# Functional Magnetic Resonance Imaging (fMRI)

*and a few other brain imaging techniques*

History, Development, and Applications

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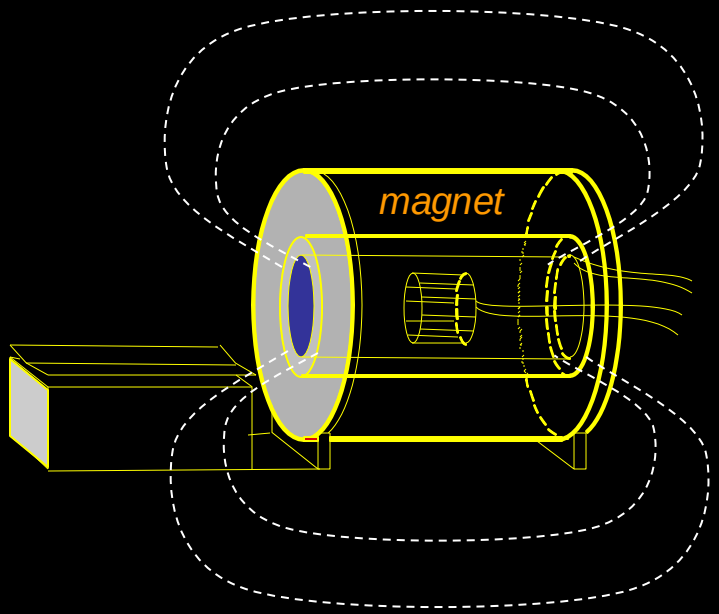
# Two Types of Neuroimaging

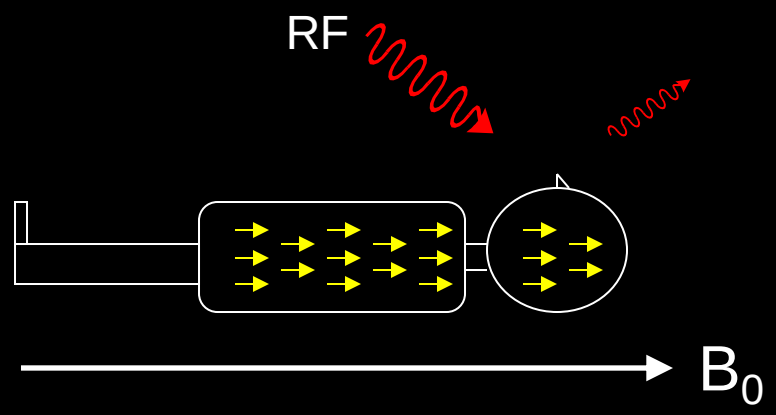
- Structural/Anatomical Imaging
- Functional Imaging

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

# Magnetic Resonance Imaging

# Magnetic Resonance Imaging (MRI)

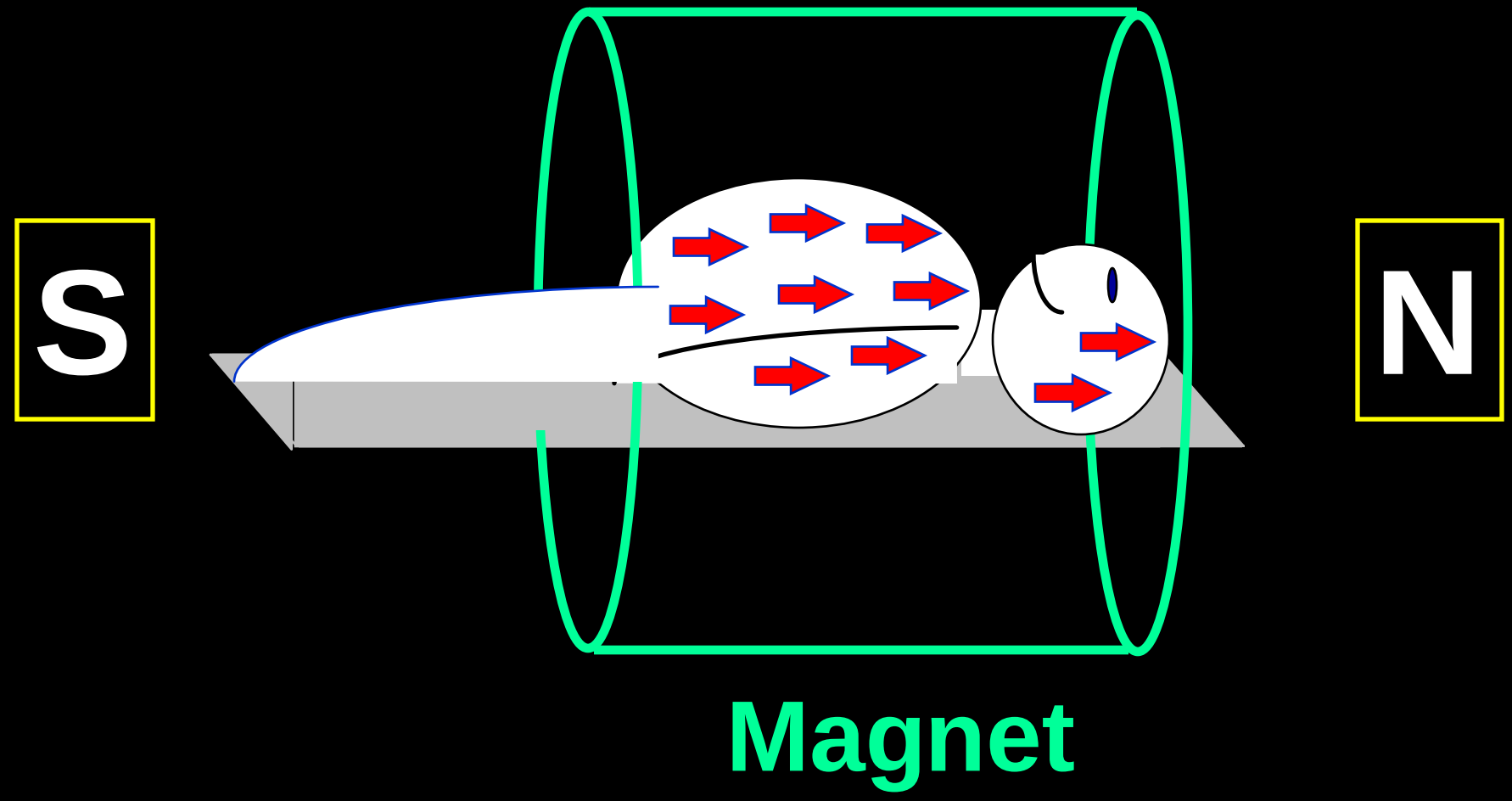


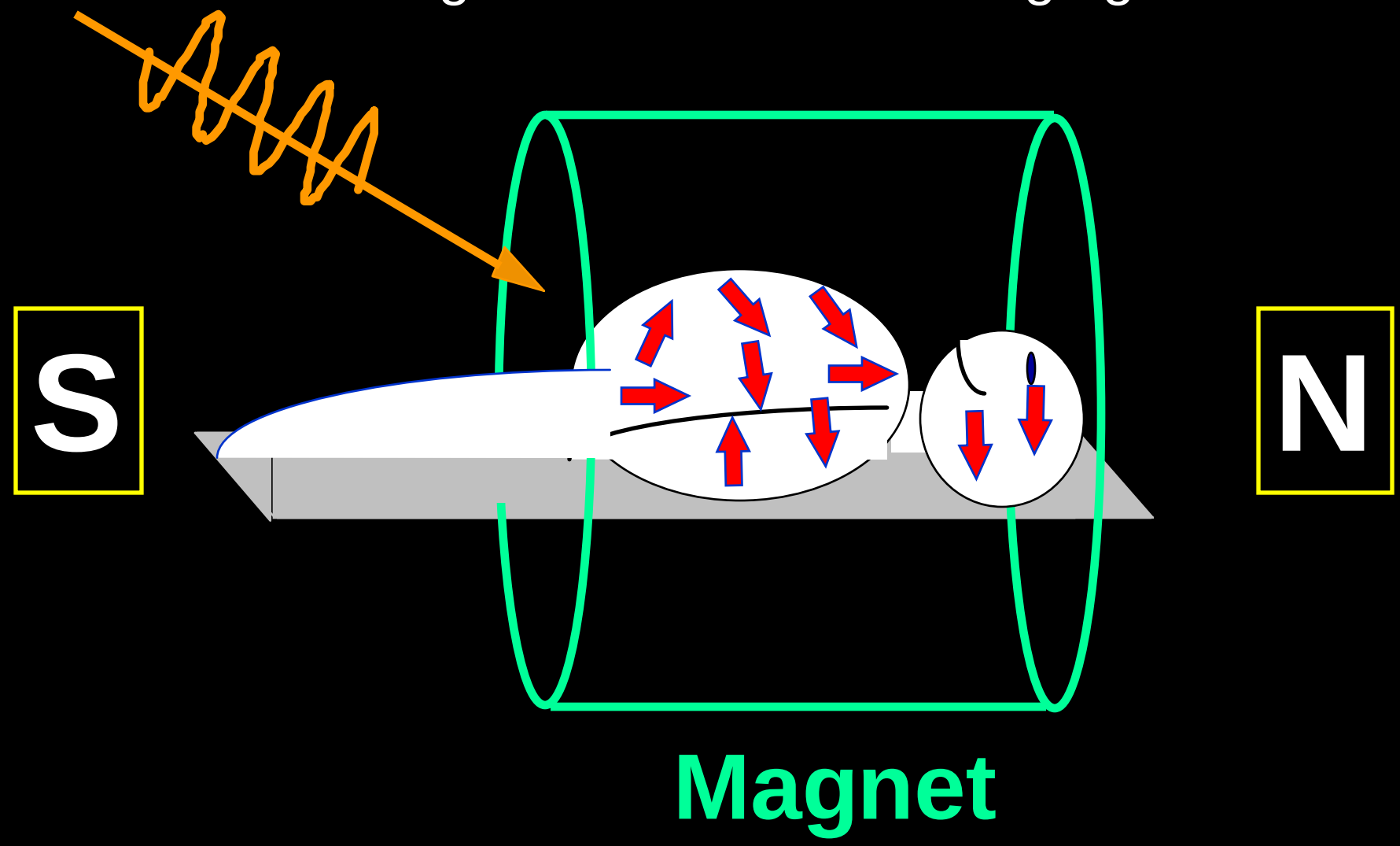

Sensitive to:

- # of protons ($H_2O$)
- Magnetic environment
  - Tissue structure

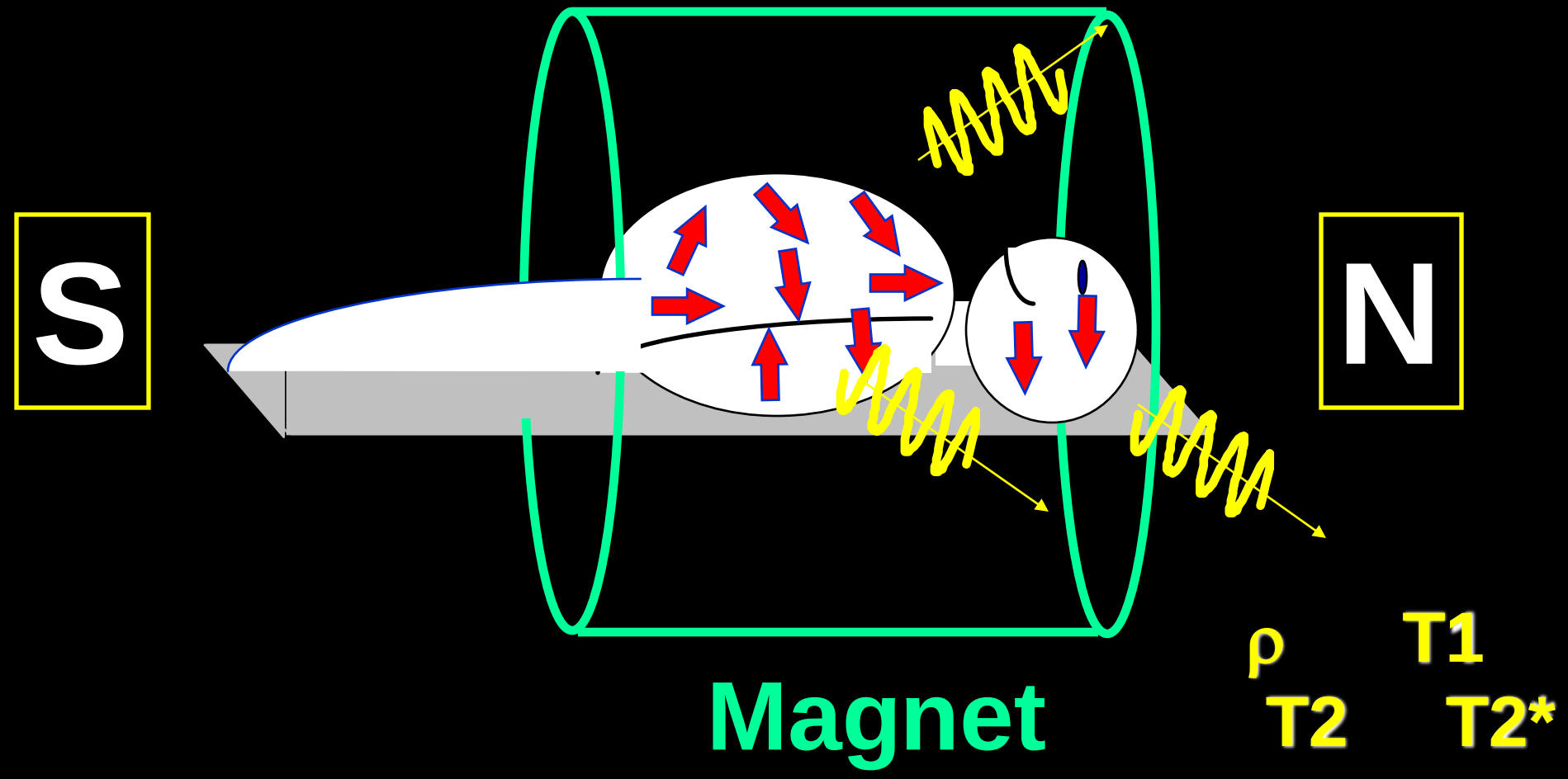
# Magnetic Resonance Imaging



# Magnetic Resonance Imaging

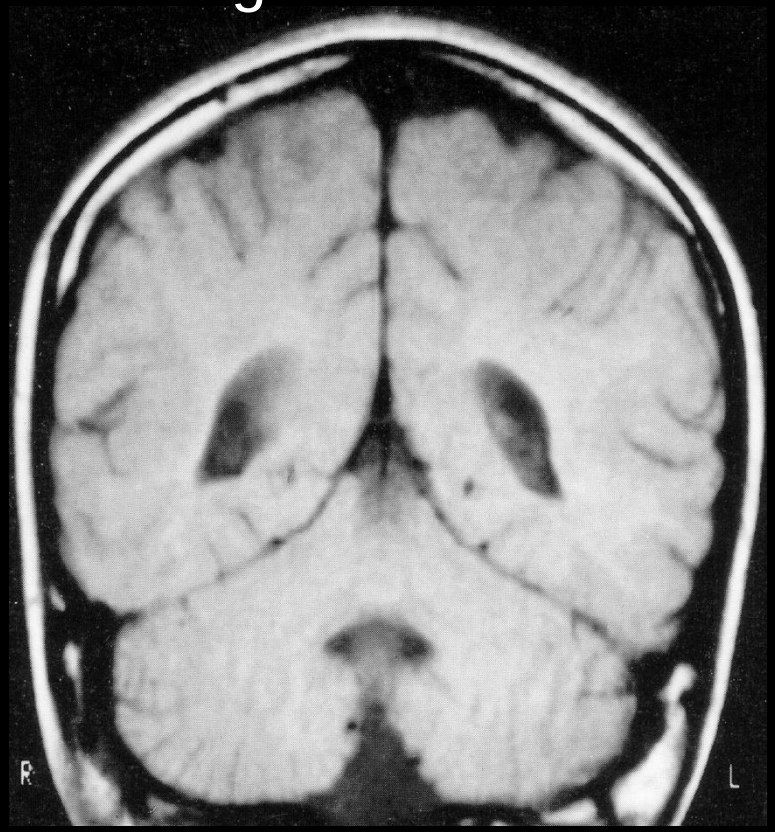


# Magnetic Resonance Imaging

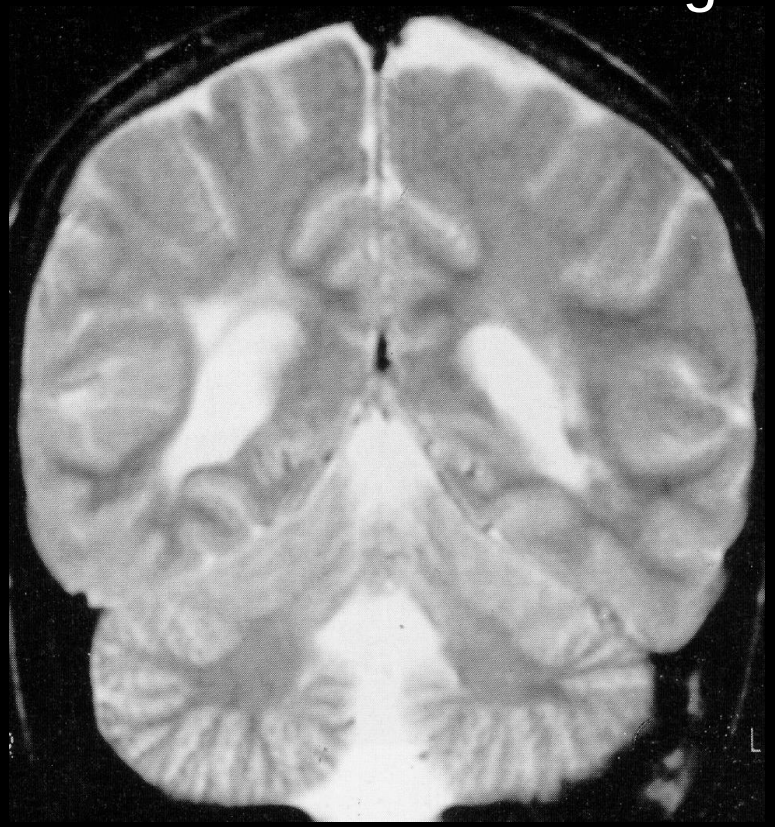


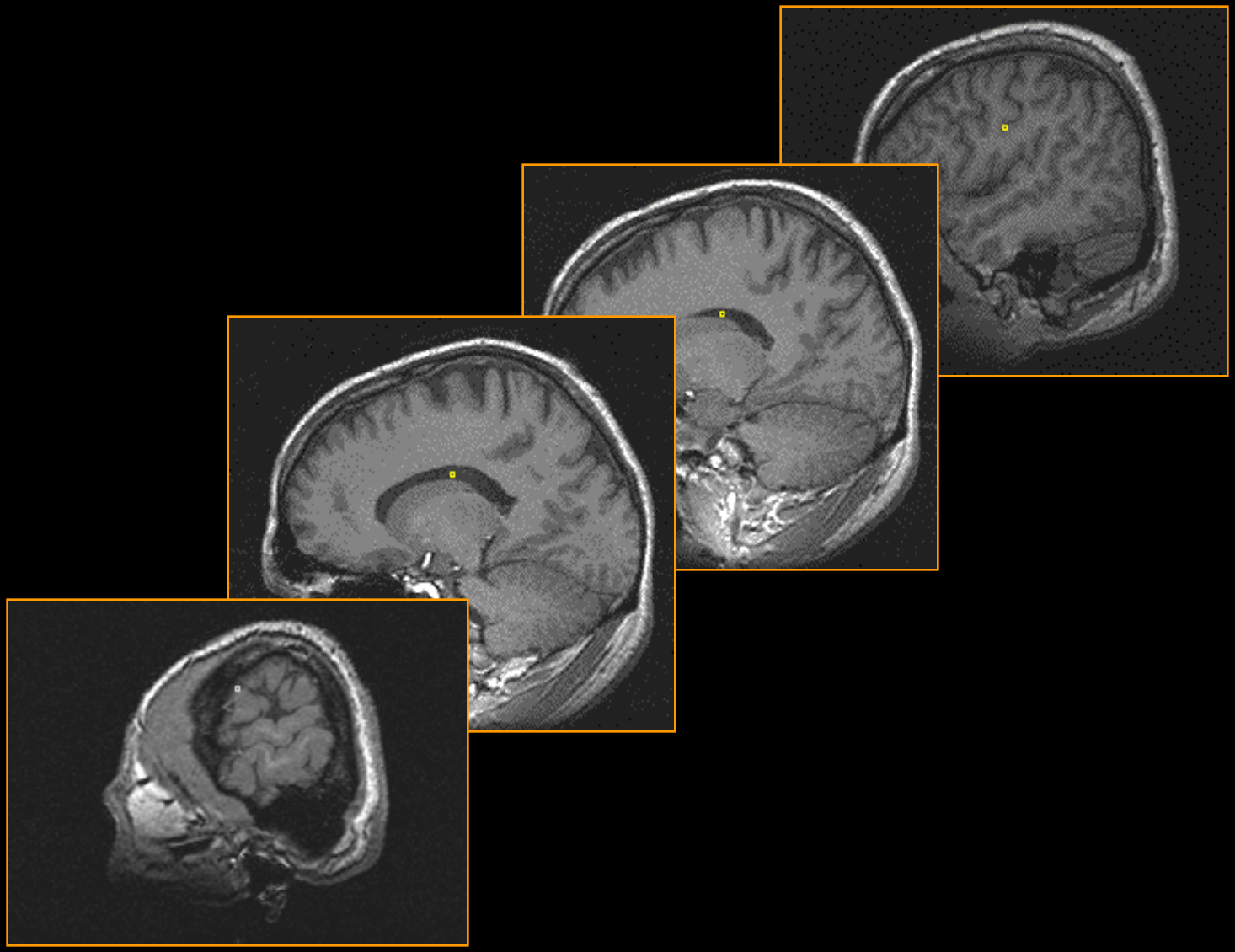
# MRI Images with Different Contrast Weighting

T1 Weighted

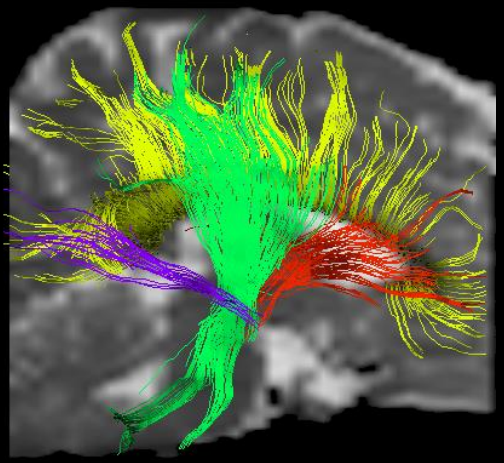



T2 Weighted





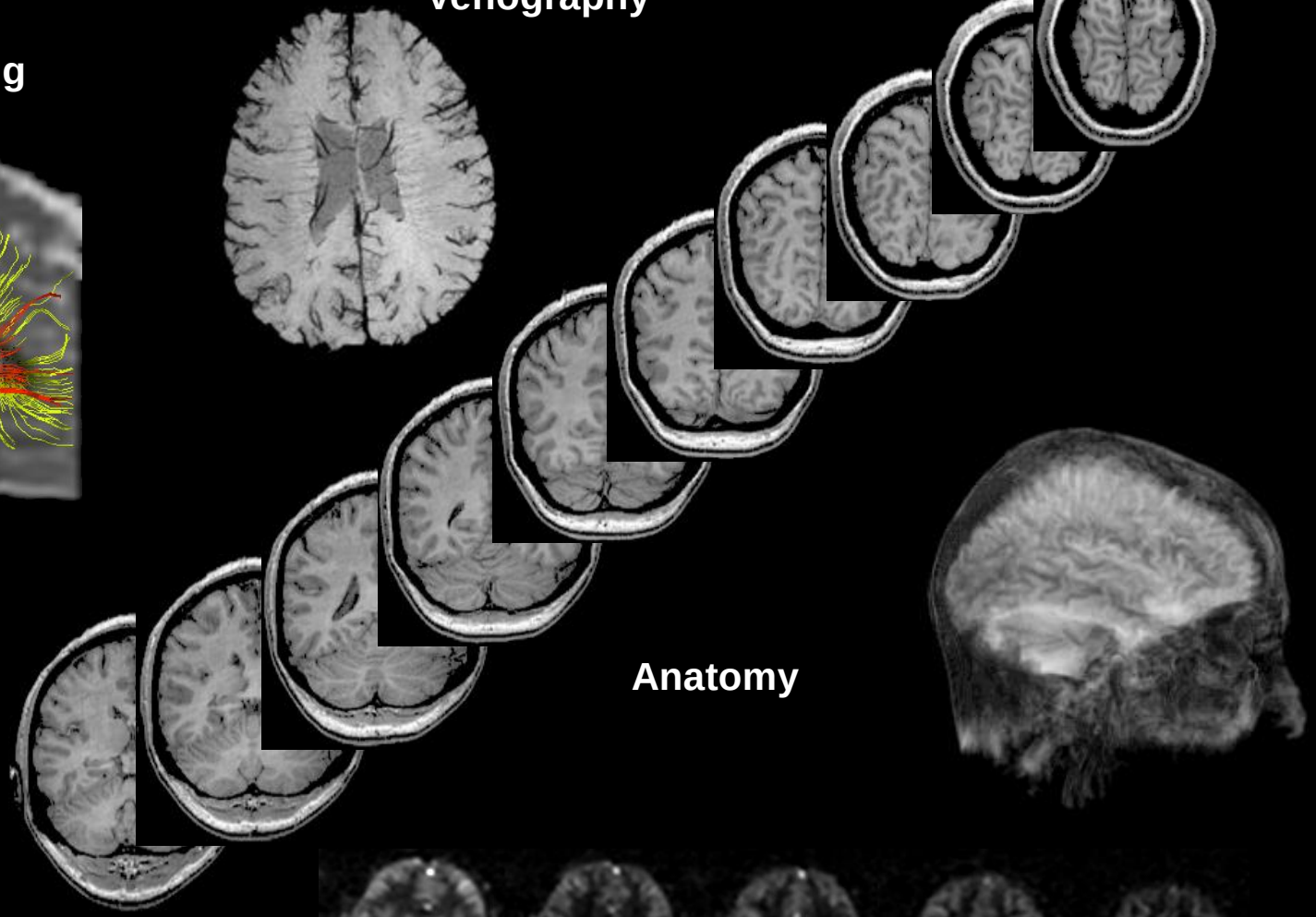
Fiber Track Imaging



Venography

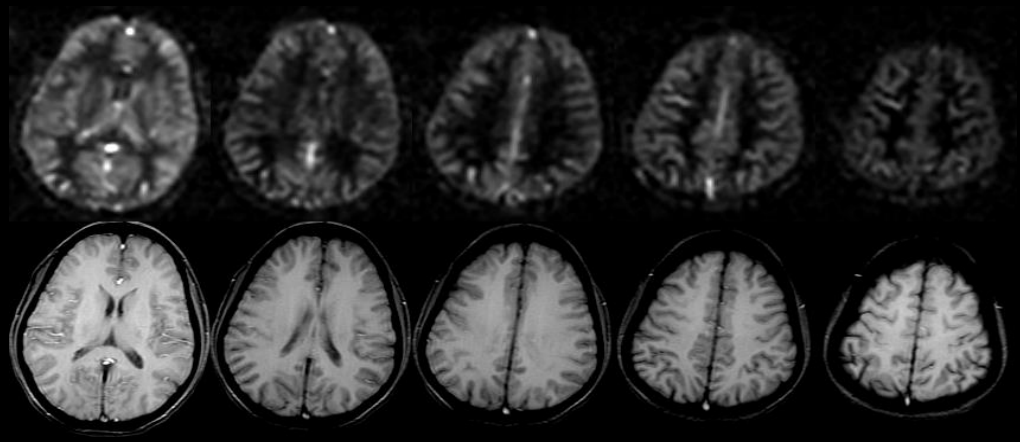


Anatomy



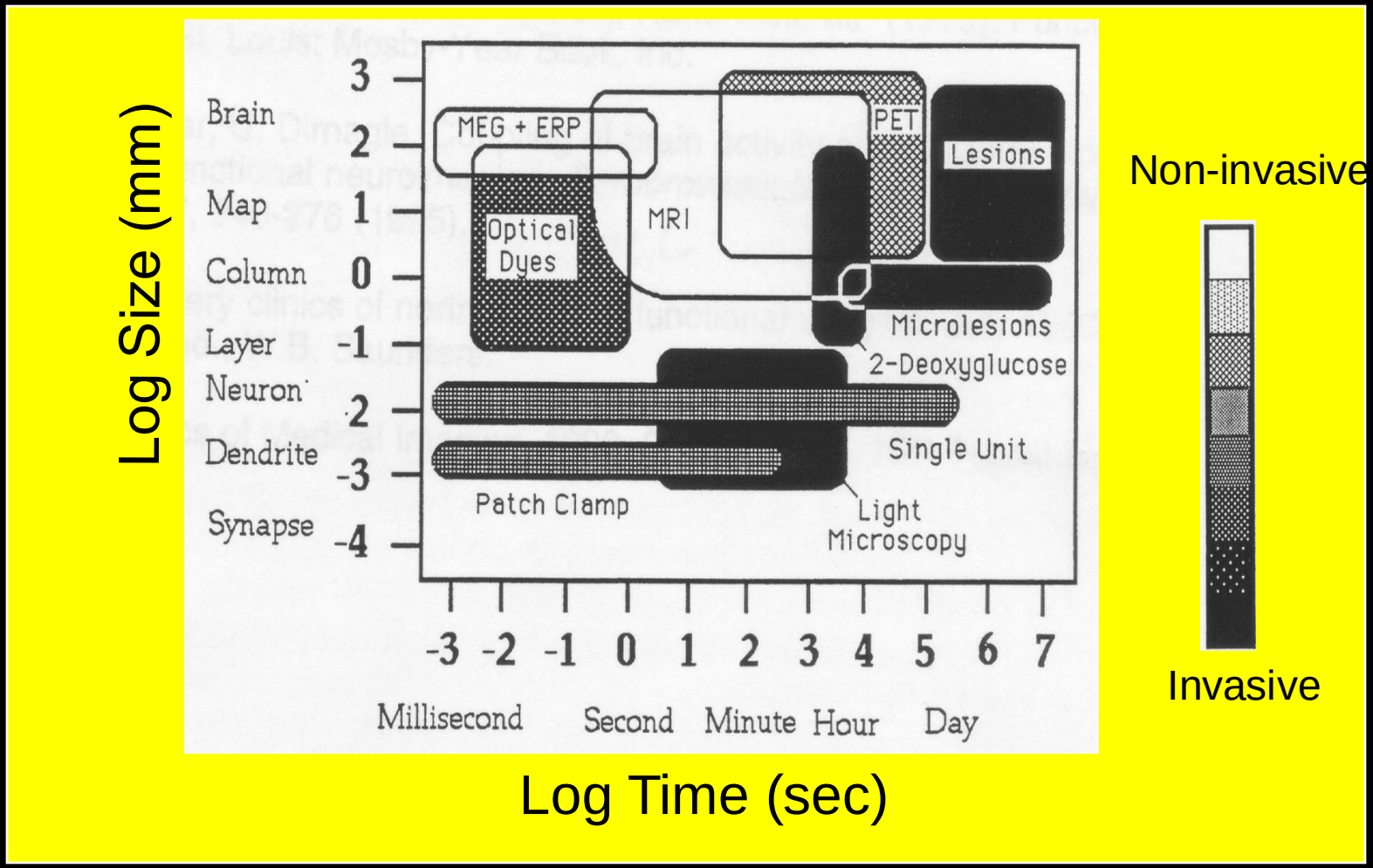
Angiography

Perfusion



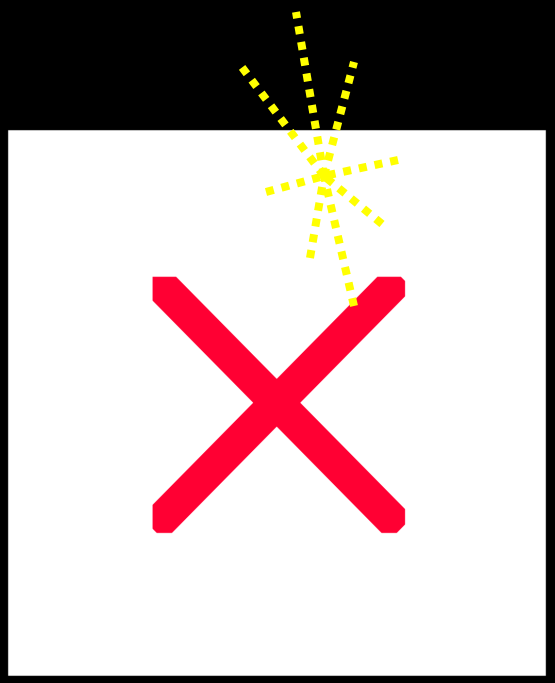
- Functional Imaging
  - Xenon Computerized Tomography (Xe CT)
  - Positron Emission Tomography (PET)
  - Single Photon Computed Tomography (SPECT)
  - Functional MRI (fMRI)
  - Electroencephalography (EEG)
  - Magnetoencphalography (MEG)
  - Transcranial Magnetic Stimulation (TMS)

# Functional Neuroimaging Techniques

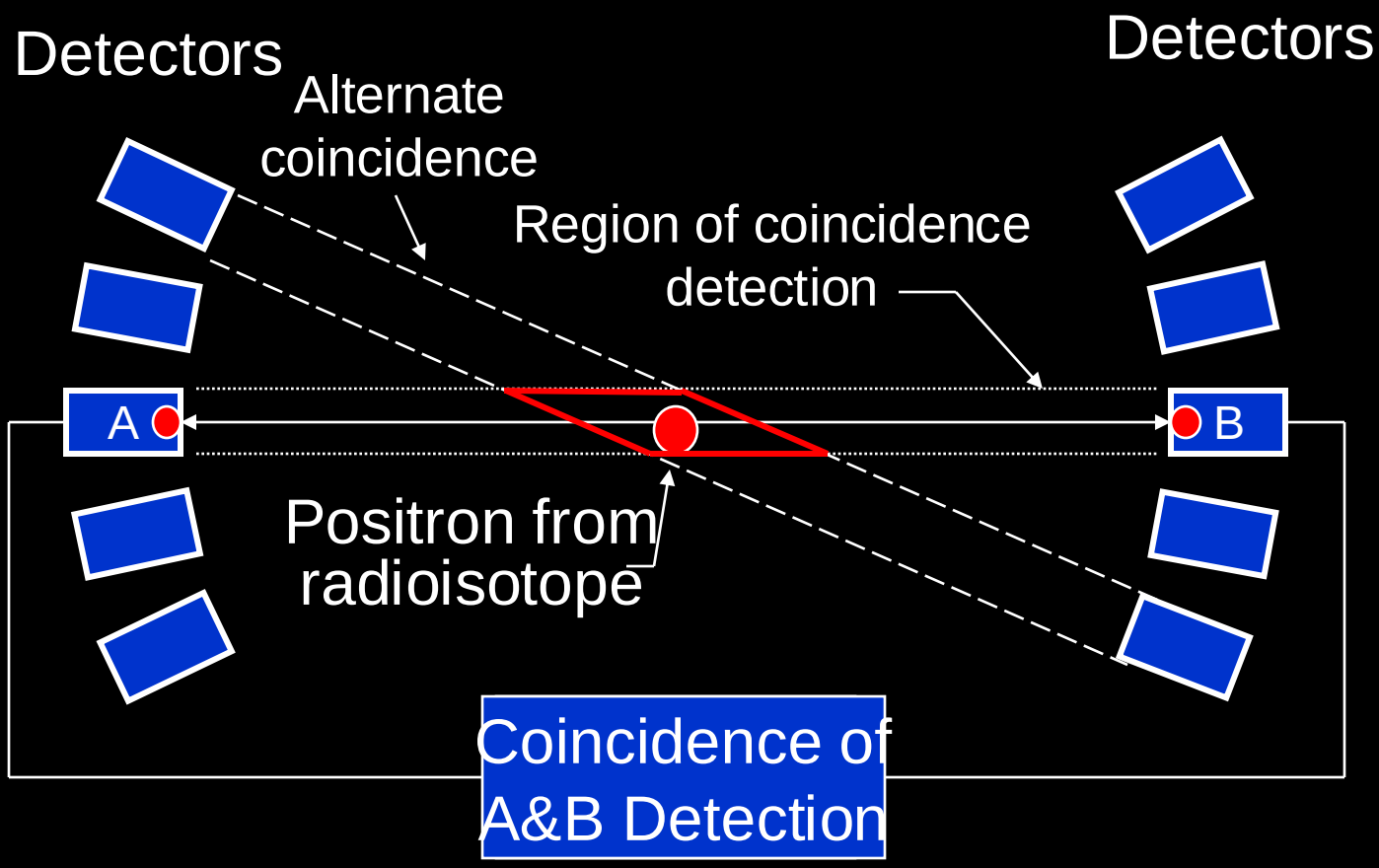


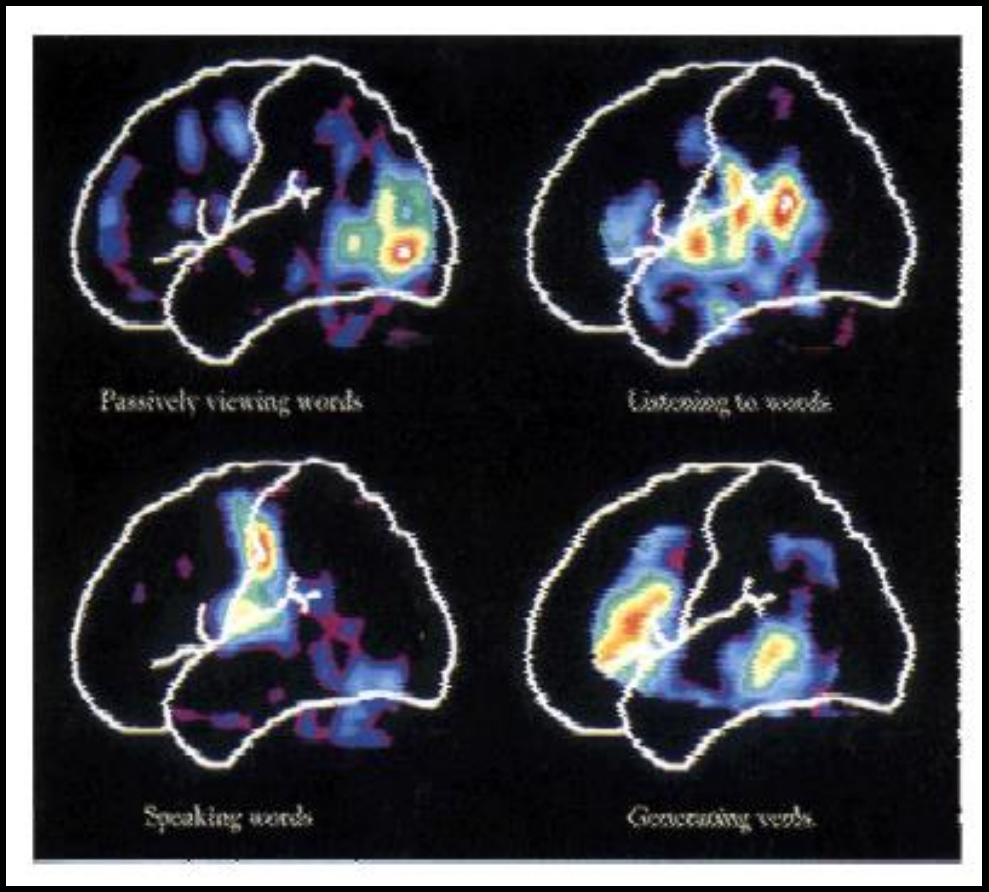
# Positron Emission Tomography (PET)

- 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.



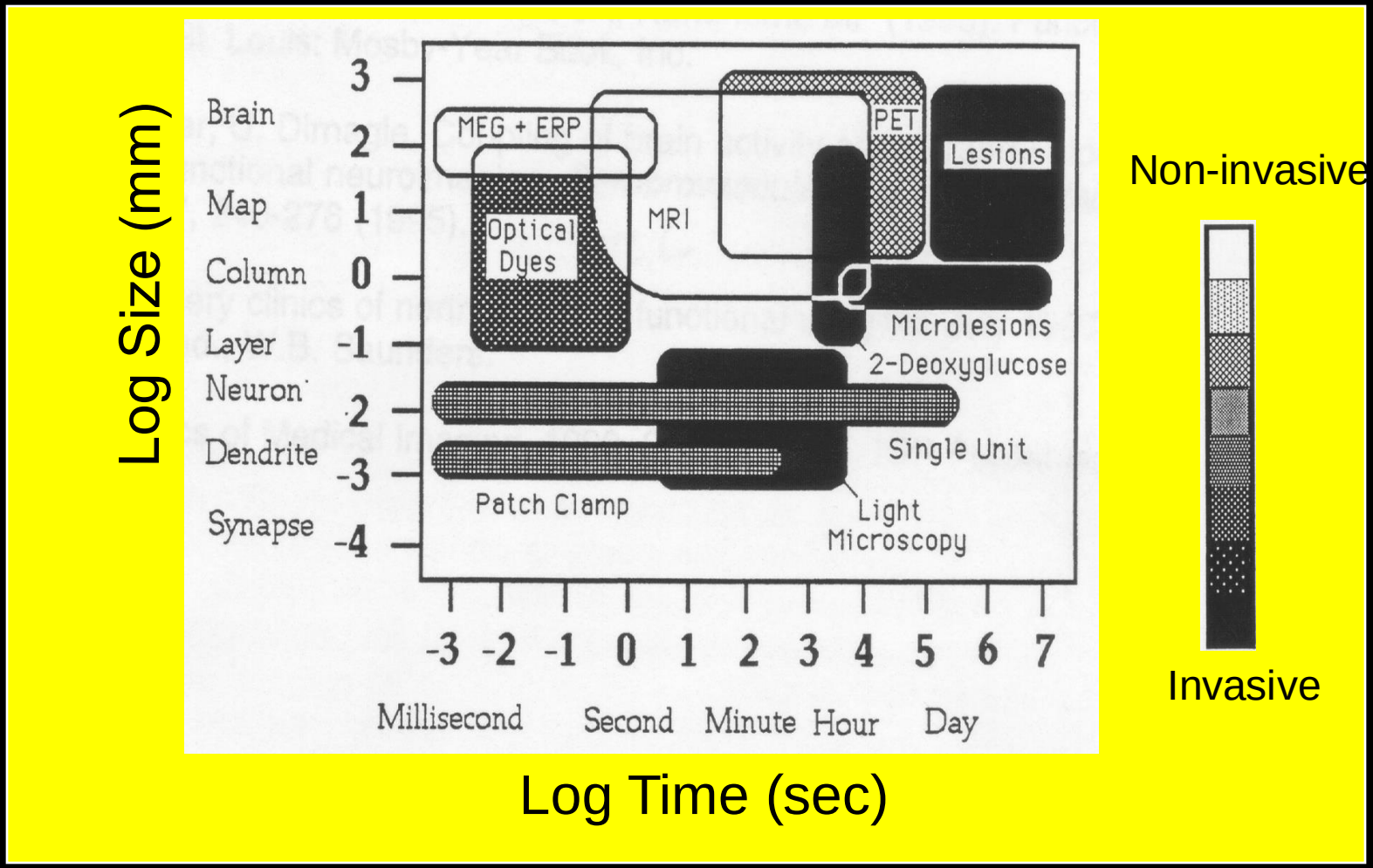
# PET mechanism




Passively viewing words
Listening to words
Speaking words
Generating verbs

# Functional Magnetic Resonance Imaging

# Functional Neuroimaging Techniques



# Scanners:

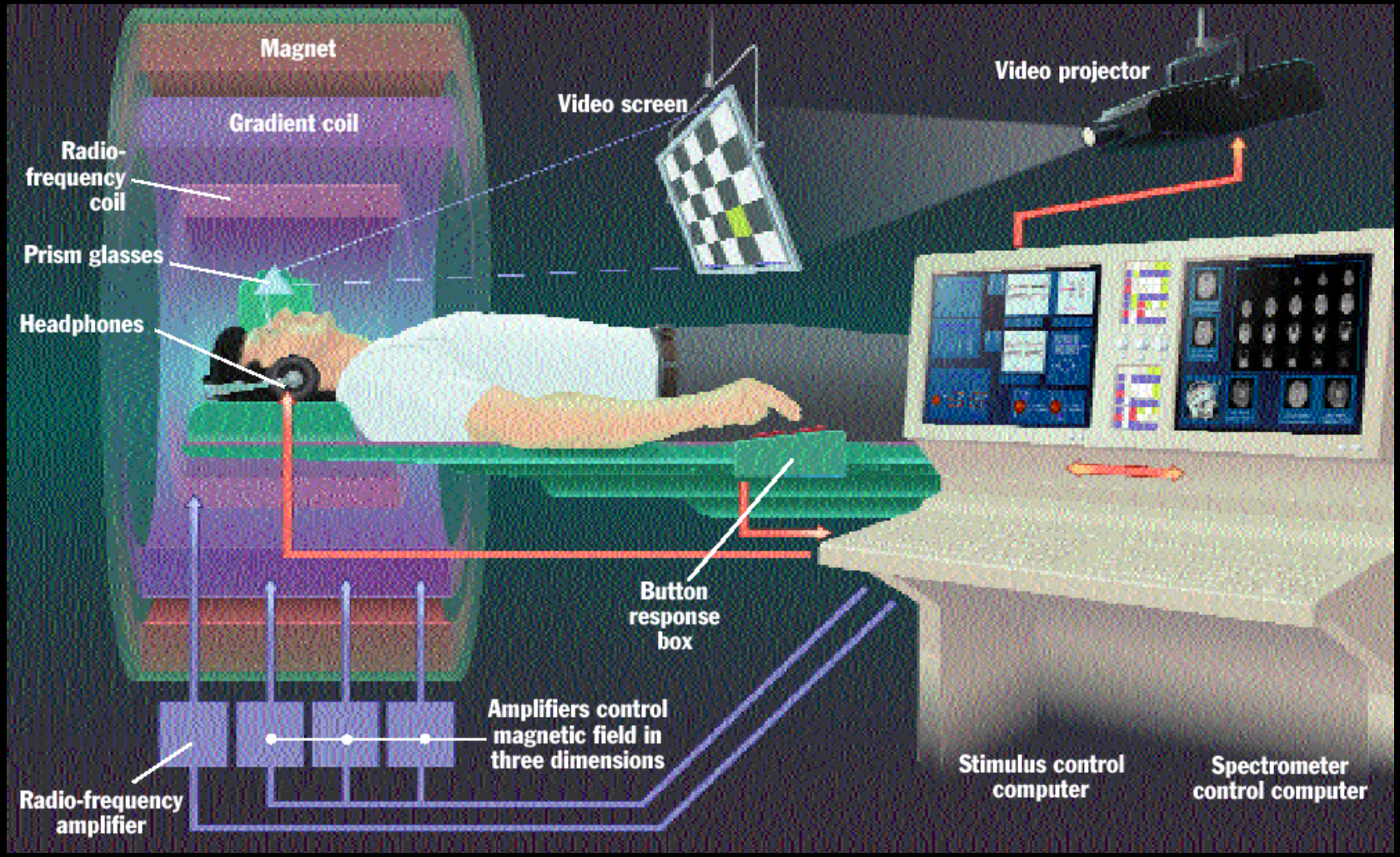
| | | |
|---|---|---|
| “3T-1” | GE 3T | (June 2000) |
| “3T-2” | GE 3T | (Nov 2002) |
| “FMRIF 1.5T” | GE 1.5T | (Sept 2004) |
| Currently being Cited | GE 3T | (Aug 2003) |


1.5T

3T-1

3T-2

# fMRI Setup

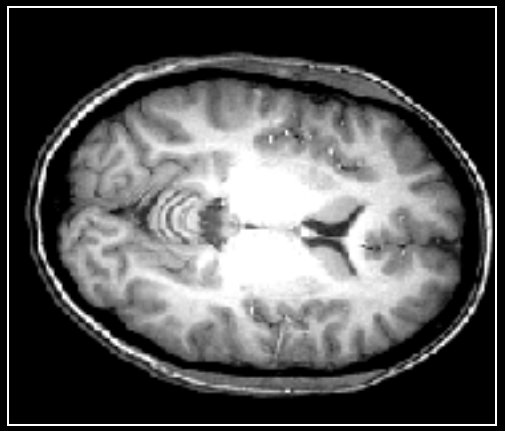



Courtesy, Robert Cox, Scientific and Statistical Computing Core Facility, NIMH

# MRI vs. fMRI

MRI

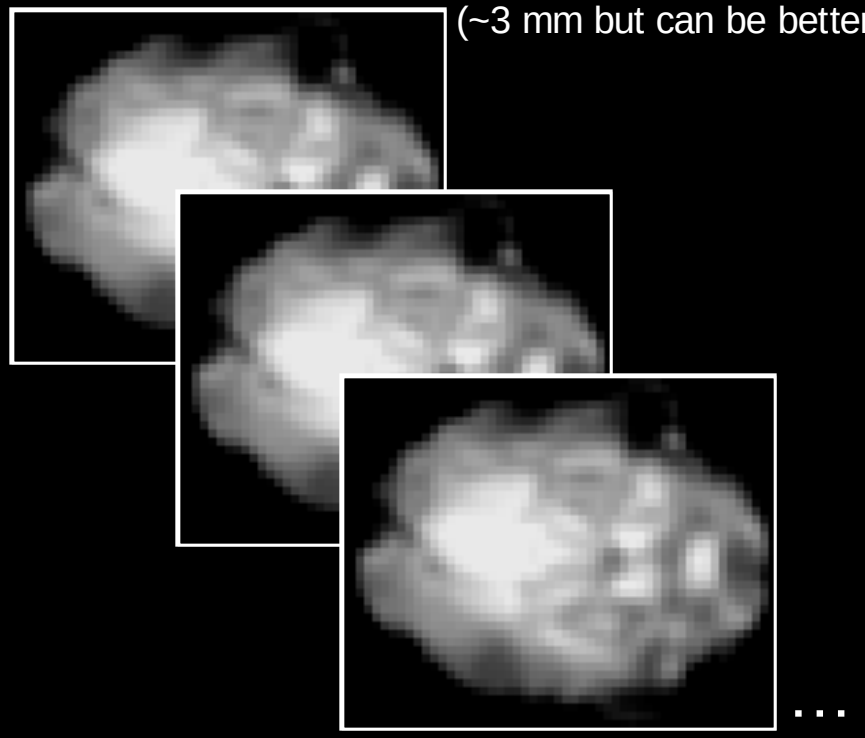
high resolution
(1 mm)



one image

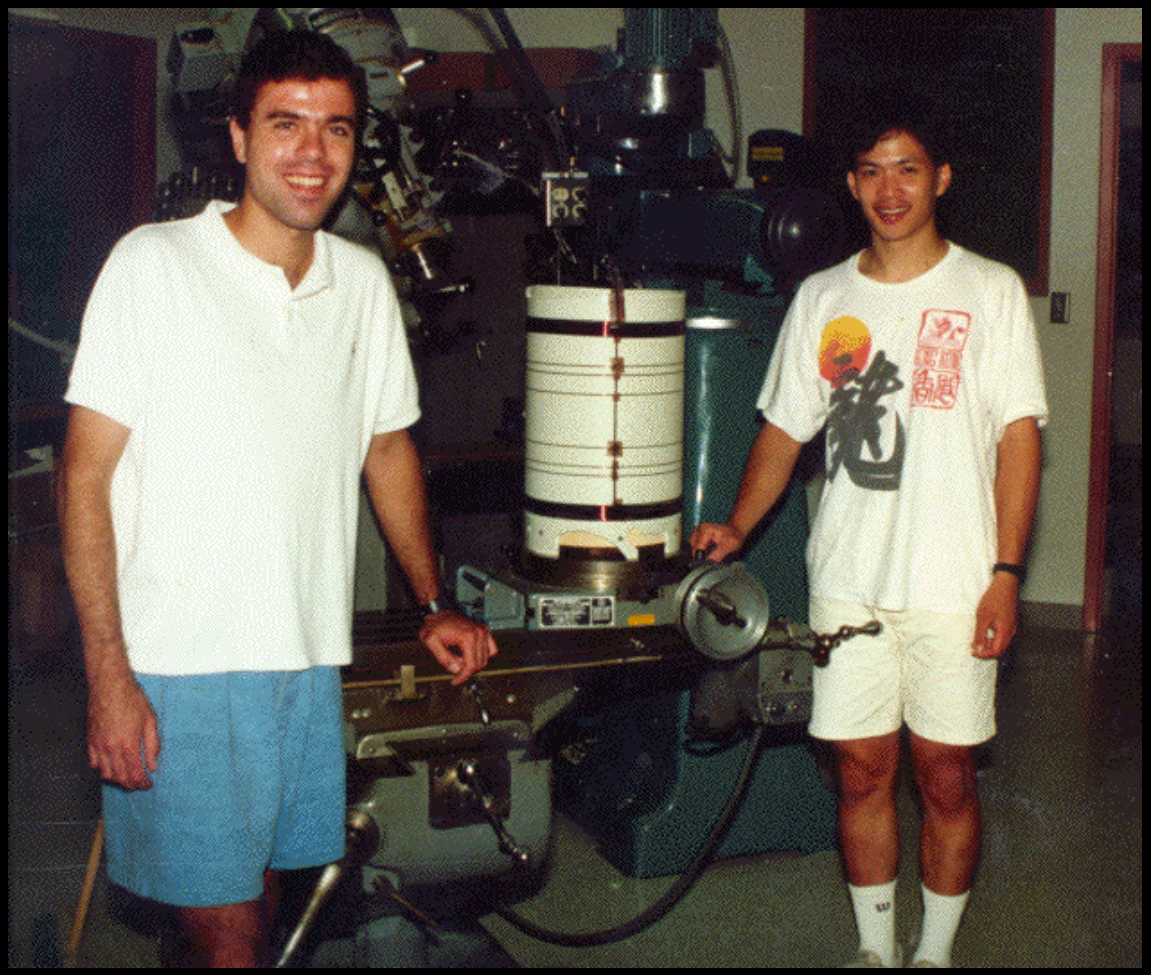
fMRI

low resolution
(~3 mm but can be better)



...

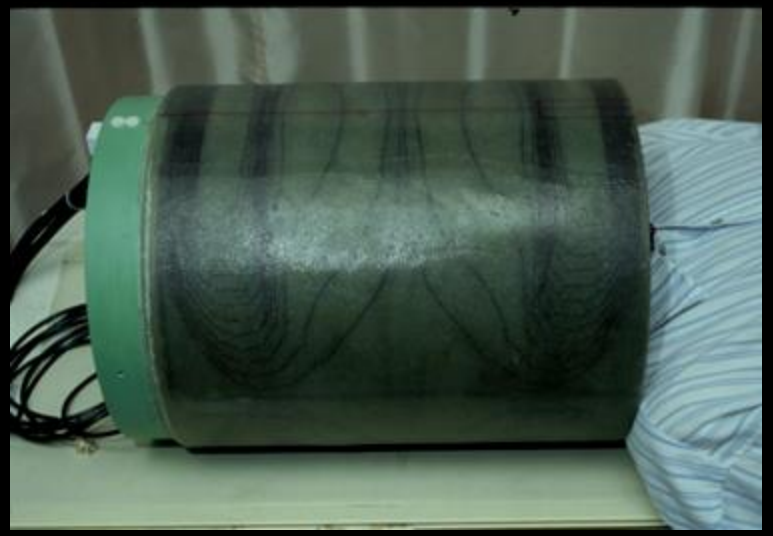
many images
(e.g., every 2 sec for 5 mins)



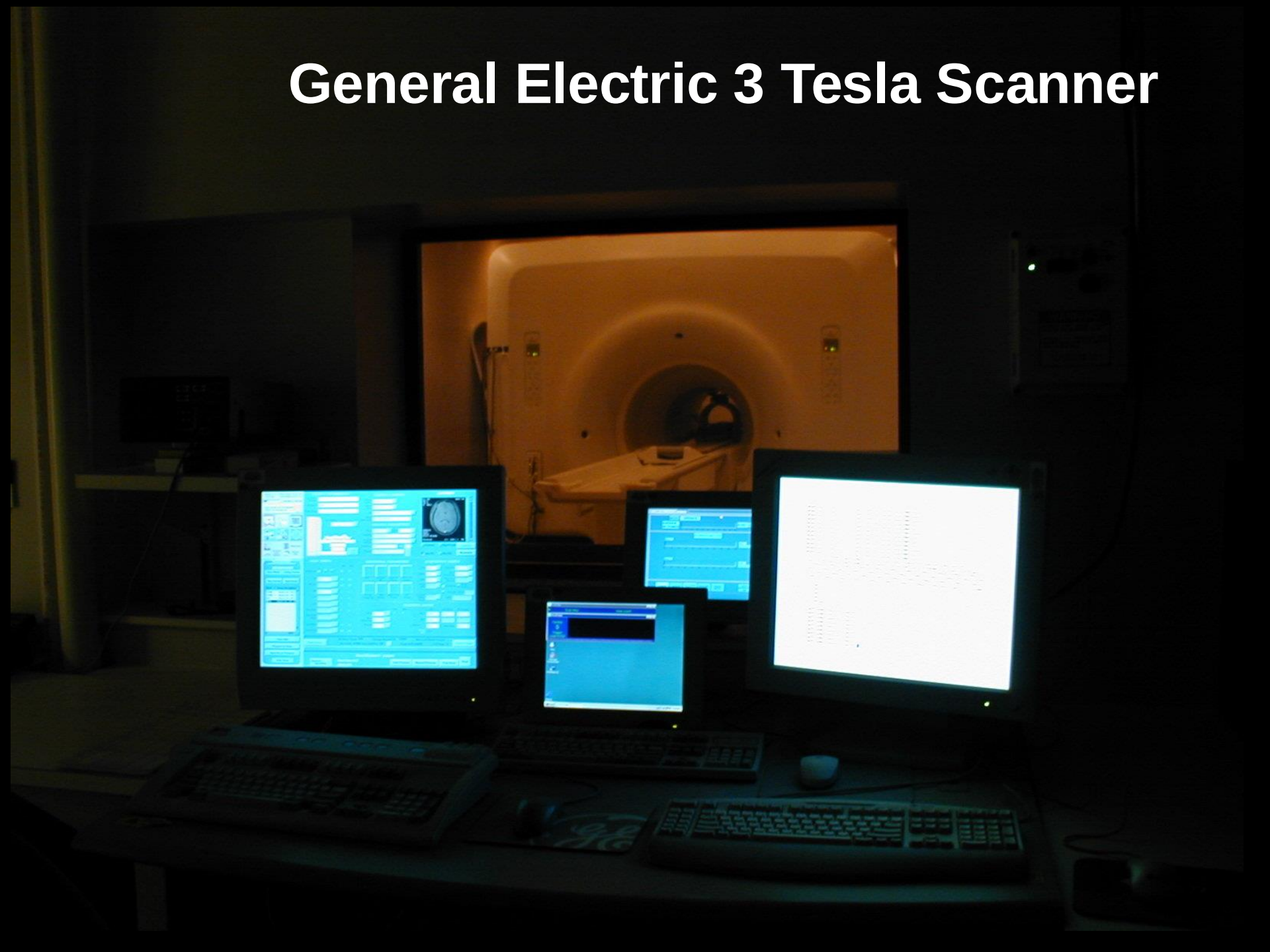
August, 1991

1991-1992

1992-1999

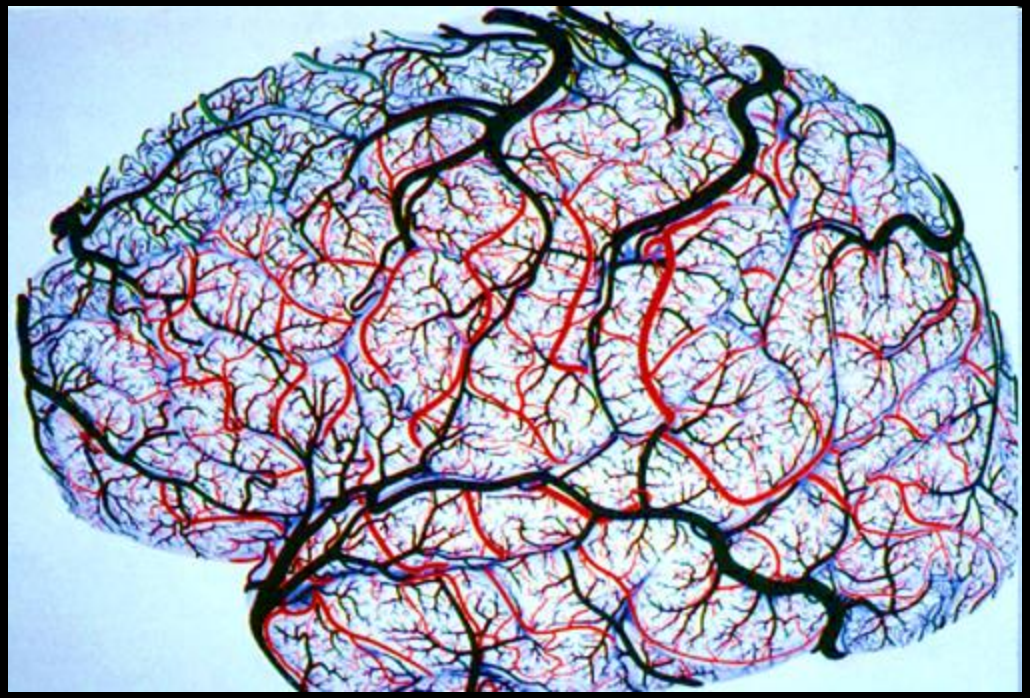


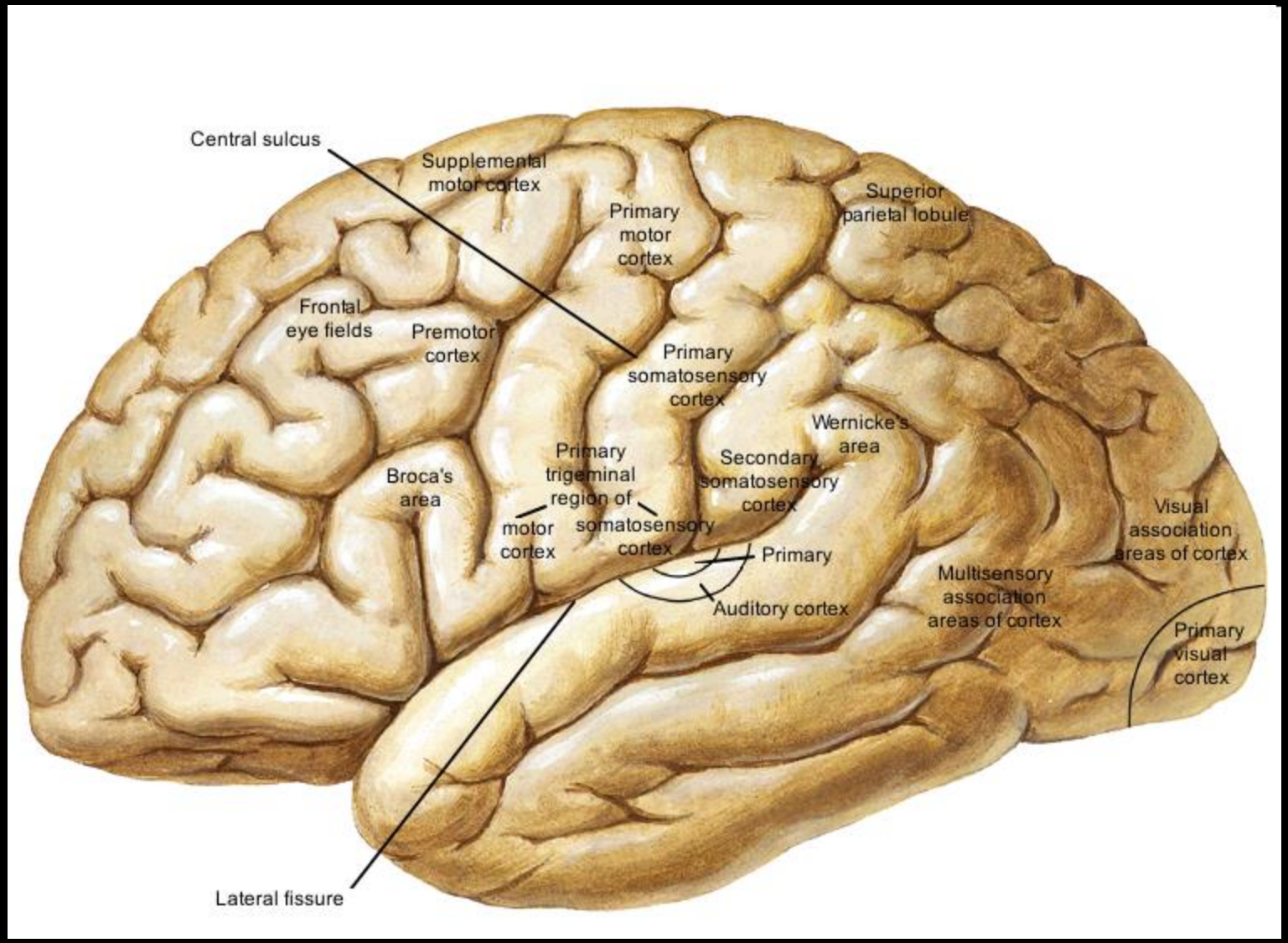
# General Electric 3 Tesla Scanner



# Contrast in Functional MRI

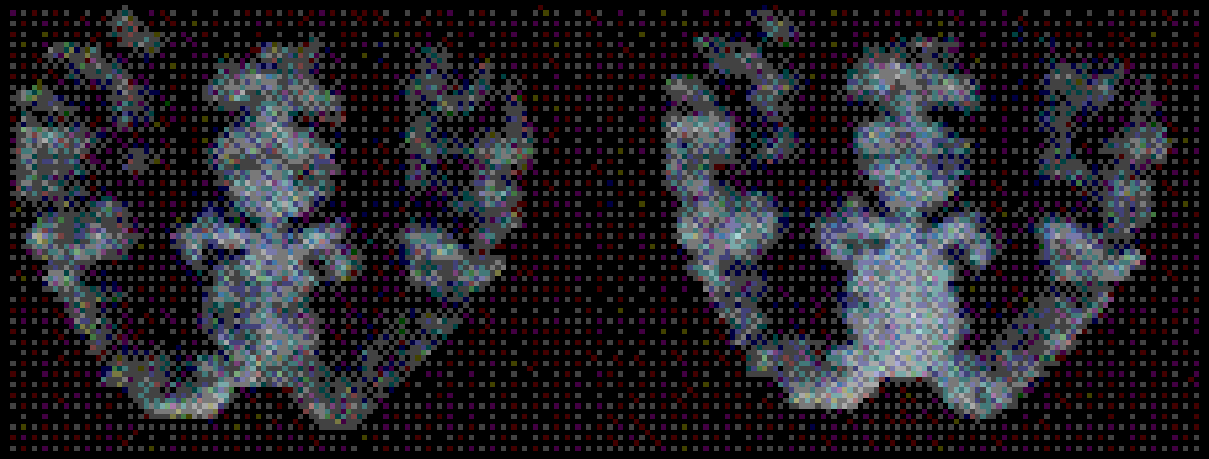
- Blood Volume
- Blood Oxygenation Changes
  - Blood Oxygenation Level Dependent Contrast (BOLD)
- Blood Perfusion

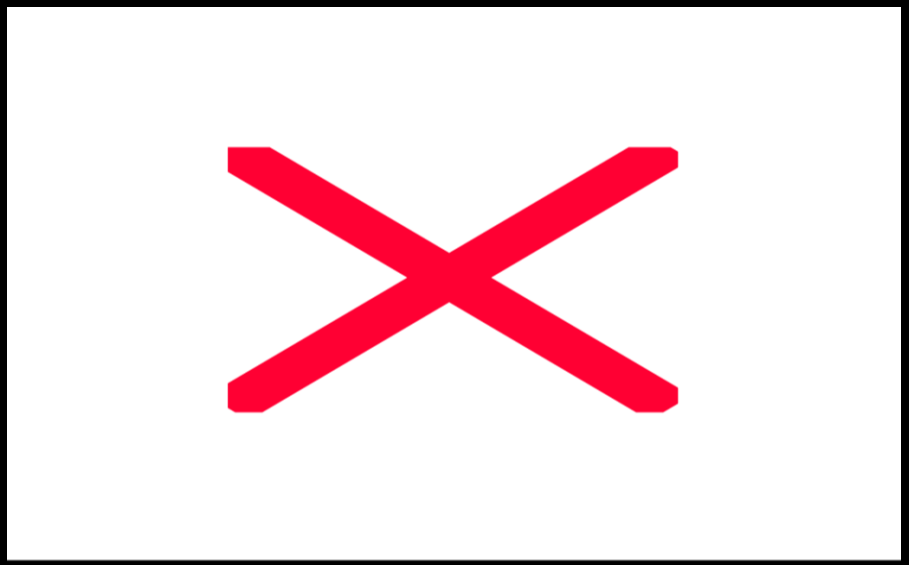


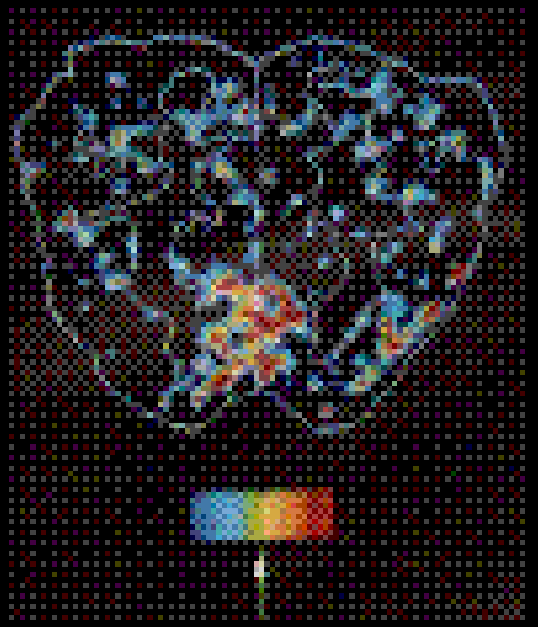

Central sulcus
Supplemental motor cortex
Primary motor cortex
Superior parietal lobule
Frontal eye fields
Premotor cortex
Primary somatosensory cortex
Wernicke's area
Broca's area
Primary trigeminal region of somatosensory cortex
Secondary somatosensory cortex
motor cortex
Primary
Visual association areas of cortex
Multisensory association areas of cortex
Auditory cortex
Primary visual cortex
Lateral fissure

# Blood Volume Changes with Brain Activation

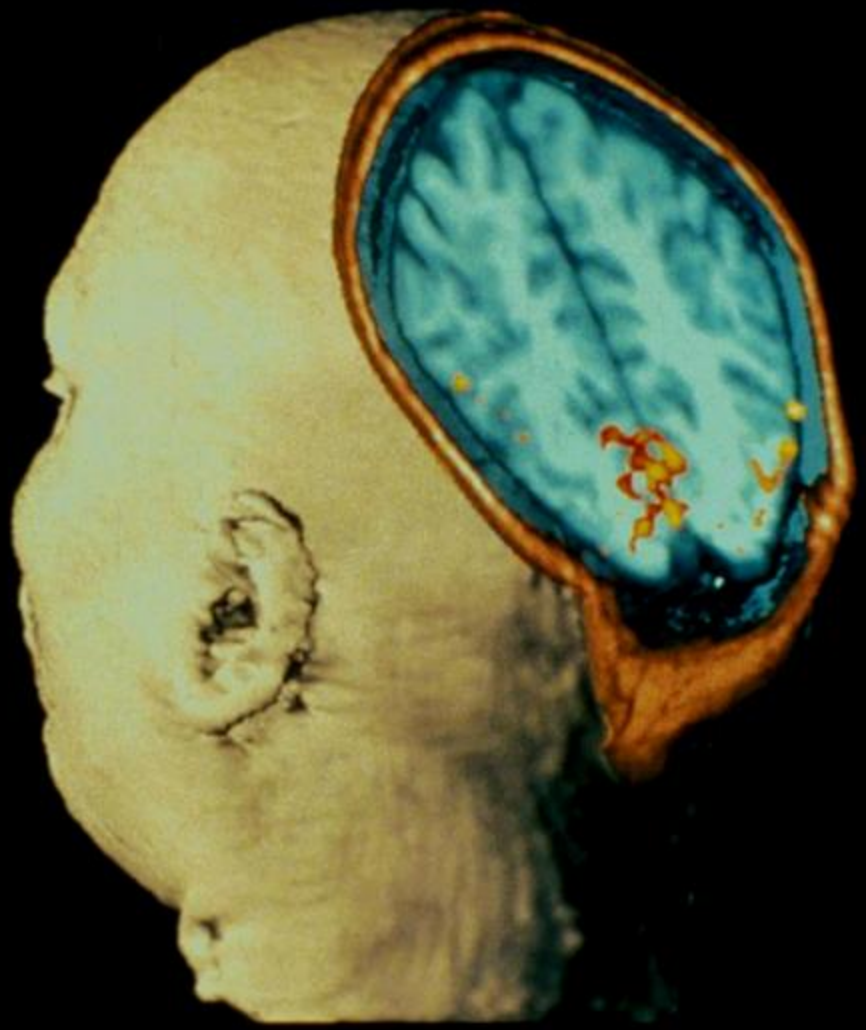
**Resting** **Active**







# Photic Stimulation



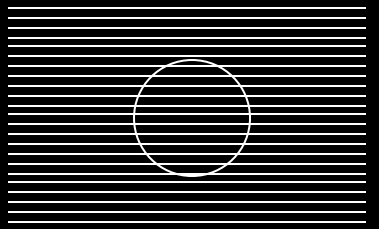
MRI Image showing activation of the Visual Cortex

From Belliveau, et al. Science Nov 1991

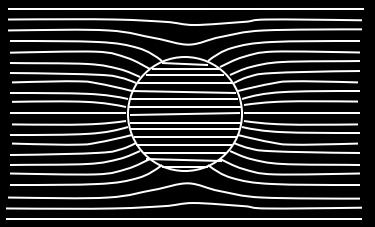
*Oxygenated and deoxygenated red blood cells have different magnetic properties*

red blood cells

oxygenated



deoxygenated




L. Pauling, C. D. Coryell, *Proc.Natl. Acad. Sci. USA 22, 210-216*, **1936**.

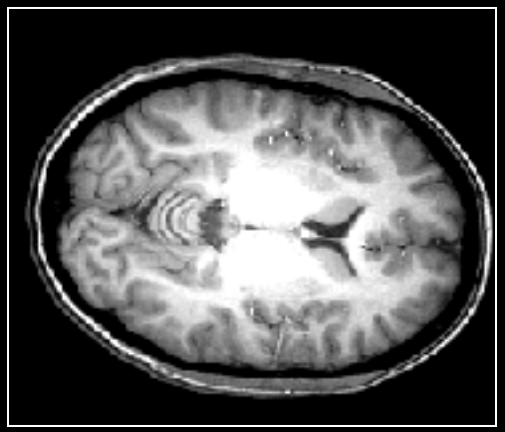
K.R. Thulborn, J. C. Waterton, et al., *Biochim. Biophys. Acta. 714: 265-270*, **1982**.

S. Ogawa, T. M. Lee, A. R. Kay, D. W. Tank, *Proc. Natl. Acad. Sci. USA 87, 9868-9872*, **1990**.

# MRI vs. fMRI

MRI

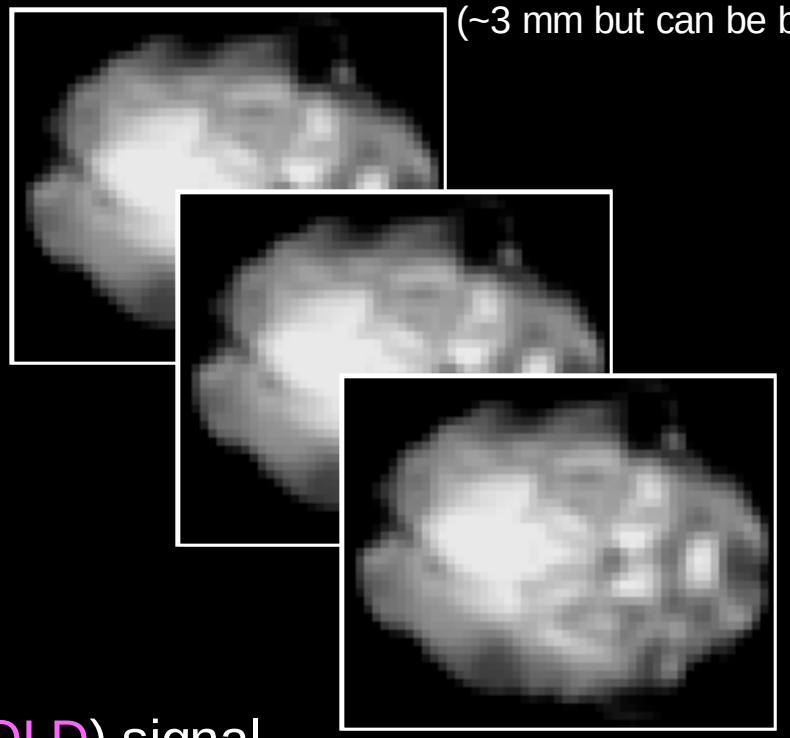
high resolution
(1 mm)



one image

fMRI

low resolution
(~3 mm but can be better)



…

many images
(e.g., every 2 sec for 5 mins)

fMRI

Blood Oxygenation Level Dependent (BOLD) signal
indirect measure of neural activity

↑ neural activity ➔ ↑ blood oxygen ➔ ↑ fMRI signal

**Courtesy, Robert Cox, Scientific and Statistical Computing Core Facility, NIMH**

# BOLD

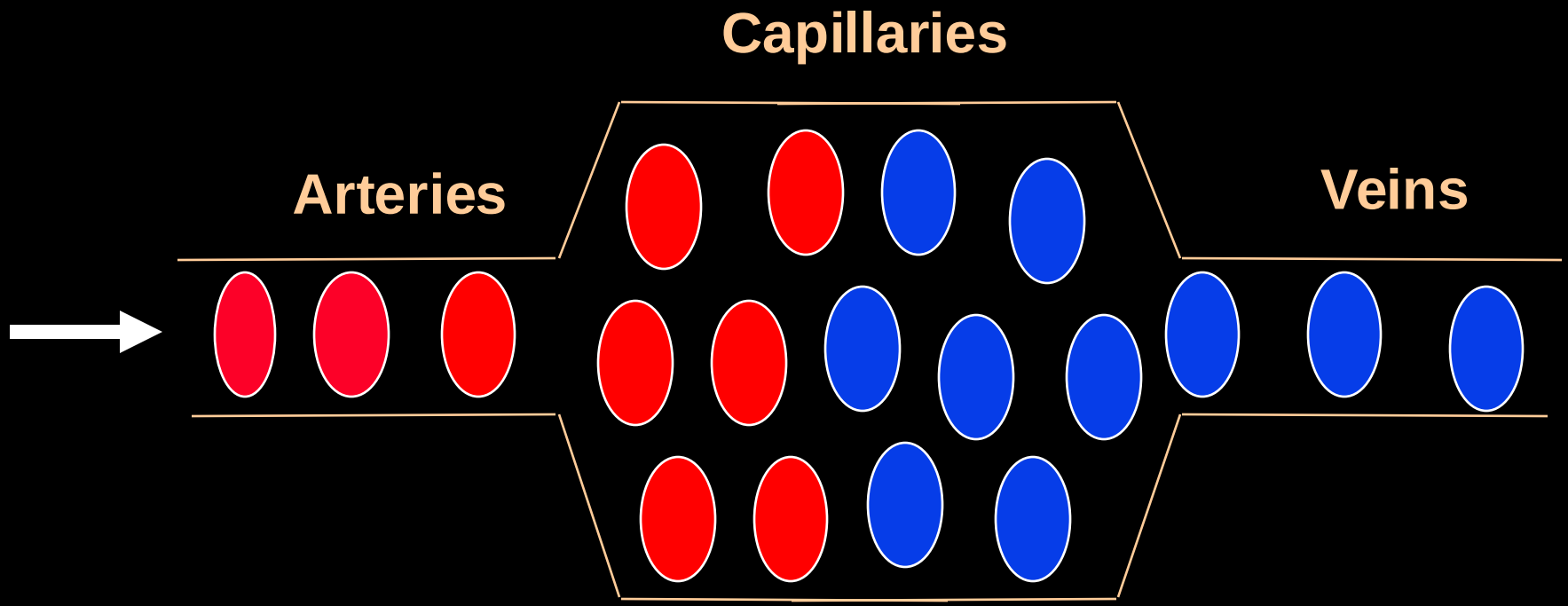
(blood oxygenation level dependence)

**blood flow** 

**oxygenated-blood** 

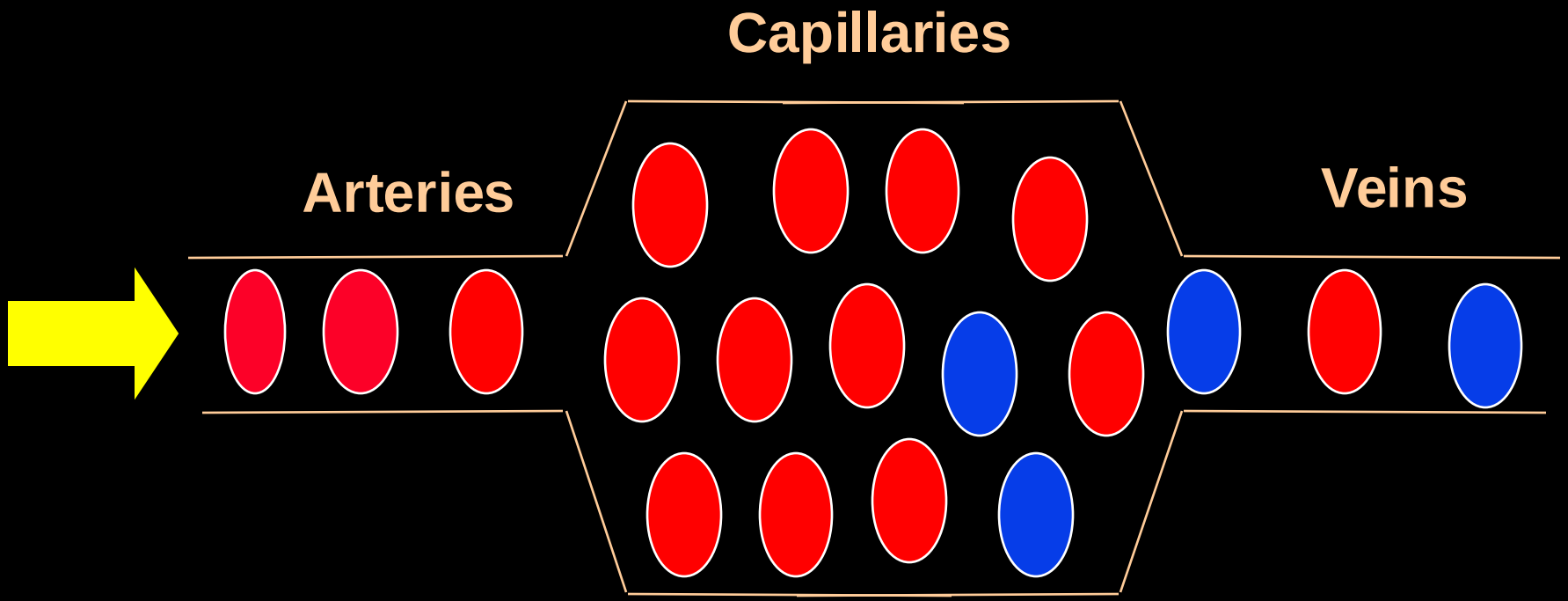
**MR signal** 

# BOLD: Resting flow

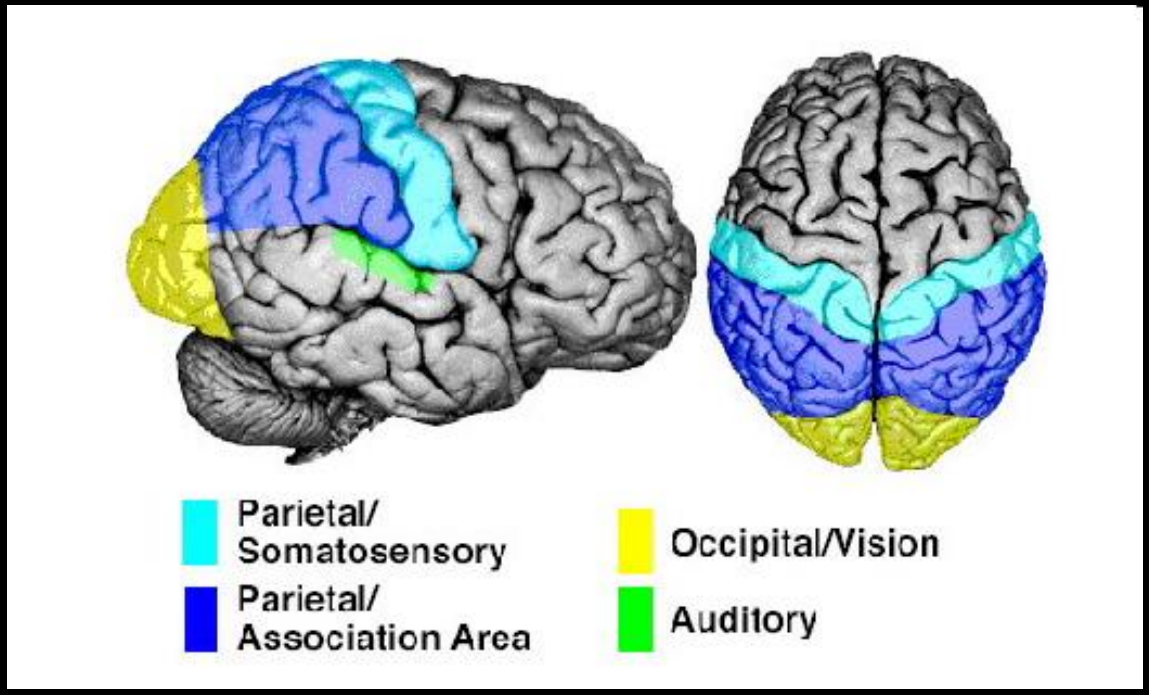


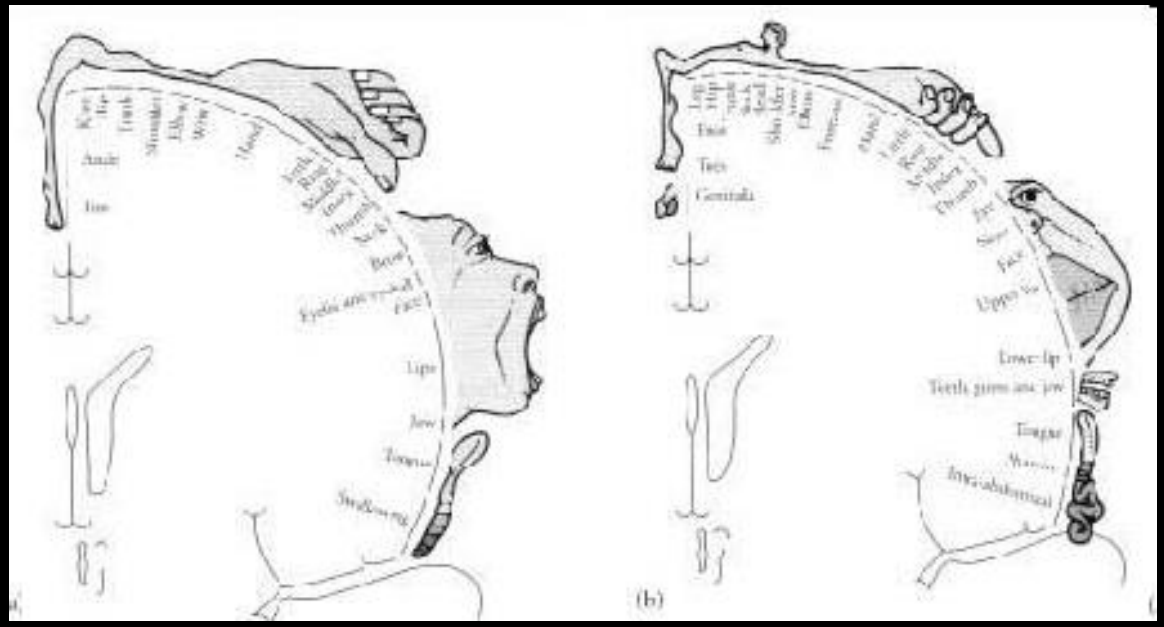

SIGNAL

# BOLD: Activated flow




**SIGNAL**


Parietal/
Somatosensory
Parietal/
Association Area
Occipital/Vision
Auditory


(b)

# Alternating Left and Right Finger Tapping

~ 1992

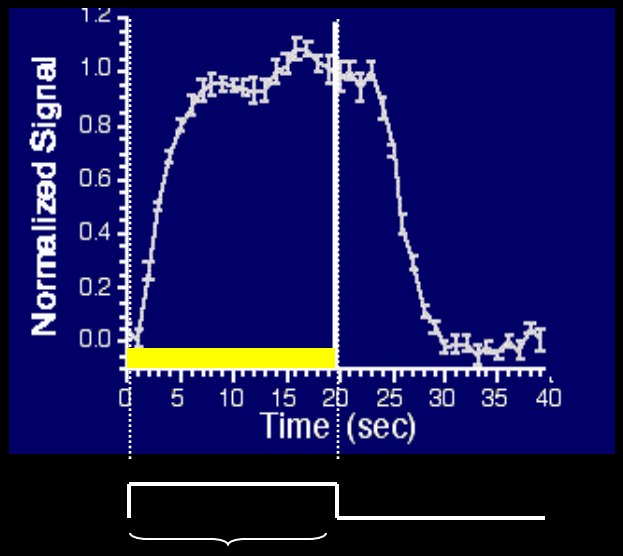
# Real Time Brain Activation Imaging

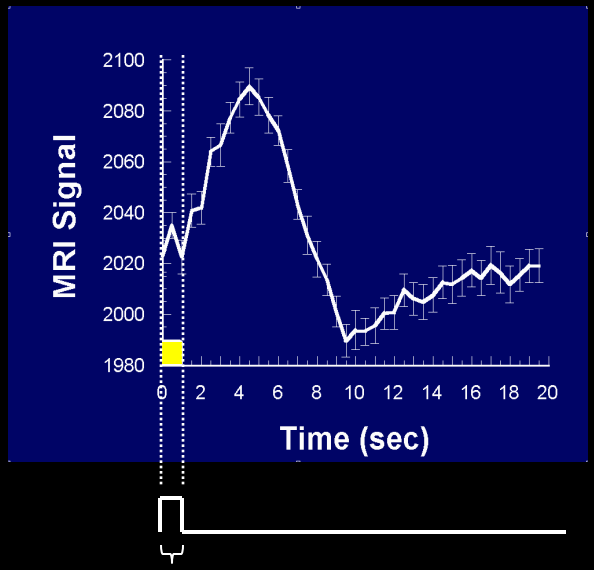

•K. K. Kwong, et al, (1992) "Dynamic magnetic resonance imaging of human brain activity during primary sensory stimulation." Proc. Natl. Acad. Sci. USA. 89, 5675-5679.

•S. Ogawa, et al., (1992) "Intrinsic signal changes accompanying sensory stimulation: functional brain mapping with magnetic resonance imaging. Proc. Natl. Acad. Sci. USA." 89, 5951-5955.

•P. A. Bandettini, et al., (1992) "Time course EPI of human brain function during task activation." Magn. Reson. Med 25, 390-397.

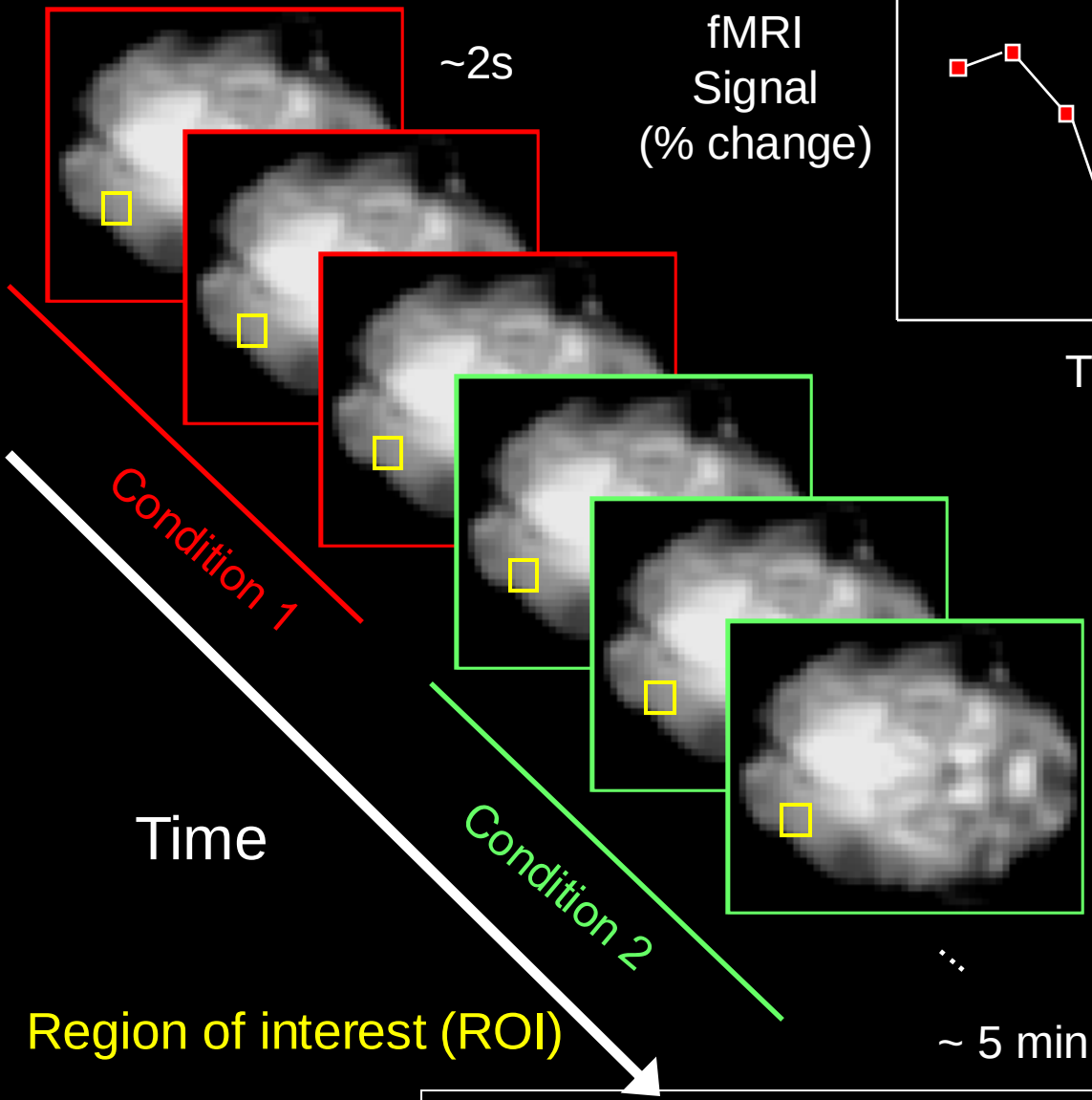
•Blamire, A. M., et al. (1992). "Dynamic mapping of the human visual cortex by high-speed magnetic resonance imaging." Proc. Natl. Acad. Sci. USA 89: 11069-11073.

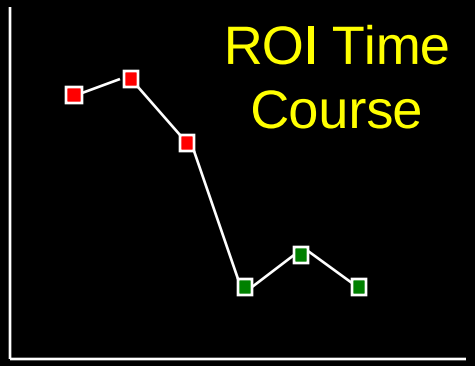



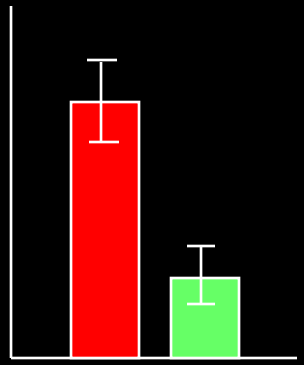
# Activation Statistics

Functional images

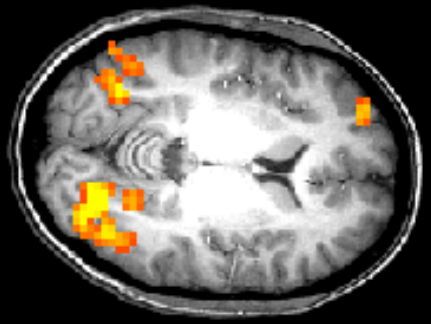



fMRI Signal (% change)

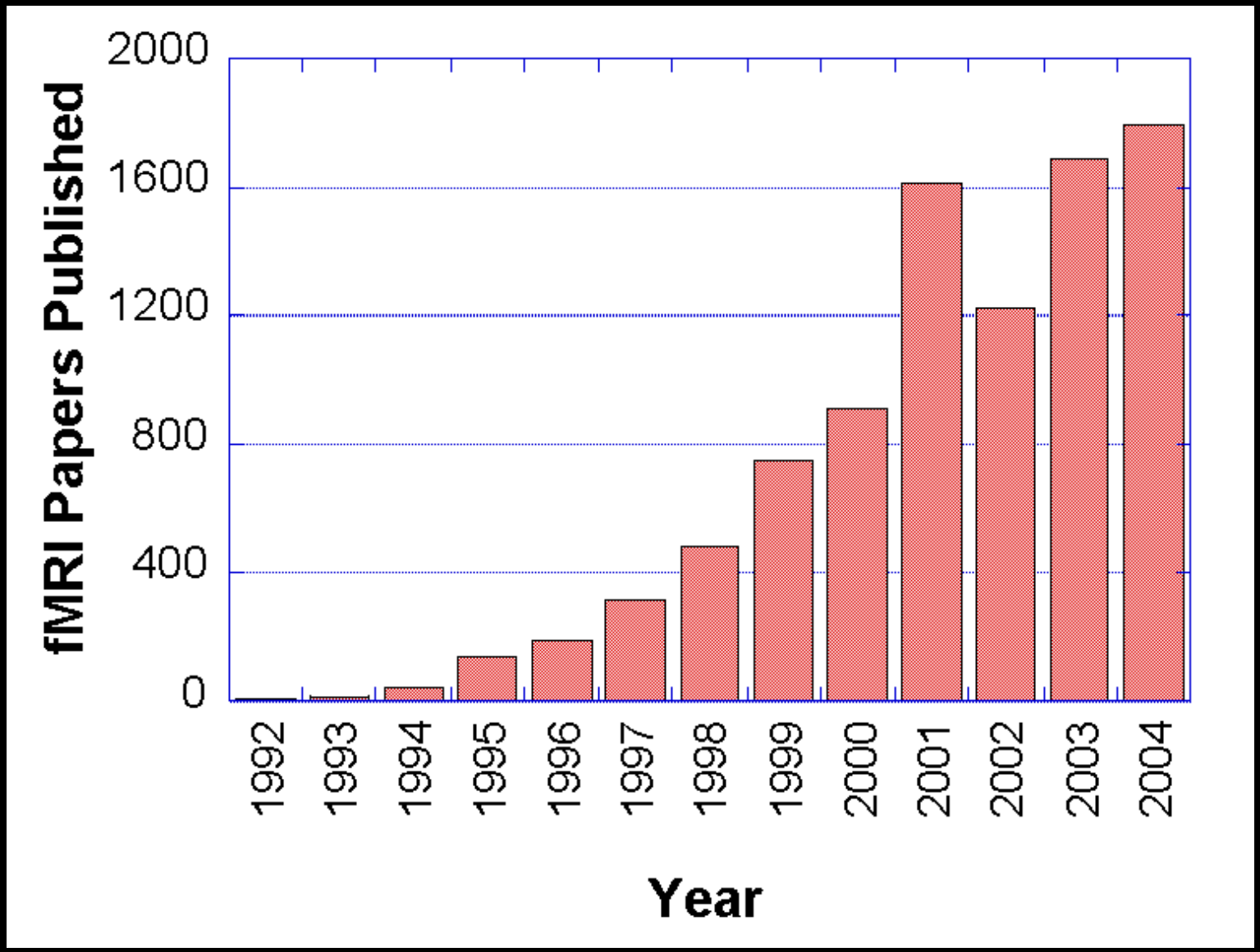


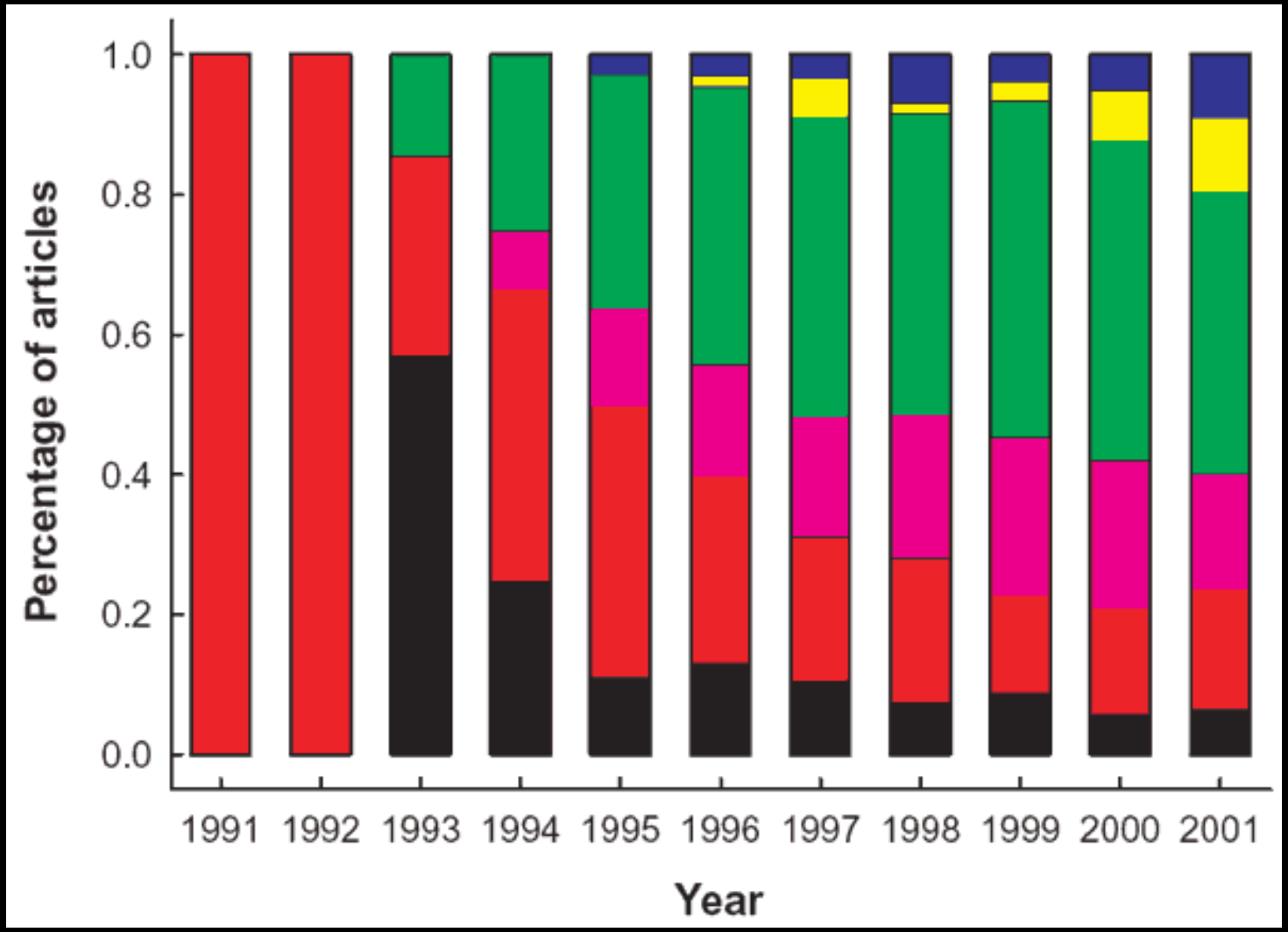




Statistical Map
superimposed on anatomical MRI image



Courtesy, Robert Cox, Scientific and Statistical Computing Core Facility, NIMH


fMRI Papers Published
2000
1600
1200
800
400
0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Year




Motor (black)
Primary Sensory (red)
Integrative Sensory (violet)
Basic Cognition (green)
High-Order Cognition (yellow)
Emotion (blue)

J. Illes, M. P. Kirschen, J. D. E. Gabrielli, Nature Neuroscience, 6 (3)m p.205

## Current Uses of fMRI

Understanding normal brain organization and changes

- -networks involved with specific tasks (low to high level processing)
- -changes over time (seconds to years)
- -correlates of behavior (response accuracy, performance changes…)

Clinical research

- -correlates of specifically activated networks to clinical populations
- -presurgical mapping
- -epileptic foci mapping
- -drug effects

## Potential uses of fMRI

*Complementary* use for clinical diagnosis

- -utilization of clinical research results

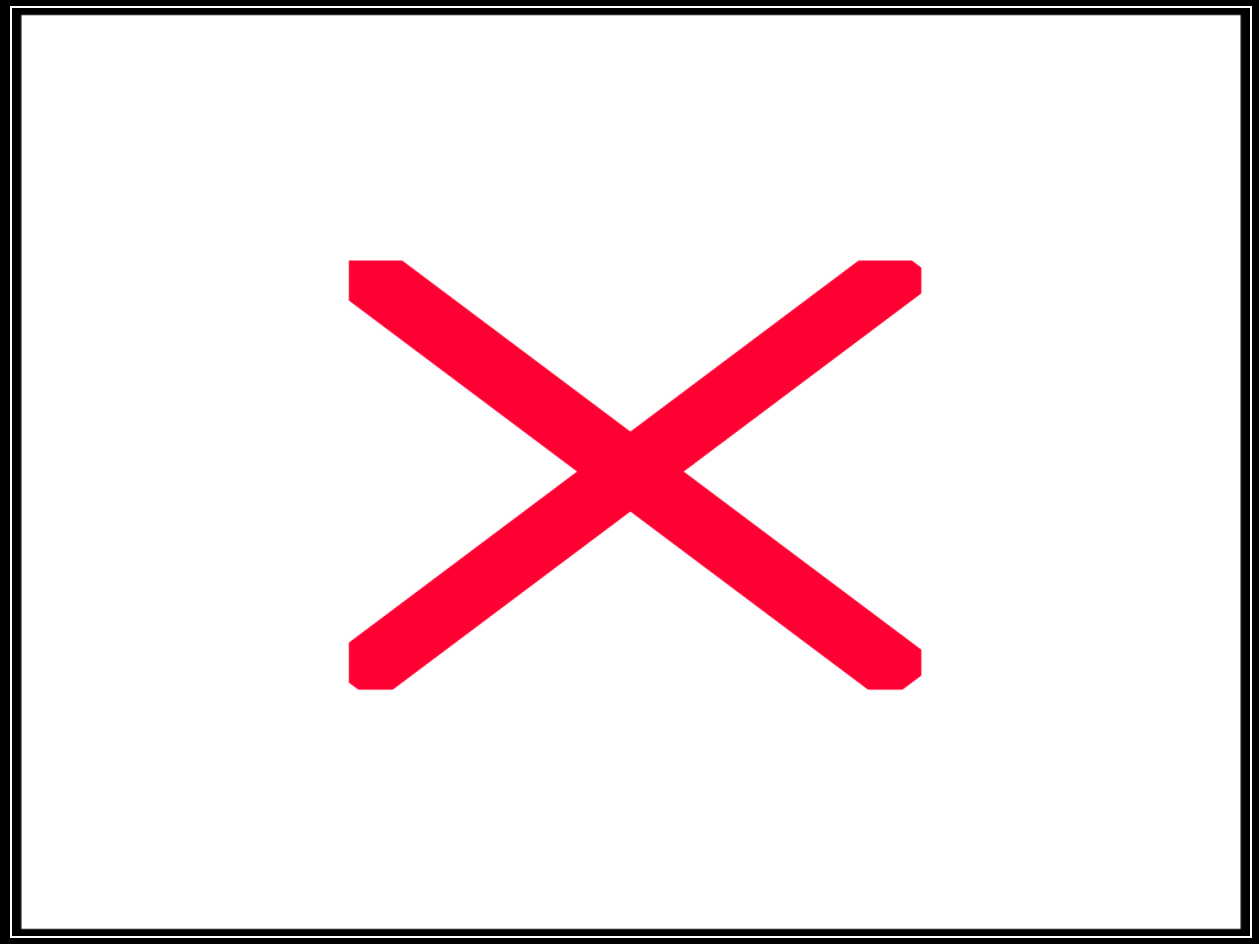
Clinical treatment and assessment

- -drug, therapy, rehabilitation, biofeedback

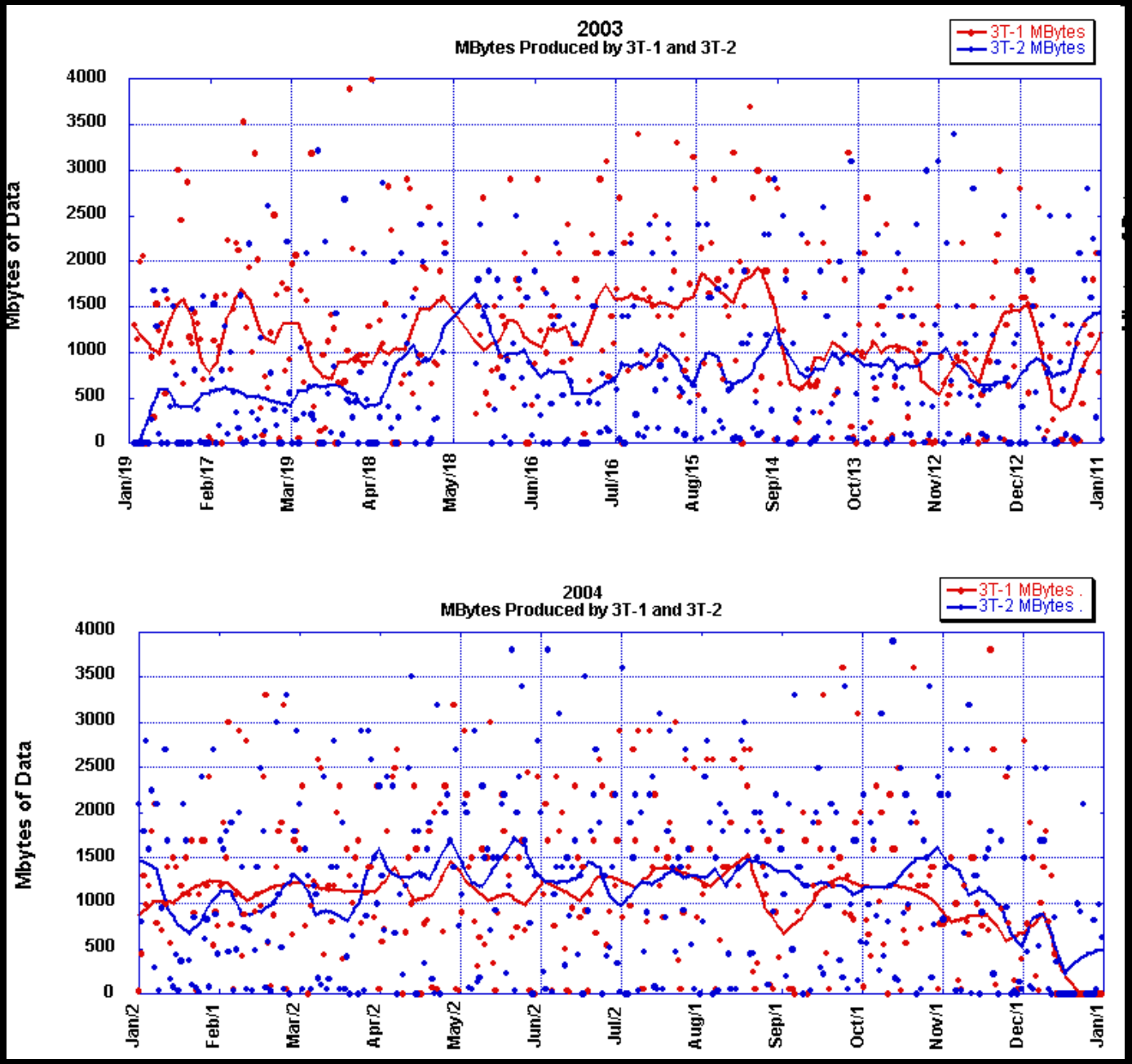
Non clinical uses

- -complementary use with behavioral results
- -lie detection
- -prediction of behavior tendencies (many contexts)
- -brain/computer interface

# A typical day in the fMRI scan room…



1.5 Gbytes/Day
max: 5.4 Gbytes


2003
MBytes Produced by 3T-1 and 3T-2
3T-1 MBytes
3T-2 MBytes
Mbytes of Data
4000
3500
3000
2500
2000
1500
1000
500
0
Jan/19
Feb/17
Mar/19
Apr/18
May/18
Jun/16
Jul/16
Aug/15
Sep/14
Oct/13
Nov/12
Dec/12
Jan/11
2004
MBytes Produced by 3T-1 and 3T-2
3T-1 MBytes .
3T-2 MBytes .
Mbytes of Data
4000
3500
3000
2500
2000
1500
1000
500
0
Jan/2
Feb/1
Mar/2
Apr/2
May/2
Jun/2
Jul/2
Aug/1
Sep/1
Oct/1
Nov/1
Dec/1
Jan/1

# What my group cares about…

Understanding, Developing, and Implementing Functional MRI

1. Methodology
2. Interpretation
3. Technology
4. Applications

Neuronal Activation

?

Measured Signal

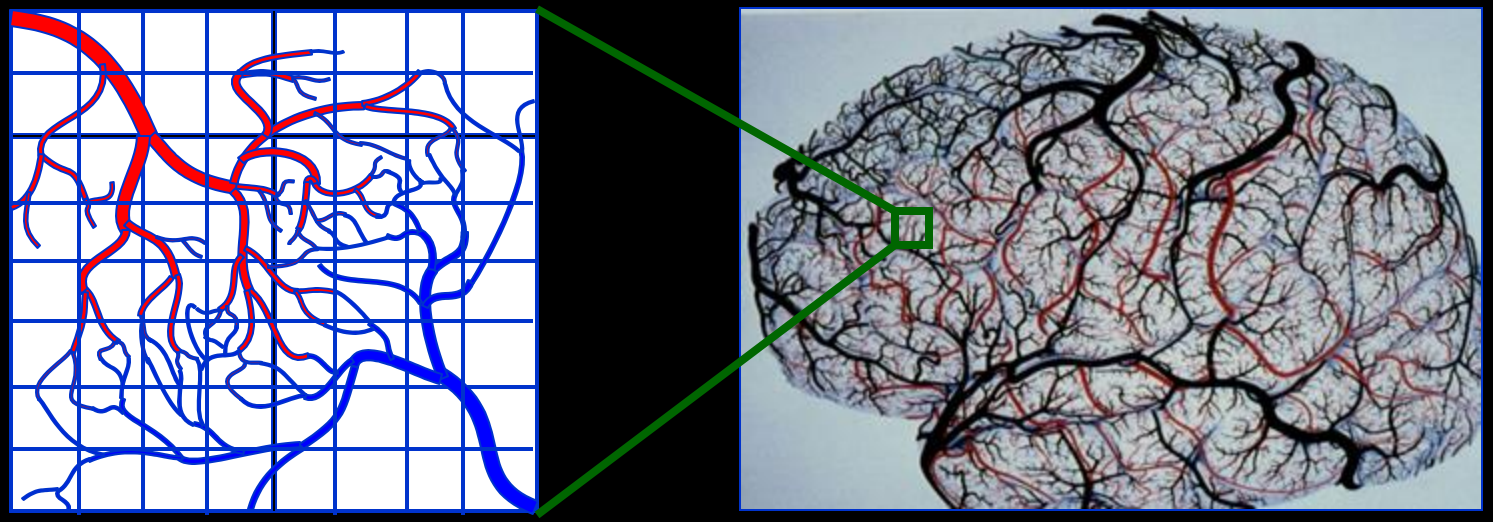
?

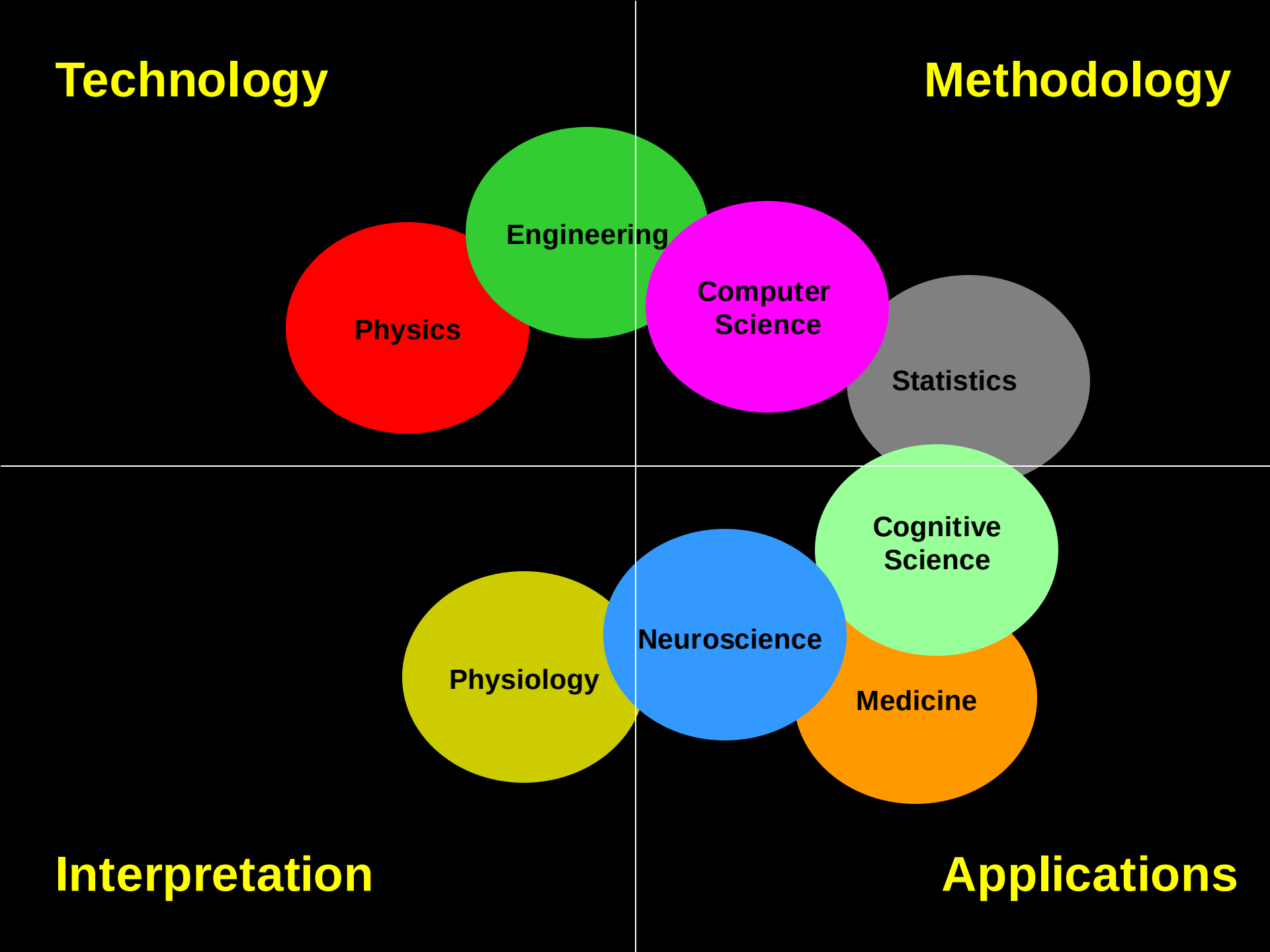
?

Hemodynamics

?

Noise




Technology
Methodology
Engineering
Physics
Computer Science
Statistics
Cognitive Science
Neuroscience
Physiology
Medicine
Interpretation
Applications

# My Group at the NIH

*Section on Functional Imaging Methods*

Peter Bandettini (Physics/Physiology/Neuroscience)

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David Knight (Neuroscience)
Anthony Boemio (Physics/Neuroscience)

Niko Kriegeskorte (Psychology/Statistics)

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Najah Waters (Psychology)
Douglass Ruff (Psychology)
David Ruff (Neuroscience)
Marieke Mur (Neuroscience)

*FMRI Core Facility*

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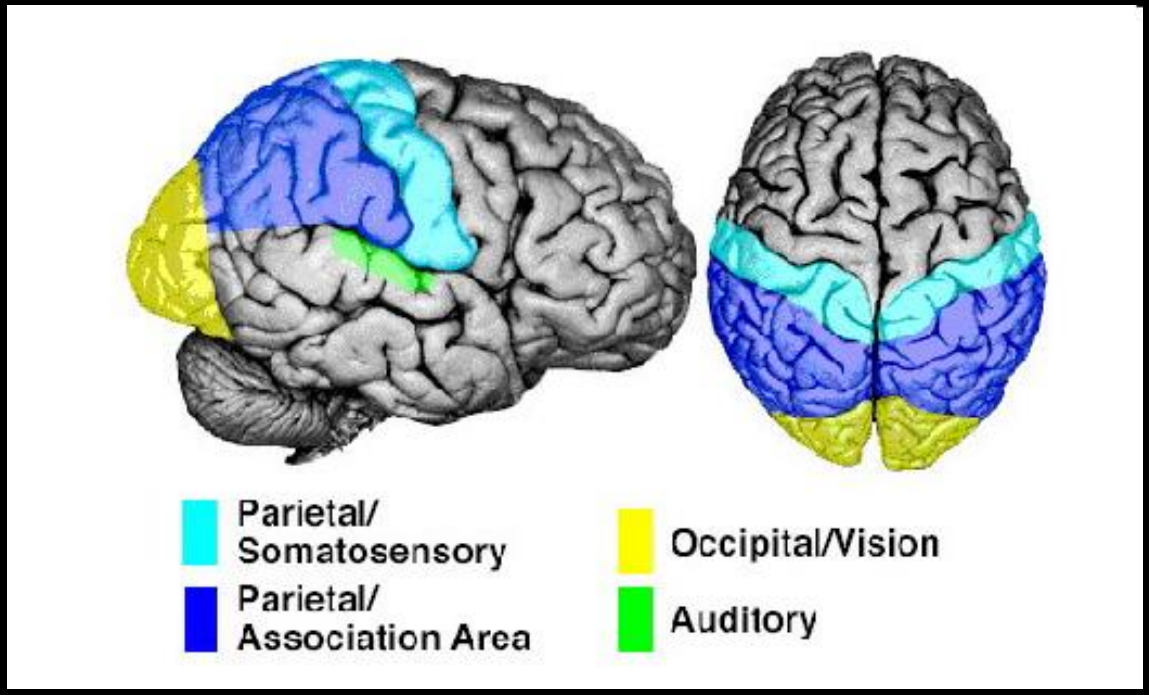
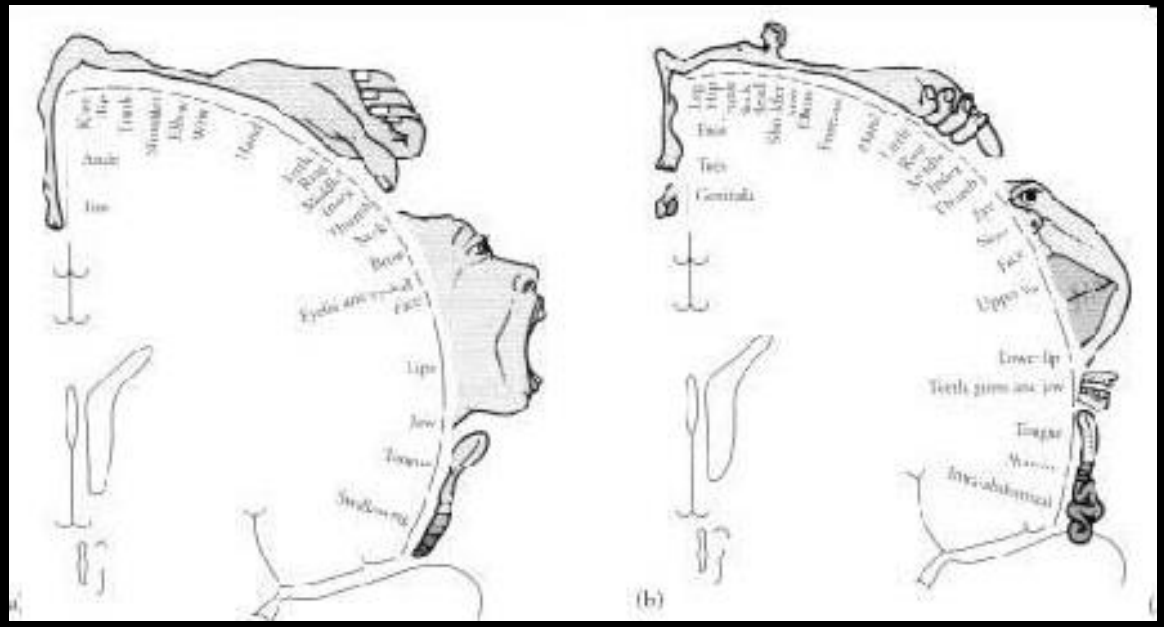
Frank Ye (Physics)
Wen-Ming Luh (Physics)

Adam Thomas (Computers/Neurosci)
Karen Bove-Bettis (MR Tech)
Paula Rowser (MR Tech)
Alda Ottley (MR Tech)
Ellen Condon (MR Tech)

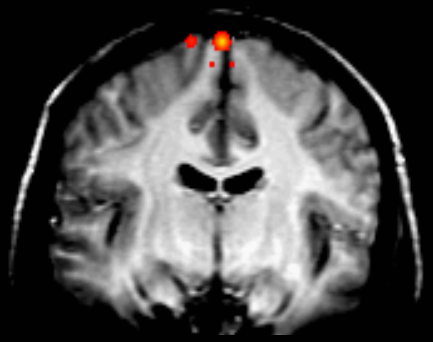

Parietal/
Somatosensory
Parietal/
Association Area
Occipital/Vision
Auditory

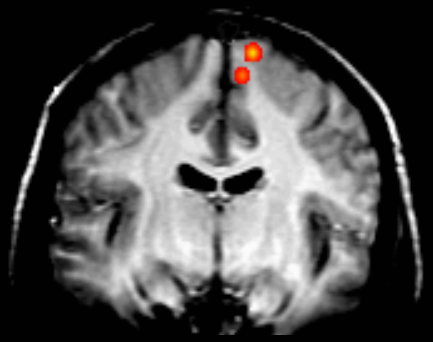

(b)

Left

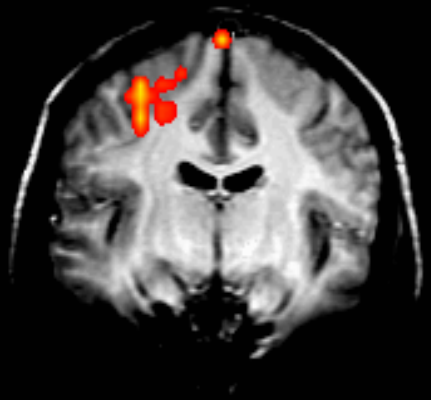
Right

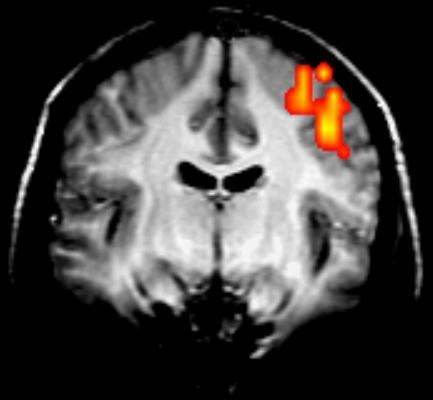
Toe movement



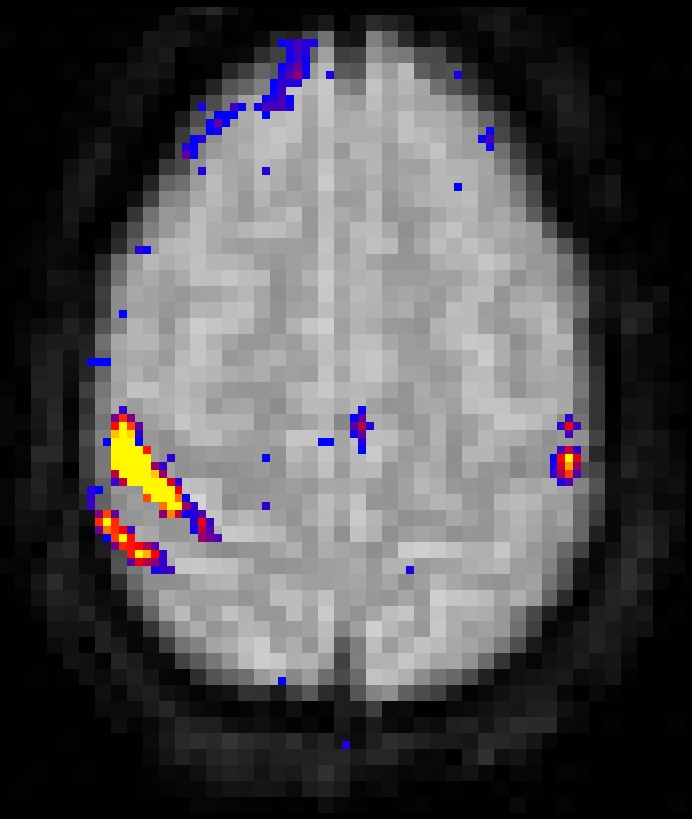


Finger movement

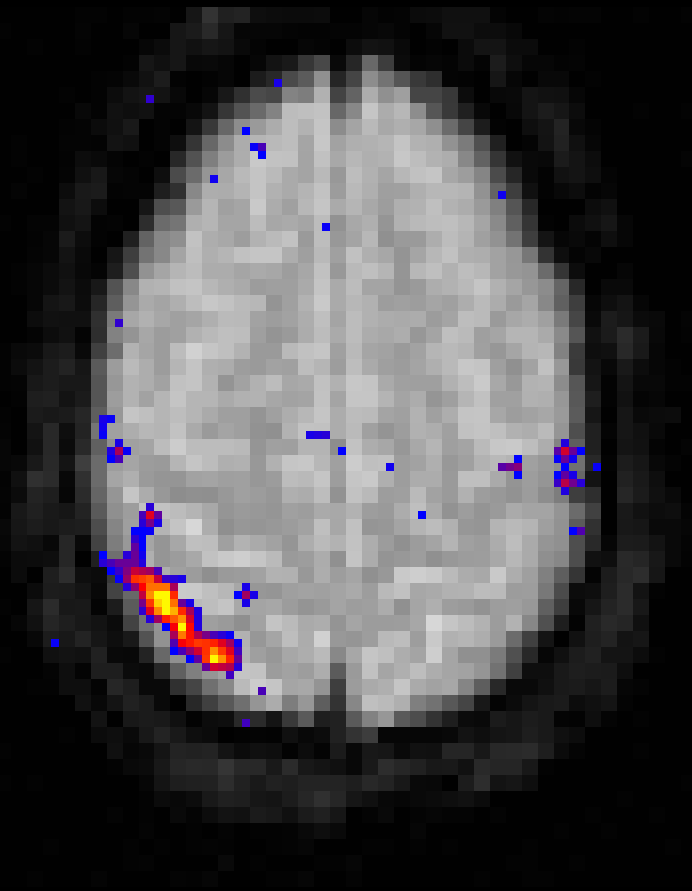


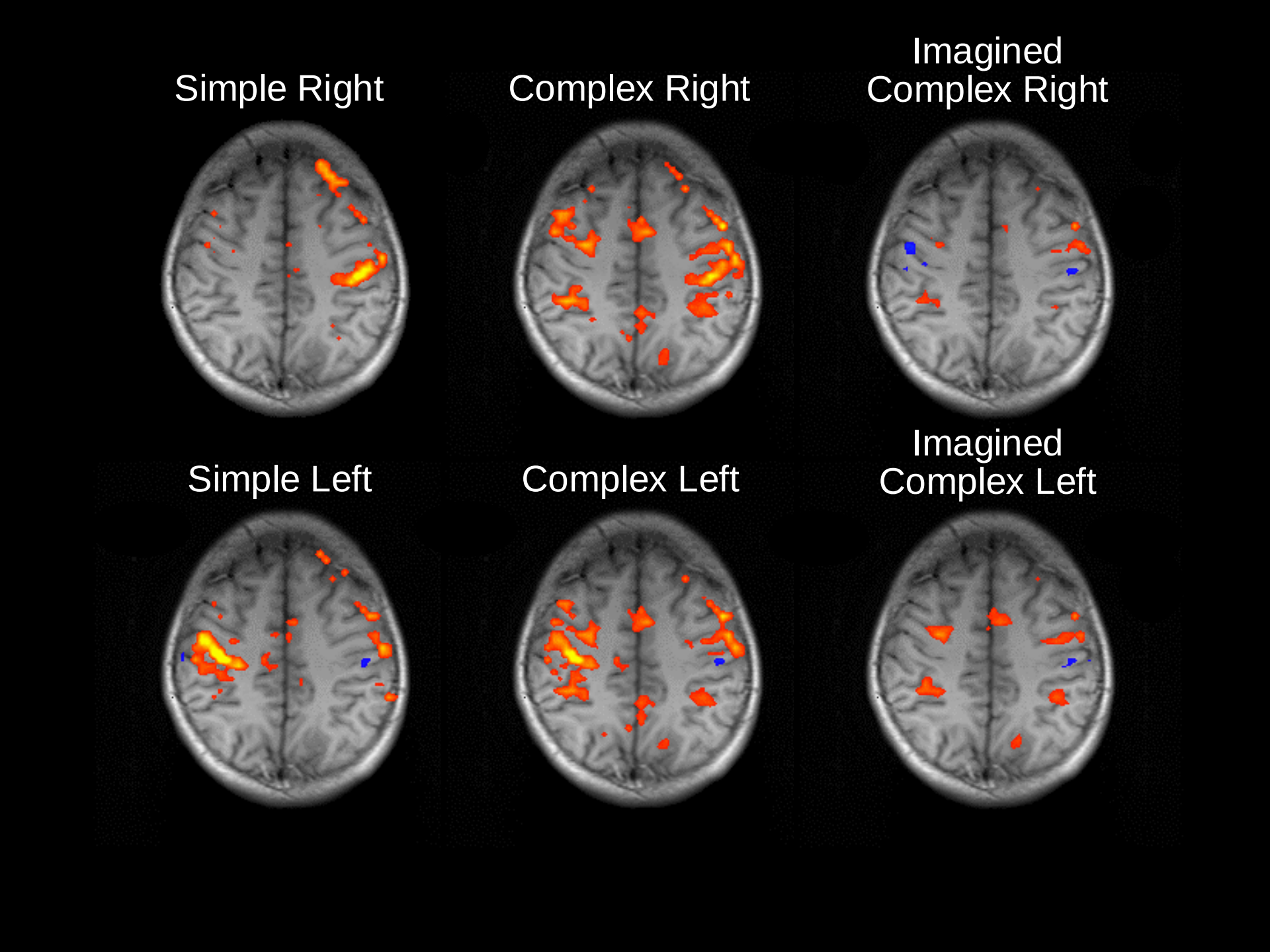


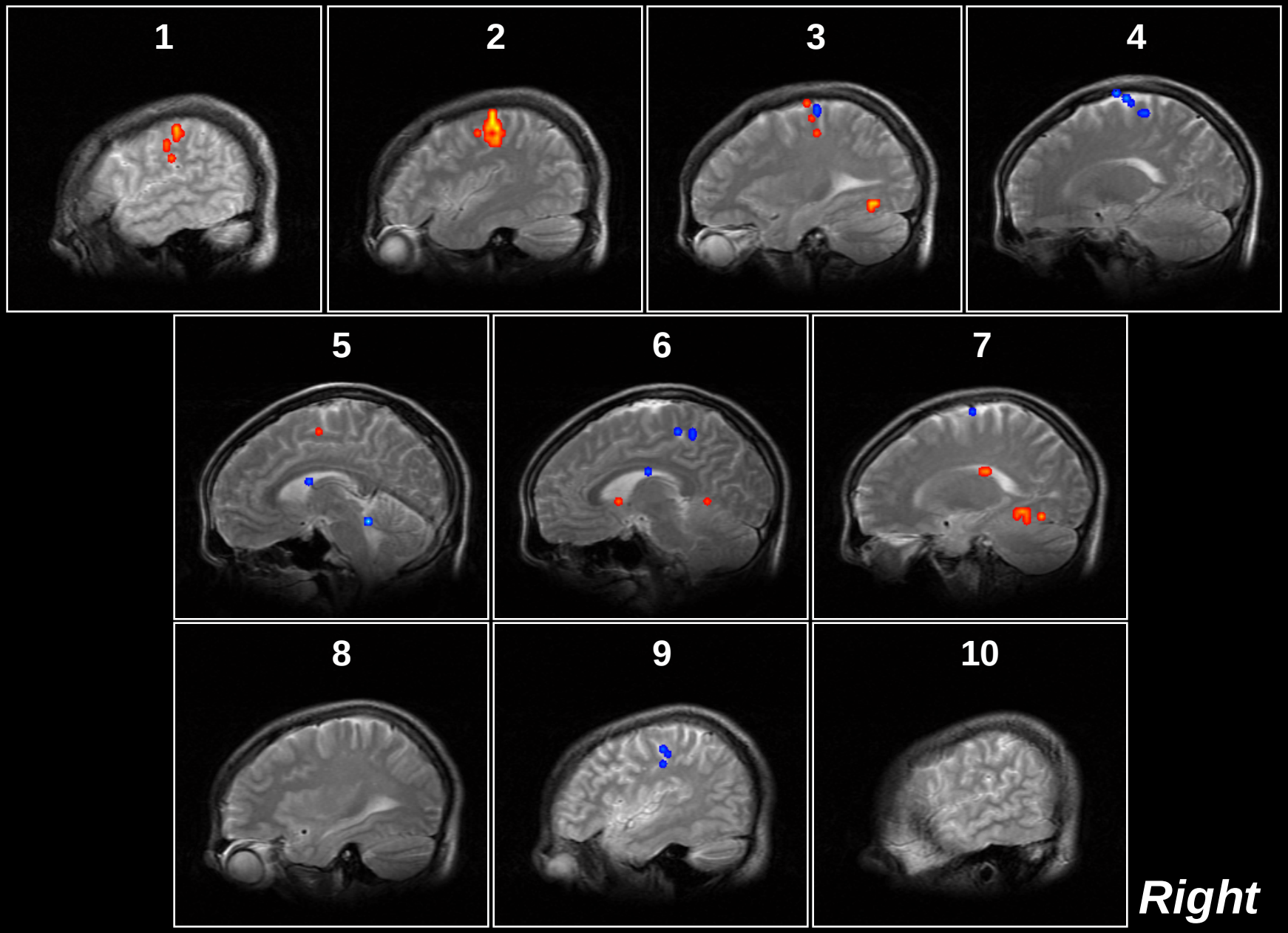
Finger Movement

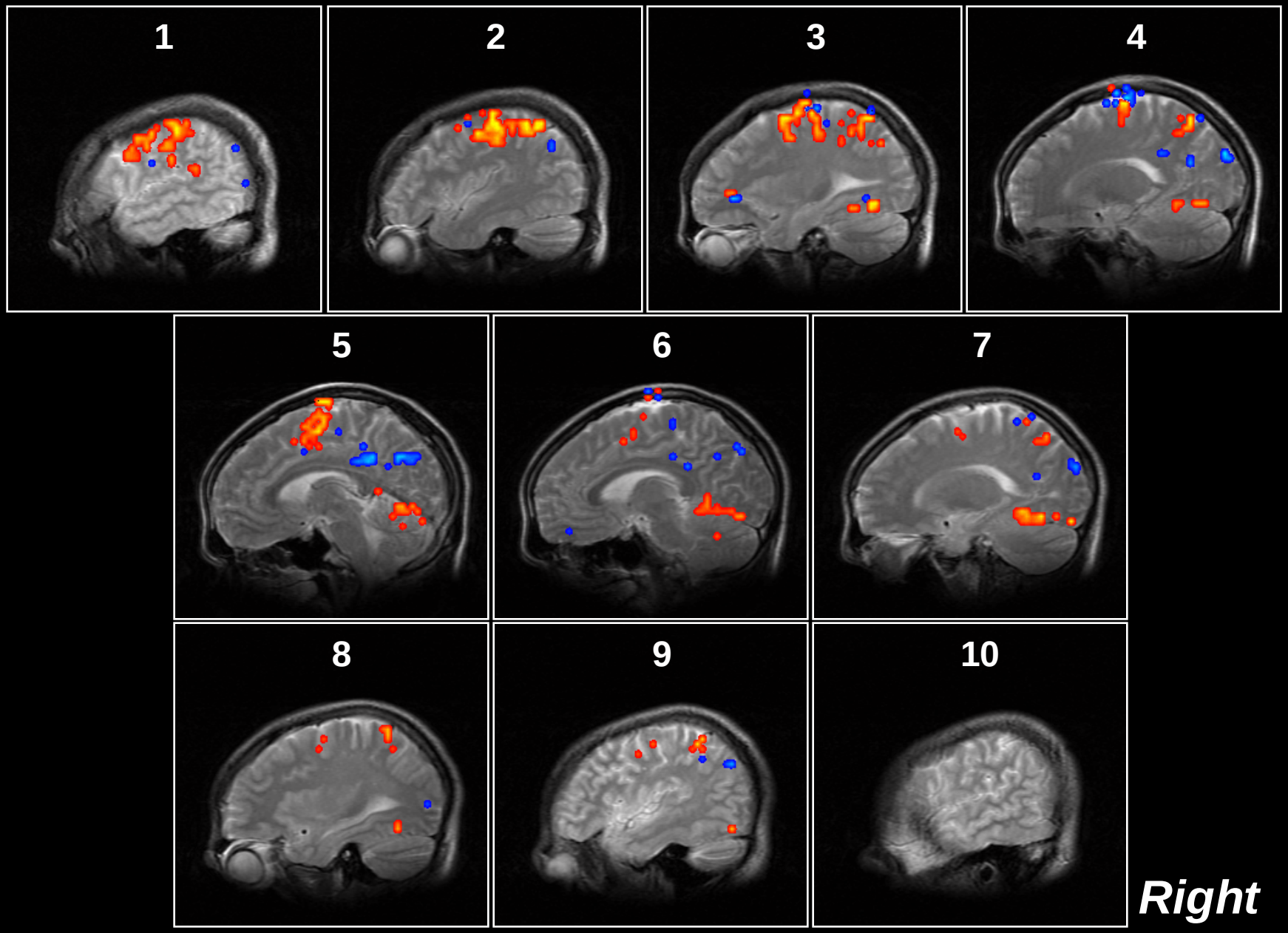


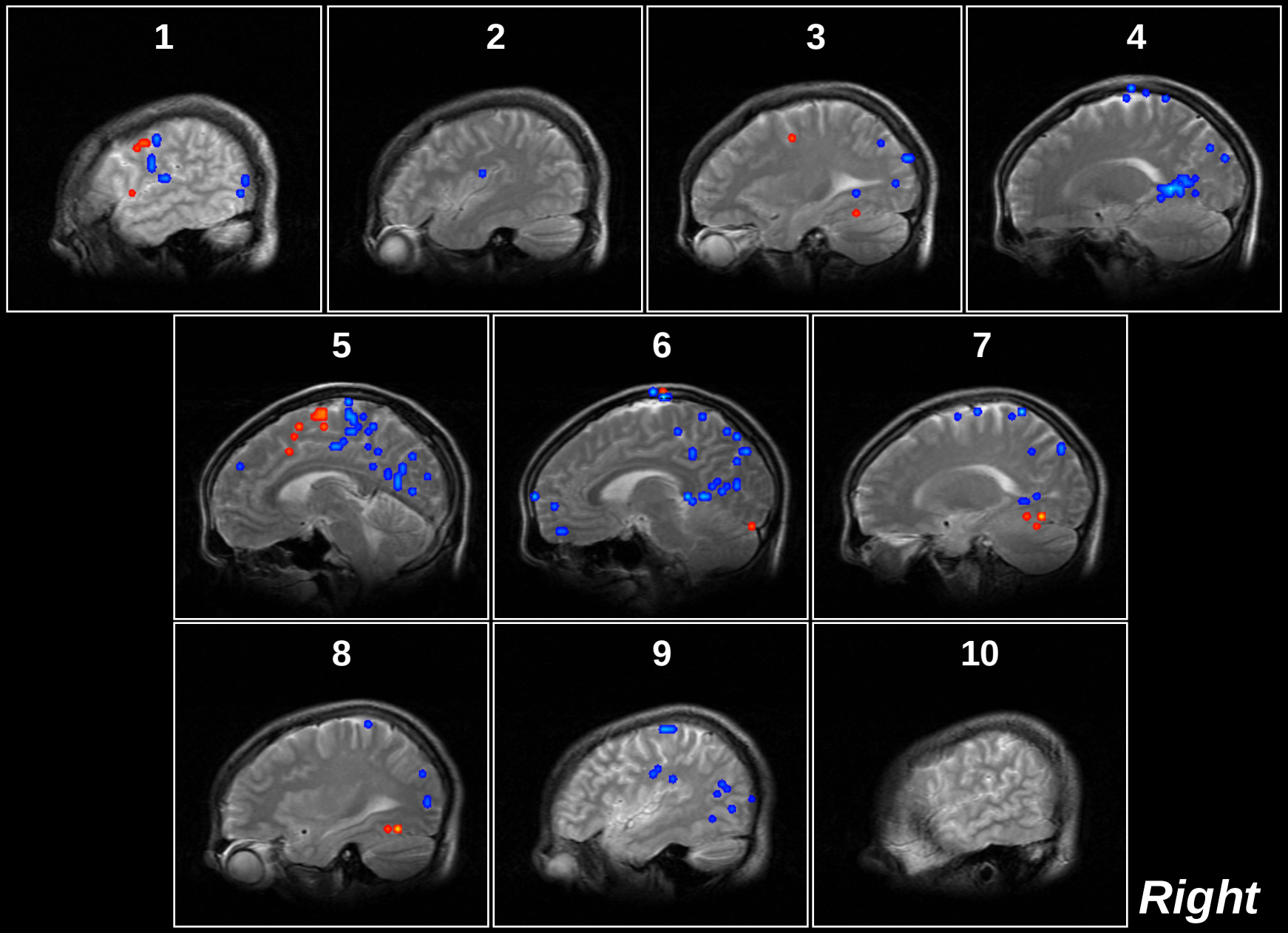
Tactile Stimulation




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

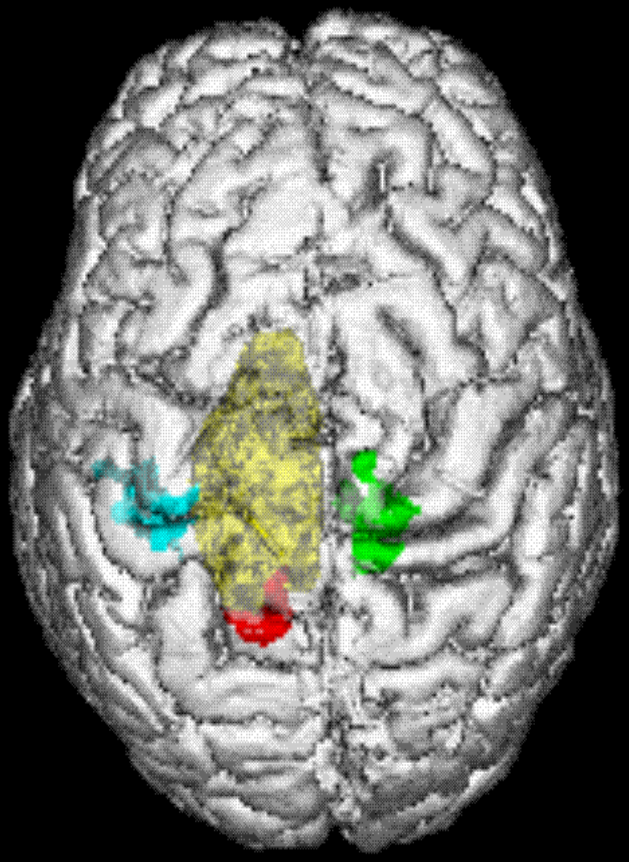

Left
Simple Finger Movement on the RIght Hand
1
2
3
4
5
6
7
8
9
10
Right

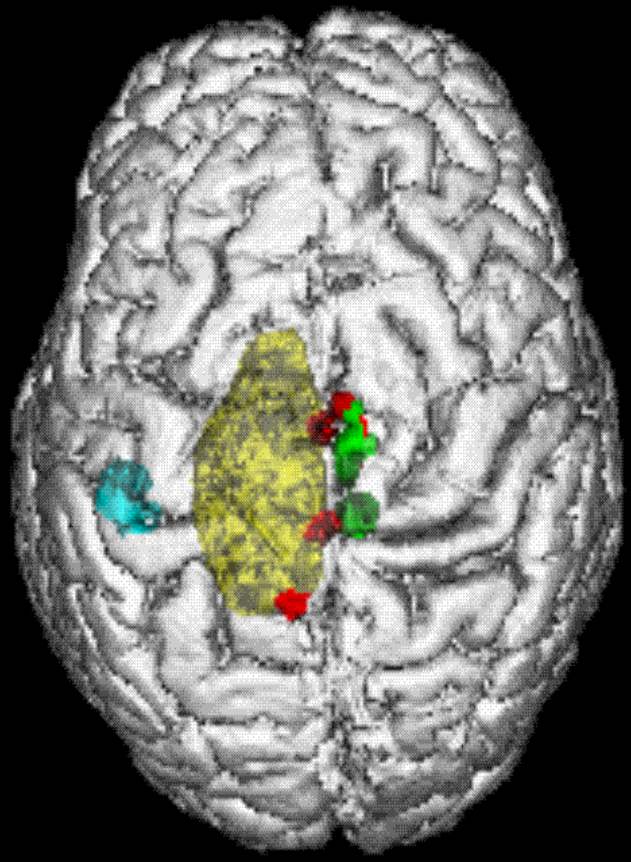

Left
Complex Finger Movement on the Right Hand
1
2
3
4
5
6
7
8
9
10
Right


Left
Imagined Complex Finger Movement on the Right Hand
1
2
3
4
5
6
7
8
9
10
Right

# Presurgical Mapping

Left Foot Tumor Right Foot Right Hand

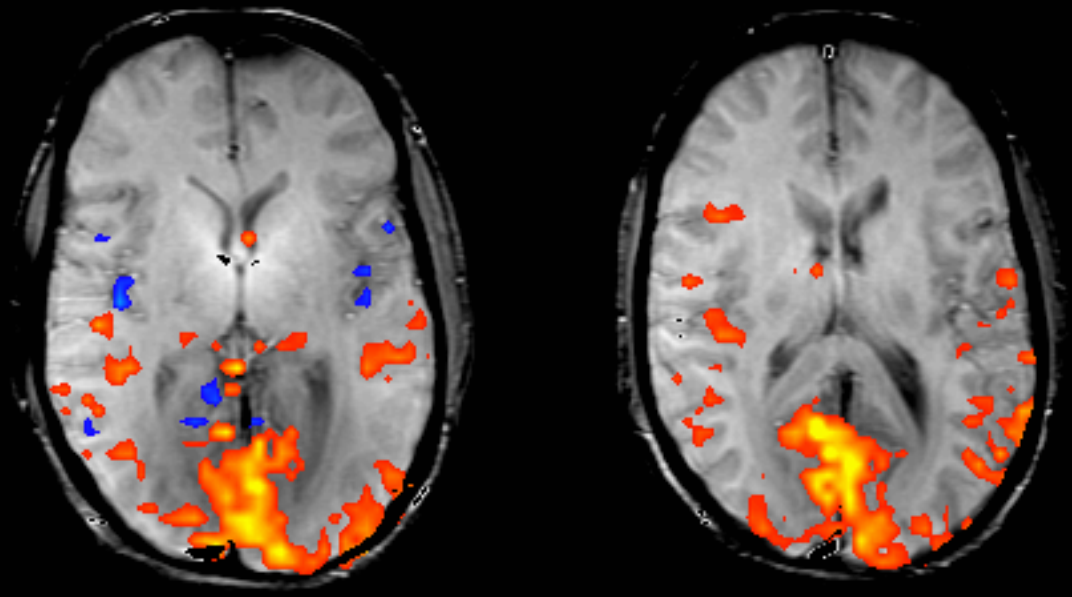




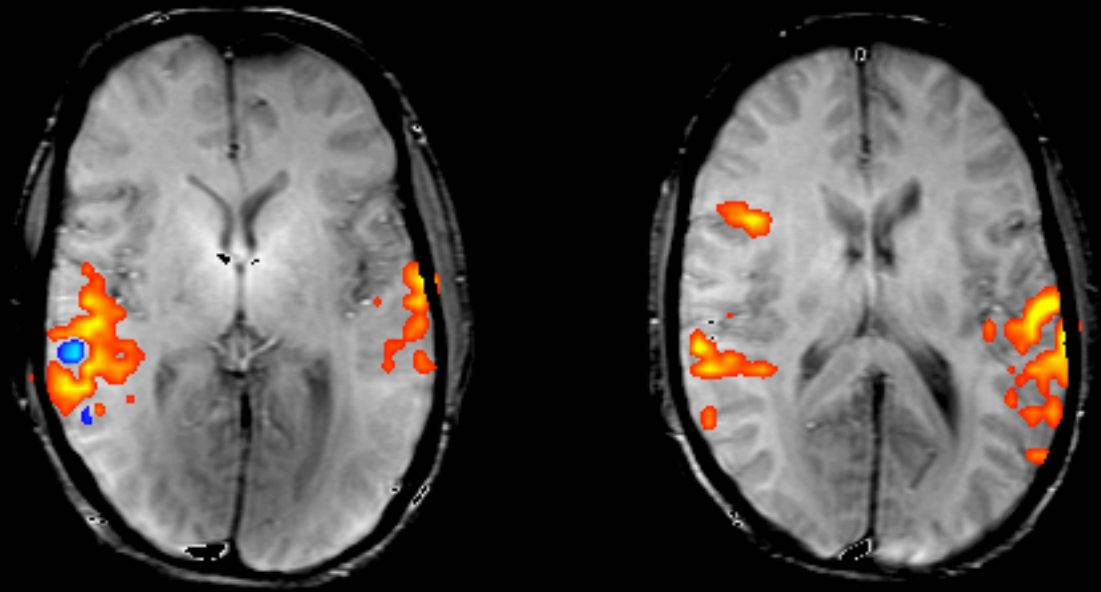
fMRI

O-15 PET

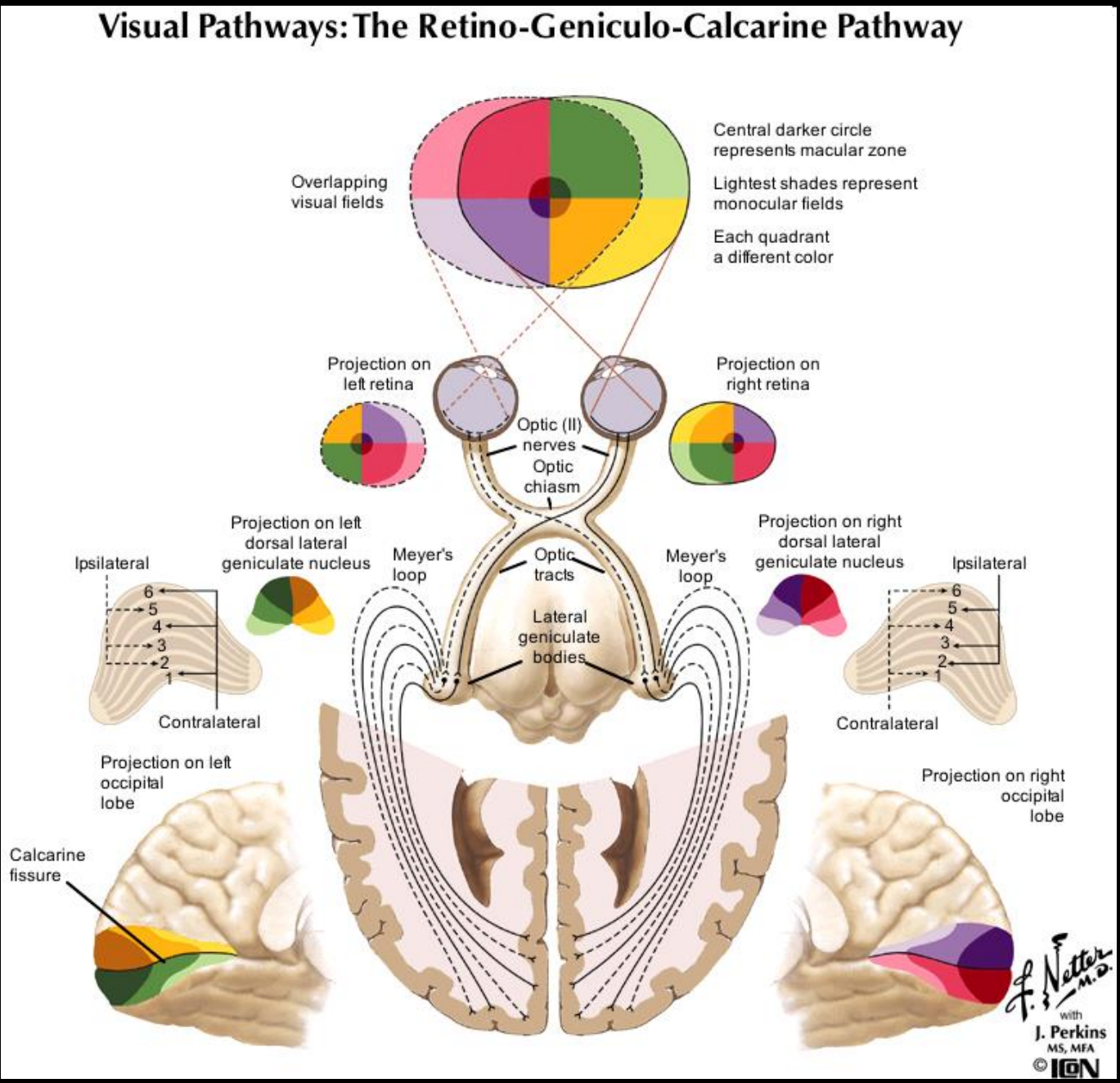
Reading

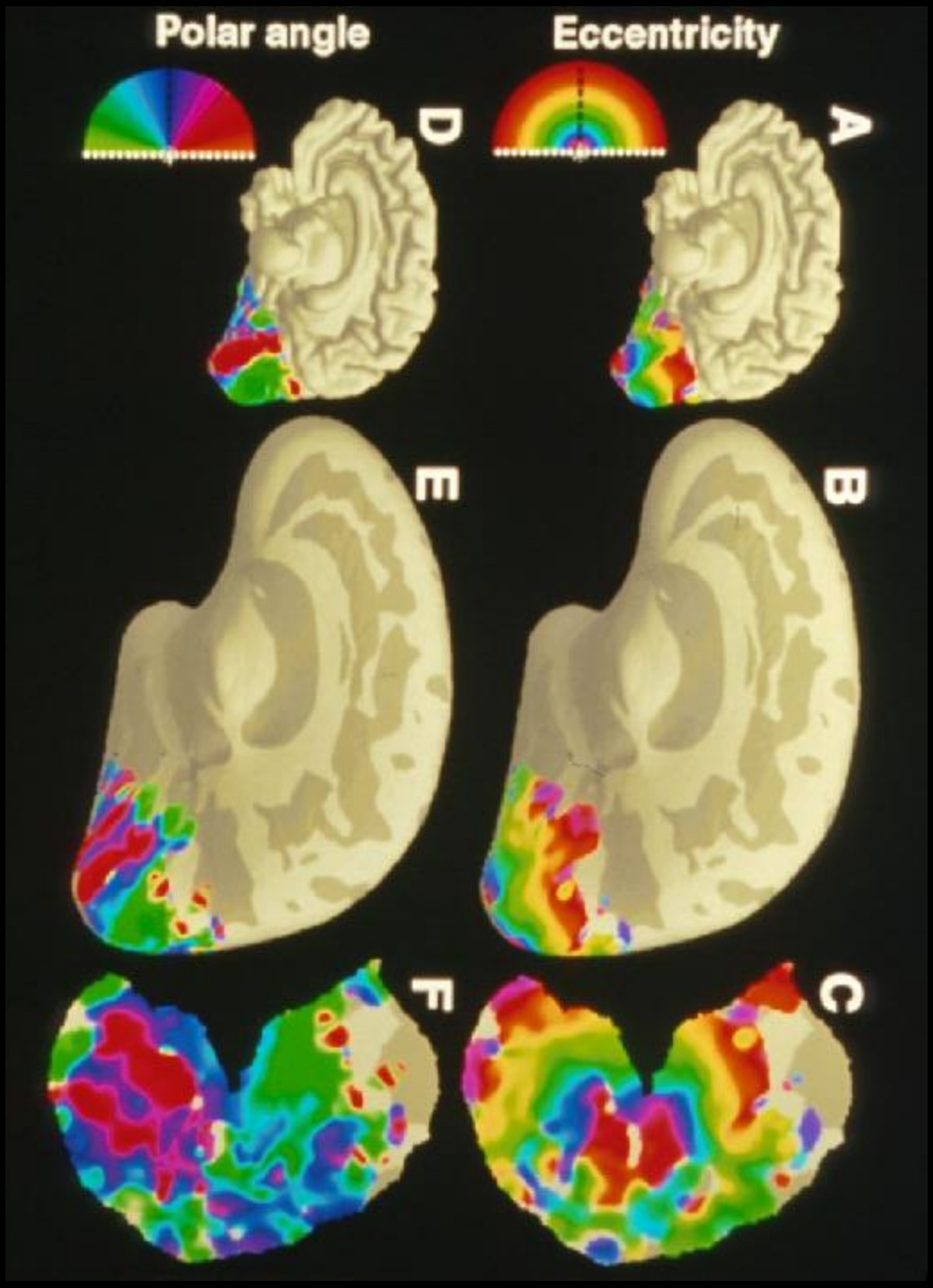


Listening

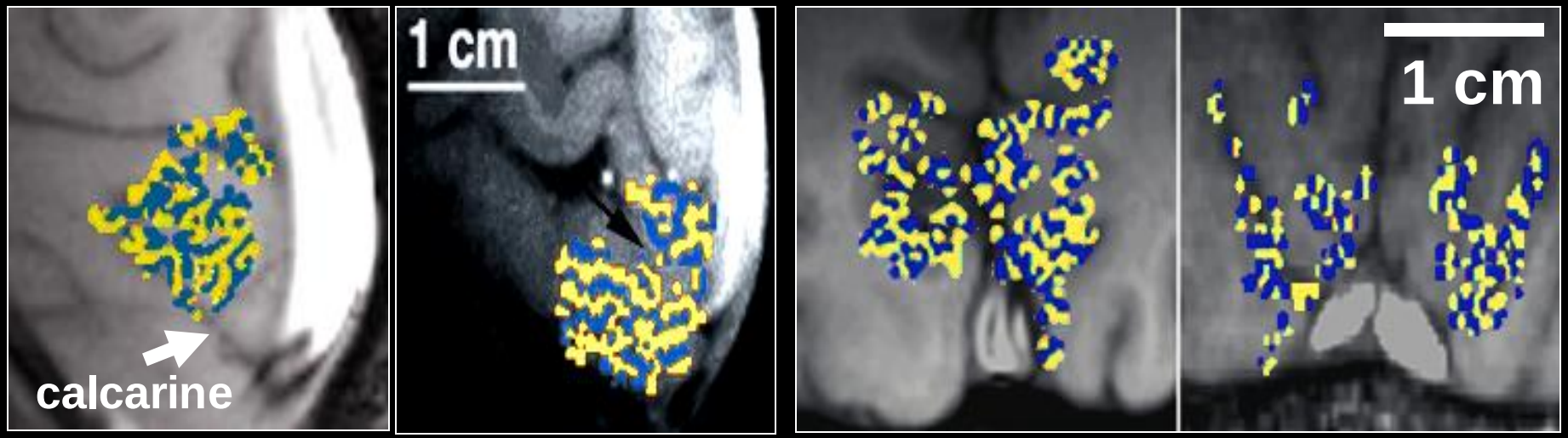


# Visual Pathways: The Retino-Geniculo-Calcarine Pathway




Polar angle
Eccentricity
D
A
E
B
F
C

# ODC Maps using fMRI

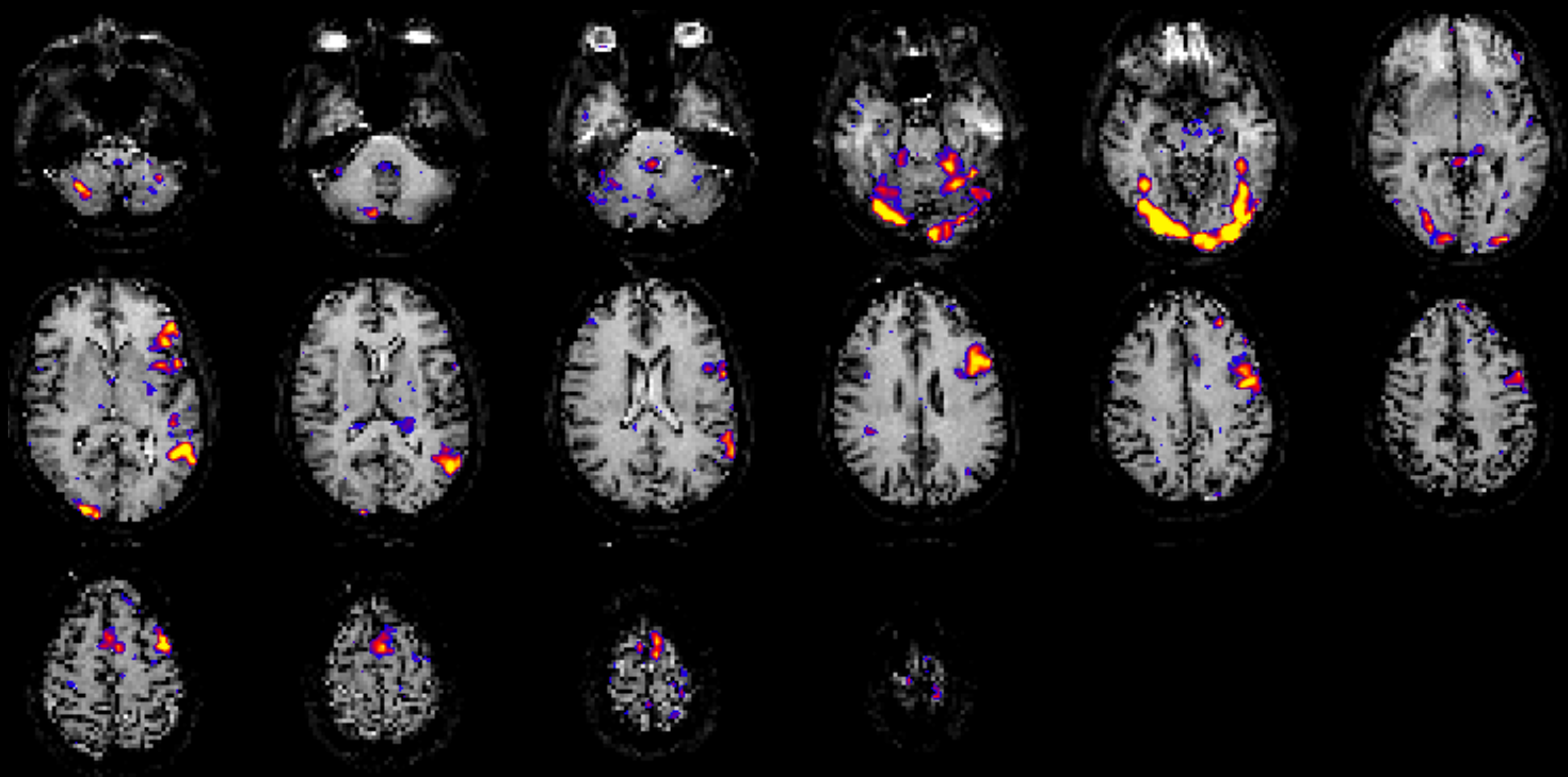



• Identical in size, orientation, and appearance to those obtained by optical imaging[1] and histology[3,4].

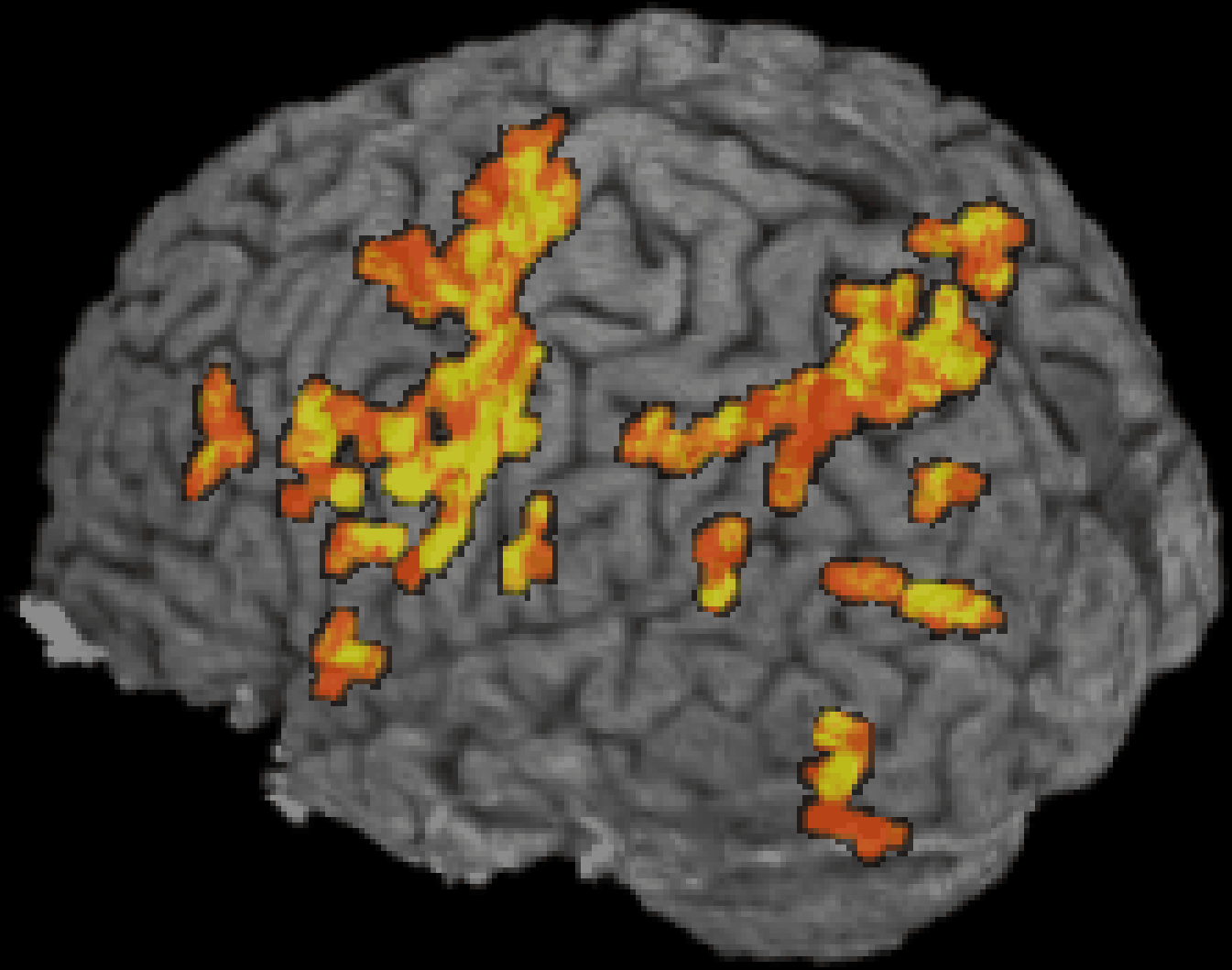
Menon et al.

[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).

# Word stem completion



# End of Acquisition



< 1 s to render

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

Blocks: 12345678

Color shows
through brain

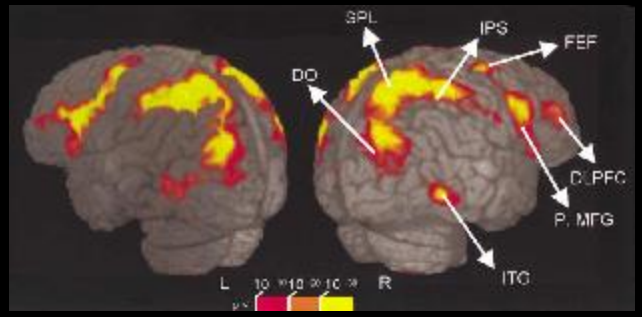
Correlation > 0.45

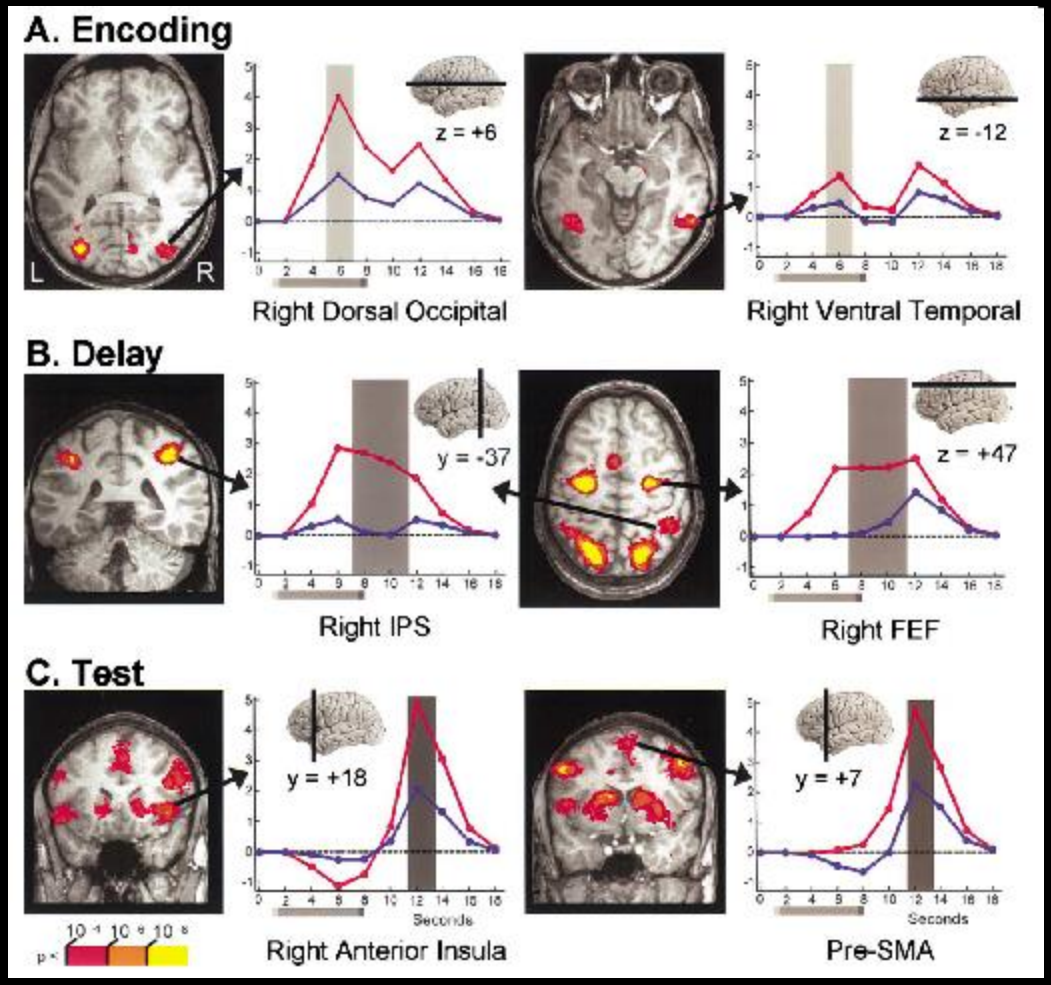
The End

Neuron, Vol. 35, 975–987, August 29, 2002, Copyright ©2002 by Cell Press

# Neural Correlates of Visual Working Memory: fMRI Amplitude Predicts Task Performance

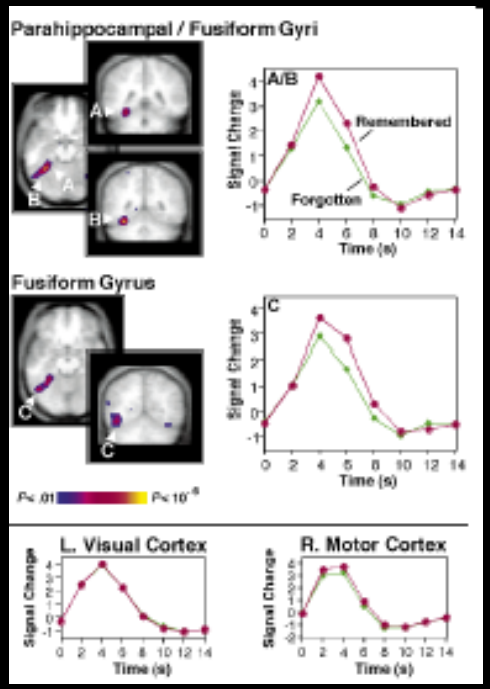
Luiz Pessoa,[1] Eva Gutierrez, Peter A. Bandettini, and Leslie G. Ungerleider
Laboratory of Brain and Cognition
National Institute of Mental Health
National Institutes of Health
Bethesda, Maryland 20892

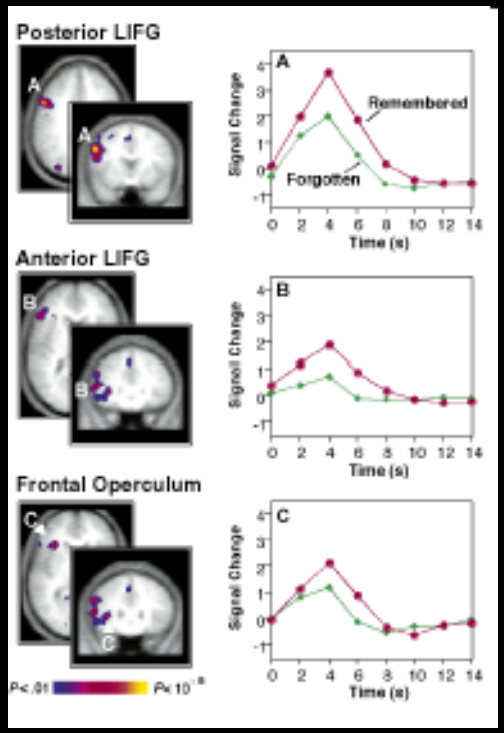


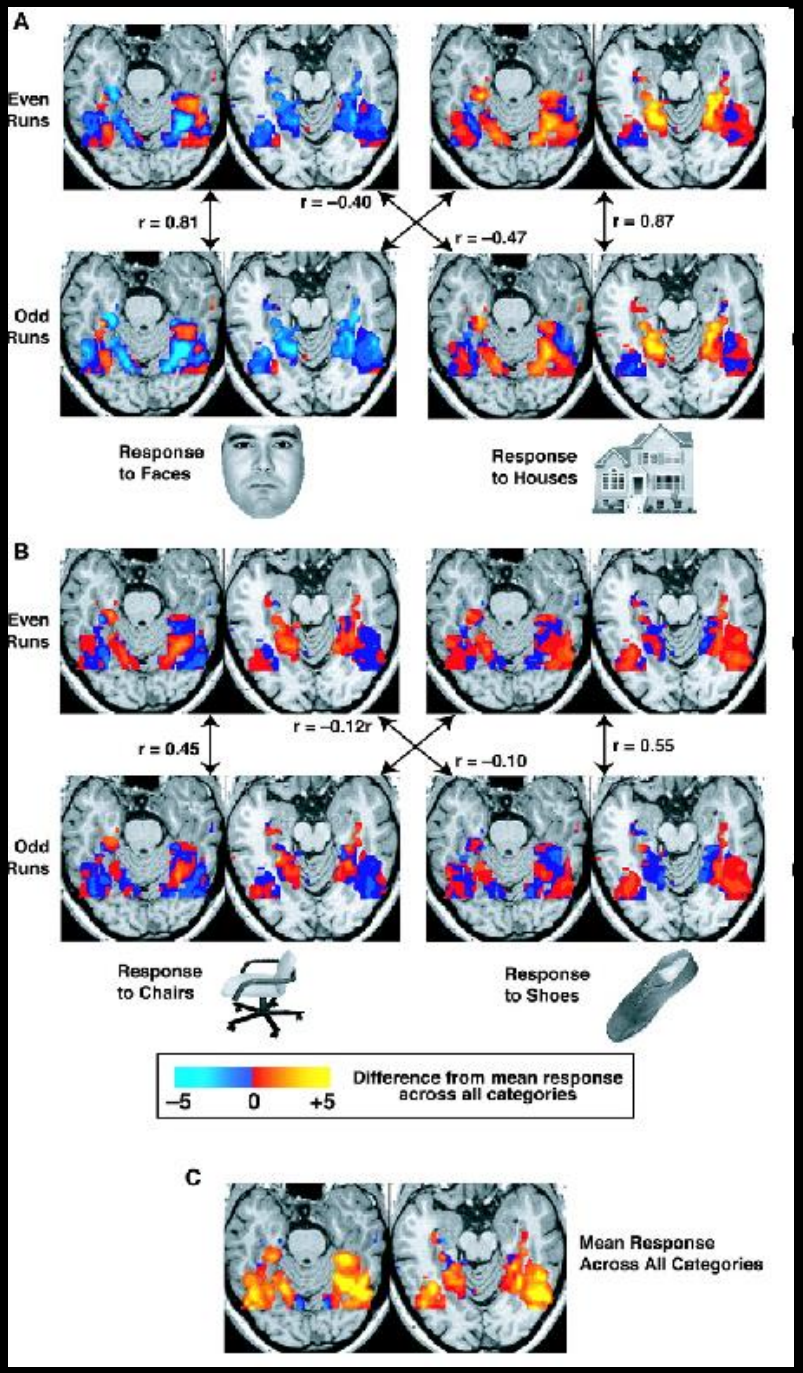
# Building Memories: Remembering and Forgetting of Verbal Experiences as Predicted by Brain Activity

Anthony D. Wagner,* Daniel L. Schacter, Michael Rotte,†
Wilma Koutstaal, Anat Maril, Anders M. Dale, Bruce R. Rosen,
Randy L. Buckner



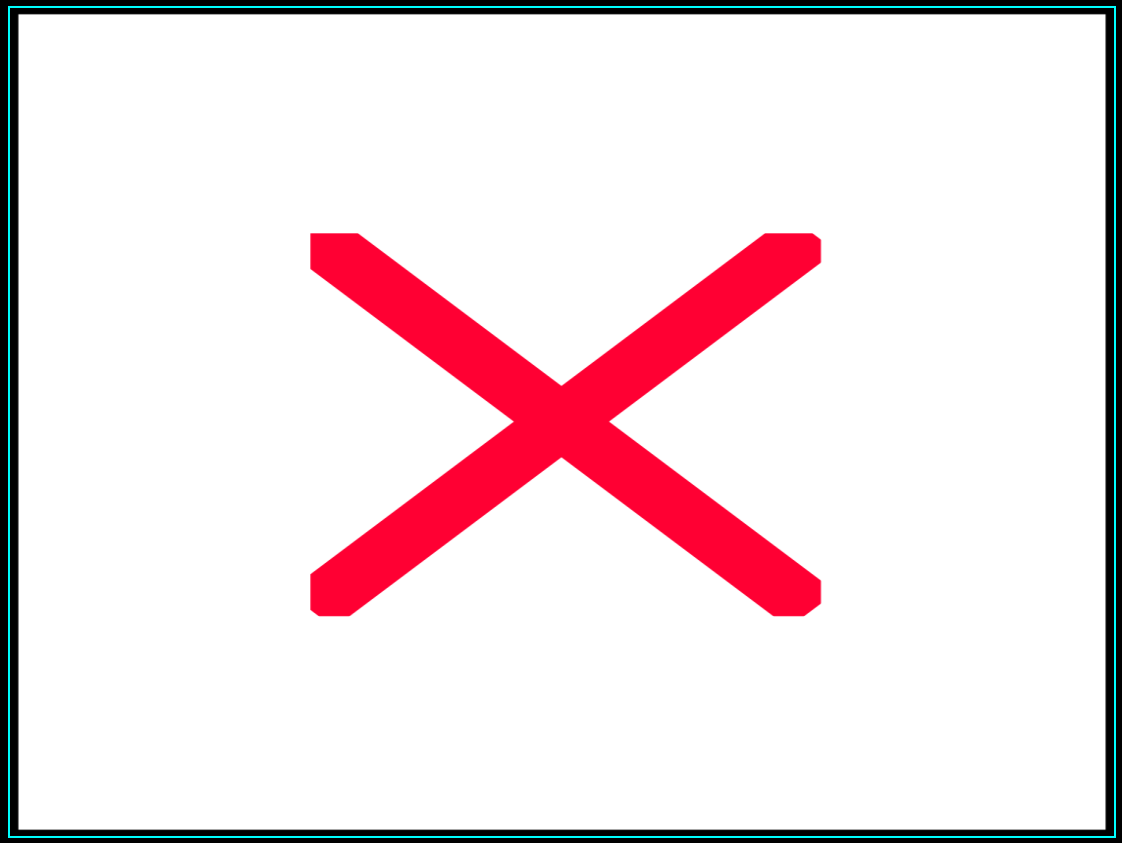

Science, Vol 281, August 1998

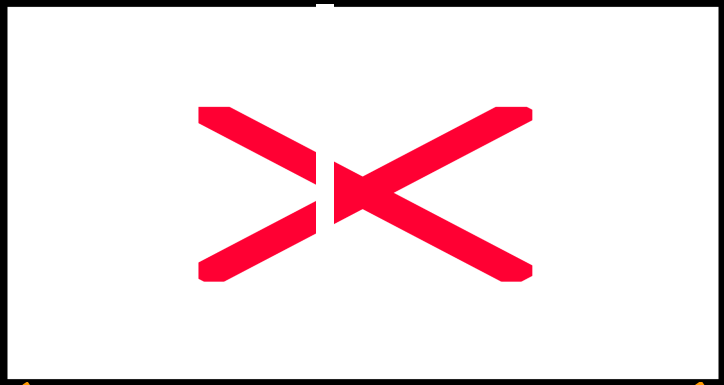


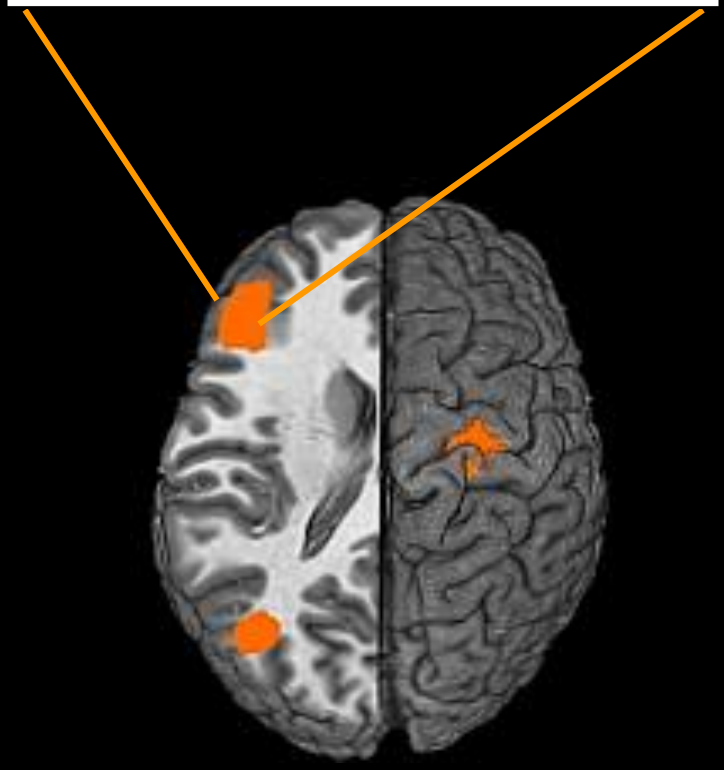

Haxby et al (2001)

Word vs. Non-word

0°, 60°, 120° Rotation





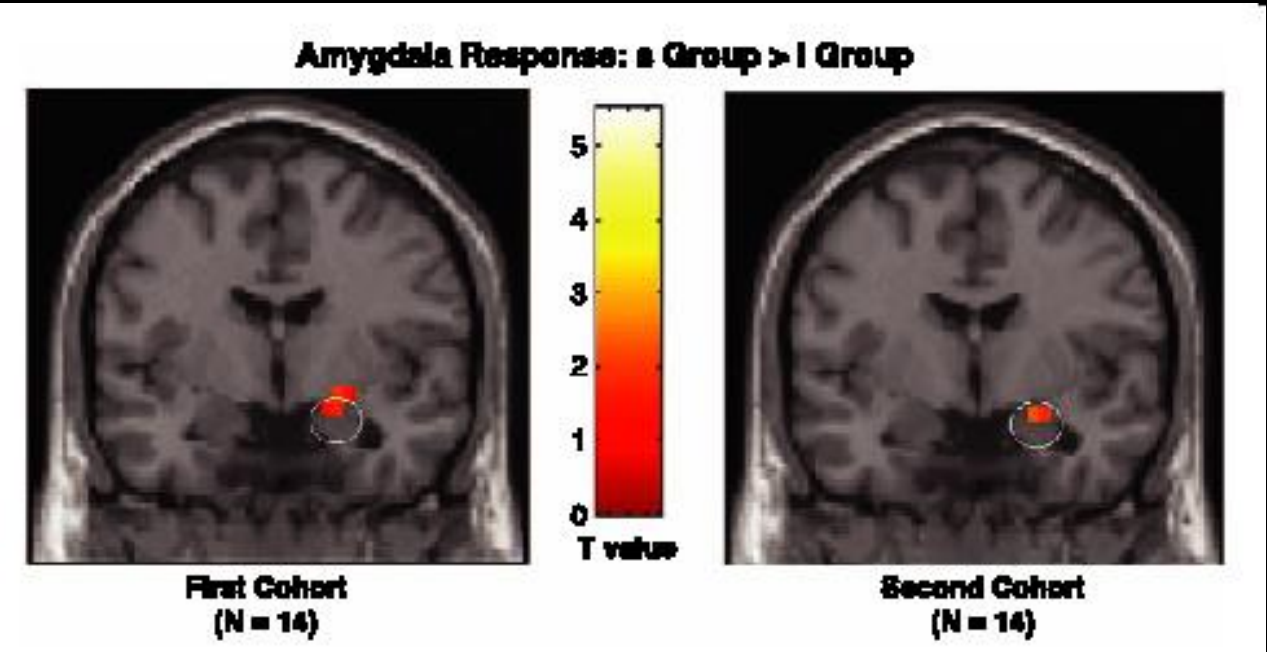


Bellgowan, et al (2003), PNAS 100, 15820–15283

**Comparison of two groups of *normal* individuals with differences in the Serotonin Transporter Gene**

# Serotonin Transporter Genetic Variation and the Response of the Human Amygdala

Ahmad R. Hariri,[1] Venkata S. Mattay,[1] Alessandro Tessitore,[1] Bhaskar Kolachana,[1] Francesco Fera,[1] David Goldman,[2] Michael F. Egan,[1] Daniel R. Weinberger[1]*




SCIENCE VOL 297 19 JULY 2002

◆ Human Brain Mapping 15:157–164(2002) ◆
DOI 10.1002/hbm.10020

# Lie Detection by Functional Magnetic Resonance Imaging

Tatia M.C. Lee,[1*] Ho-Ling Liu,[2] Li-Hai Tan,[3] Chetwyn C.H. Chan,[4]
Srikanth Mahankali,[5] Ching-Mei Feng,[5] Jinwen Hou,[5]
Peter T. Fox,[5] and Jia-Hong Gao[5]

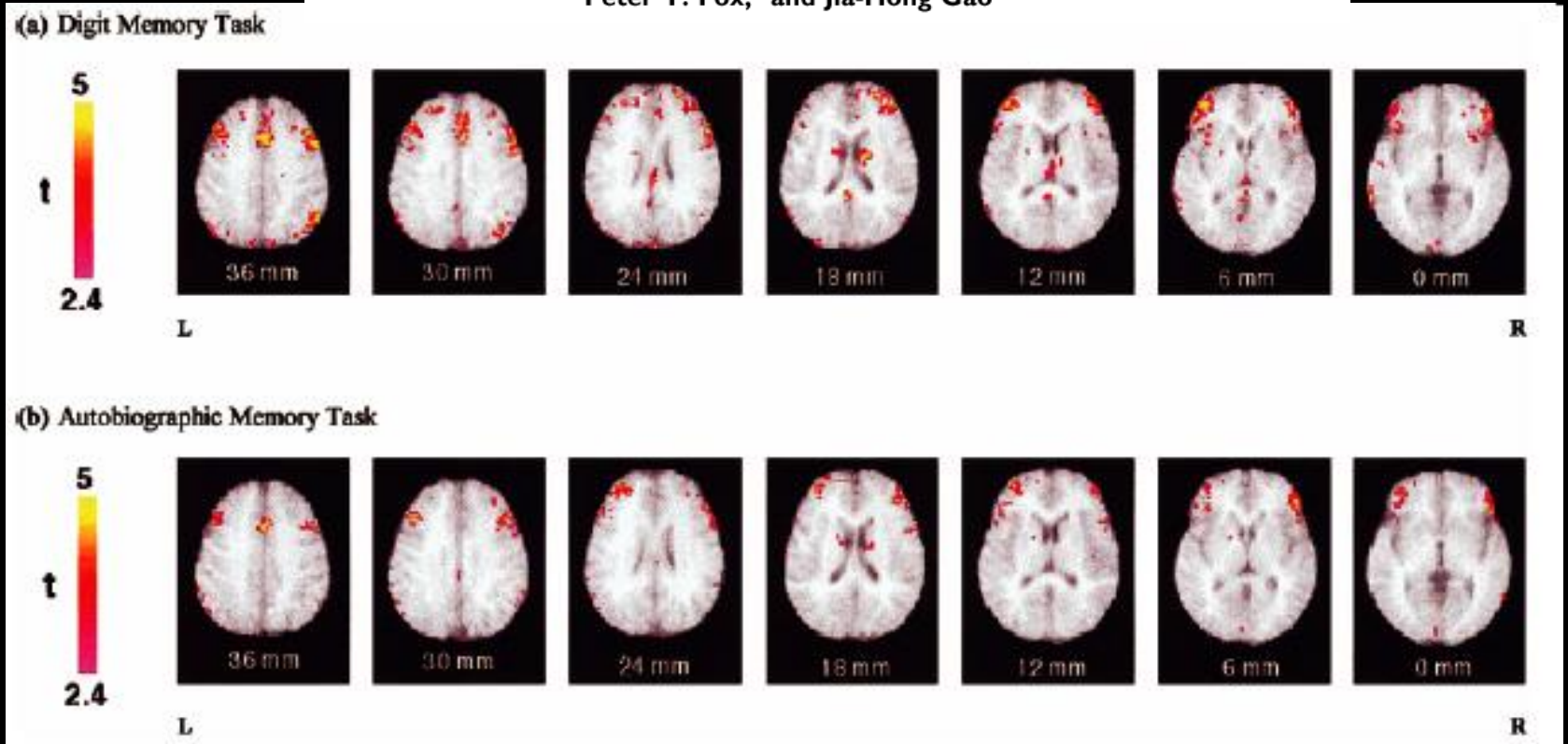
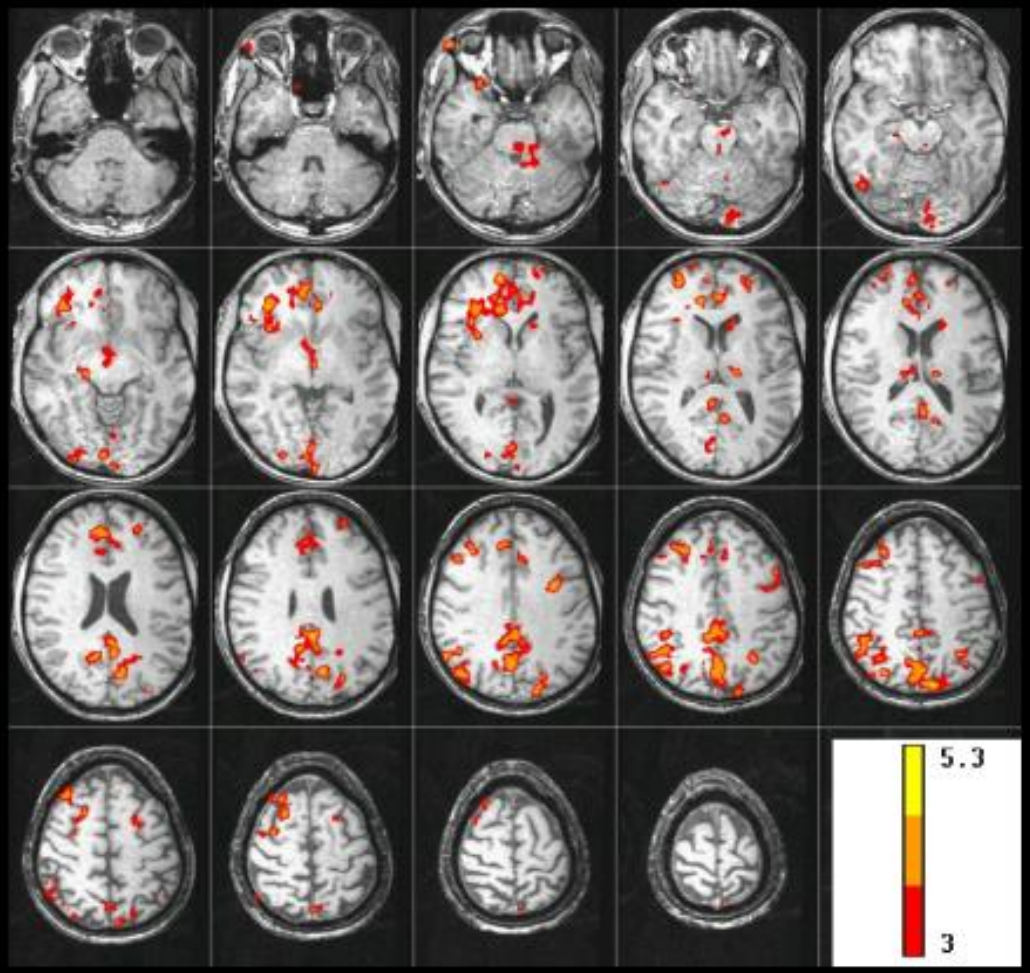
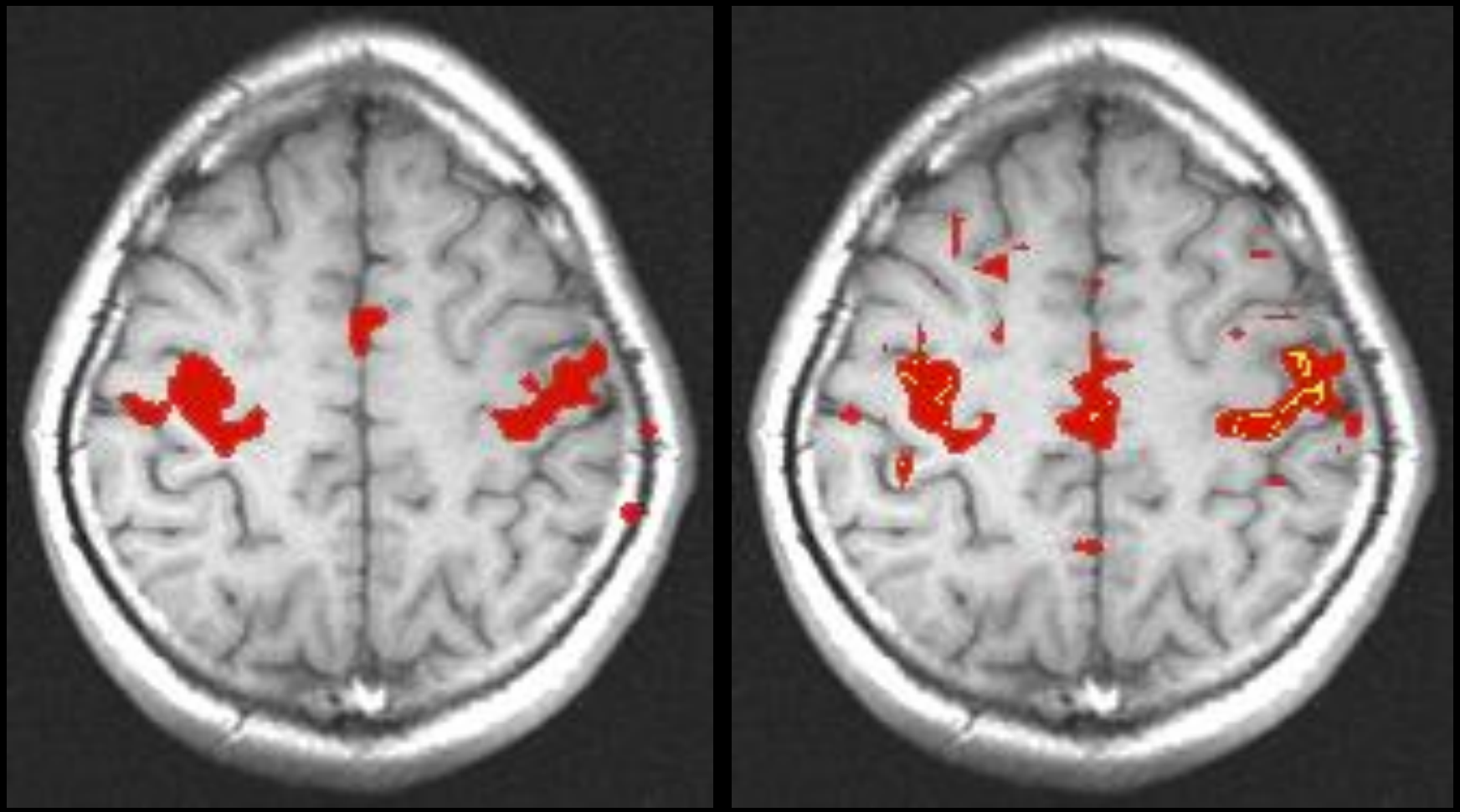



**Figure 1.**

Functional maps. Normalized activation brain maps averaged across five subjects demonstrating the statistically significant activations ($P < 0.01$) in the faking memory impairment condition with the activation for making accurate recall removed when performing on forced choice testing using (**a**) Digit Memory and (**b**) Autobiographic Memory tasks. Planes are axial sections, labeled with the height (mm) relative to the bicommissural line. L, left hemisphere; R, right hemisphere.

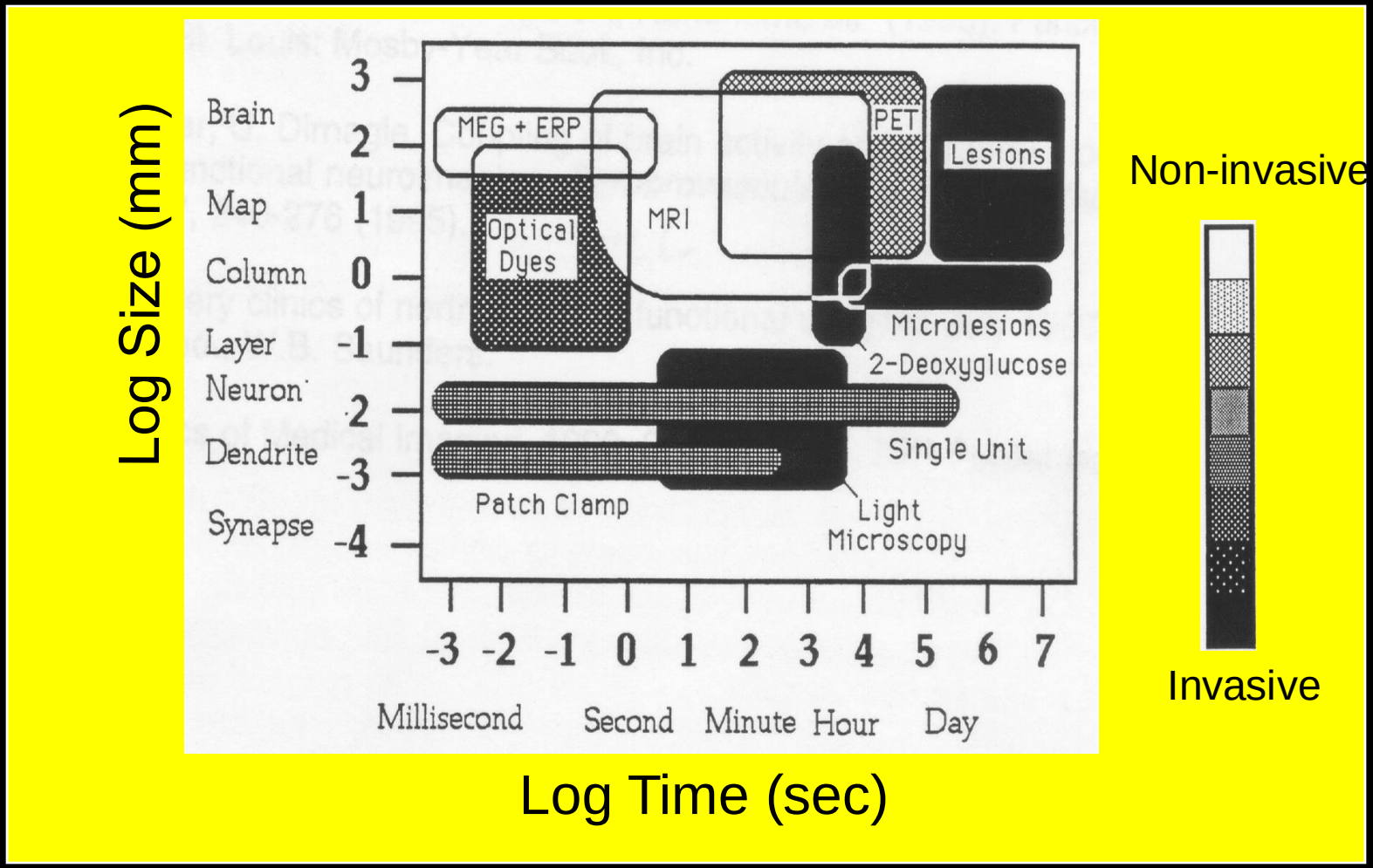
# Activation in the brain correlated with skin conductance changes

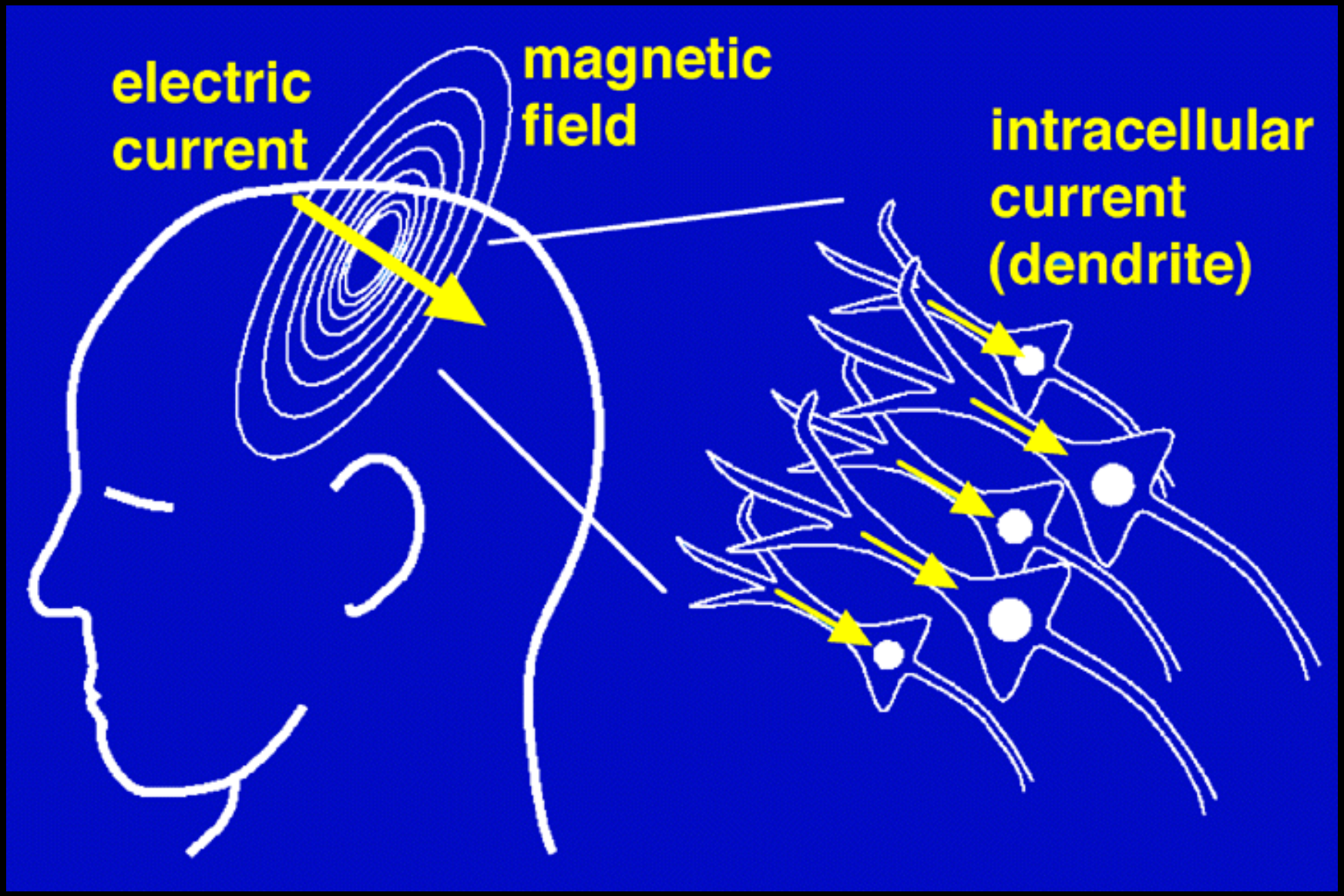


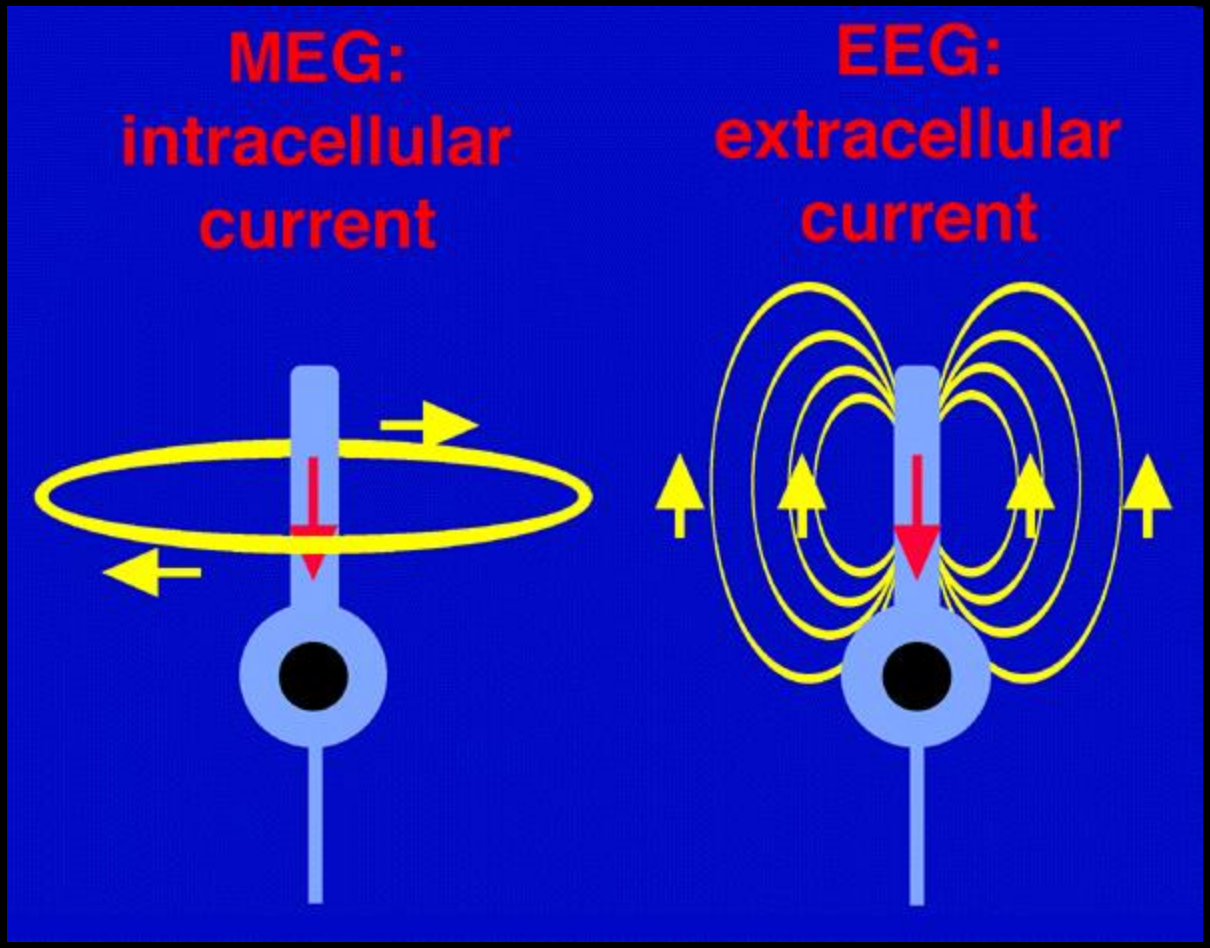


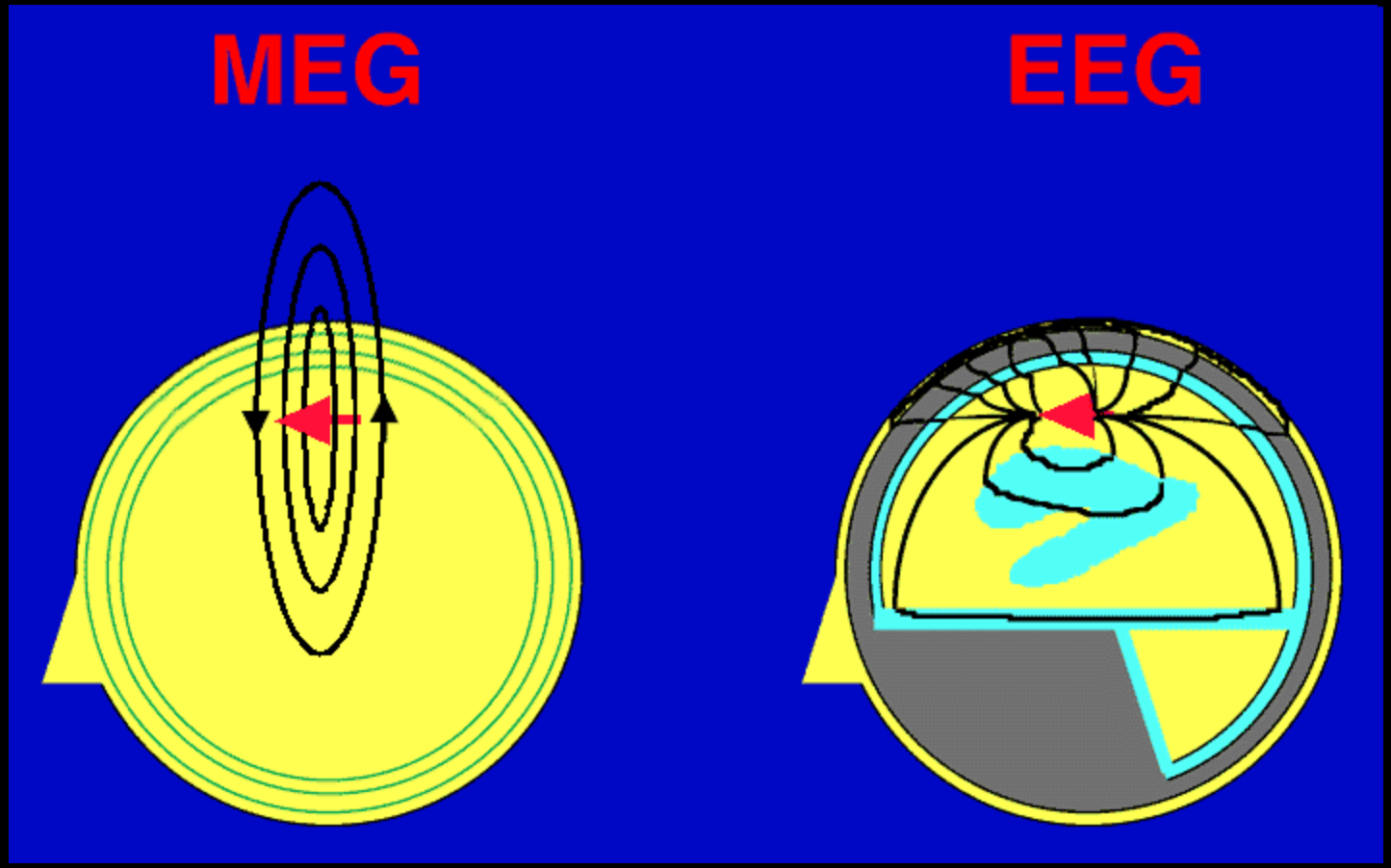
Biswal, et al (1995), MRM 34, 537-541

# Functional Neuroimaging Techniques

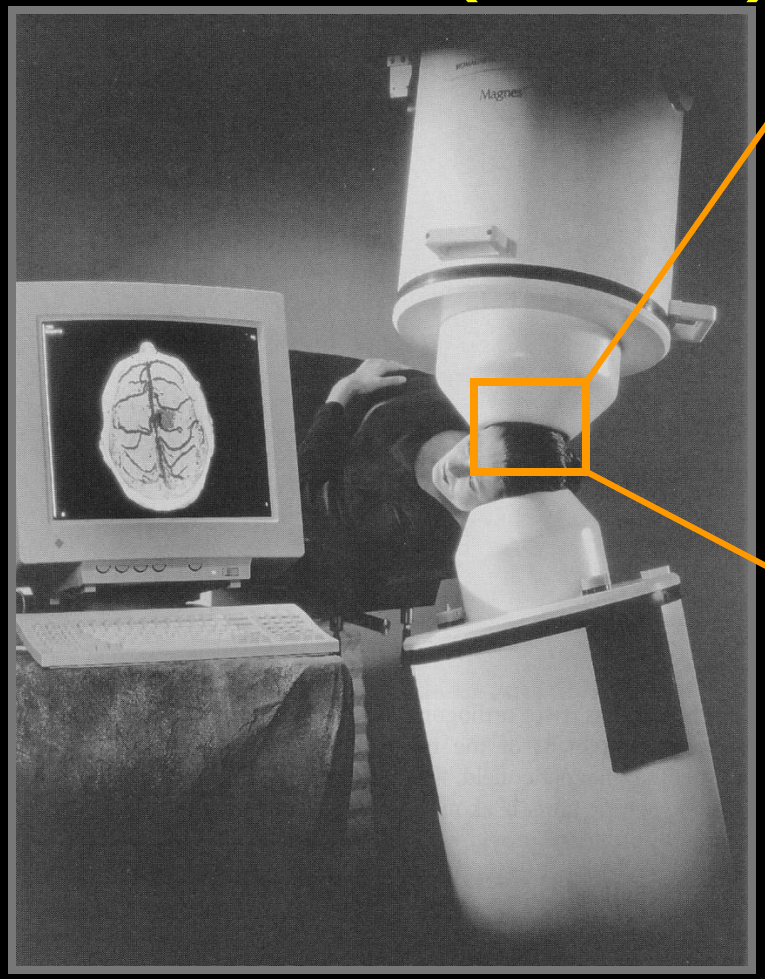


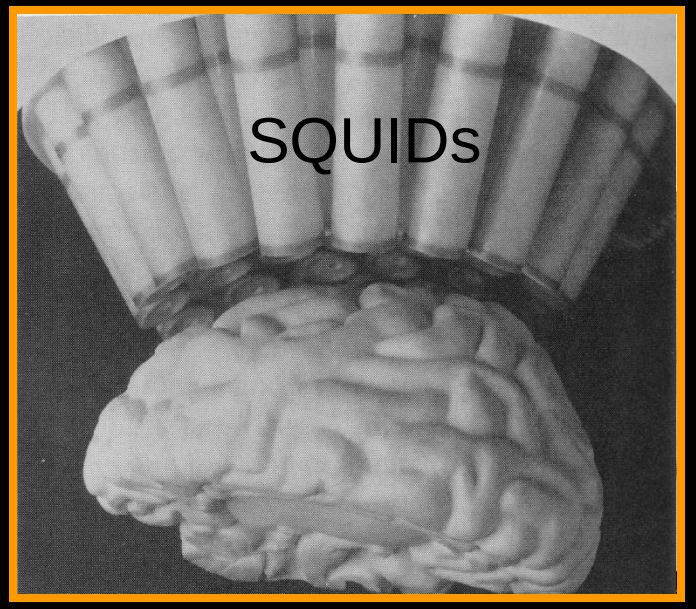

electric
current
magnetic
field
intracellular
current
(dendrite)


MEG:
intracellular
current
EEG:
extracellular
current

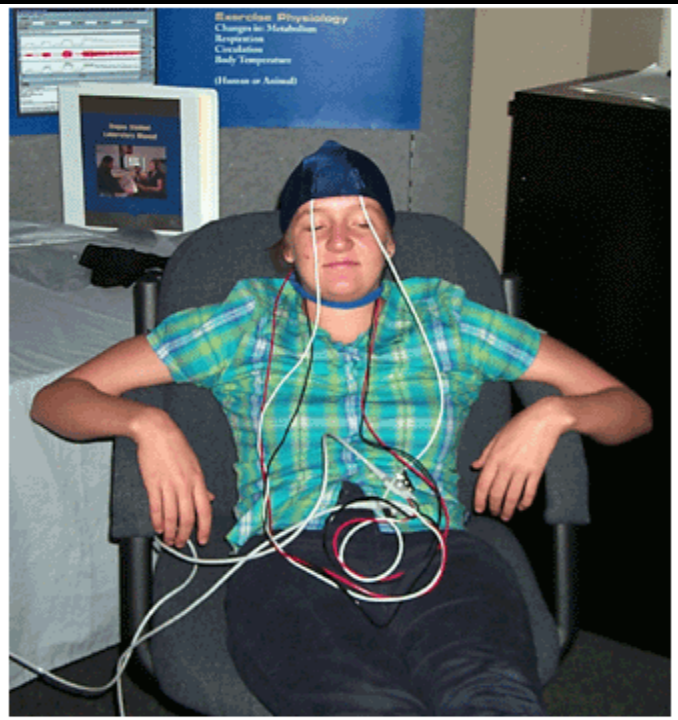

MEG
EEG

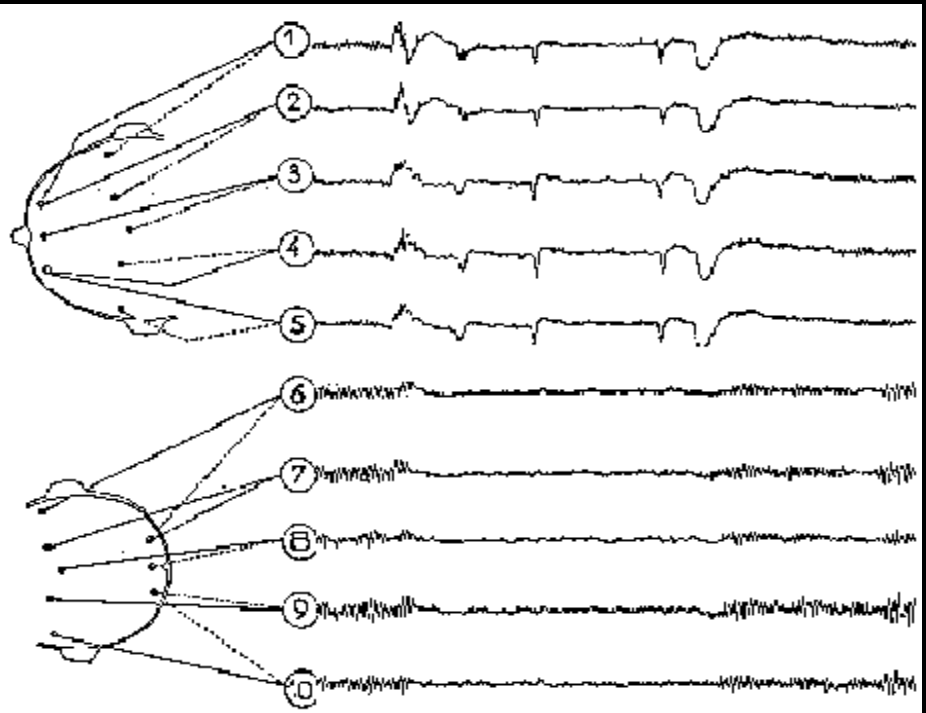
# Magnetoencephalography (MEG)

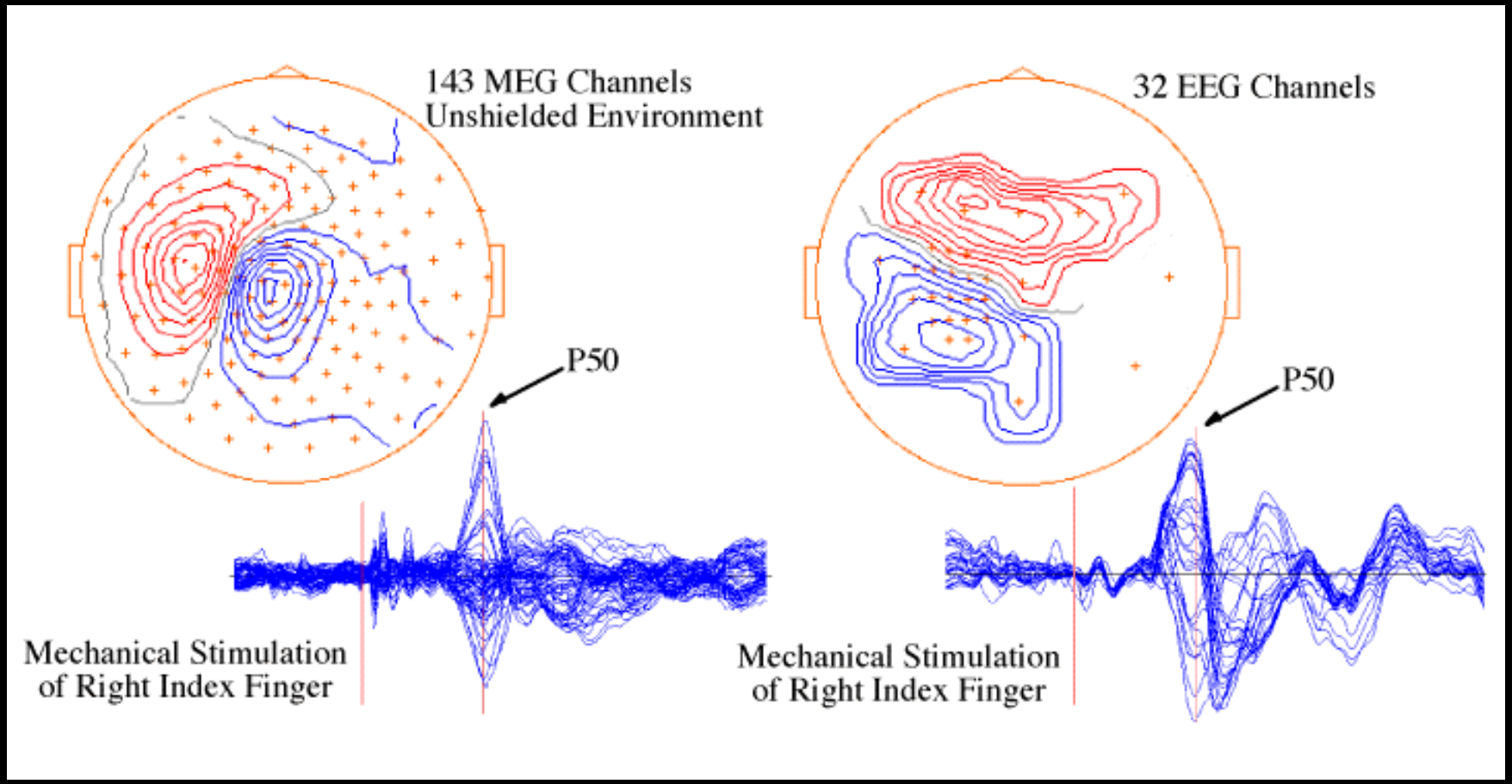




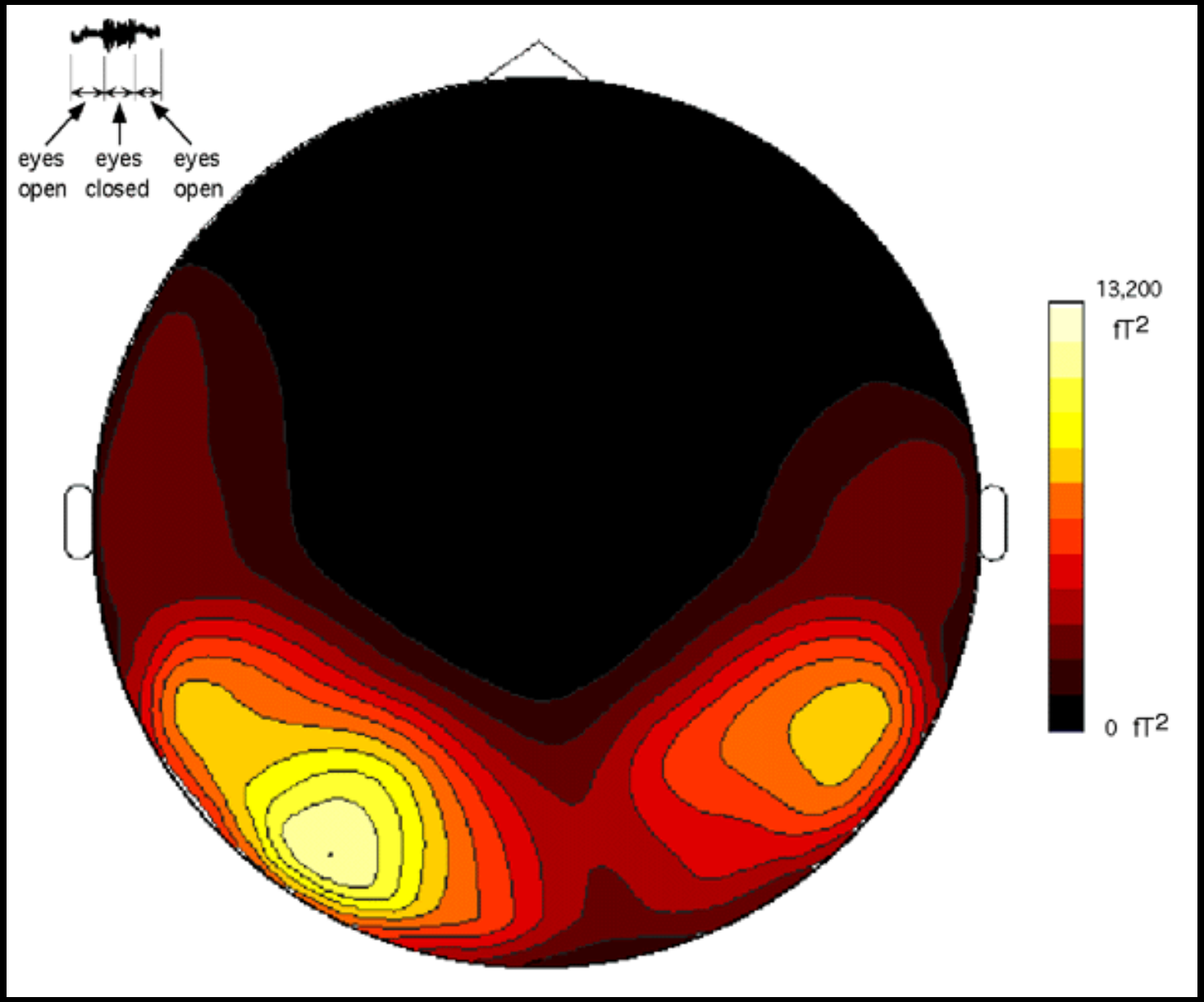

SQUID:
Superconducting Quantum Interference Device


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

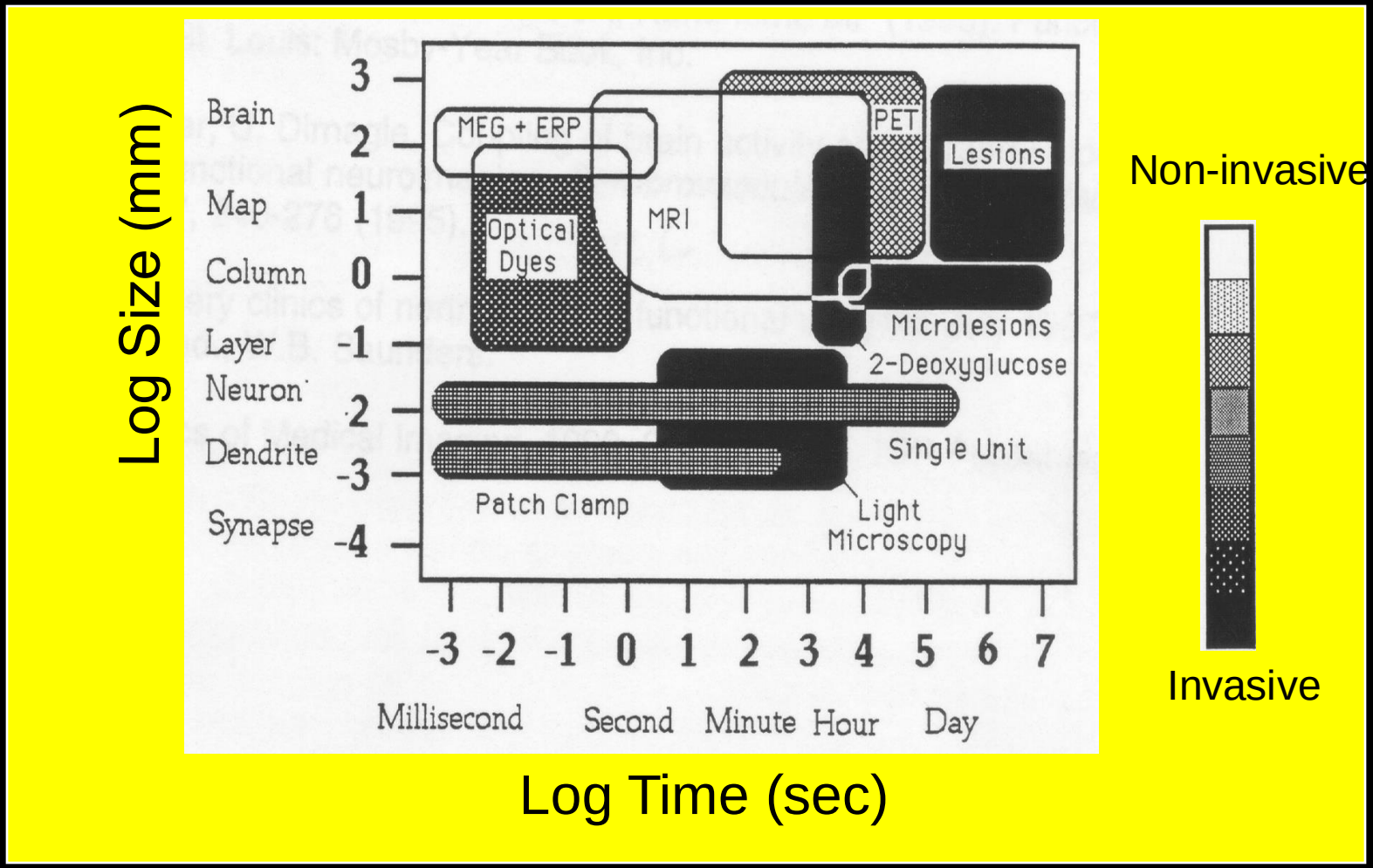

1
2
3
4
5
6
7
8
9
0


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

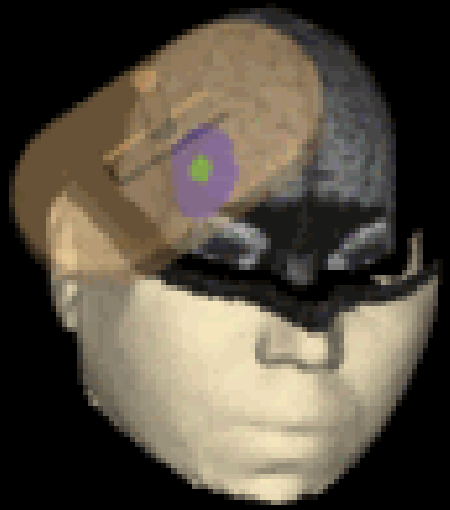
# Alpha Wave Activity Mapped with MEG

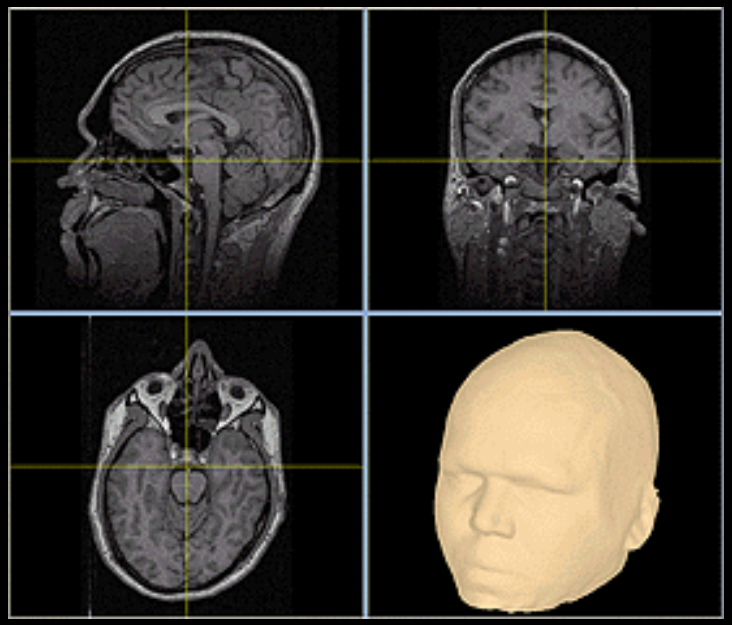


# Functional Neuroimaging Techniques



# 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
Susumu 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

# Section on Functional Imaging Methods & FMRI Facility