Functional Magnetic Resonance Imaging (fMRI)

and a few other brain imaging techniques

History, Development, and Applications

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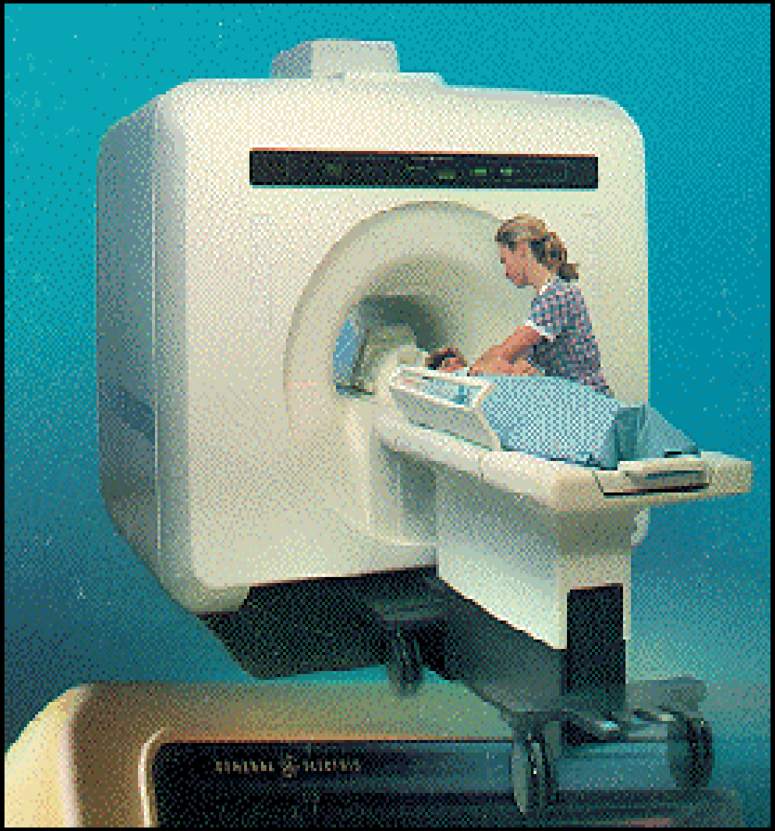
Two Types of Neuroimaging

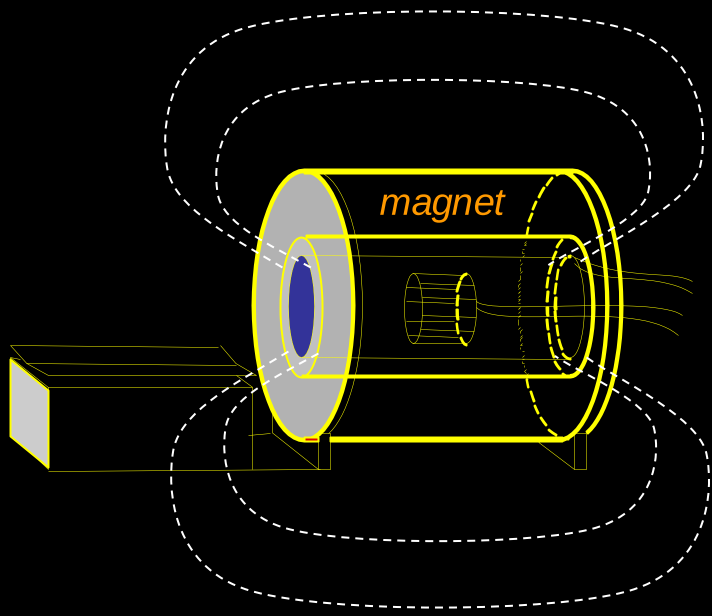
- Structural/Anatomical Imaging
- Functional Imaging

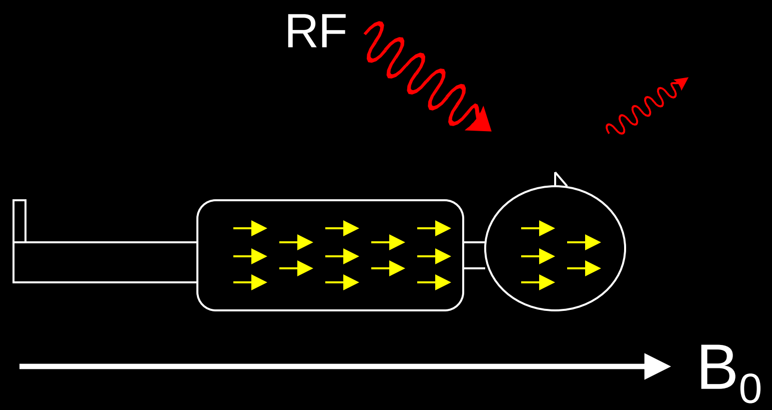
- Structural/Anatomical Imaging
  - X-ray
  - Computerized Tomography (CT)
  - Magnetic Resonance Imaging (MRI)
    - Angiography
    - Venography
    - Perfusion
    - Diffusion Tensor Imaging

Magnetic Resonance Imaging



Magnetic Resonance Imaging (MRI)

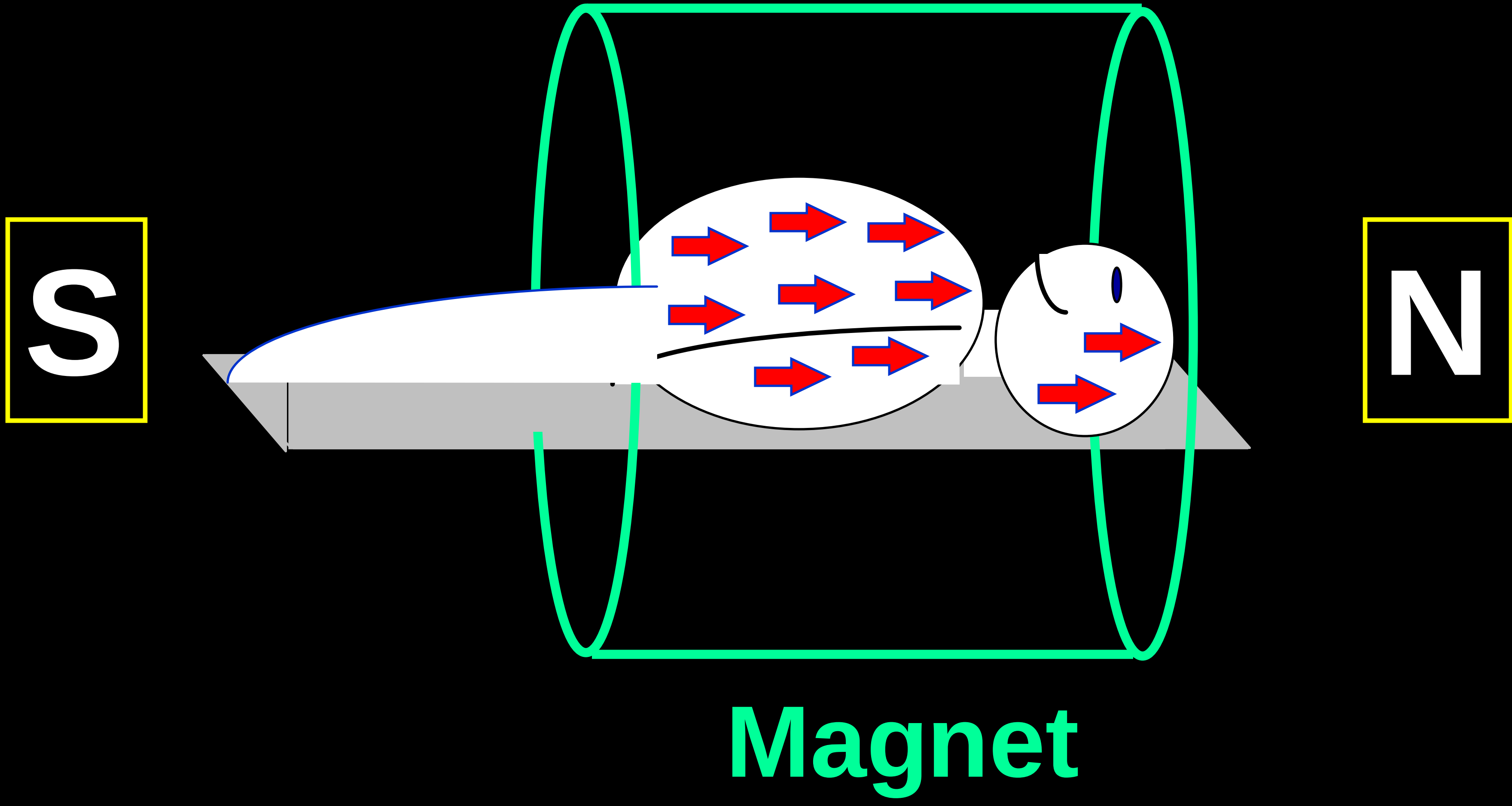




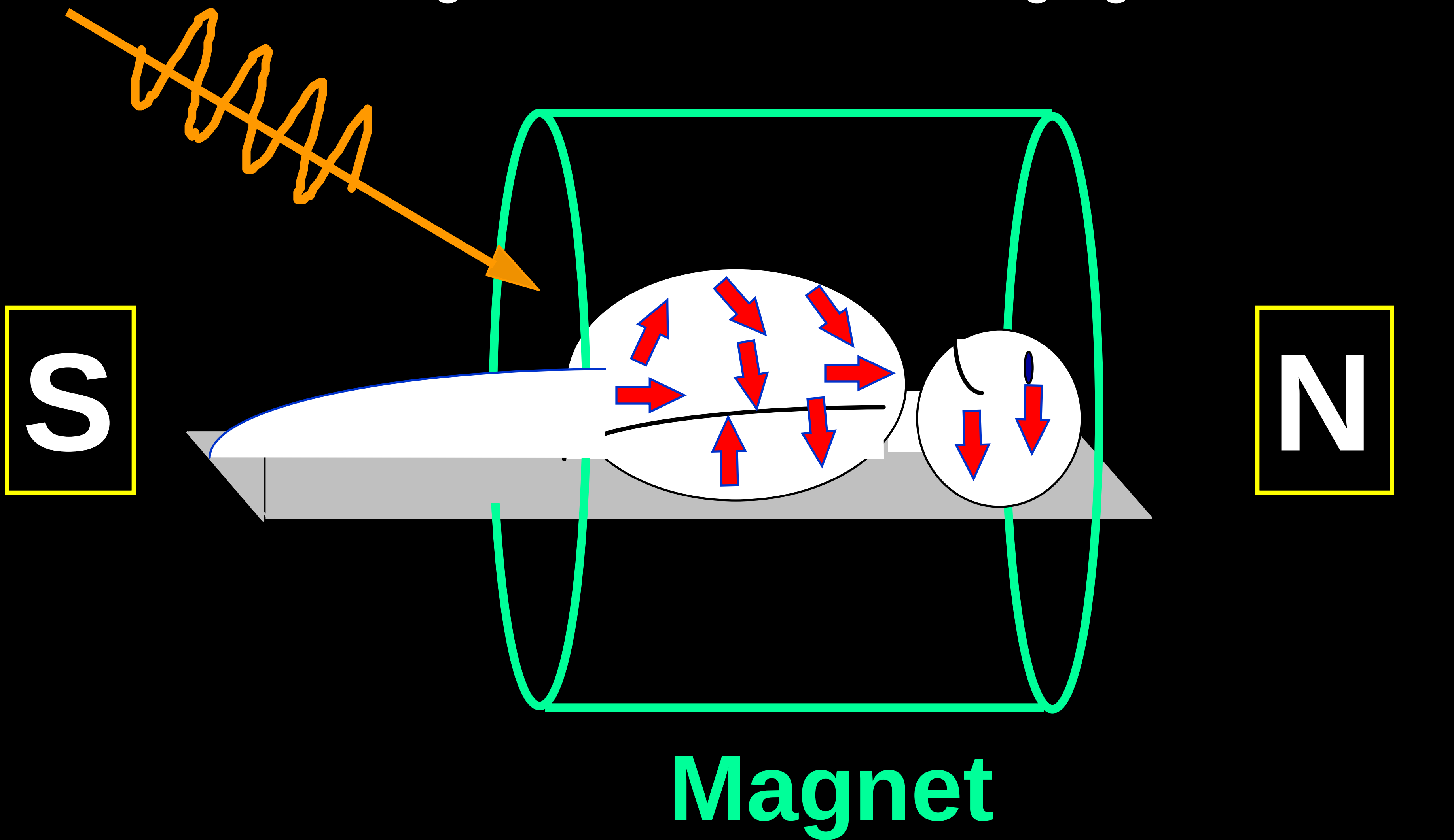
Sensitive to:

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

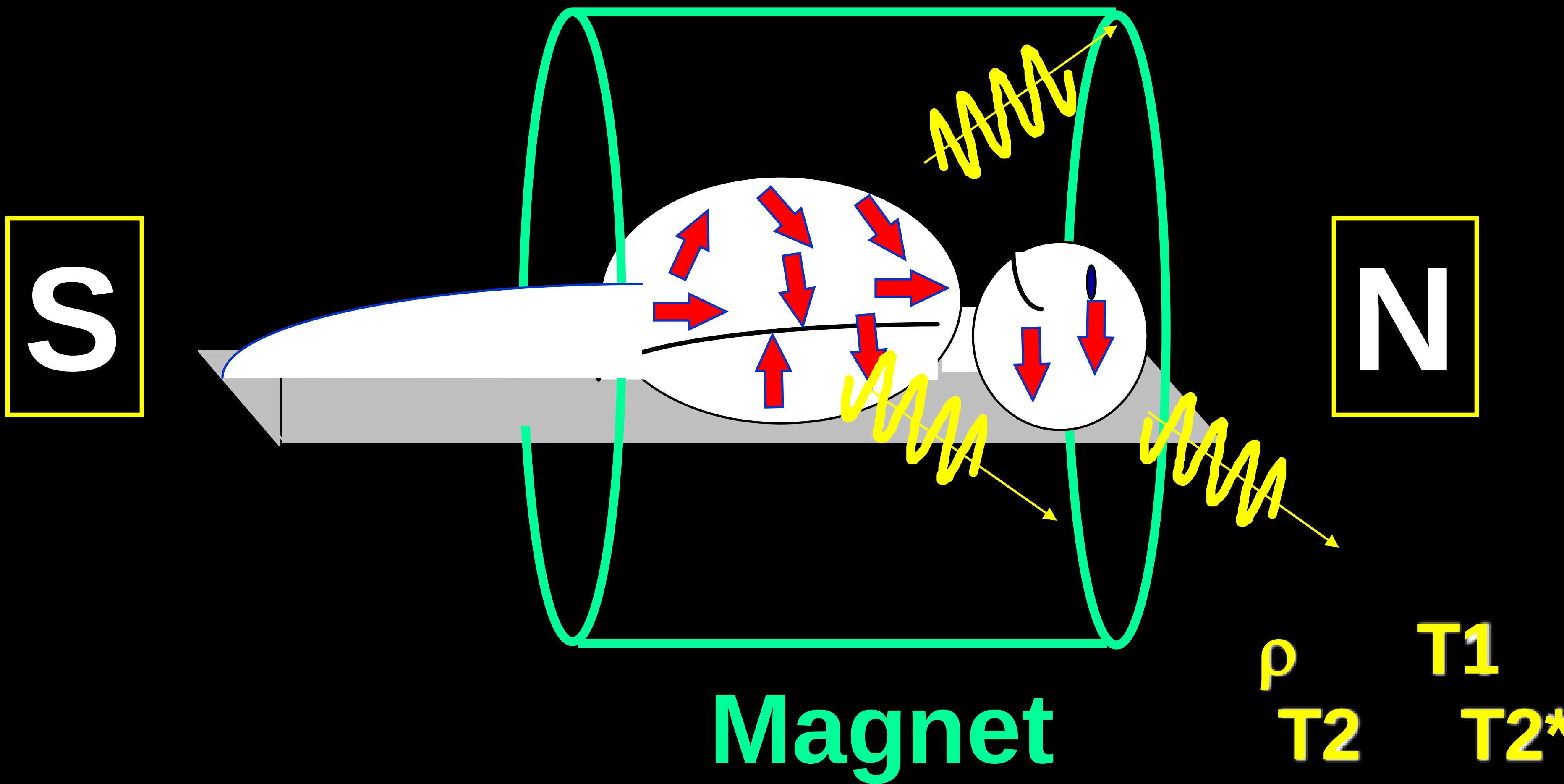
Magnetic Resonance Imaging



Magnetic Resonance Imaging

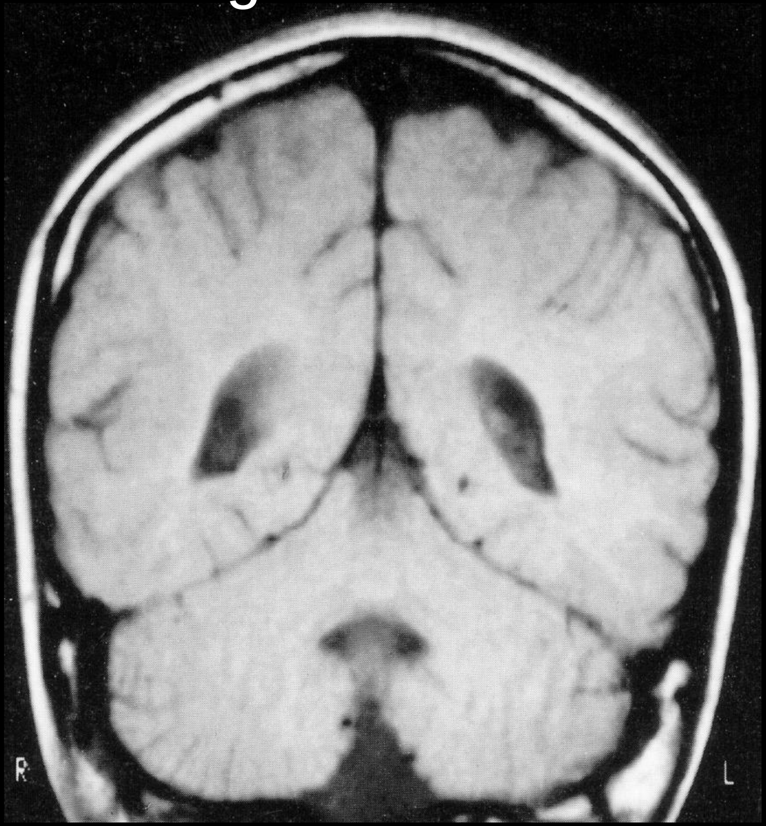


Magnetic Resonance Imaging

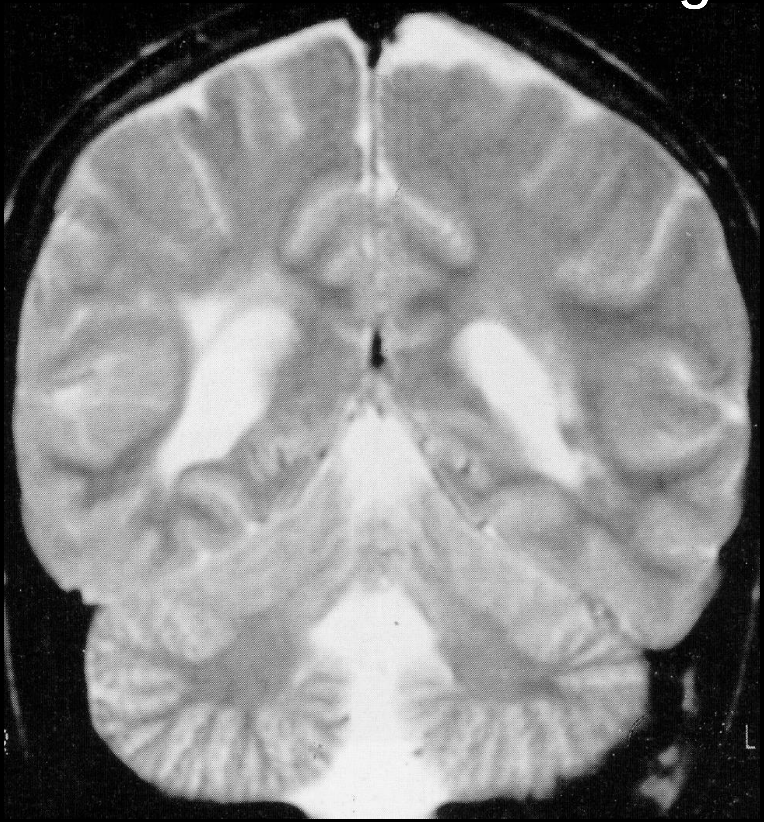


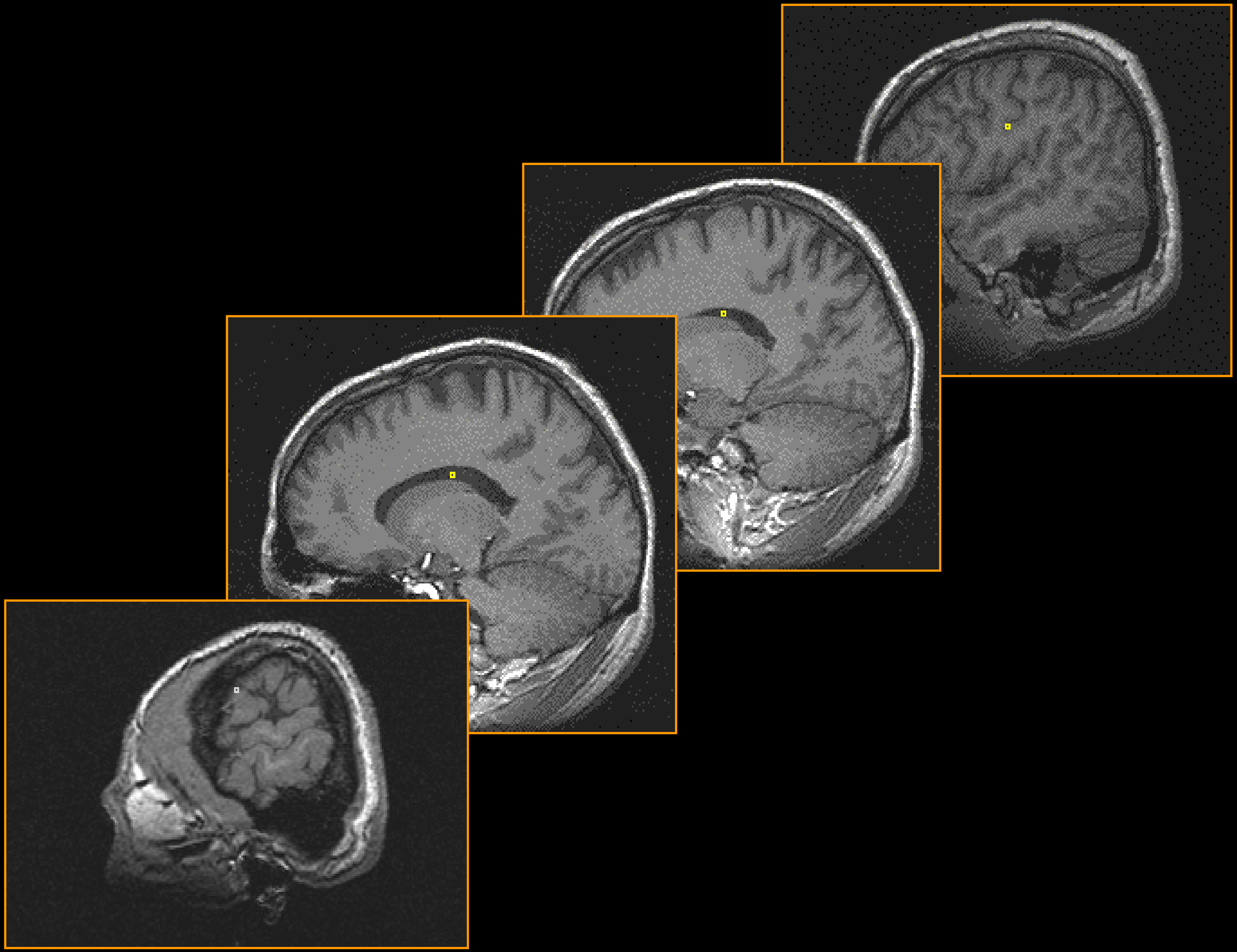
MRI Images with Different Contrast Weighting

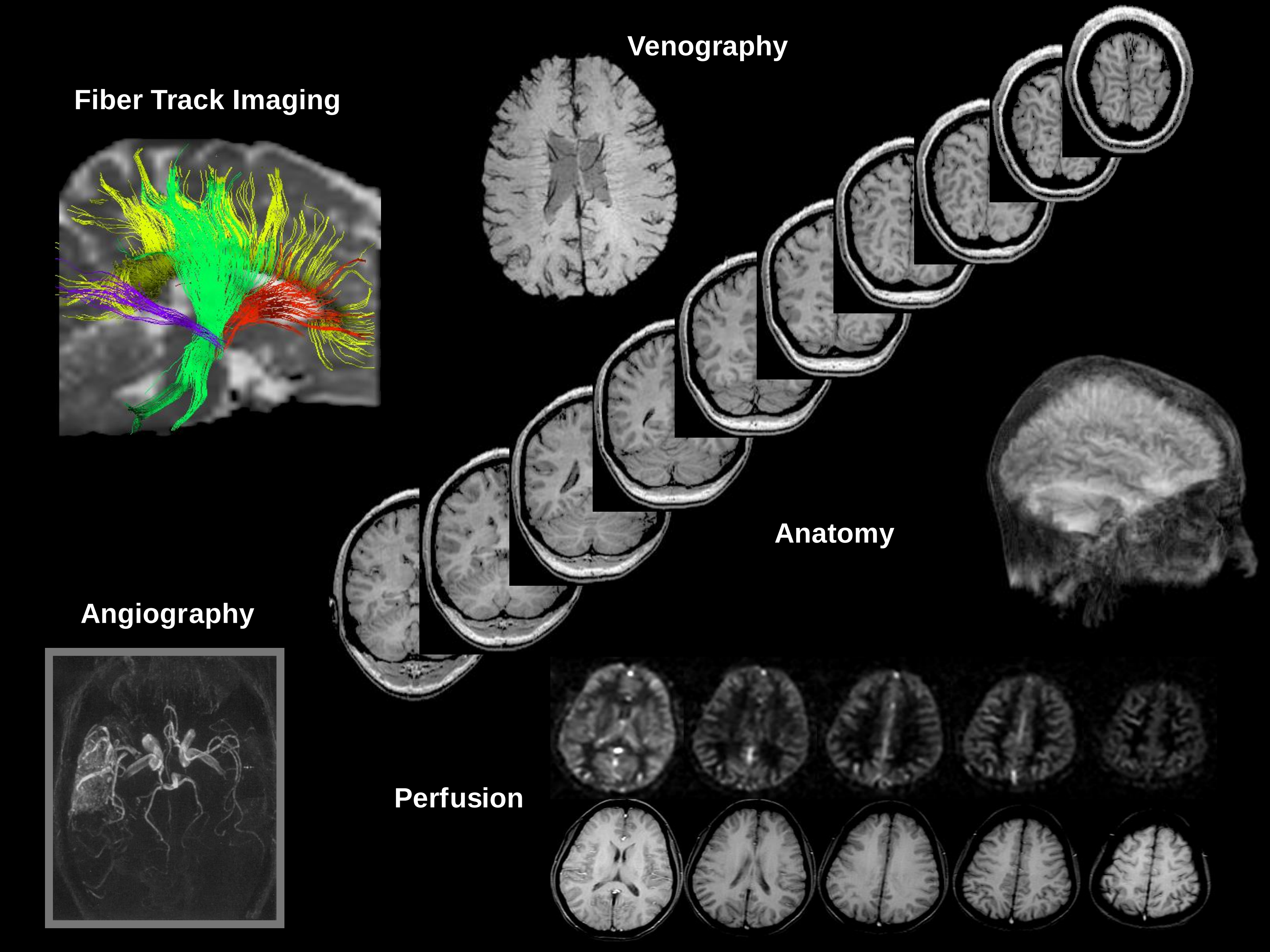
T1 Weighted



T2 Weighted

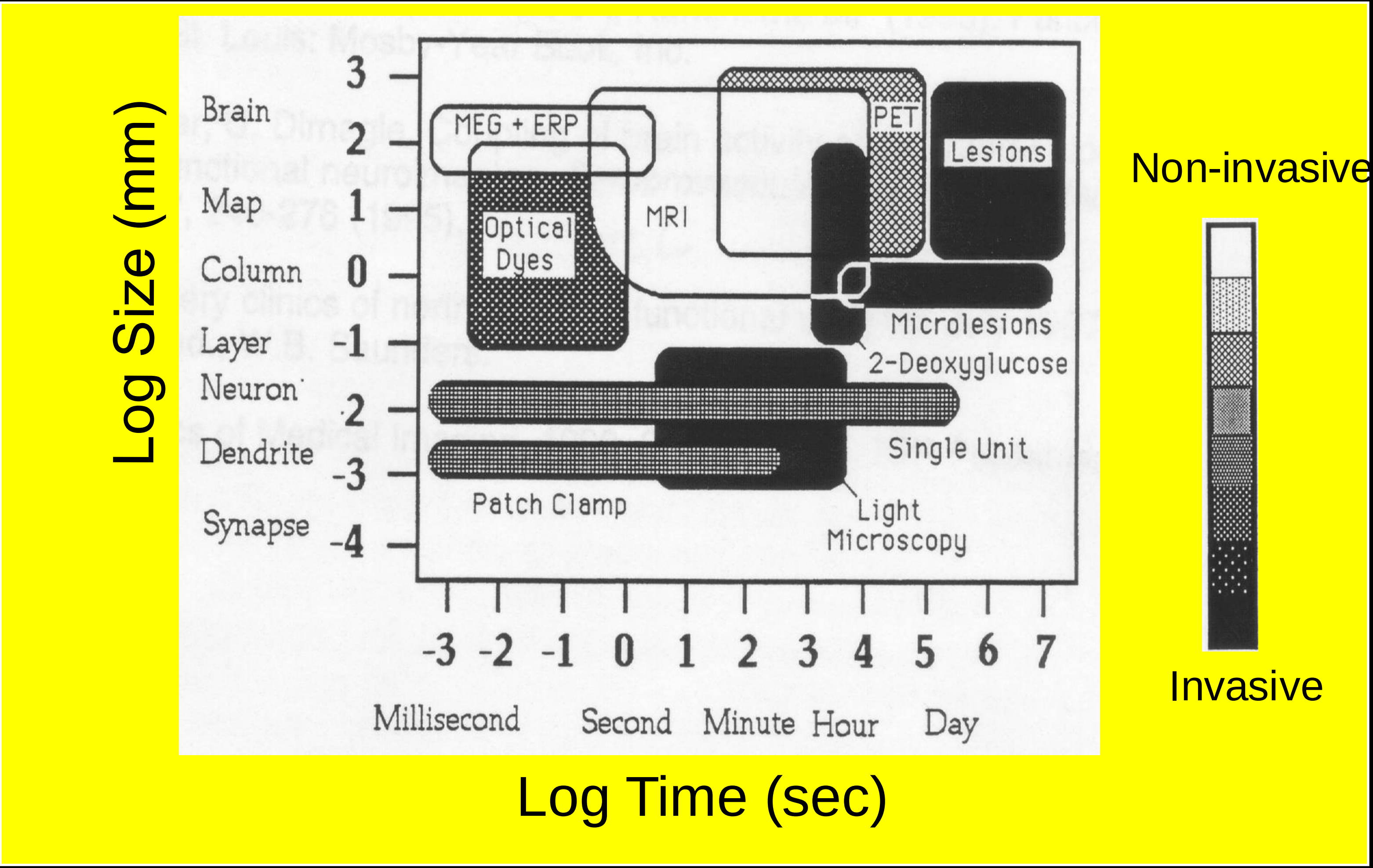





Venography
Fiber Track Imaging
Anatomy
Angiography
Perfusion

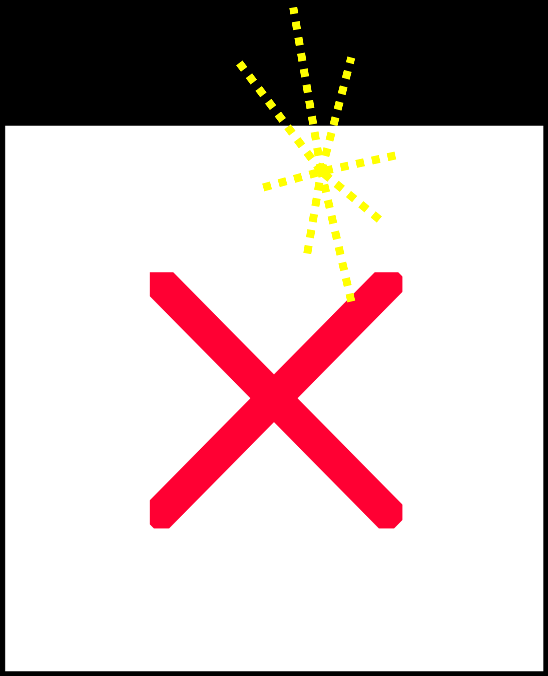
- Functional Imaging
  - Xenon Computerized Tomography (Xe CT)
  - Positron Emission Tomography (PET)
  - Single Photon Computed Tomography (SPECT)
  - Functional MRI (fMRI)
  - Electroencephalography (EEG)
  - Magnetoencphalography (MEG)
  - Transcranial Magnetic Stimulation (TMS)

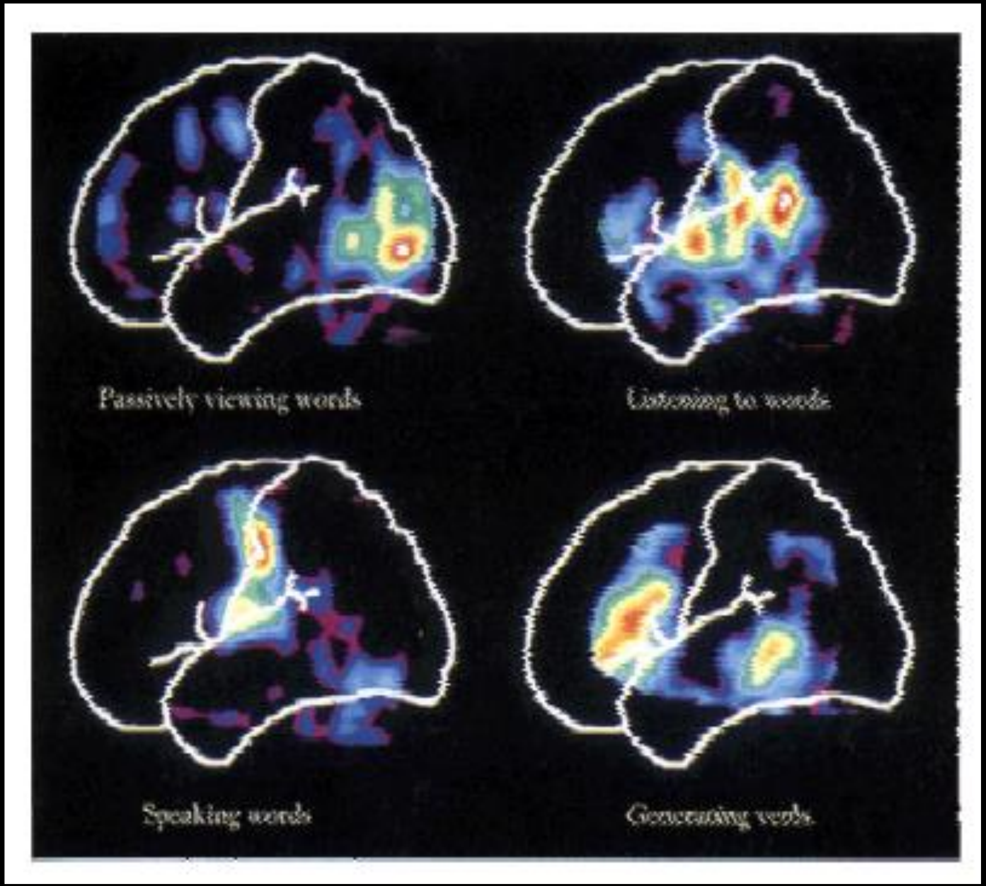
Functional Neuroimaging Techniques



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 <u>biochemical and physiological processes</u> within living organs.

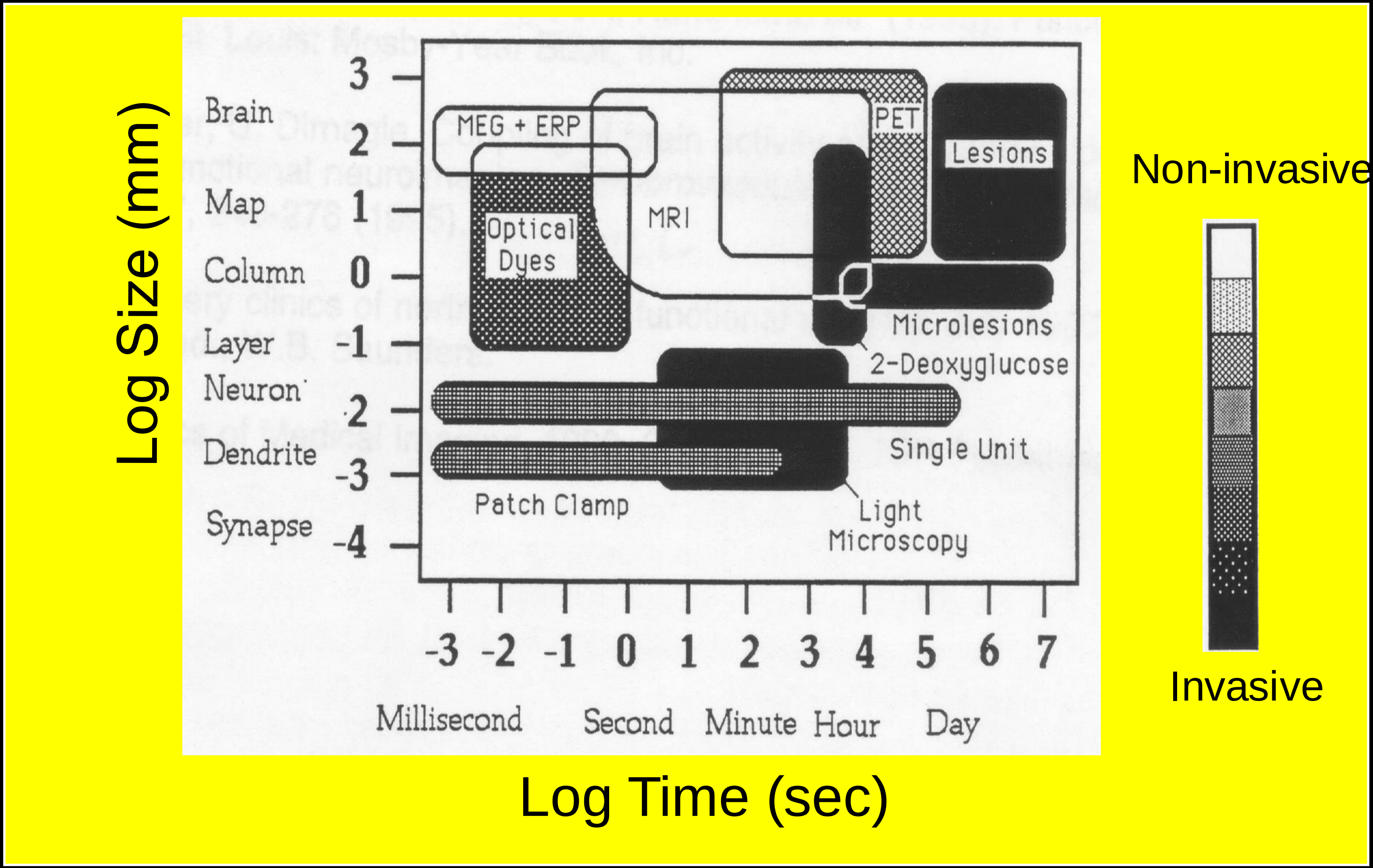




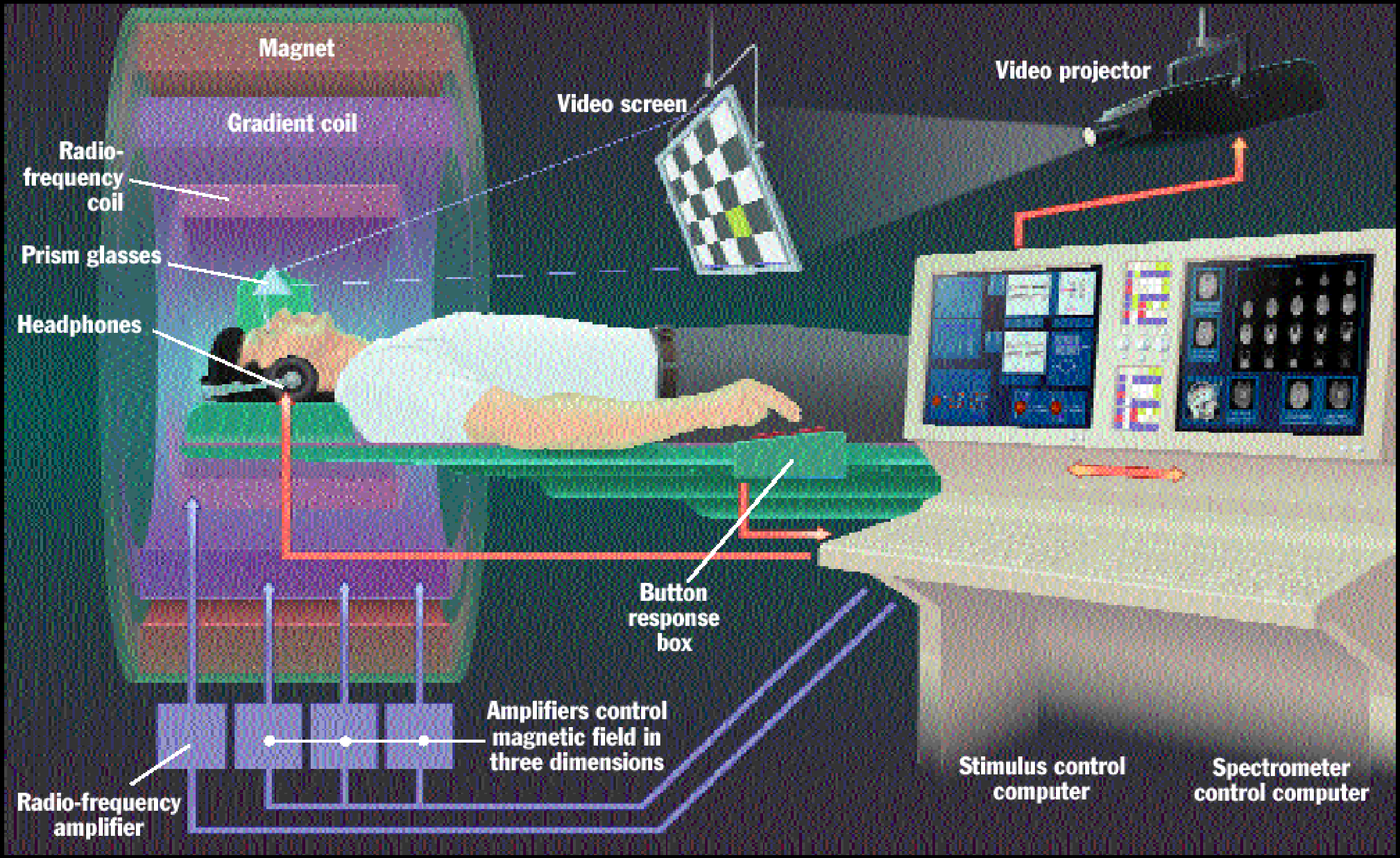
Passively viewing words
Listening to words
Speaking words
Generating verbs

Functional Magnetic Resonance Imaging

Functional Neuroimaging Techniques



fMRI Setup



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

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

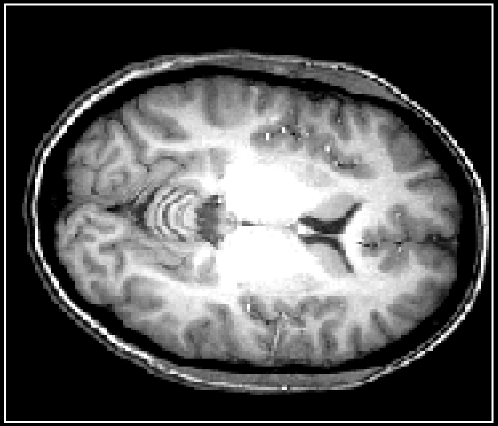
3T-1

3T-2

MRI vs. fMRI

MRI

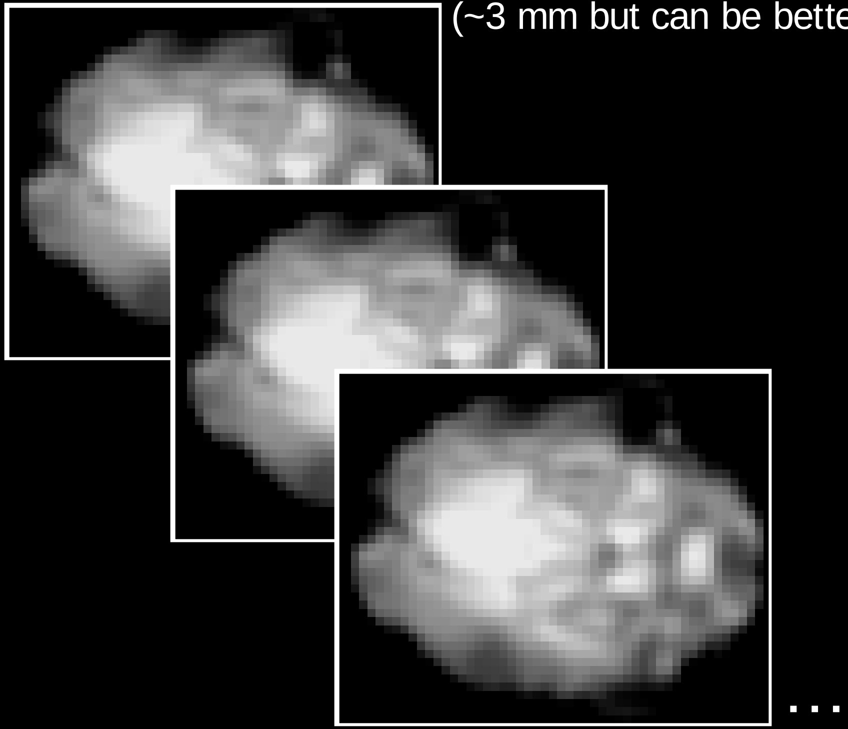
high resolution
(1 mm)



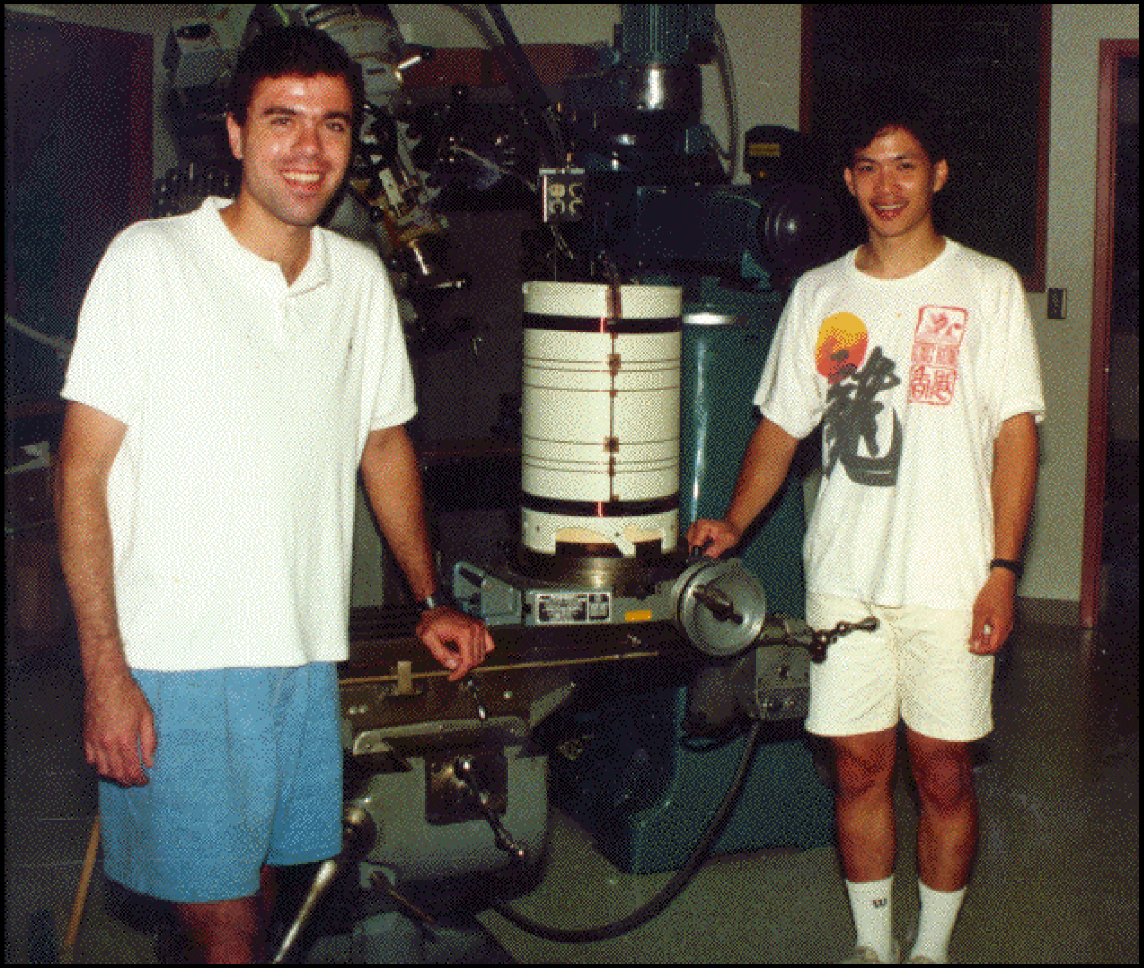
one image

fMRI

low resolution
(~3 mm but can be better)



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



August, 1991

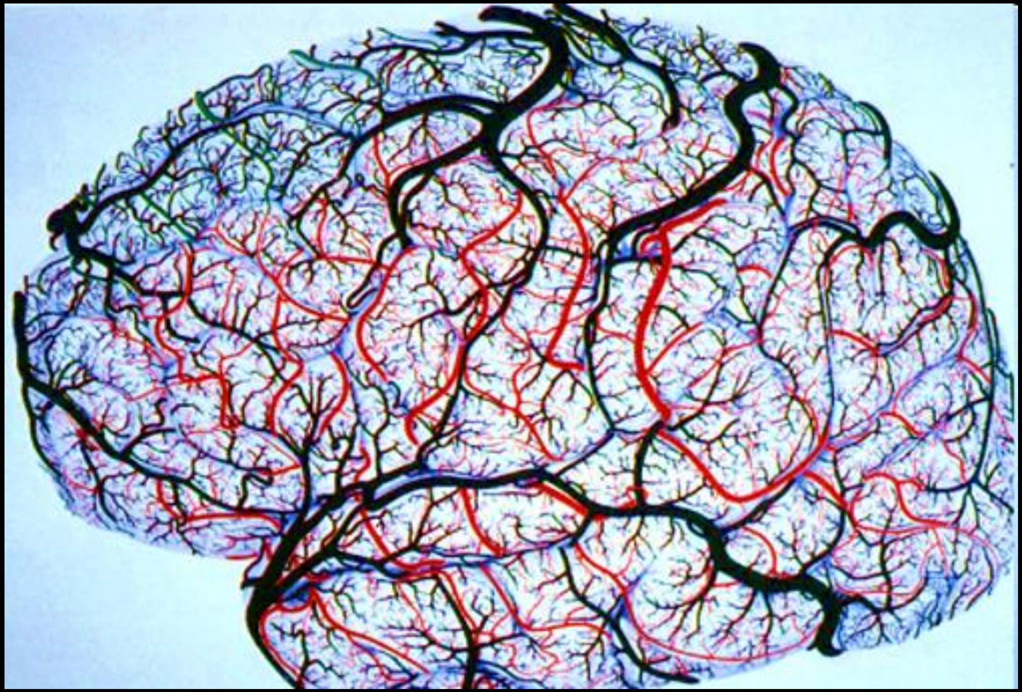
1991-1992

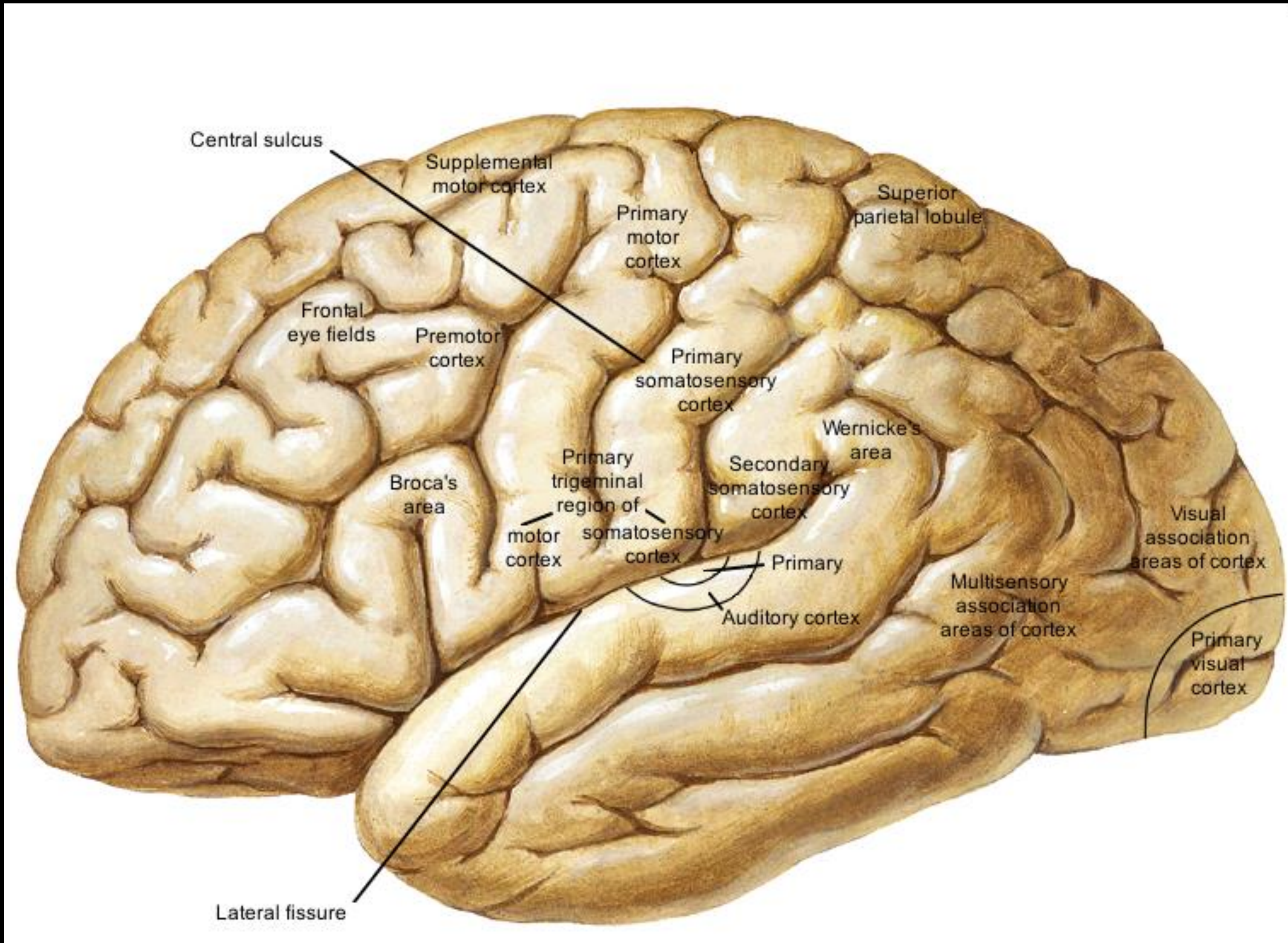
1992-1999

General Electric 3 Tesla Scanner

Contrast in Functional MRI

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

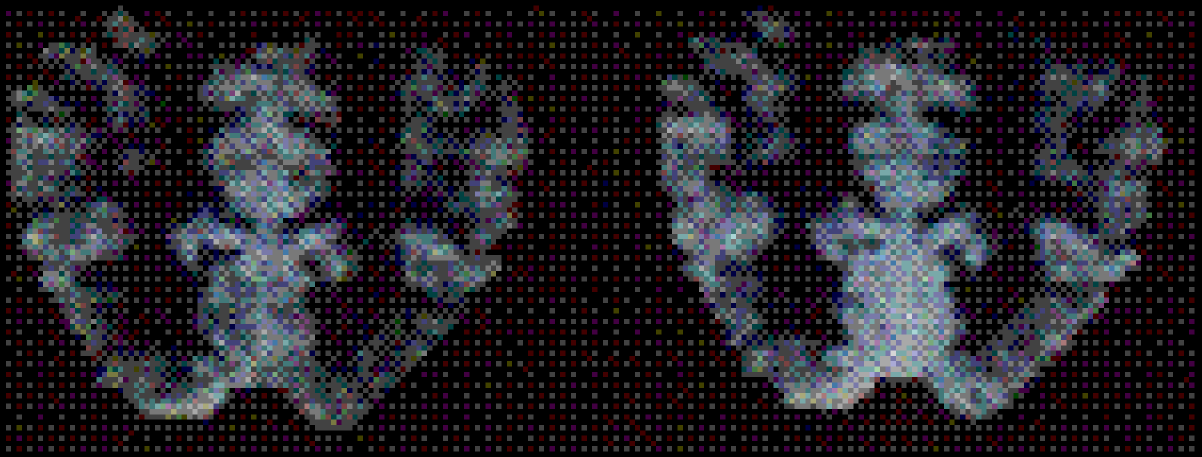


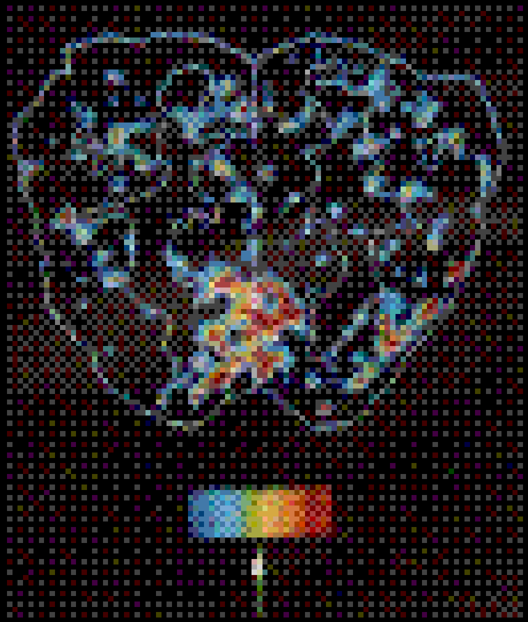


Central sulcus
Supplemental motor cortex
Primary motor cortex
Superior parietal lobule
Frontal eye fields
Premotor cortex
Primary somatosensory cortex
Wernicke's area
Broca's area
Primary trigeminal region of
motor cortex
somatosensory cortex
Secondary somatosensory cortex
Primary
Auditory cortex
Visual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

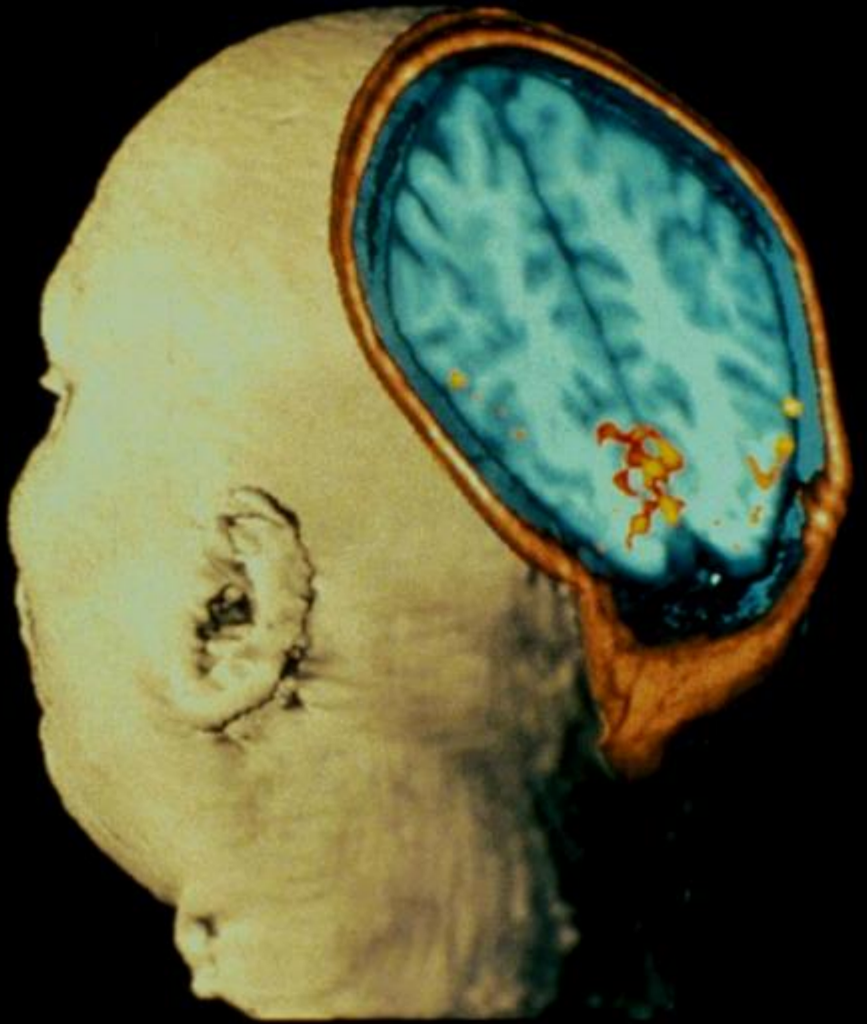
Blood Volume Changes with Brain Activation

Resting **Active**





Photic Stimulation



MRI Image showing activation of the Visual Cortex

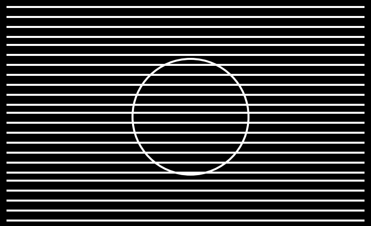
From Belliveau, et al.
Science Nov 1991

MSC - perfusion

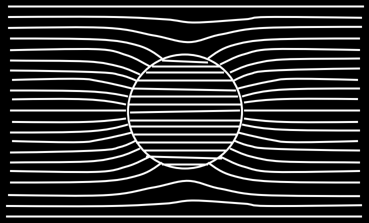
Oxygenated and deoxygenated red blood cells have different magnetic properties

red blood cells

oxygenated



deoxygenated



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

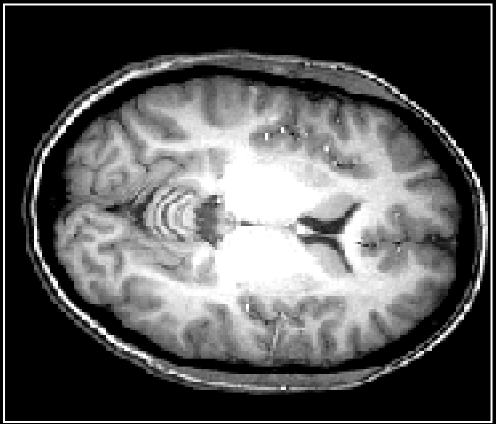
K.R. Thulborn, J. C. Waterton, et al., *Biochim. Biophys. Acta. 714: 265-270*, **1982**.

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

MRI vs. fMRI

MRI

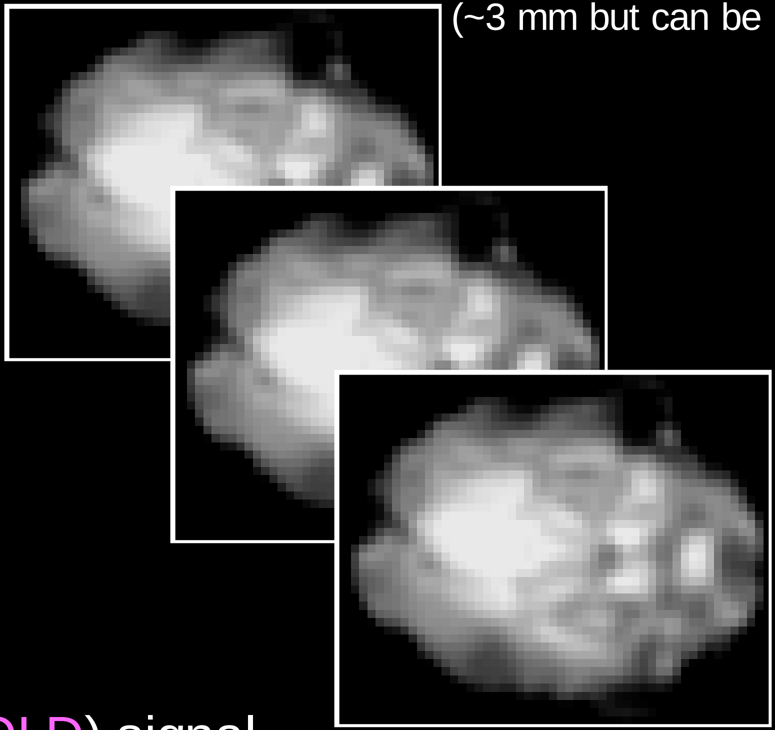
high resolution
(1 mm)



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

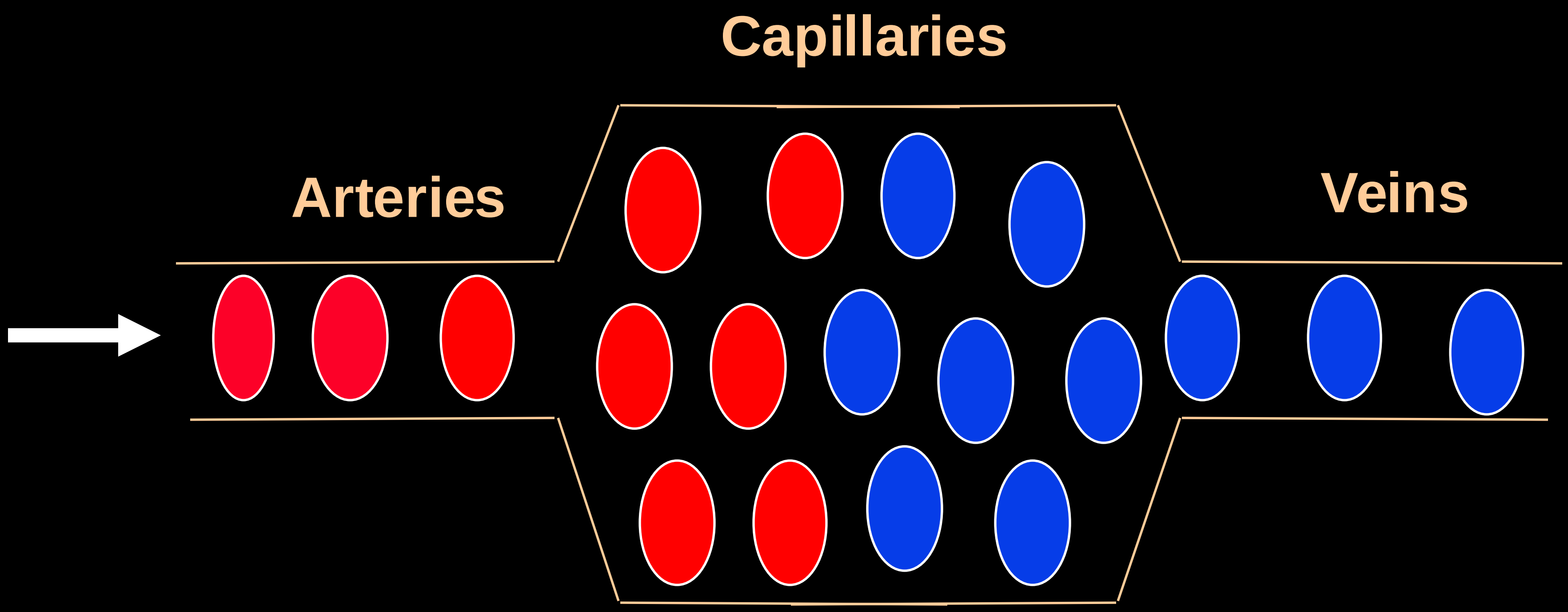
(blood oxygenation level dependence)

blood flow ↑

oxygenated-blood ↑

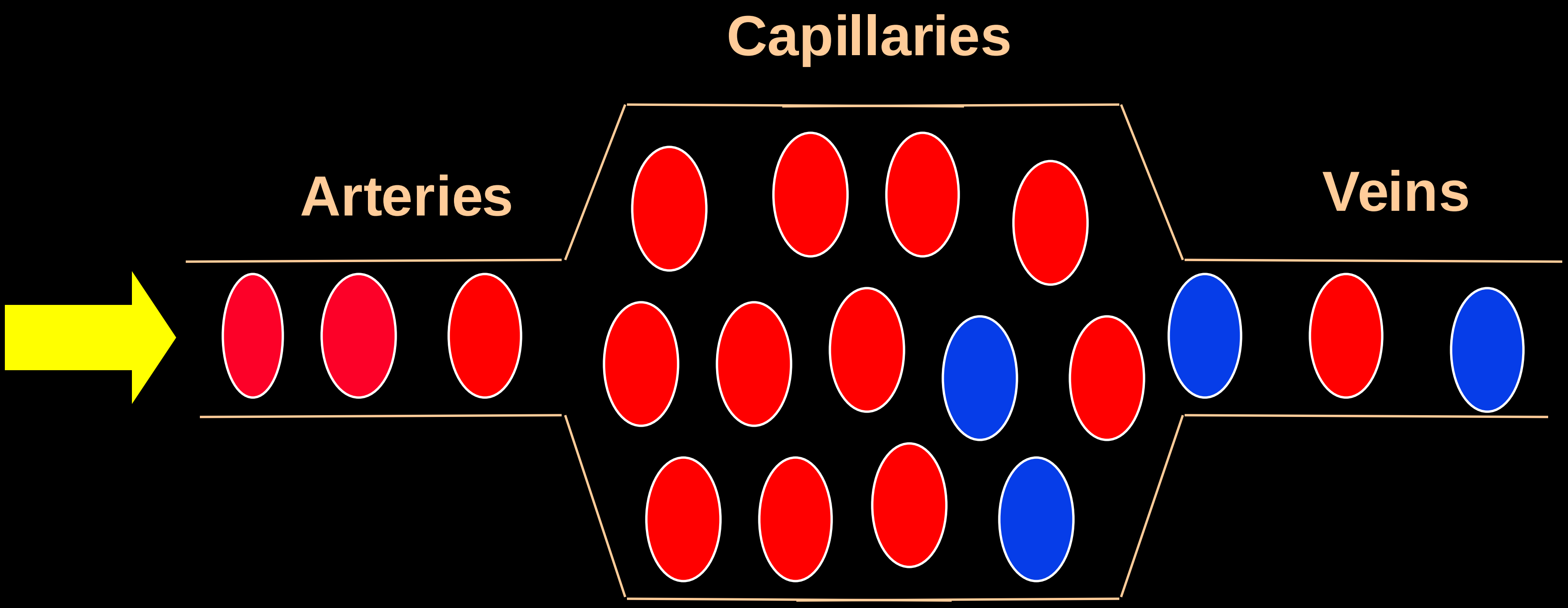
MR signal ↑

BOLD: Resting flow

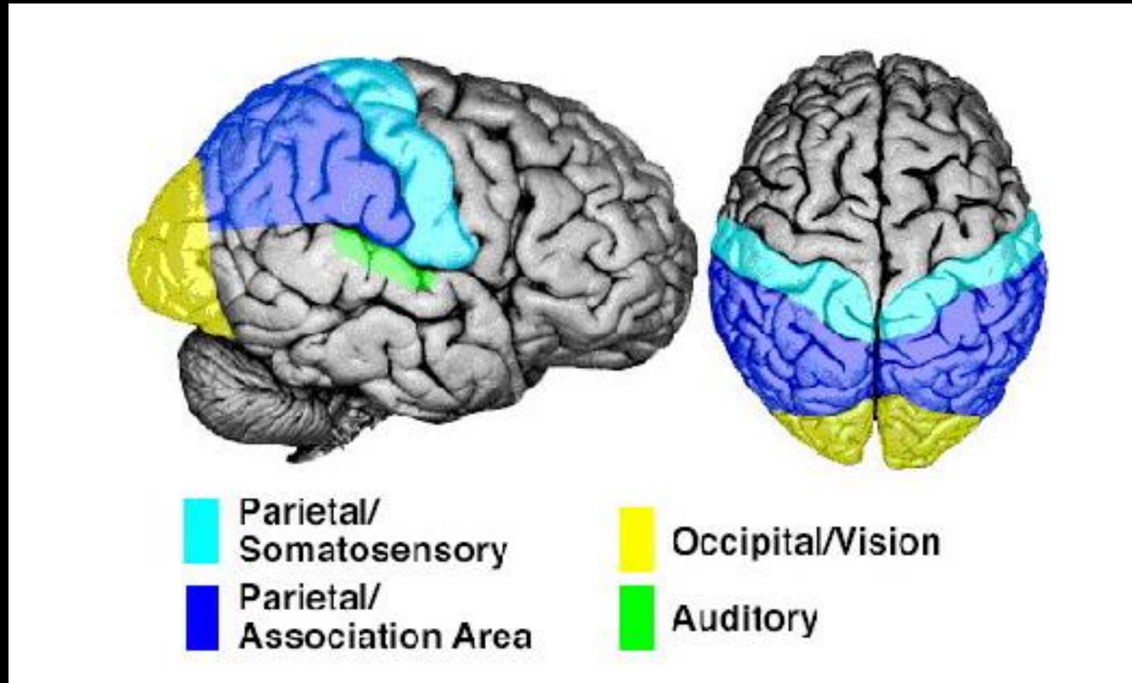


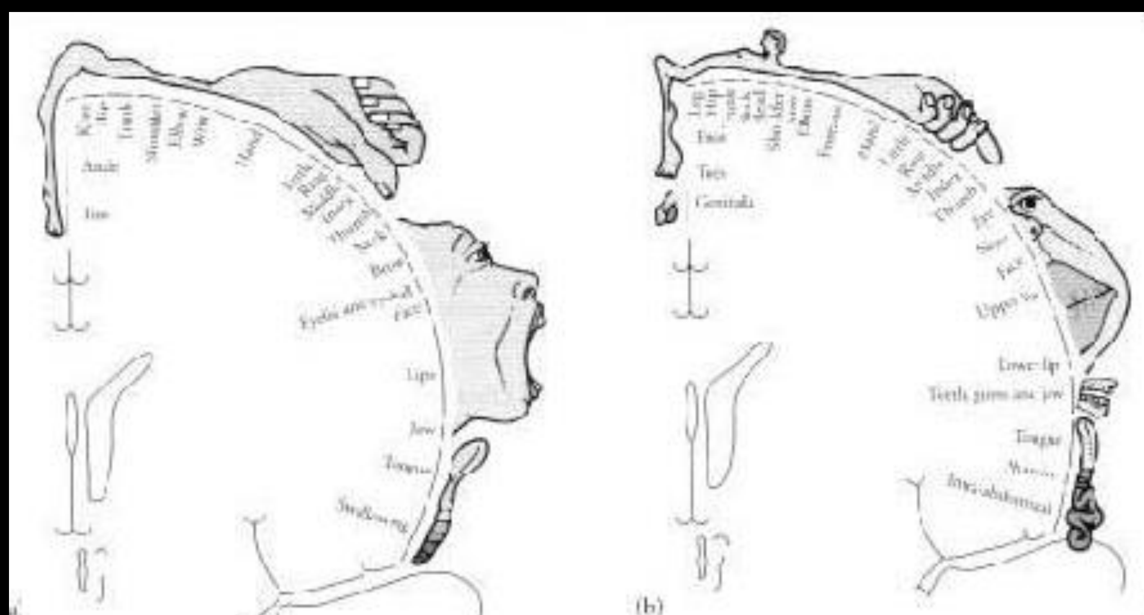
SIGNAL

BOLD: Activated flow



SIGNAL


Parietal/
Somatosensory
Parietal/
Association Area
Occipital/Vision
Auditory


(b)

Alternating Left and Right Finger Tapping

~ 1992

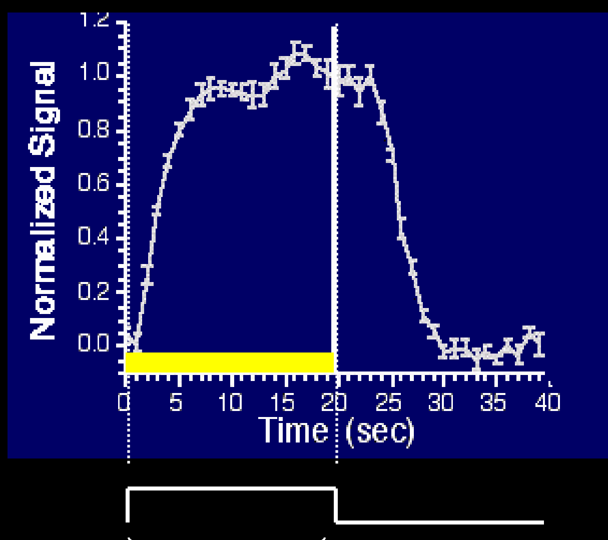
Real Time Brain Activation Imaging

•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.

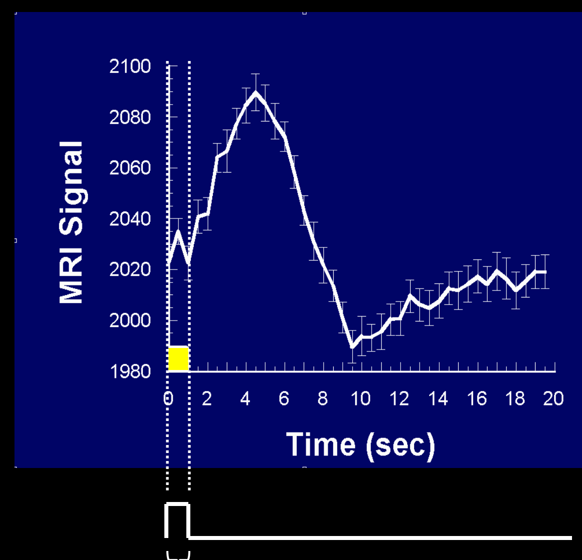
•S. Ogawa, et al., (1992) “Intrinsic signal changes accompanying sensory stimulation: functional brain mapping with magnetic resonance imaging. Proc. Natl. Acad. Sci. USA.” 89, 5951-5955.

•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.

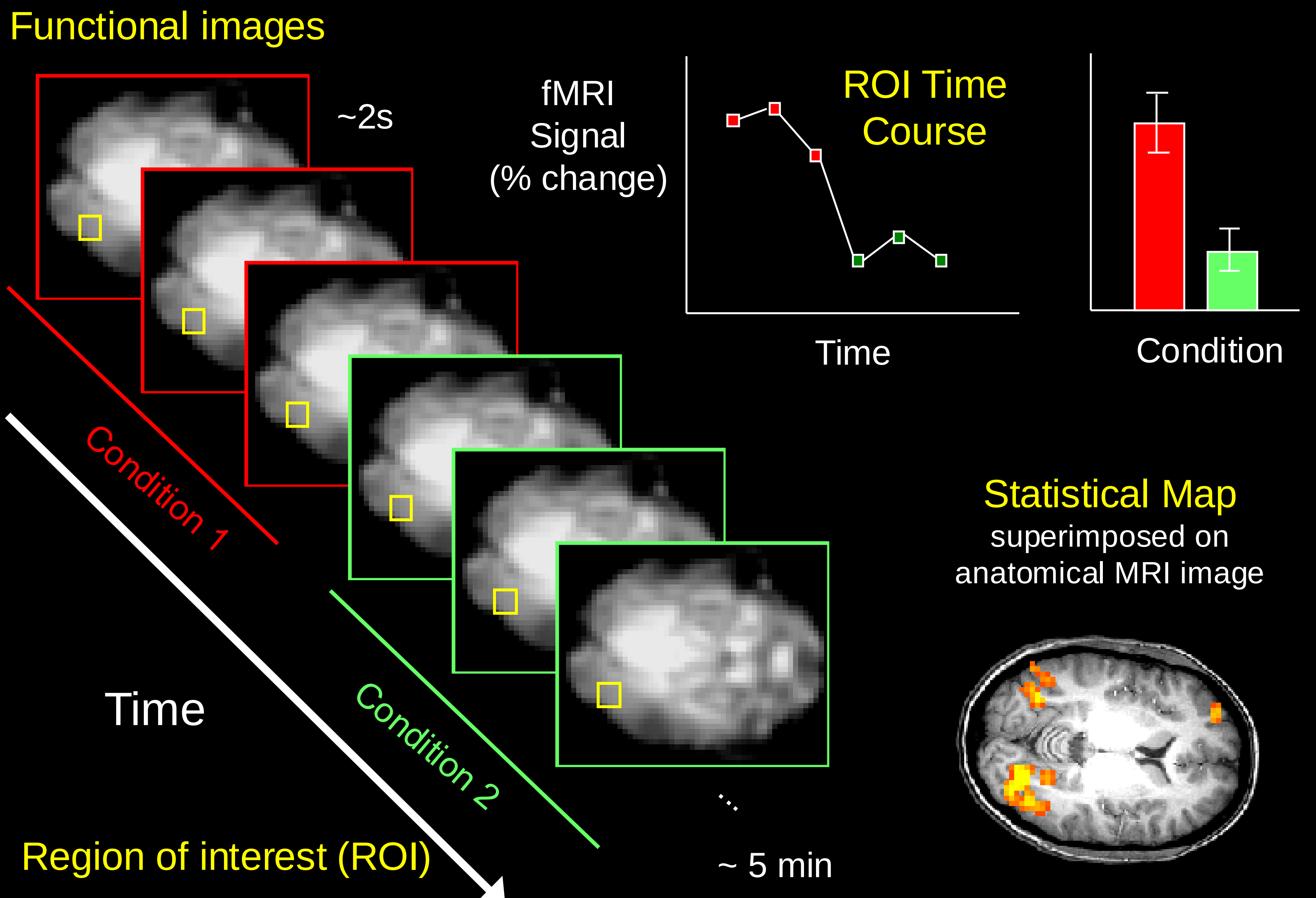


task



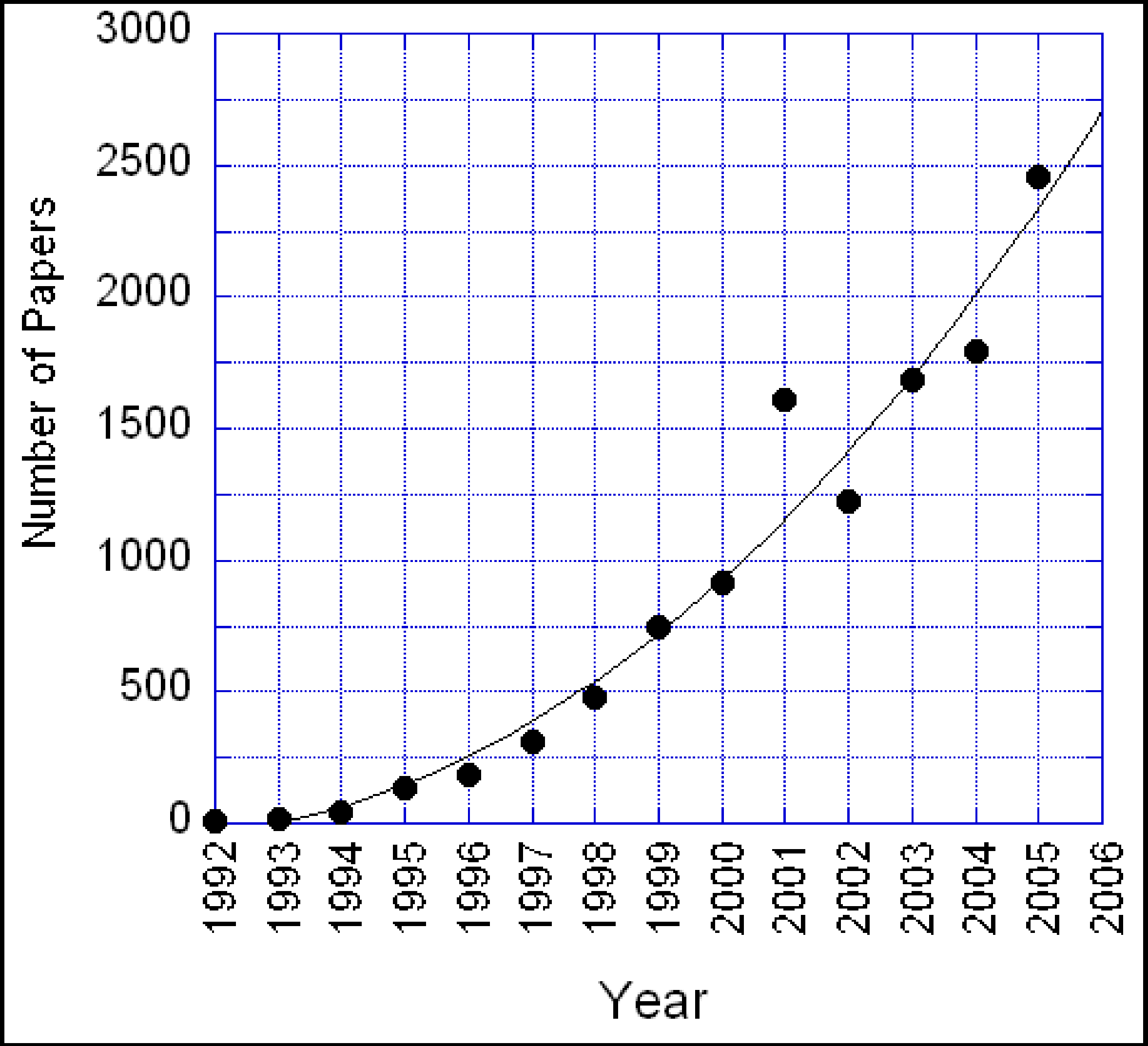
task

Activation Statistics

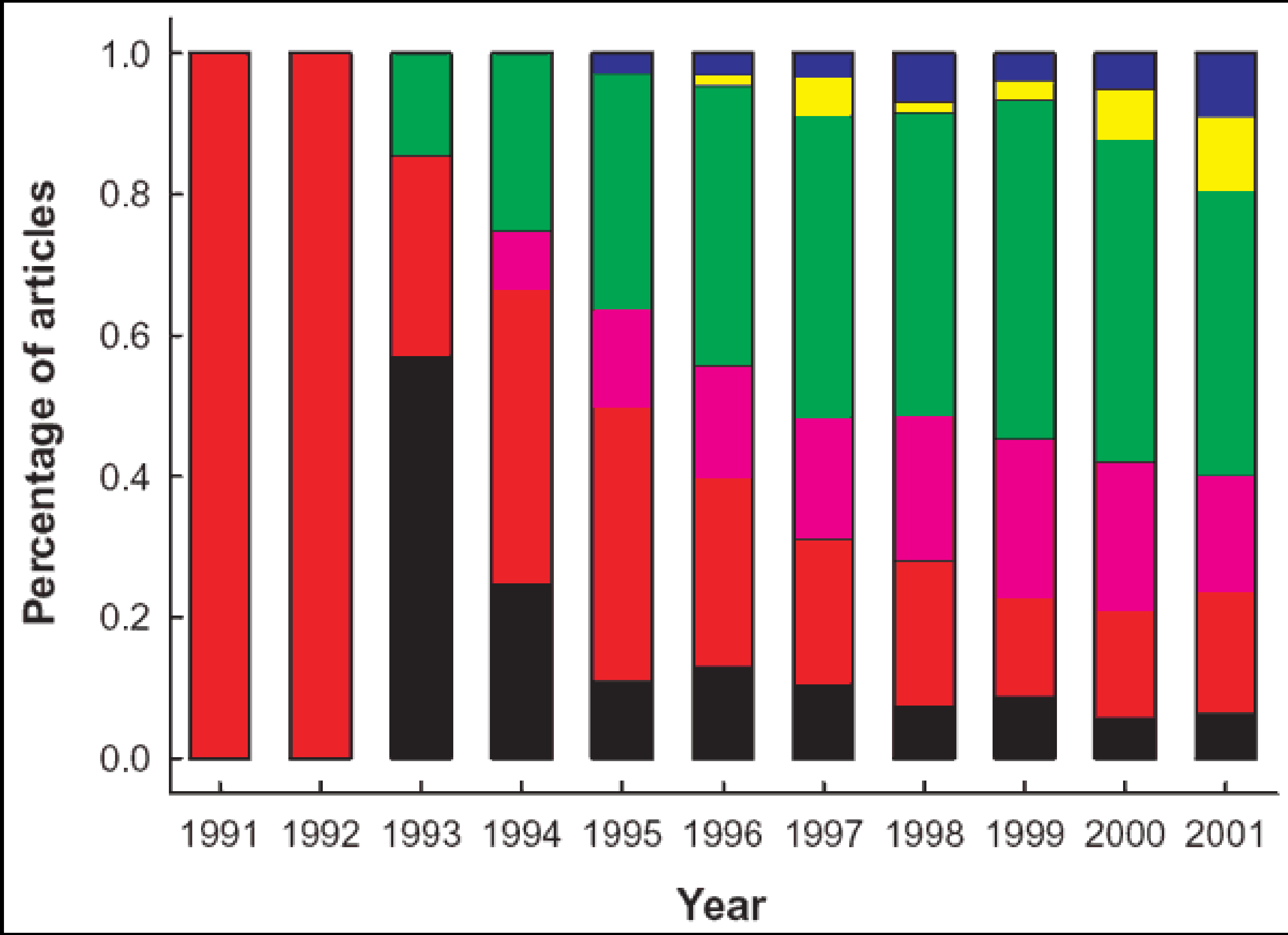


Courtesy, Robert Cox, Scientific and Statistical Computing Core Facility, NIMH

fMRI Papers Published per Year



"fMRI" or "functional MRI"



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**

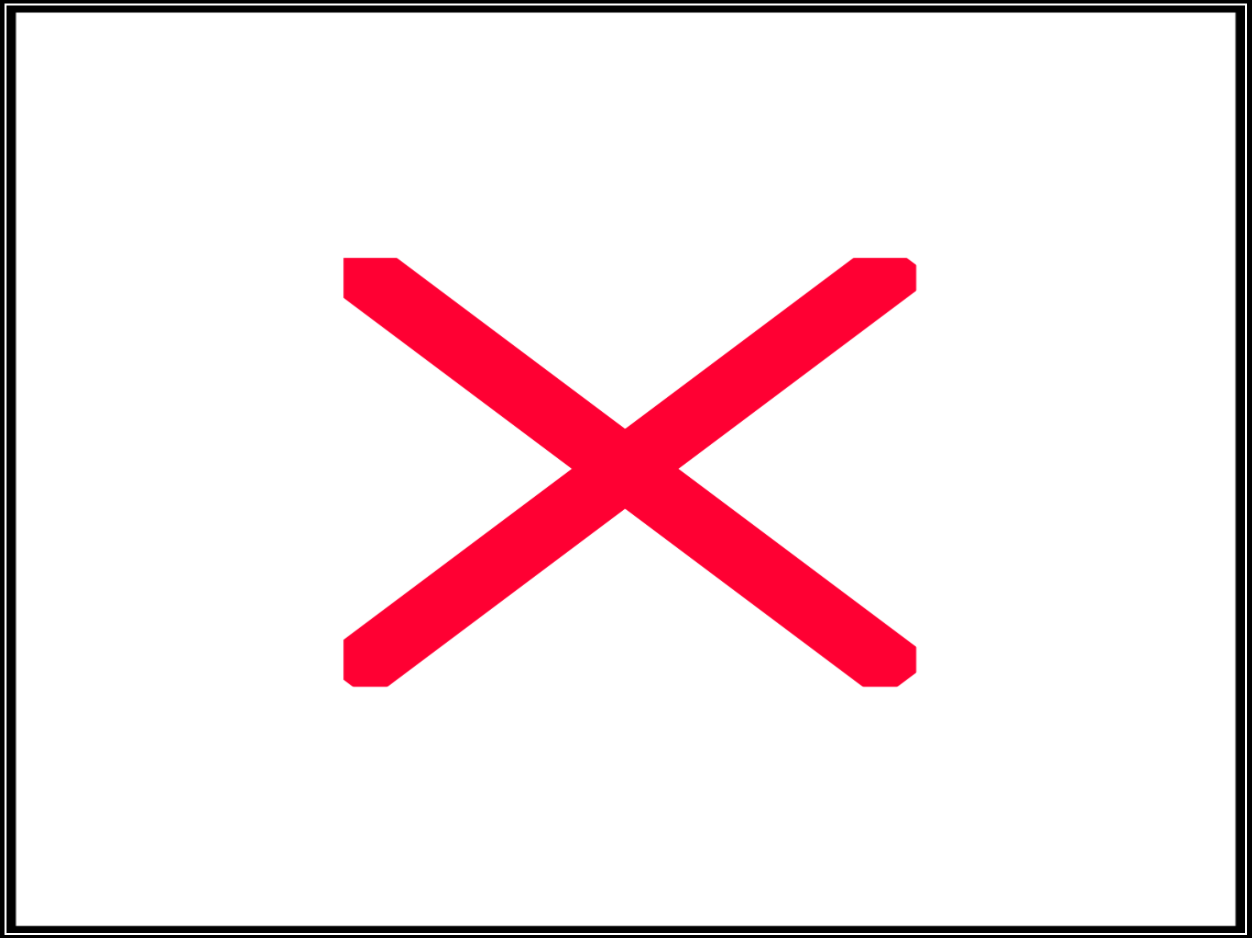
Clinical treatment and assessment

- **-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…

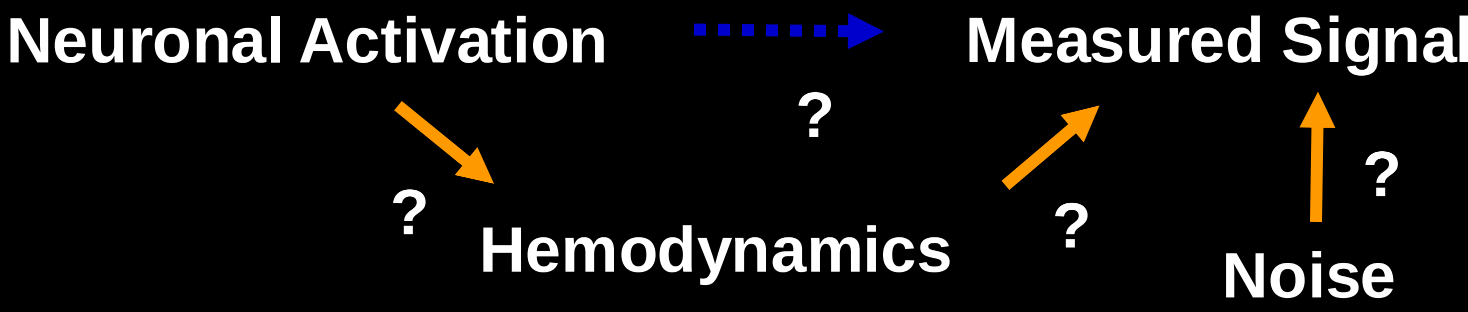


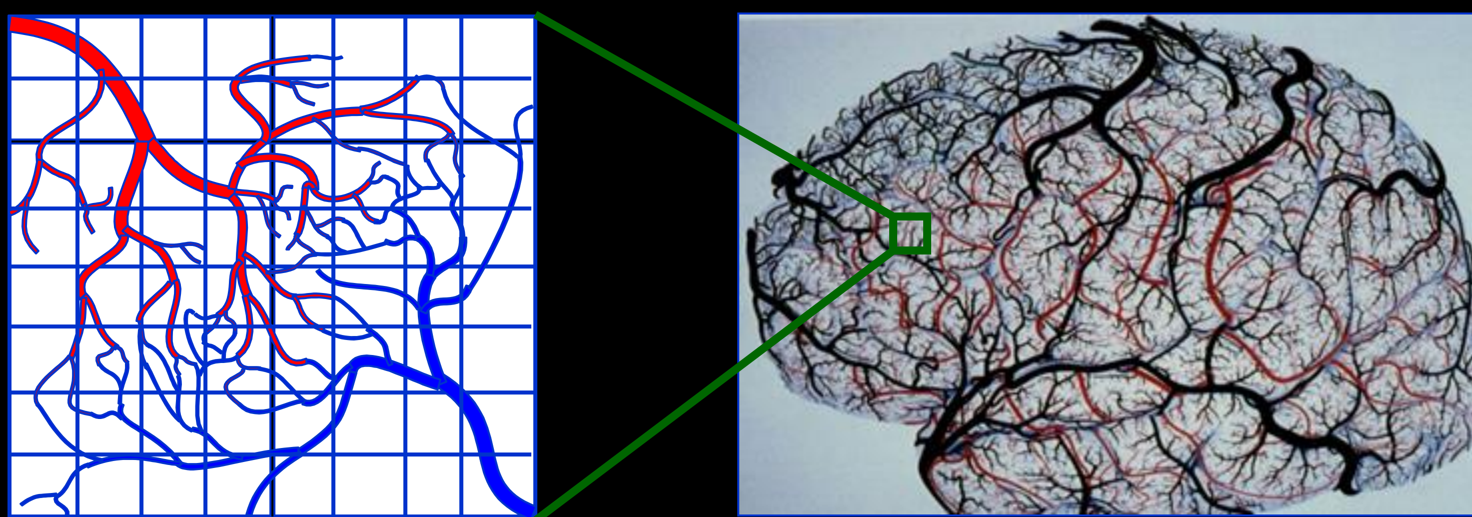
1.5 Gbytes/Day
max: 5.4 Gbytes

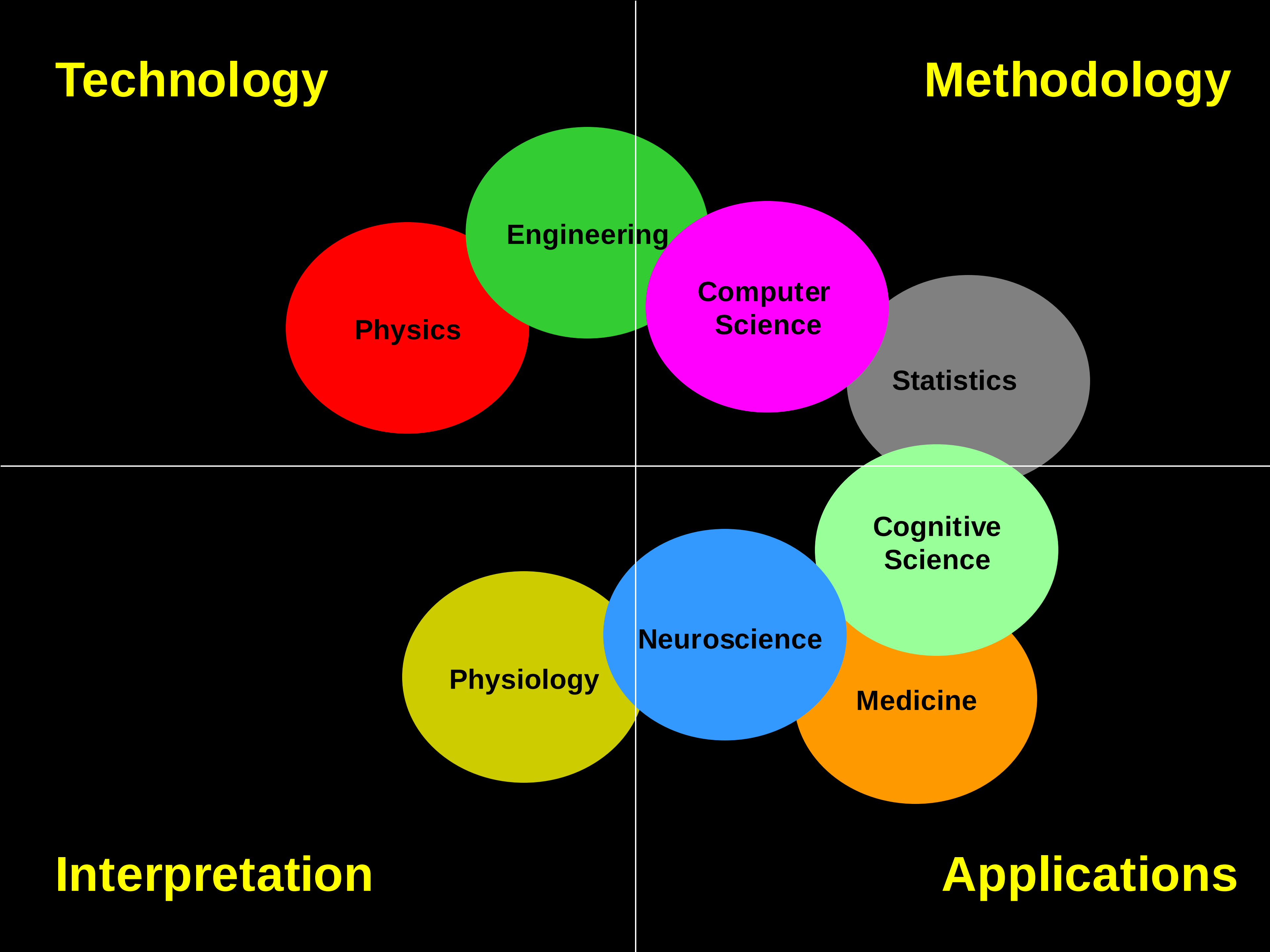
What my group is working on…

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)

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

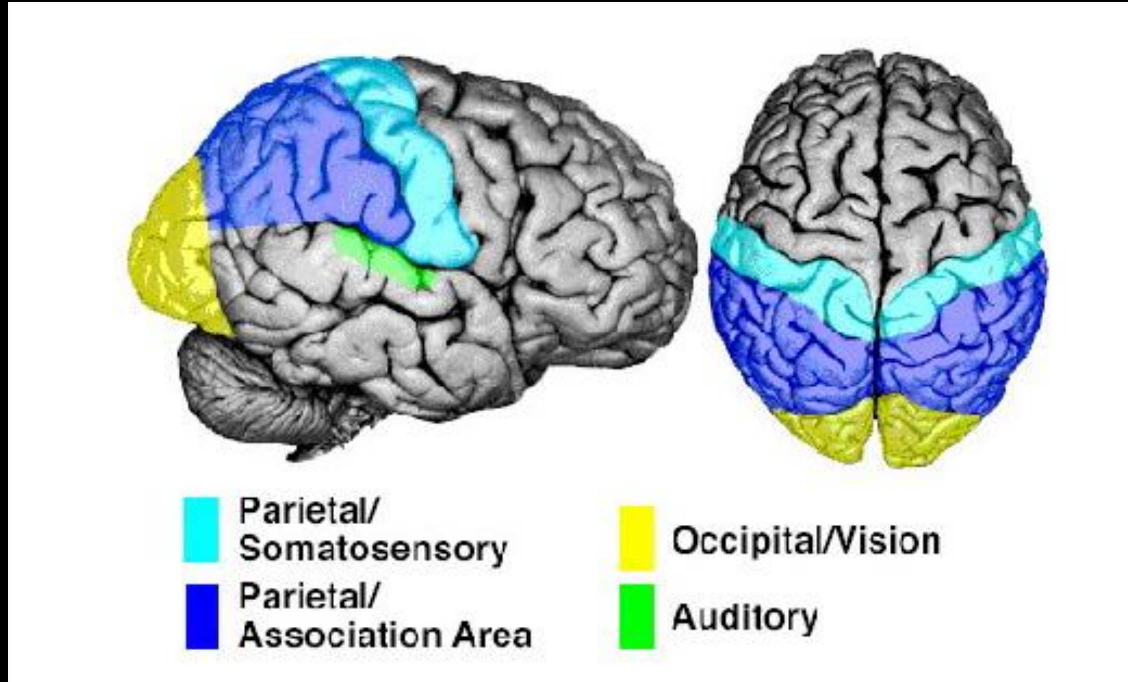
Niko Kriegeskorte (Psychology/Statistics)

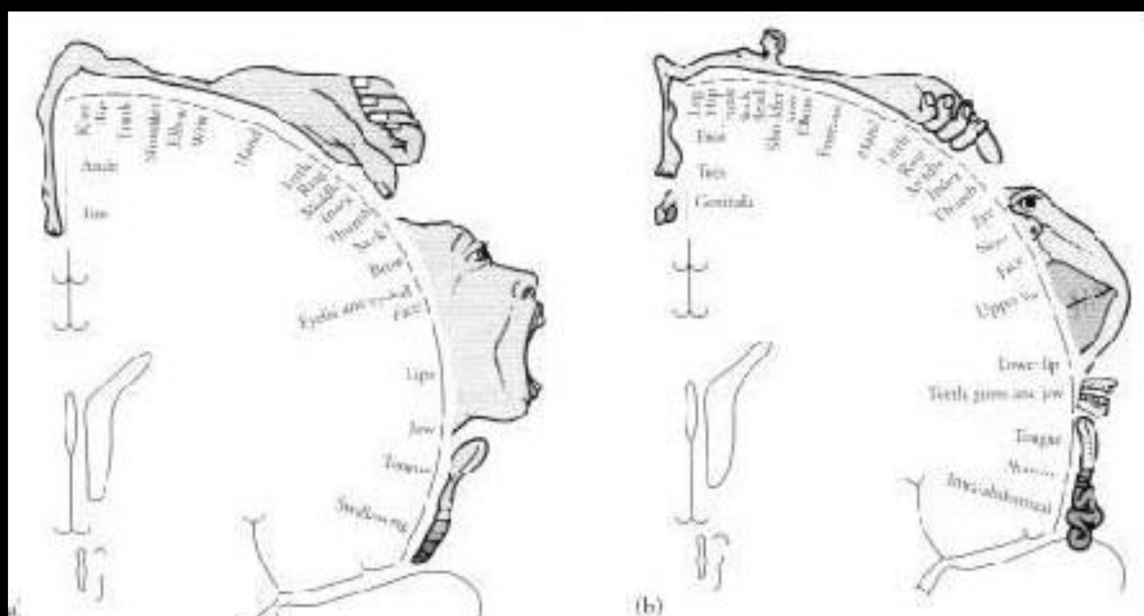
Monica Smith (Physics)
Najah Waters (Psychology)
Douglass Ruff (Psychology)
David Ruff (Neuroscience)
Marieke Mur (Neuroscience)

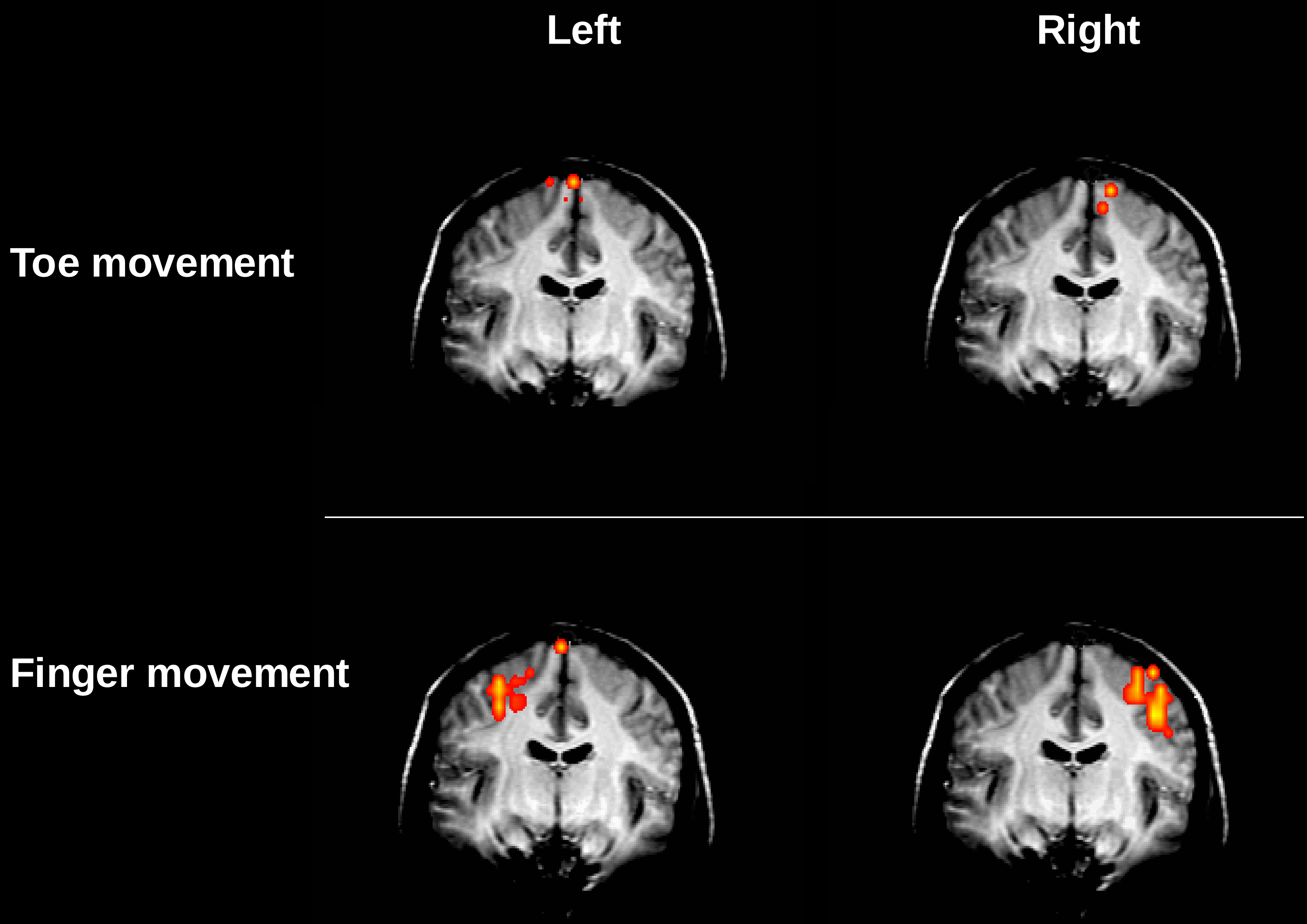
FMRI Core Facility

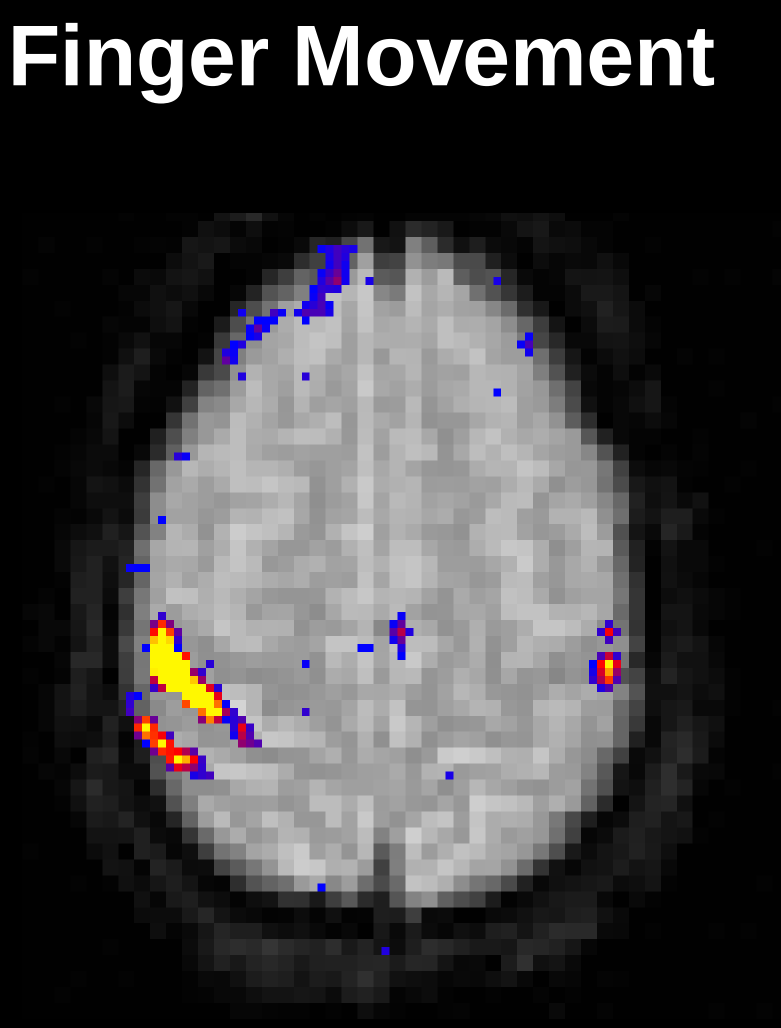
Jerzy Bodurka (Physics)
Sean Marrett (Neuroscience)
Frank Ye (Physics)
Wen-Ming Luh (Physics)

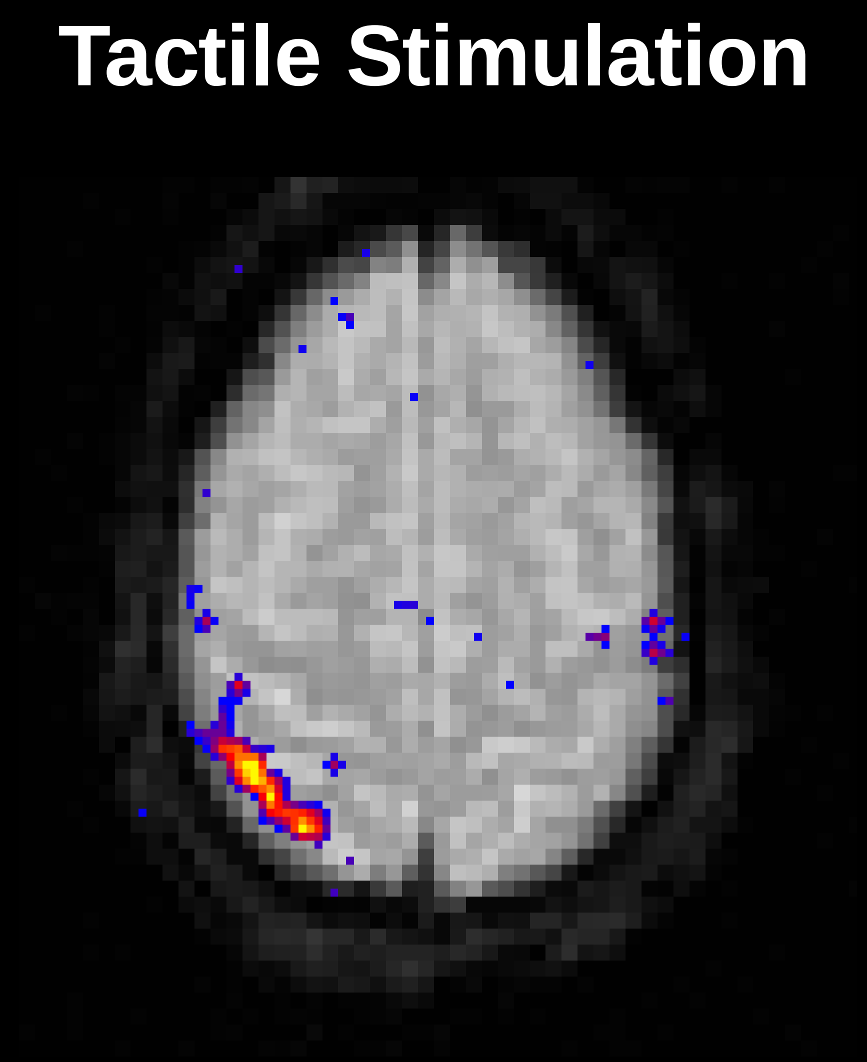
Adam Thomas (Computers/Neurosci)
Karen Bove-Bettis (MR Tech)
Paula Rowser (MR Tech)
Alda Ottley (MR Tech)
Ellen Condon (MR Tech)

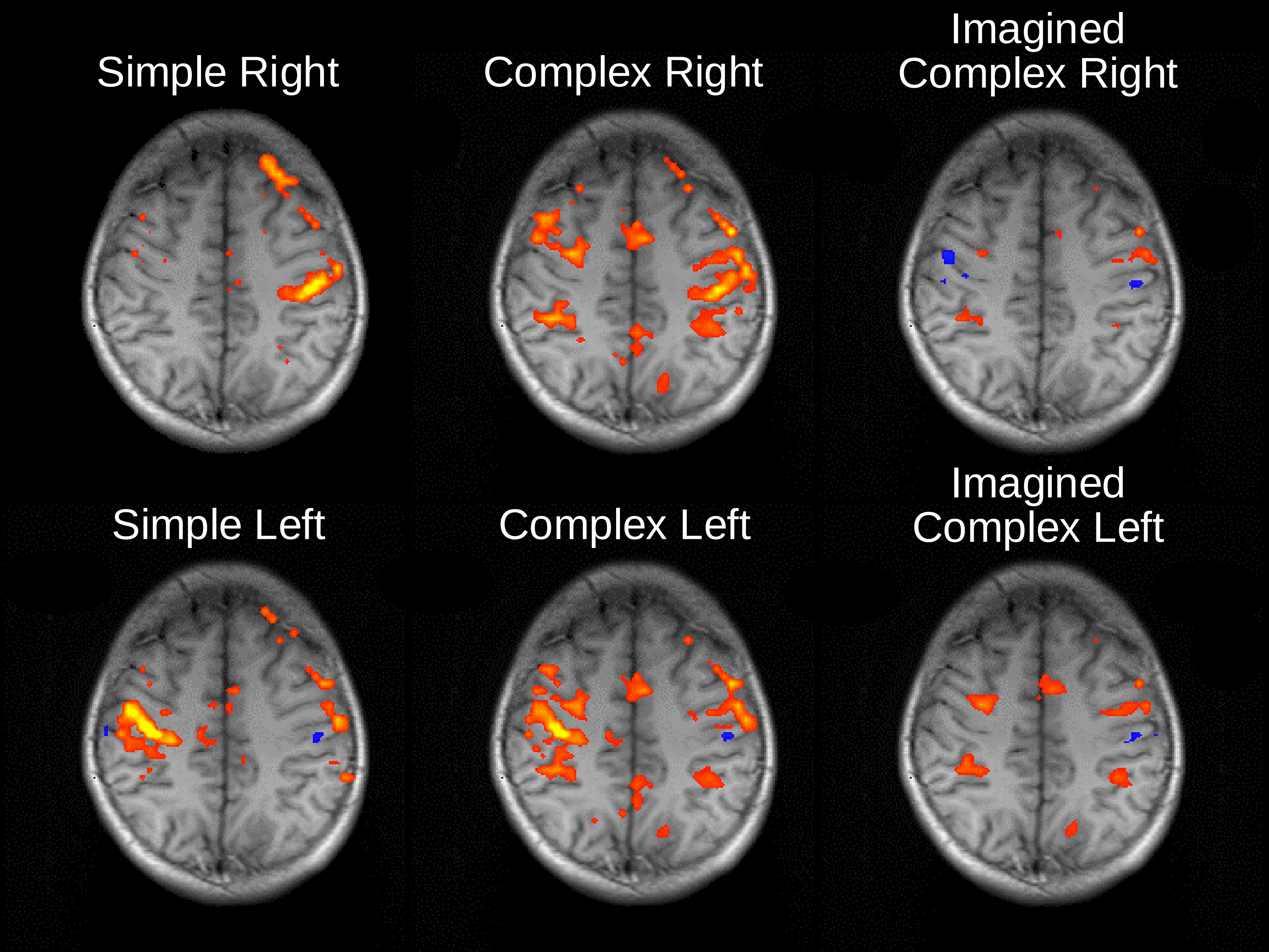

Parietal/
Somatosensory
Parietal/
Association Area
Occipital/Vision
Auditory

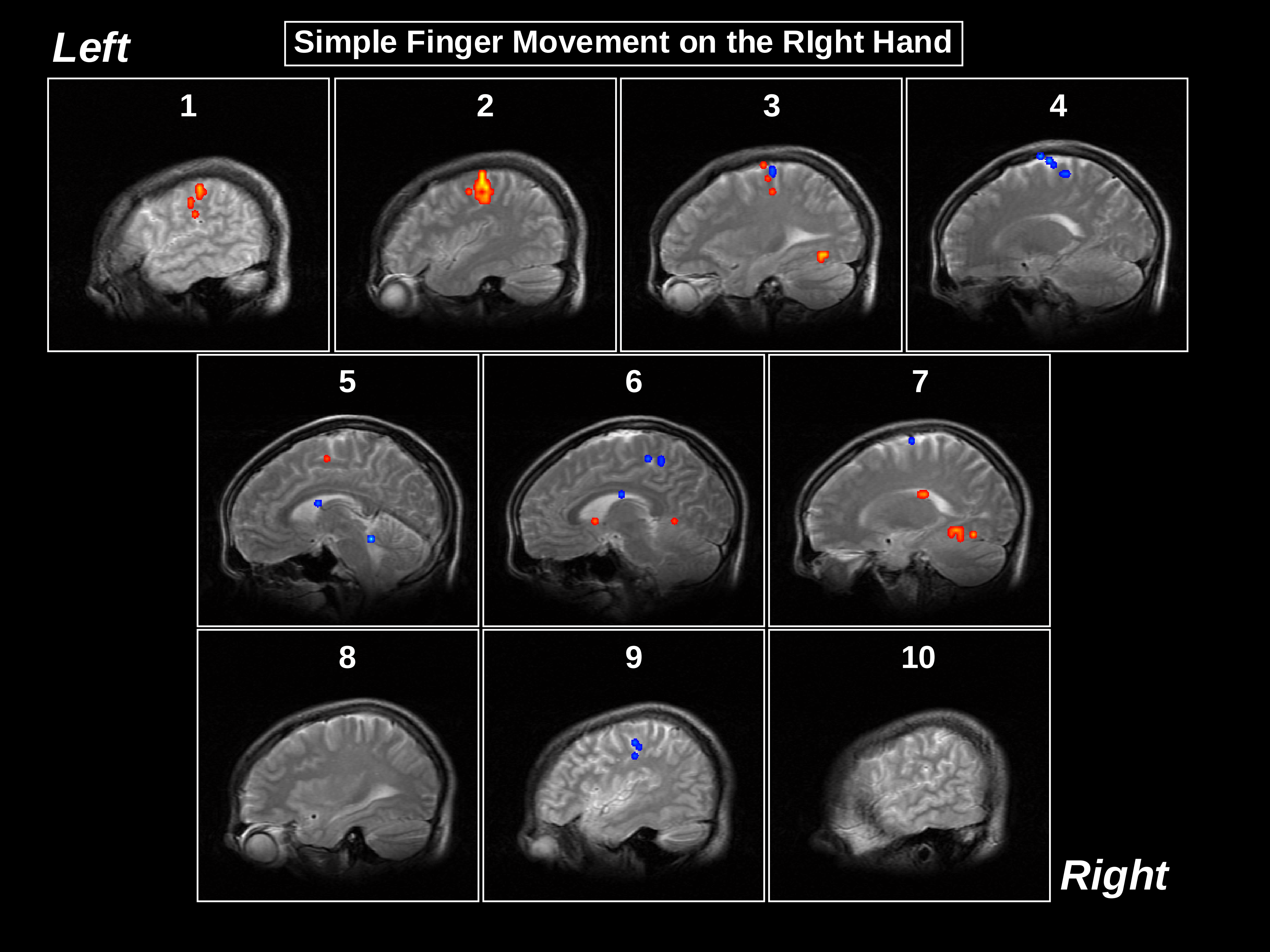

Brow
Lips
Jaw
Swallowing
Genitals
Face
Lower lip
Tongue
(b)

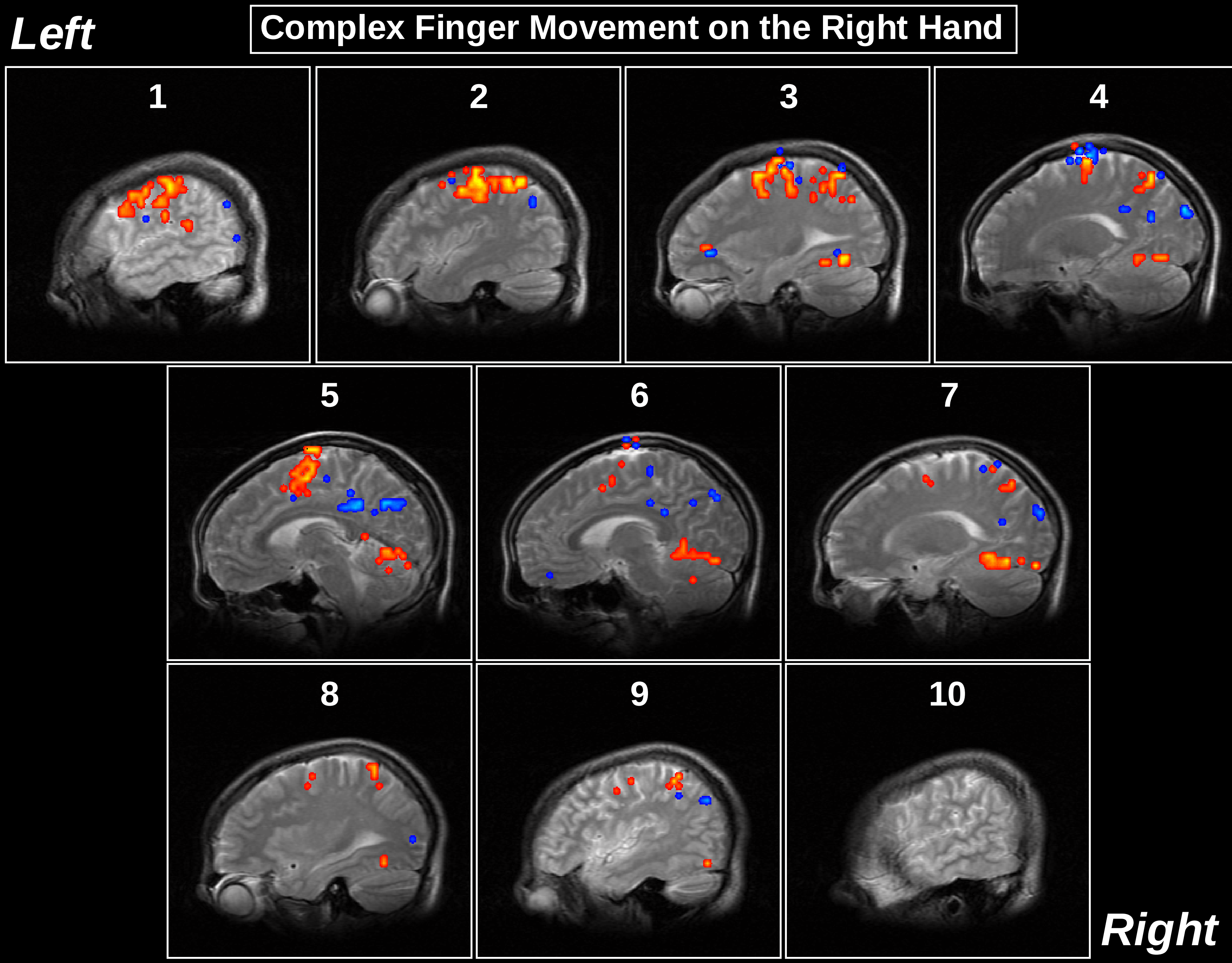

Left
Right
Toe movement
Finger movement

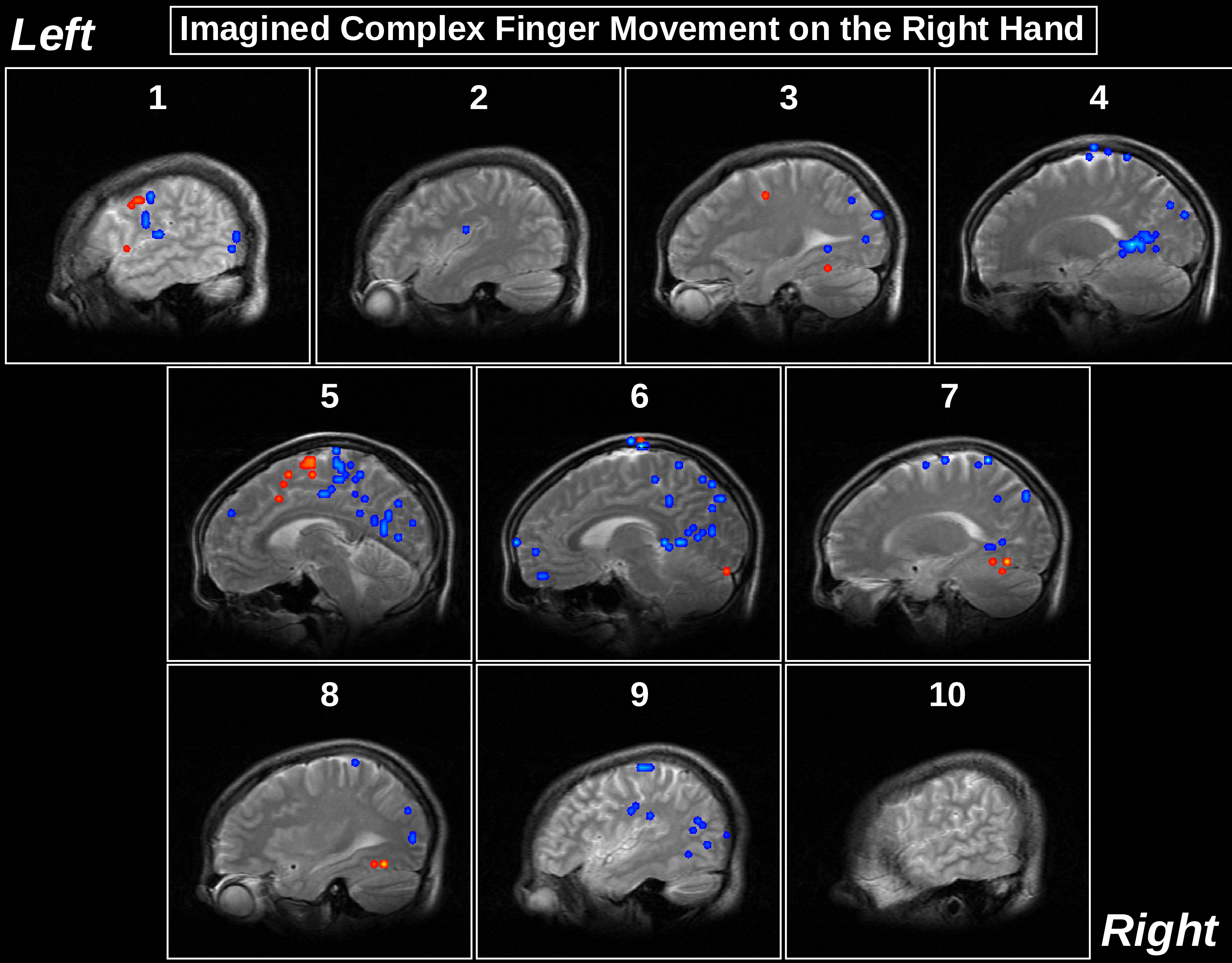

Finger Movement


Tactile Stimulation


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

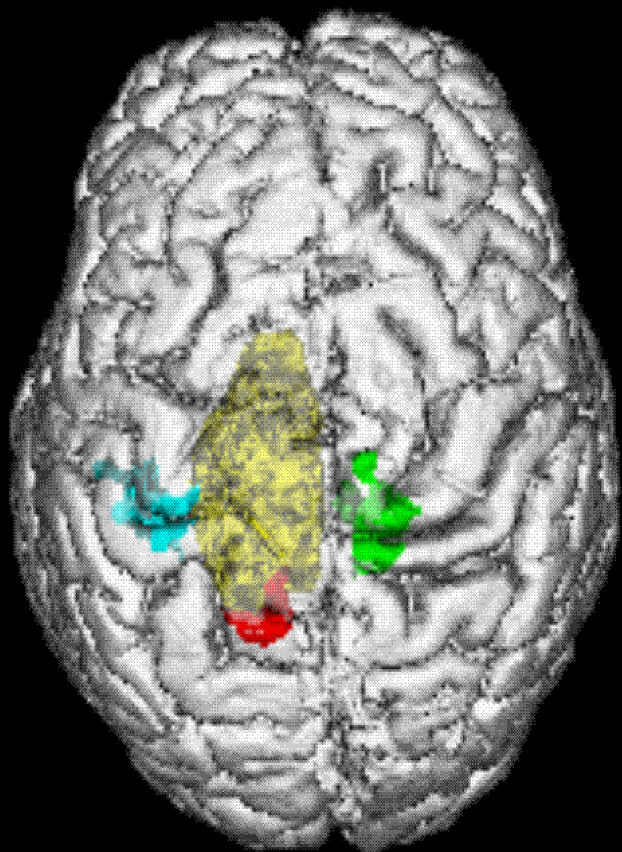

Left
Simple Finger Movement on the RIght Hand
1
2
3
4
5
6
7
8
9
10
Right


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

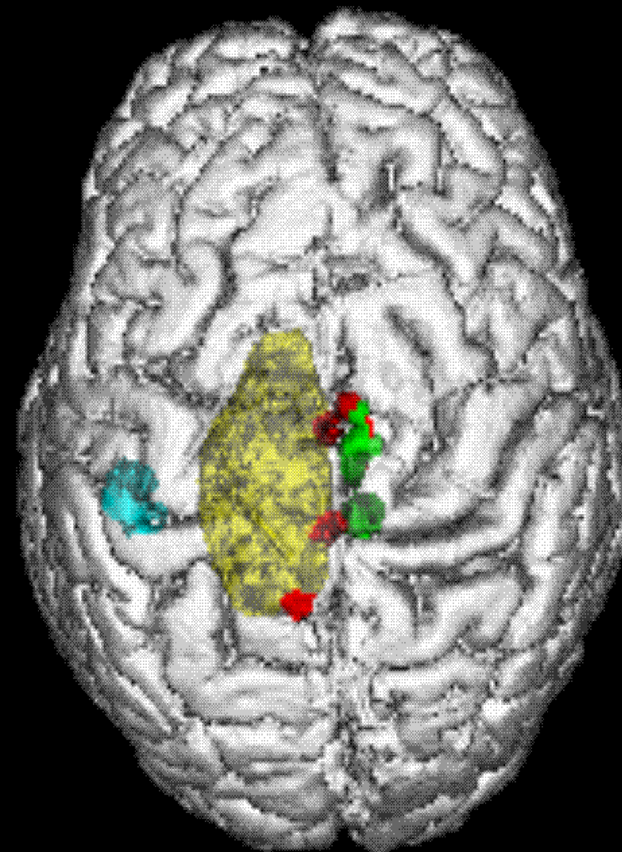

Left
Imagined Complex Finger Movement on the Right Hand
1
2
3
4
5
6
7
8
9
10
Right

Presurgical Mapping

Left Foot Tumor Right Foot Right Hand

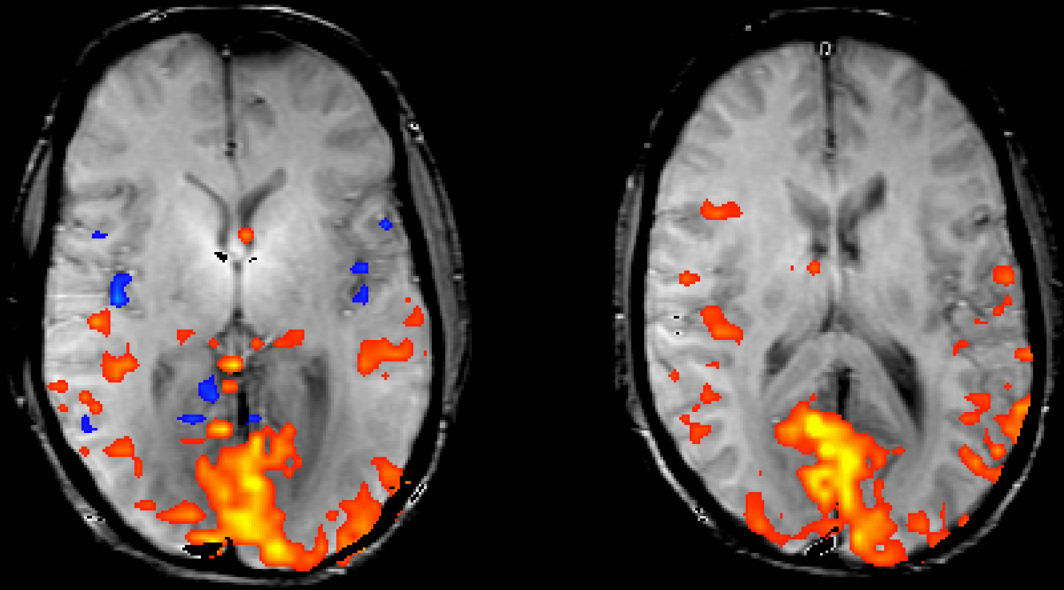


fMRI

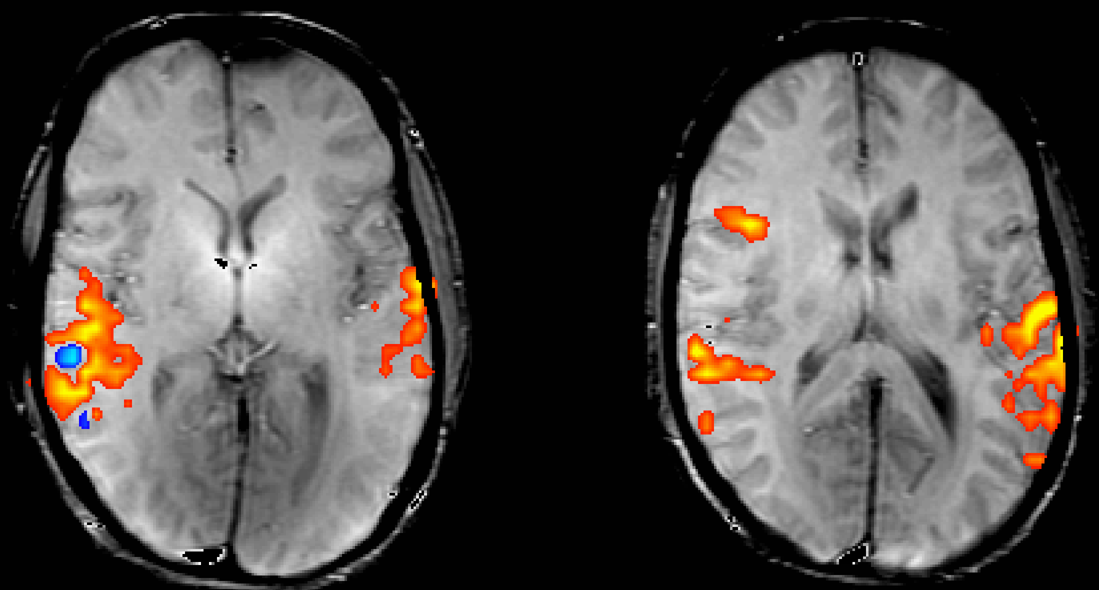


O-15 PET

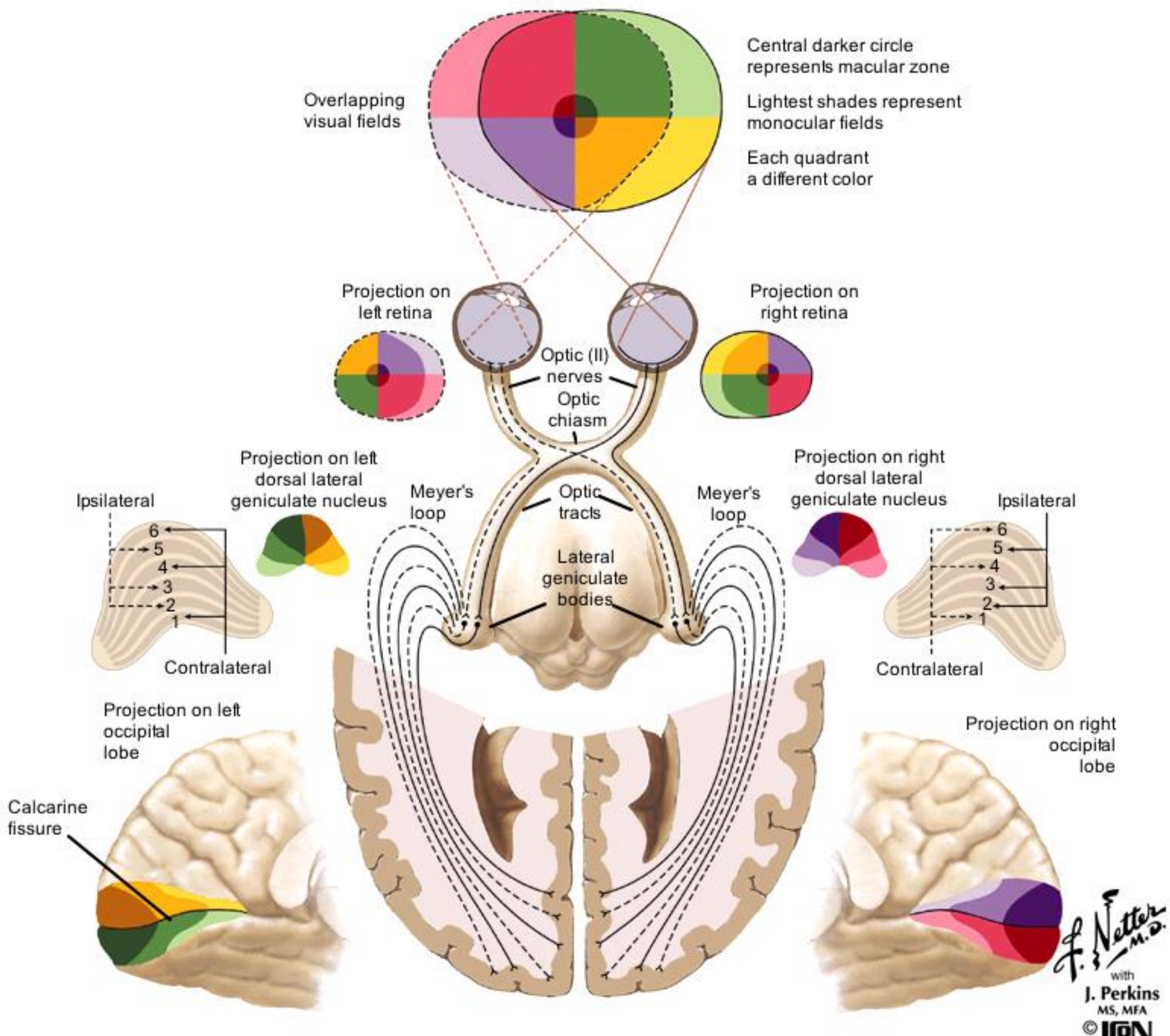
Reading

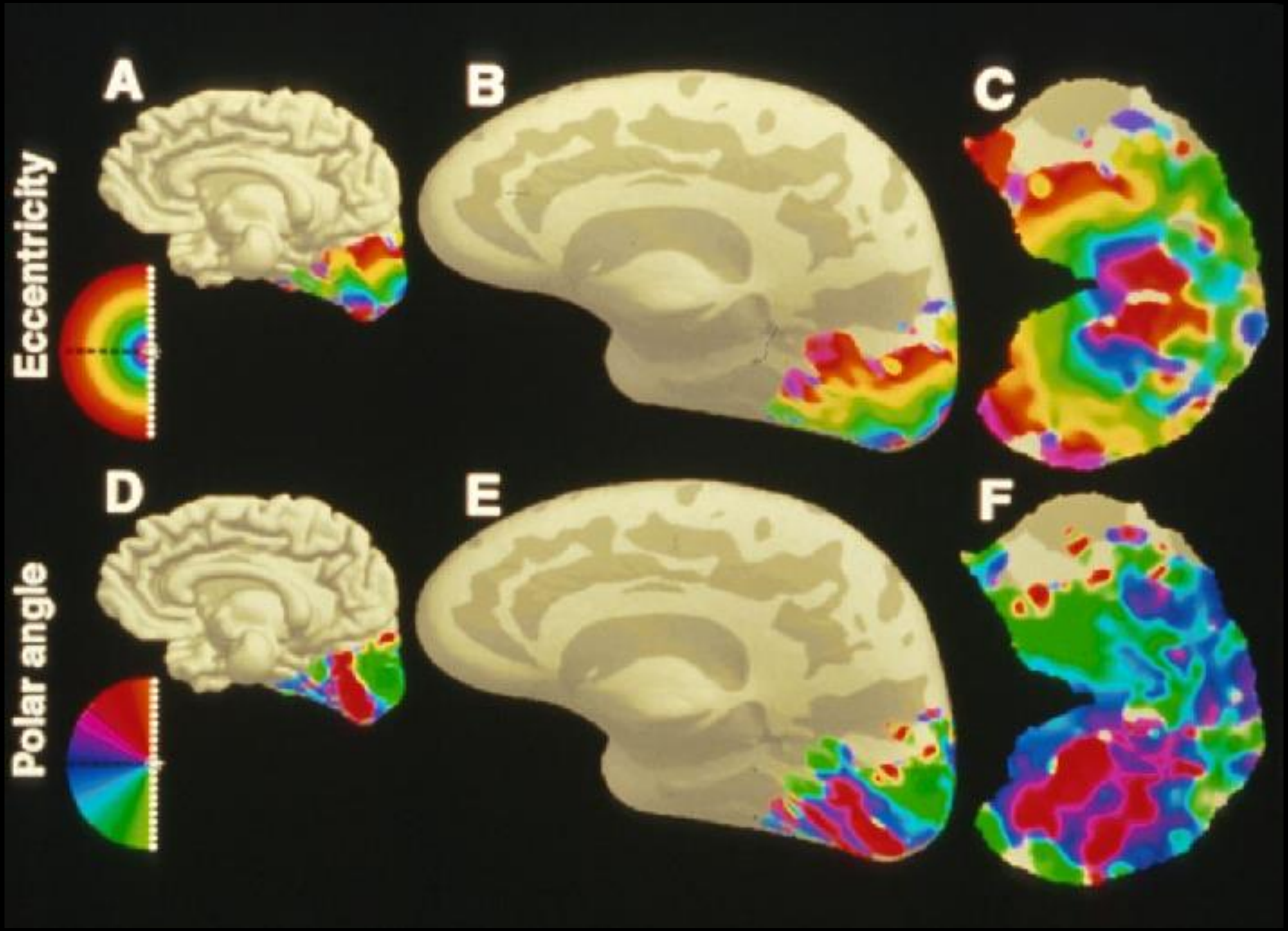


Listening



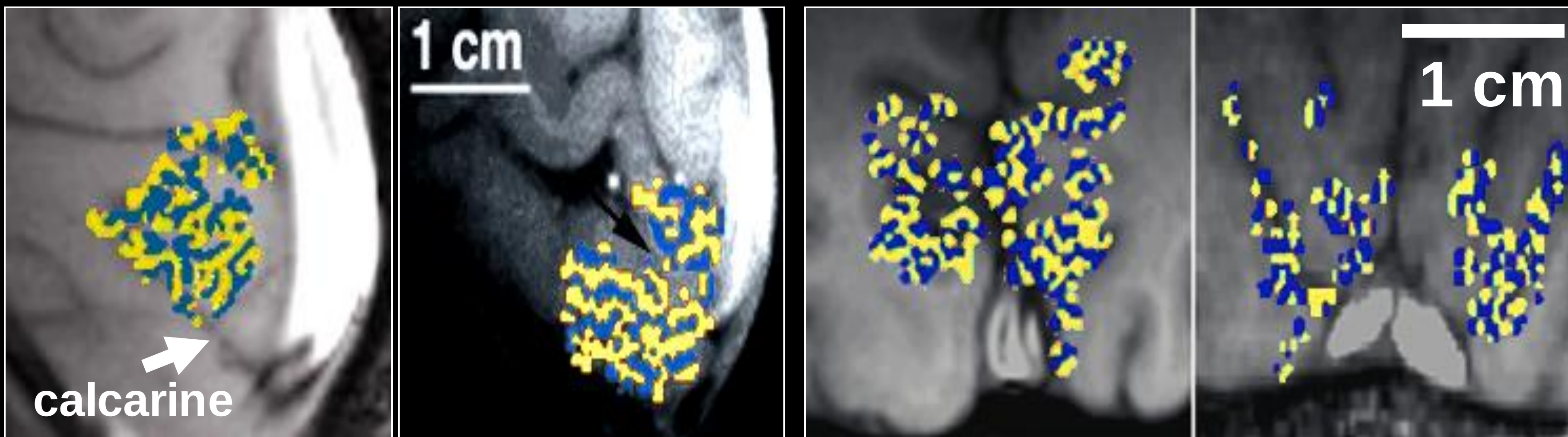
Visual Pathways: The Retino-Geniculo-Calcarine Pathway





A
B
C
Eccentricity
D
E
F
Polar angle

ODC Maps using fMRI

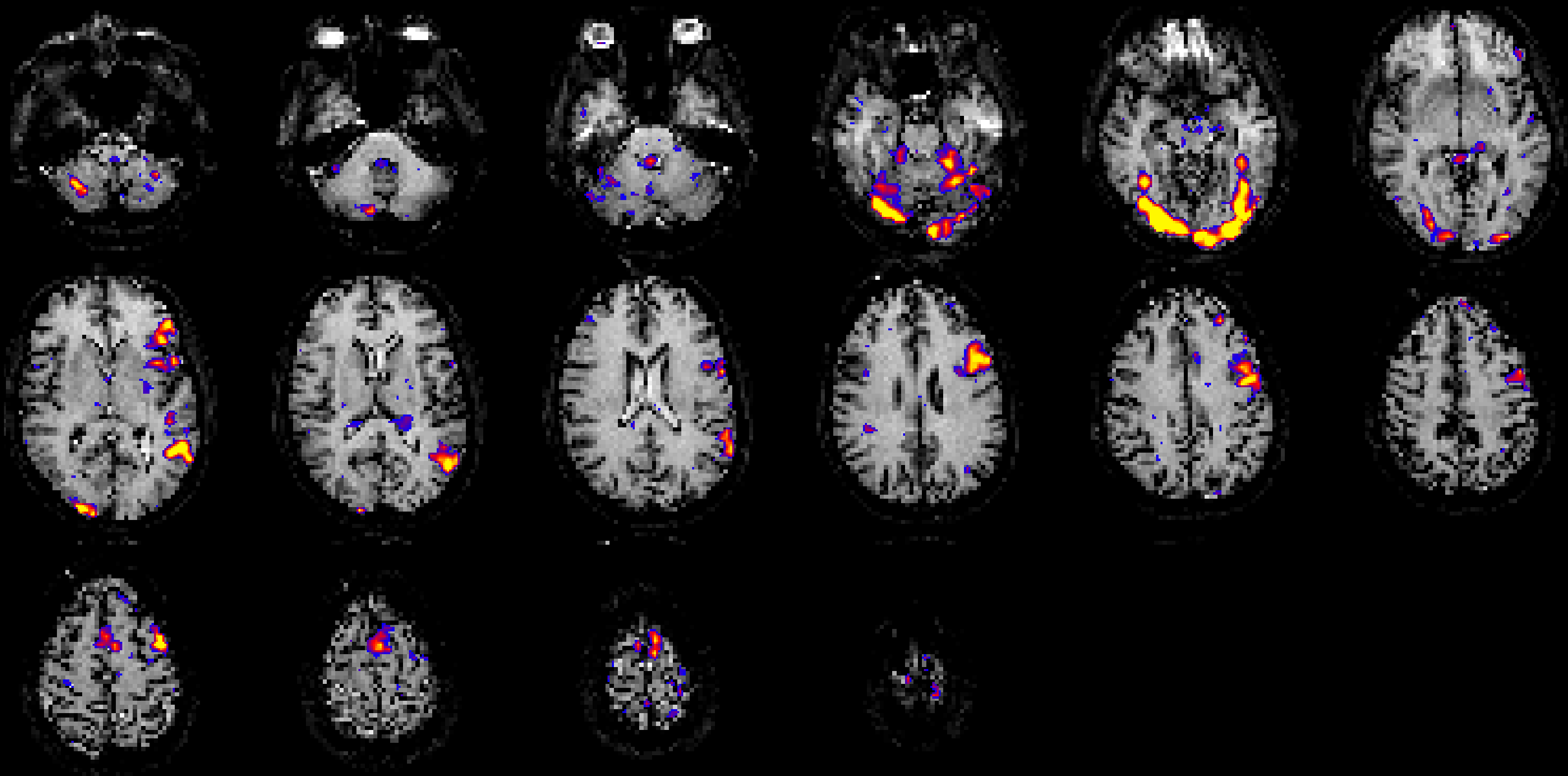


• Identical in size, orientation, and appearance to those obtained by optical imaging[1] and histology[3,4].

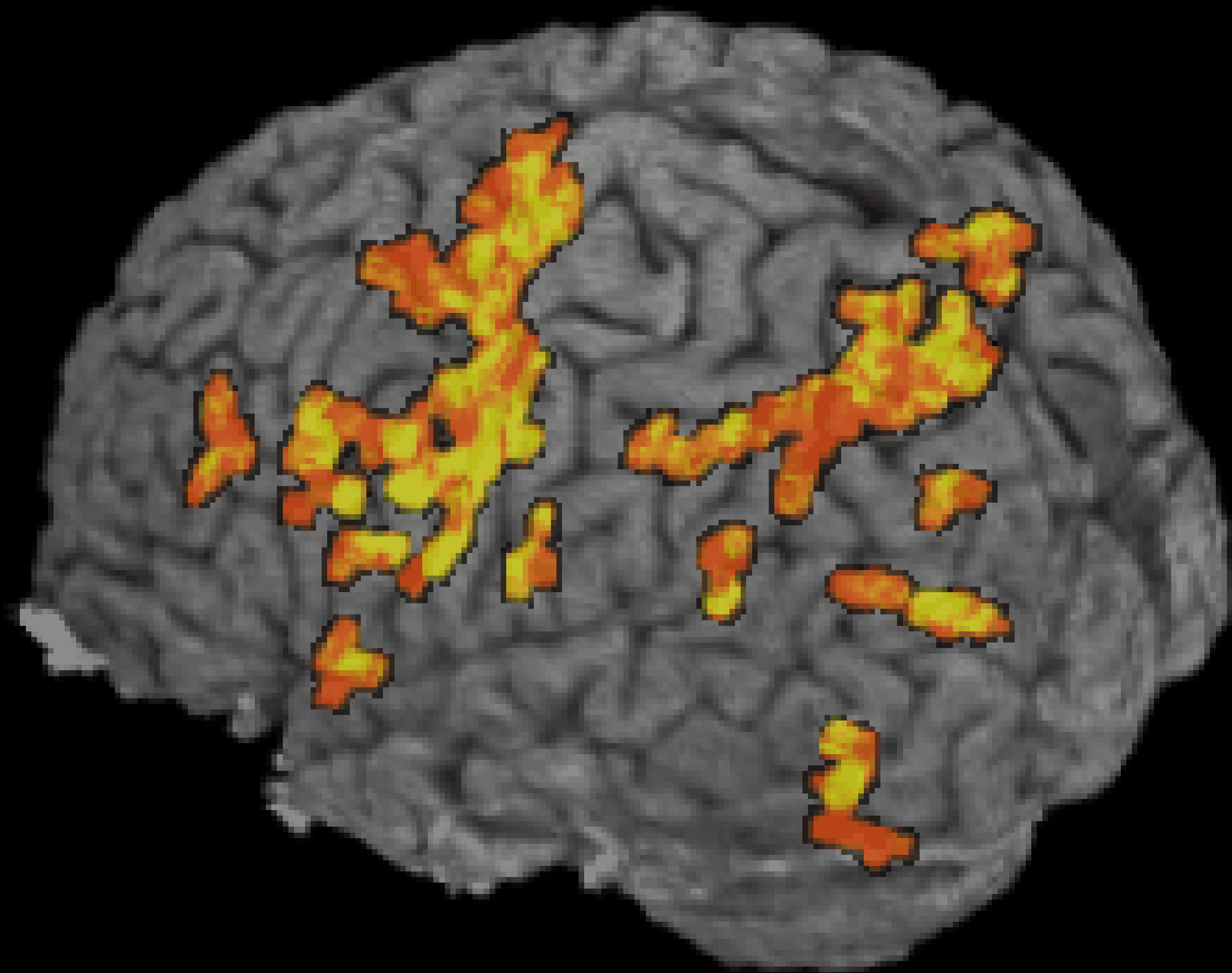
Menon et al.

[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

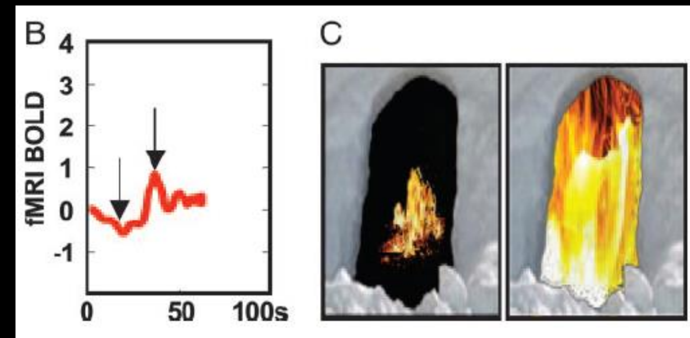
Color shows
through brain

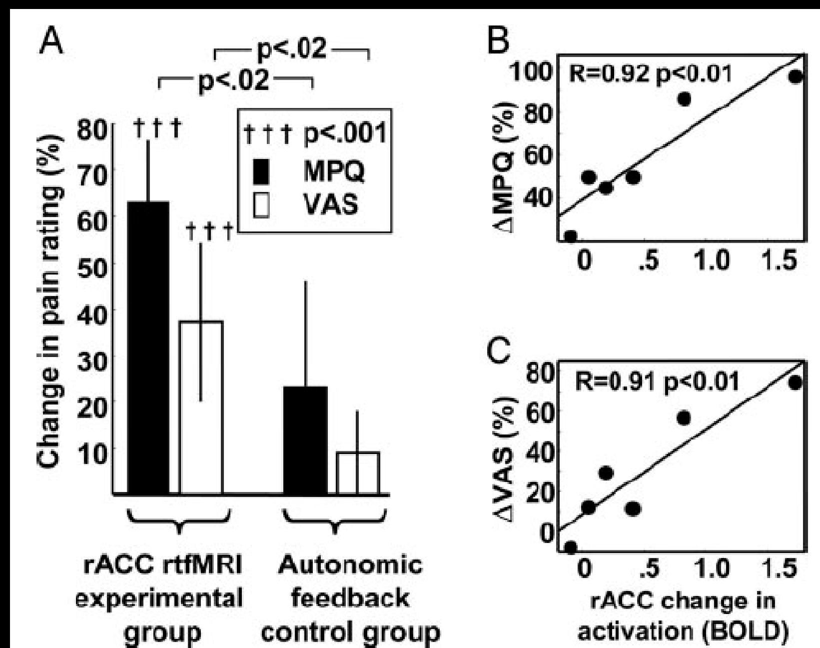
Correlation > 0.45

The End

Applications

Real time fMRI feedback to reduce chronic pain



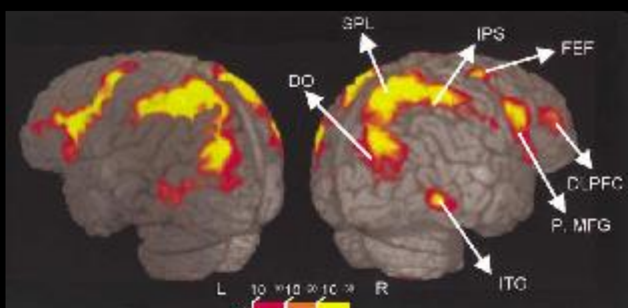


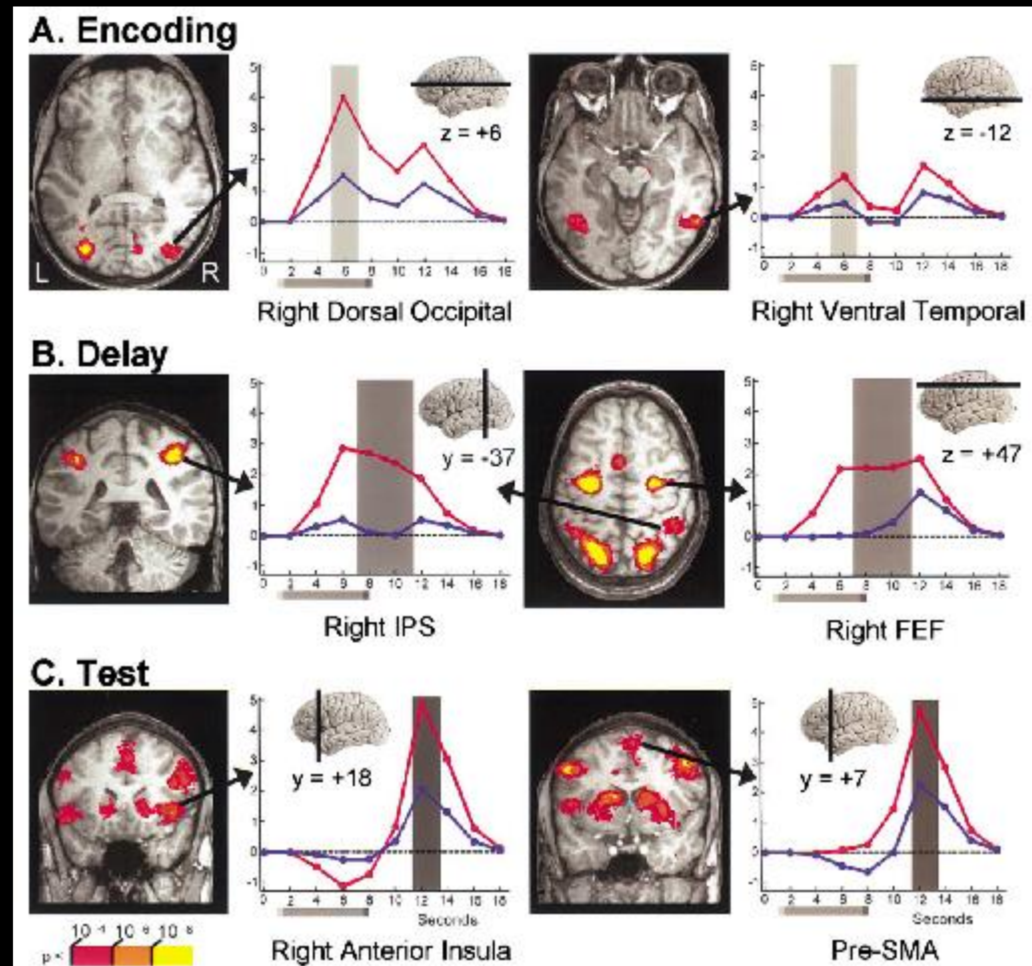
Control over brain activation and pain learned by using real-time functional MRI, R. C. deCharms, et al. PNAS, 102; 18626-18631 (2005)

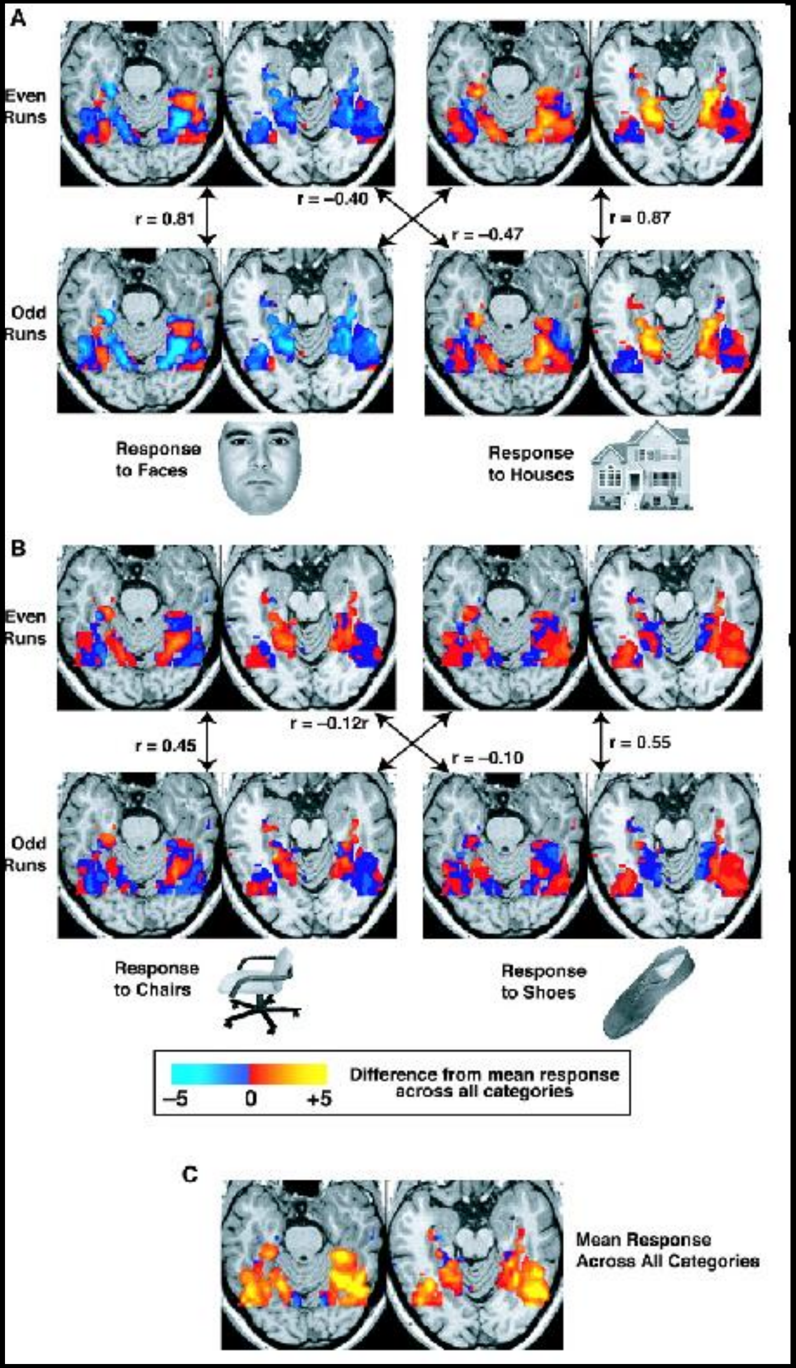
Neuron, Vol. 35, 975–987, August 29, 2002, Copyright ©2002 by Cell Press

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





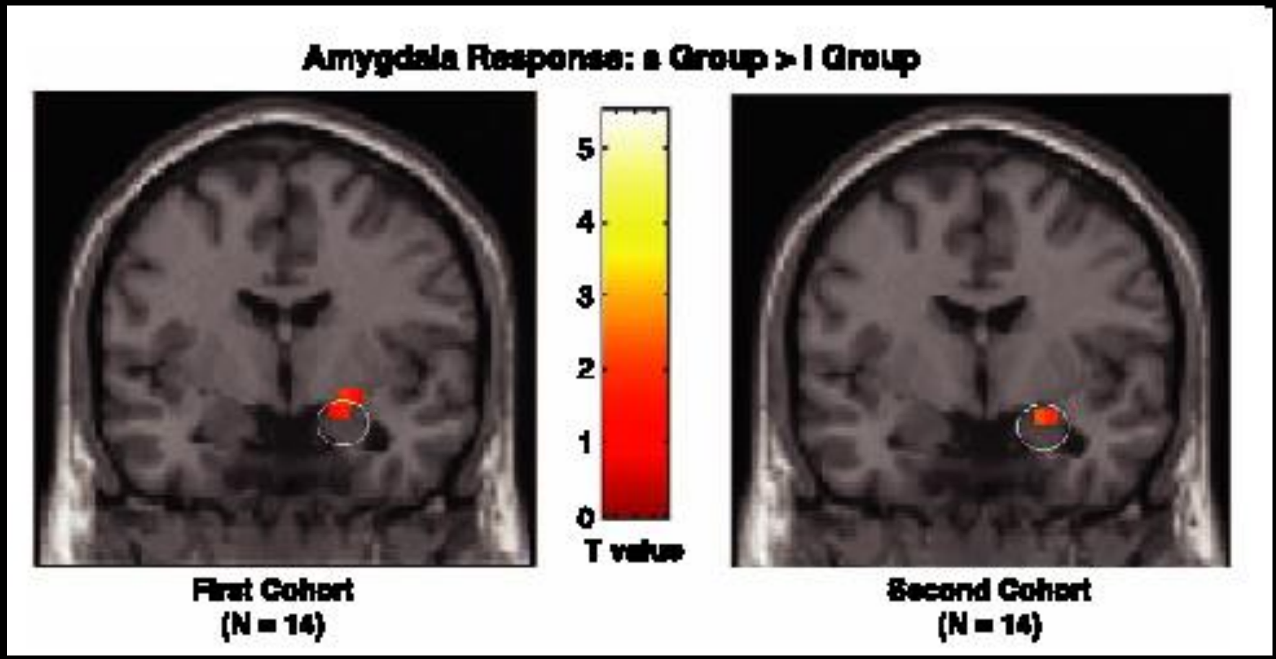


Haxby et al (2001)

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]

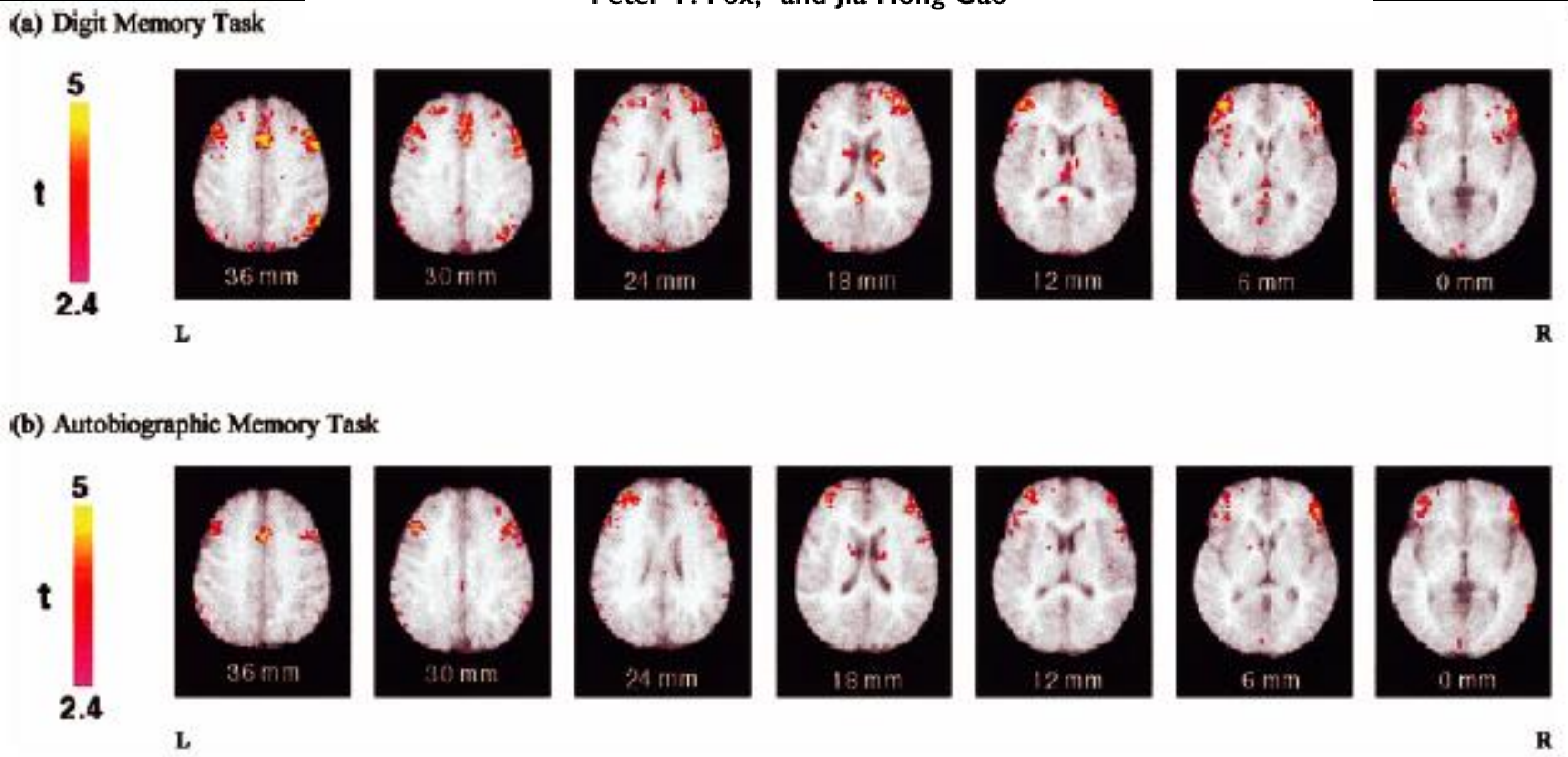
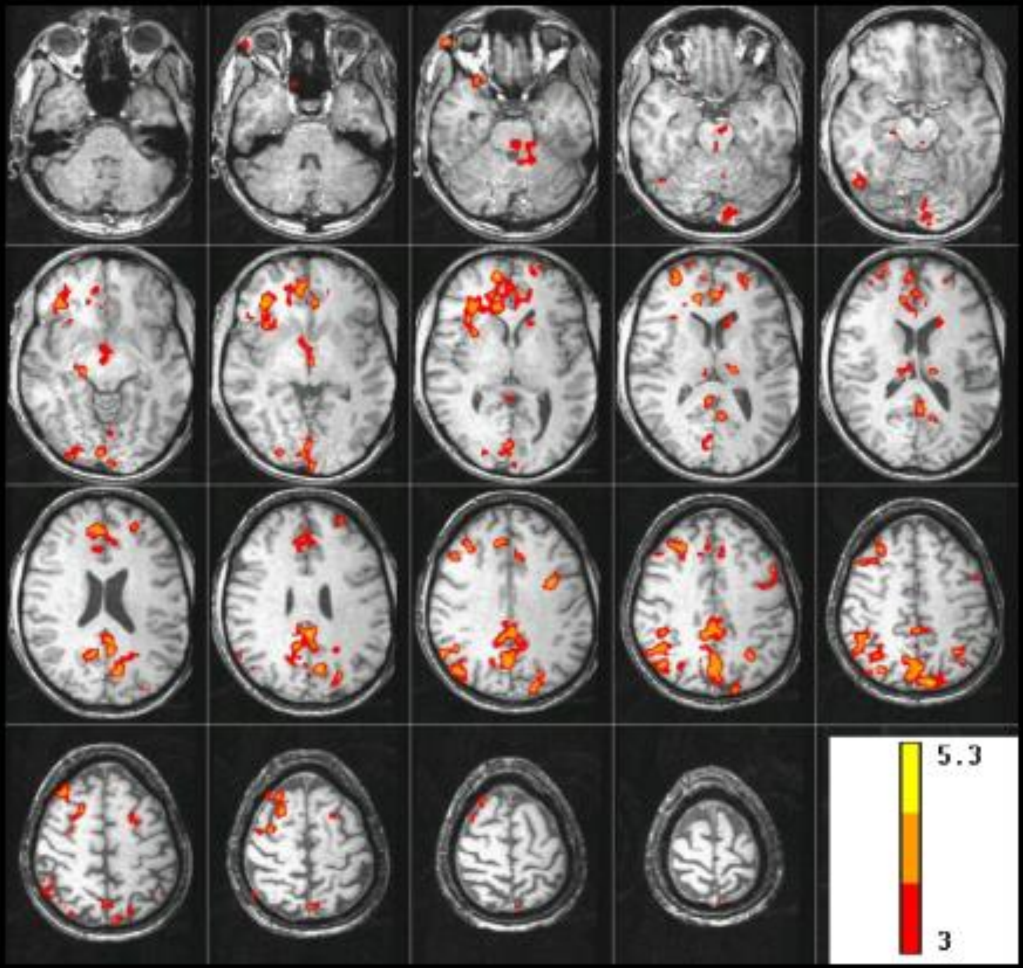
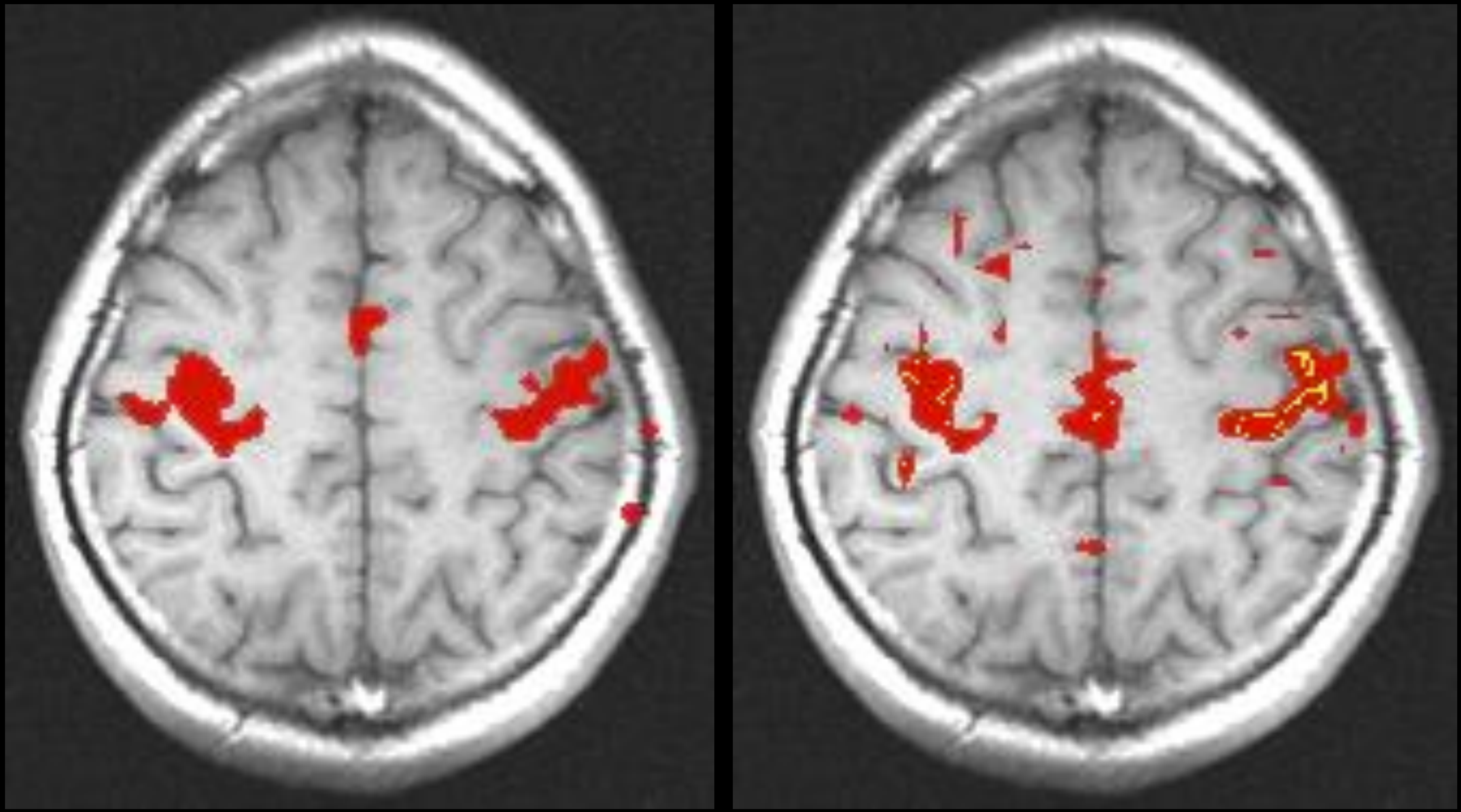


Figure 1.

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.

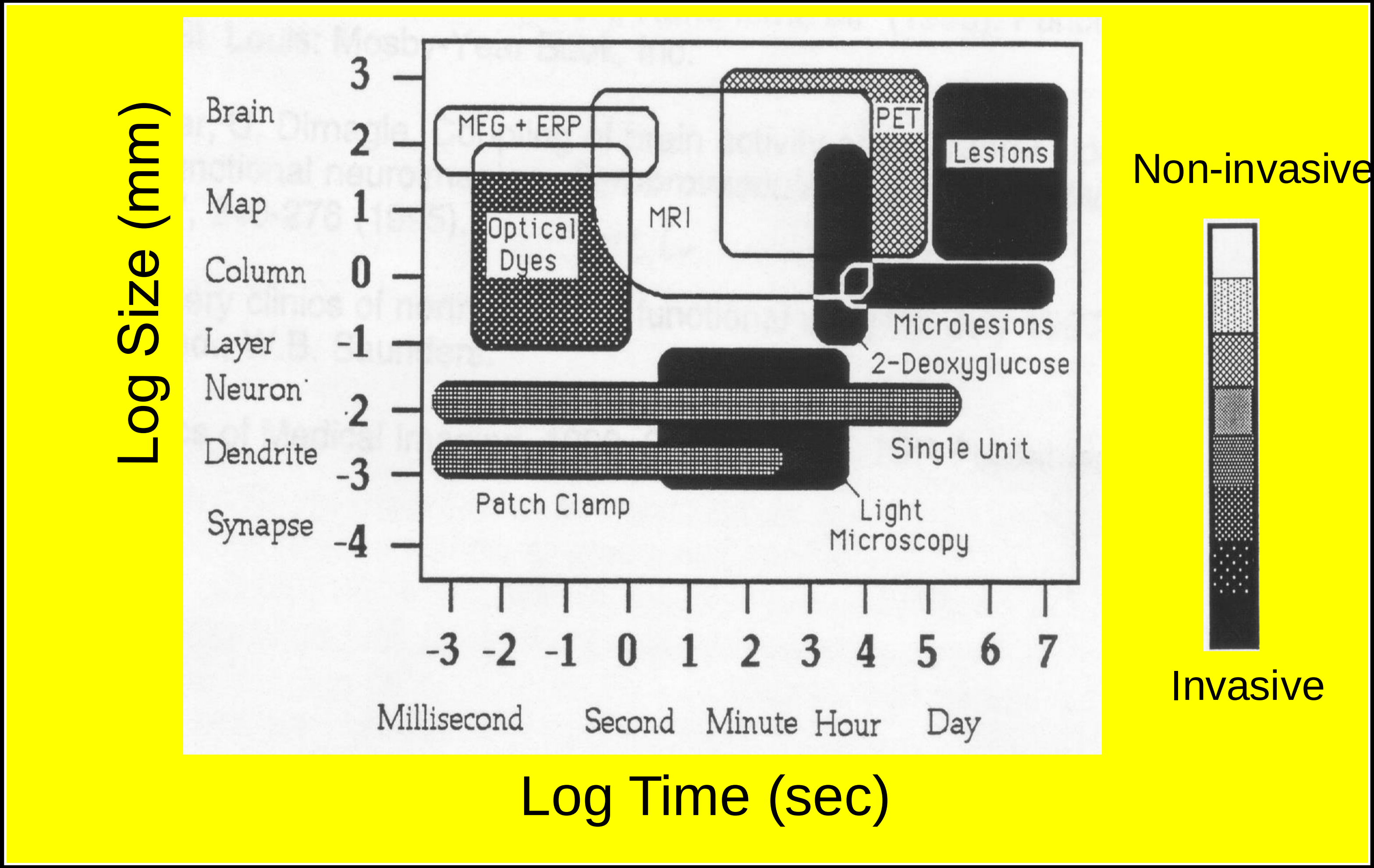
Activation in the brain correlated with skin conductance changes

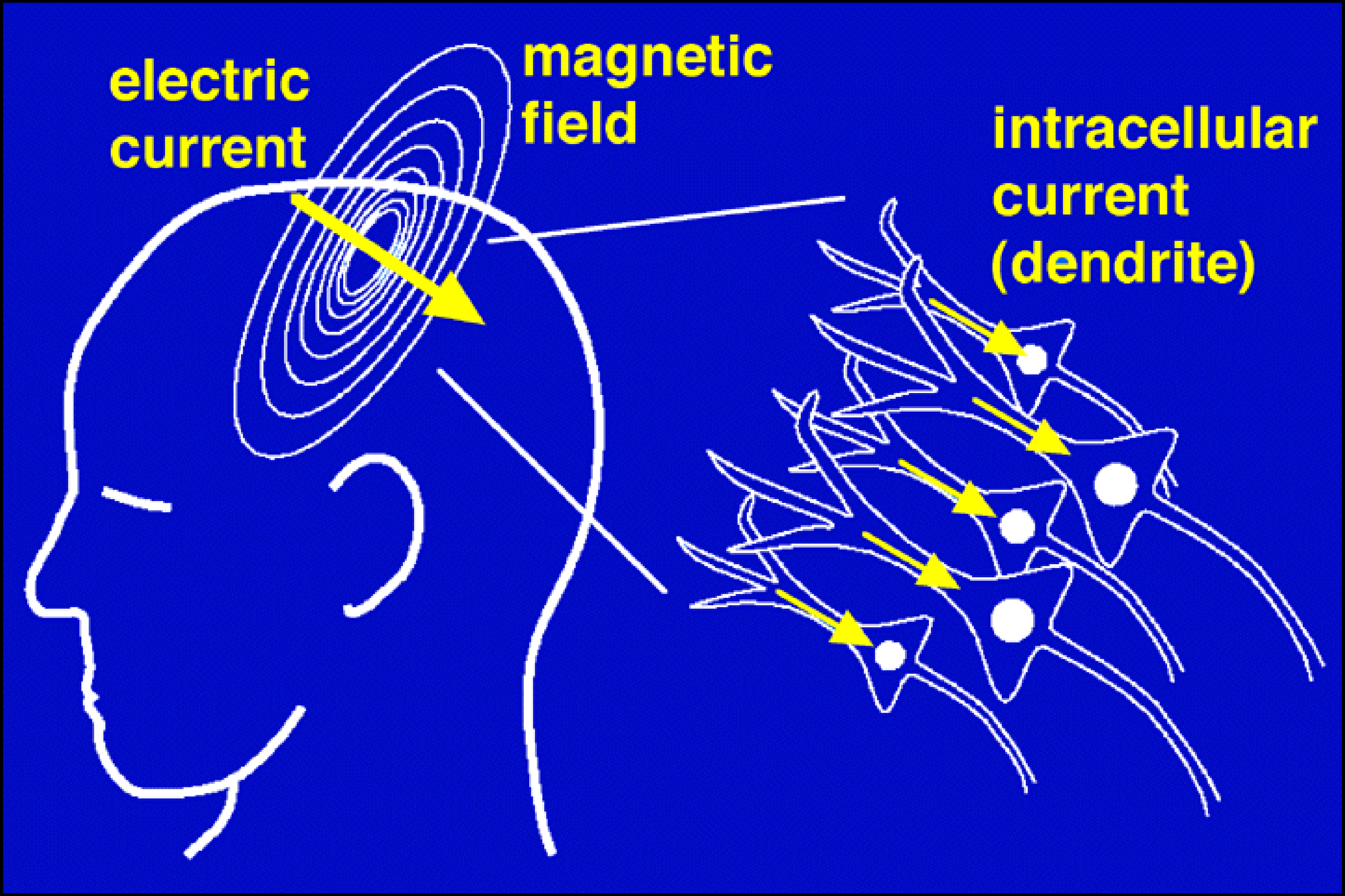




Biswal, et al (1995), MRM 34, 537-541

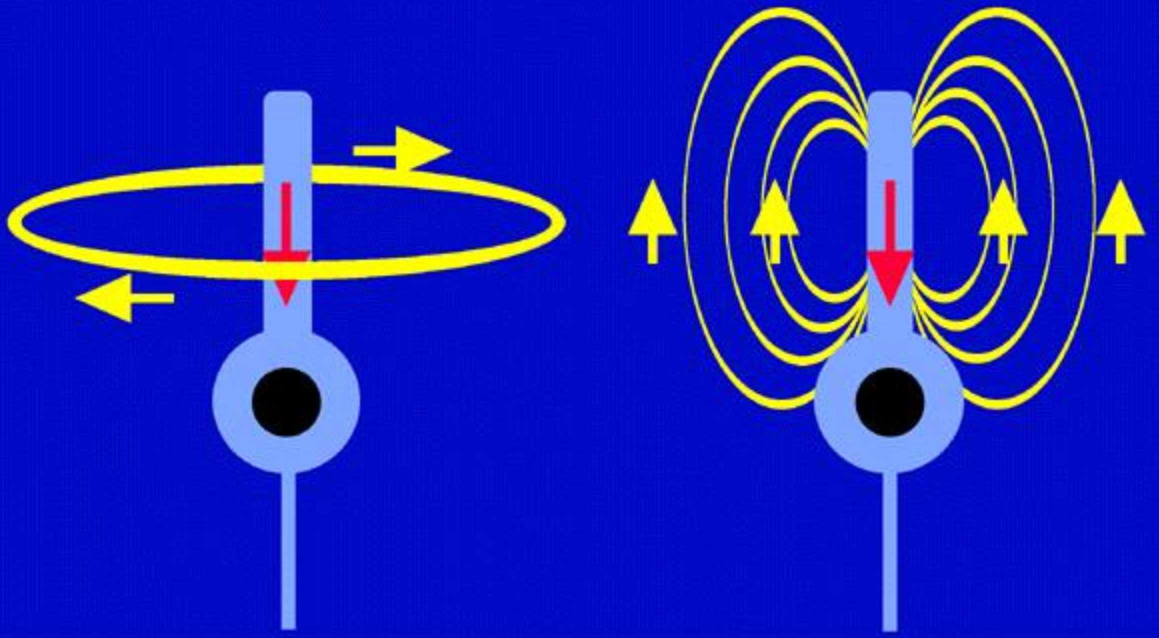
Functional Neuroimaging Techniques

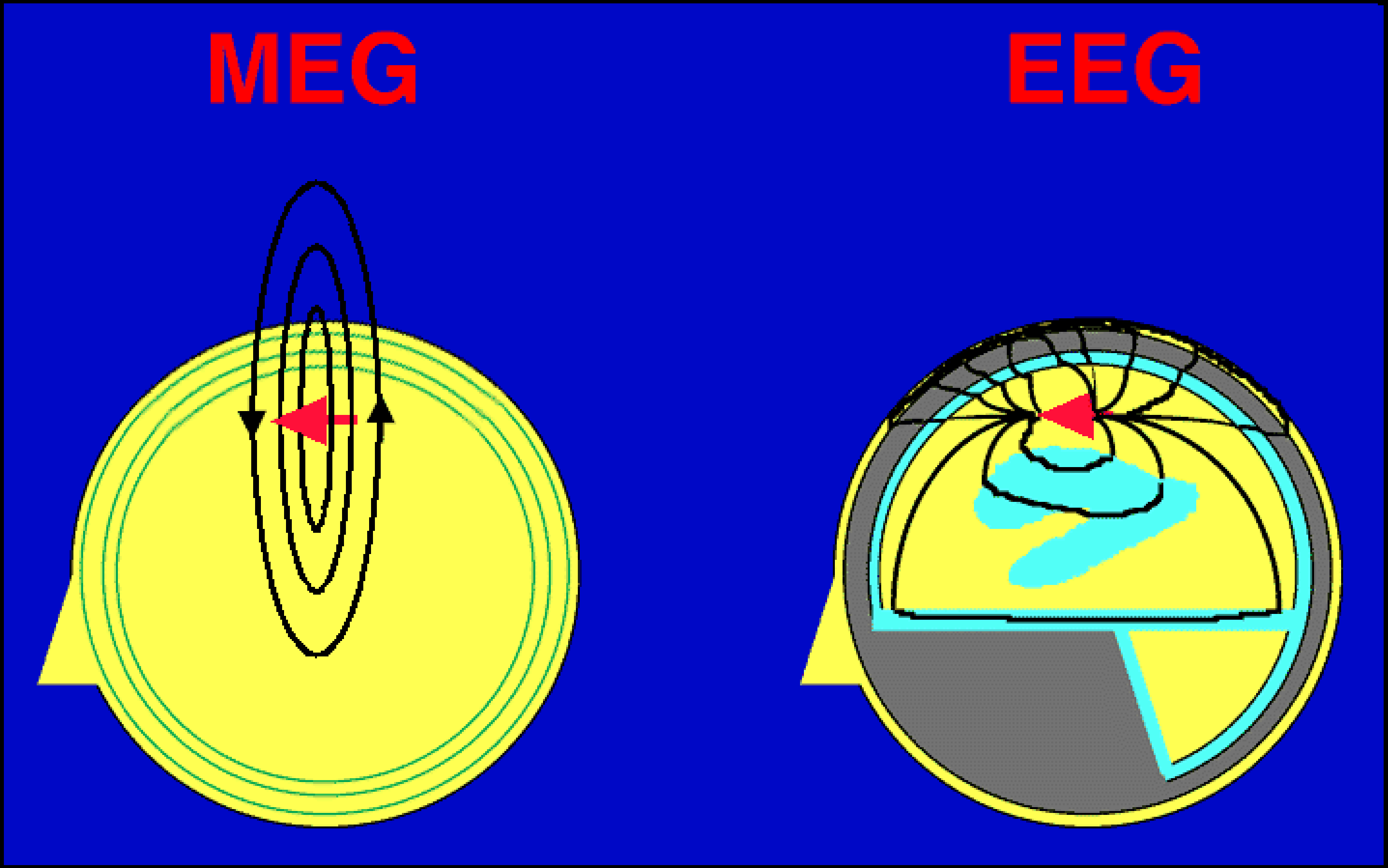



electric
current
magnetic
field
intracellular
current
(dendrite)

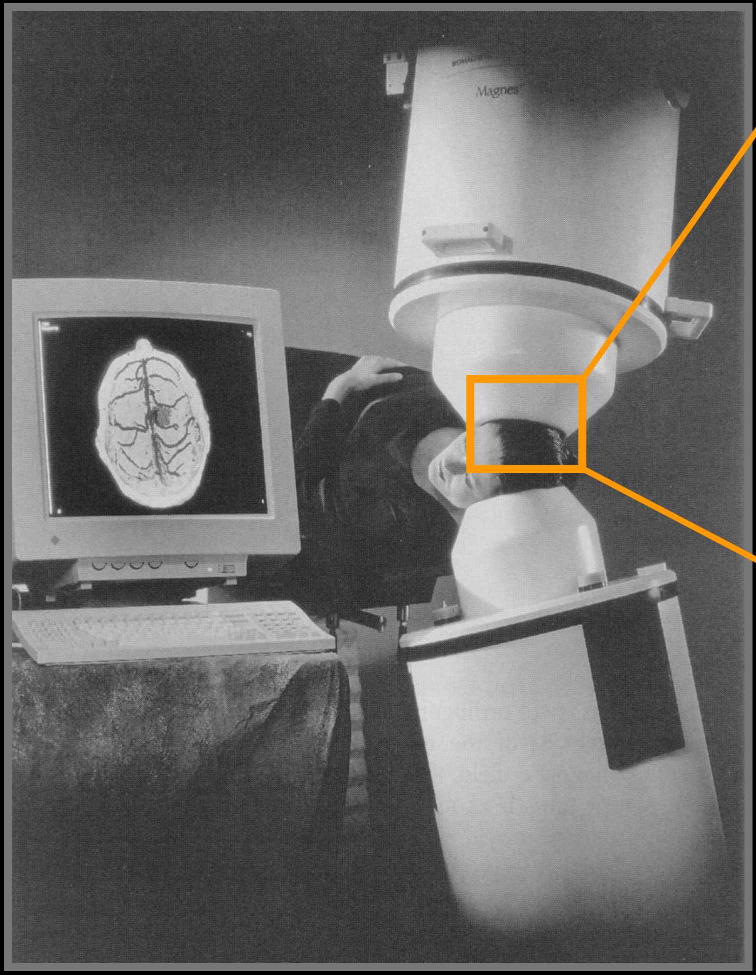
MEG: intracellular current

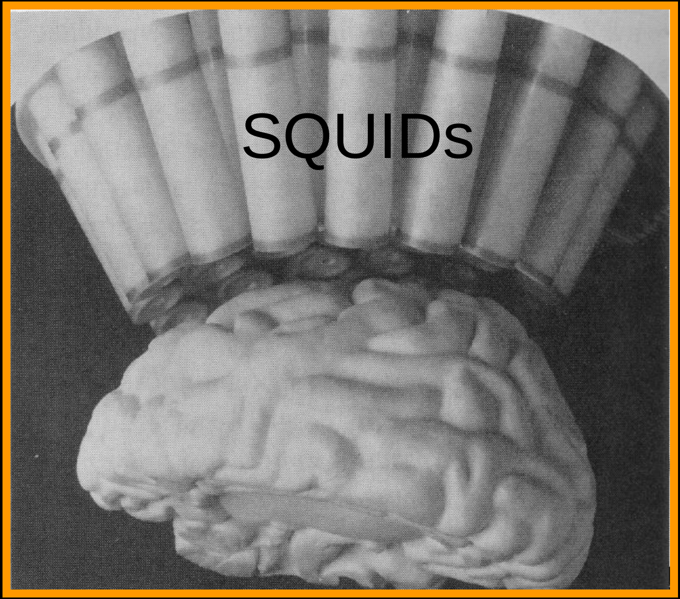
EEG: extracellular current



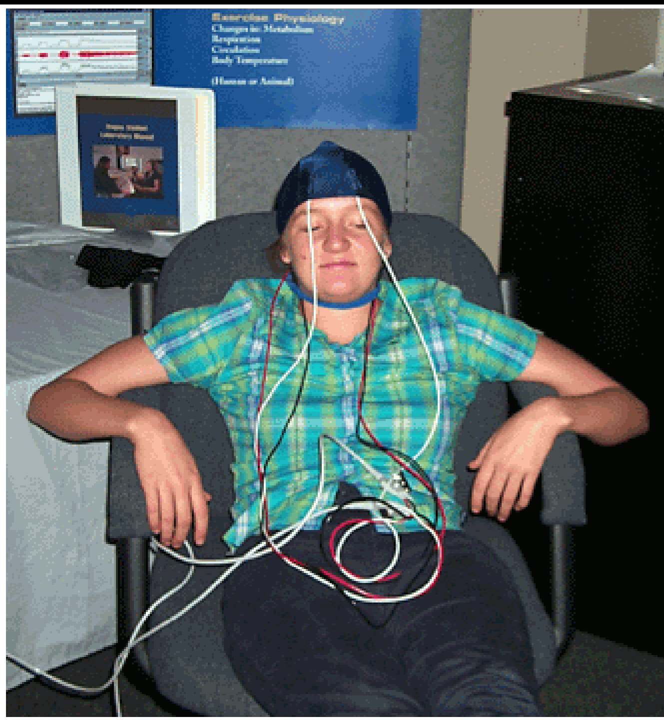

MEG
EEG

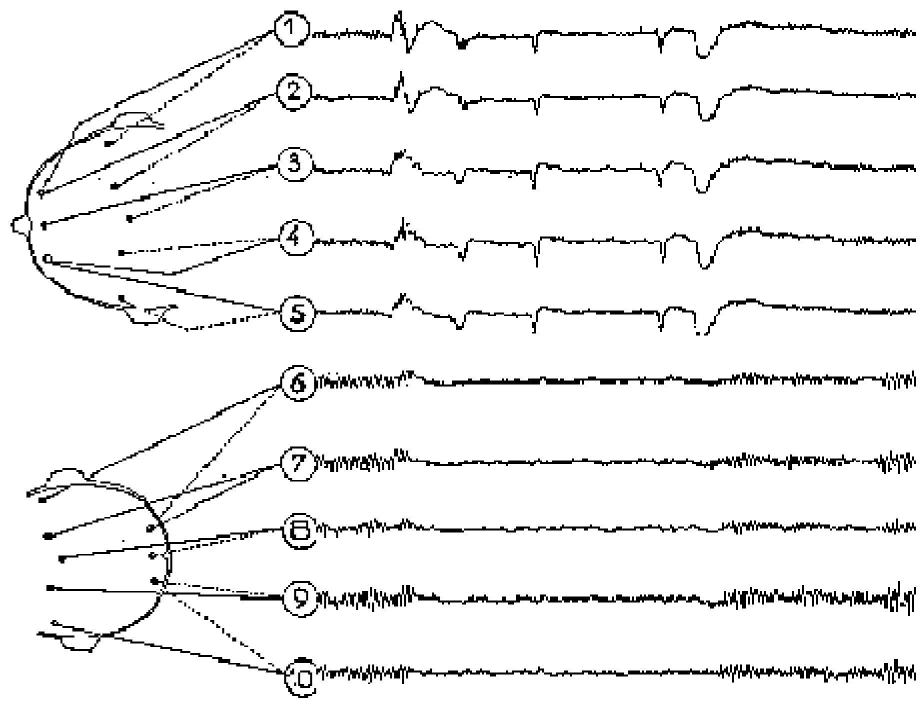
Magnetoencephalography (MEG)





SQUID:
Superconducting Quantum Interference Device


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


1
2
3
4
5
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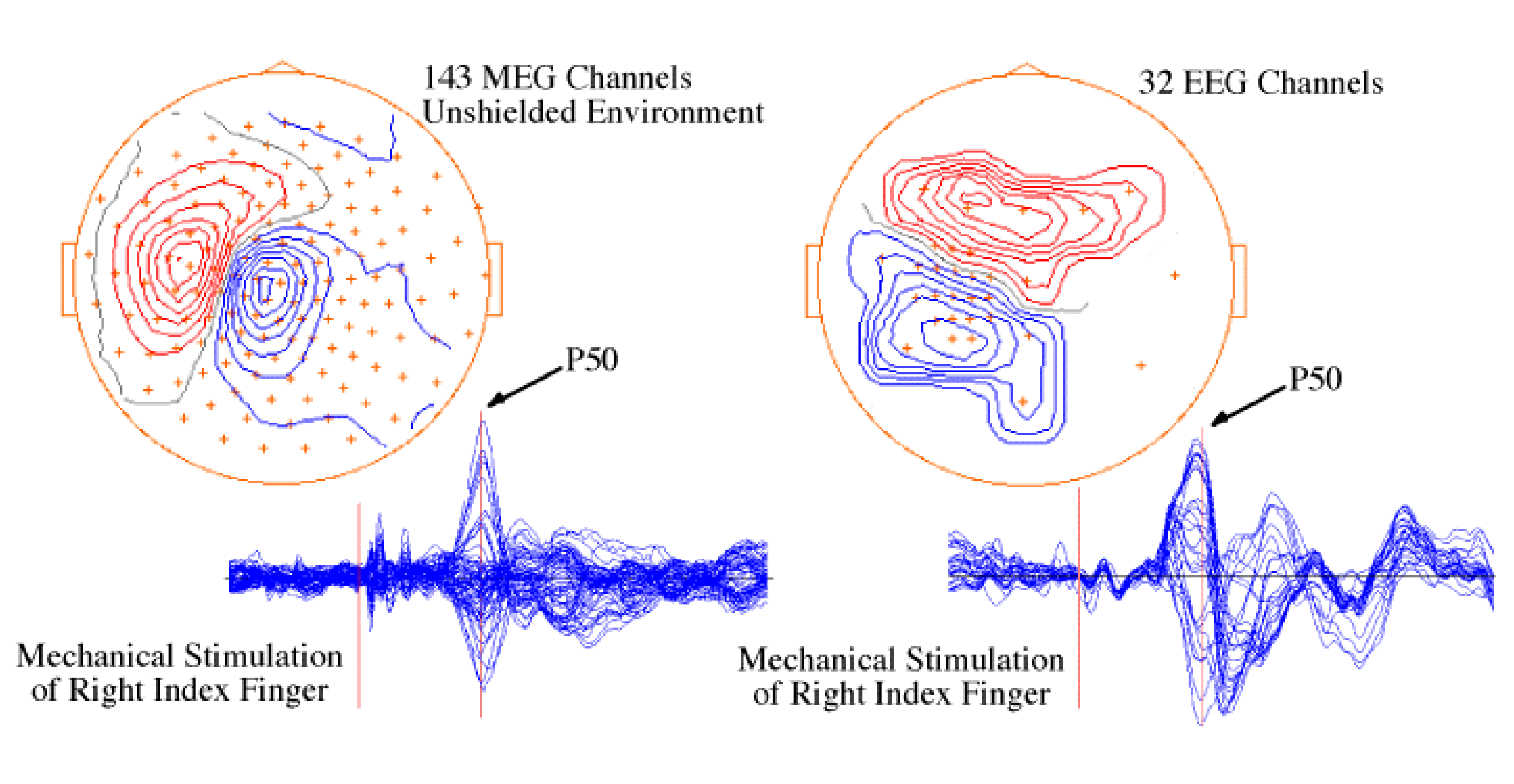
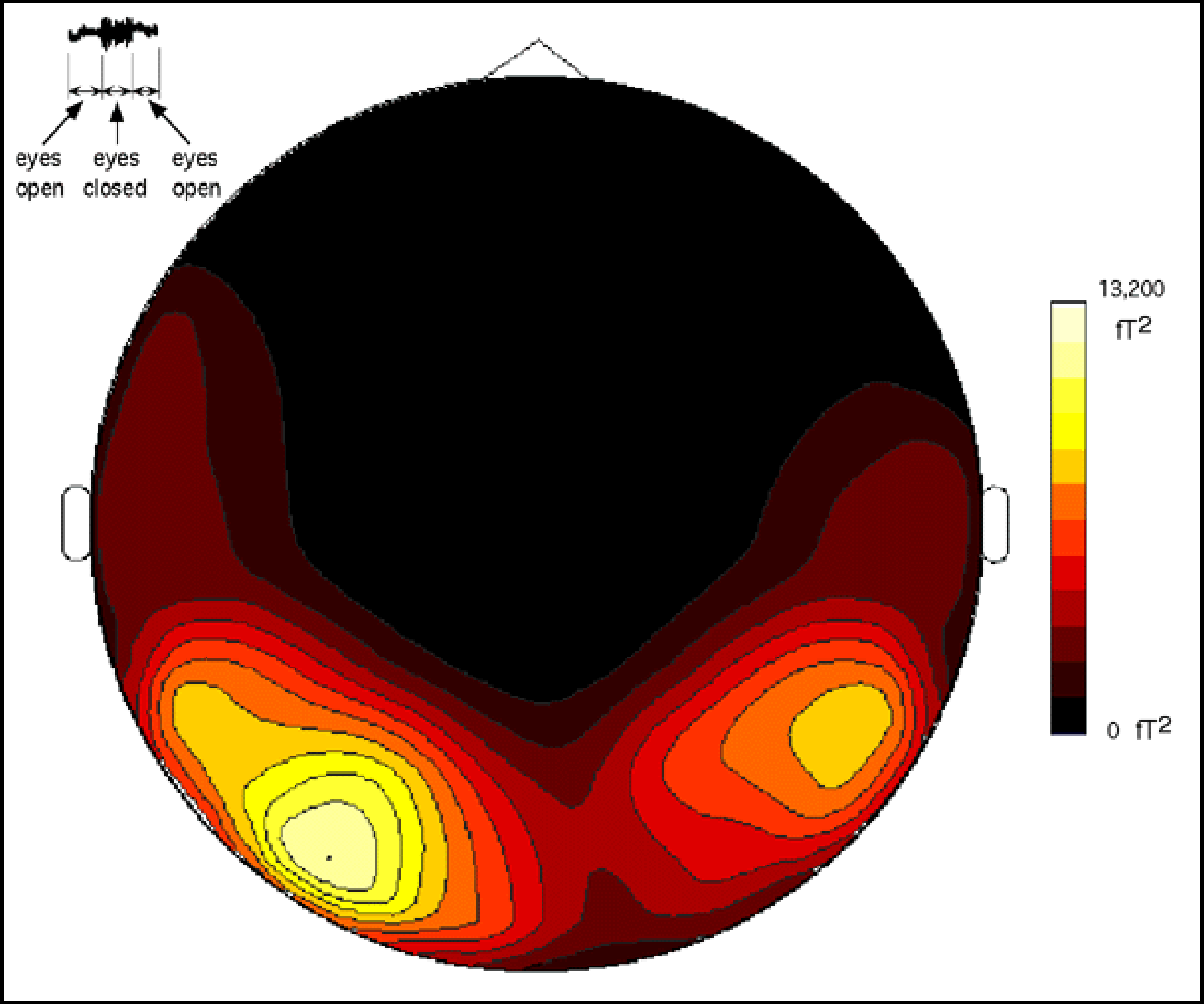
9
10

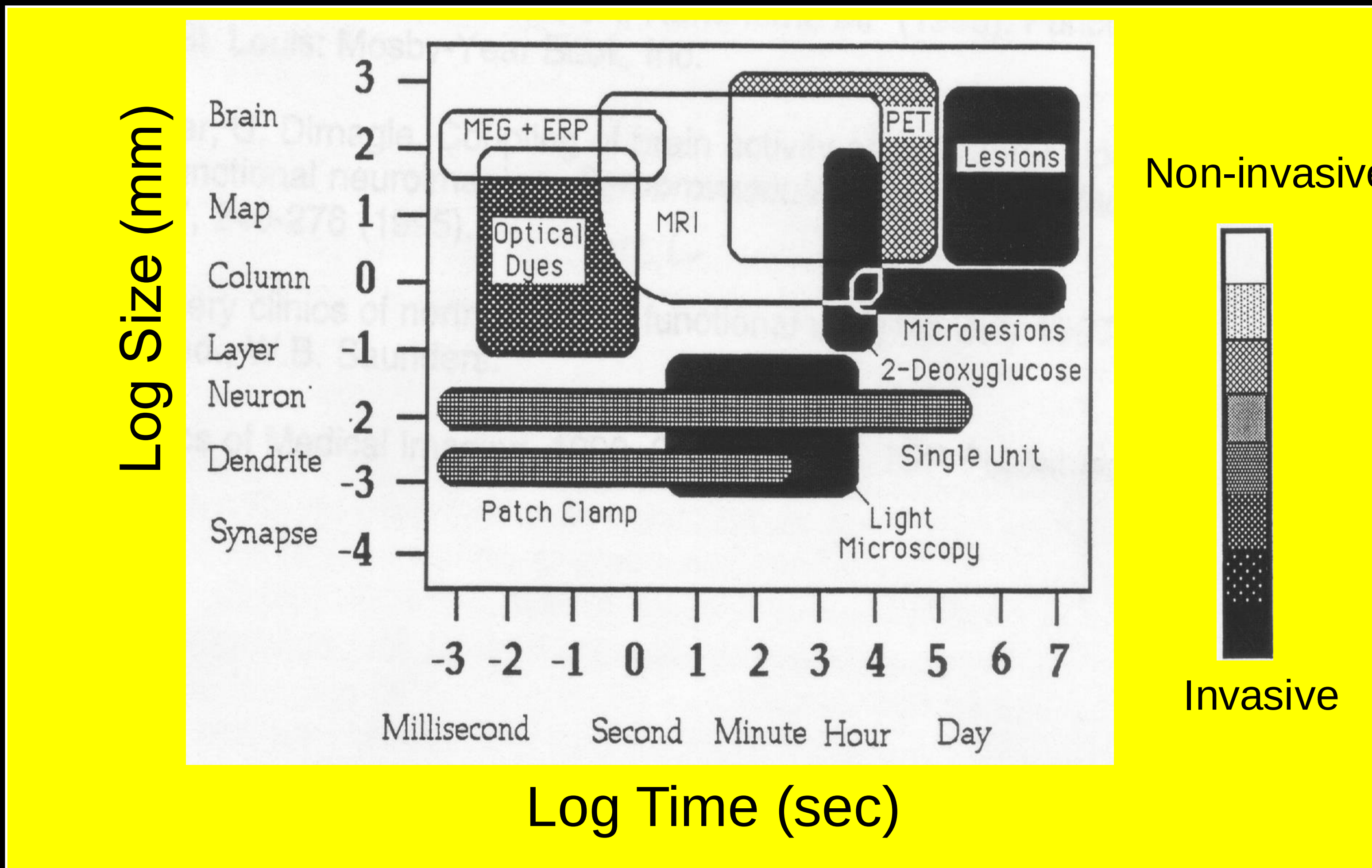


143 MEG Channels
Unshielded Environment
P50
Mechanical Stimulation
of Right Index Finger
32 EEG Channels
P50
Mechanical Stimulation
of Right Index Finger

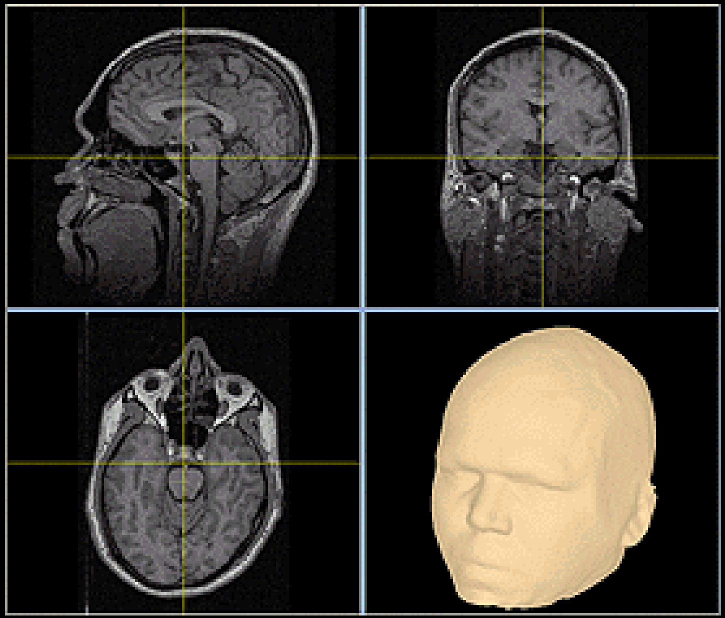
Alpha Wave Activity Mapped with MEG



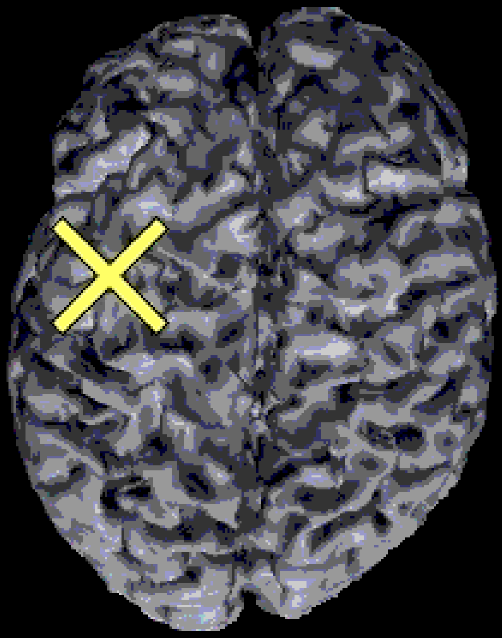
Functional Neuroimaging Techniques



Transcranial Magnetic Stimulation



Transcranial Magnetic Stimulation (TMS)



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Section on Functional Imaging Methods & FMRI Facility