Functional Magnetic Resonance Imaging (fMRI)

-and a few other techniques

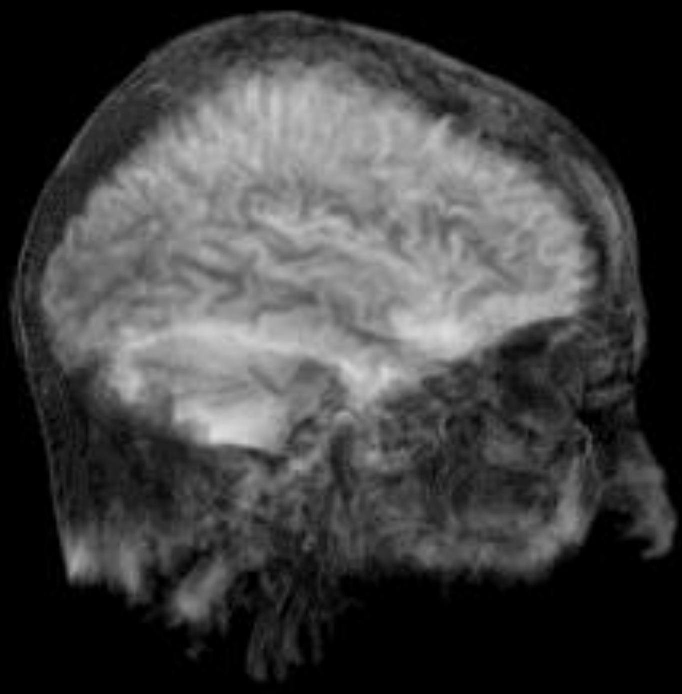
Peter A. Bandettini, Ph.D.
National Institutes of Health
bandettini@nih.gov

fim.nimh.nih.gov

fmrif.nimh.nih.gov

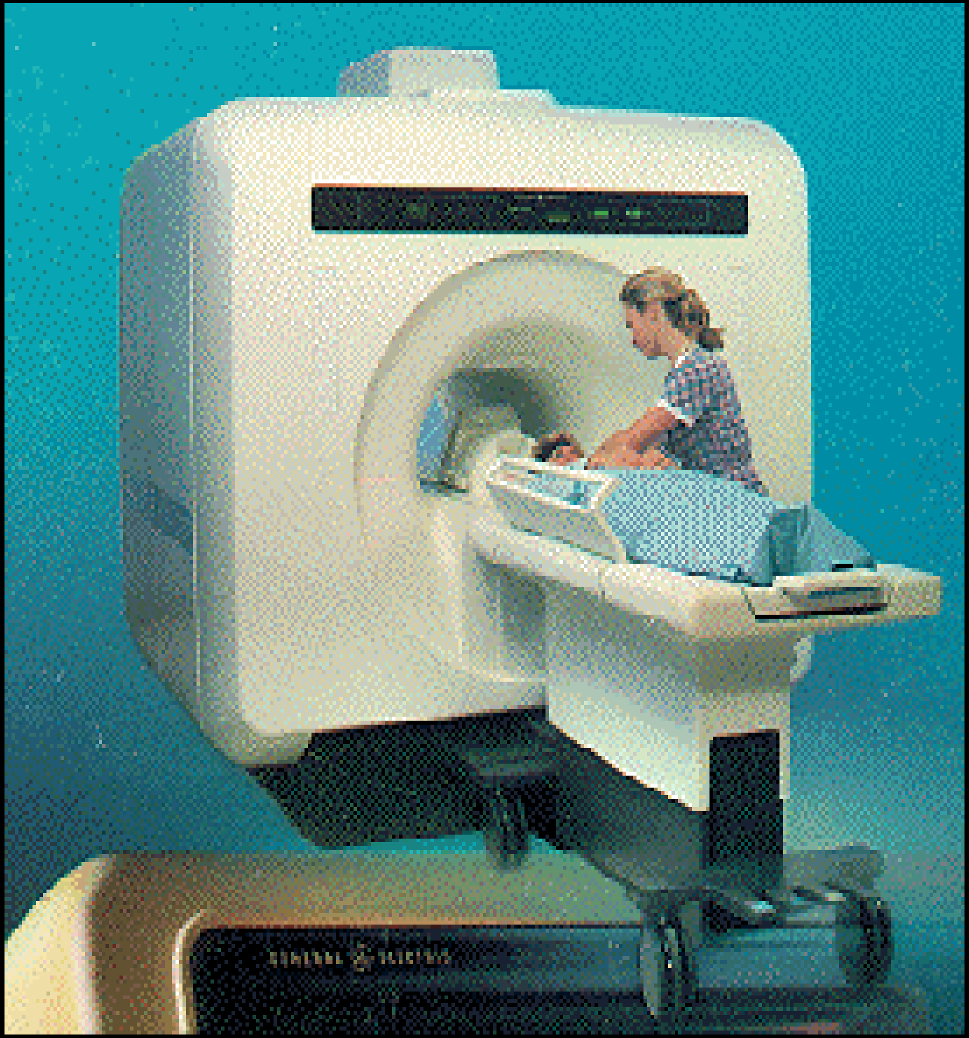
Two Types of Neuroimaging

- Structural/Anatomical Imaging
- Functional Imaging



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

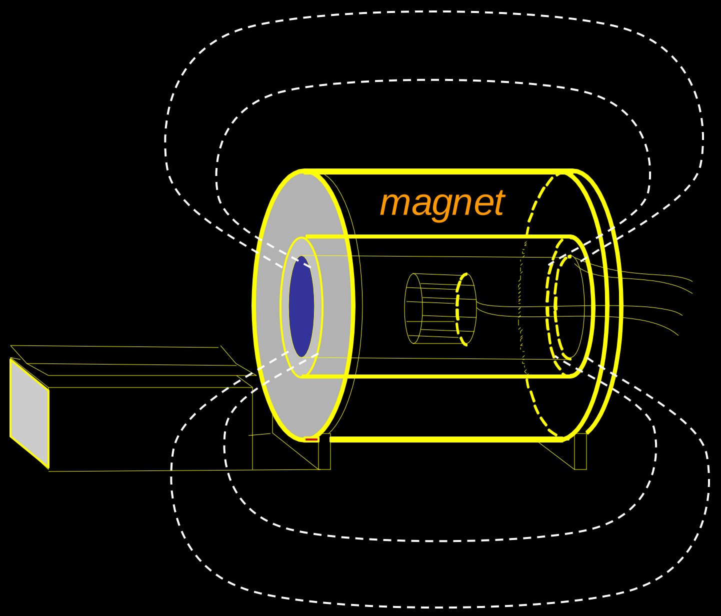
Magnetic Resonance Imaging

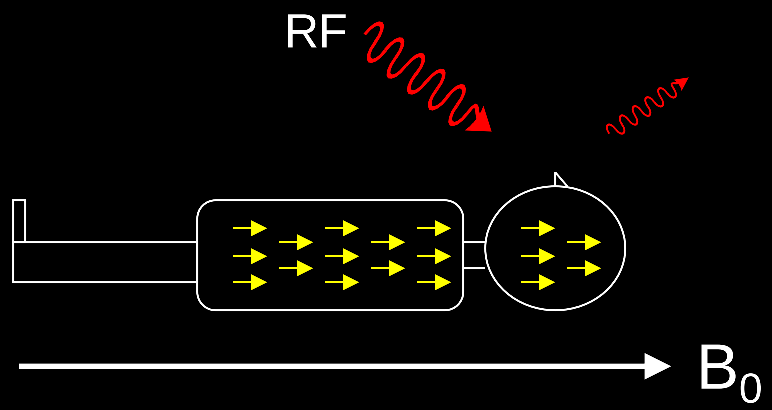


Water: 42 MHz/Tesla

1.5 Tesla = 63 MHz
3 Tesla = 126 MHz
7 Tesla = 294 MHz

Magnetic Resonance Imaging (MRI)

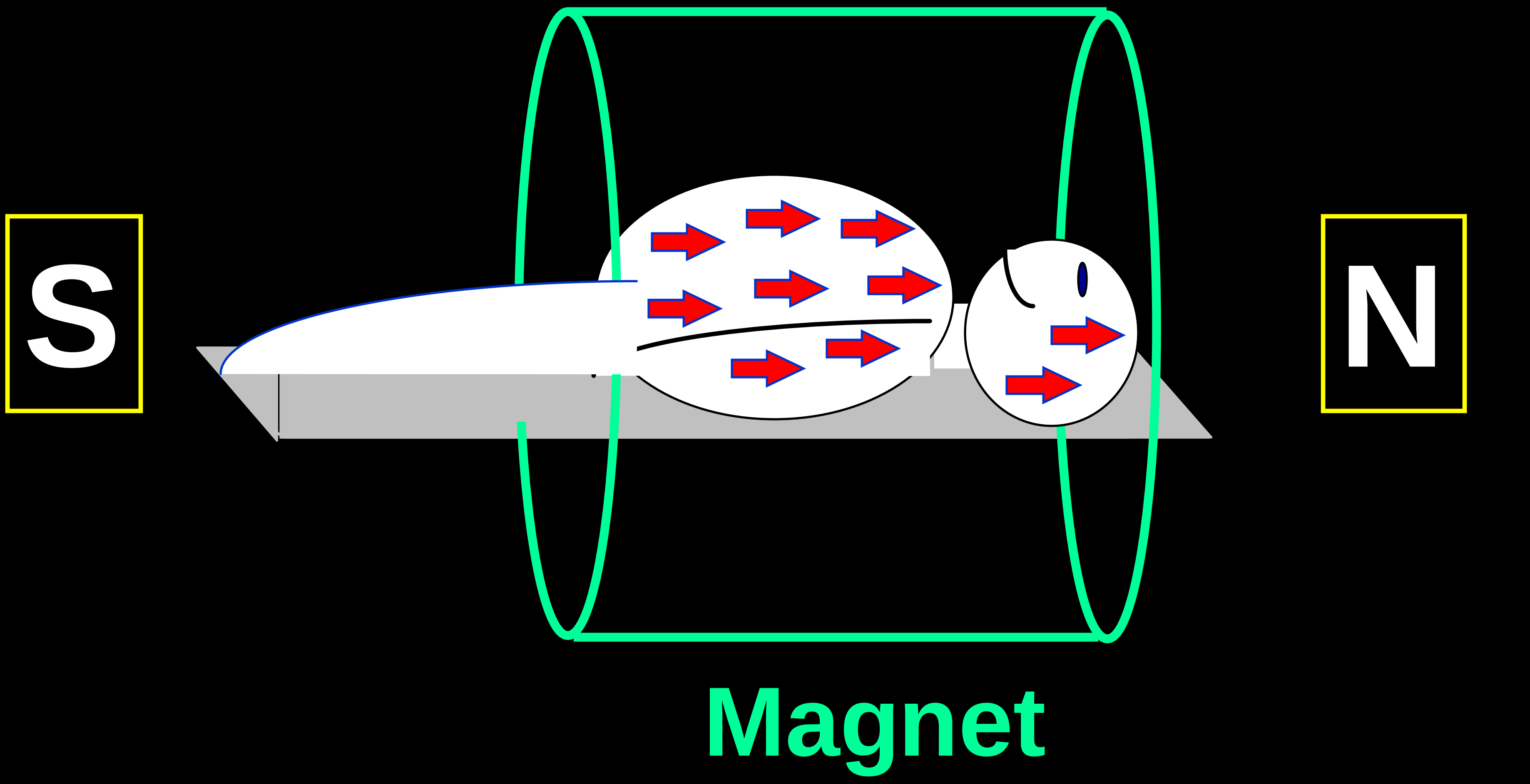




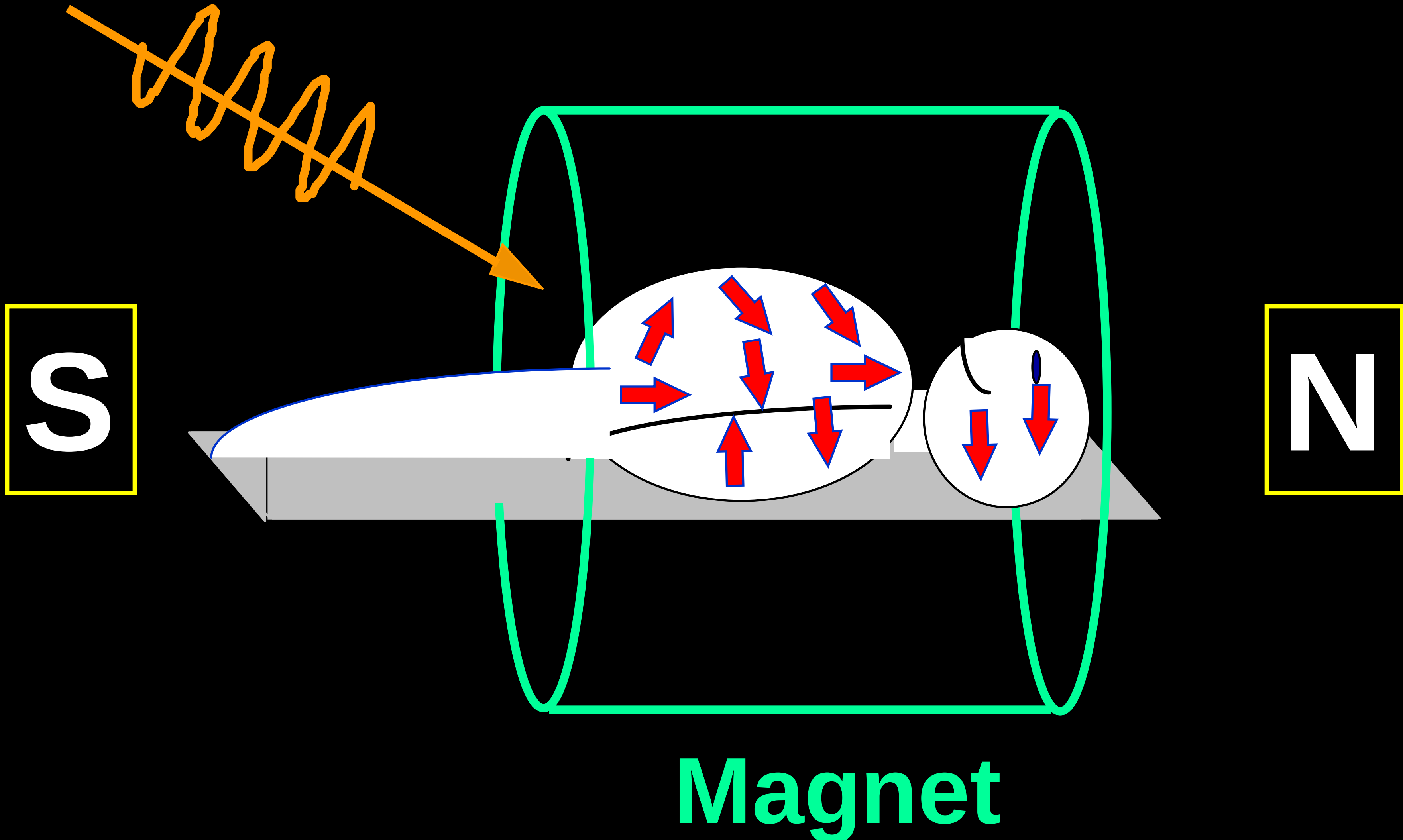
Sensitive to:

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

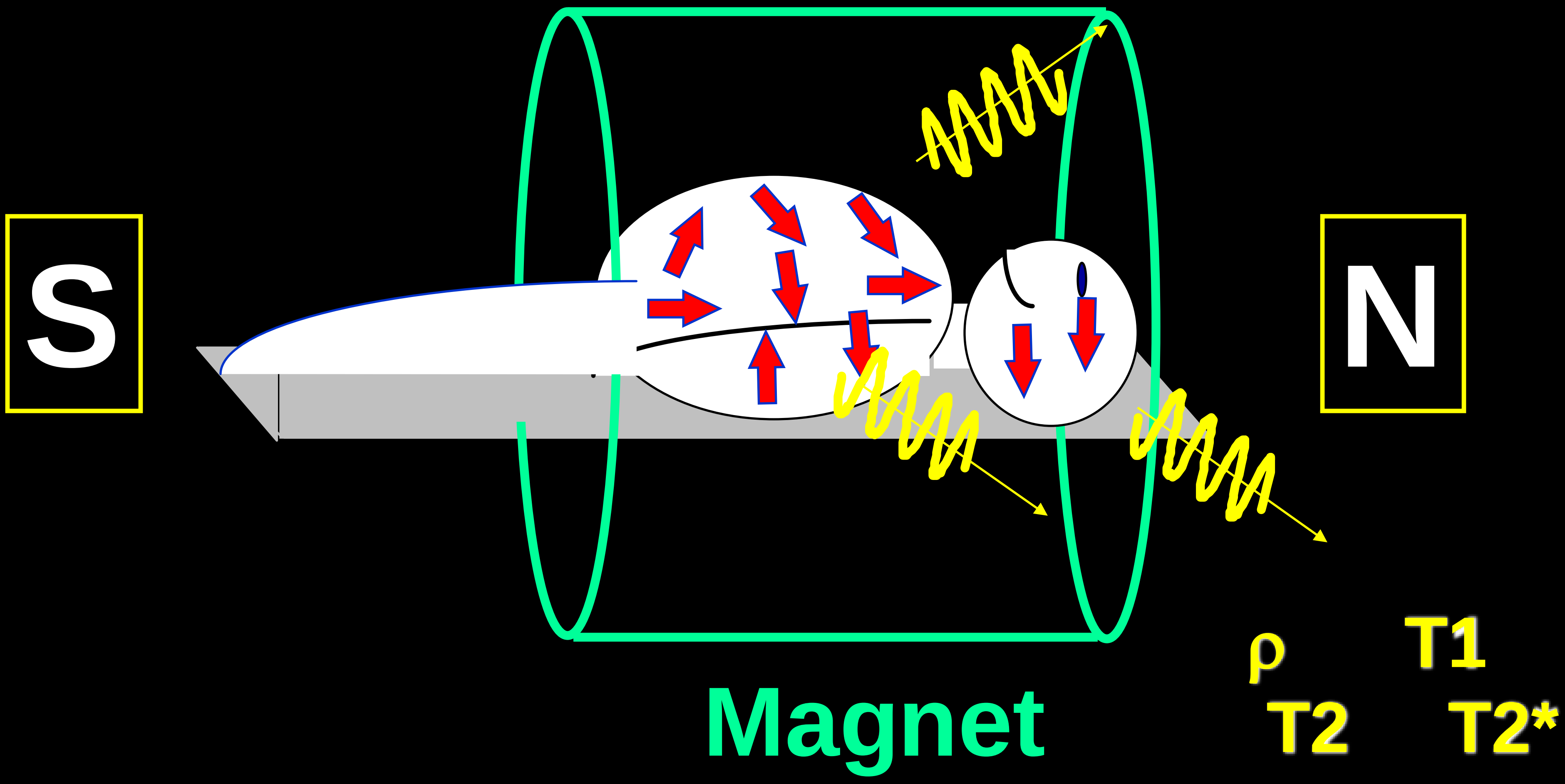
Magnetic Resonance Imaging



Magnetic Resonance Imaging

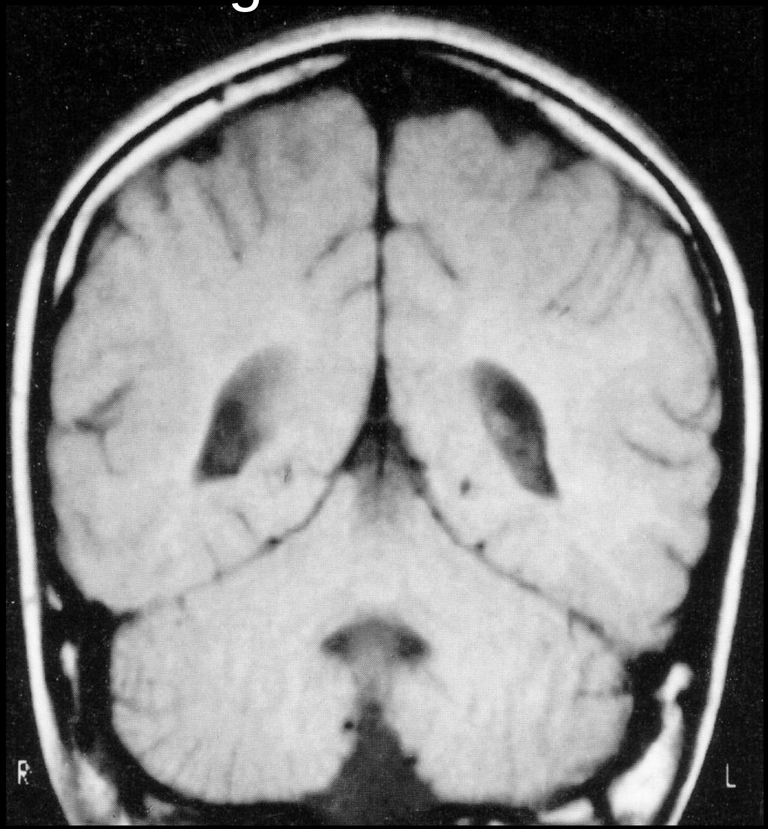


Magnetic Resonance Imaging

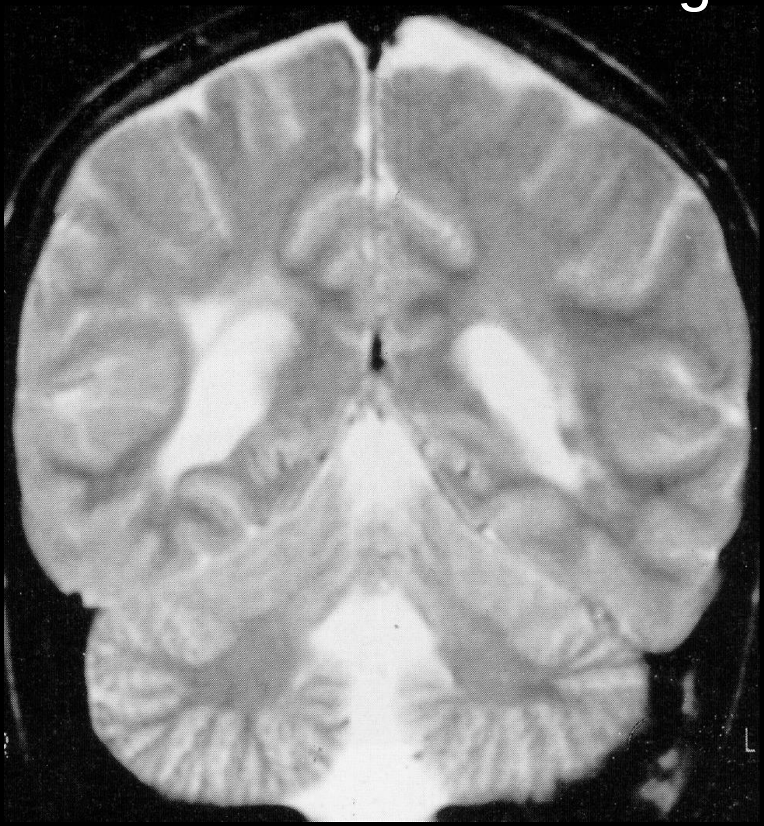


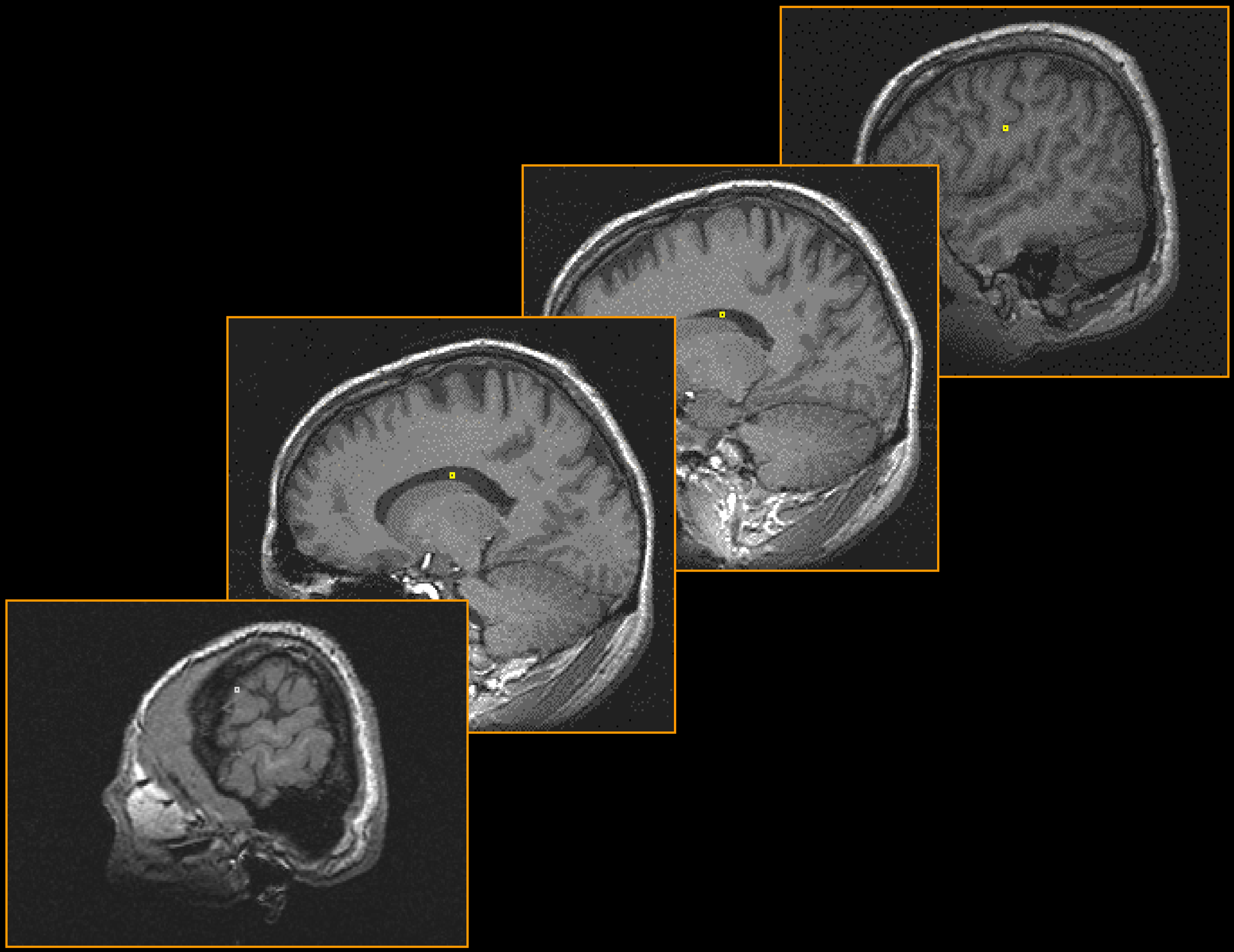
MRI Images with Different Contrast Weighting

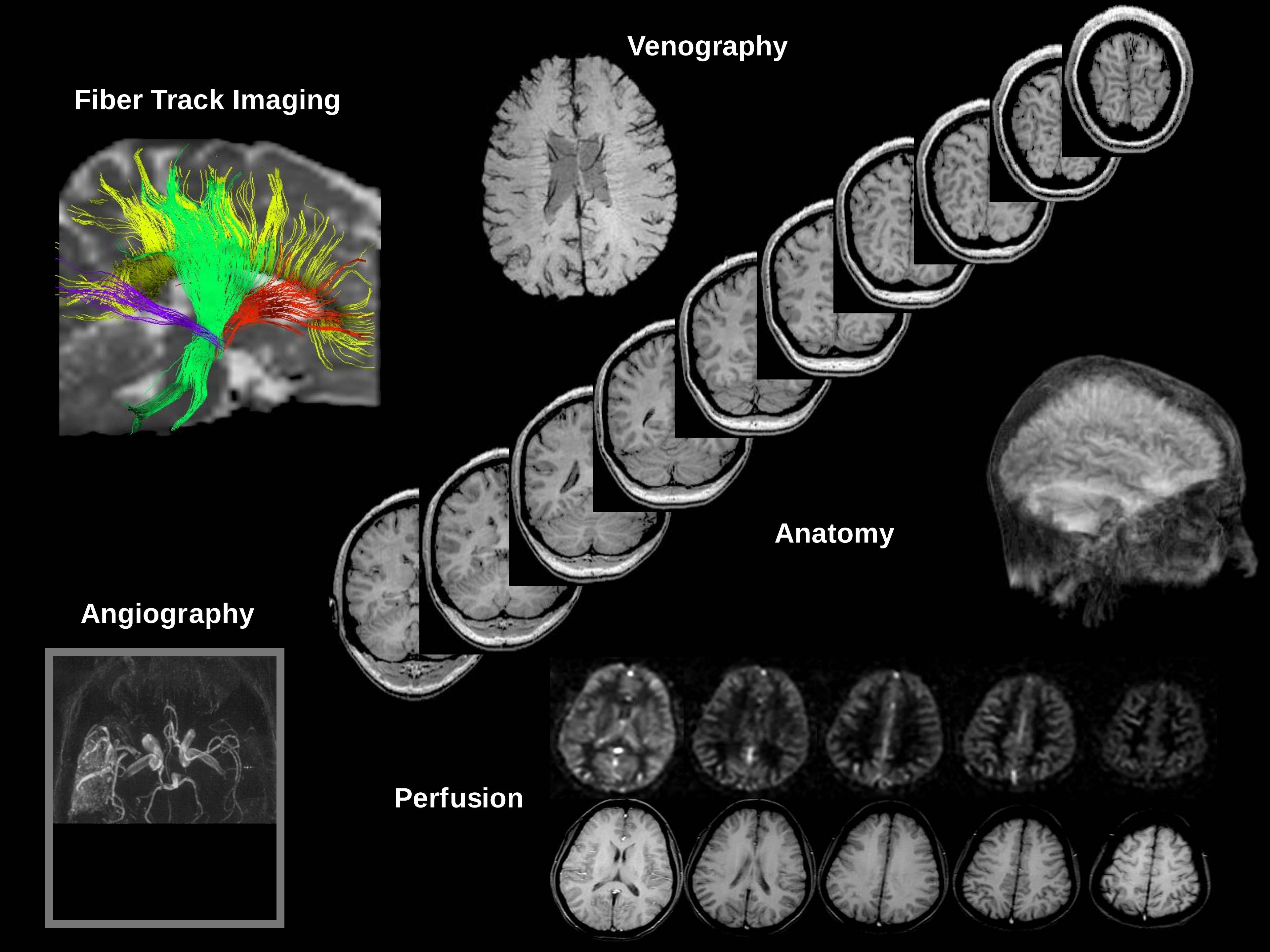
T1 Weighted

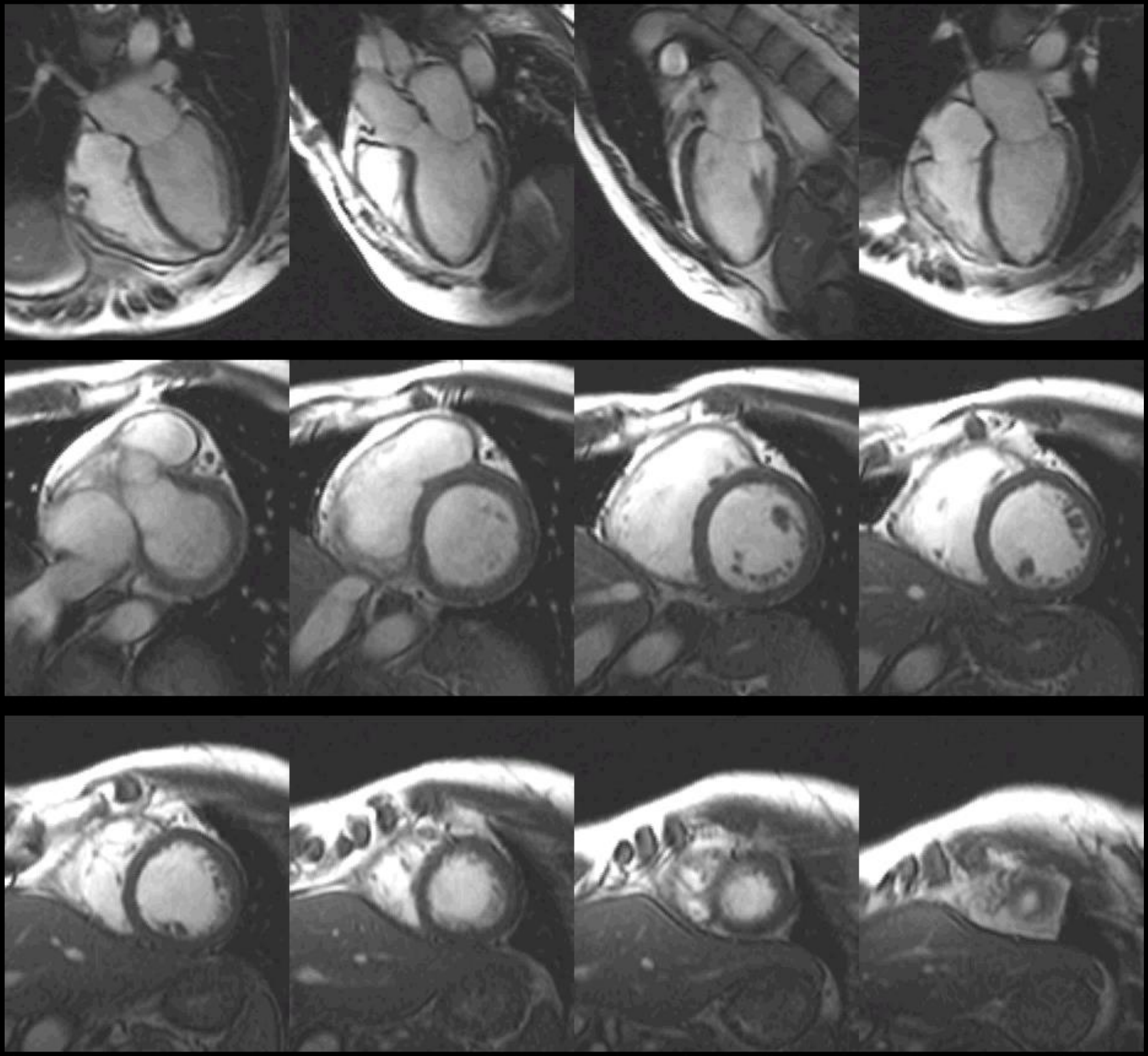


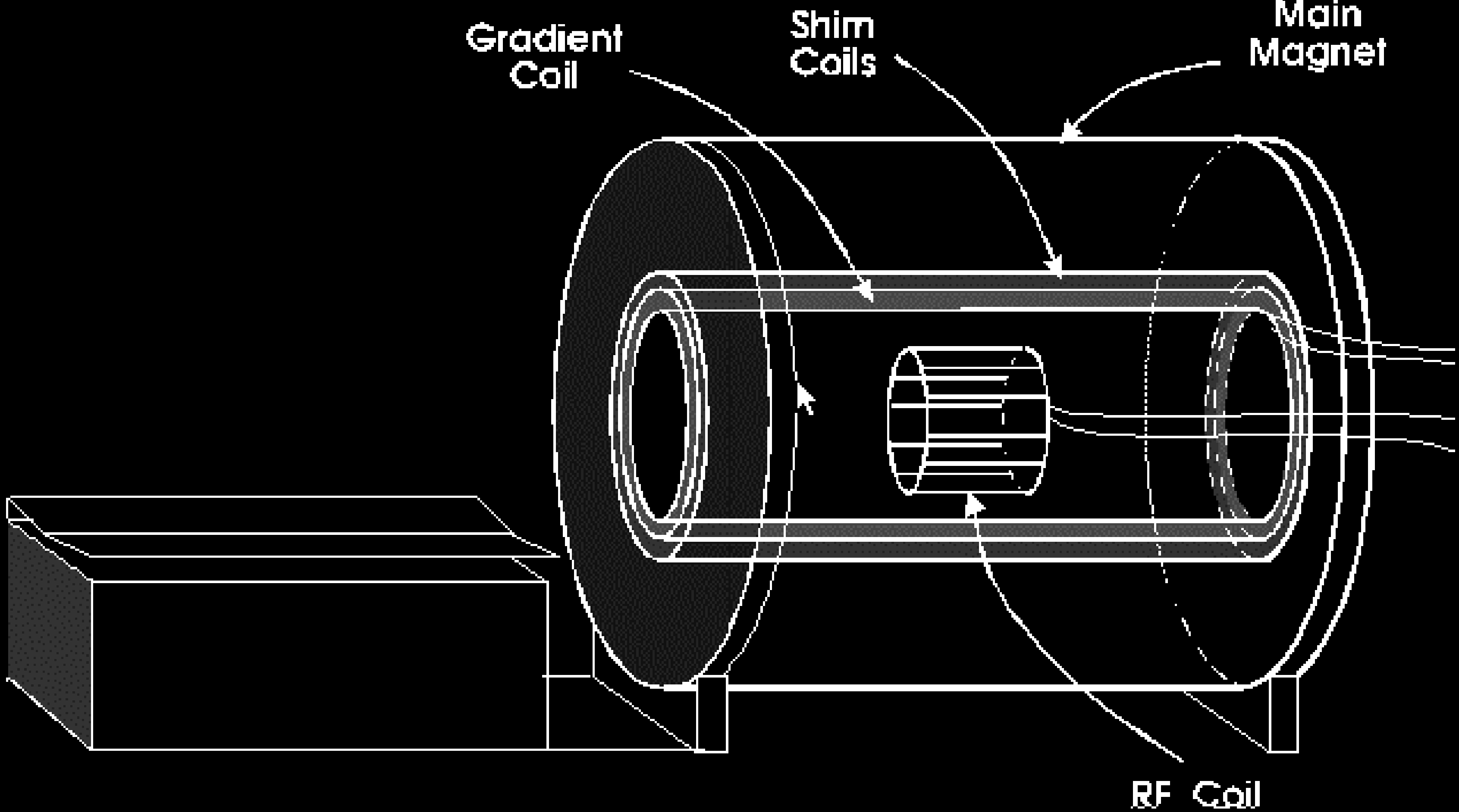
T2 Weighted





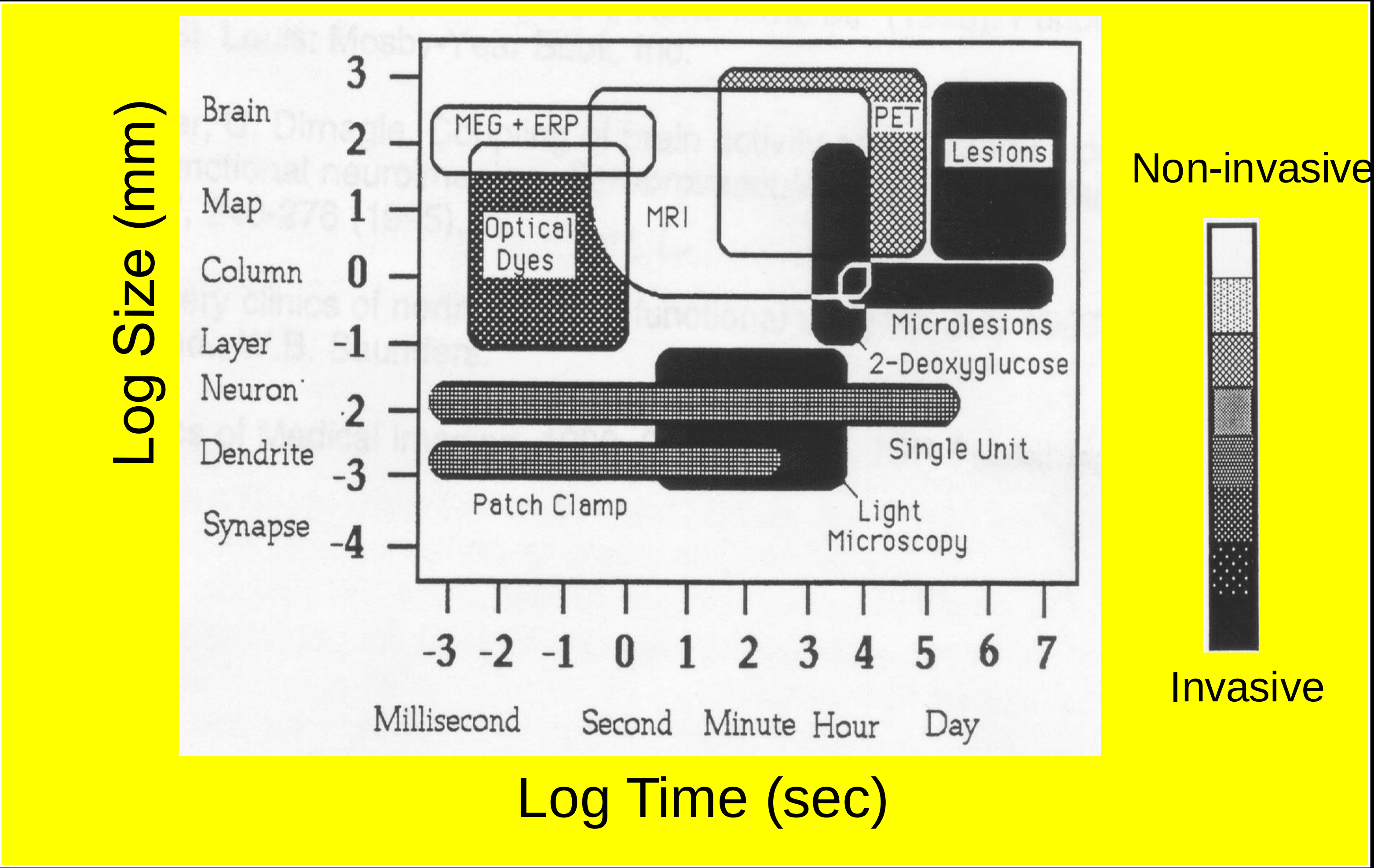

Venography
Fiber Track Imaging
Anatomy
Angiography
Perfusion




Gradient Coil
Shim Coils
Main Magnet
RF Coil

- 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)

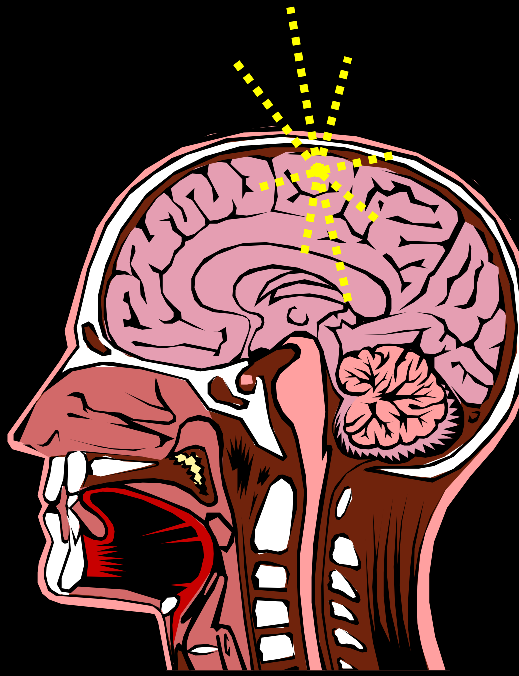
Functional Neuroimaging Techniques

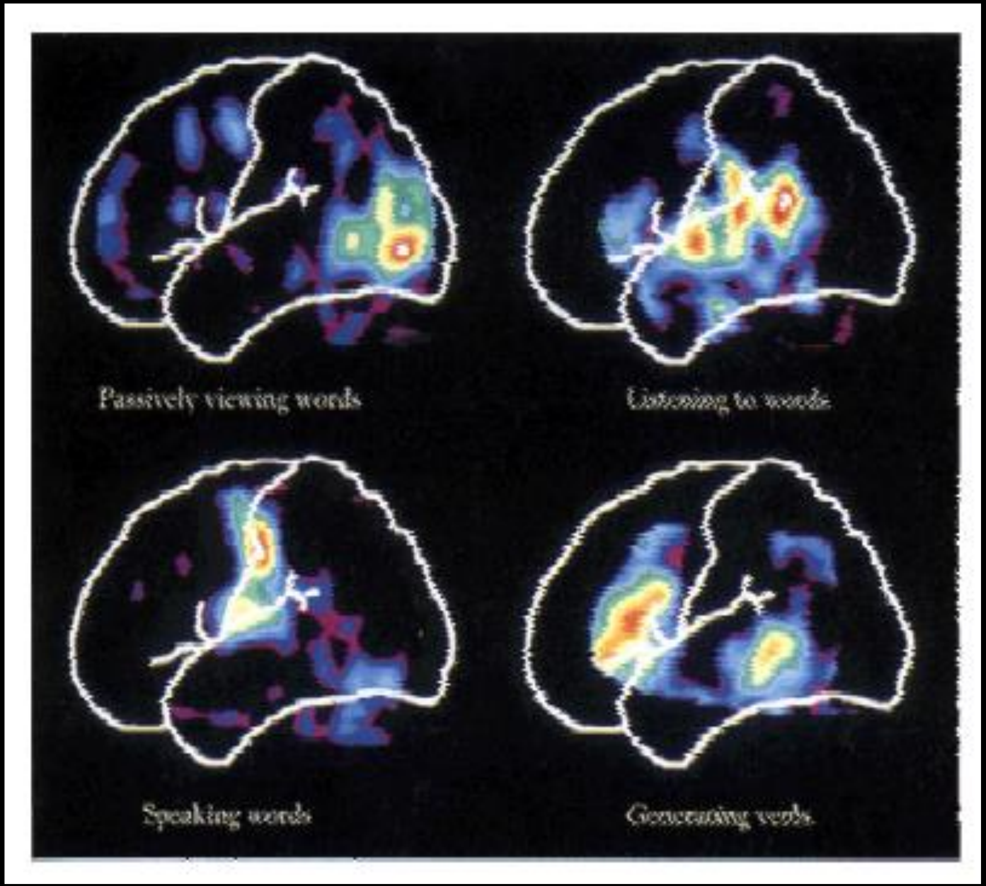


Positron Emission Tomography (PET)

- 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.

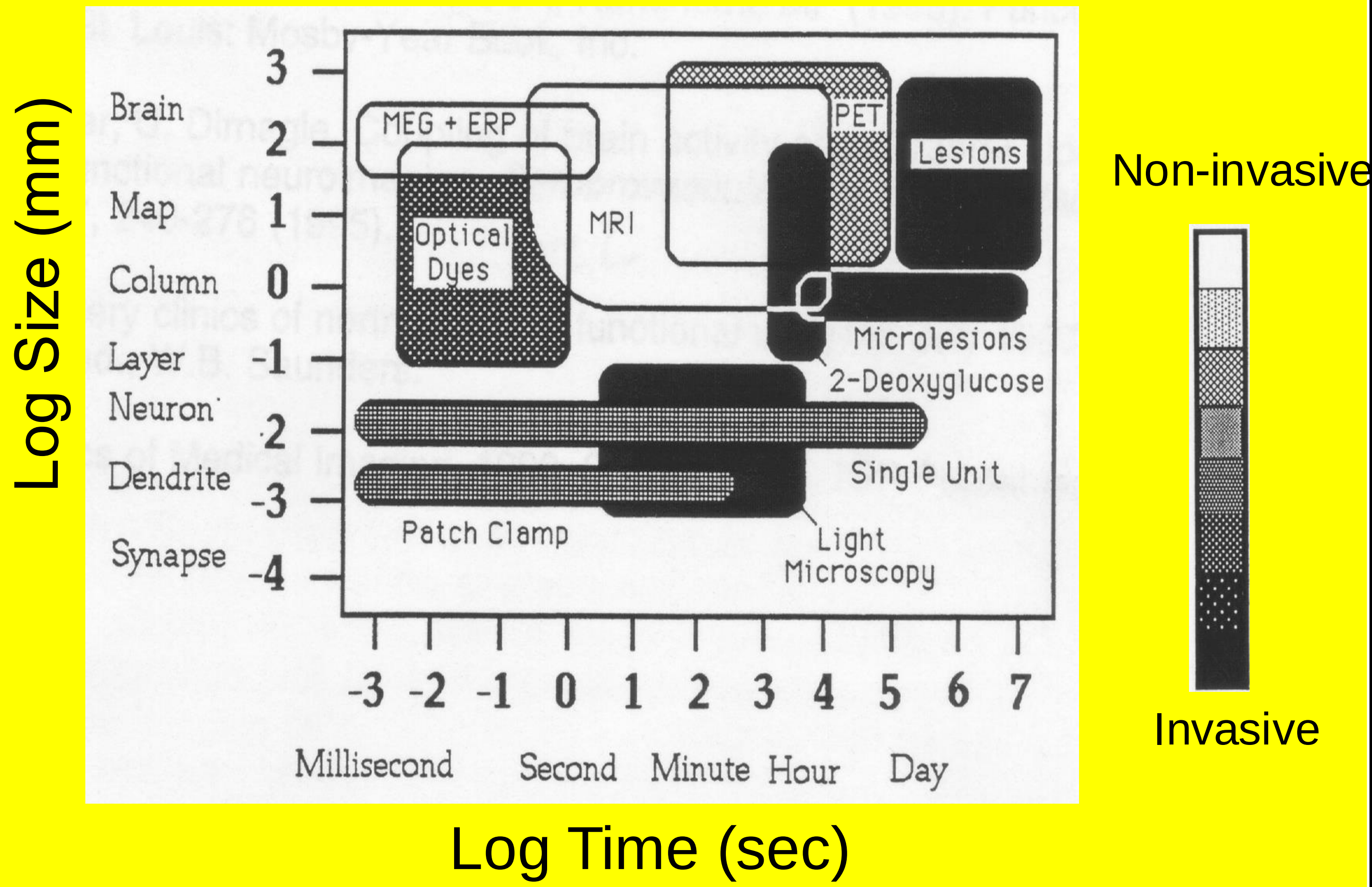




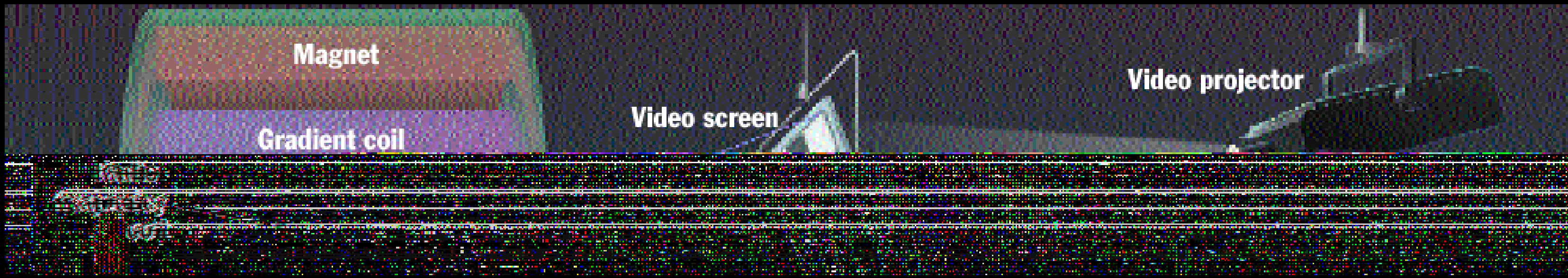
Passively viewing words
Listening to words
Speaking words
Generating verbs

Functional Magnetic Resonance Imaging

Functional Neuroimaging Techniques



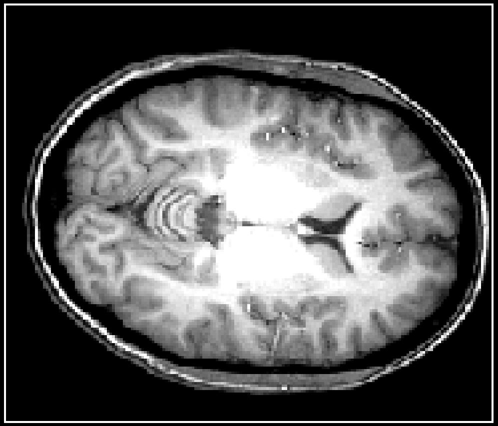
fMRI Setup



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

MRI vs. fMRI

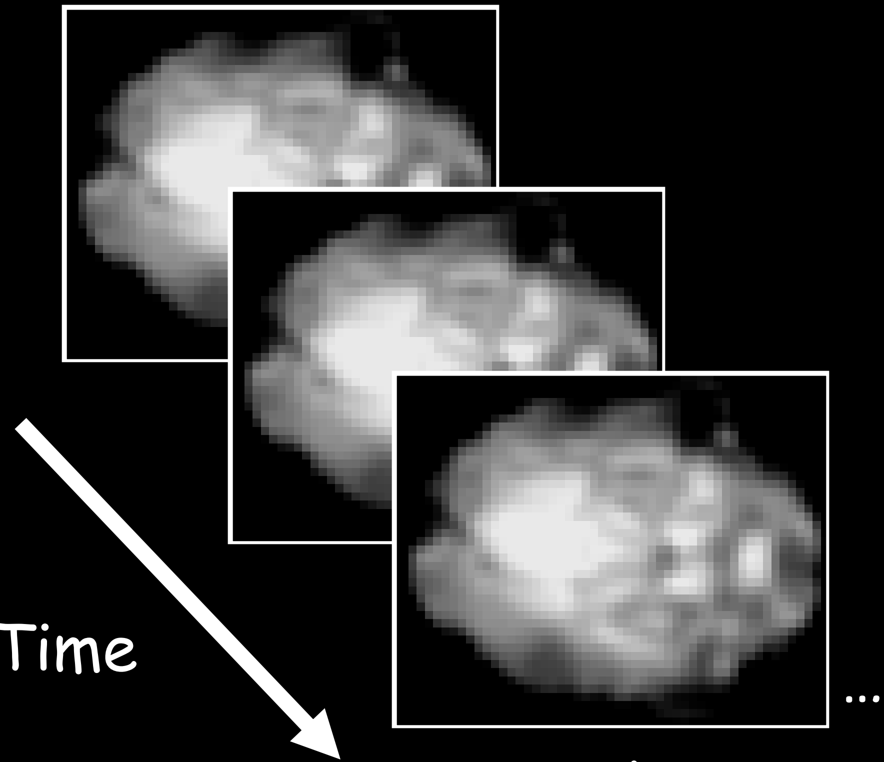
MRI



one image

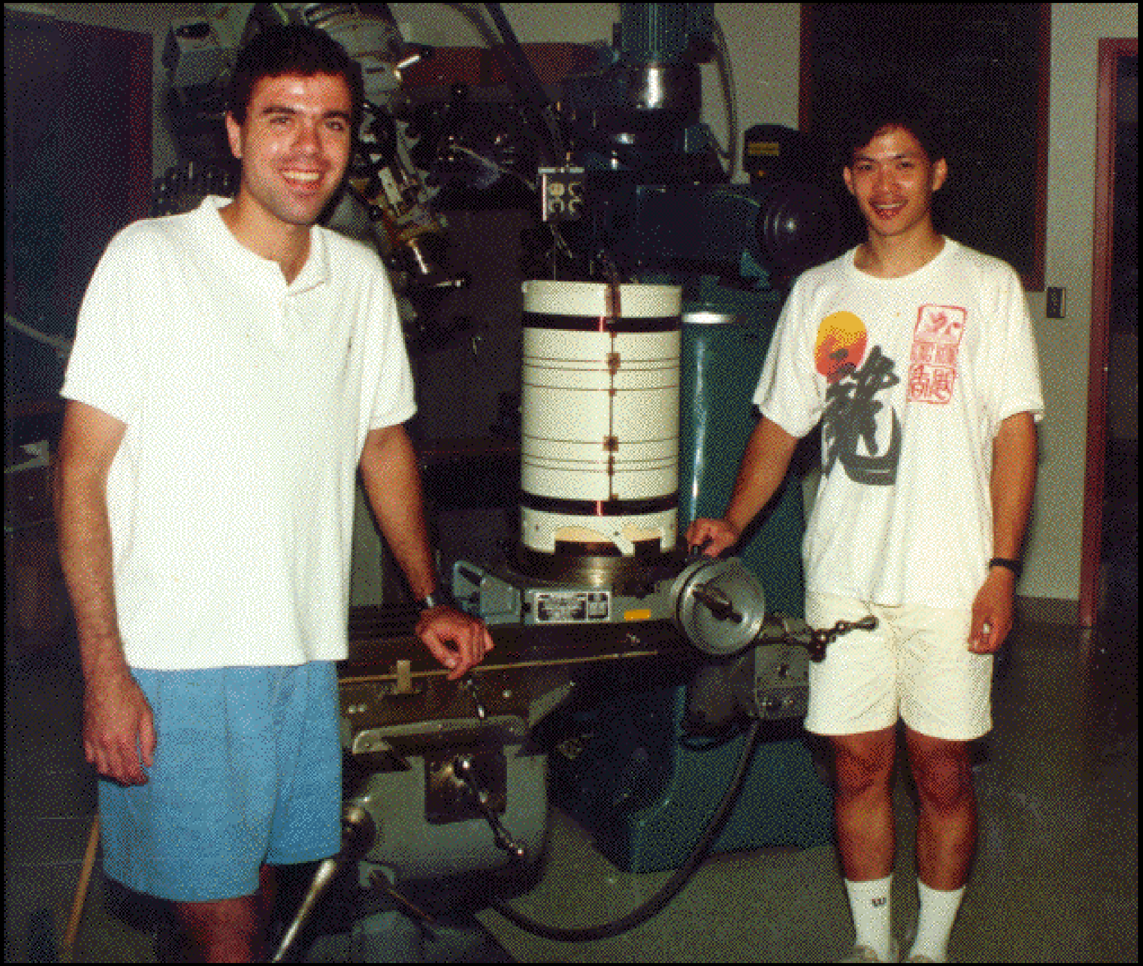
high resolution
(1 mm or less)

fMRI



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

low resolution
(1.5 to 4 mm)



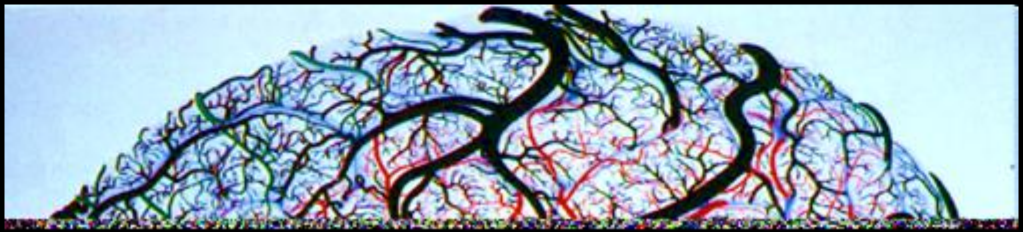
August, 1991

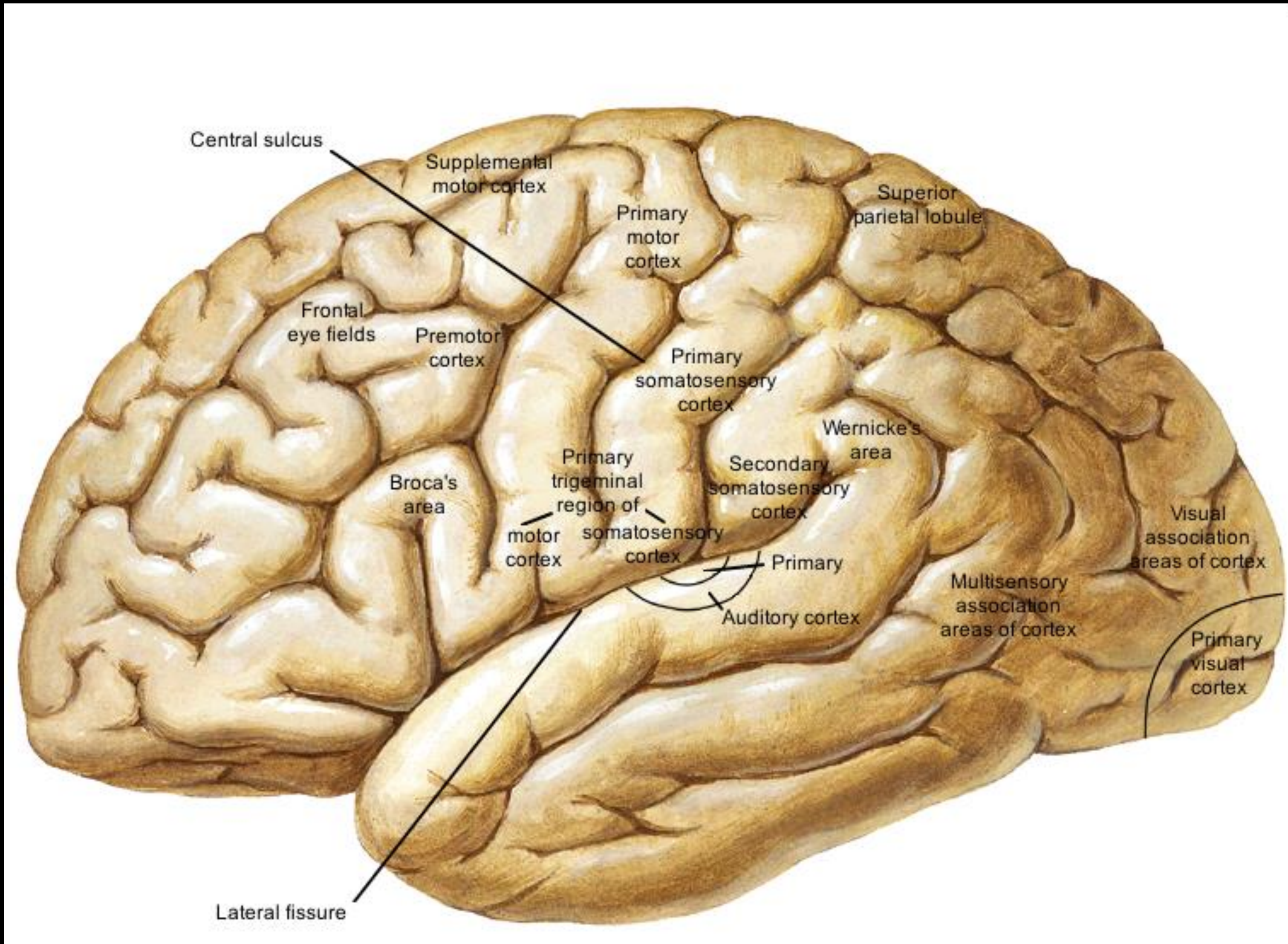
1991-1992

1992-1999

Contrast in Functional MRI

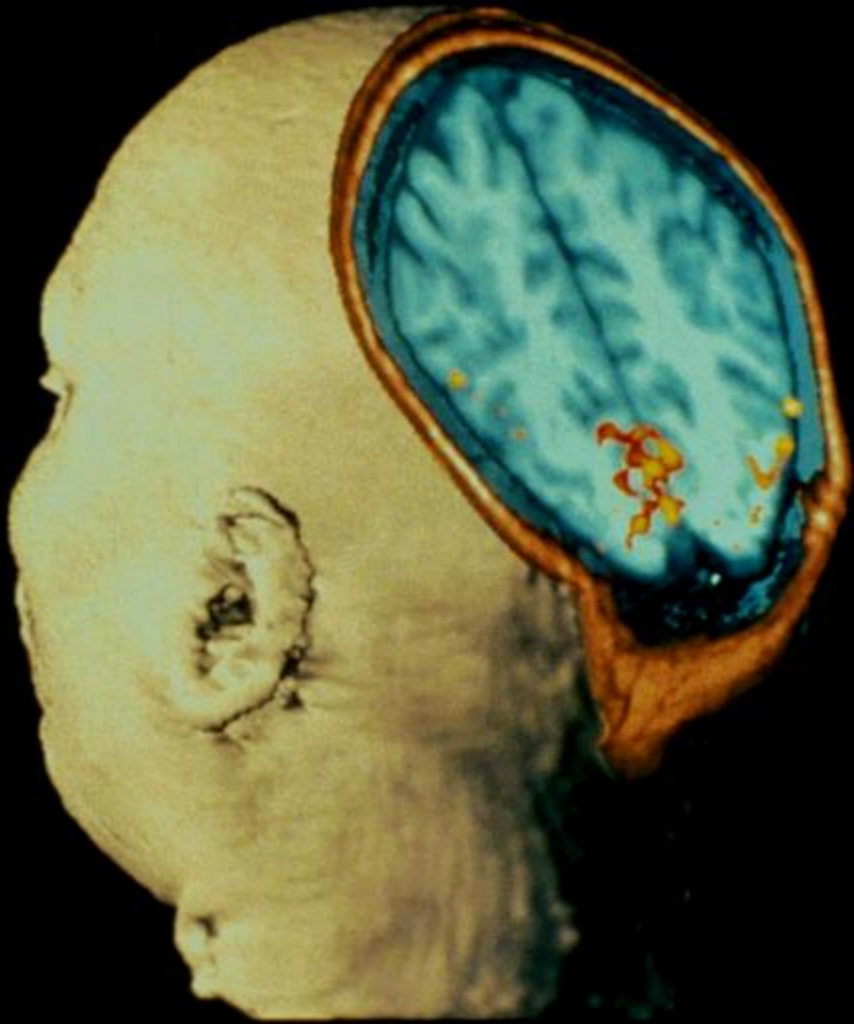
- **Blood Volume**
- **Blood Oxygenation Changes**
  - **Blood Oxygenation Level Dependent Contrast (BOLD)**
- **Blood Perfusion**





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
Secondary somatosensory cortex
motor cortex
somatosensory cortex
Primary
Auditory cortex
Visual association areas of cortex
Multisensory association areas of cortex
Primary visual cortex
Lateral fissure

Photic Stimulation



MRI Image showing activation of the Visual Cortex

From Belliveau, et al.
Science Nov 1991

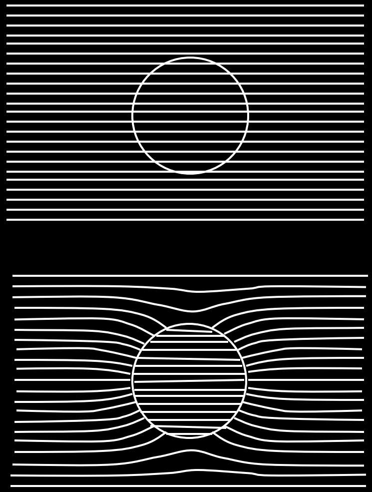
MSC - perfusion

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**.

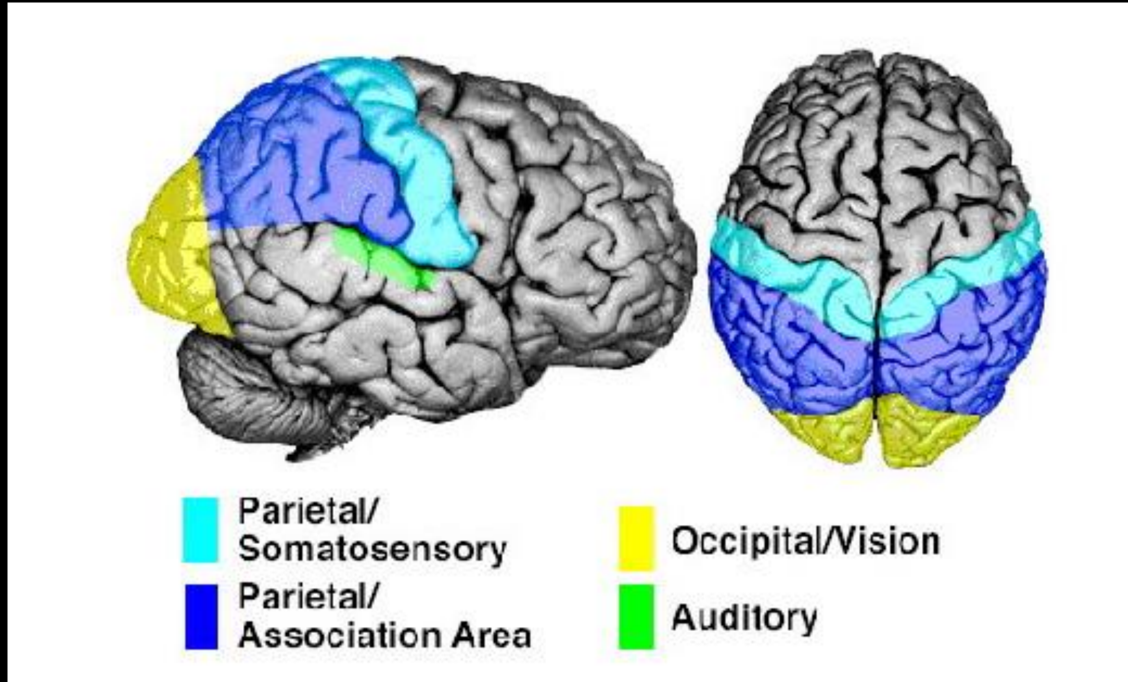
BOLD

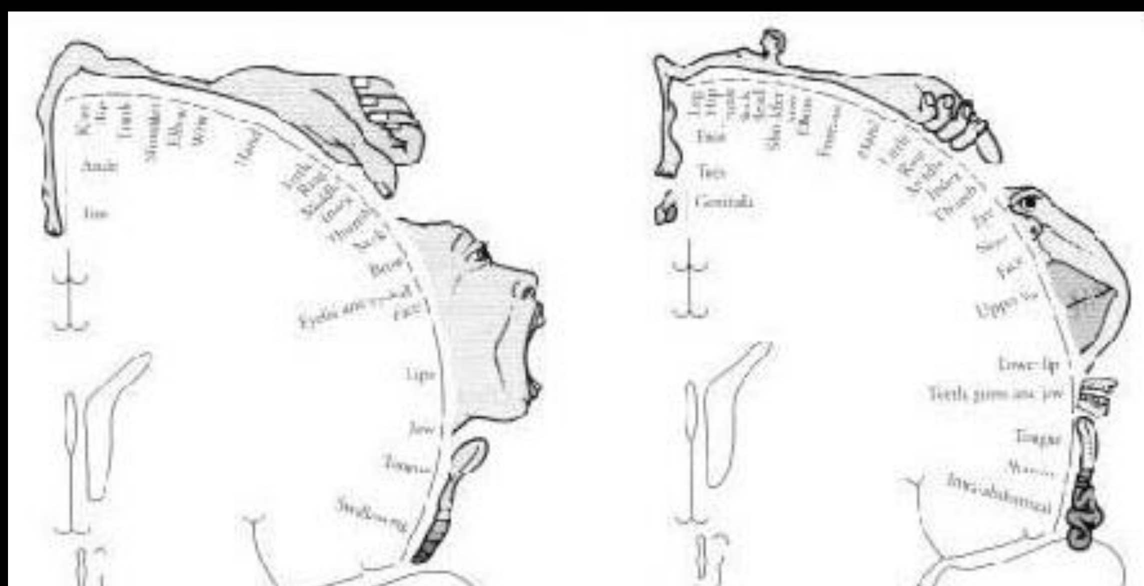
(blood oxygenation level dependence)

blood flow ↑

oxygenated-blood ↑

MR signal ↑


Parietal/
Somatosensory
Parietal/
Association Area
Occipital/Vision
Auditory



(b)

Alternating Left and Right Finger Tapping

~ 1992

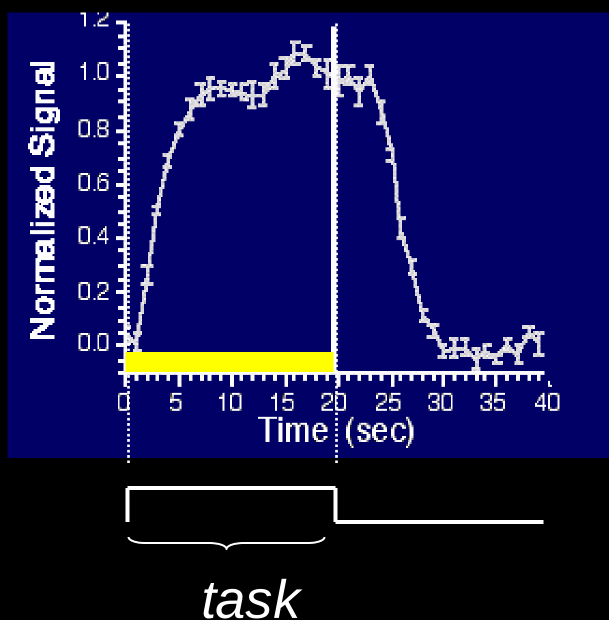
Real Time Brain Activation Imaging

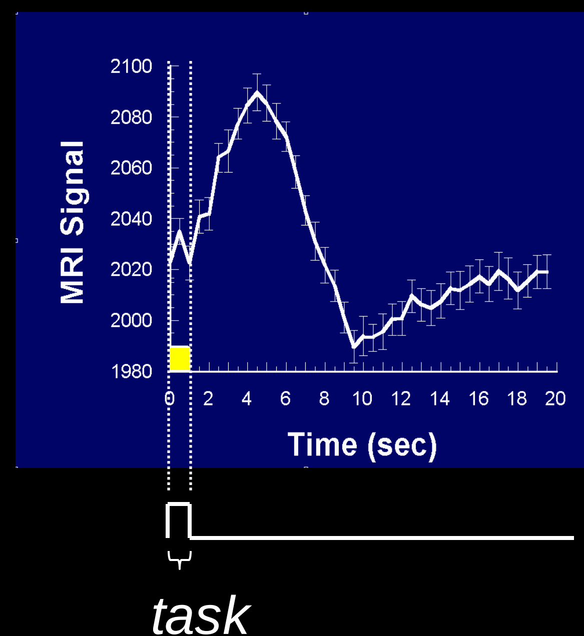
•K. K. Kwong, et al, (1992) "Dynamic magnetic resonance imaging of human brain activity during primary sensory stimulation." Proc. Natl. Acad. Sci. USA. 89, 5675-5679.

•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.

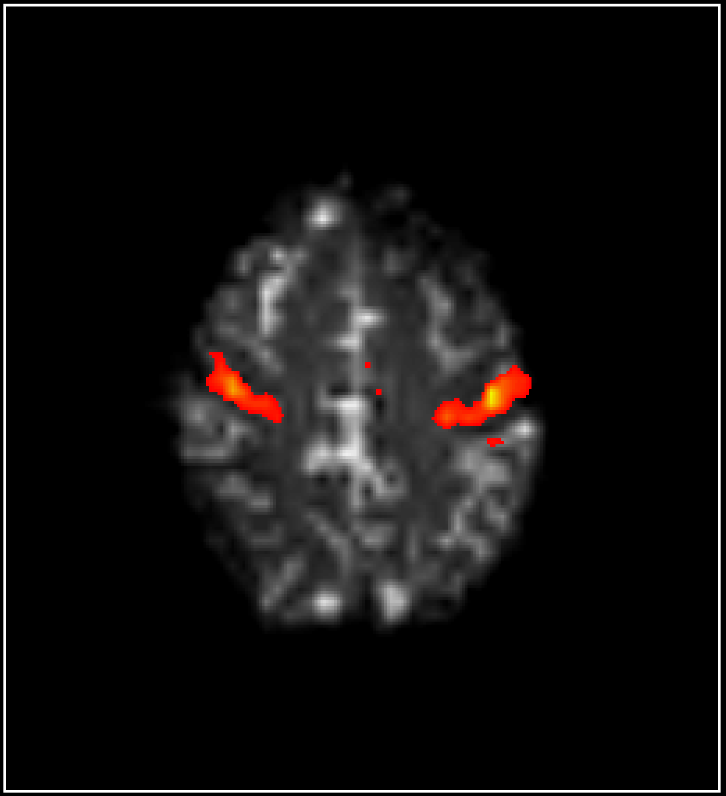
•P. A. Bandettini, et al., (1992) "Time course EPI of human brain function during task activation." Magn. Reson. Med 25, 390-397.

•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.

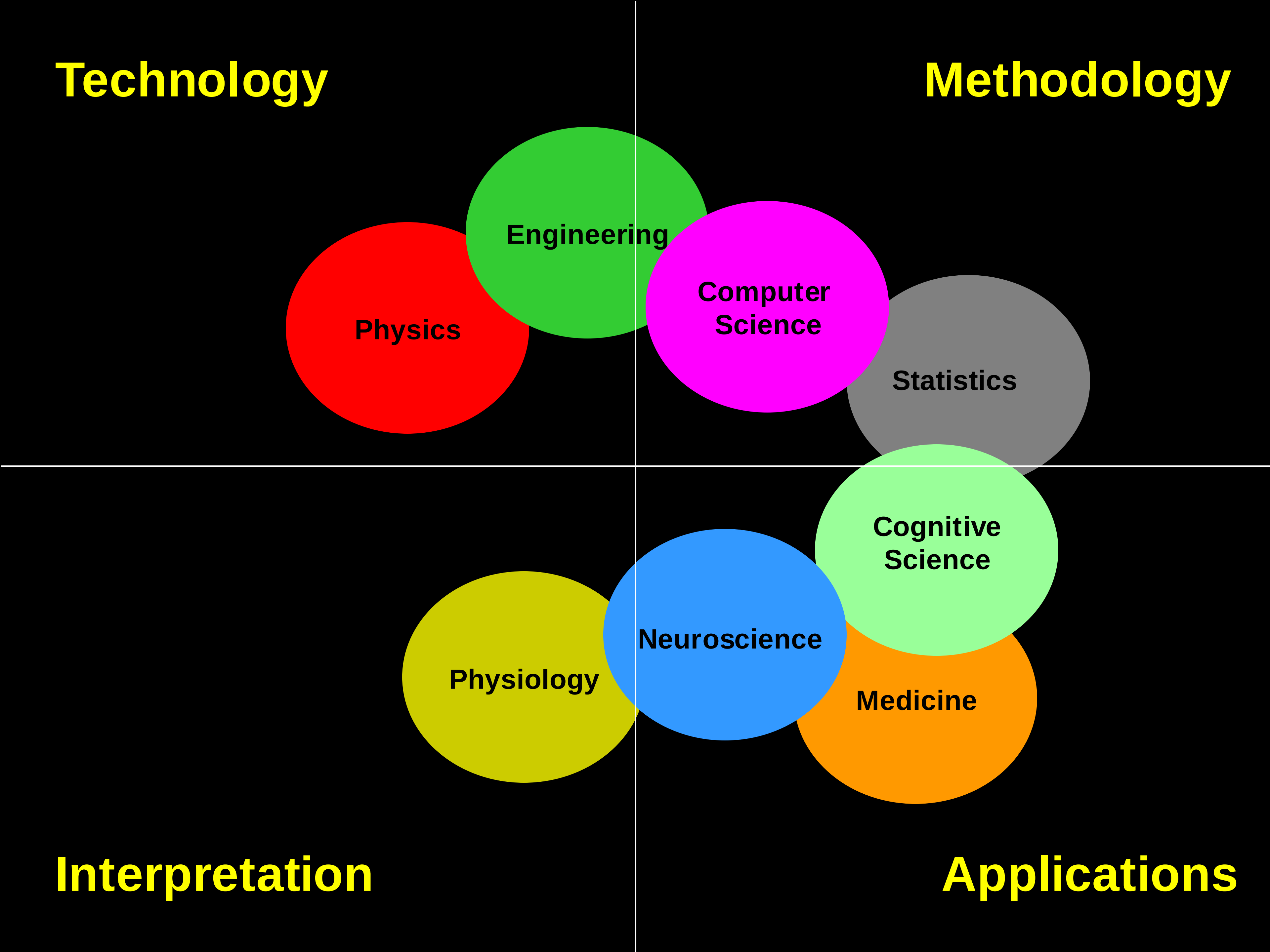


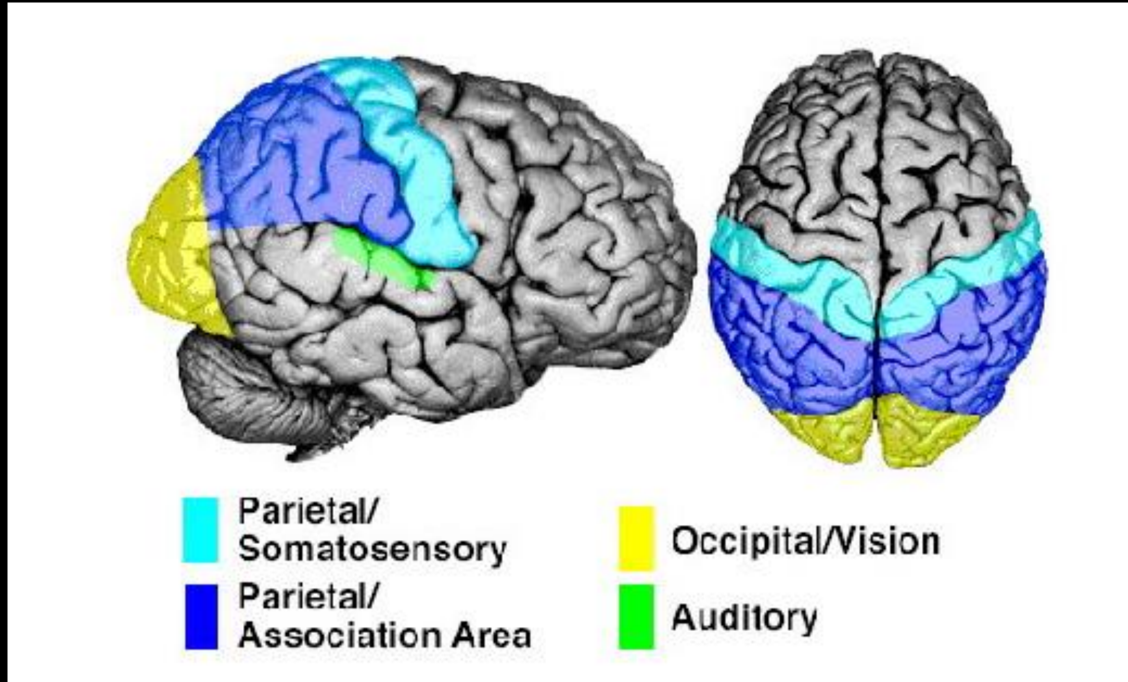


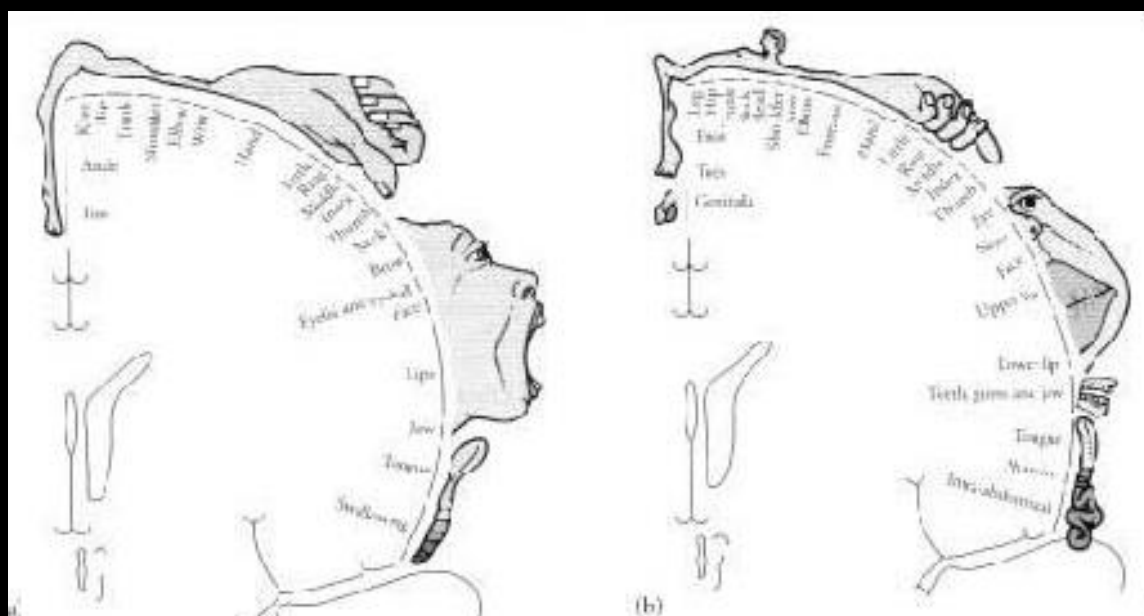
Cross Correlation Image

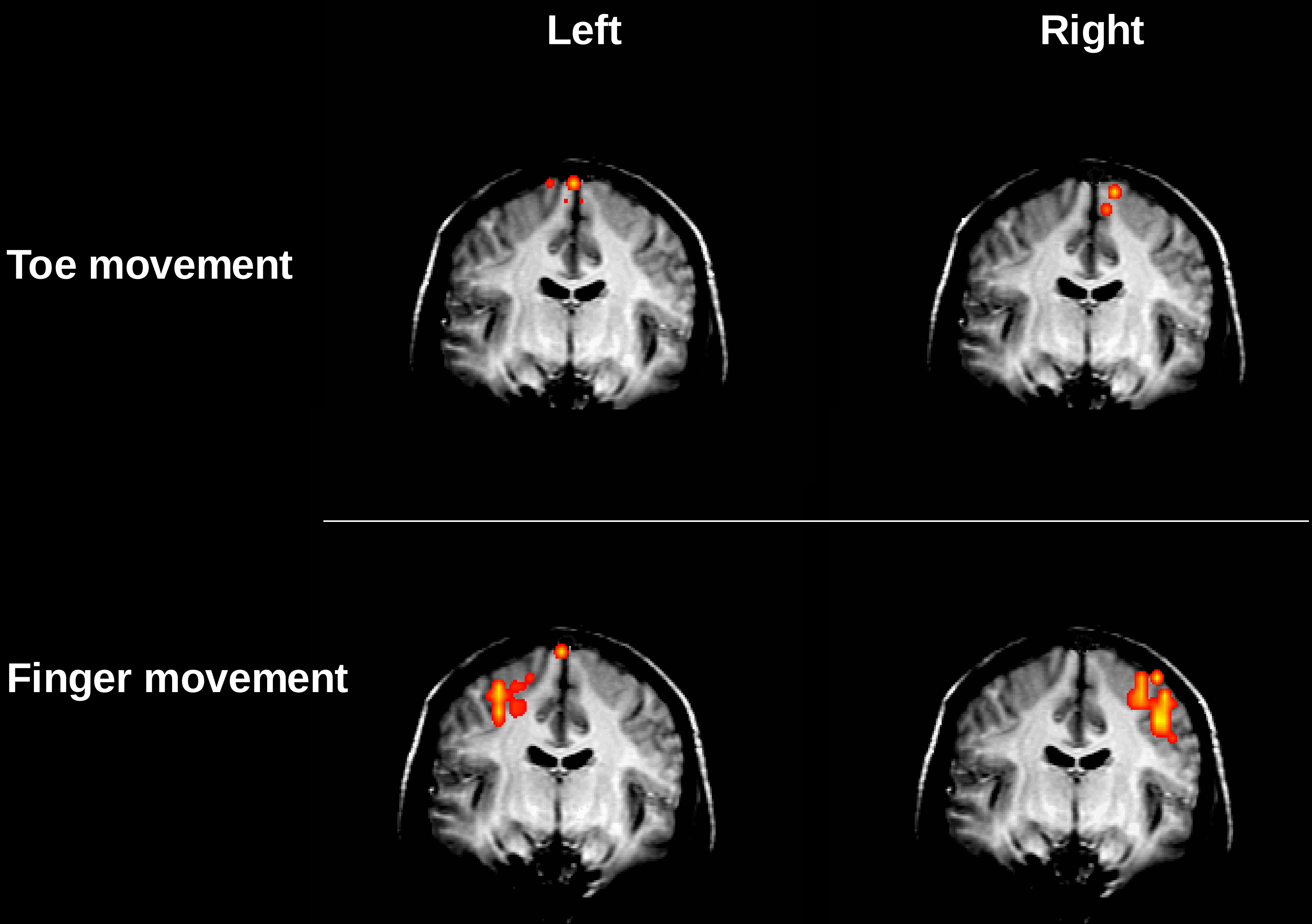


Cross Correlation Image
Anatomical Image

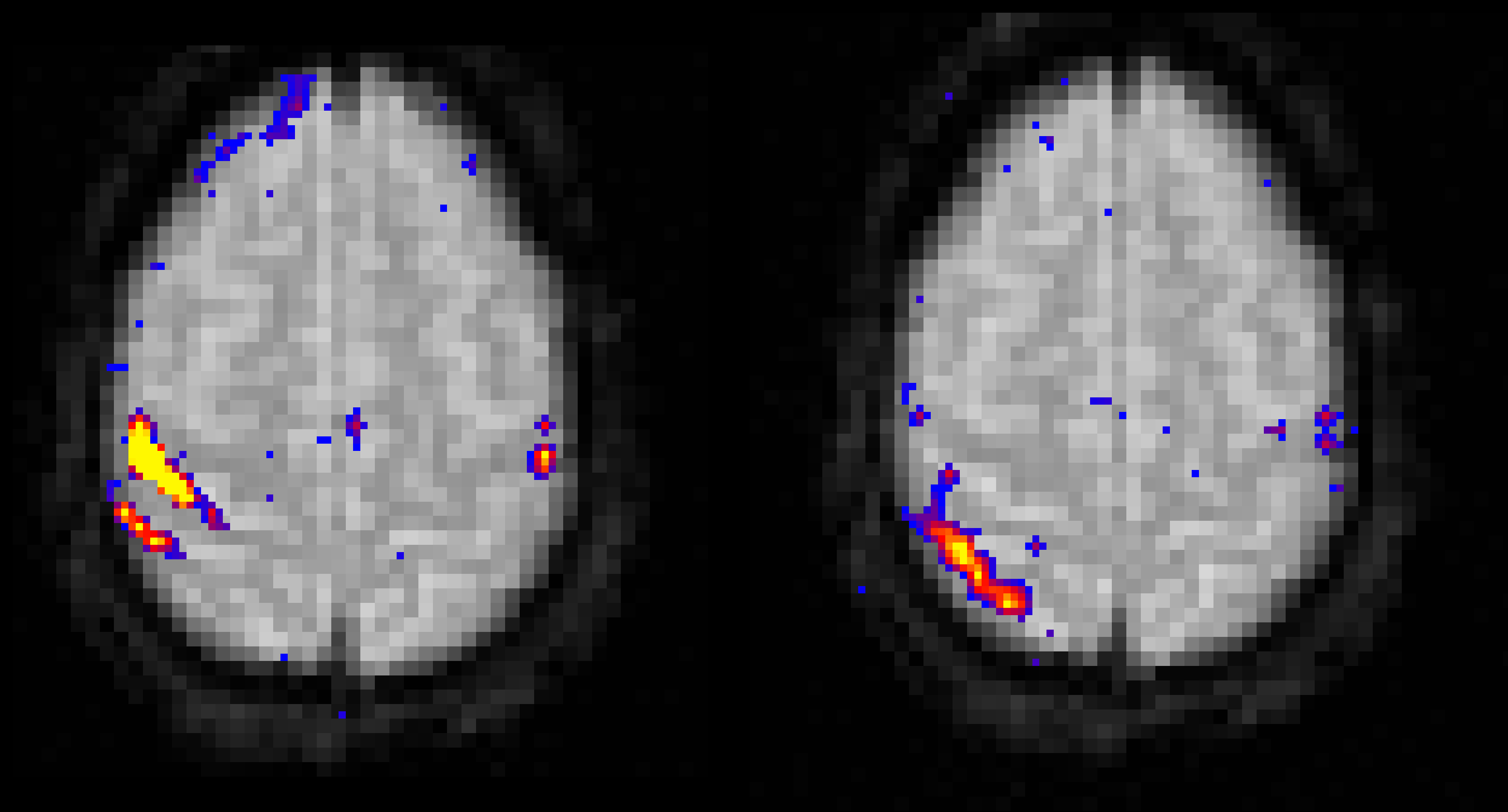

Technology
Methodology
Engineering
Physics
Computer Science
Statistics
Cognitive Science
Neuroscience
Physiology
Medicine
Interpretation
Applications

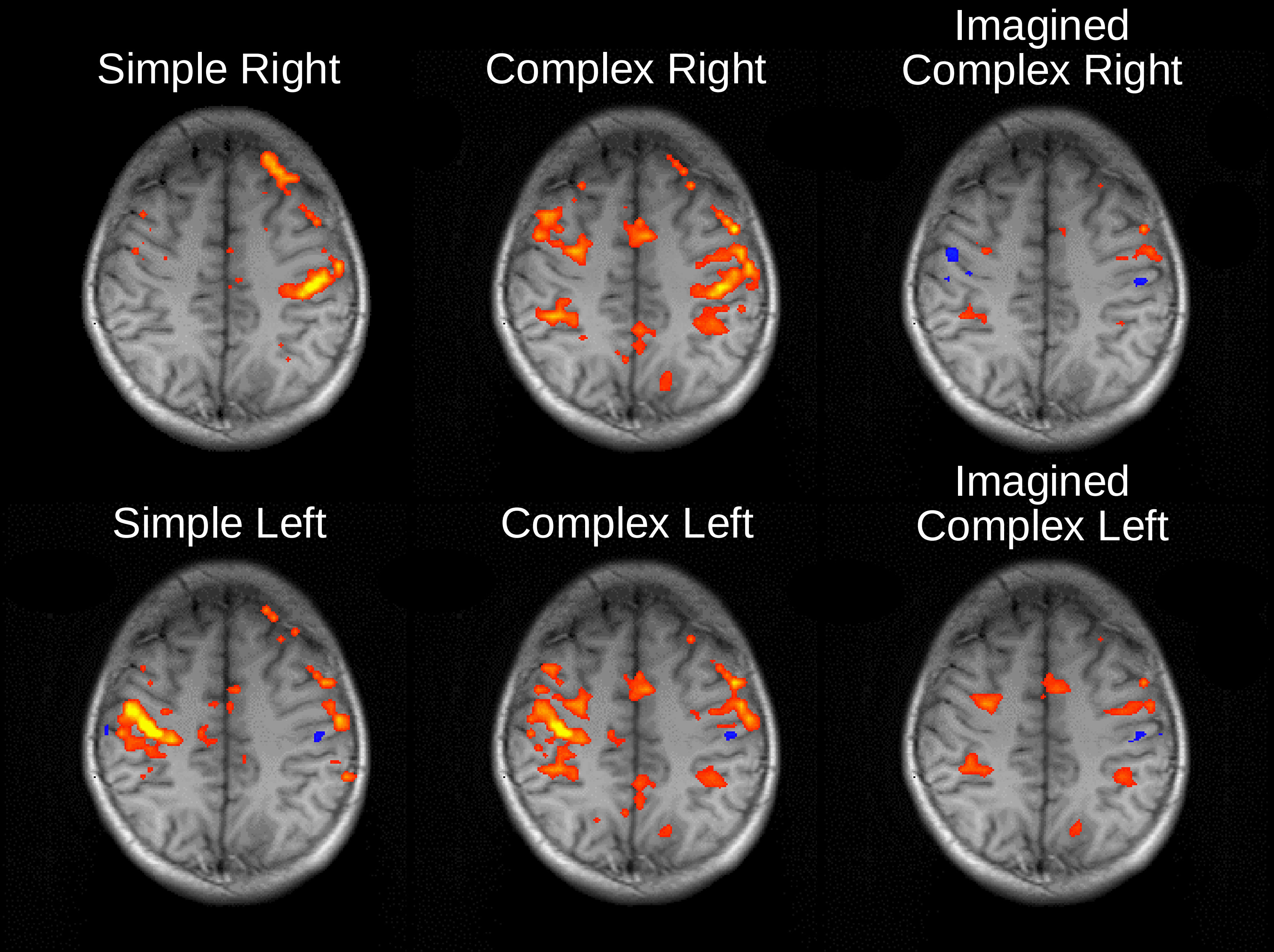

Parietal/
Somatosensory
Parietal/
Association Area
Occipital/Vision
Auditory

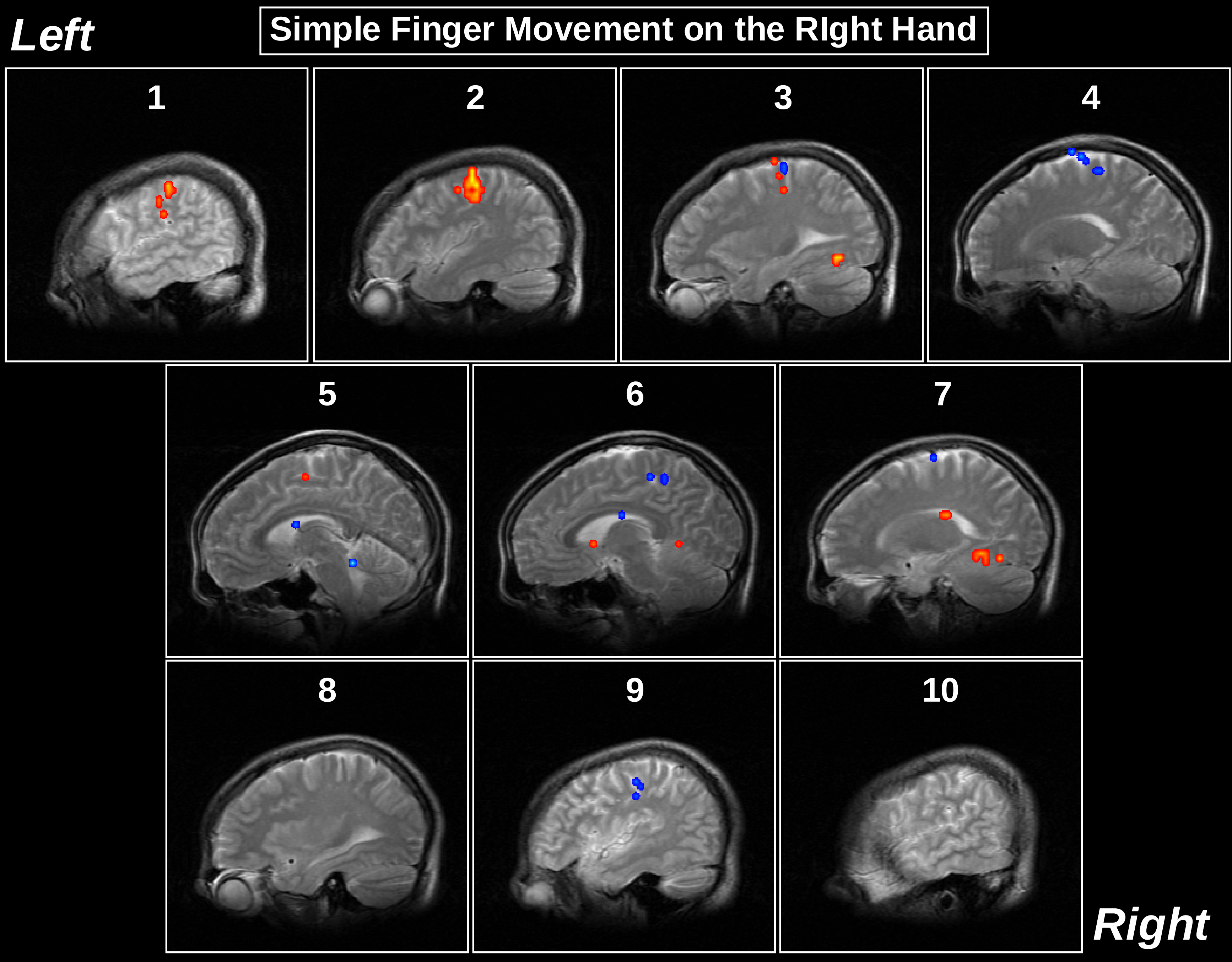

Ankle
Trunk
Shoulder
Elbow
Wrist
Hand
Neck
Brow
Face
Lips
Jaw
Swallowing
Foot
Toes
Genitals
Forearm
Nose
Face
Lower lip
Tongue
Intra-abdominal
(b)


Left
Right
Toe movement
Finger movement

Finger Movement **Tactile Stimulation**

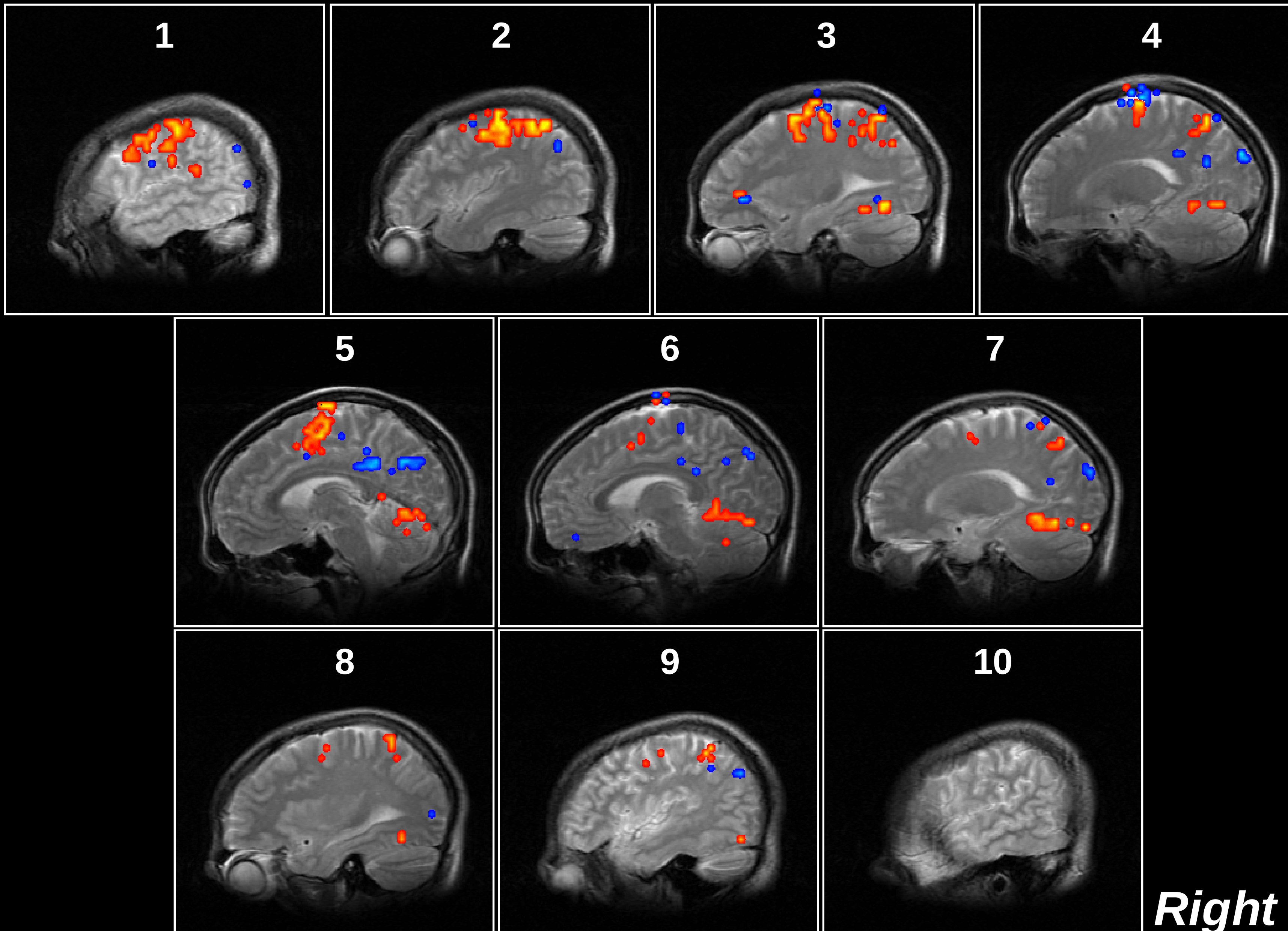



Simple Right
Complex Right
Imagined Complex Right
Simple Left
Complex Left
Imagined Complex Left

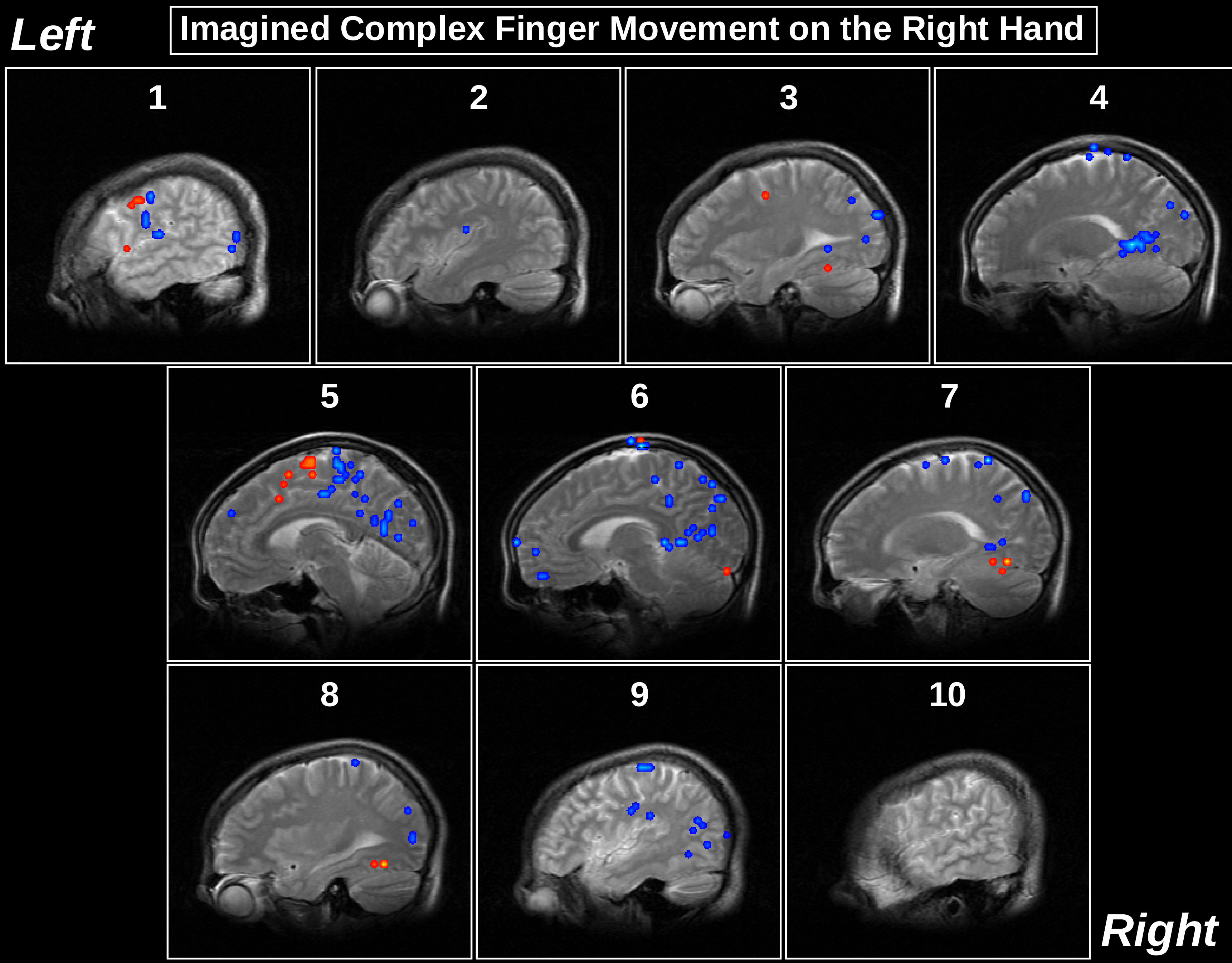

Left
Simple Finger Movement on the RIght Hand
1
2
3
4
5
6
7
8
9
10
Right

Left

Complex Finger Movement on the Right Hand

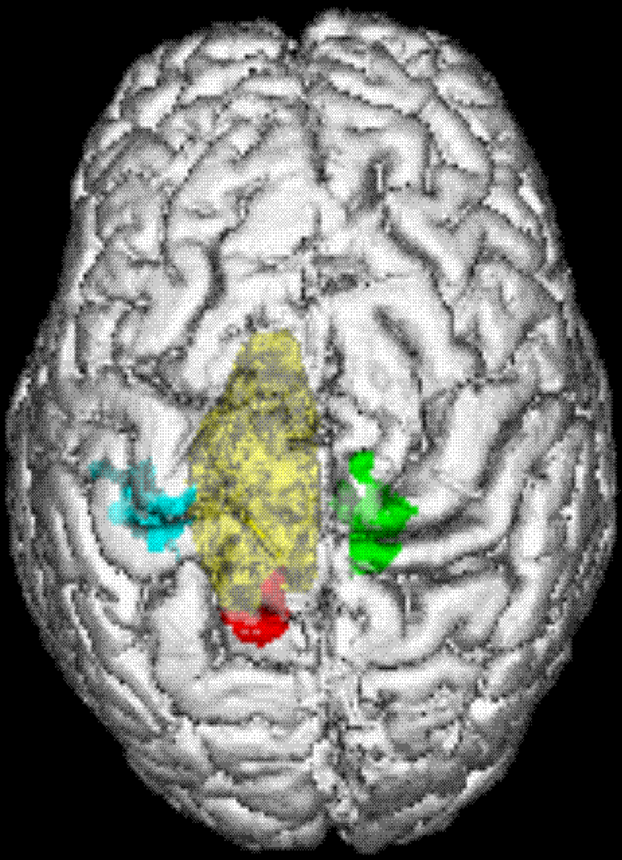


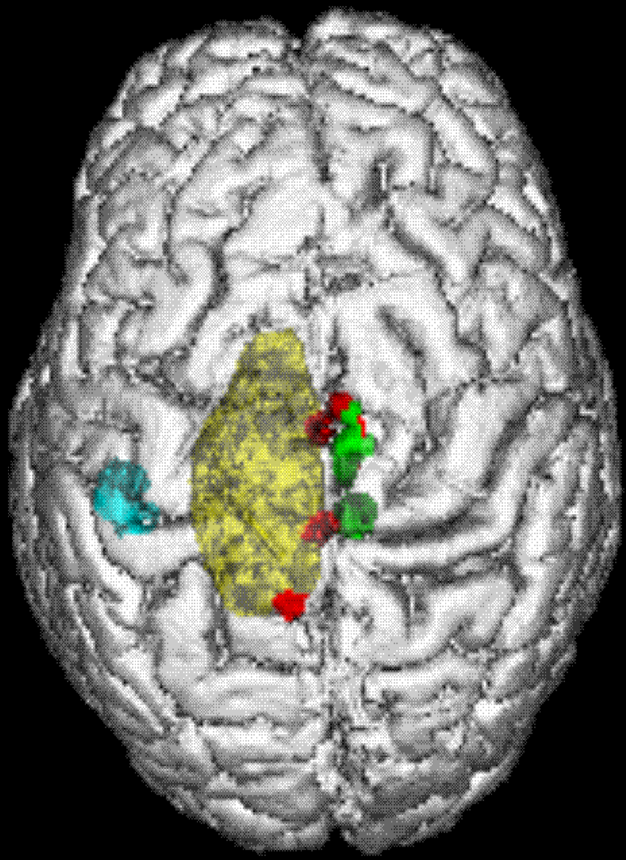
Right


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

Presurgical Mapping

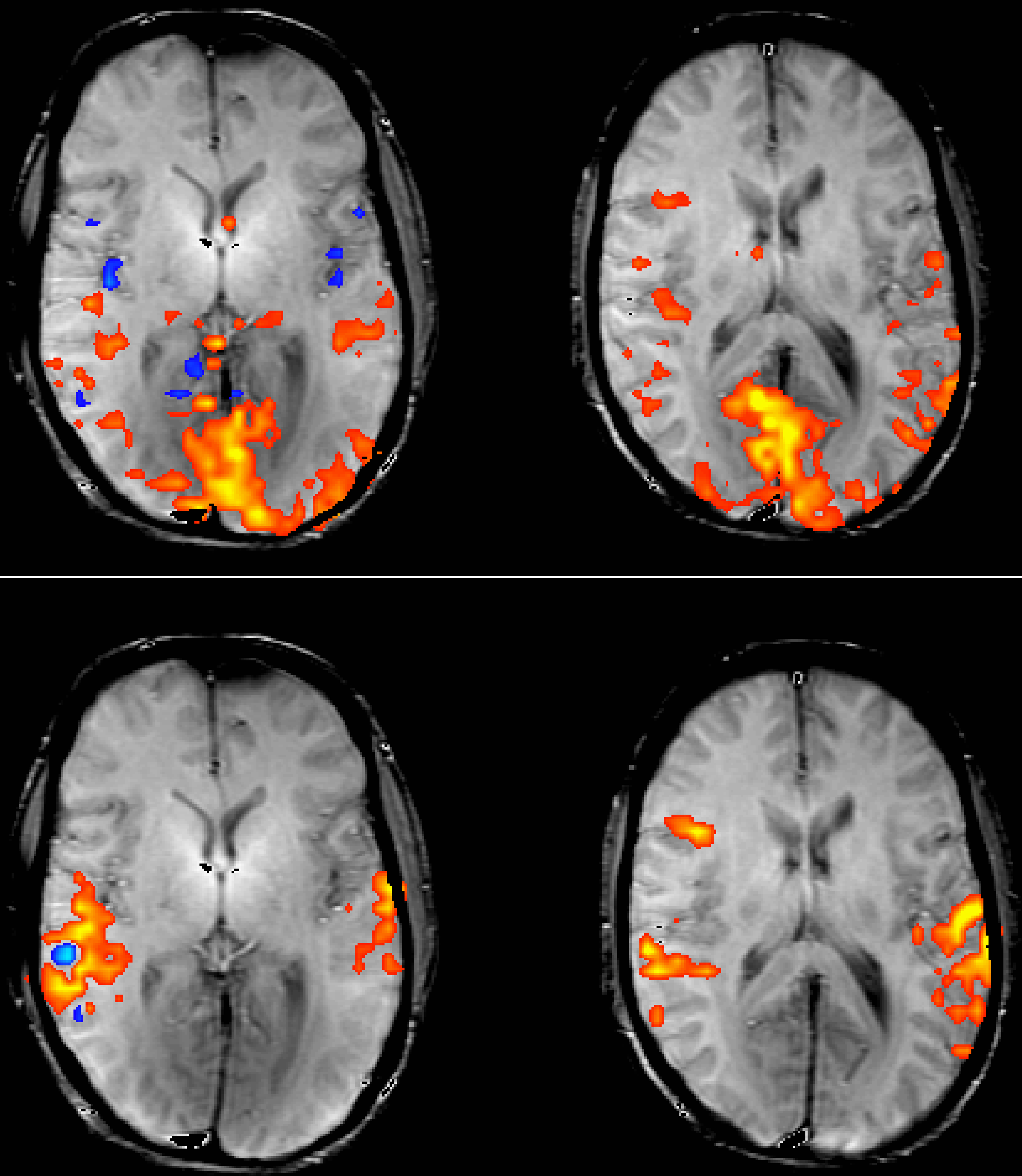
Left Foot Tumor Right Foot Right Hand





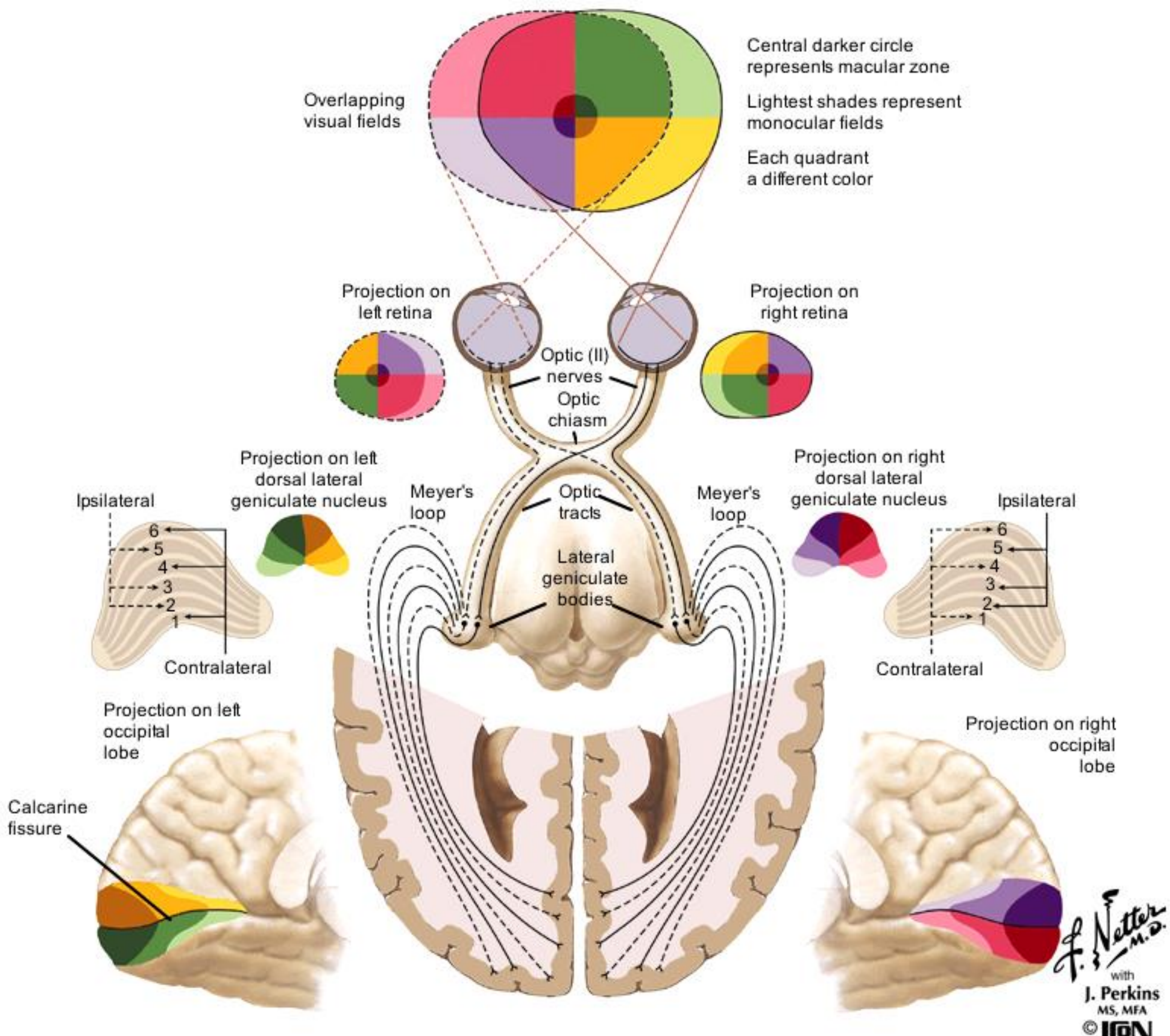
fMRI O-15 PET

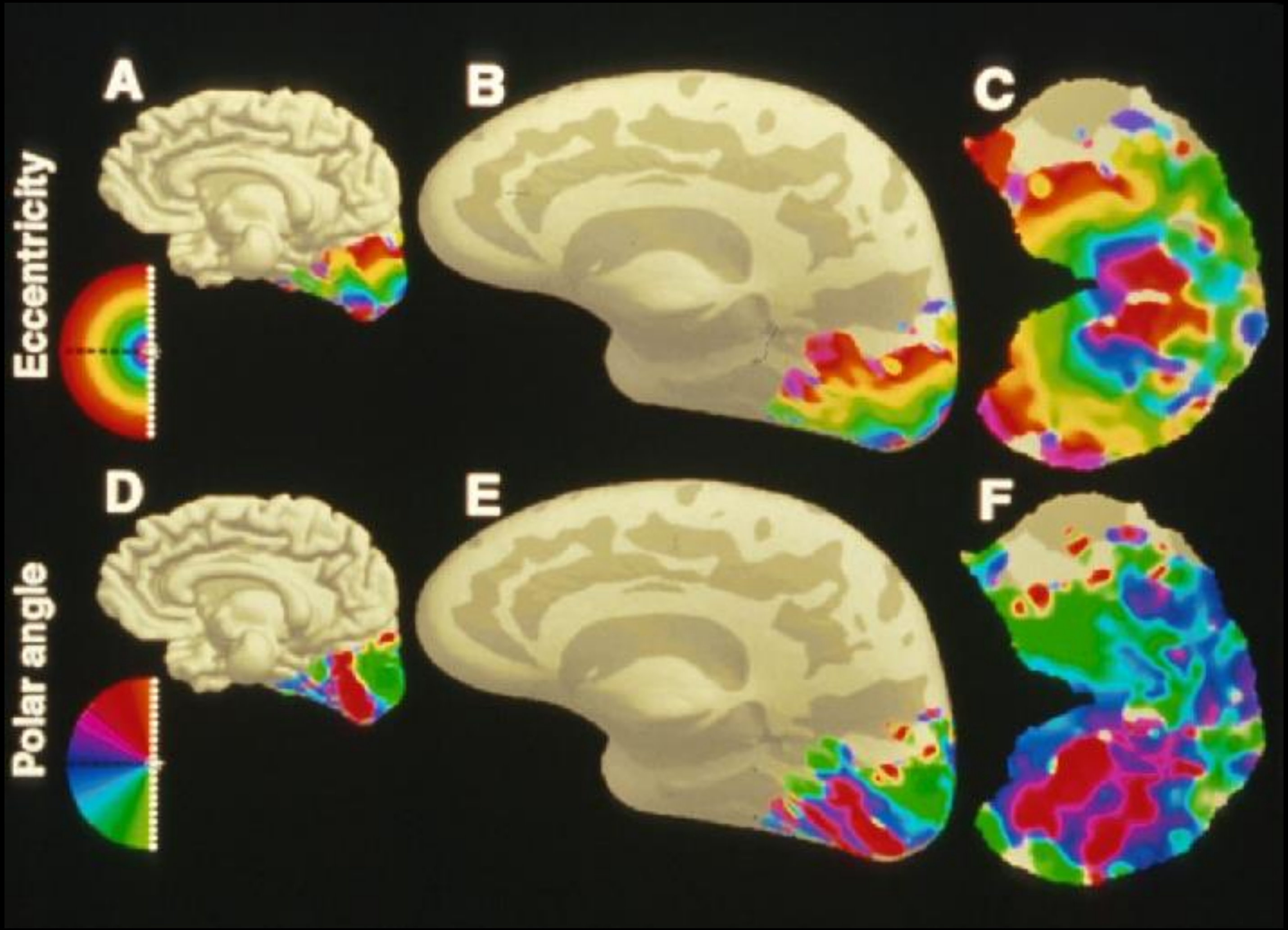
Reading



Listening

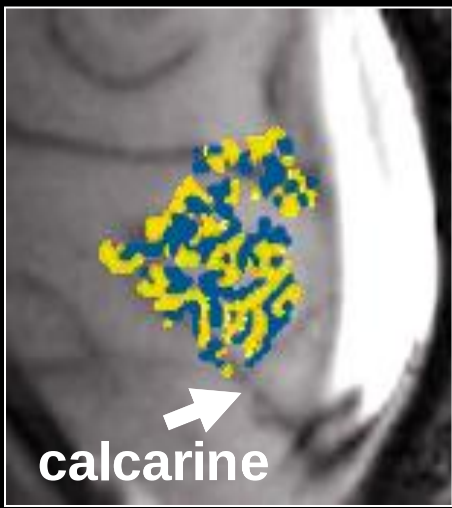
Visual Pathways: The Retino-Geniculo-Calcarine Pathway

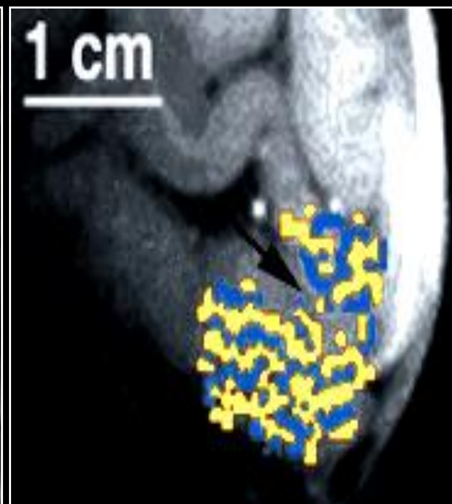


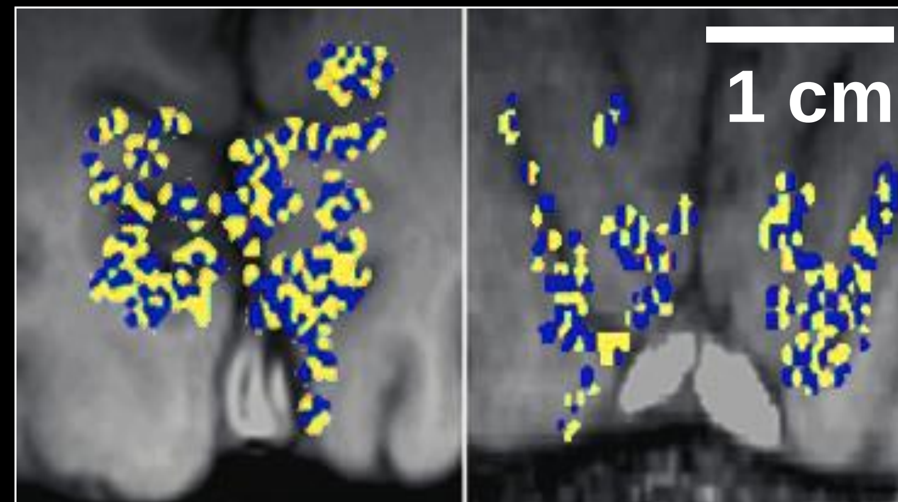


A
B
C
D
E
F
Eccentricity
Polar angle

ODC Maps using fMRI





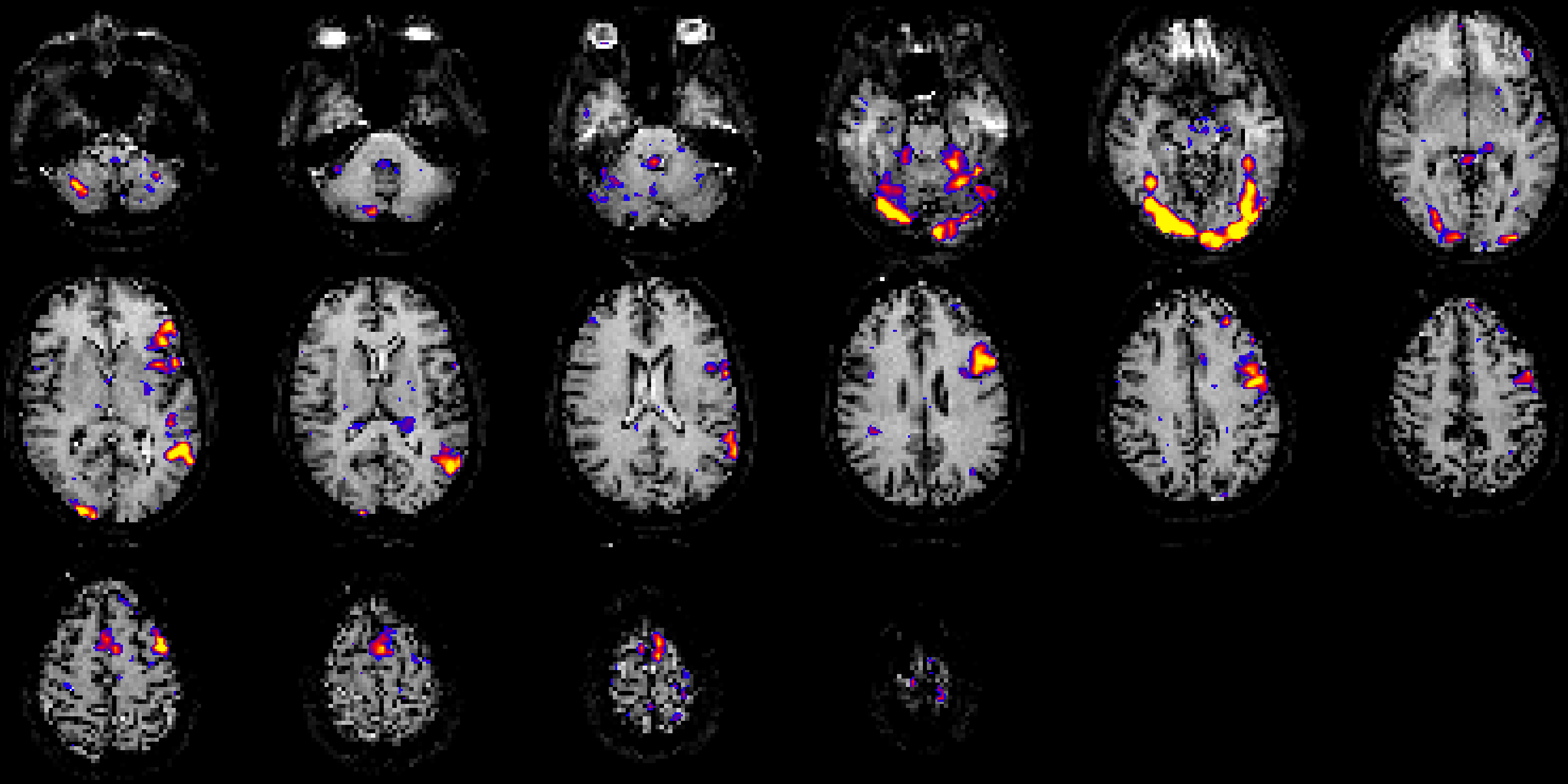


Menon et al.

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

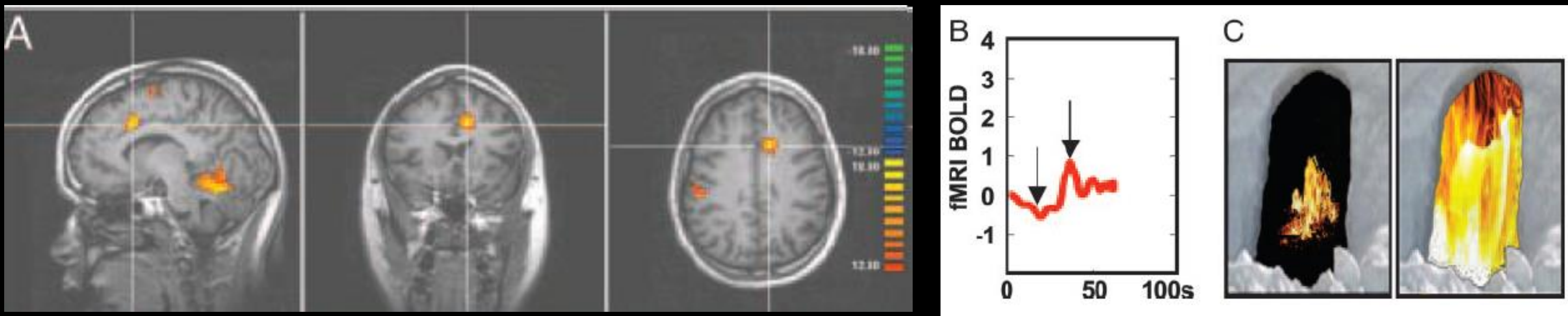
[1]Malonek D, Grinvald A. *Science* 272, 551-4 (1996).
[3]Horton JC, Hocking DR. *J Neurosci* 16, 7228-39 (1996).
[4]Horton JC, et al. *Arch Ophthalmol* 108, 1025-31 (1990).

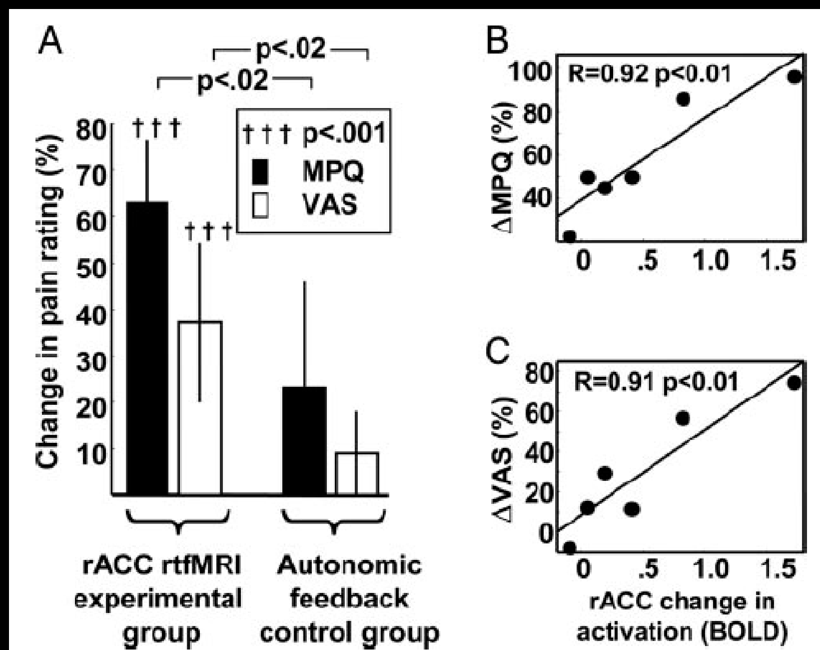
Word stem completion



Applications

Real time fMRI feedback to reduce chronic pain



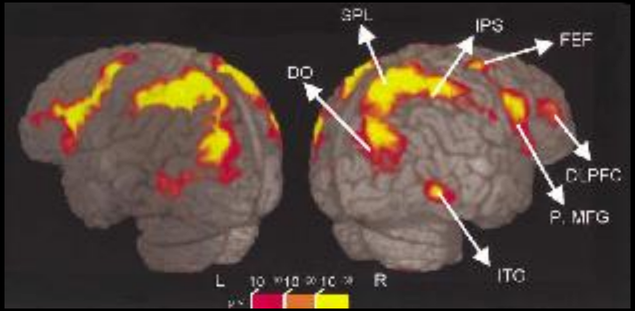


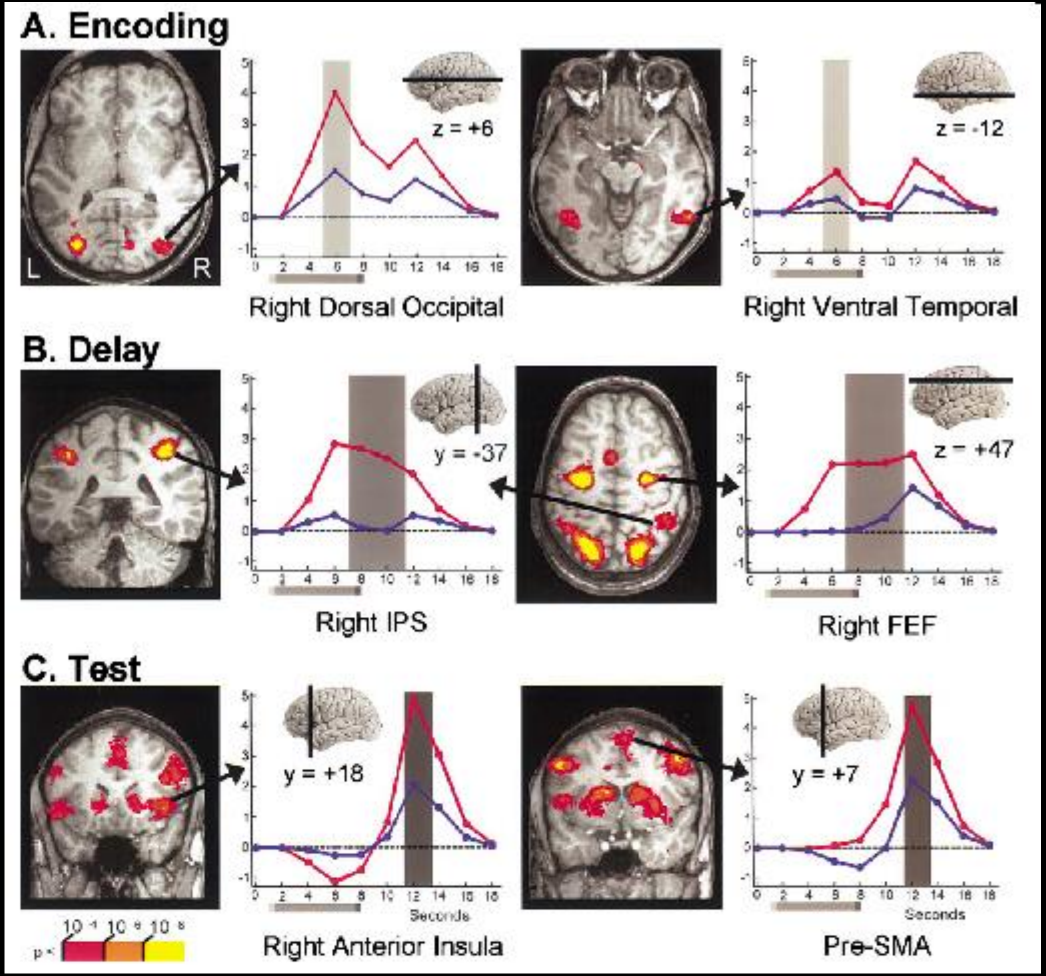
Control over brain activation and pain learned by using real-time functional MRI, R. C. deCharms, et al. PNAS, 102; 18626-18631 (2005)

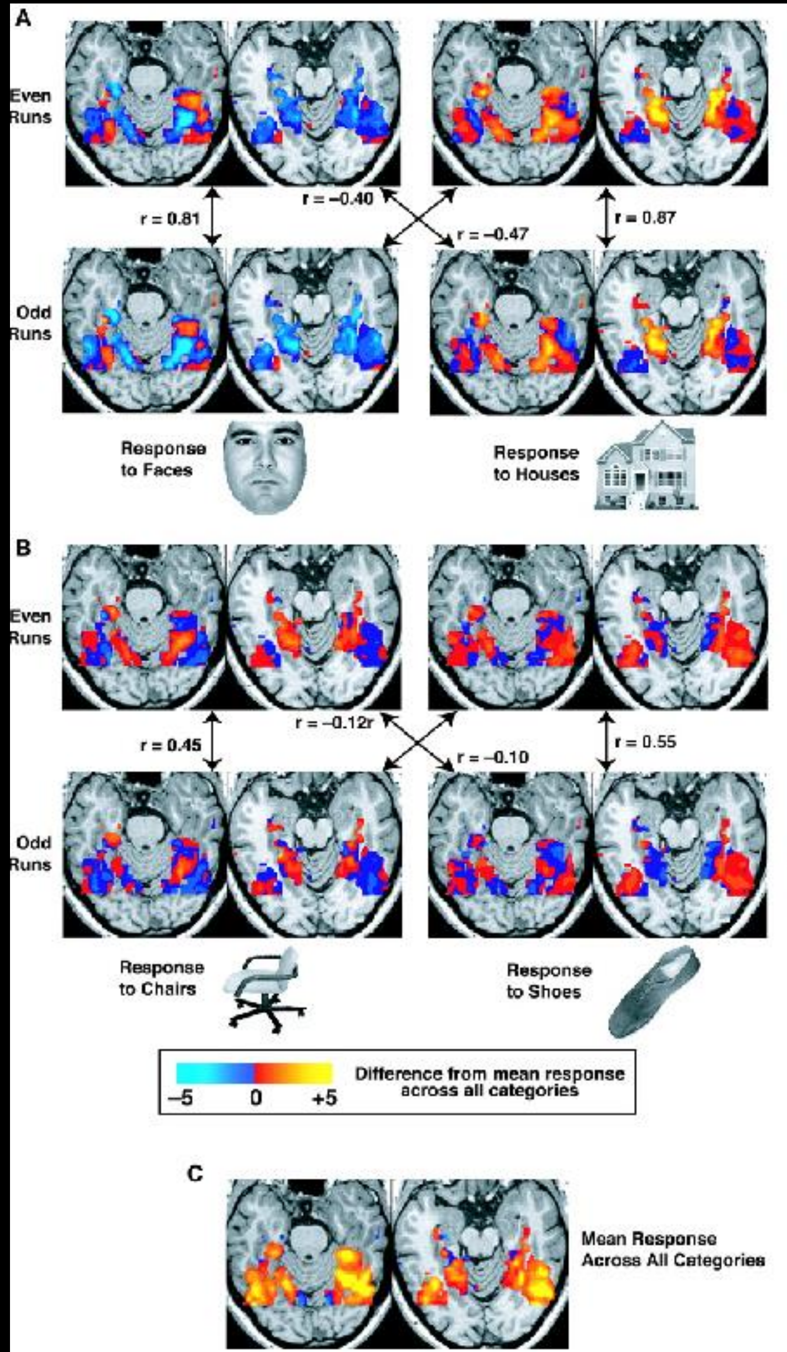
Neuron, Vol. 35, 975–987, August 29, 2002, Copyright ©2002 by Cell Press

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)

• 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]

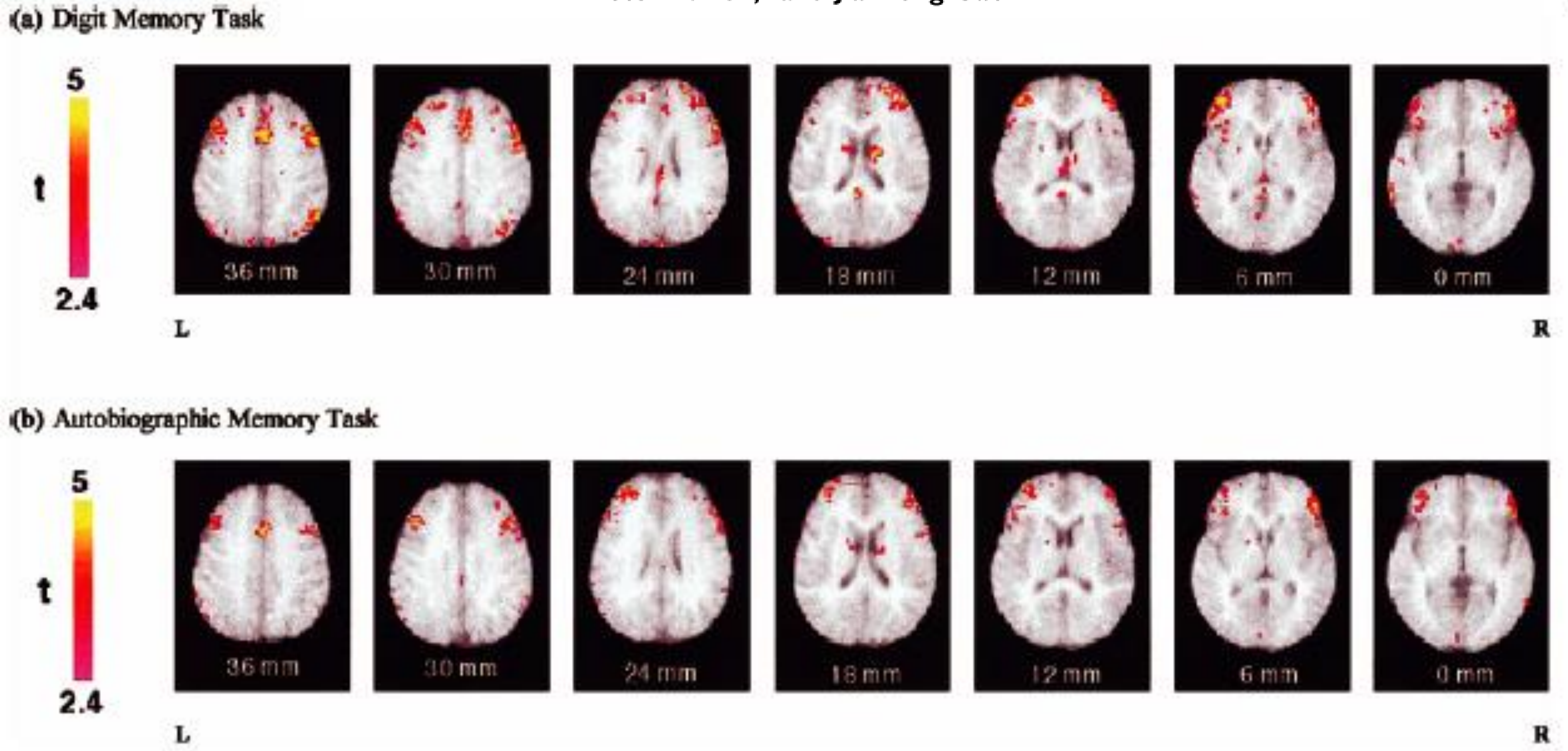
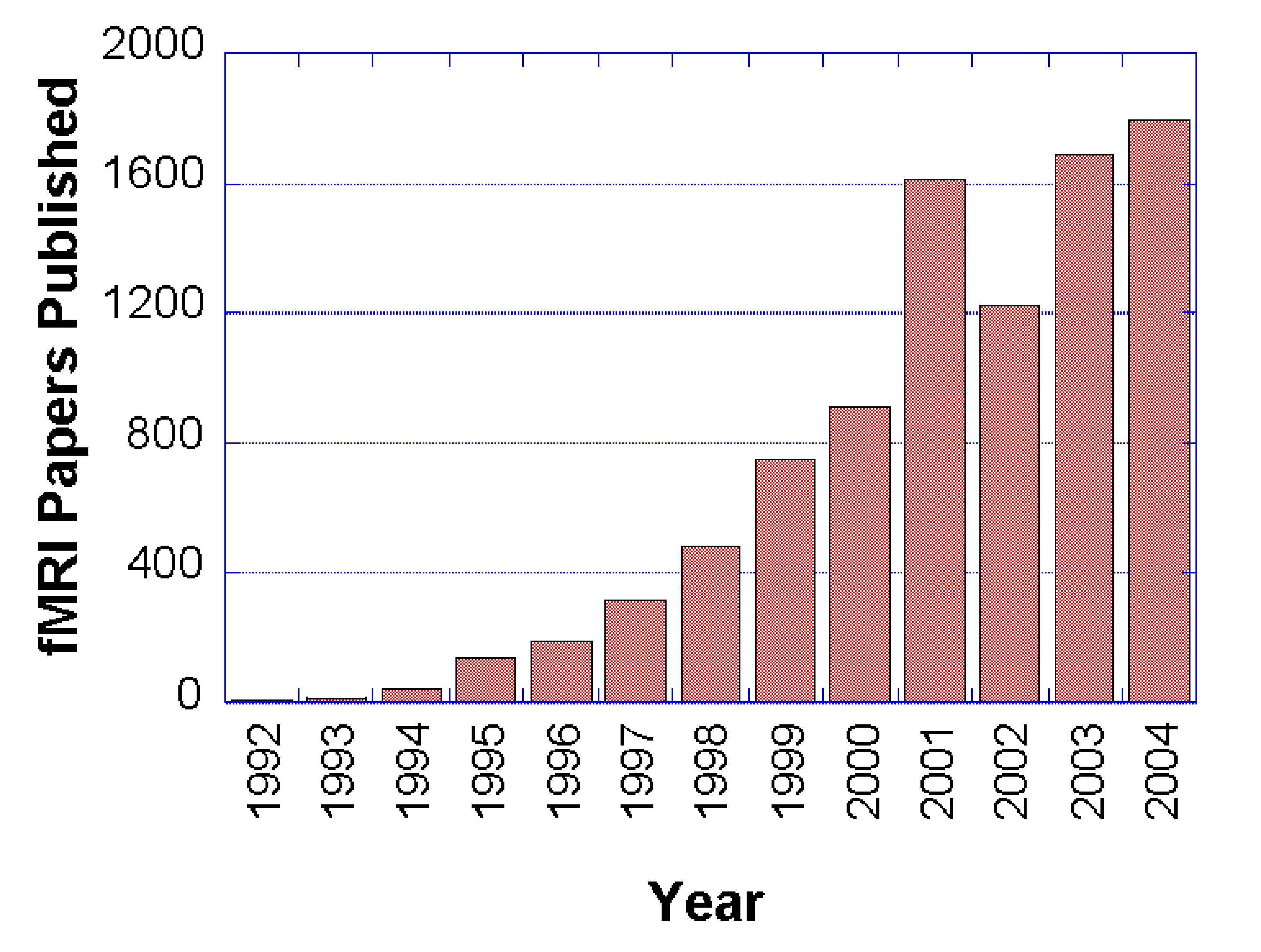


Figure 1.

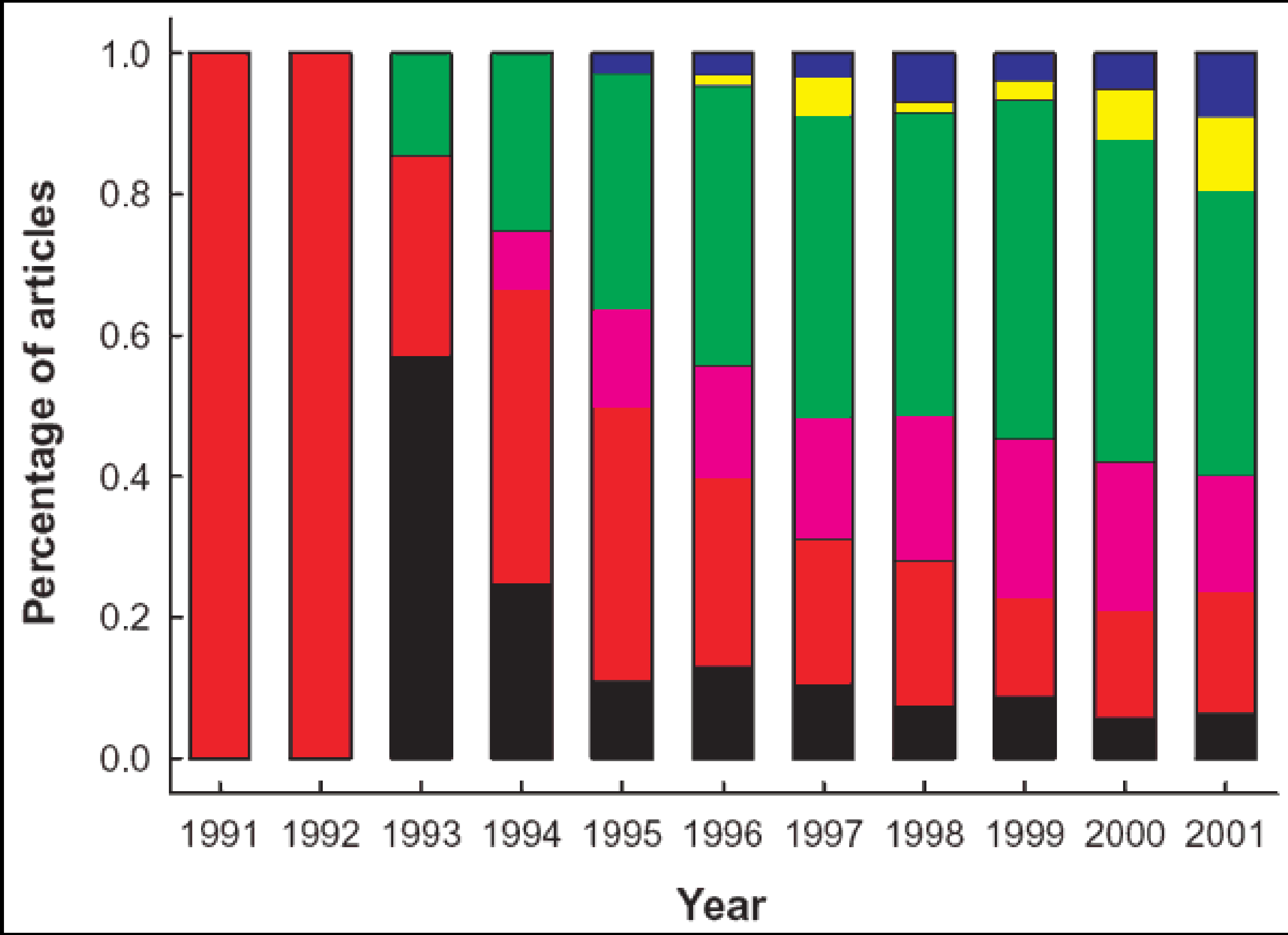
Functional maps. Normalized activation brain maps averaged across five subjects demonstrating the statistically significant activations ($P < 0.01$) in the faking memory impairment condition with the activation for making accurate recall removed when performing on forced choice testing using (**a**) 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.

Topics Studied with fMRI at the NIH

- Epilepsy
- Visual processing
- Mood disorders
- Learning
- Habituation
- Plasticity
- Motor Function
- Auditory processing
- Attention
- Language
- Speech
- Stroke
- Social Interaction
- Development
- Aging
- Genetics



2000
1600
1200
800
400
0
fMRI Papers Published
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

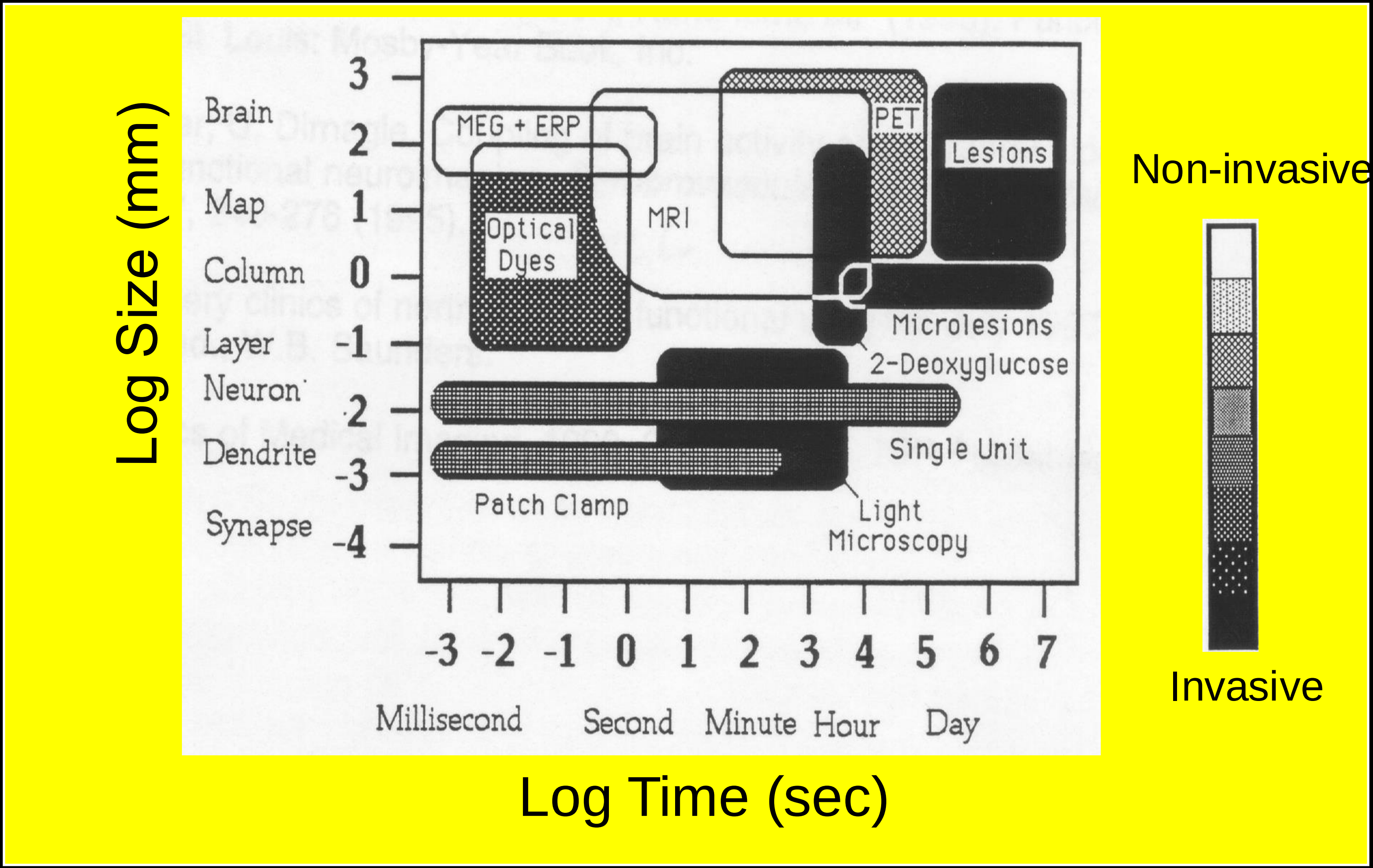
Clinical treatment and assessment

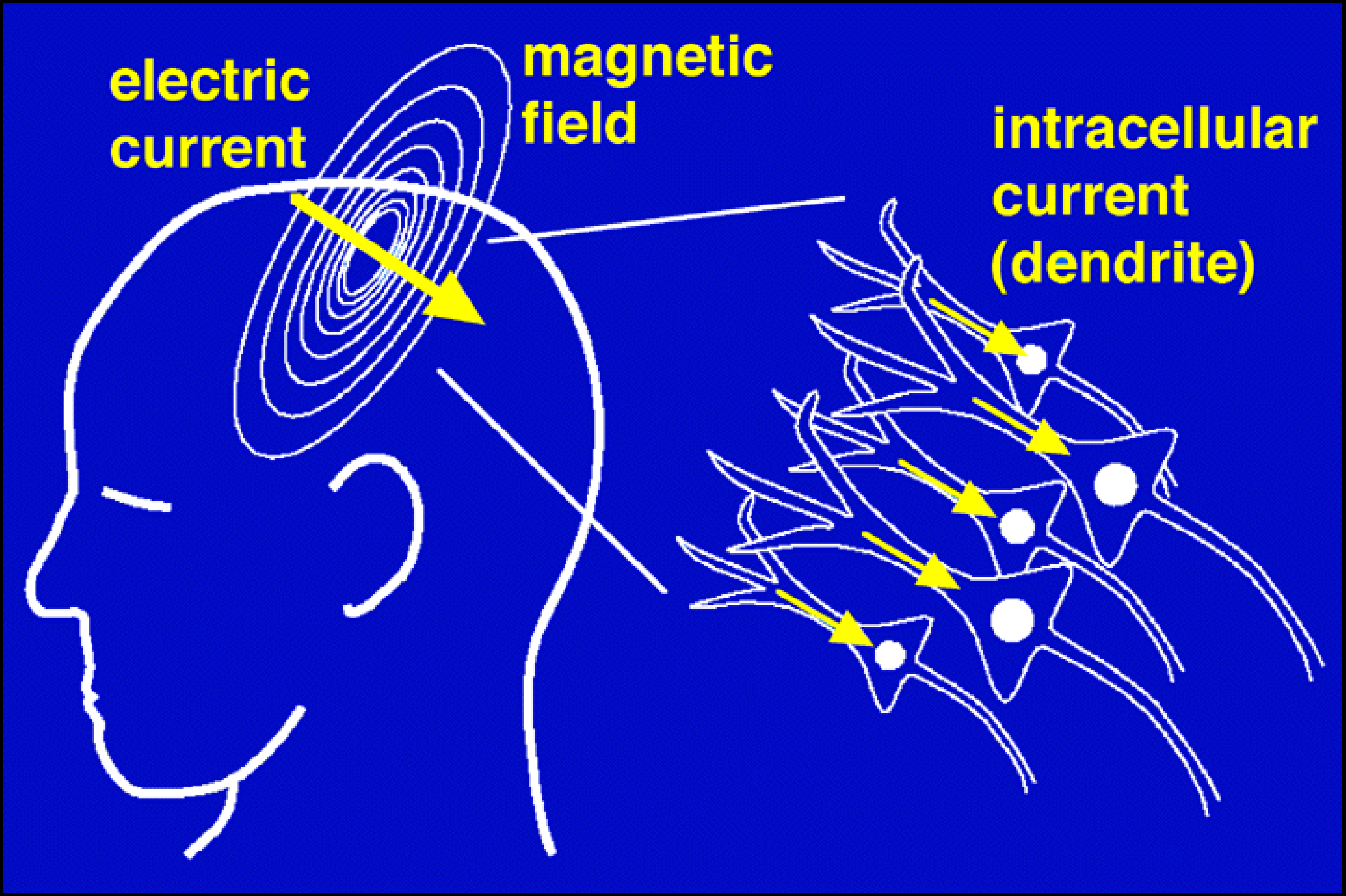
- -drug, therapy, rehabilitation, biofeedback

Non clinical uses

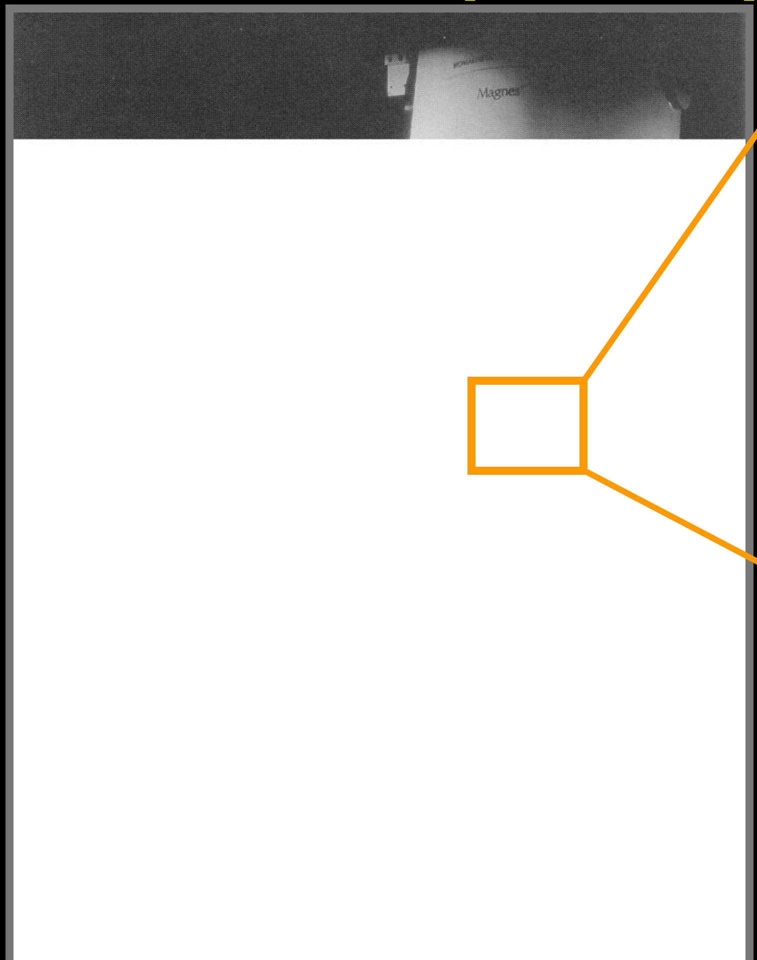
- -complementary use with behavioral results
- -lie detection
- -prediction of behavior tendencies (many contexts)
- -brain/computer interface

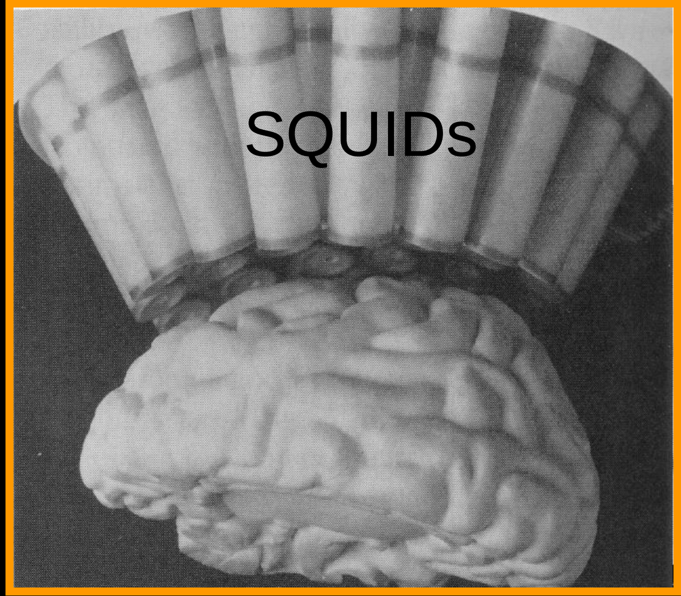
Functional Neuroimaging Techniques




electric
current
magnetic
field
intracellular
current
(dendrite)

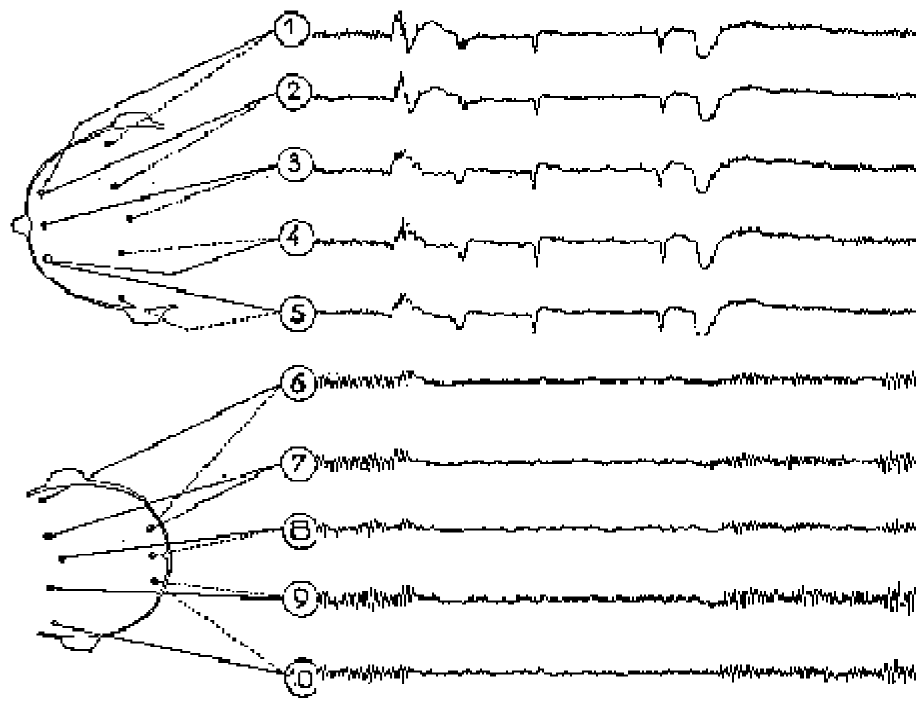
Magnetoencephalography (MEG)



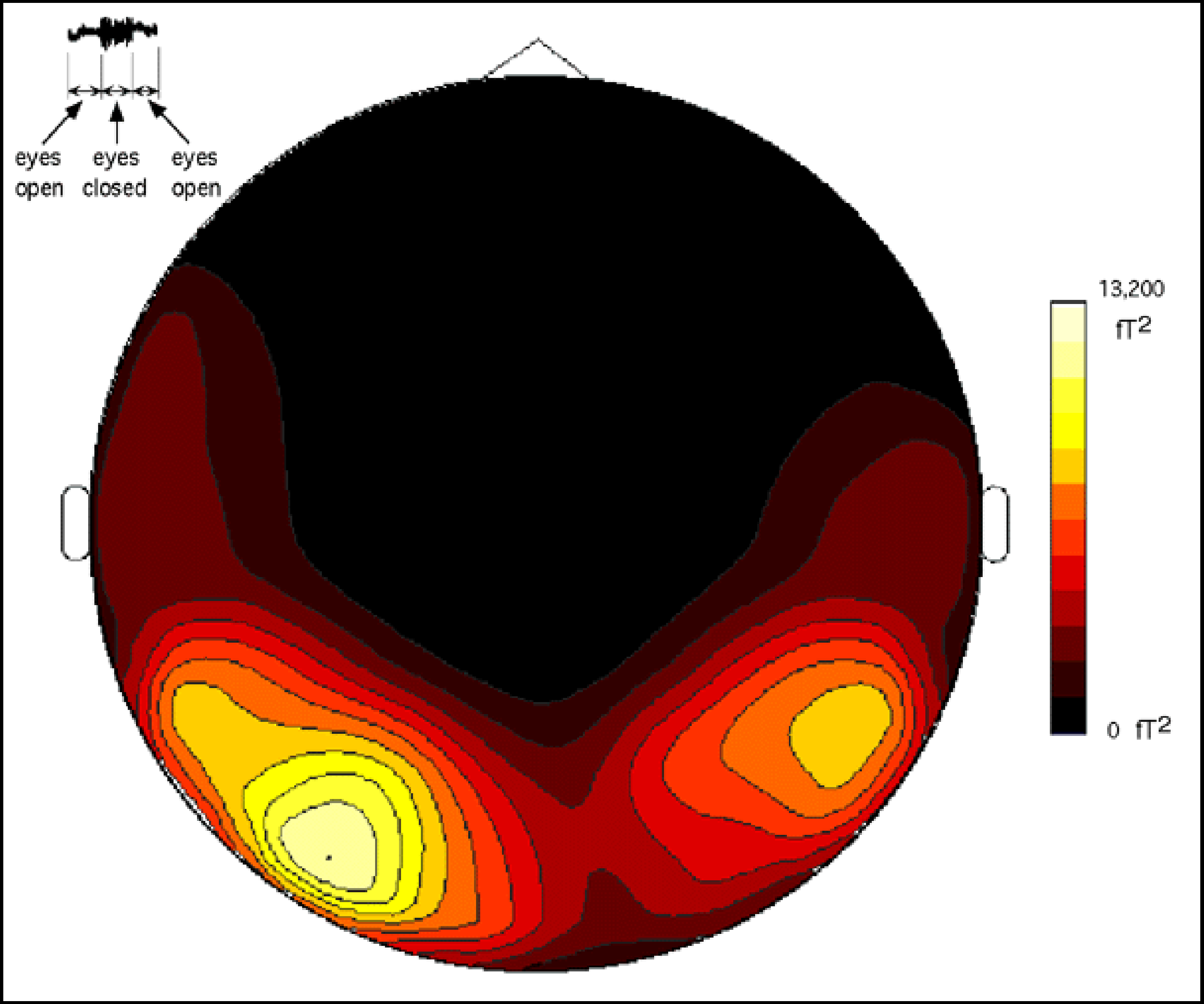


SQUID:
Superconducting Quantum Interference Device

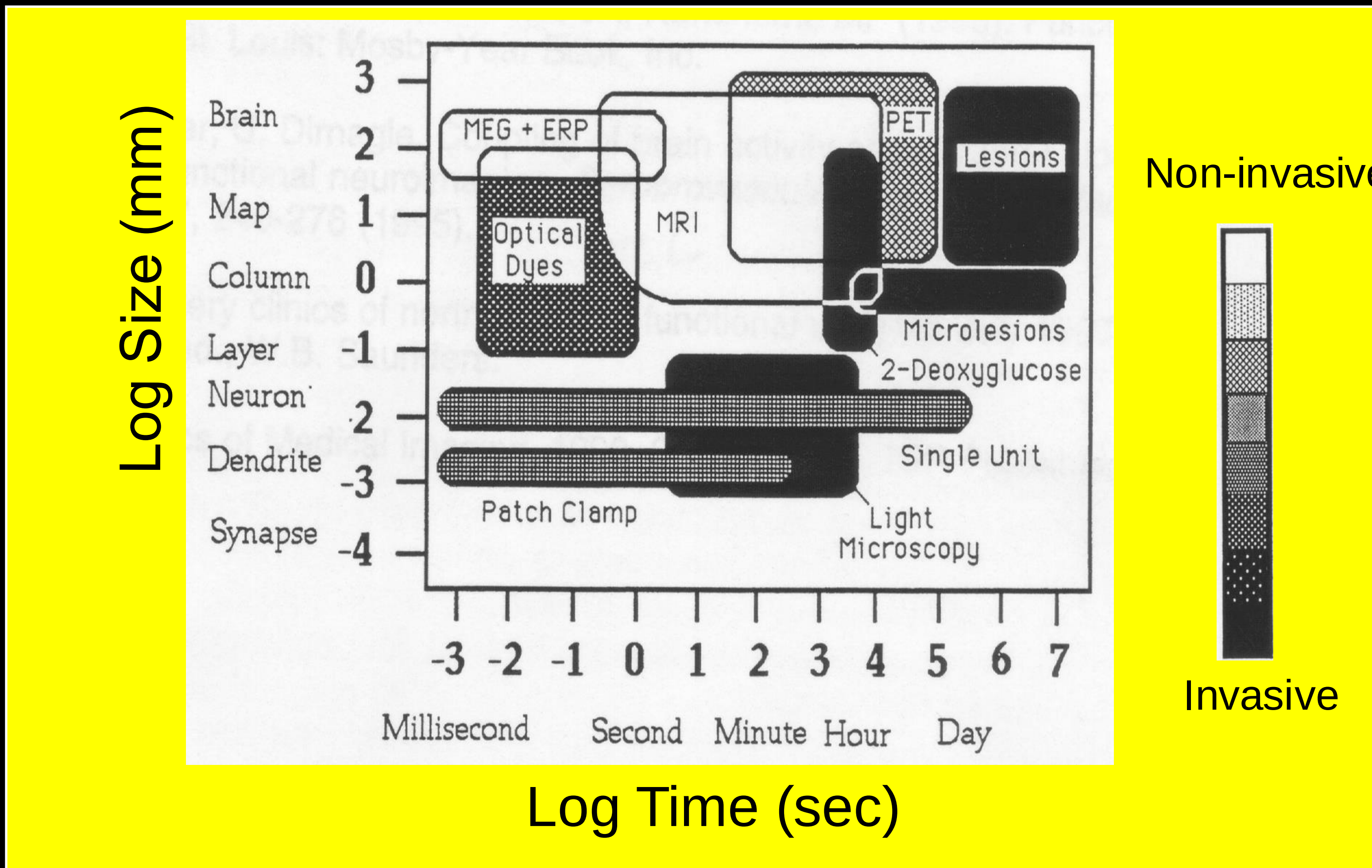

Exercise Physiology
Changes in: Metabolism
Respiration
Circulation
Body Temperature
(Human or Animal)


1
2
3
4
5
6
7
8
9
10

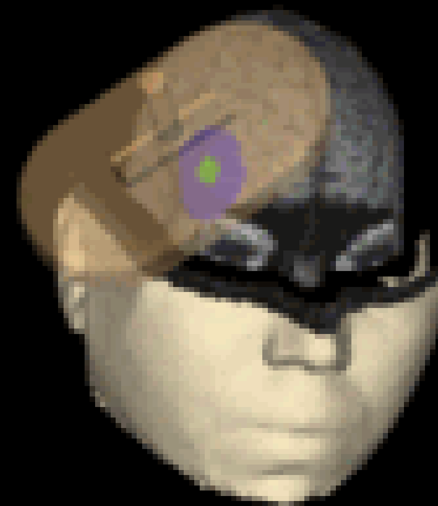
Alpha Wave Activity Mapped with MEG

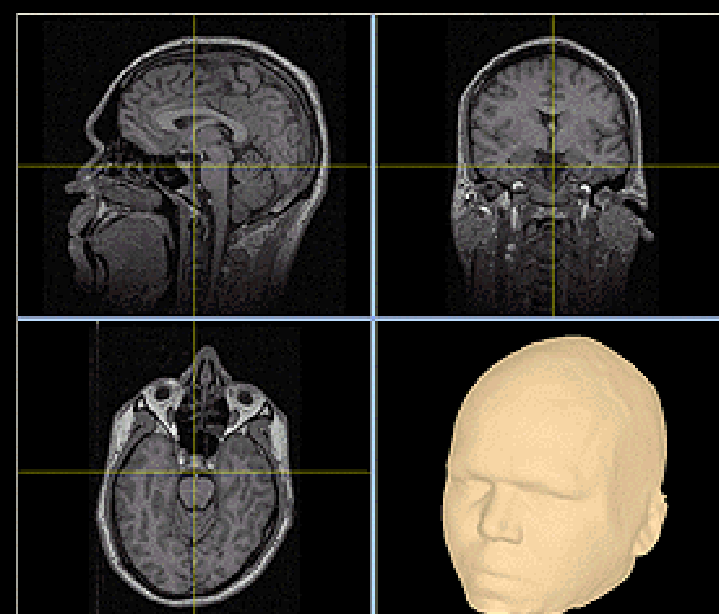


Functional Neuroimaging Techniques

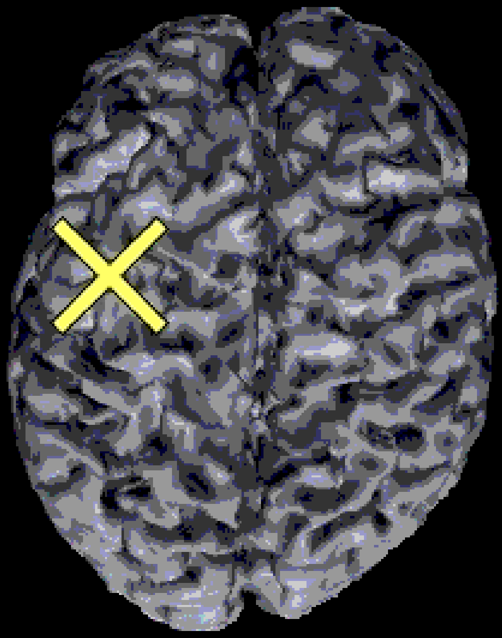


Transcranial Magnetic Stimulation





Transcranial Magnetic Stimulation (TMS)



Section on Functional Imaging Methods & Functional MRI Facility Jan 19, 2007

Back row: Wenming Luh, Niko Kriegeskorte, Rasmus Birn, Tyler Jones, Sean Marrett
Middle row: Jon West, Kay Kuhns, Anthony Boemio, Peter Bandettini, Joey Dunsmoor, Doug Ruff, Kevin Murphy
Front row: Dorian Van Tassel, Jerzy Bodurka, Adam Thomas, Marieke Mur, David Knight