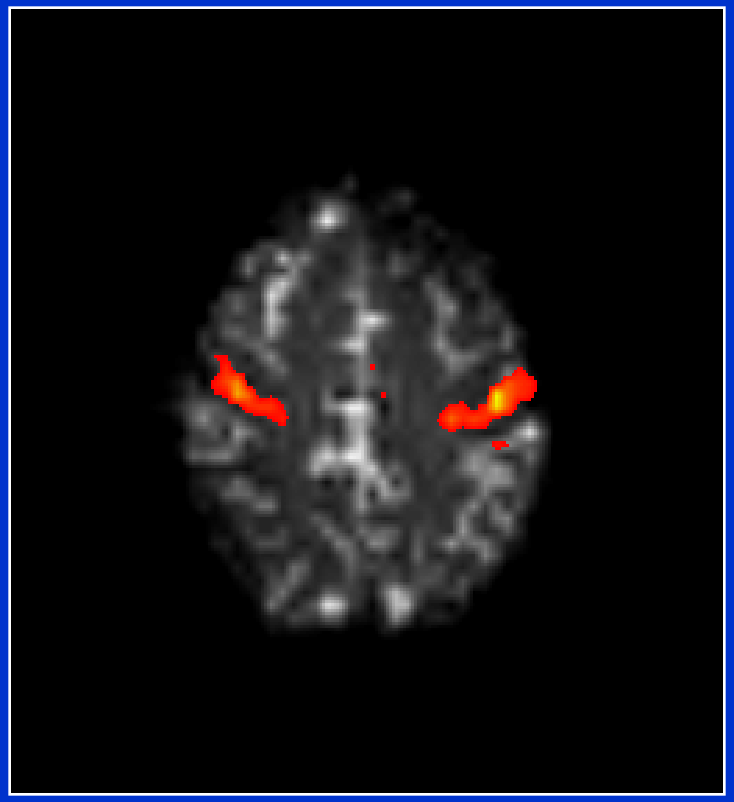
MR signal

BOLD: Motor Cortex Activation

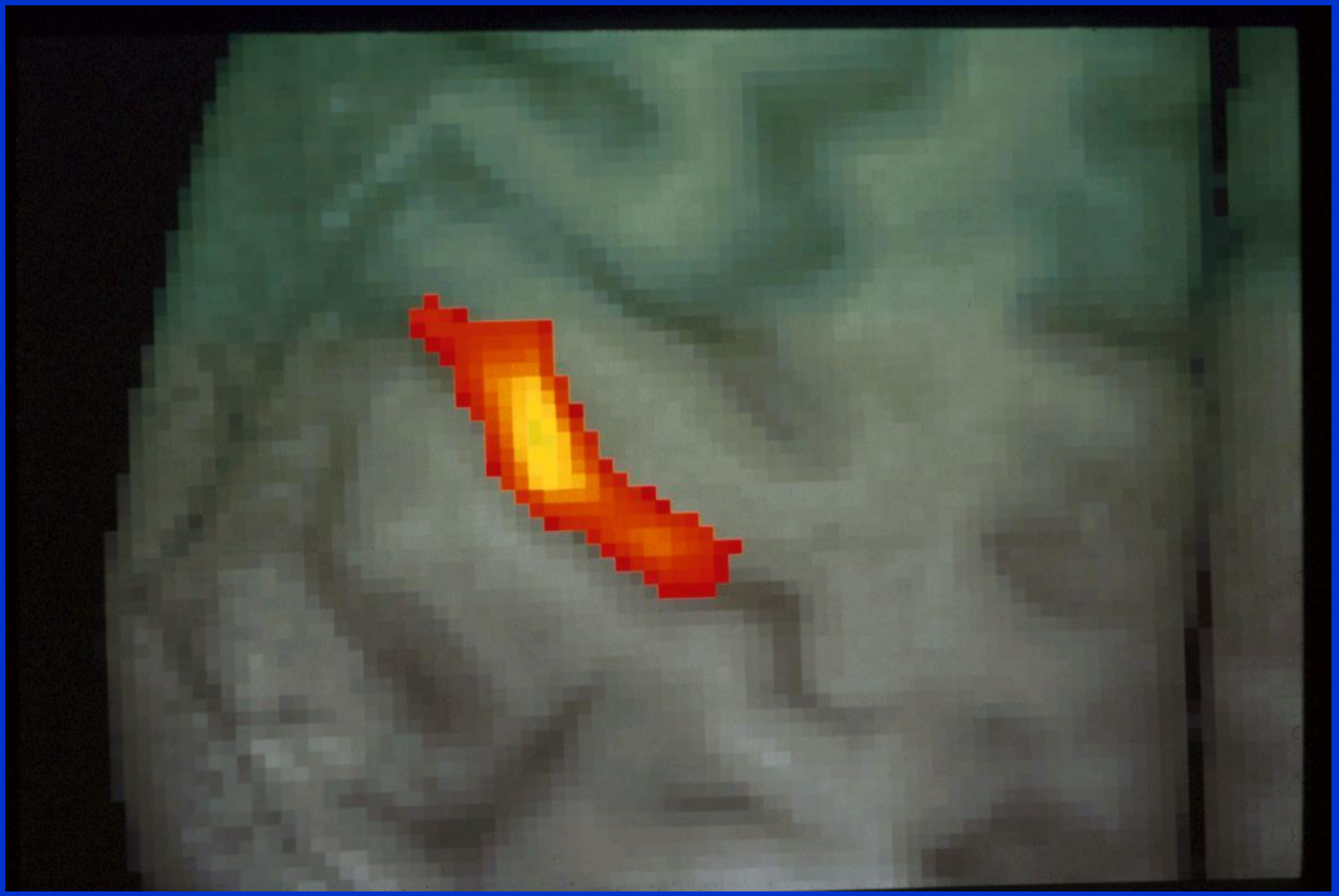




Cross Correlation Image

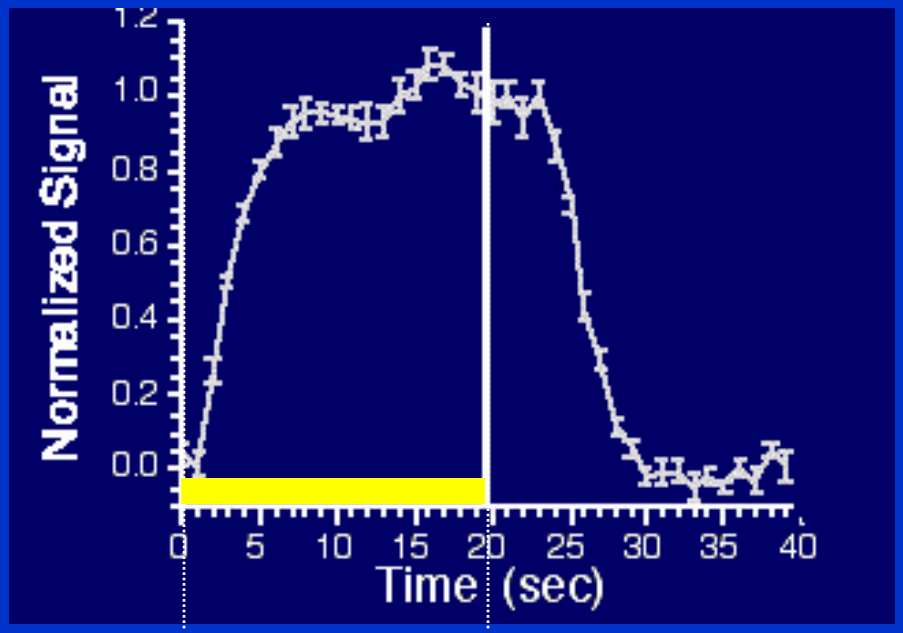


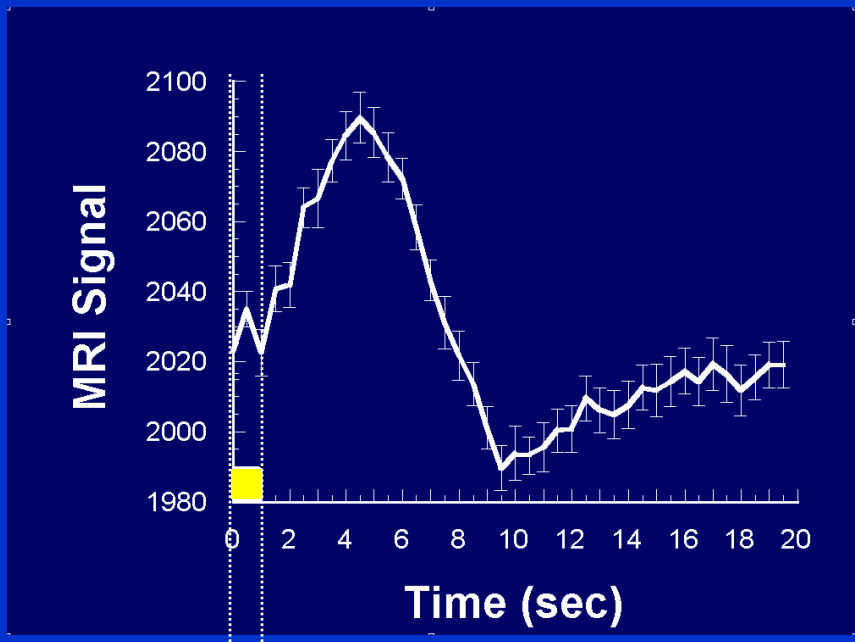
Cross Correlation Image
Anatomical Image



The BOLD Signal

Blood Oxygenation Level Dependent (BOLD) signal changes



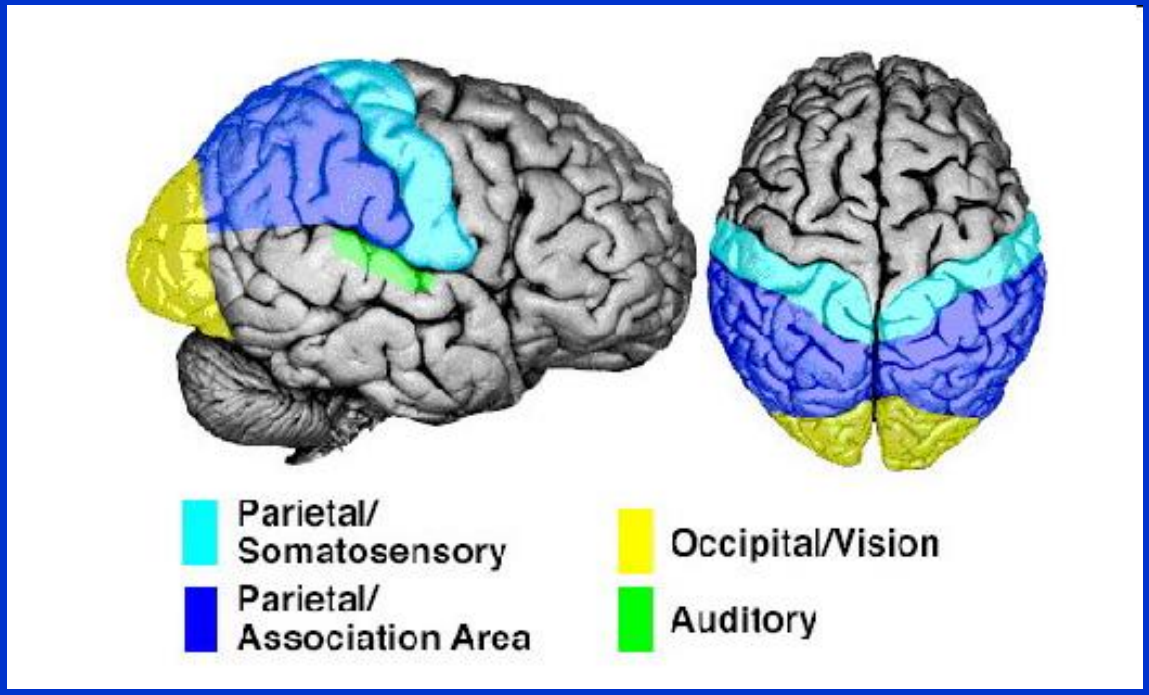


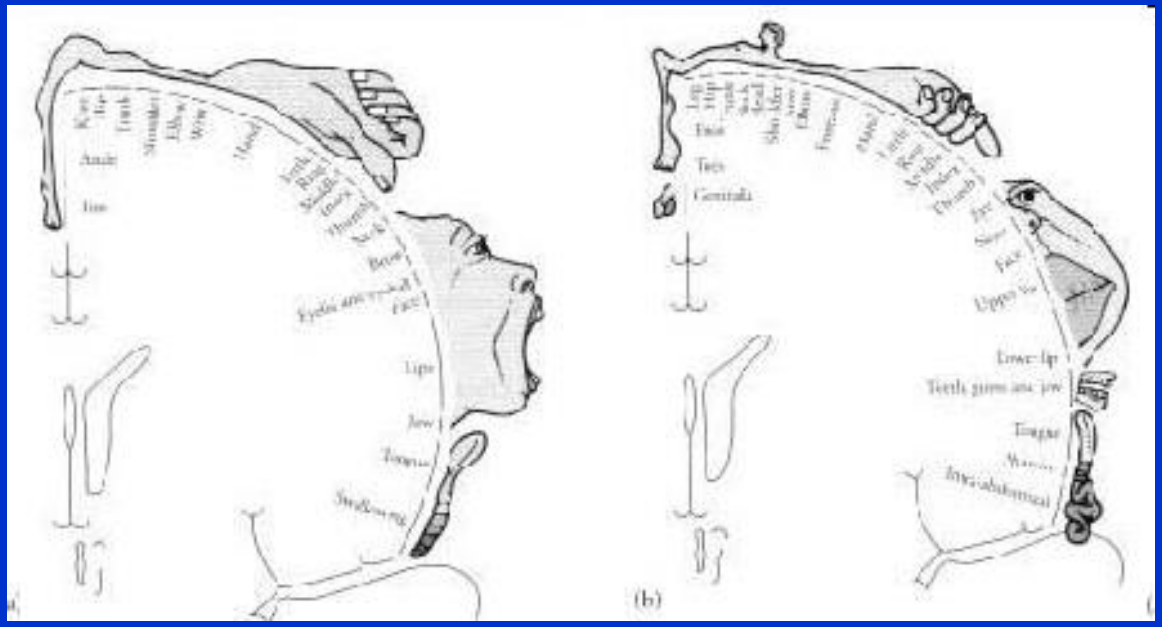
task

task

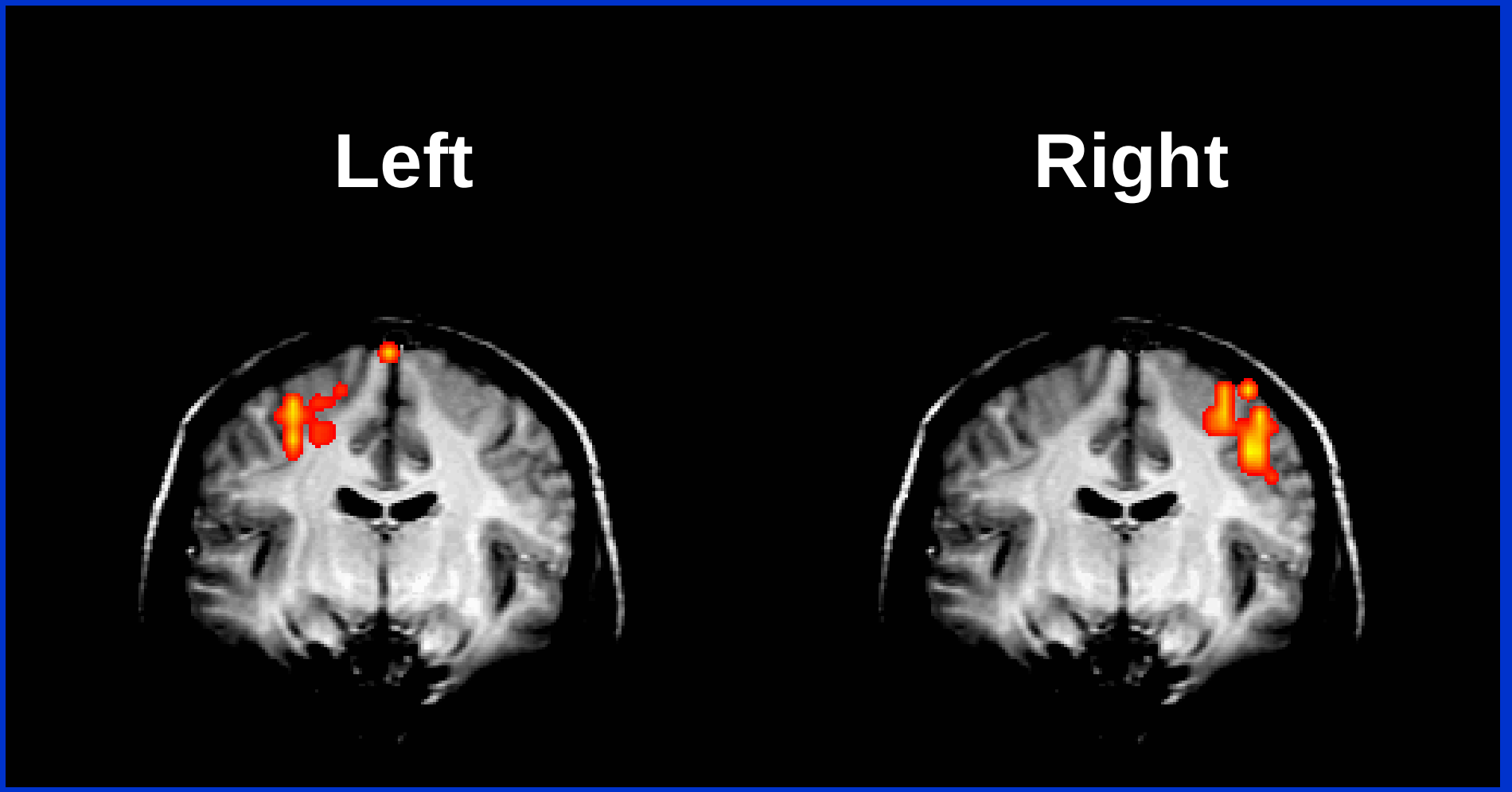
Alternating Left and Right Finger Tapping

~ 1992

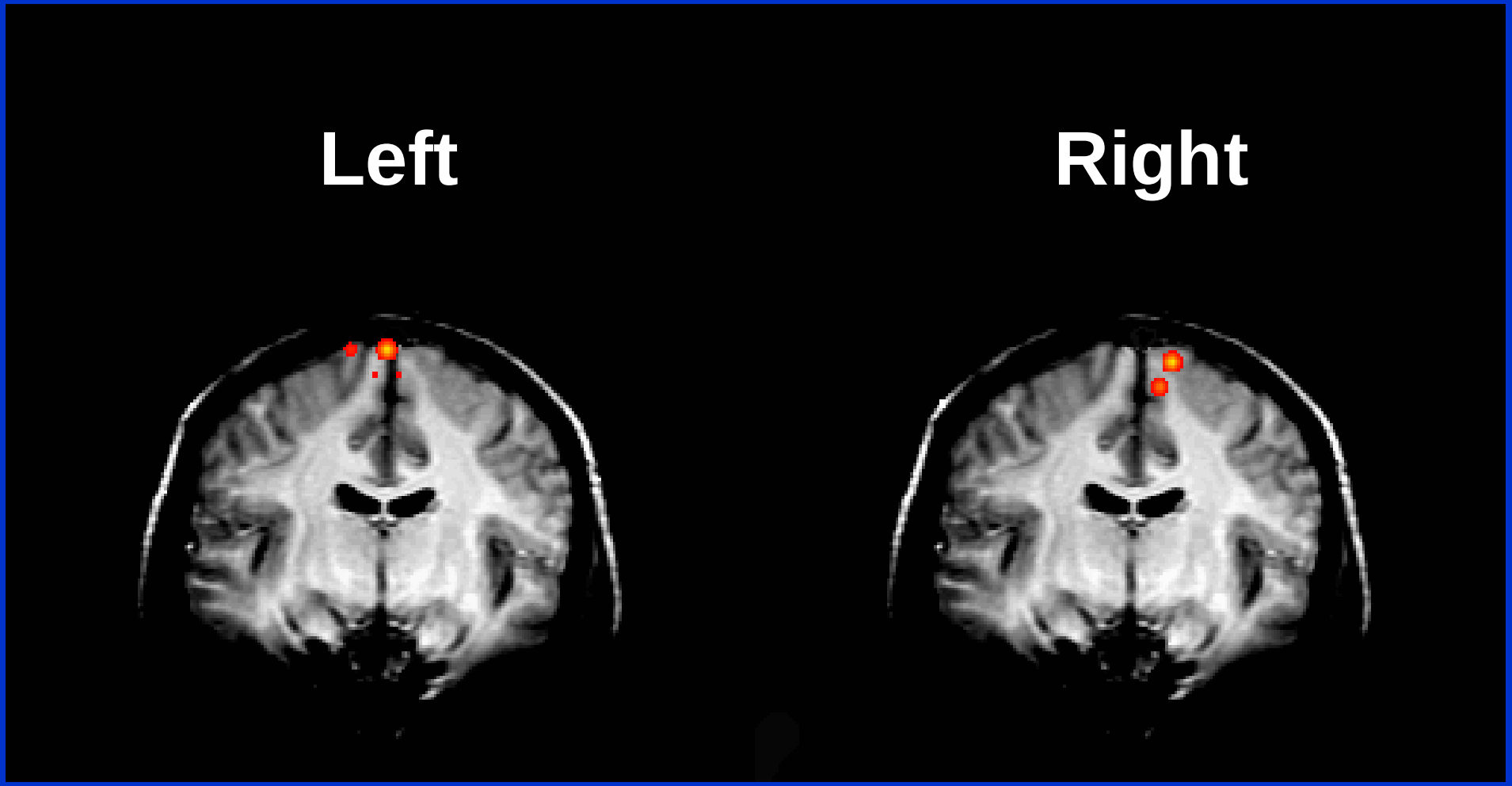

Parietal/
Somatosensory
Occipital/Vision
Parietal/
Association Area
Auditory


(b)

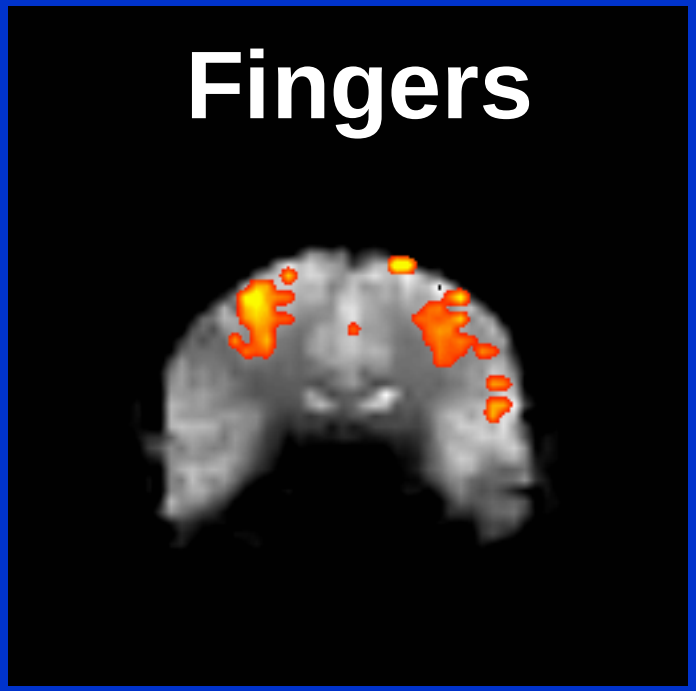
Finger Movement



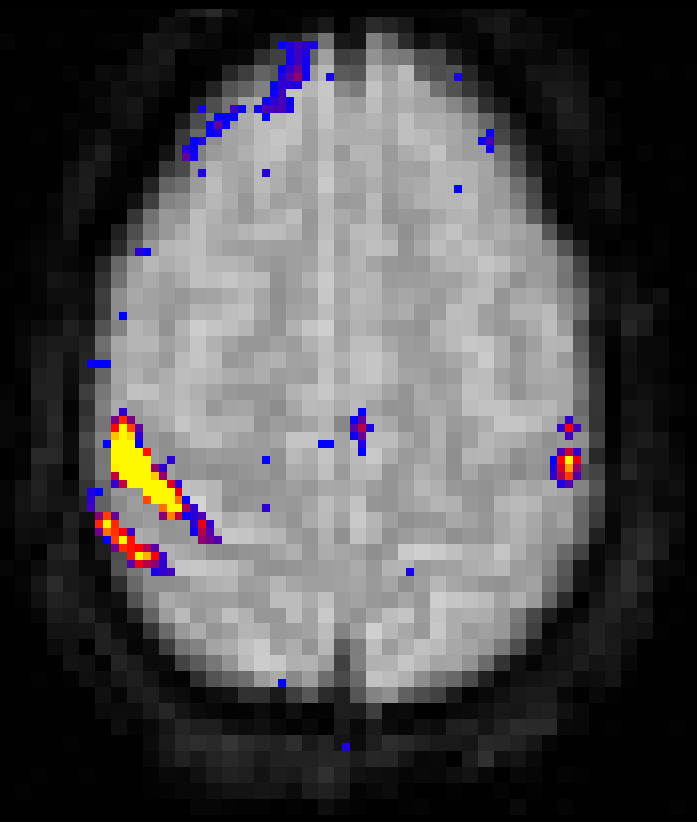
Toe Movement



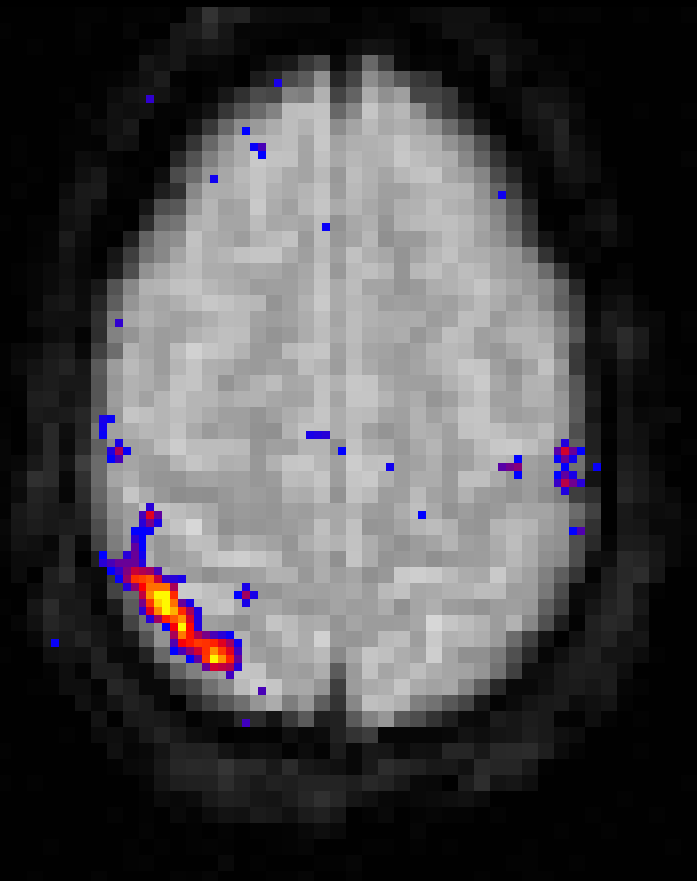
Wrist

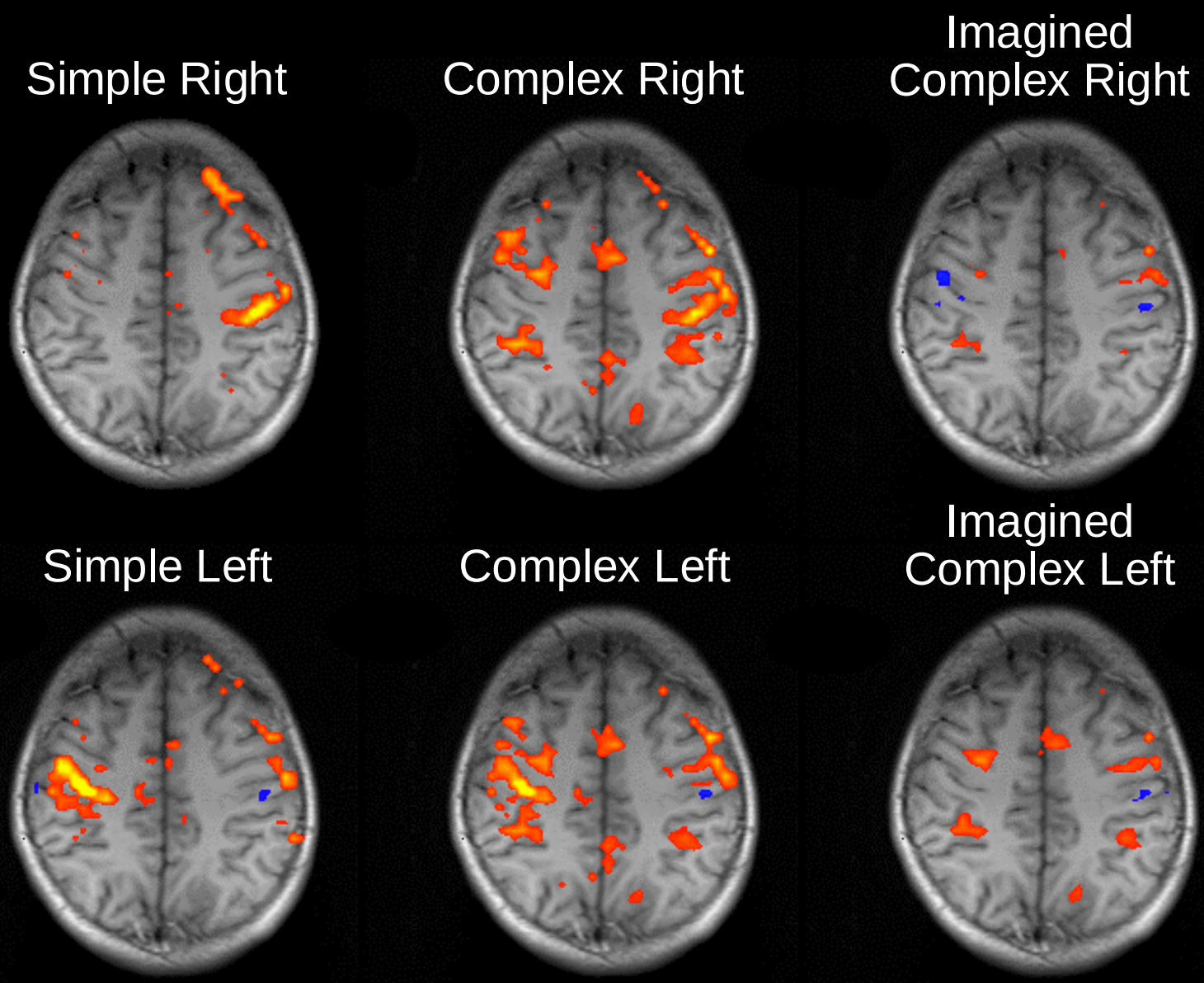

Fingers

Finger Movement



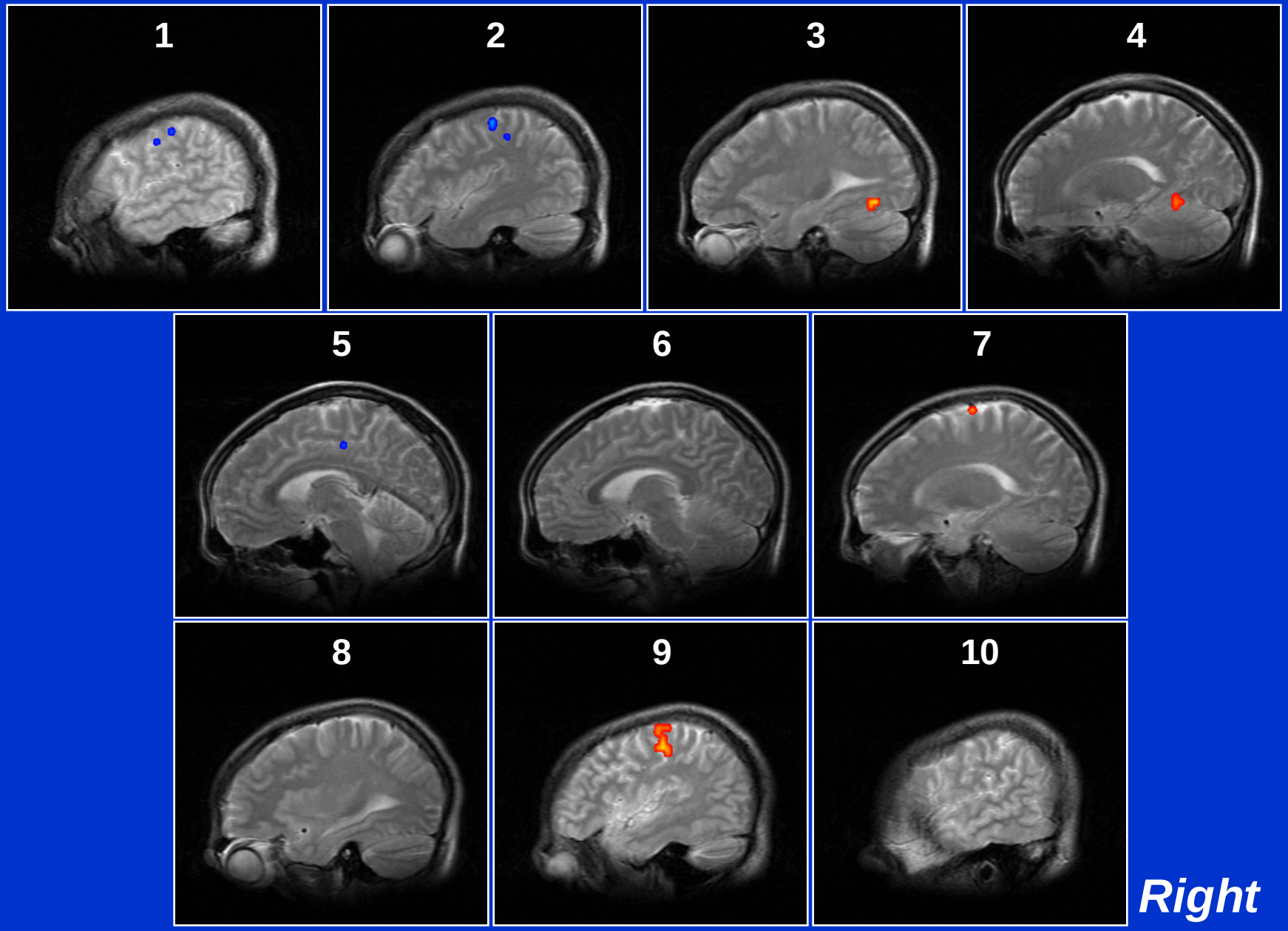
Tactile Stimulation




Simple Right
Complex Right
Imagined Complex Right
Simple Left
Complex Left
Imagined Complex Left

Left

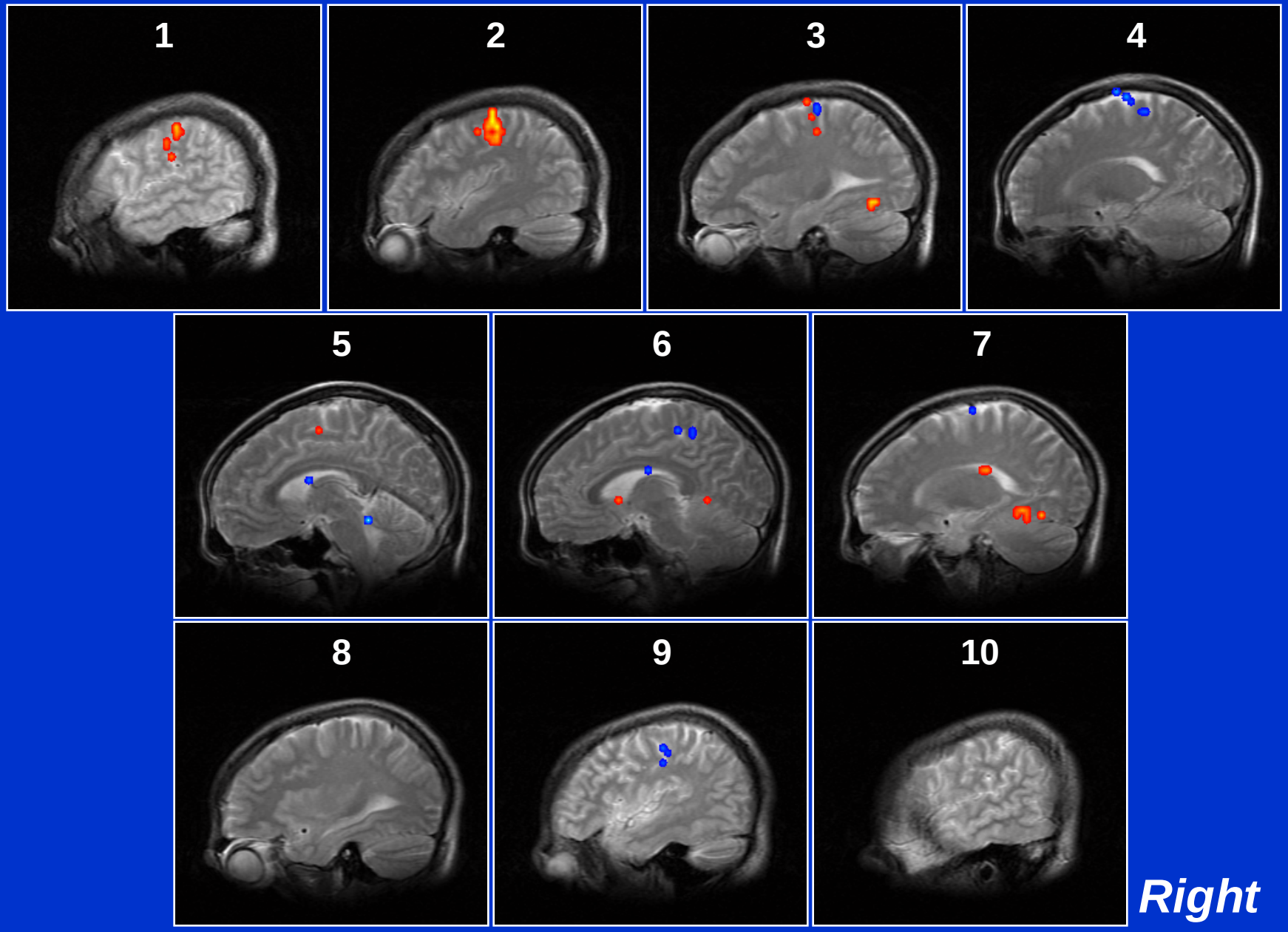
Simple Finger Movement on the Left Hand



Right

Left

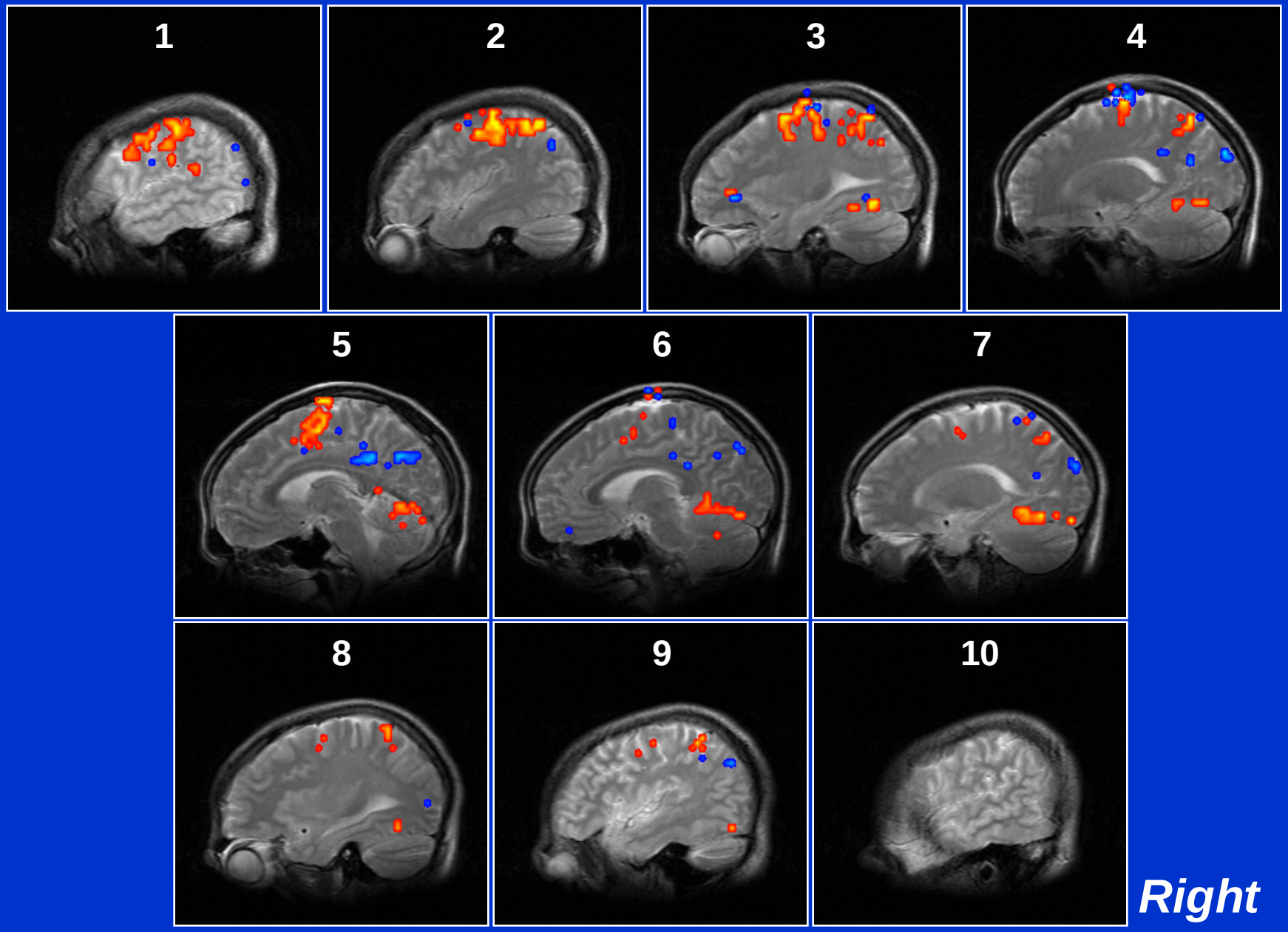
Simple Finger Movement on the RIght Hand



Right

Left

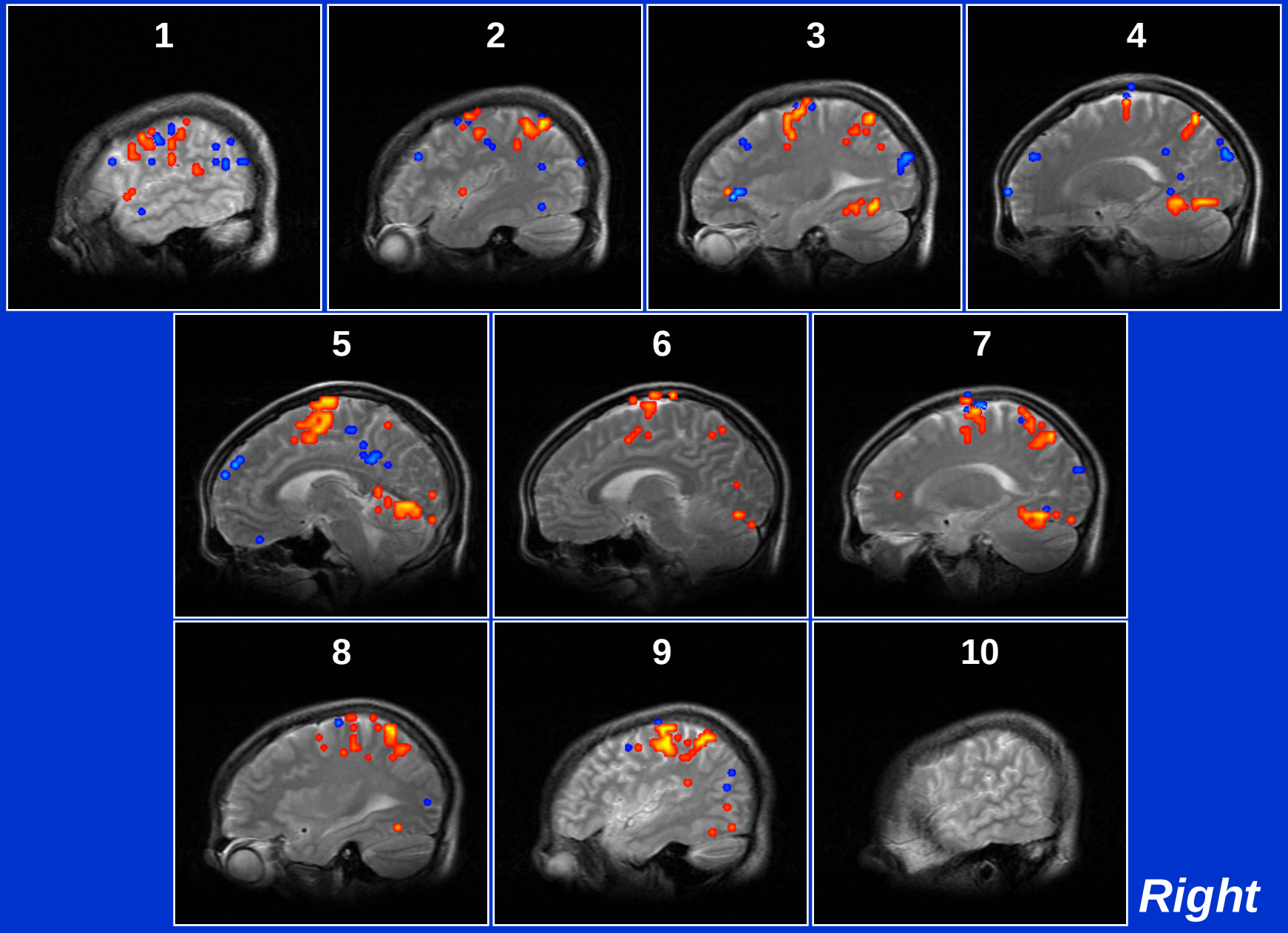
Complex Finger Movement on the Right Hand



Right

Left

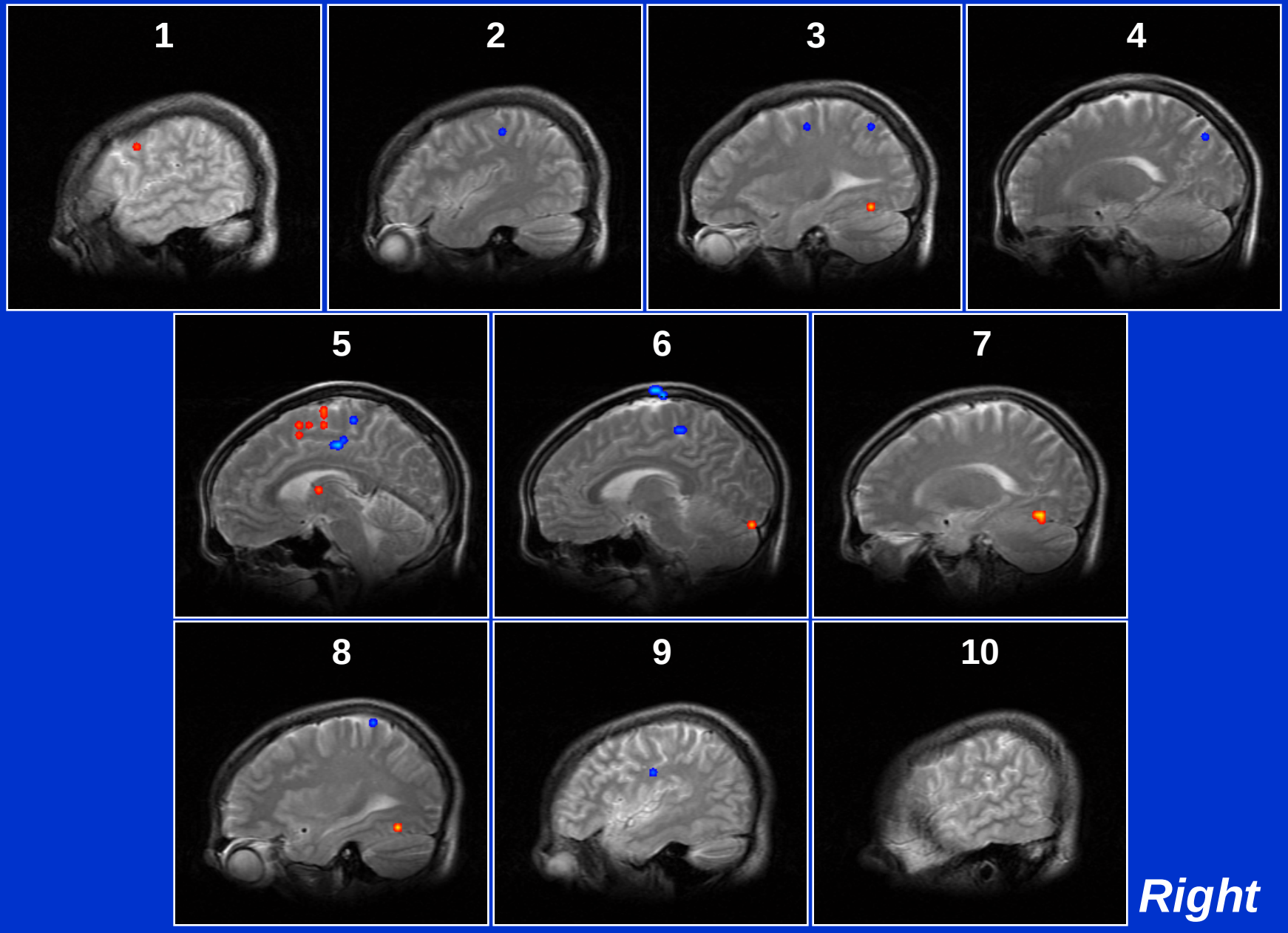
Complex Finger Movement on the Left Hand



Right

Left

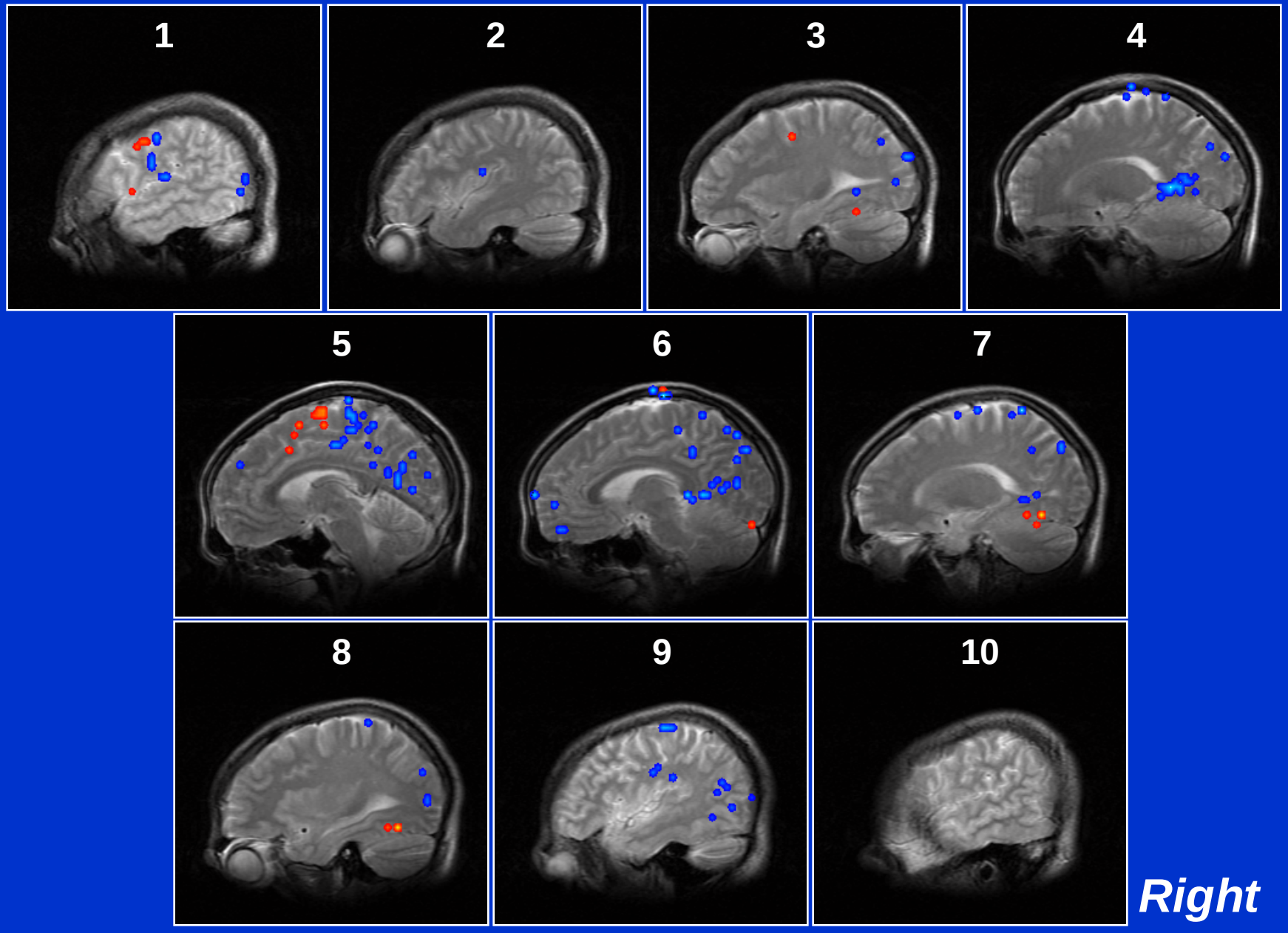
Imagined Complex Finger Movement on the Left Hand



Right

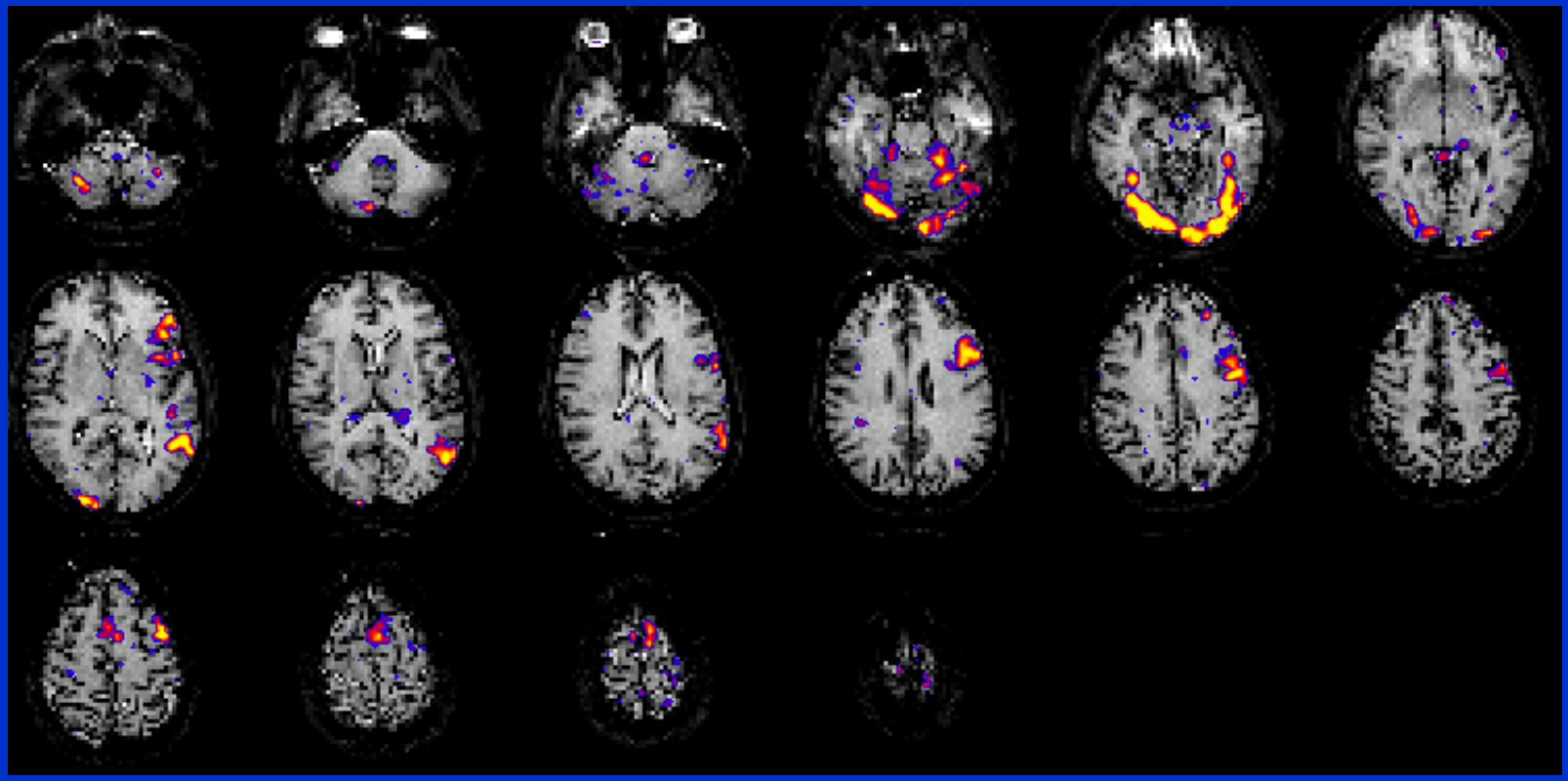
Left

Imagined Complex Finger Movement on the Right Hand

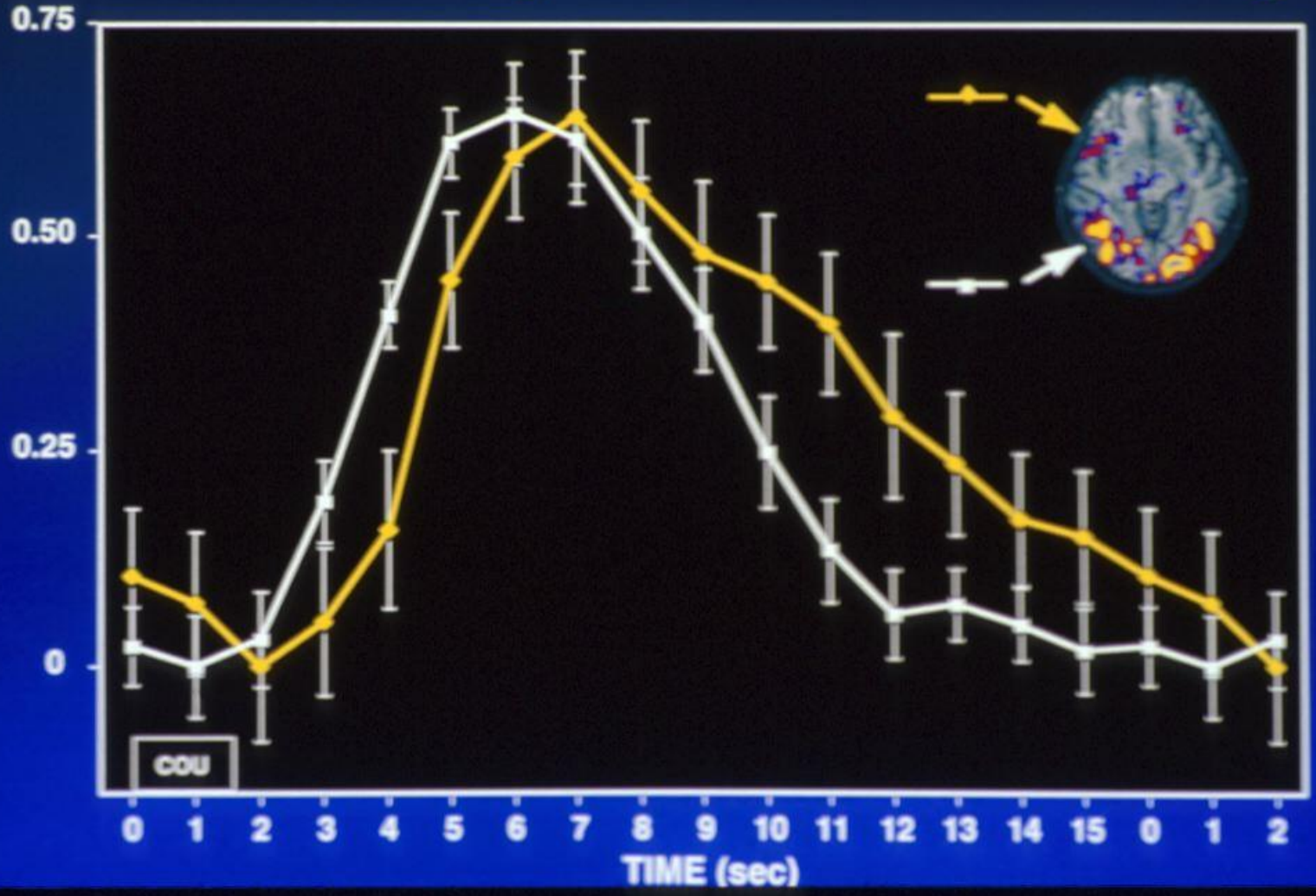


Right

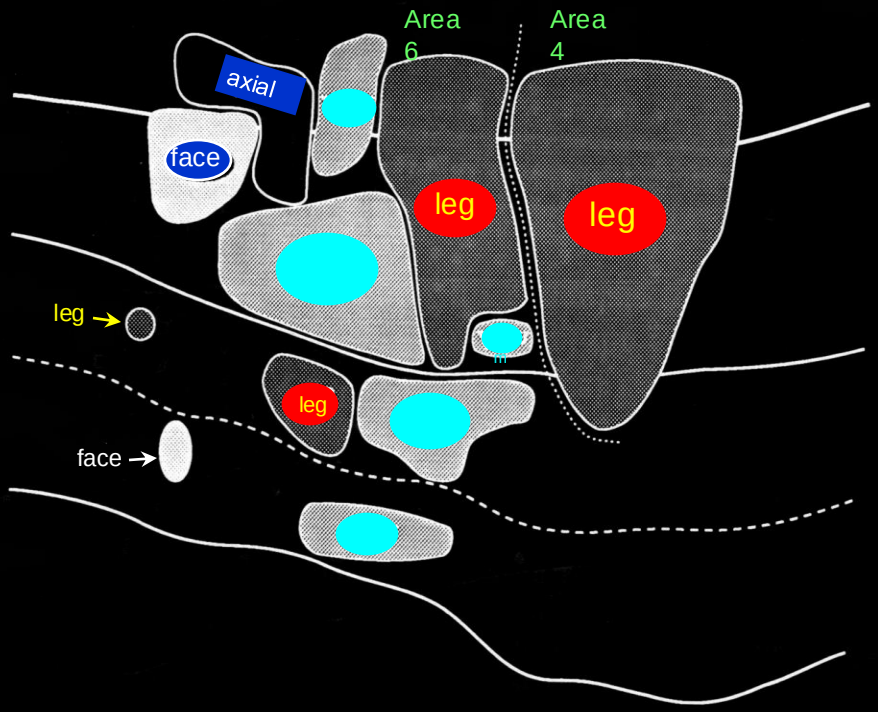
Word stem completion

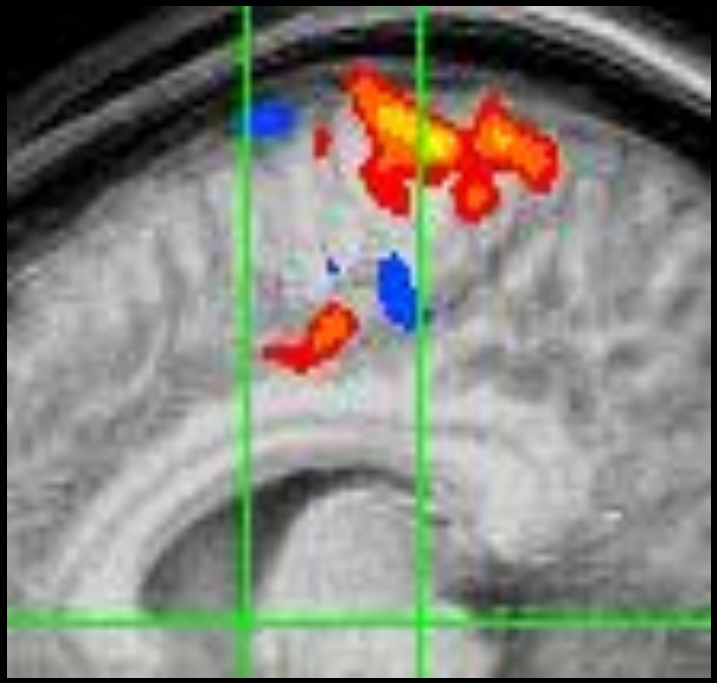


Time Course Comparison Across Brain Regions



FMRI of Leg Motor Topography - Medial Wall



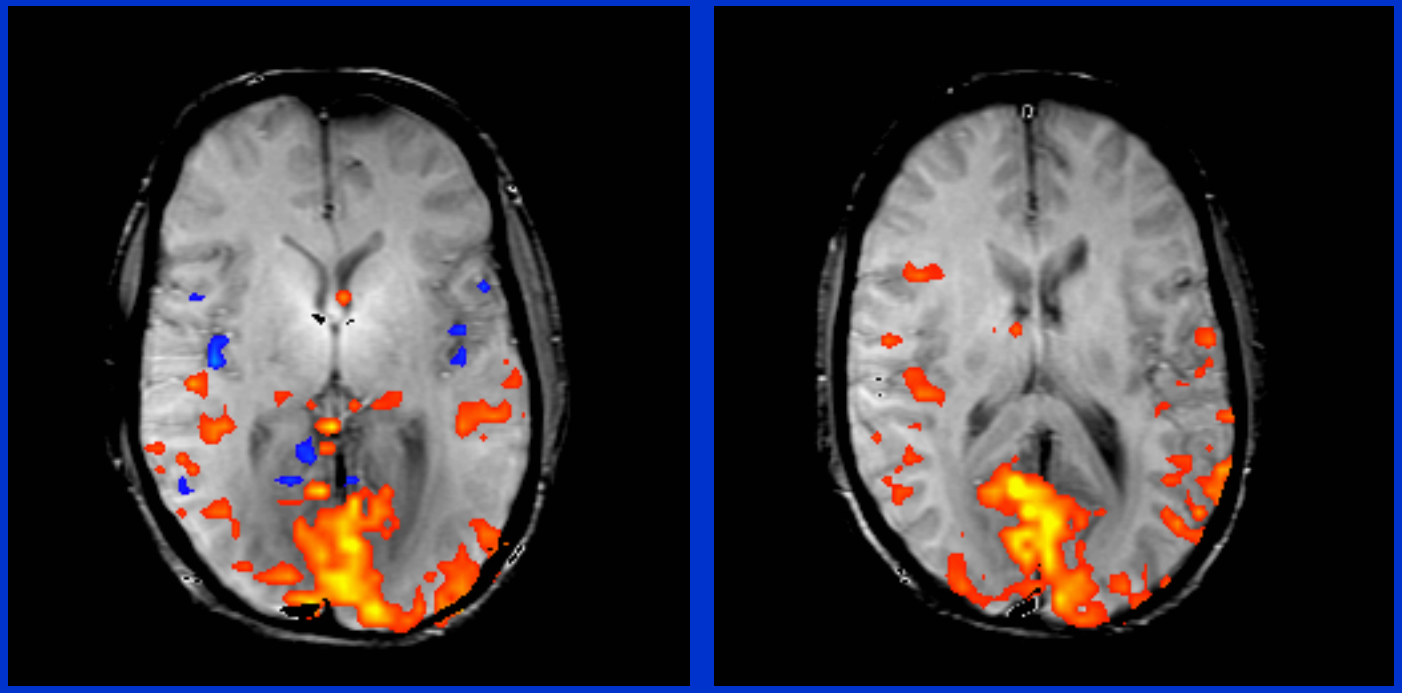


Macaque

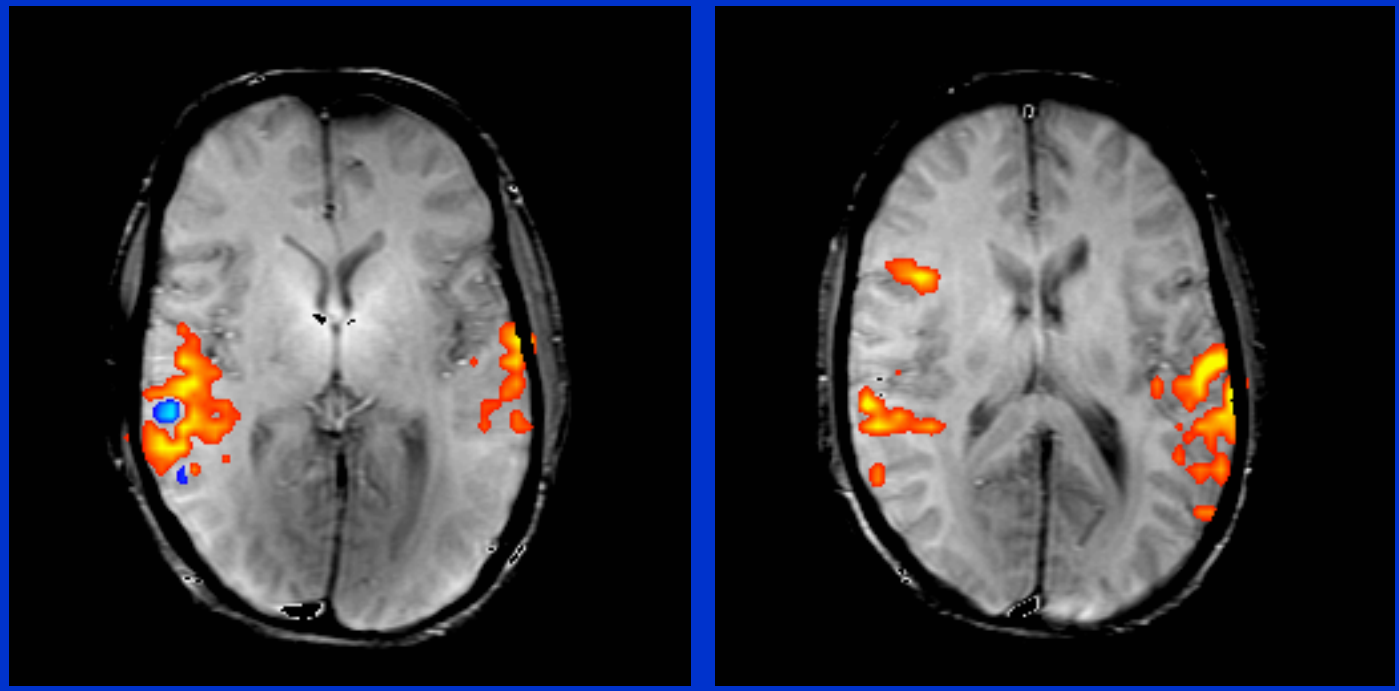
Human

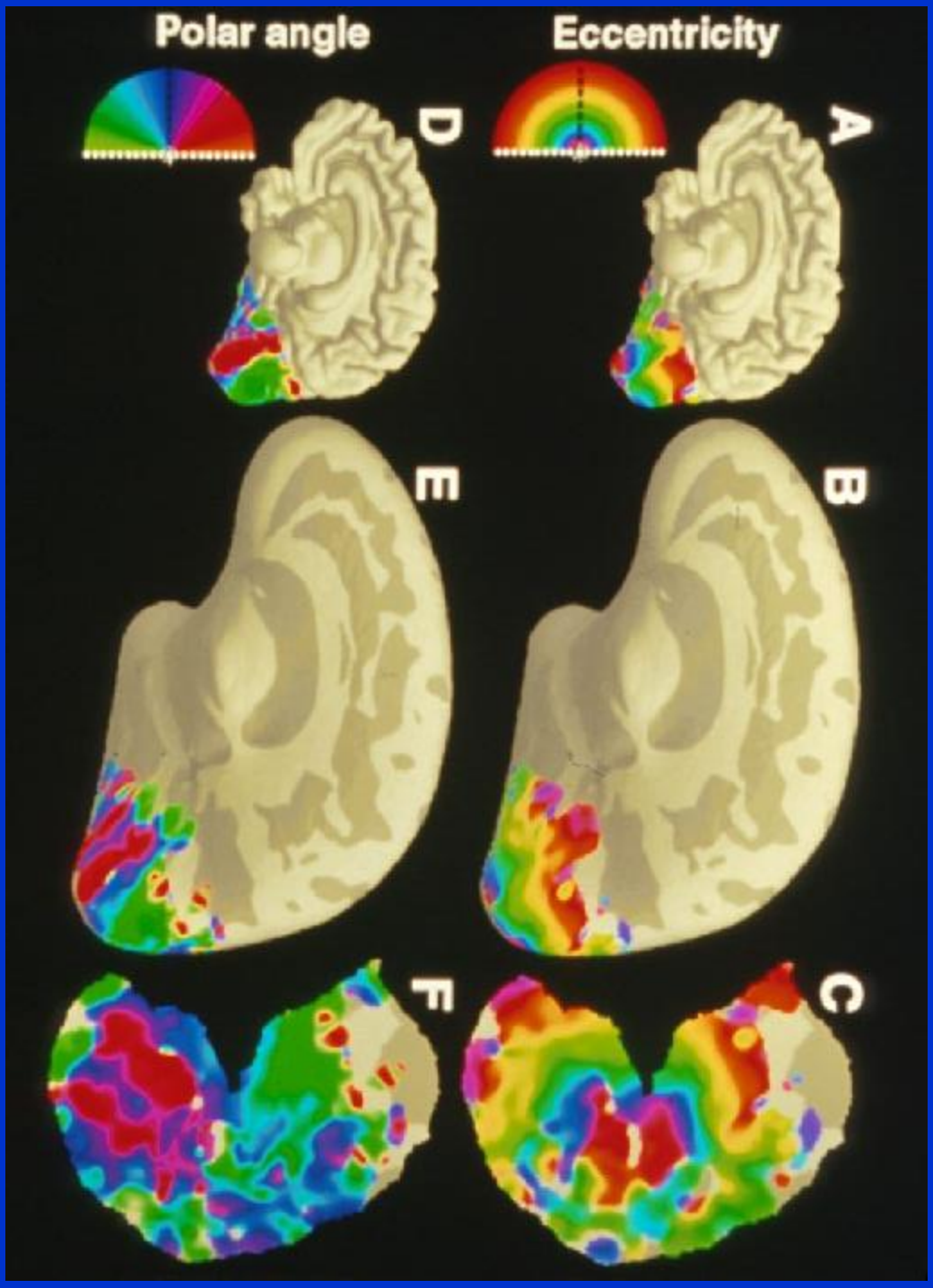
Thanks to S. Rao

Reading

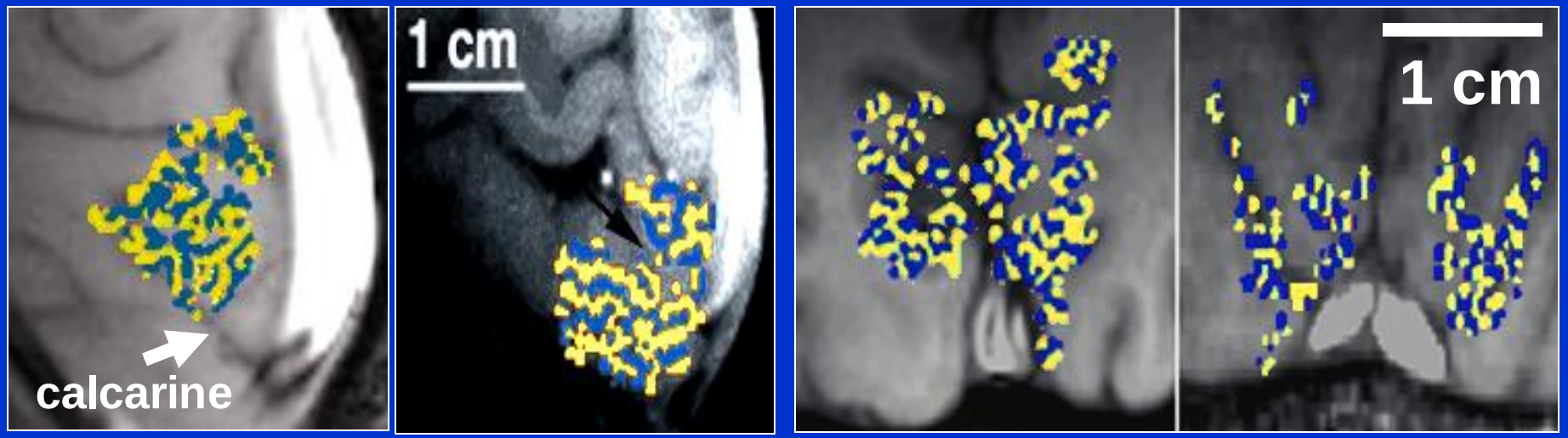


Listening to Spoken Words




Polar angle
Eccentricity
D
A
E
B
F
C

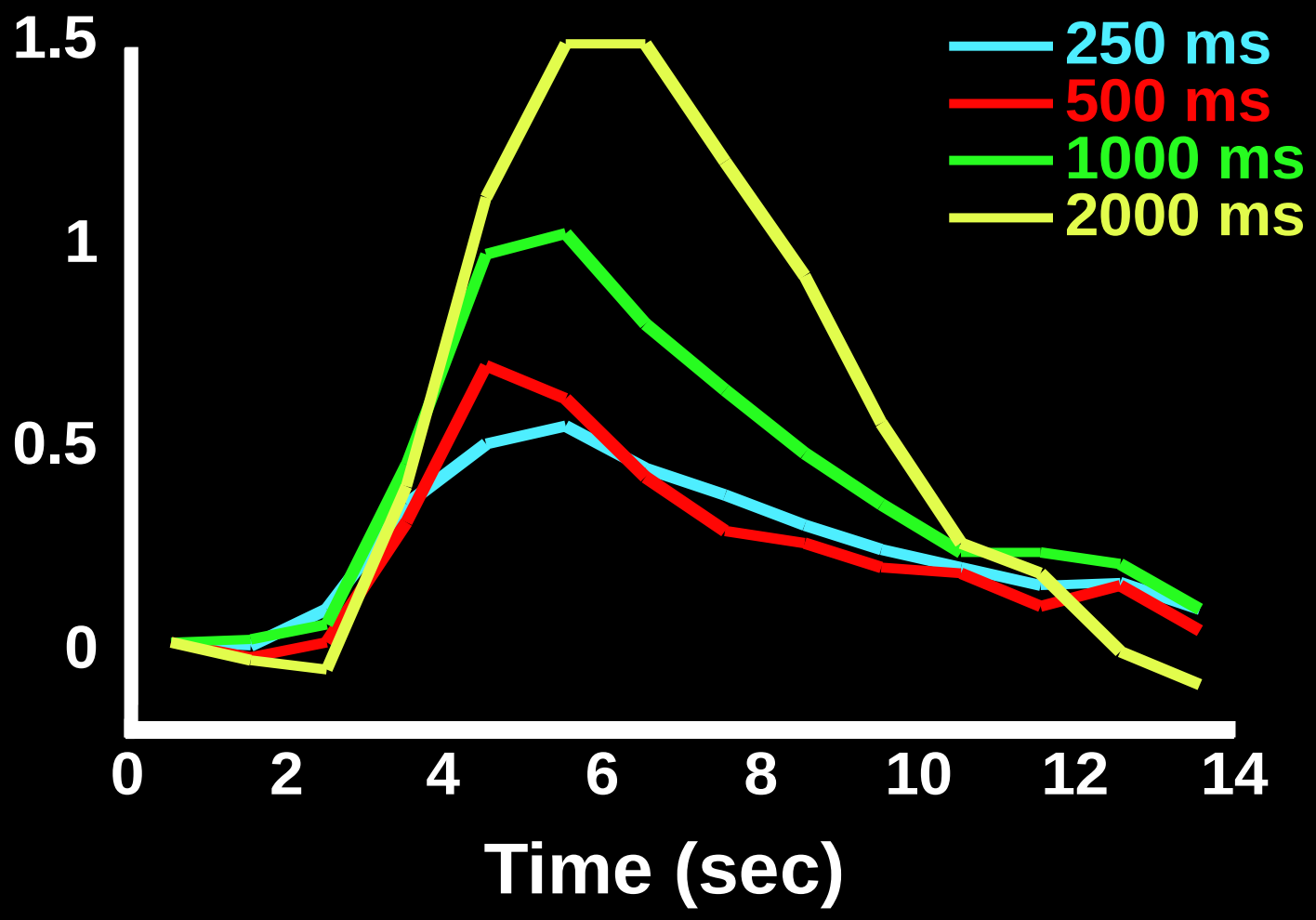
ODC Maps using fMRI



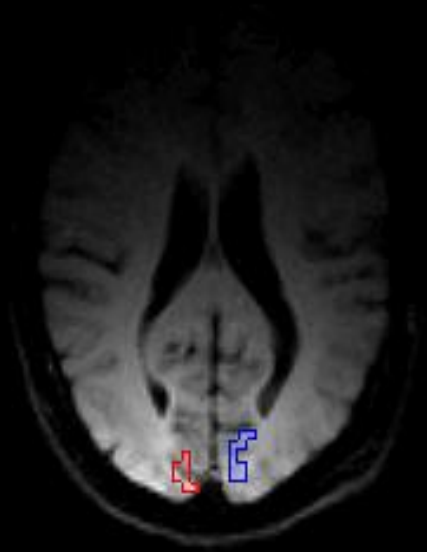
• Identical in size, orientation, and appearance to those obtained by optical imaging[1] and histology[3,4].

Menon et al.

[1]Malonek D, Grinvald A. *Science* 272, 551-4 (1996).
[3]Horton JC, Hocking DR. *J Neurosci* 16, 7228-39 (1996).
[4]Horton JC, et al. *Arch Ophthalmol* 108, 1025-31 (1990).

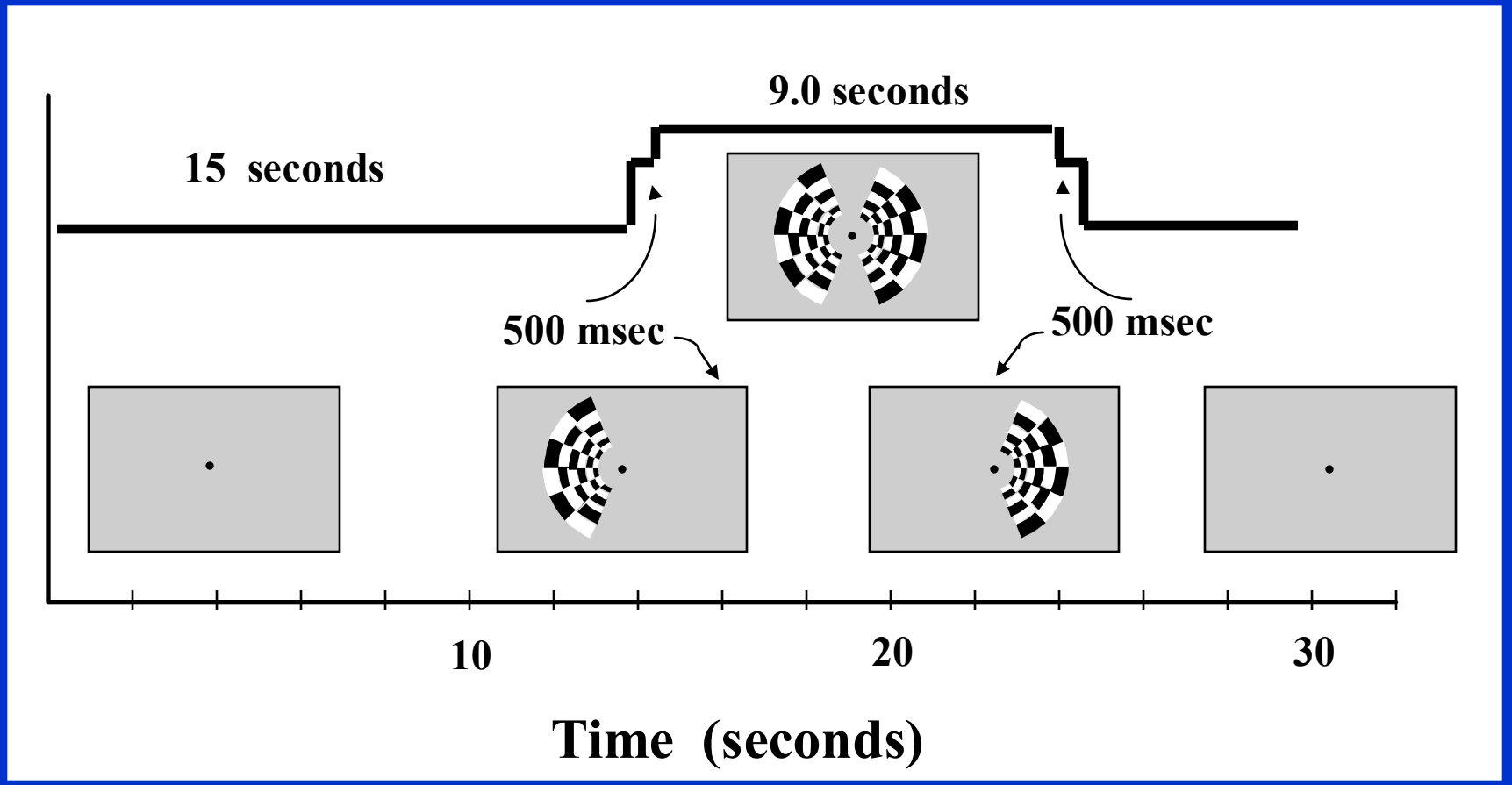

1.5
1
0.5
0
0
2
4
6
8
10
12
14
Time (sec)
250 ms
500 ms
1000 ms
2000 ms

Regions of Interest Used for Hemi-Field Experiment

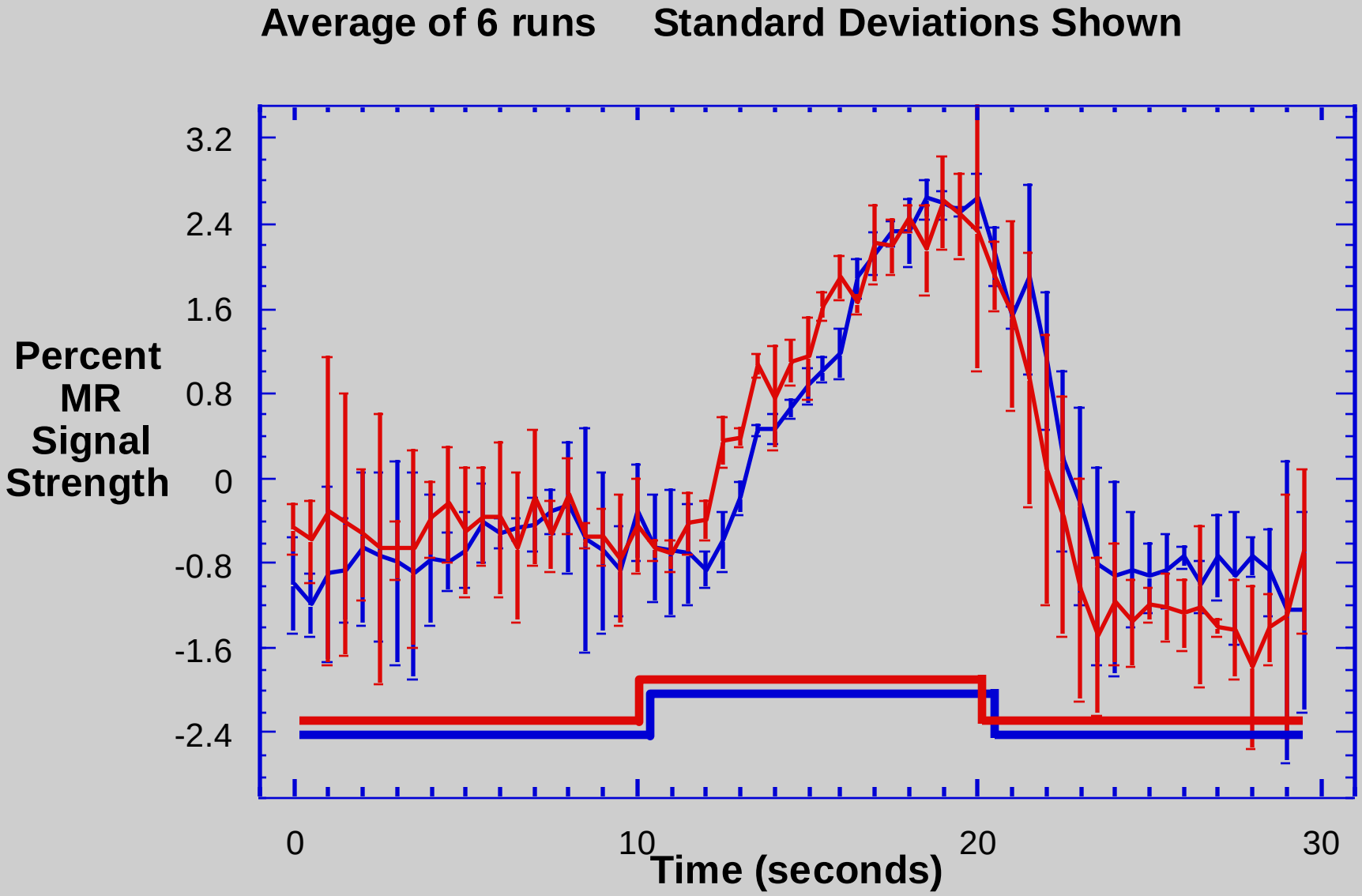


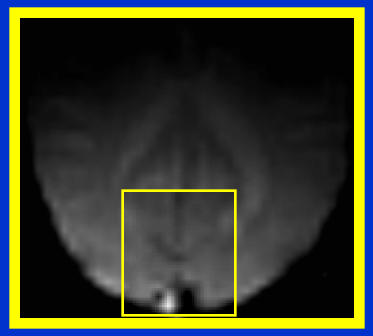
Right Hemisphere

Left Hemisphere


9.0 seconds
15 seconds
500 msec
500 msec
10
20
30
Time (seconds)

Hemi-field with 500 msec asynchrony





500 ms

500 ms

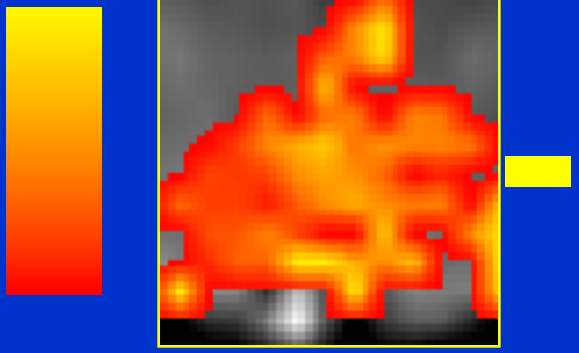
Right Hemifield

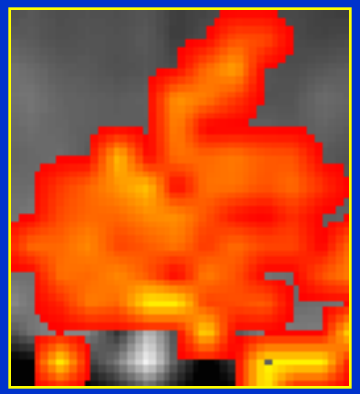
Left Hemifield

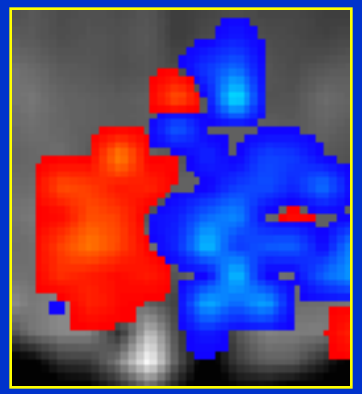
+ 2.5 s

0 s

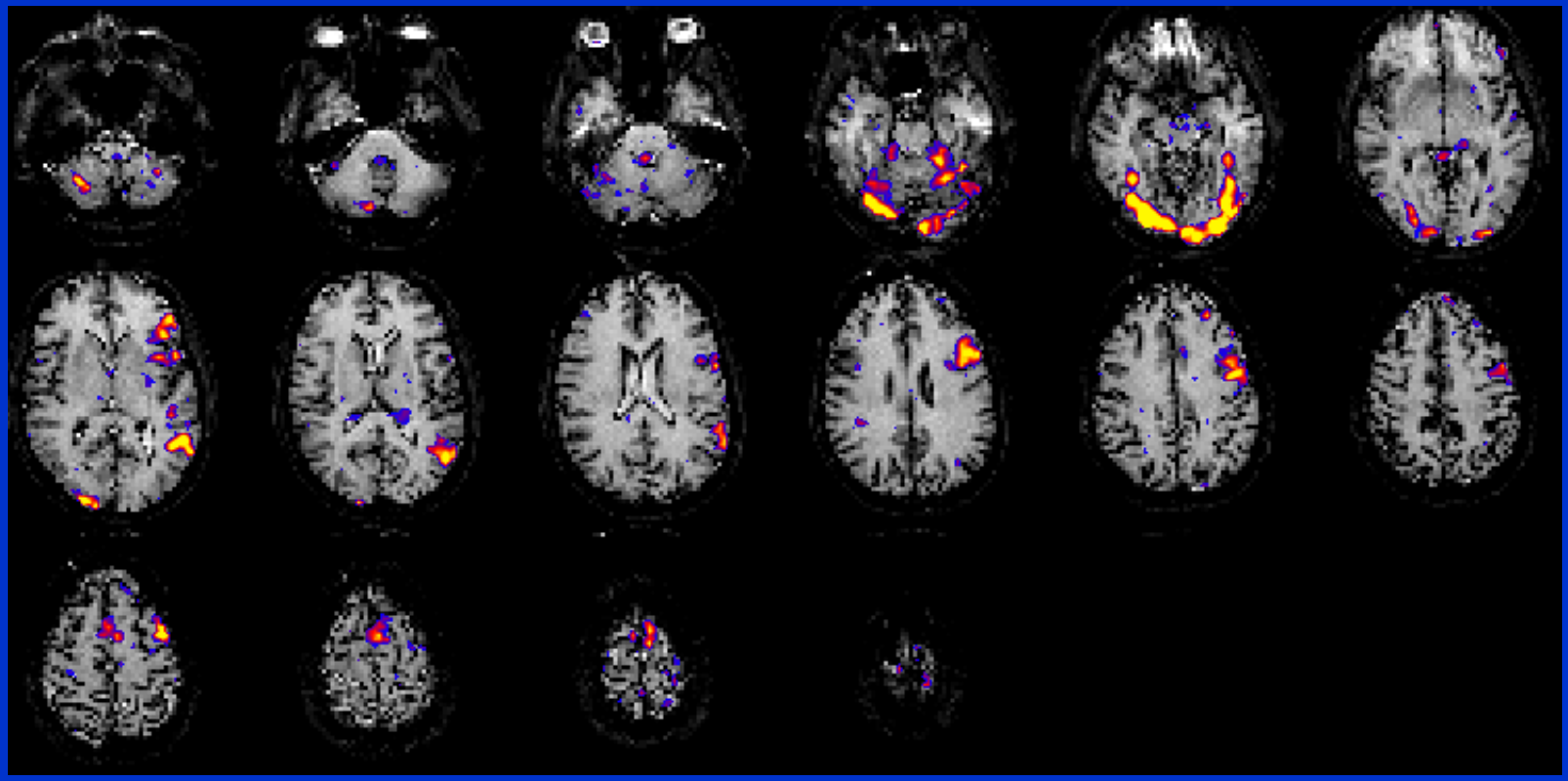
- 2.5 s





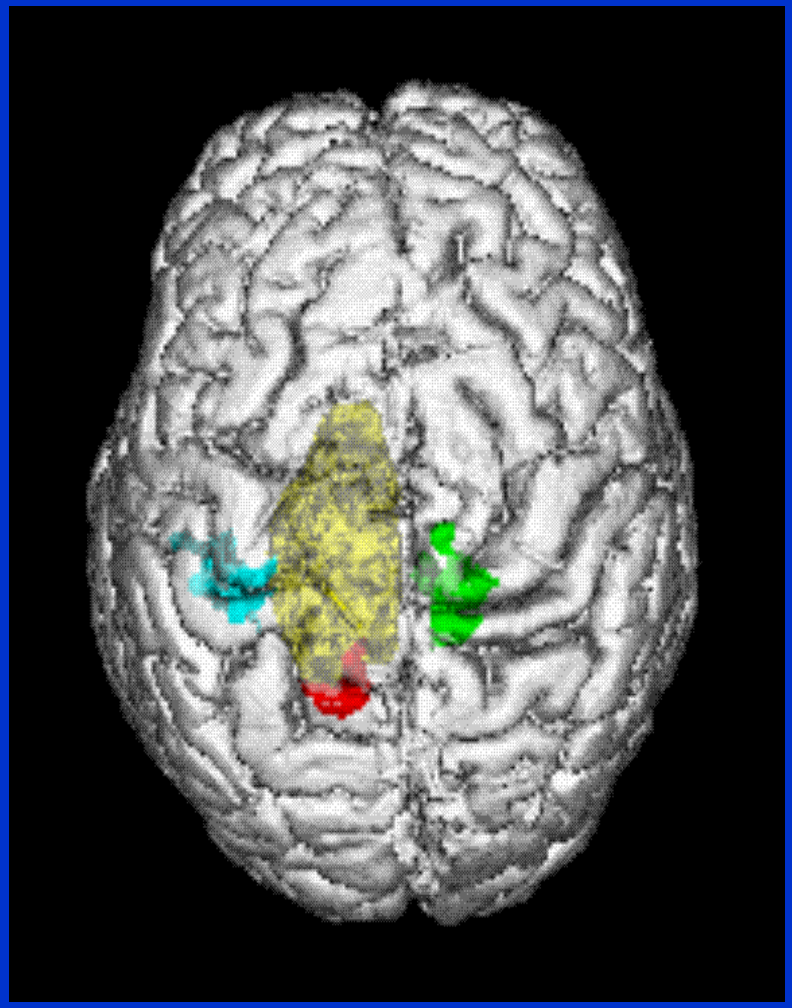


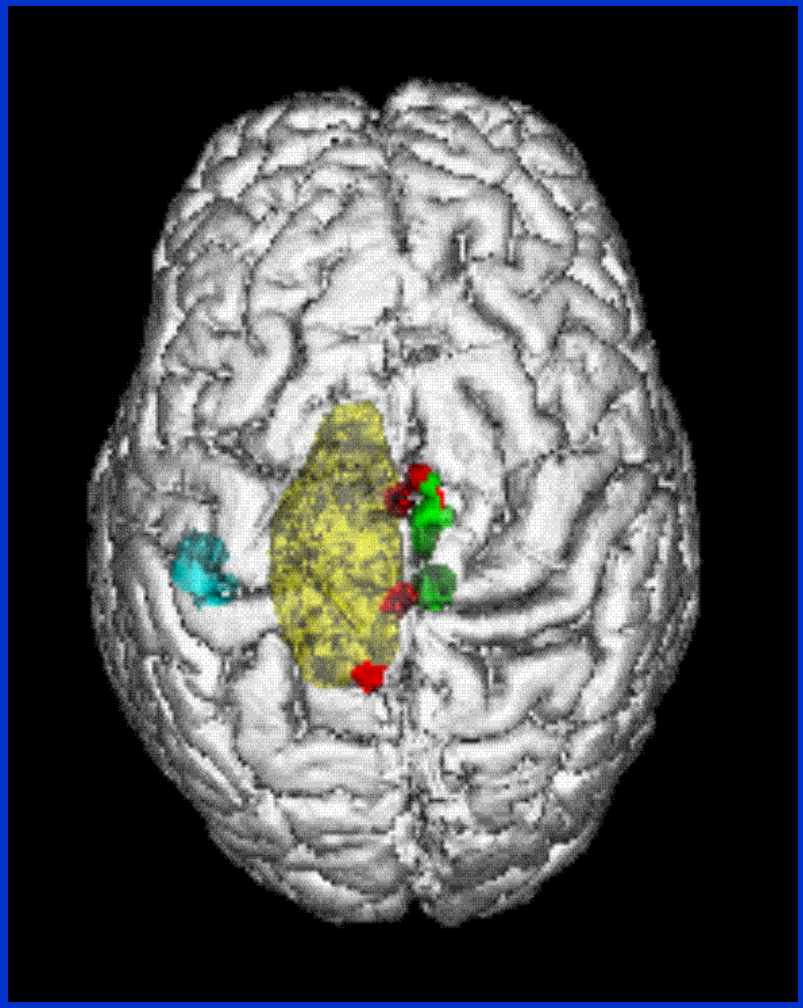
Word stem completion



Presurgical Mapping

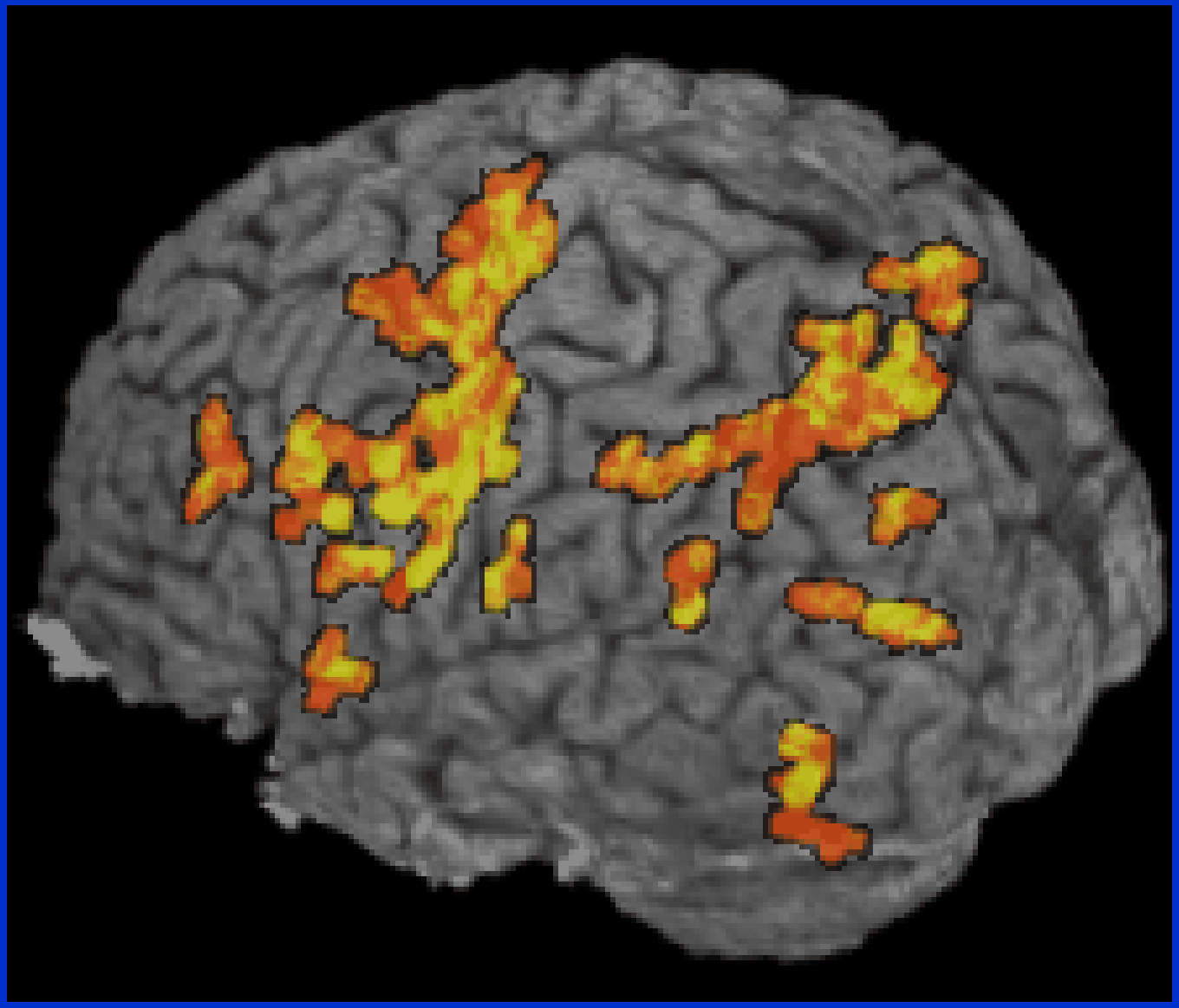
Left Foot Tumor Right Foot Right Hand





fMRI O-15 PET

End of Acquisition



< 1 s to render

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

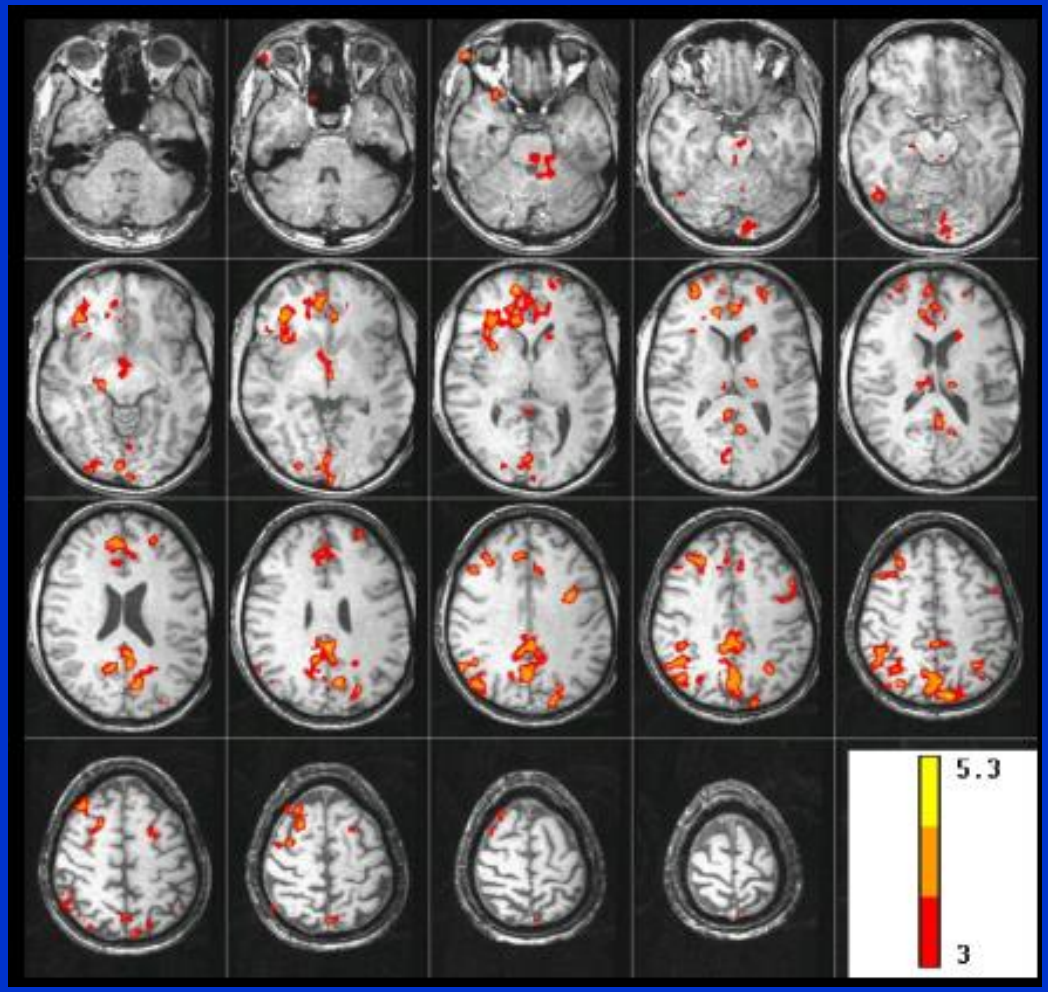
Blocks: 12345678

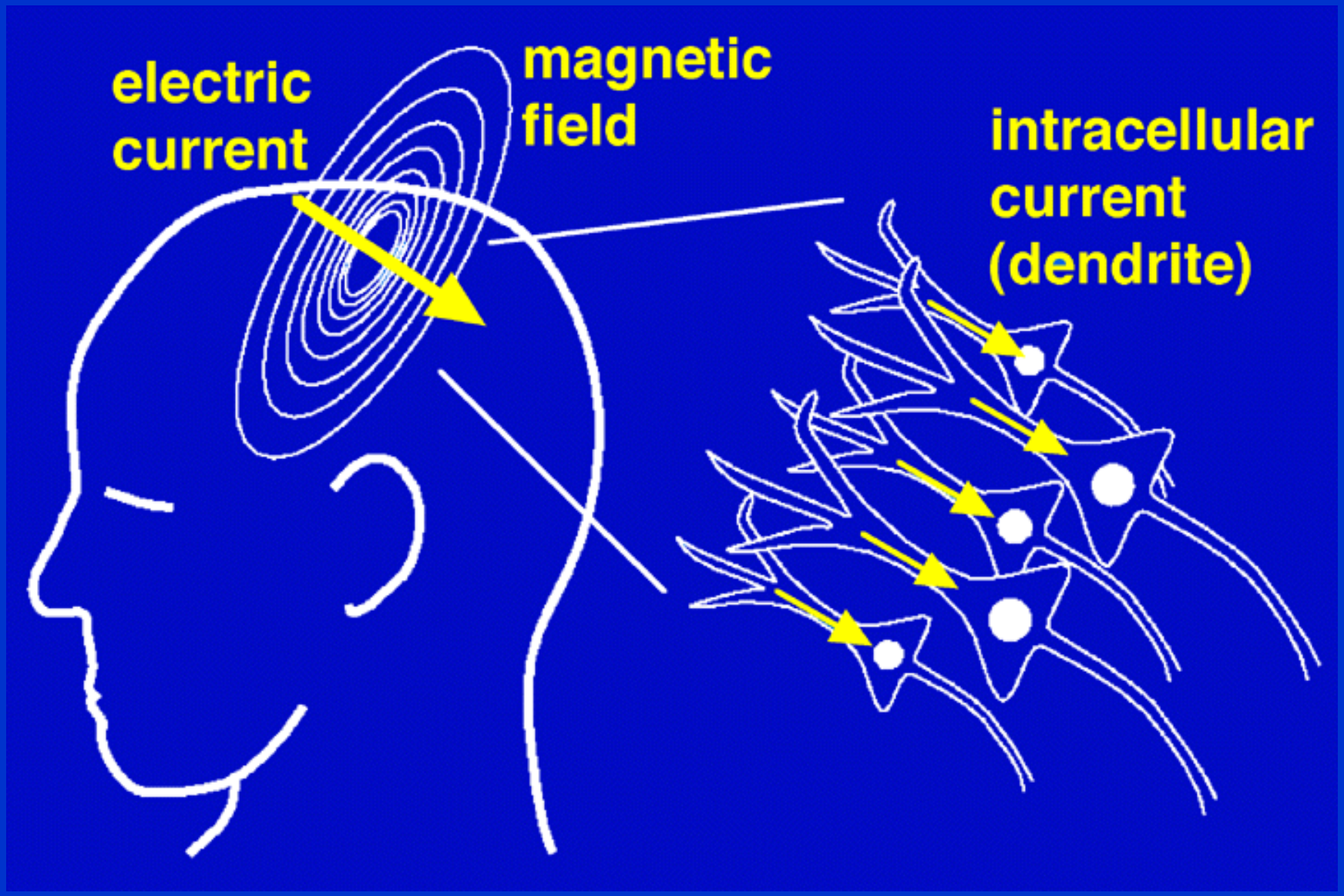
Color shows through brain

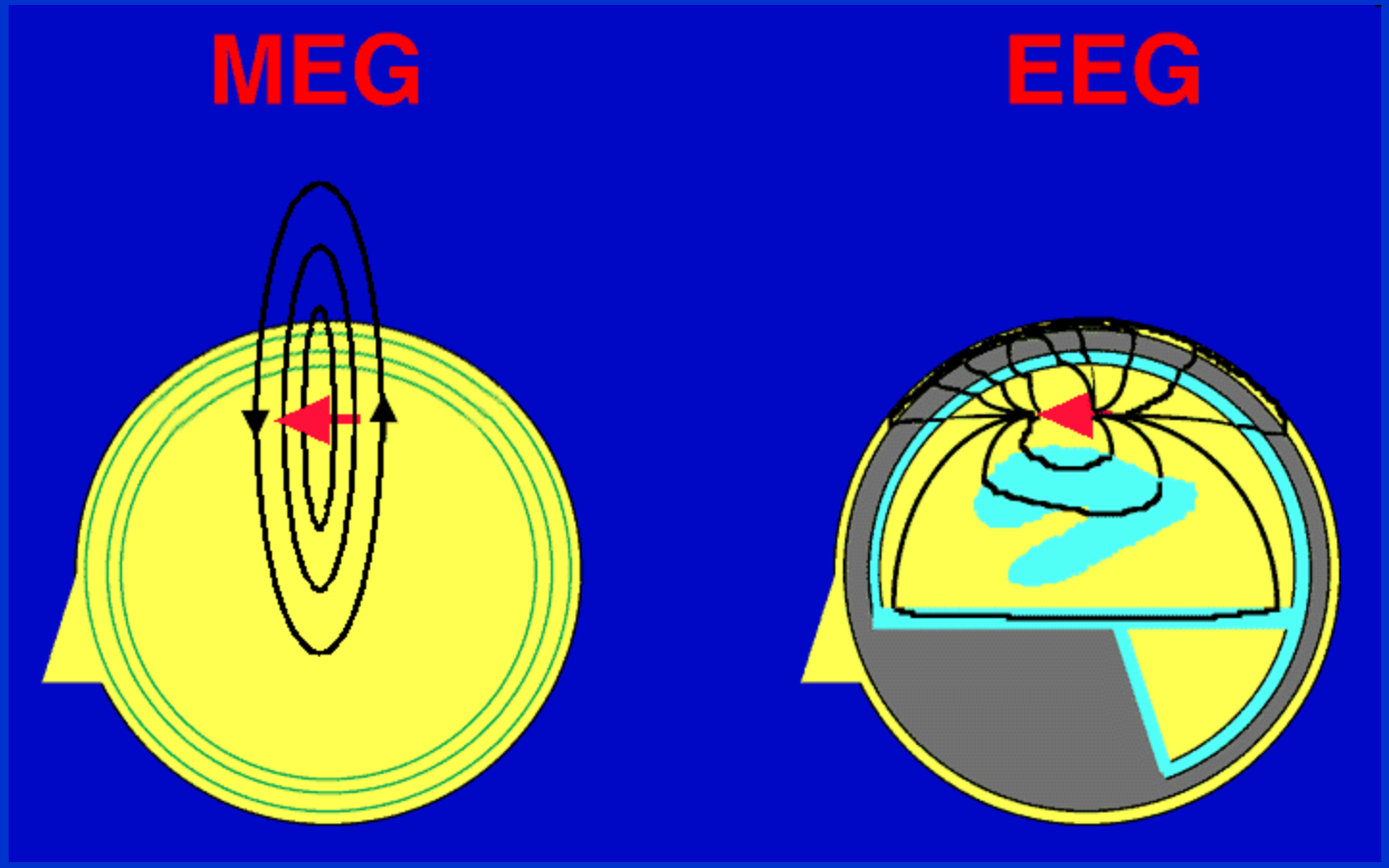
Correlation > 0.45

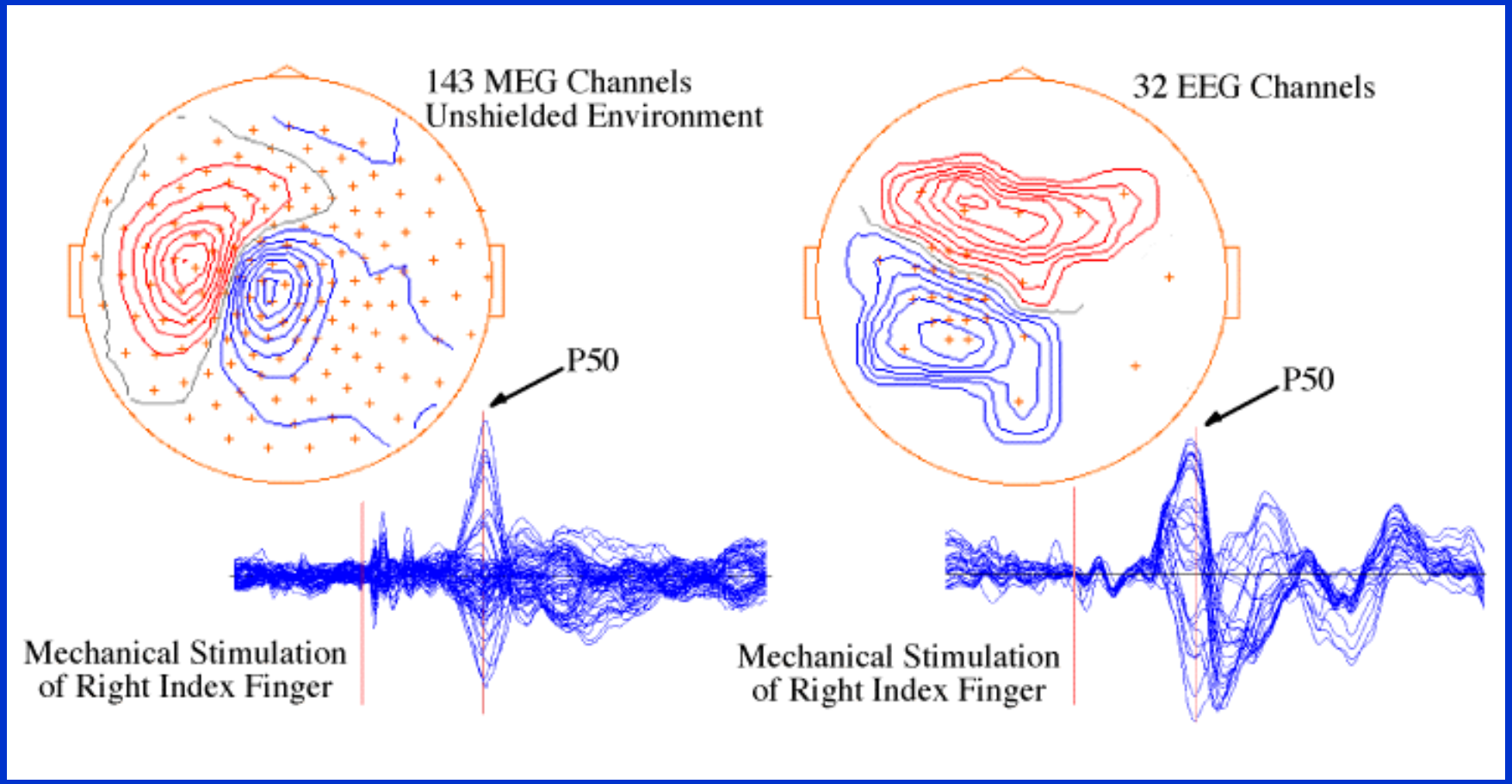
The End

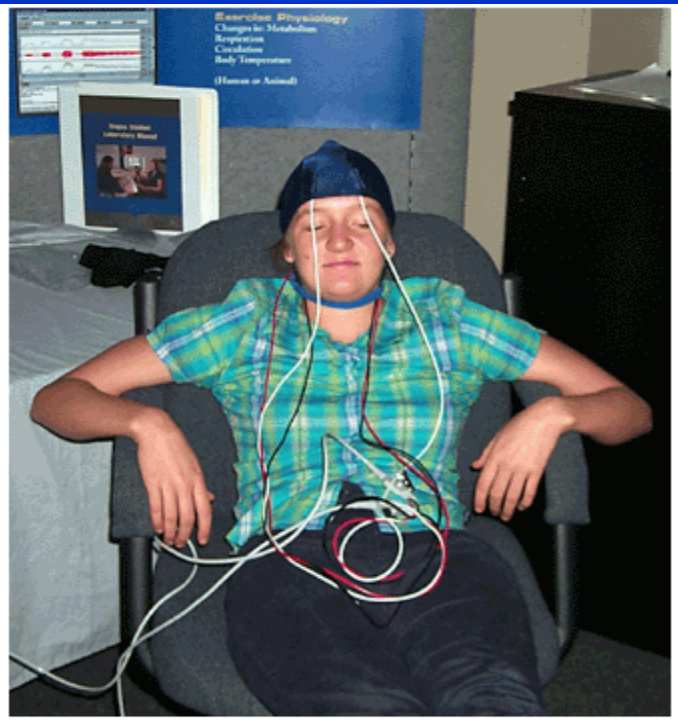
Activation in the brain correlated with skin conductance changes

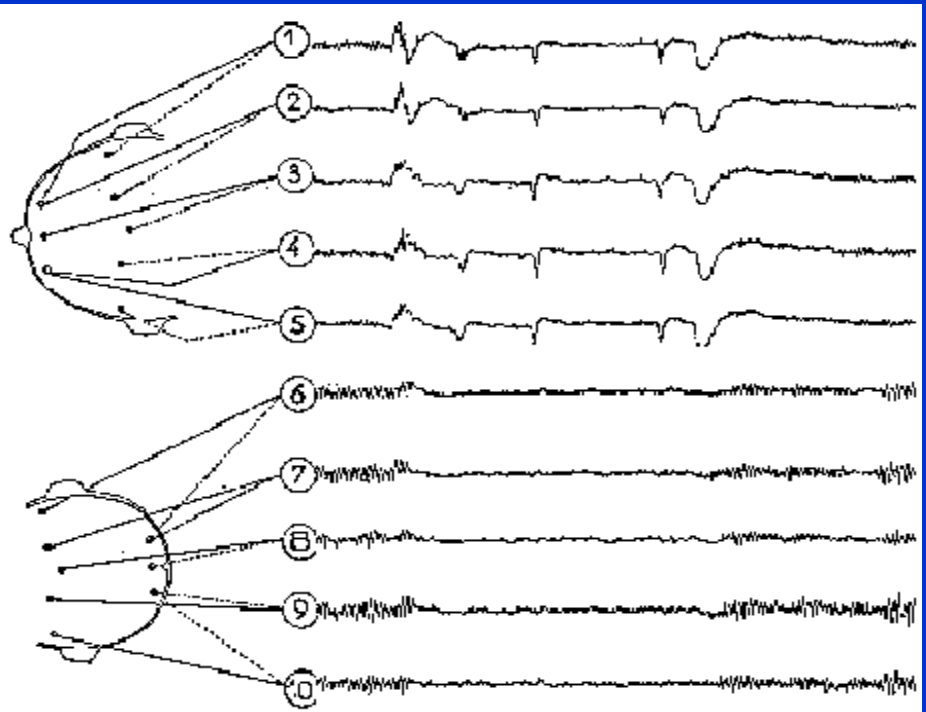



electric
current
magnetic
field
intracellular
current
(dendrite)


MEG
EEG

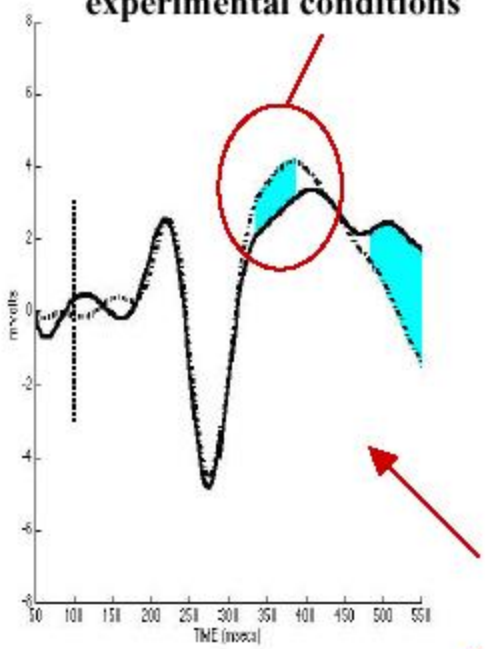

143 MEG Channels
Unshielded Environment
P50
Mechanical Stimulation
of Right Index Finger
32 EEG Channels
P50
Mechanical Stimulation
of Right Index Finger


Exercise Physiology
Changes in Metabolism
Respiration
Circulation
Body Temperature
(Human or Animal)

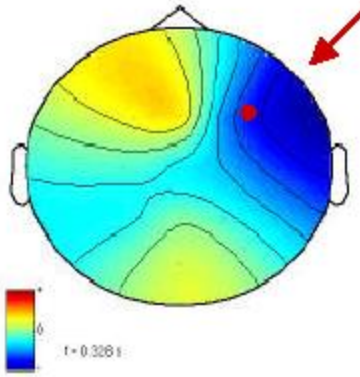

1
2
3
4
5
6
7
8
9
0

Electroencephalograghy (EEG) recording

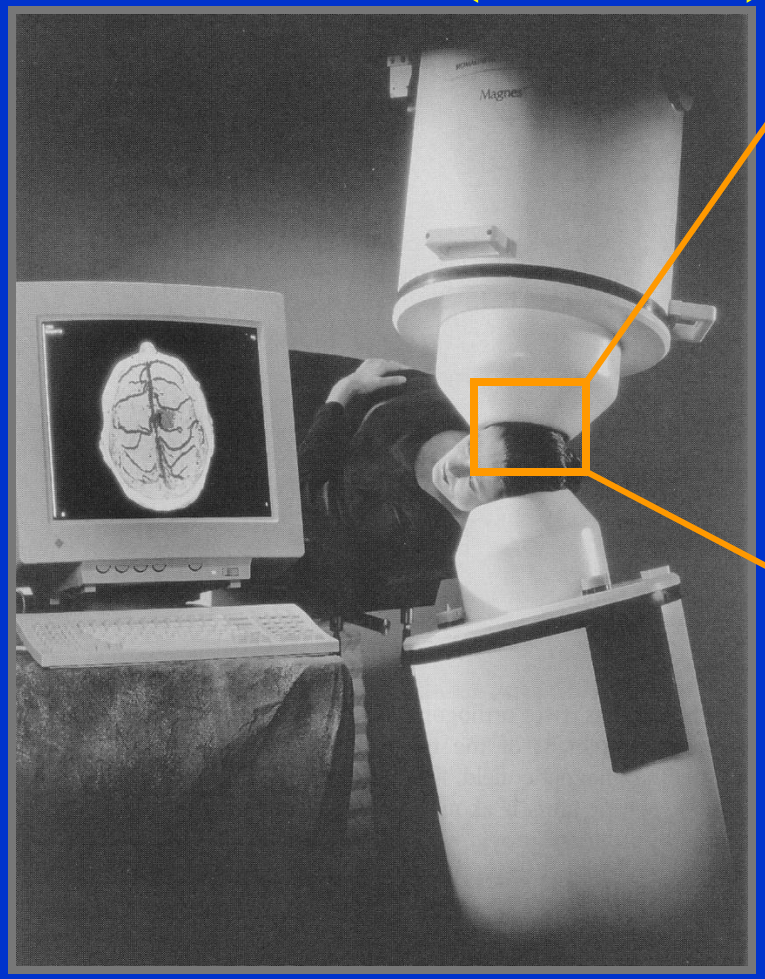
Statistical (T test) between two experimental conditions

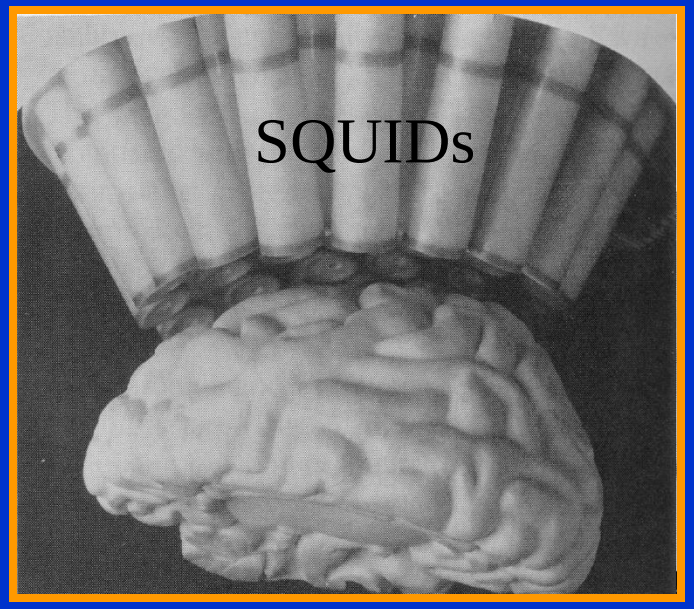


F4



Magnetoencephalography (MEG)

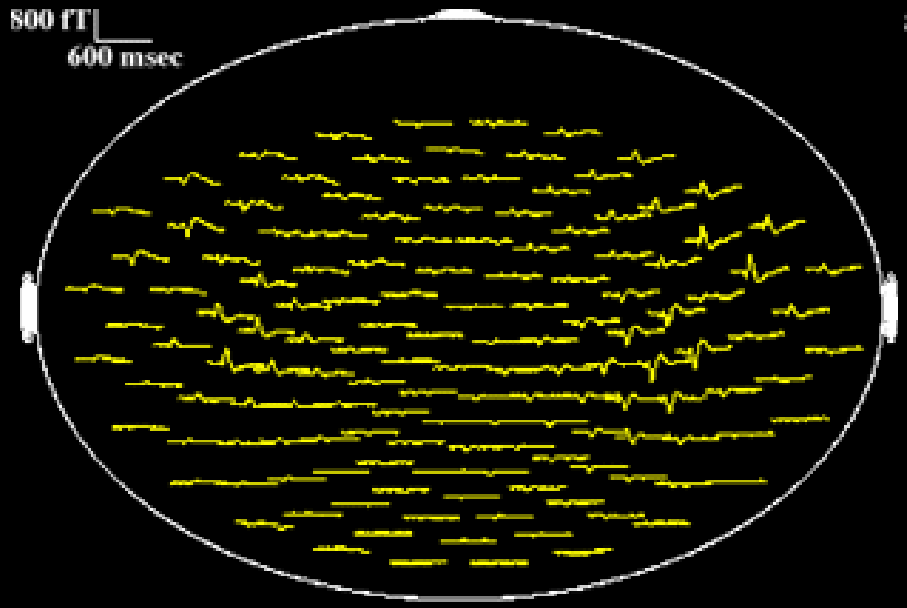


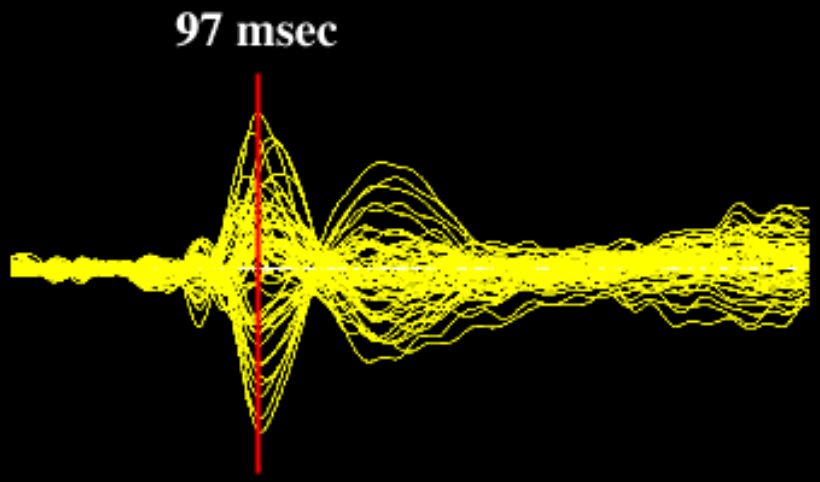


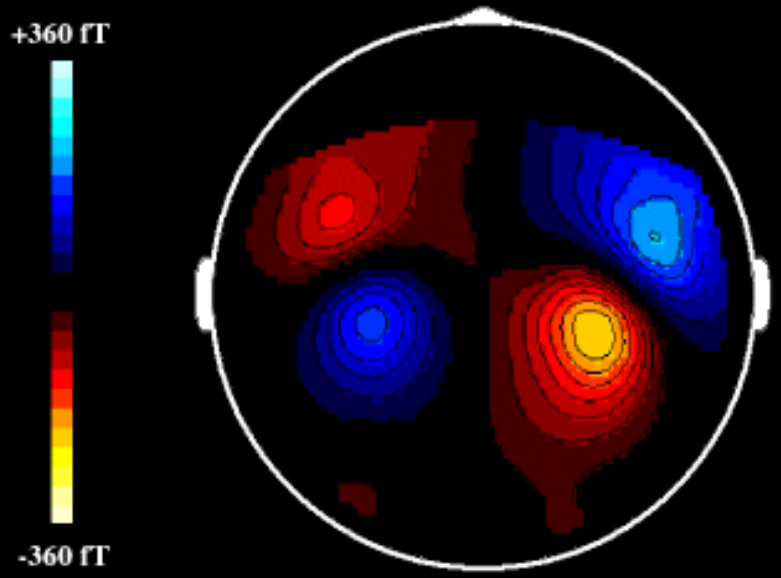
SQUID:
Superconducting Quantum Interference Device

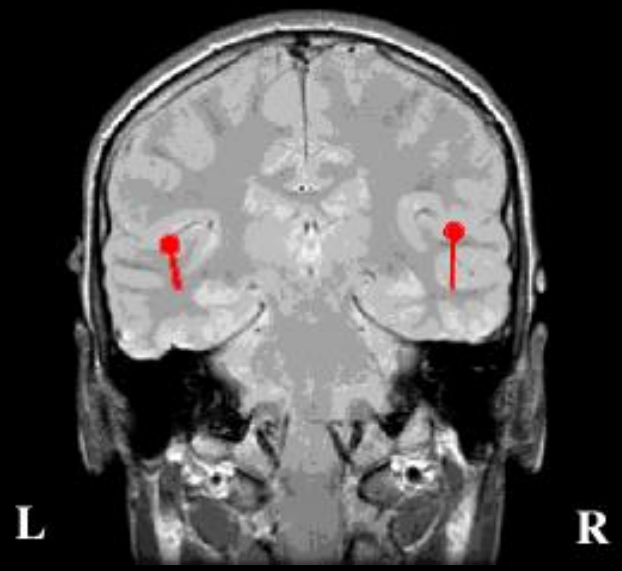
Combined MEG and EEG

MEG Mapping

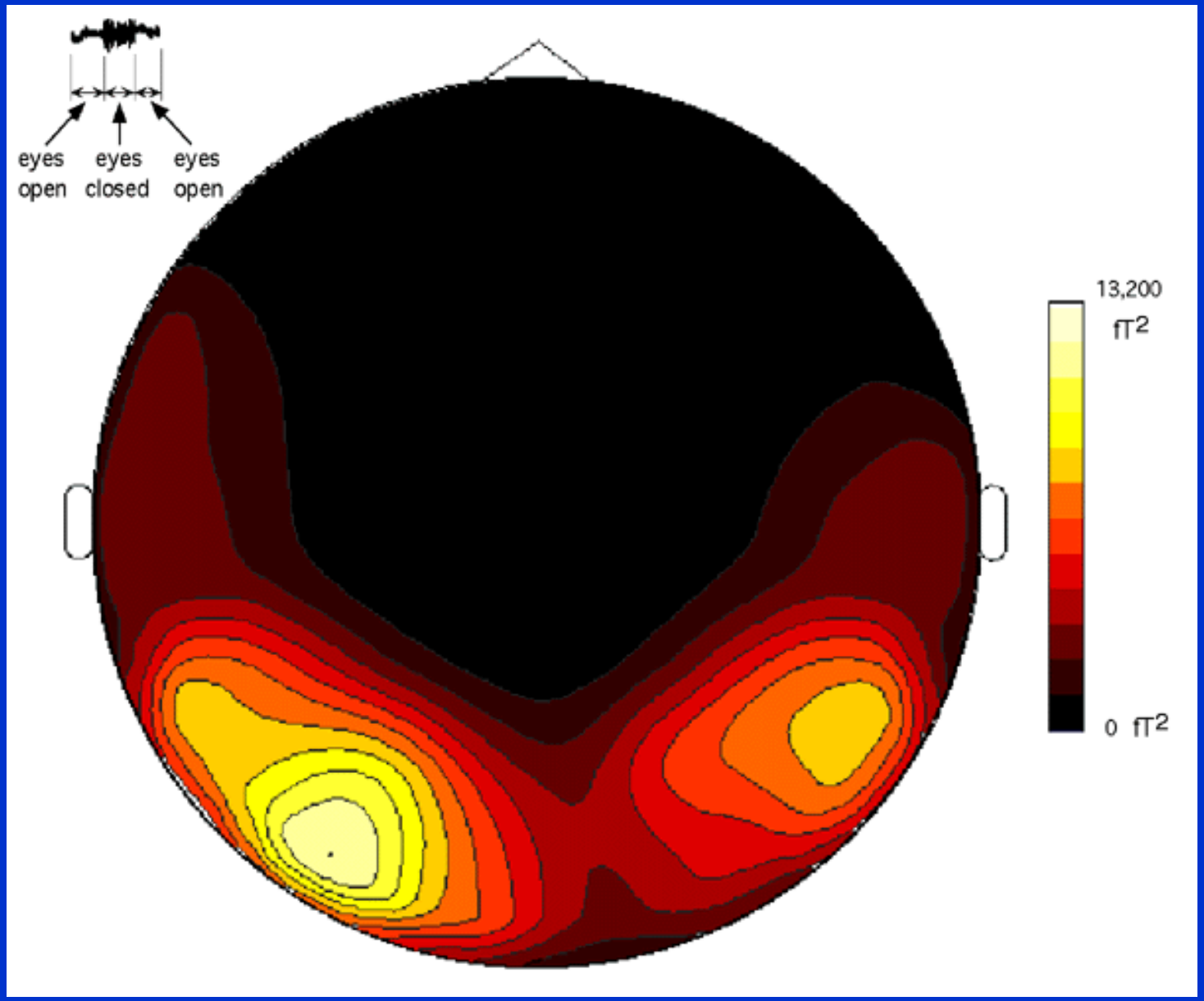




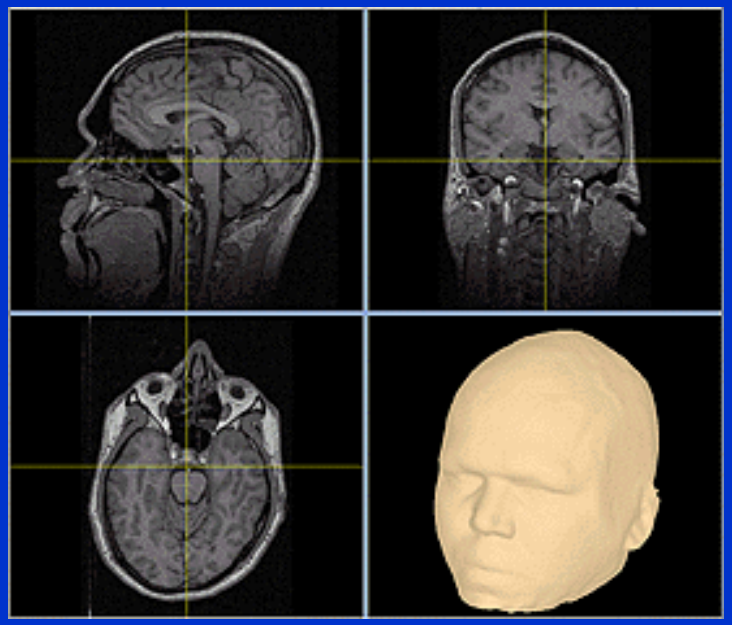




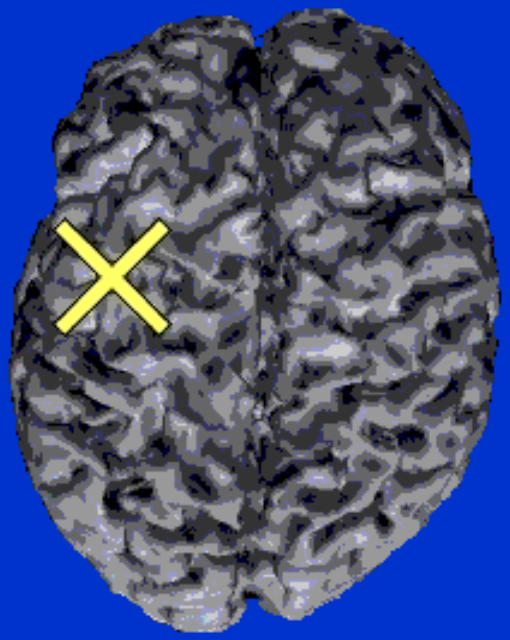
Alpha Wave Activity Mapped with MEG



Transcranial Magnetic Stimulation



Transcranial Magnetic Stimulation (TMS)



Acknowledgements

Ted Deyoe, Medical College of Wisconsin
Kathleen Schmainda, Medical College of Wisconsin
Steven Rao, Medical College of Wisconsin
Robert Savoy, Massachusetts General Hospital
Roger Tootell, Massachusetts General Hospital
Bradley Bookbinder, Massachusetts General Hospital
Randy Buckner, Washington University, St. Louis
Robert Innis, National Institute of Mental Health
Richard Coppola, National Institute of Mental Health
Sosumu Mori, Johns Hopkins University
Robert Cox, National Institute of Mental Health
Ziad Saad, National Institute of Mental Health
Eric Wong, University of California, San Diego
Ravi Menon, University of Western Ontario
Nikos Logothedis, Max Plank Institute, Germany

FIM Unit & FMRI Core Facility

Director:

Peter Bandettini

Staff Scientists:

Sean Marrett

Jerzy Bodurka

Frank Ye

Wen-Ming Luh

Computer Specialist:

Adam Thomas

Post Docs:

Rasmus Birn

Hauke Heekeren

David Knight

Patrick Bellgowan

Ziad Saad

Graduate Student:

Natalia Petridou

Post-Back. IRTA Students:

Elisa Kapler

August Tuan

Dan Kelley

Visiting Fellows:

Sergio Casciaro

Marta Maieron

Guosheng Ding

Clinical Fellow:

James Patterson

Psychologist:

Julie Frost

Summer Students:

Hannah Chang

Courtney Kemps

Douglass Ruff

Carla Wettig

Kang-Xing Jin

Program Assistant:

Kay Kuhns

Scanning Technologists:

Karen Bove-Bettis

Paula Rowser