Seventeen Years of Functional MRI: From Physics to Mind Reading

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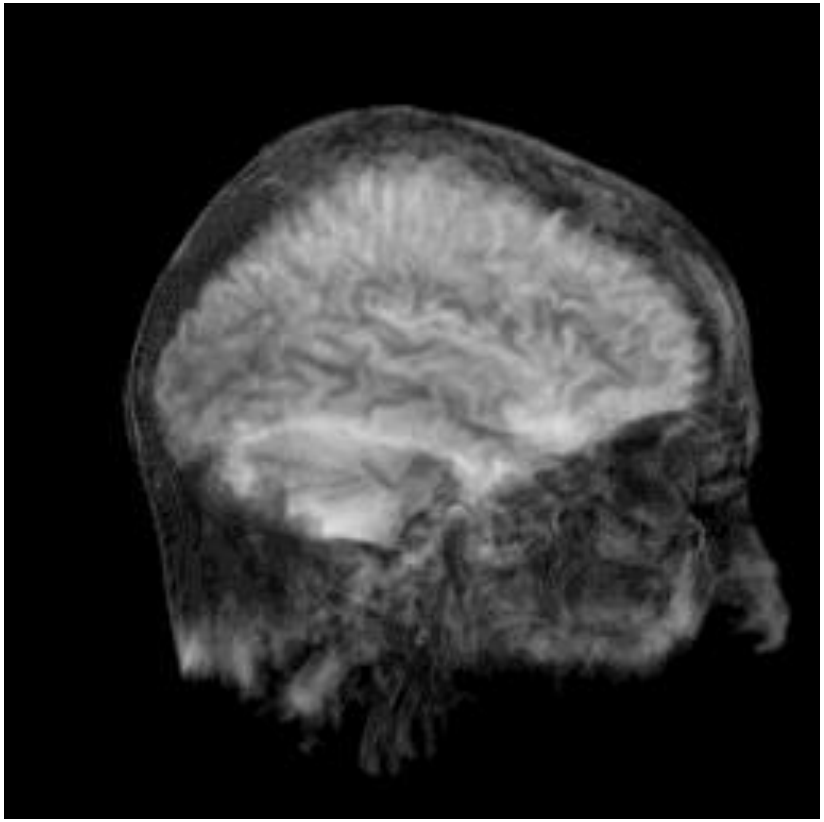
Two Types of Neuroimaging

- Structural/Anatomical Imaging

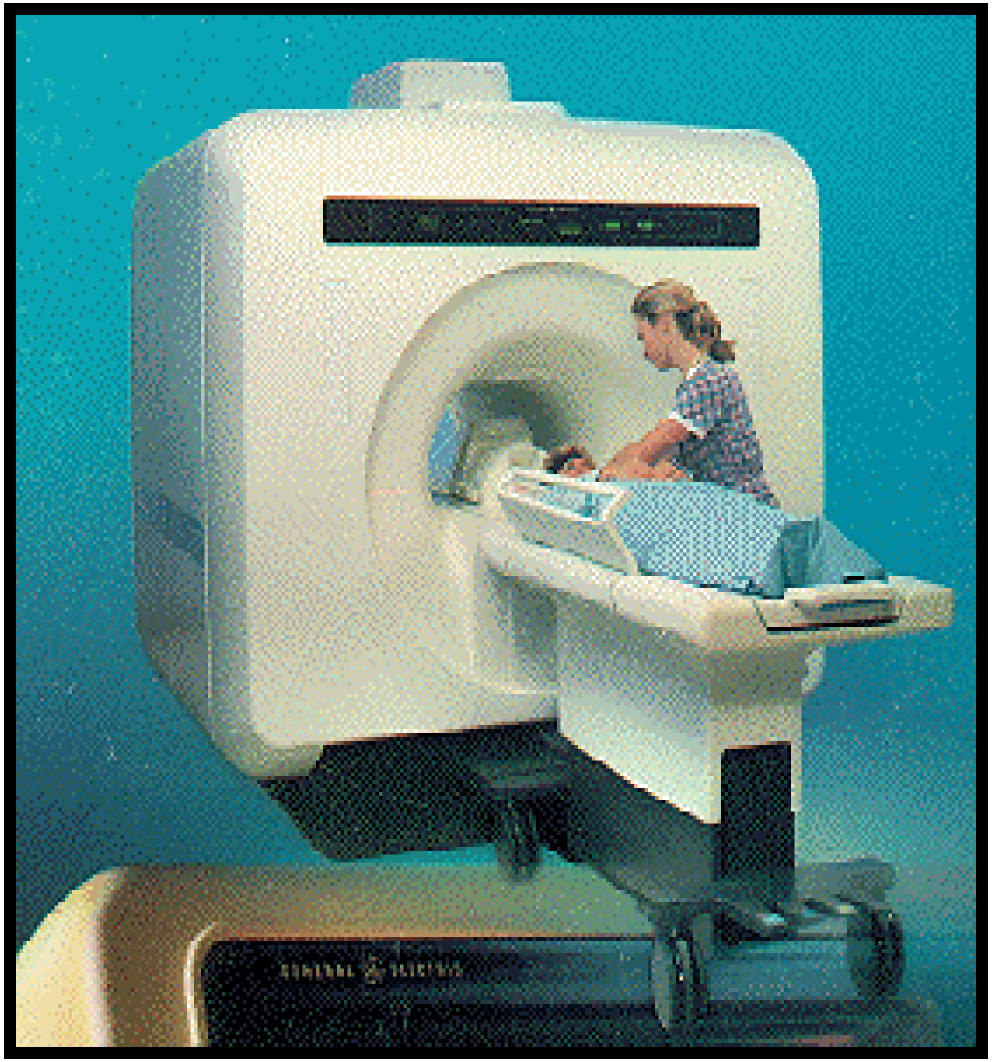
- Functional Imaging



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

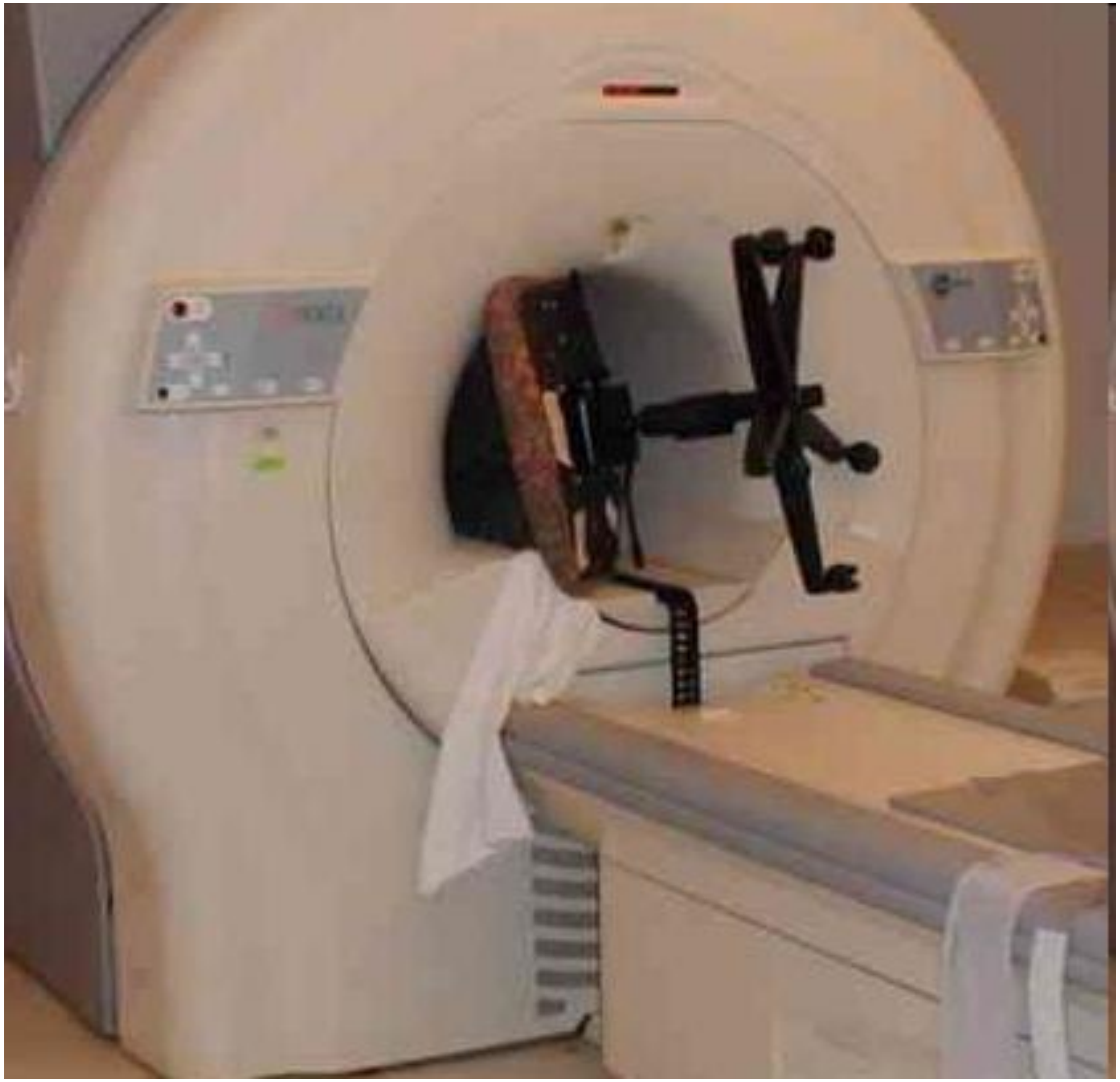
Magnetic Resonance Imaging

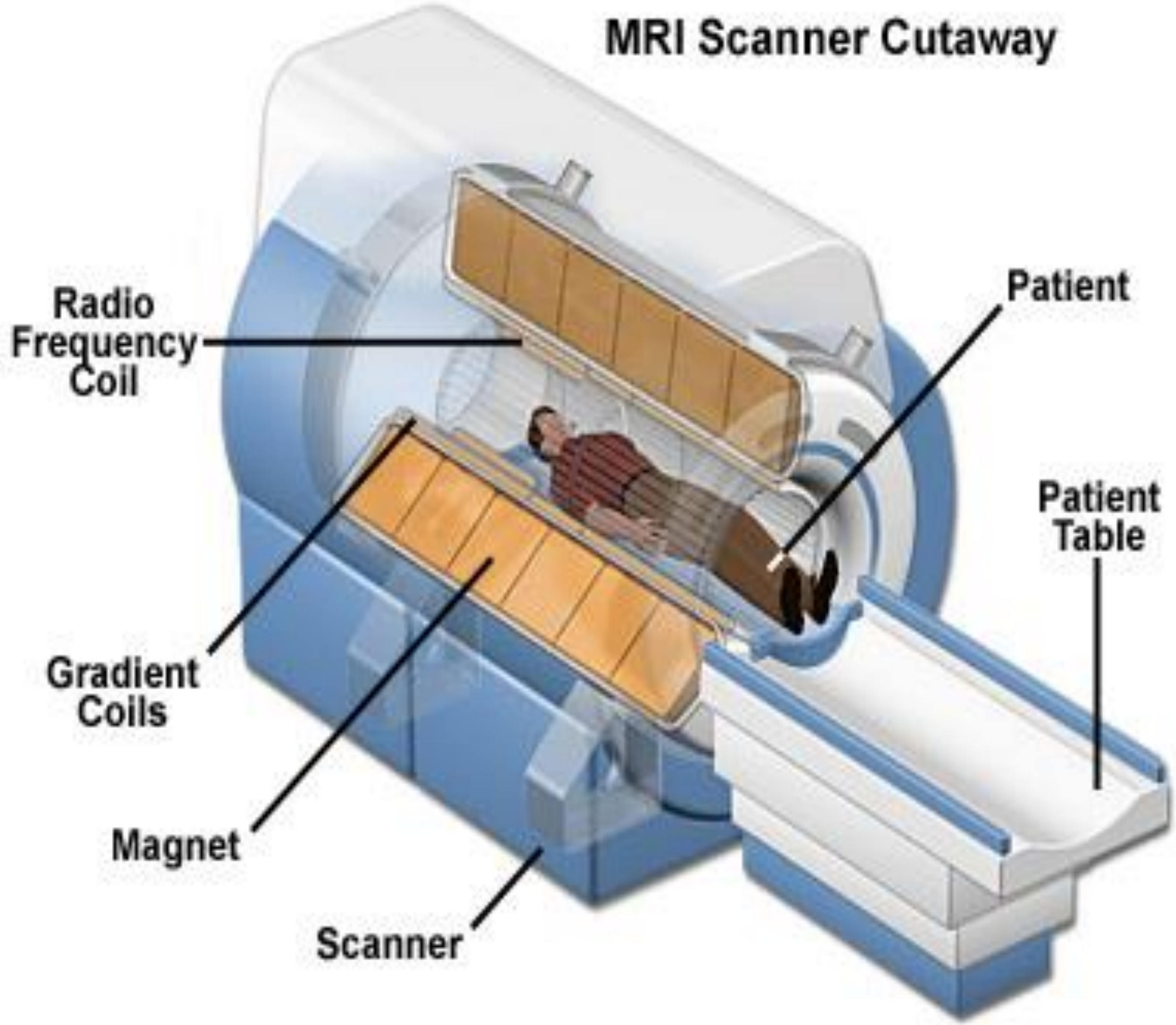
1984



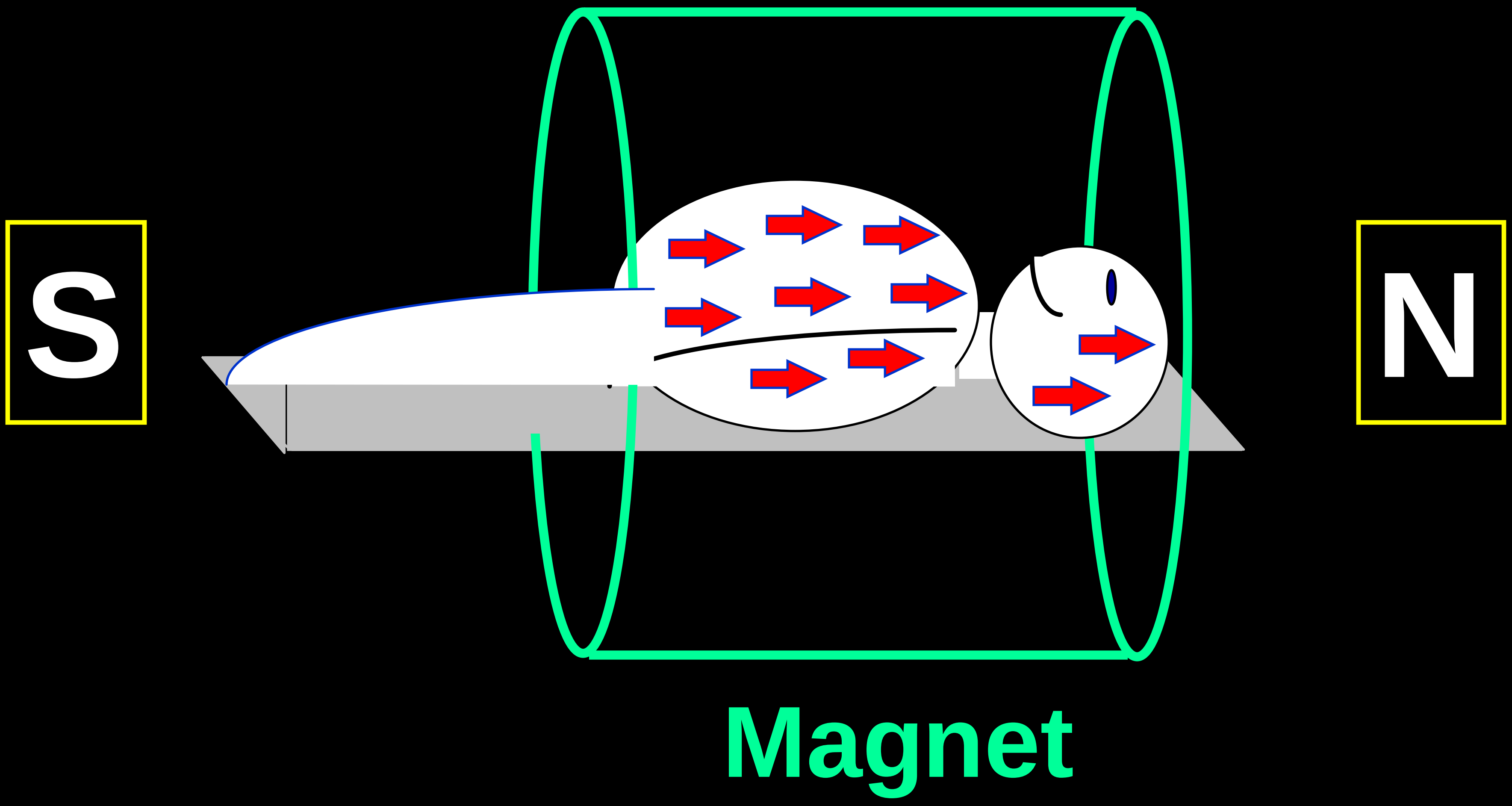
Water: 42 MHz/Tesla

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

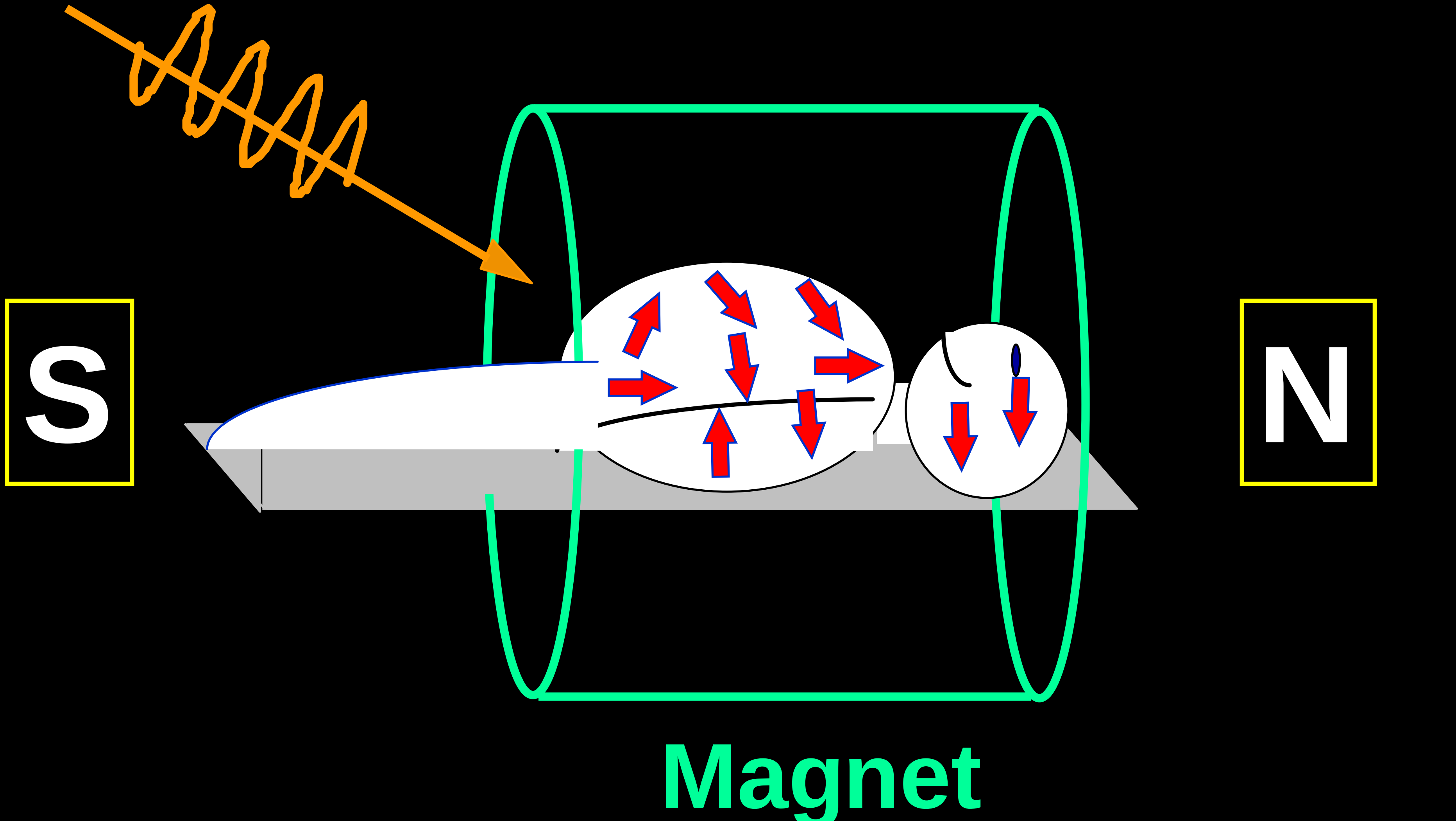



MRI Scanner Cutaway
Radio Frequency Coil
Patient
Patient Table
Gradient Coils
Magnet
Scanner

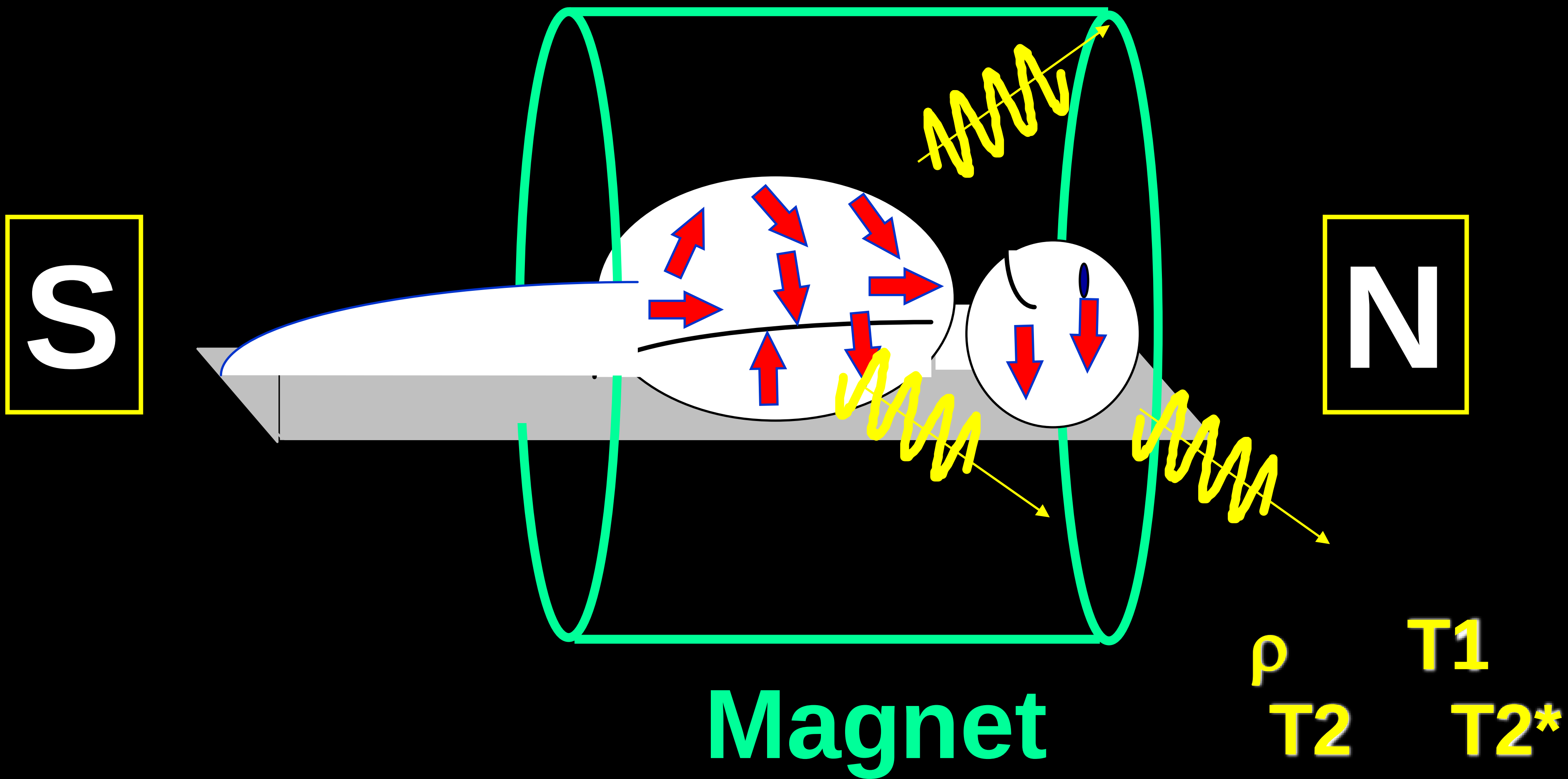
Magnetic Resonance Imaging



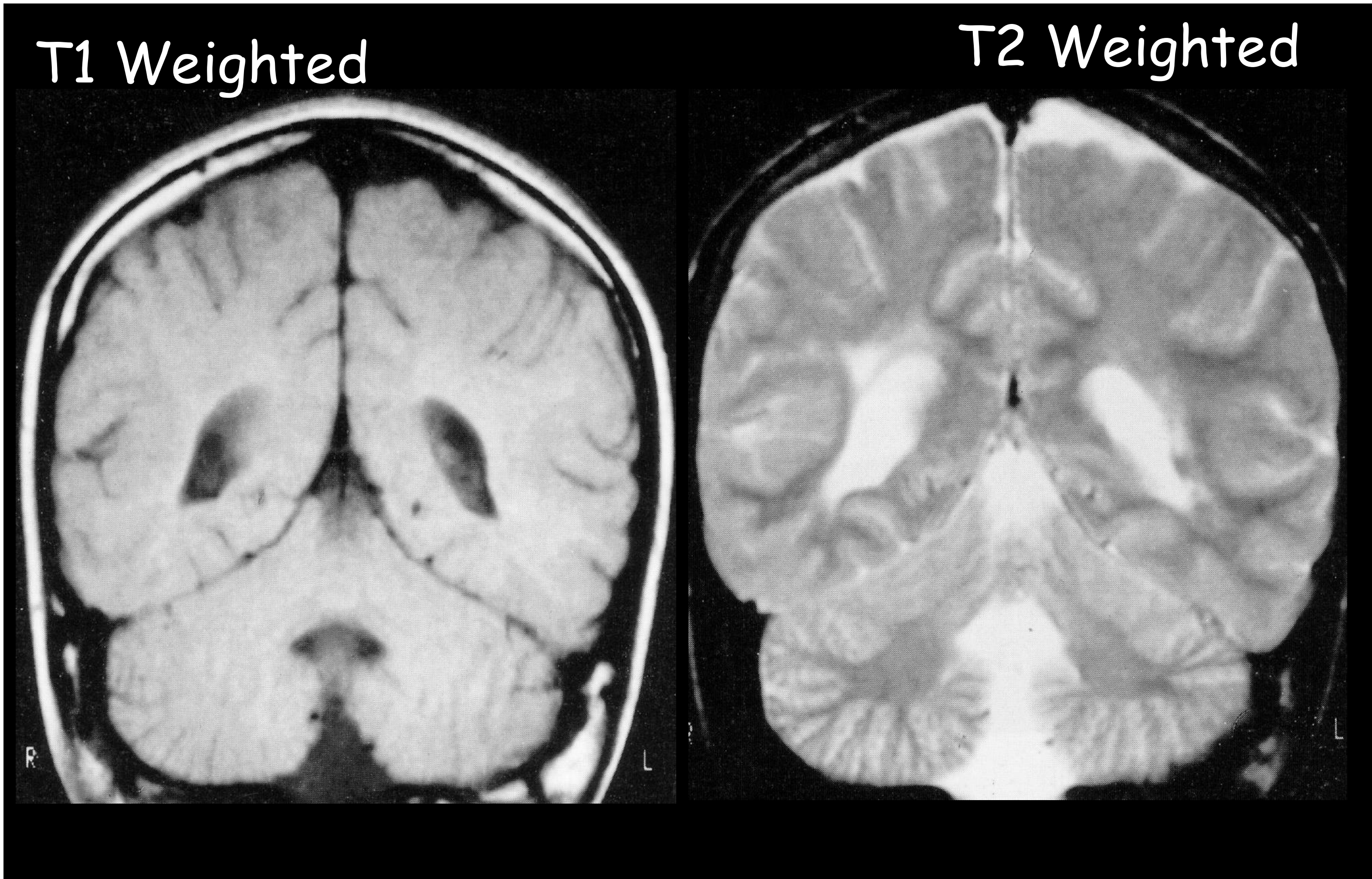
Magnetic Resonance Imaging

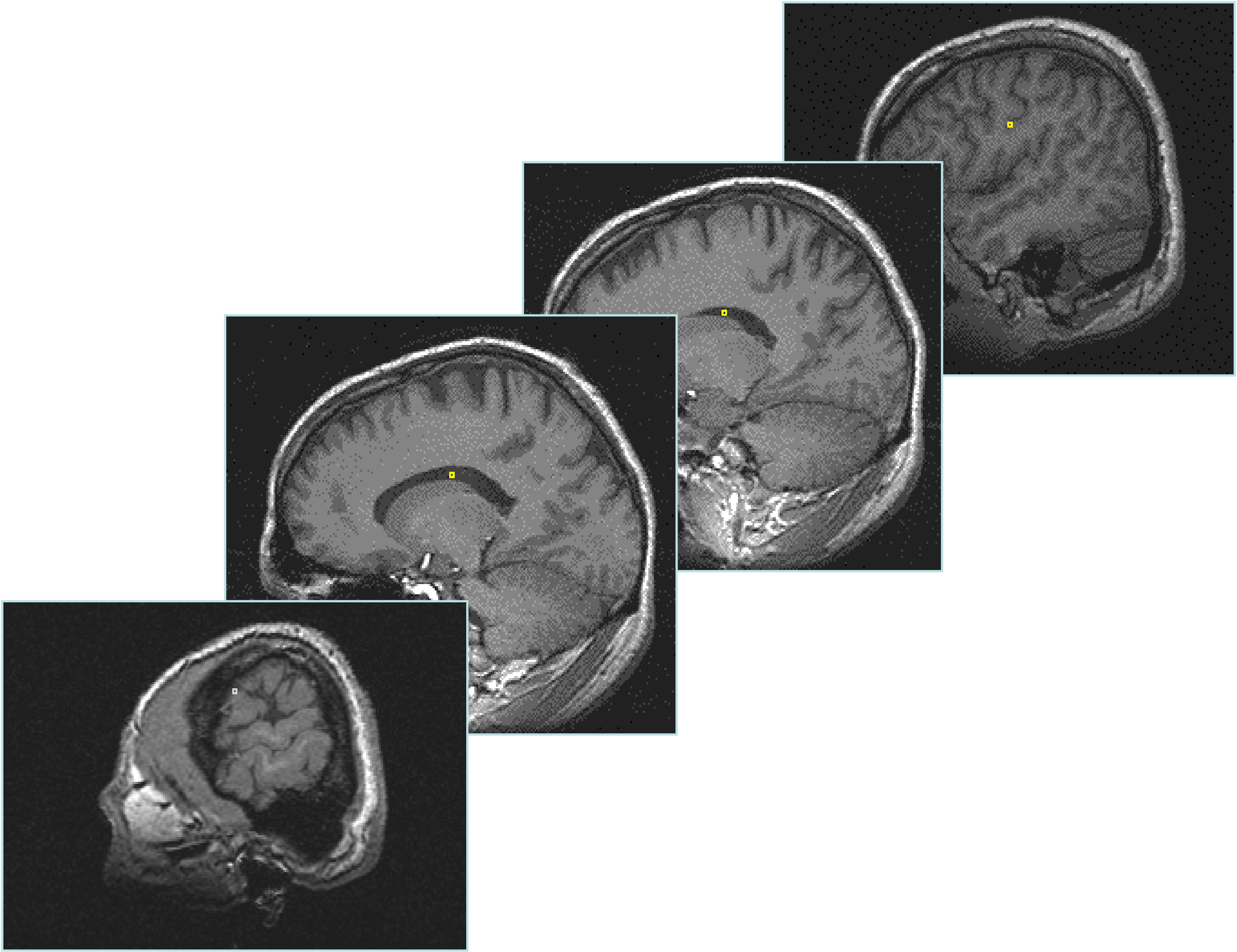


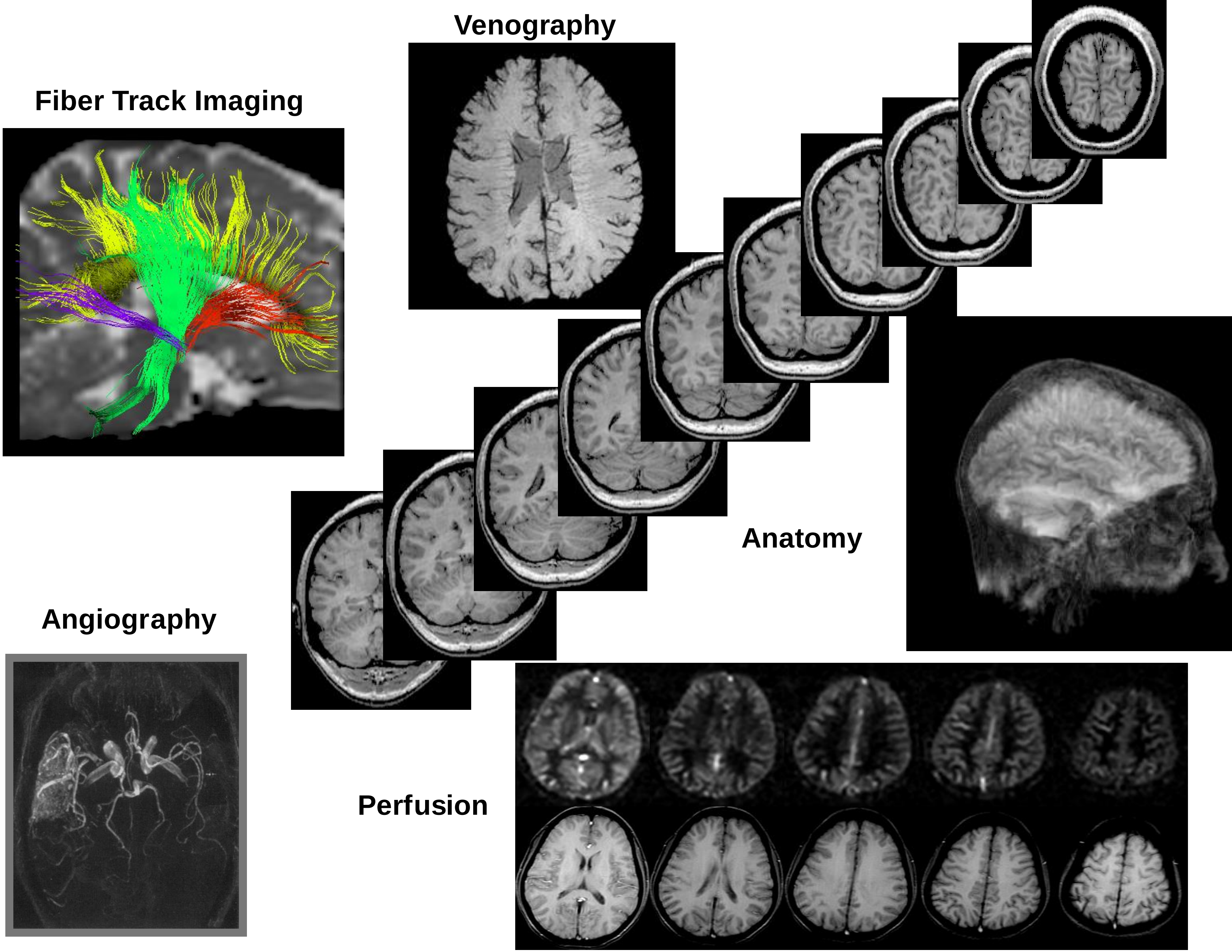
Magnetic Resonance Imaging

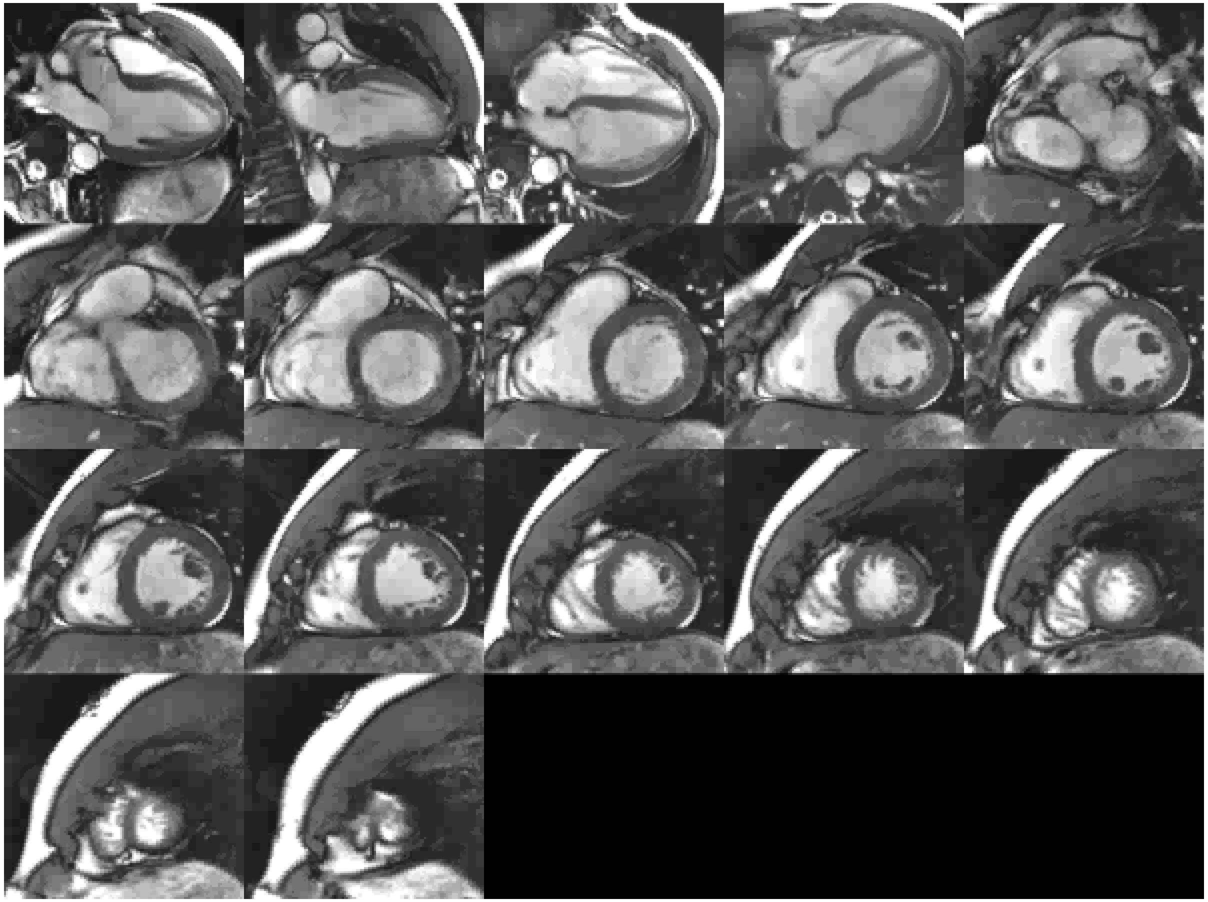


MRI Images with Different Contrast Weighting



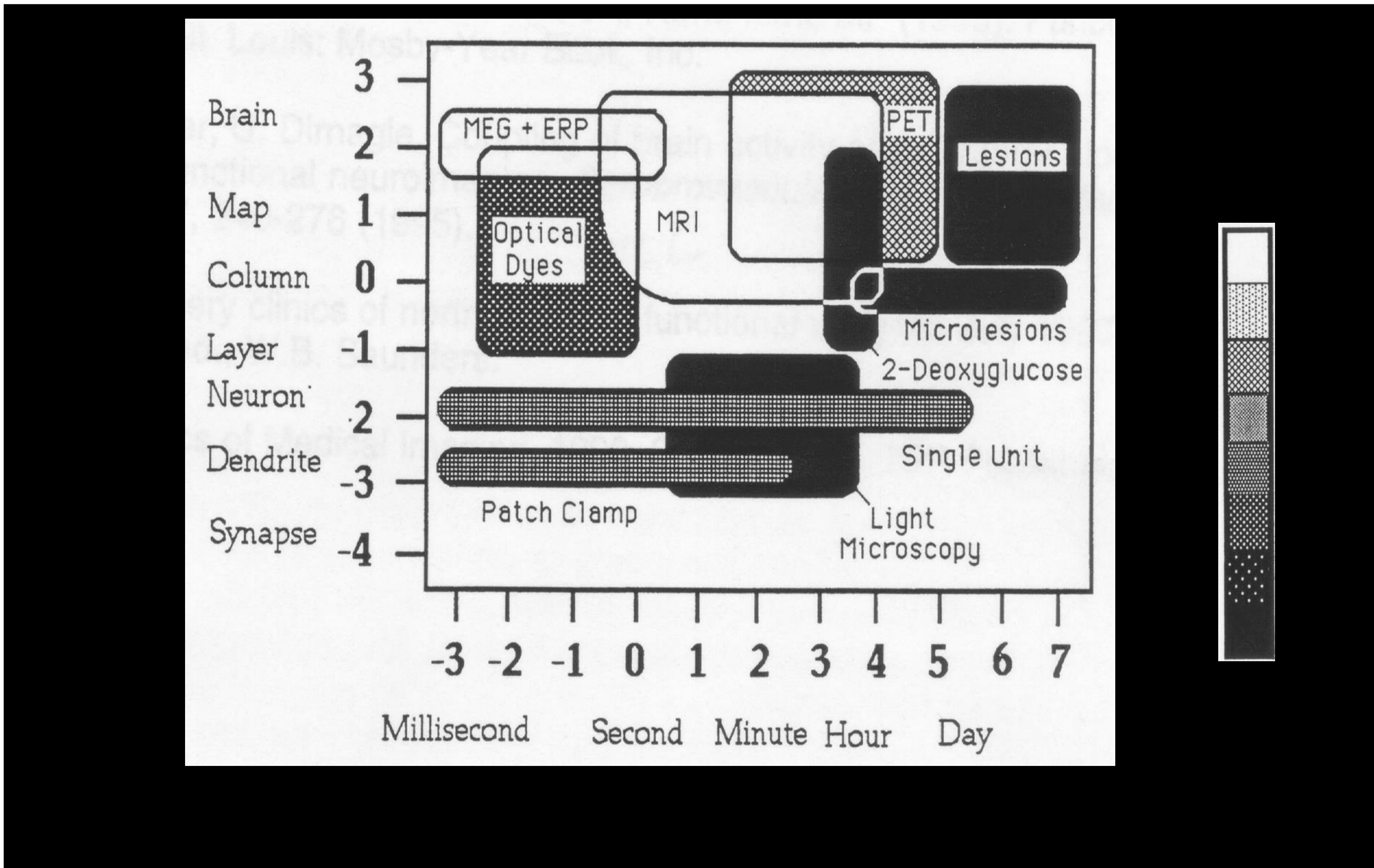



Fiber Track Imaging
Venography
Anatomy
Angiography
Perfusion



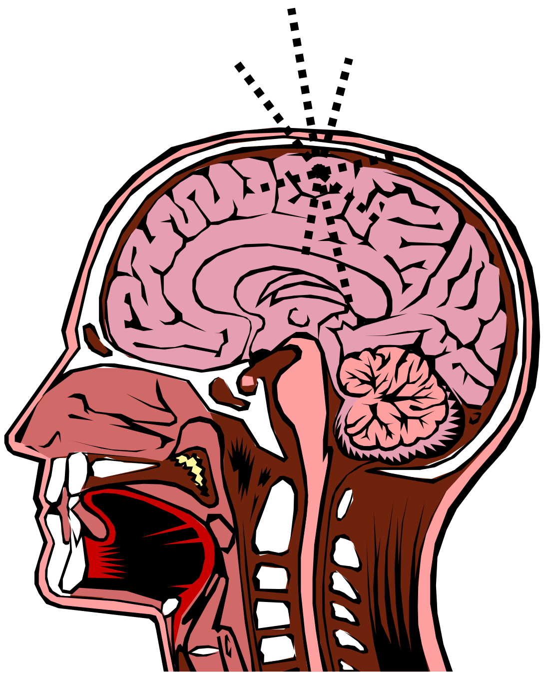
- Functional Imaging
  - Xenon Computerized Tomography (Xe CT)
  - Positron Emission Tomography (PET)
  - Single Photon Computed Tomography (SPECT)
  - Functional MRI (fMRI)
  - Electroencephalography (EEG)
  - Magnetoencphalography (MEG)
  - Transcranial Magnetic Stimulation (TMS)

Functional Neuroimaging Techniques

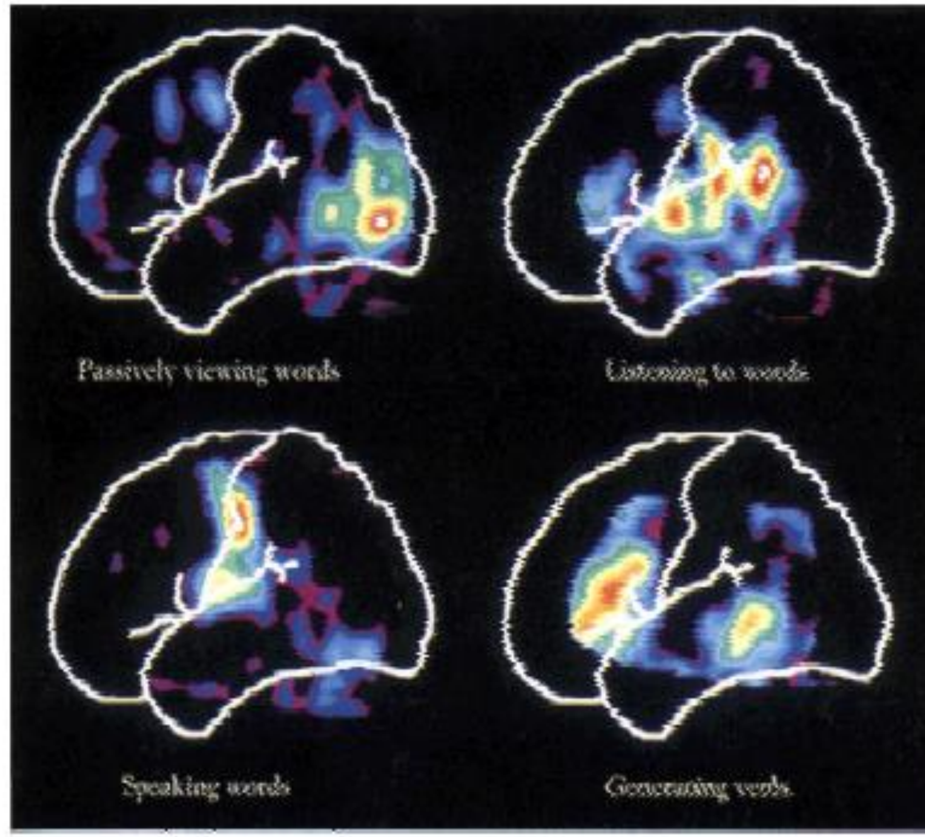


Positron Emission Tomography (PET)

- Positron emission tomography (PET) is a technique for studying functional processes *in vivo* by measuring the concentrations of positron-emitting radioisotopes within the subject.

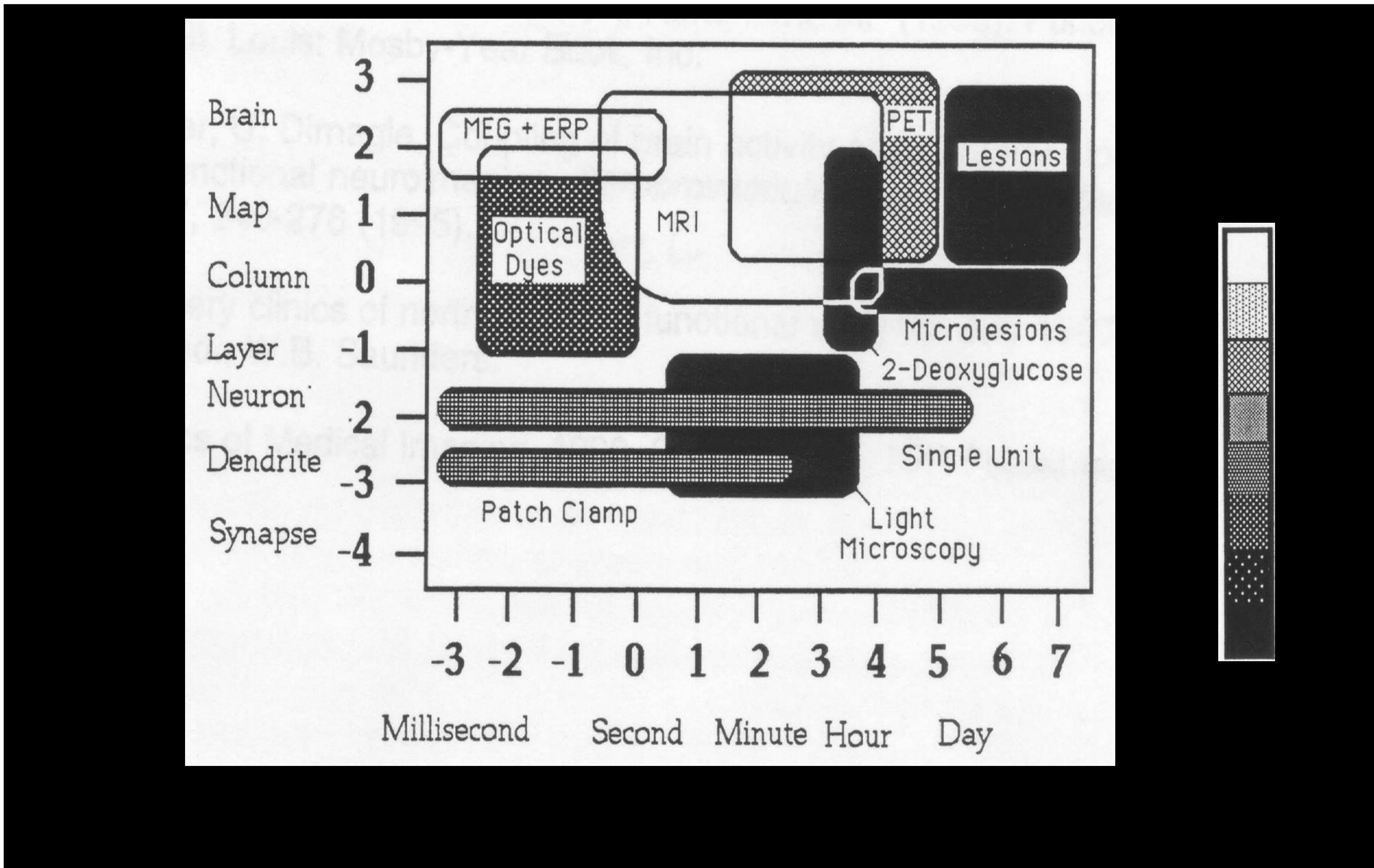


- PET is primarily used to study <u>biochemical and physiological processes</u> within living organs.

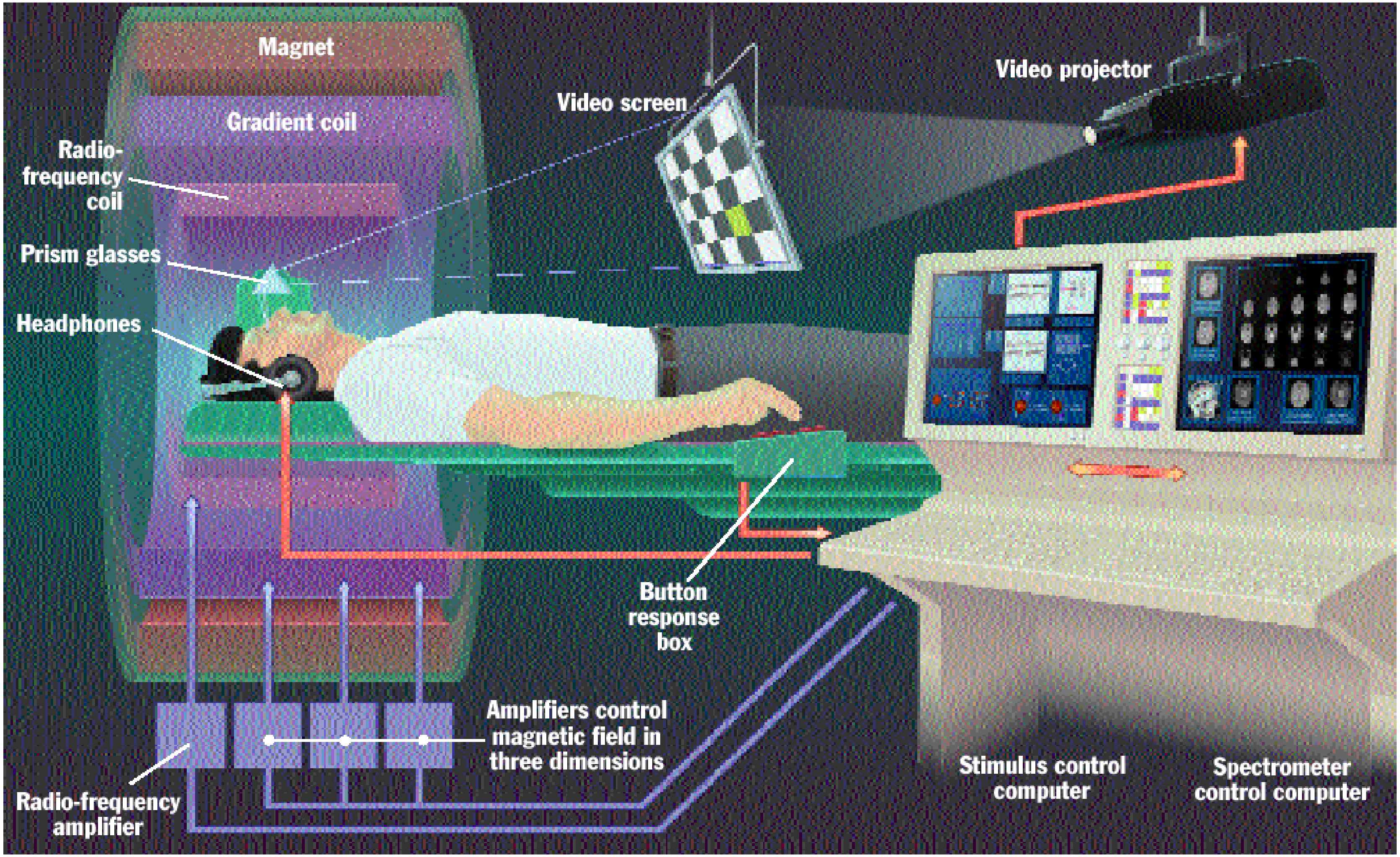

Passively viewing words
Listening to words
Speaking words
Generating verbs

Functional Magnetic Resonance Imaging

Functional Neuroimaging Techniques



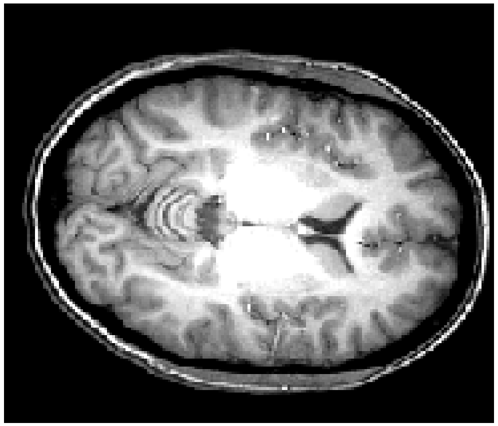
fMRI Setup



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

MRI vs. fMRI

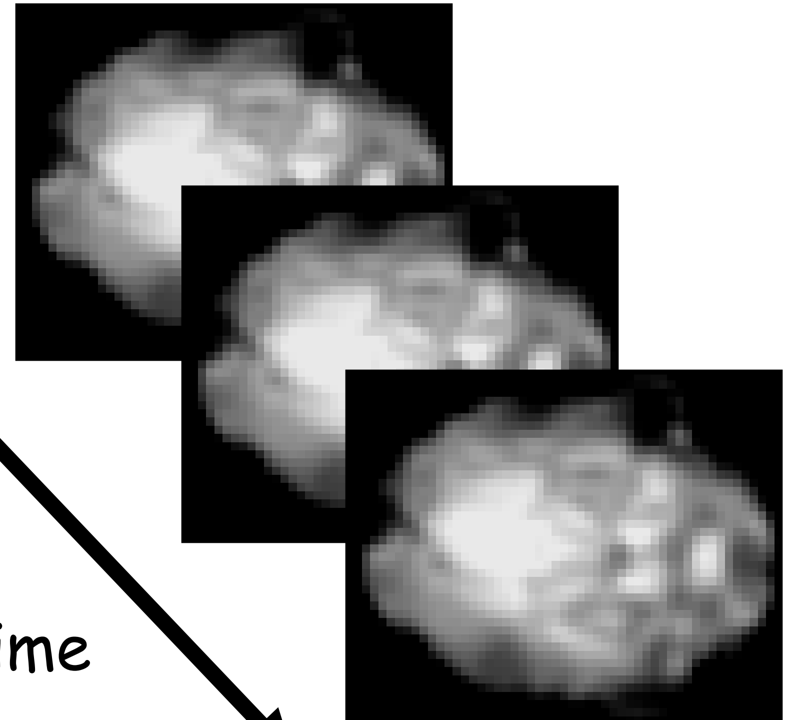
MRI



one image

high resolution
(1 mm or less)

fMRI

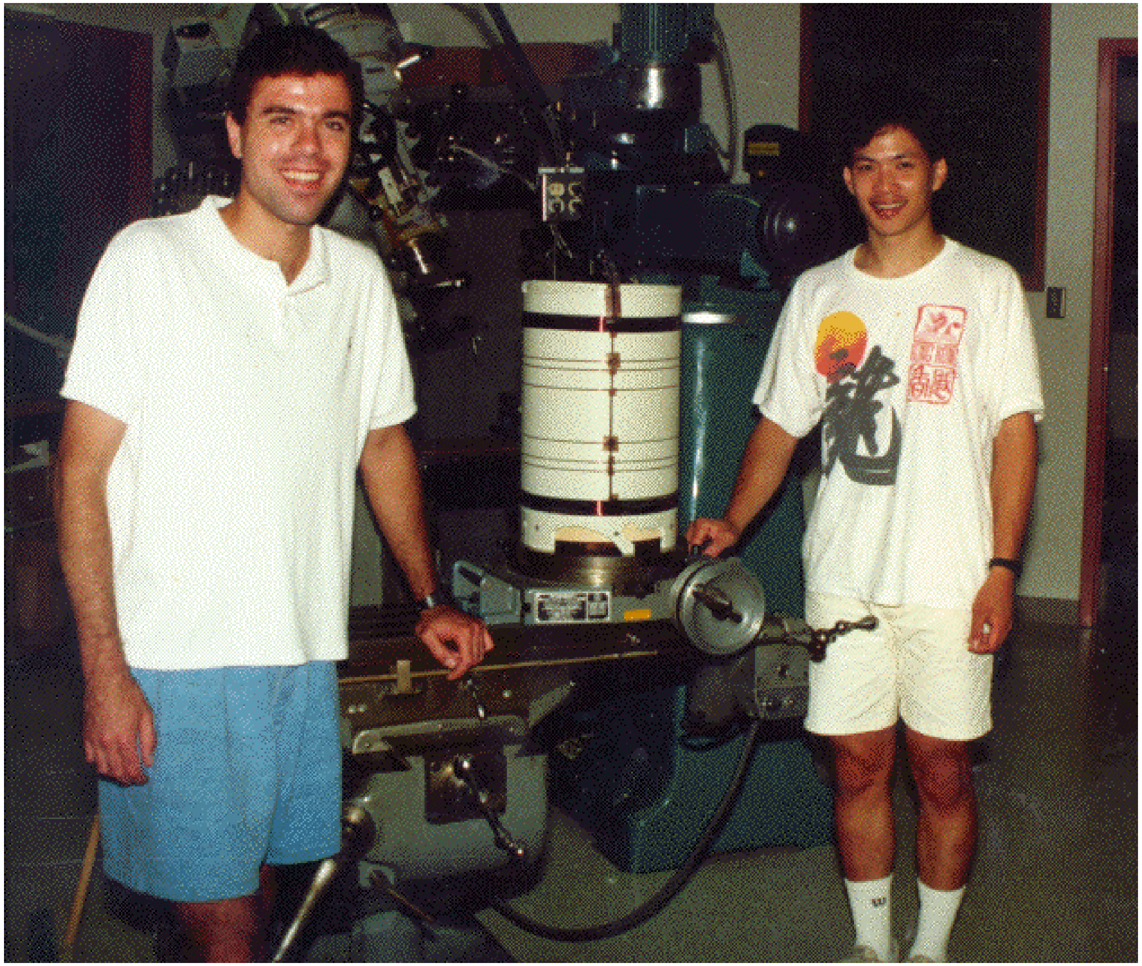


Time

...

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

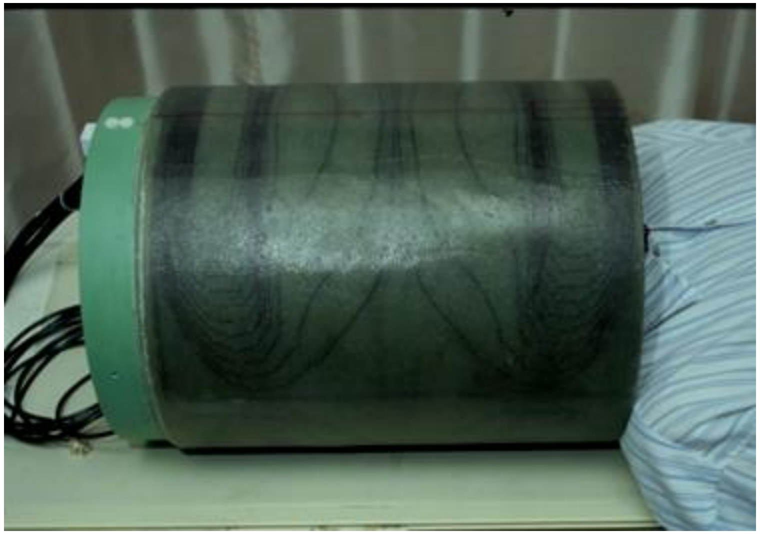
low resolution
(1.5 to 4 mm)



August, 1991

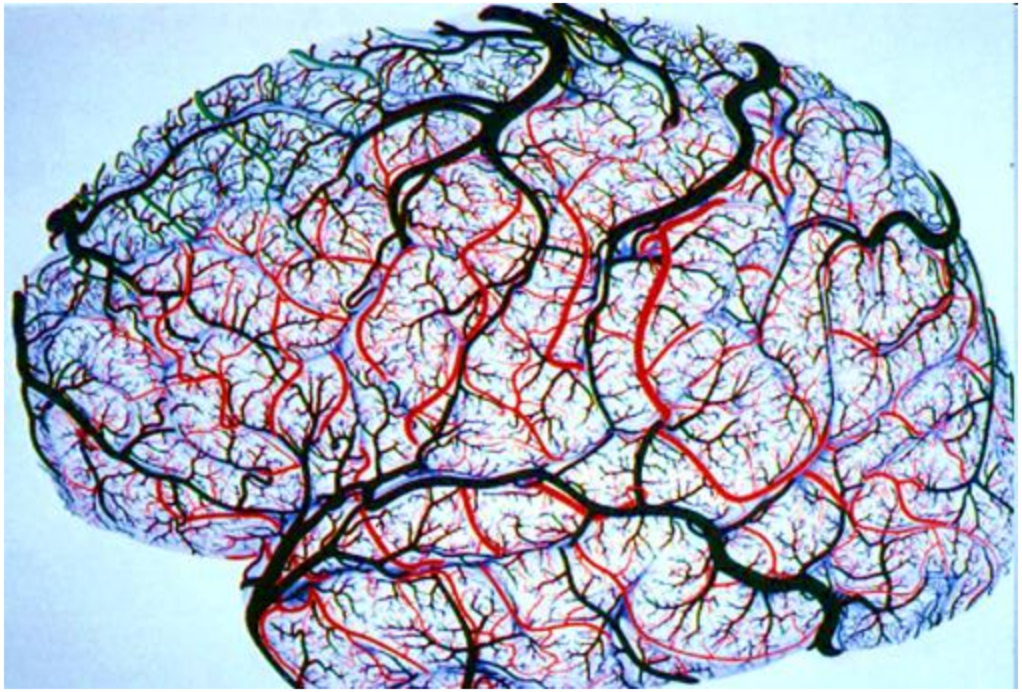
1991-1992

1992-1999

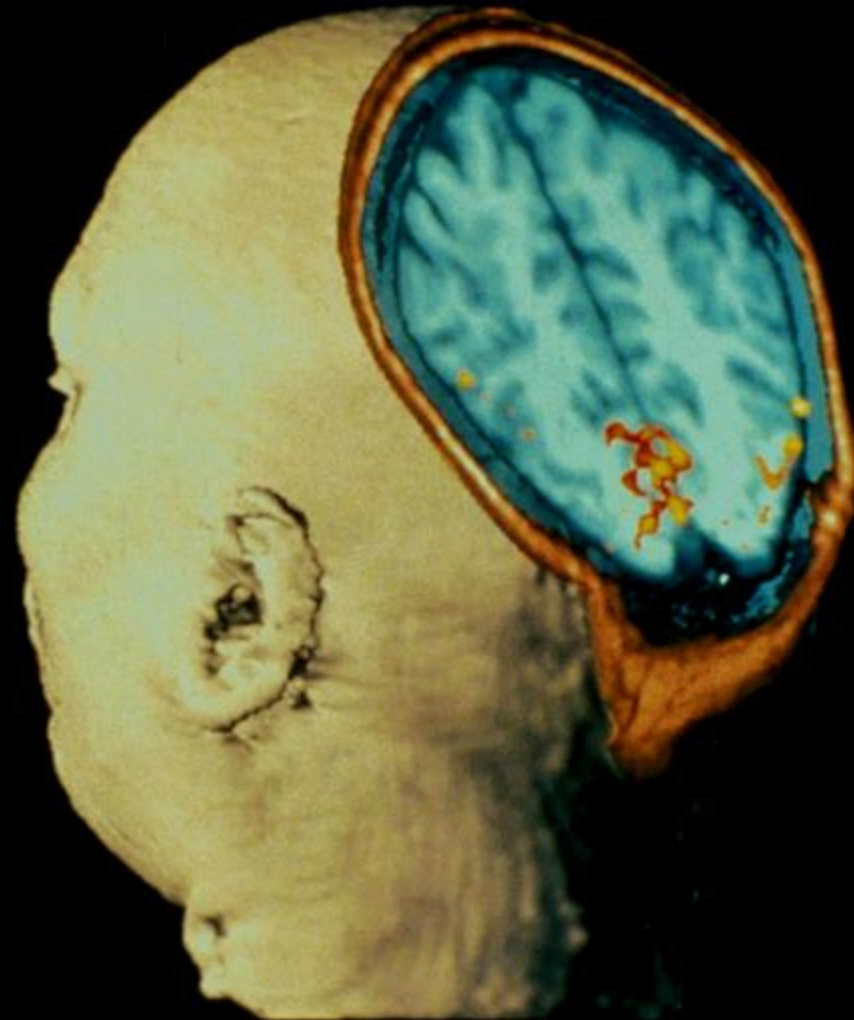


Contrast in Functional MRI

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



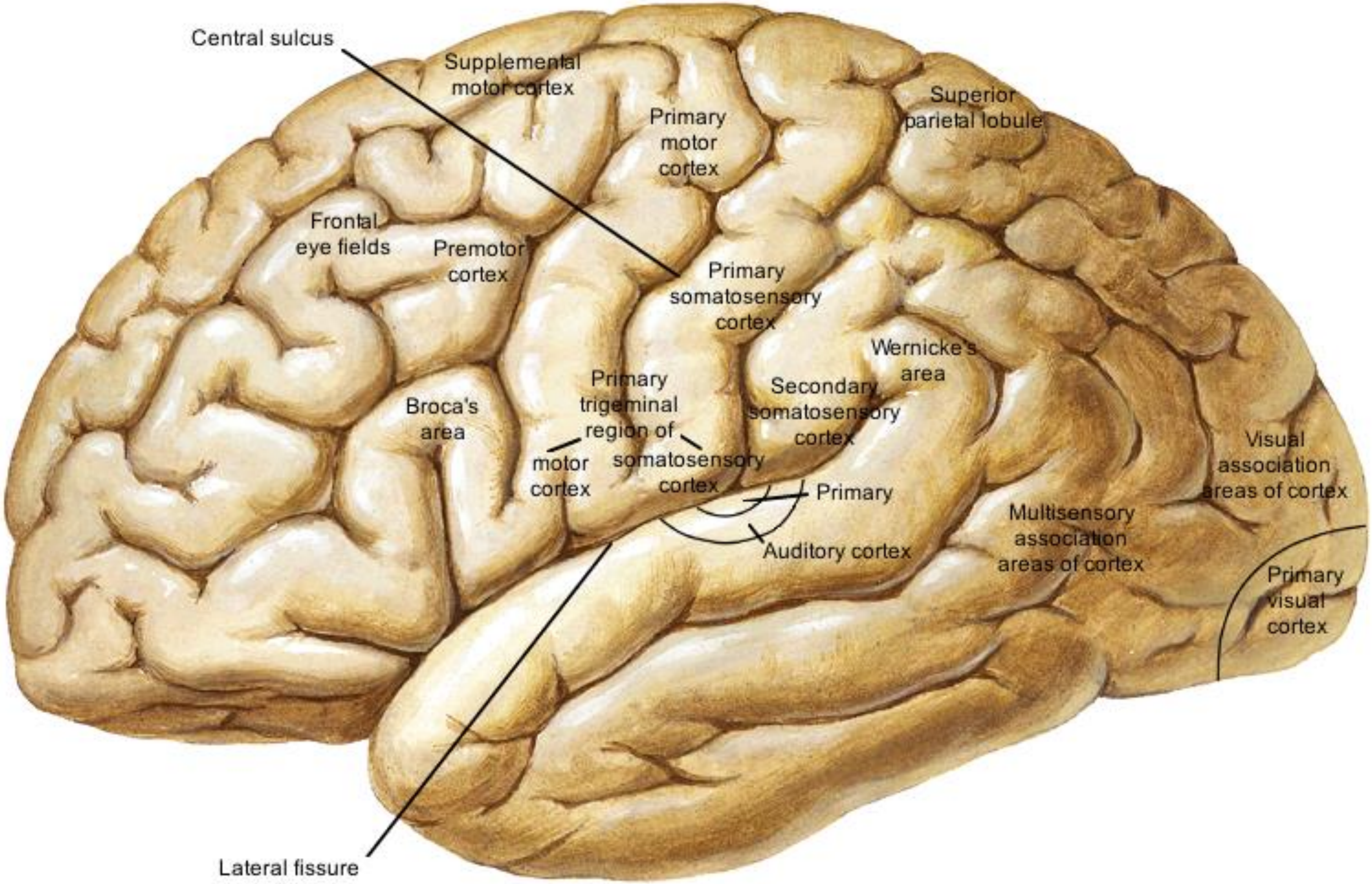
Photic Stimulation



MRI Image showing activation of the Visual Cortex

From Belliveau, et al.
Science Nov 1991

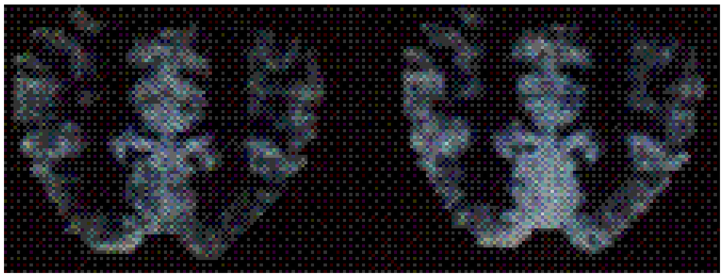
MSC - perfusion

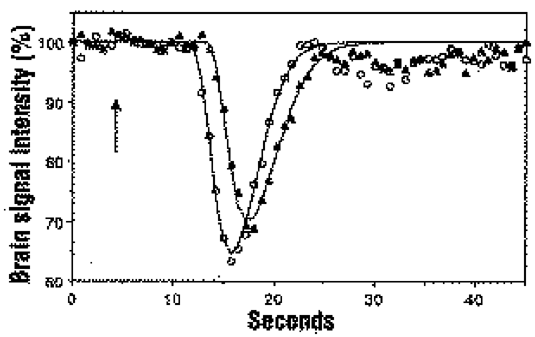


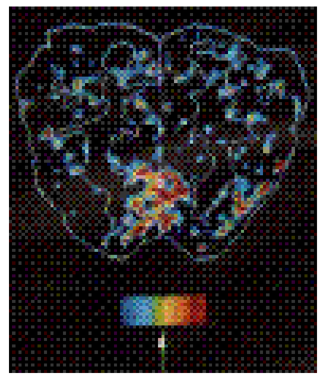
Central sulcus
Supplemental motor cortex
Primary motor cortex
Superior parietal lobule
Frontal eye fields
Premotor cortex
Primary somatosensory cortex
Wernicke's area
Primary trigeminal region of
motor cortex
somatosensory cortex
Broca's area
Secondary somatosensory cortex
Primary
Auditory cortex
Visual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

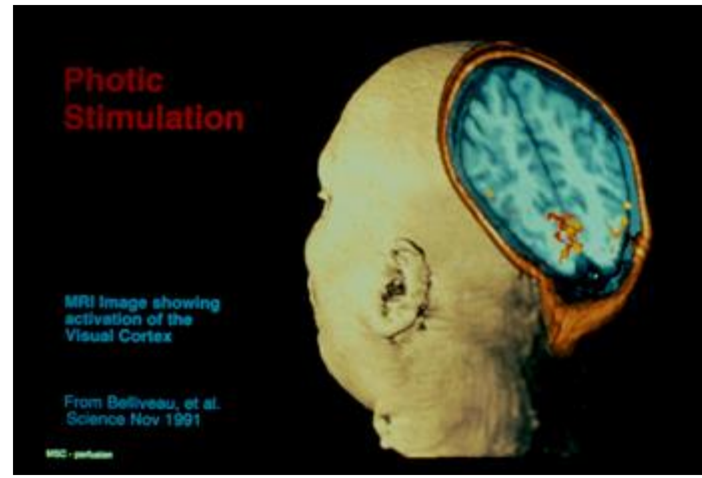
Blood Volume Imaging

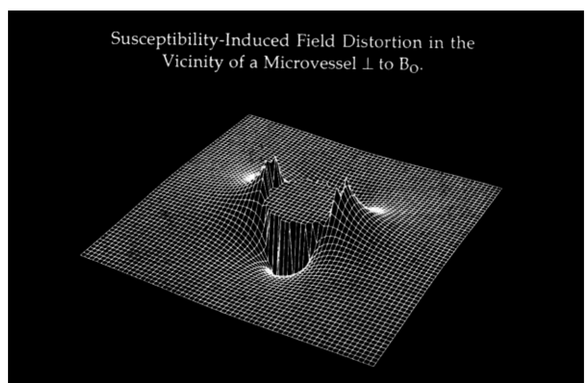
Susceptibility Contrast agent bolus injection and time series collection of T2* or T2 - weighted images



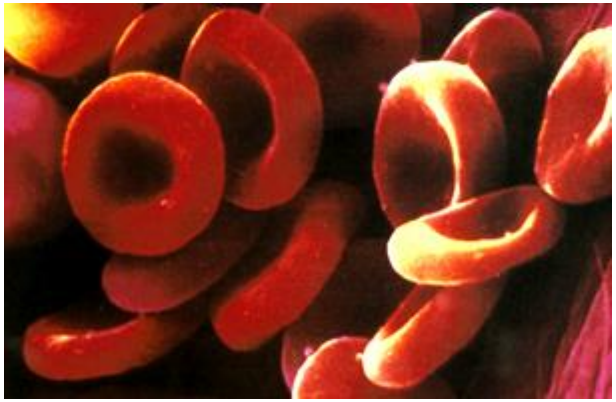






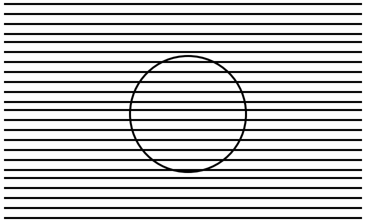


Oxygenated and deoxygenated red blood cells have different magnetic properties

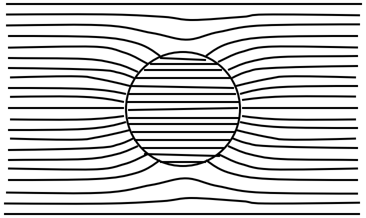


red blood cells

oxygenated



deoxygenated



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

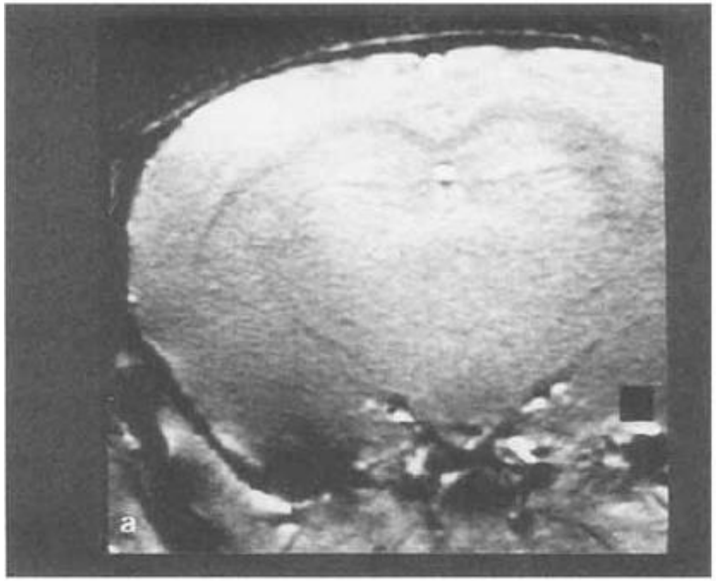
K.R. Thulborn, J. C. Waterton, et al., *Biochim. Biophys. Acta. 714: 265-270*, **1982**.

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

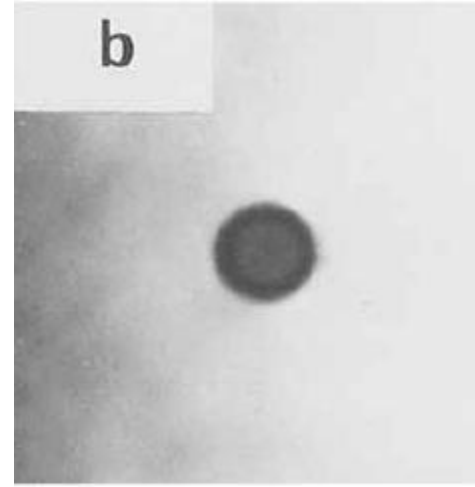
in vivo

in vitro

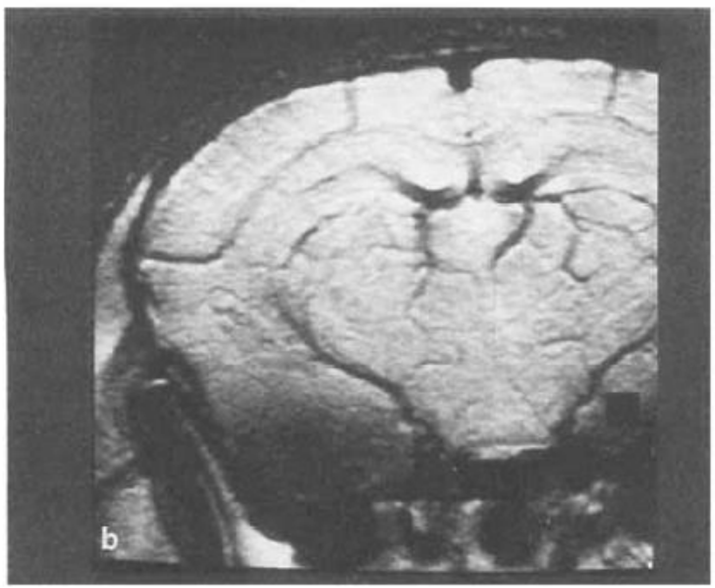
100% O_2



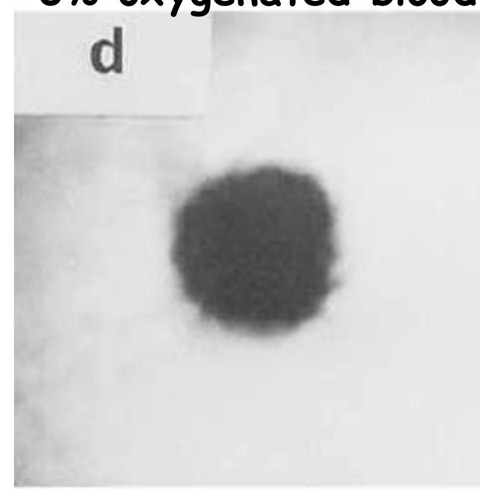
100% oxygenated blood



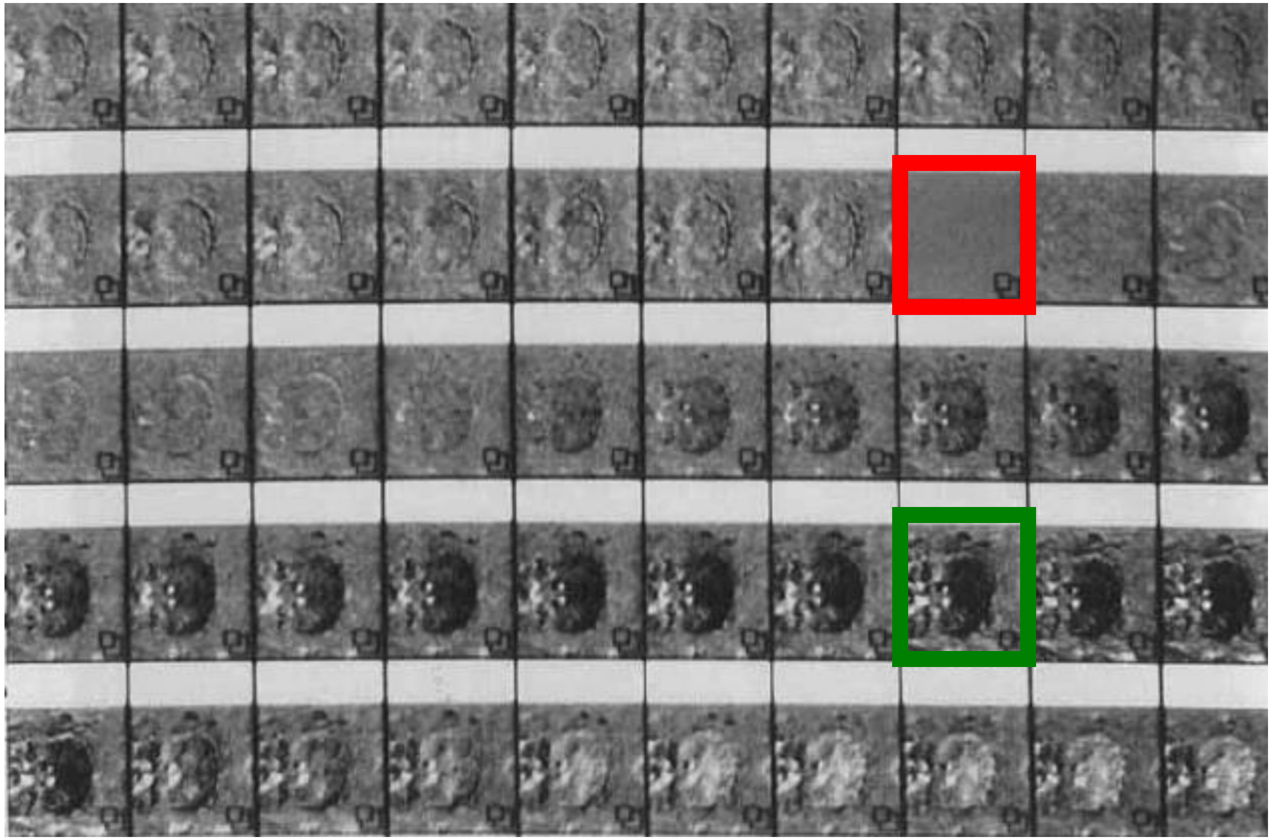
20% O_2

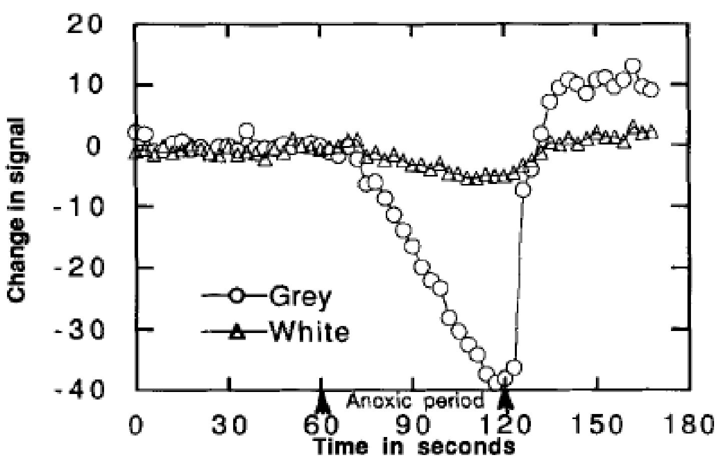


0% oxygenated blood



S. Ogawa, T.-M. Lee, A. S. Nayak, P. Glynn, Magn. Reson. Med, 14, 68-78 (1990)





R. Turner, D. LeBihan, C.T.W. Moonen, D. Despres, J. Frank, Magn. Reson. Med, 22, 159-166 (1991)

BOLD

(<u>b</u>lood <u>o</u>xygenation <u>l</u>evel <u>d</u>ependence)

blood flow $\uparrow$

oxygenated-blood $\uparrow$

MR signal $\uparrow$

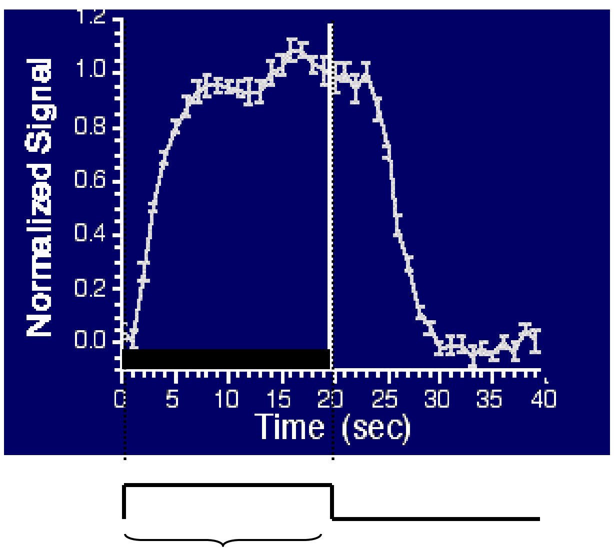
Real Time Brain Activation Imaging

•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.

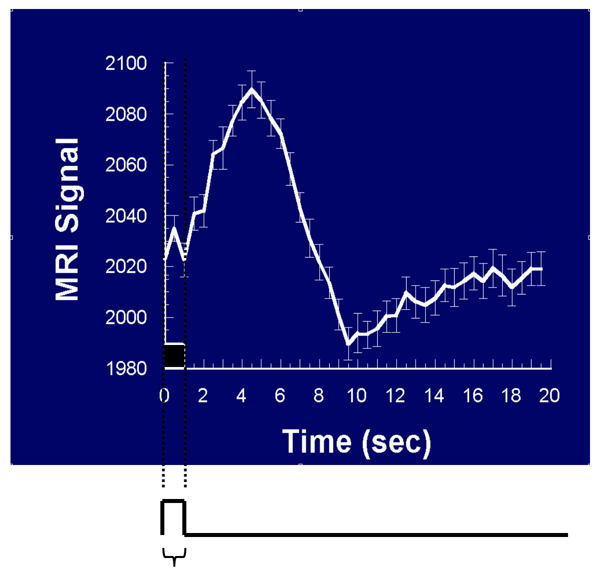
•S. Ogawa, et al., (1992) “Intrinsic signal changes accompanying sensory stimulation: functional brain mapping with magnetic resonance imaging. Proc. Natl. Acad. Sci. USA.” 89, 5951-5955.

•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.

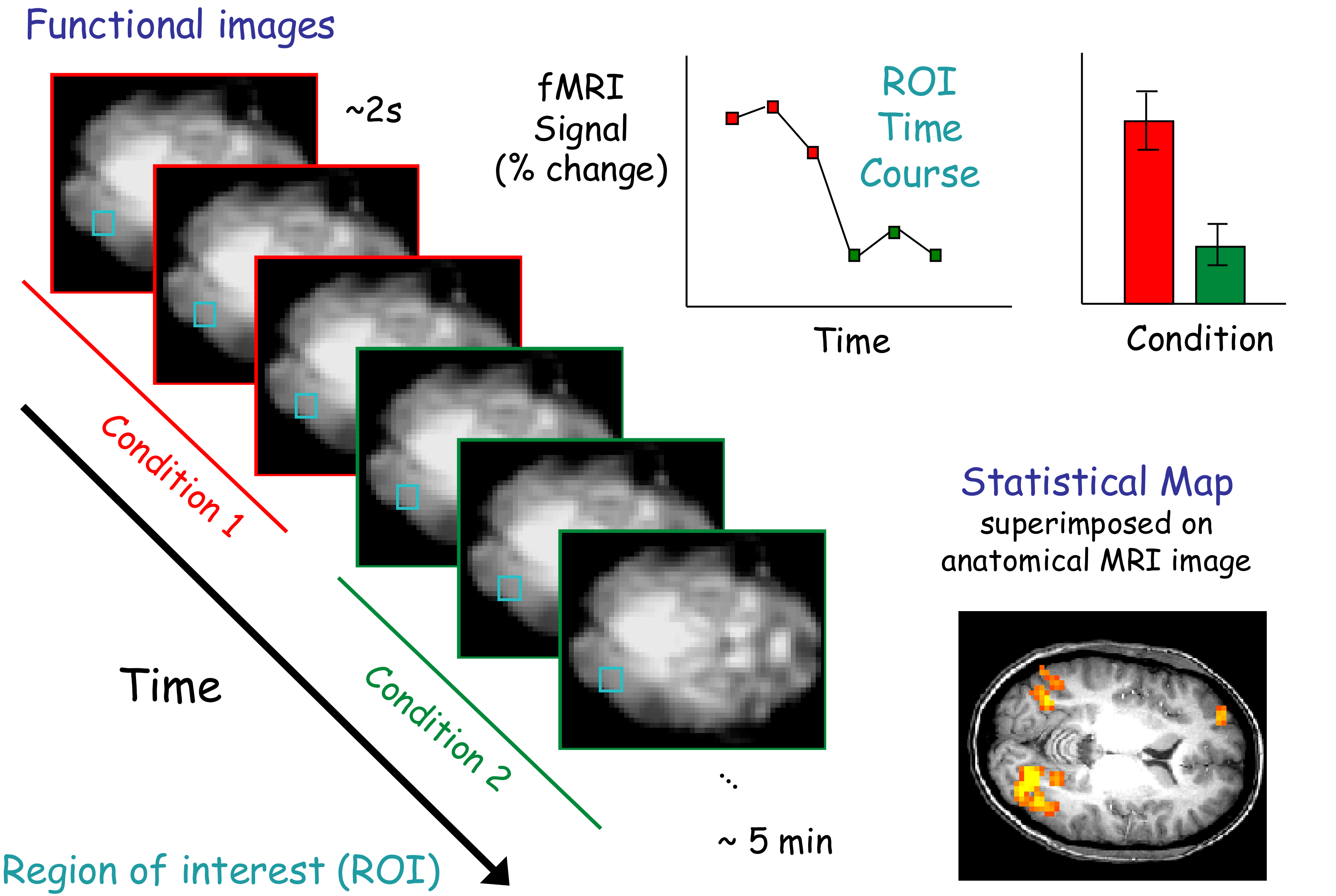


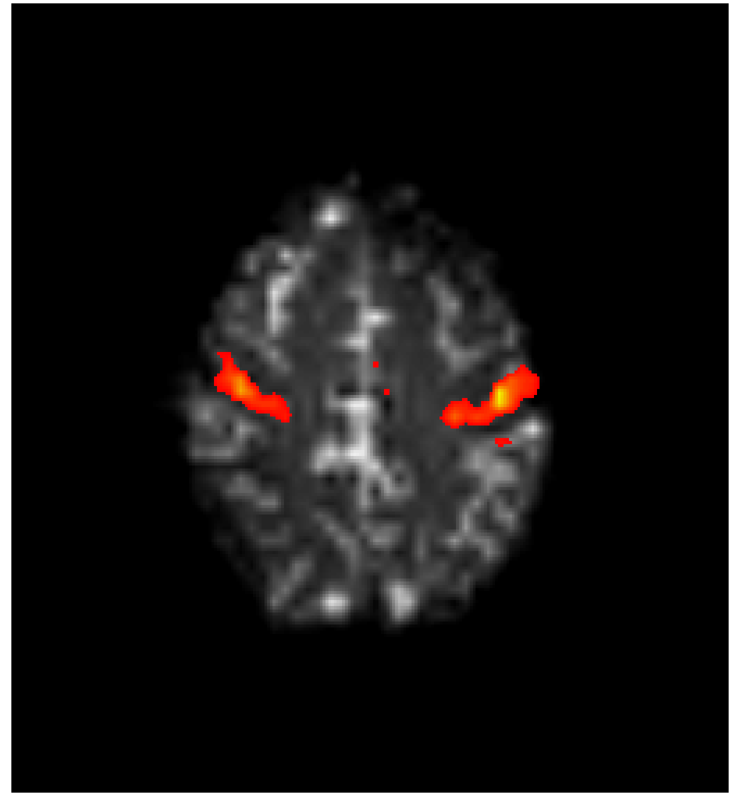
task



task

Activation Statistics

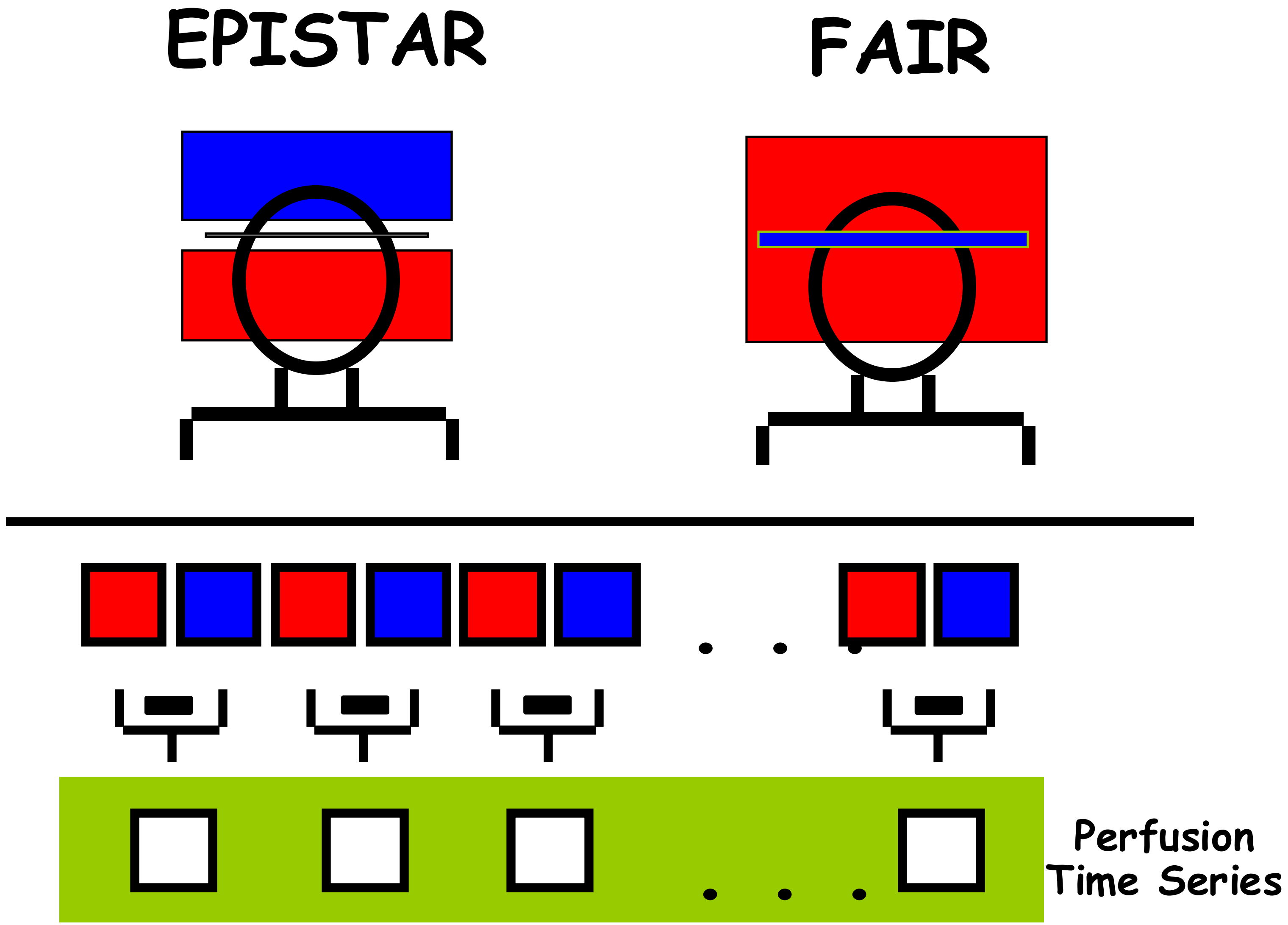




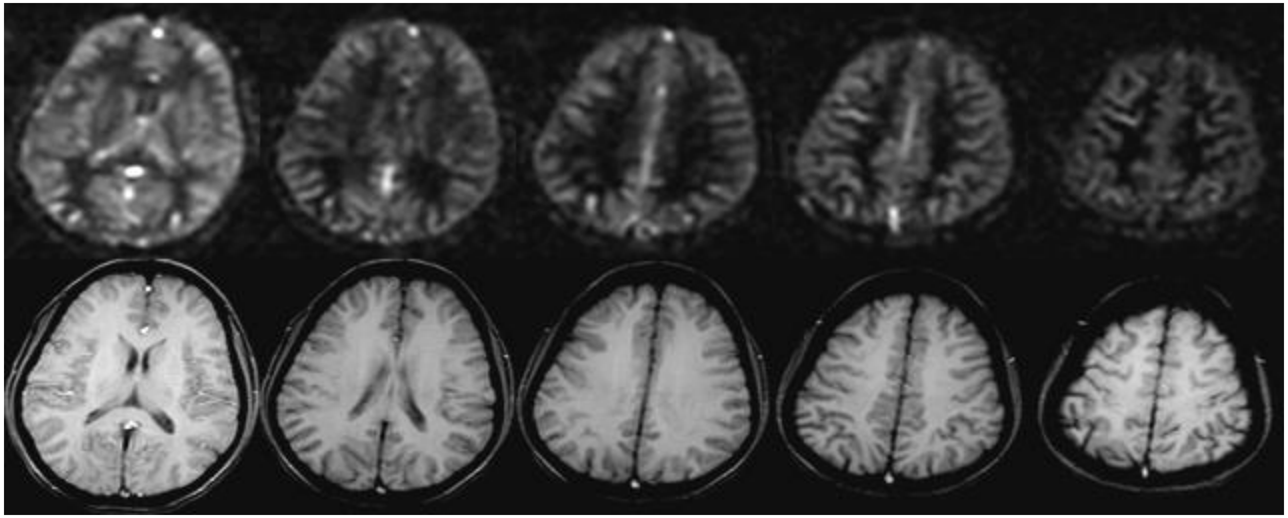
Cross Correlation Image

Cross Correlation Image
Anatomical Image

Blood Perfusion



1992…Perfusion using Arterial Spin Labeling



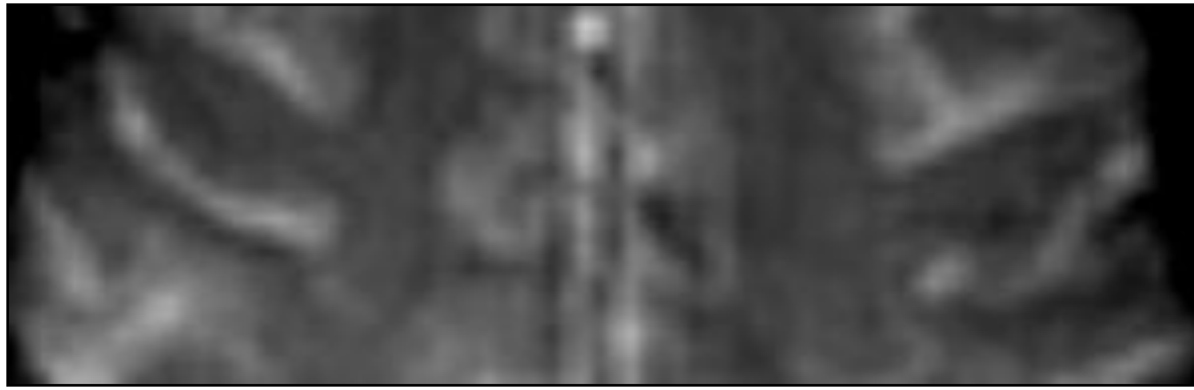
Williams, D. S., Detre, J. A., Leigh, J. S. & Koretsky, A. S. (1992) "Magnetic resonance imaging of perfusion using spin-inversion of arterial water." **Proc. Natl. Acad. Sci. USA 89, 212-216.**

Edelman, R., Siewert, B. & Darby, D. (1994) "Qualitative mapping of cerebral blood flow and functional localization with echo planar MR imaging ans signal targeting with alternating radiofrequency (EPISTAR)." **Radiology 192, 1-8.**

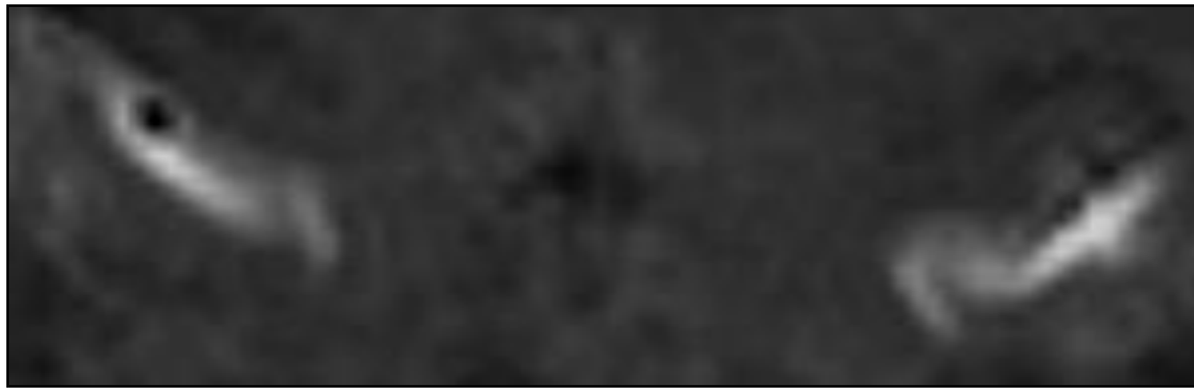
Kim, S.-G. (1995) "Quantification of relative cerebral blood flow change by flow-sensitive alternating inversion recovery (FAIR) technique: application to functional mapping." **Magn. Reson. Med. 34, 293-301**.

Kwong, K. K. et al. (1995) "MR perfusion studies with T1-weighted echo planar imaging."**Magn. Reson. Med. 34,878-887.**

Anatomy

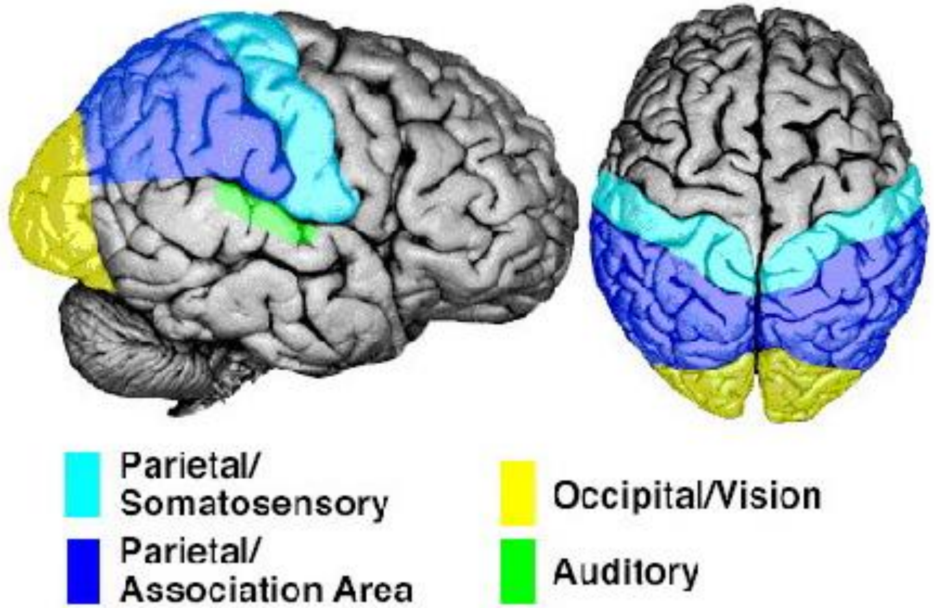


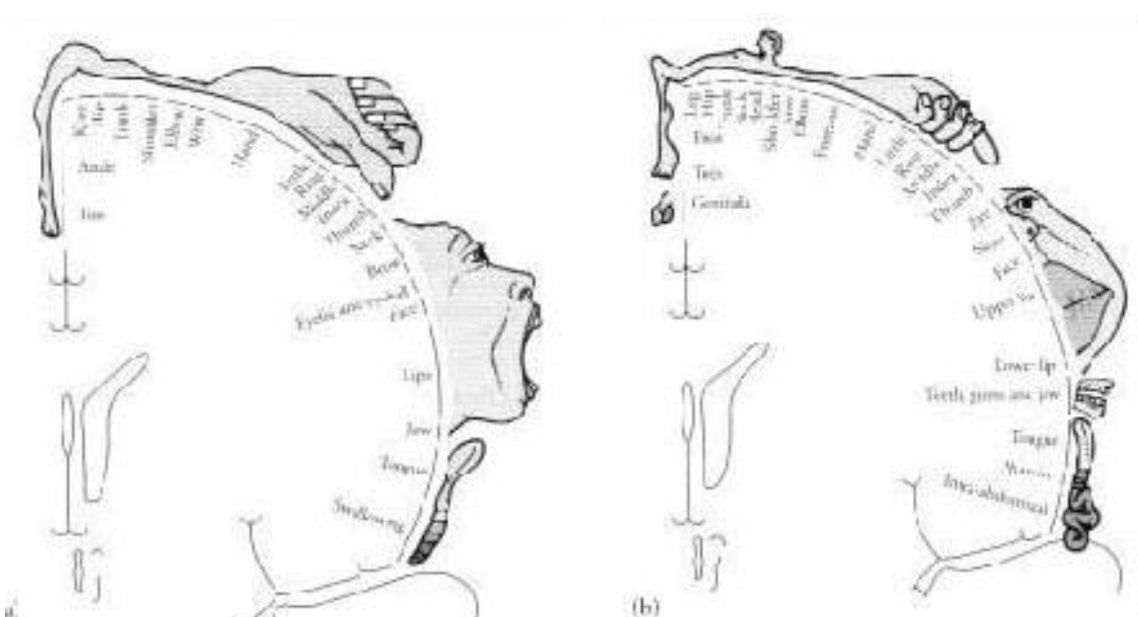
BOLD



Perfusion

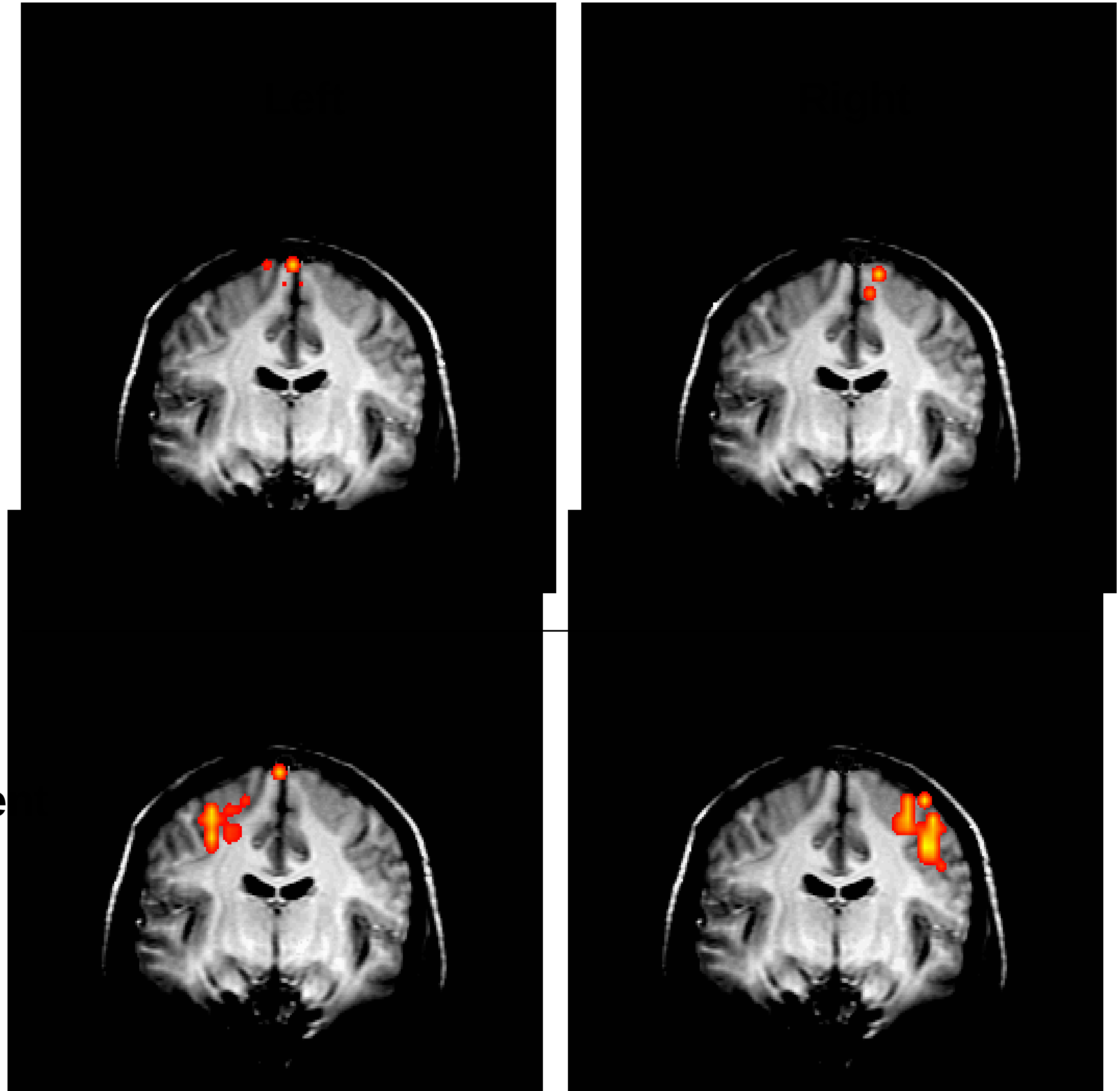
P. A. Bandettini, E. C. Wong, Magnetic resonance imaging of human brain function: principles, practicalities, and possibilities, *in* "Neurosurgery Clinics of North America: Functional Imaging" (M. Haglund, Ed.), p.345-371, W. B. Saunders Co., 1997.

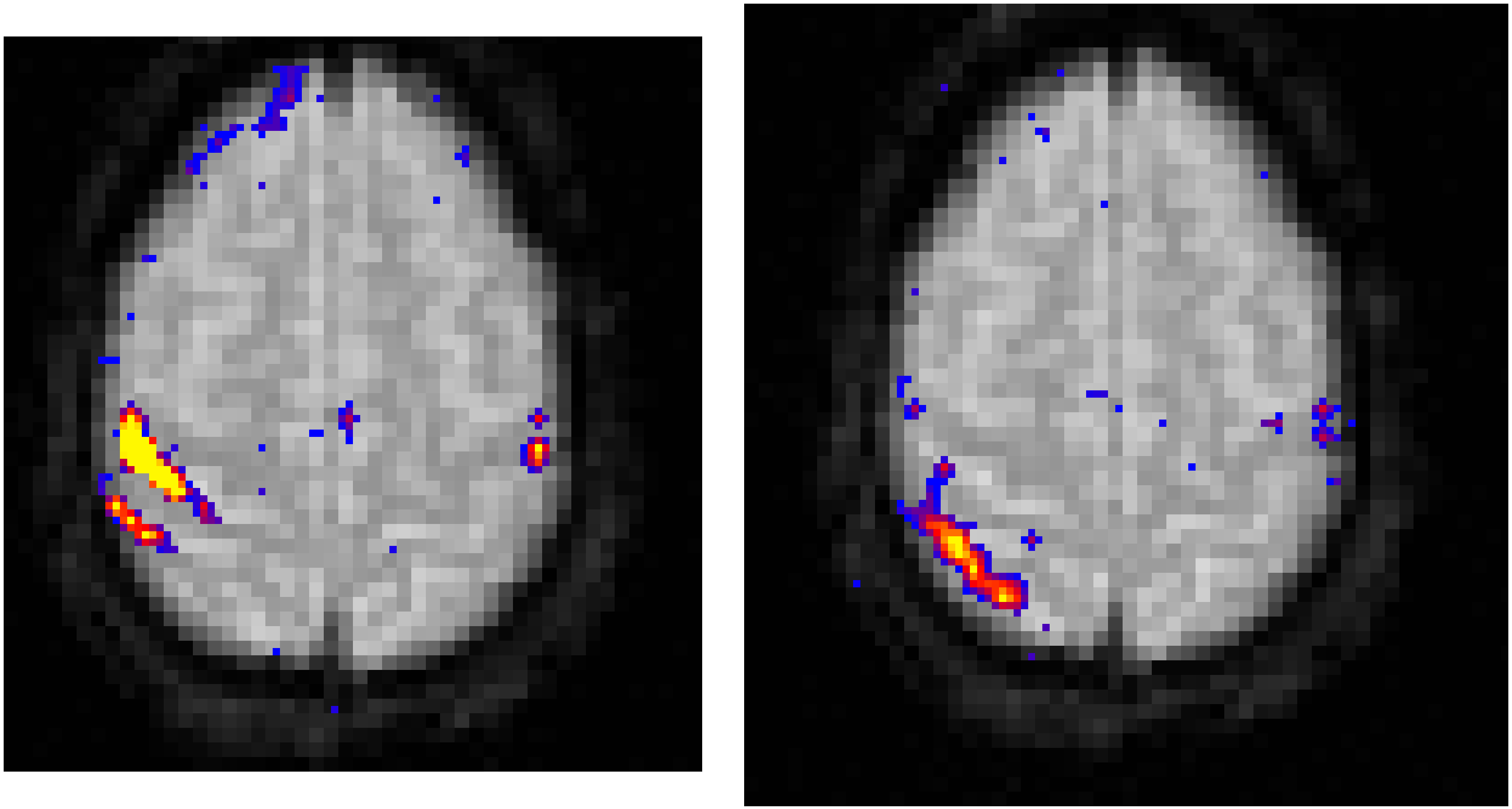

Parietal/
Somatosensory
Parietal/
Association Area
Occipital/Vision
Auditory

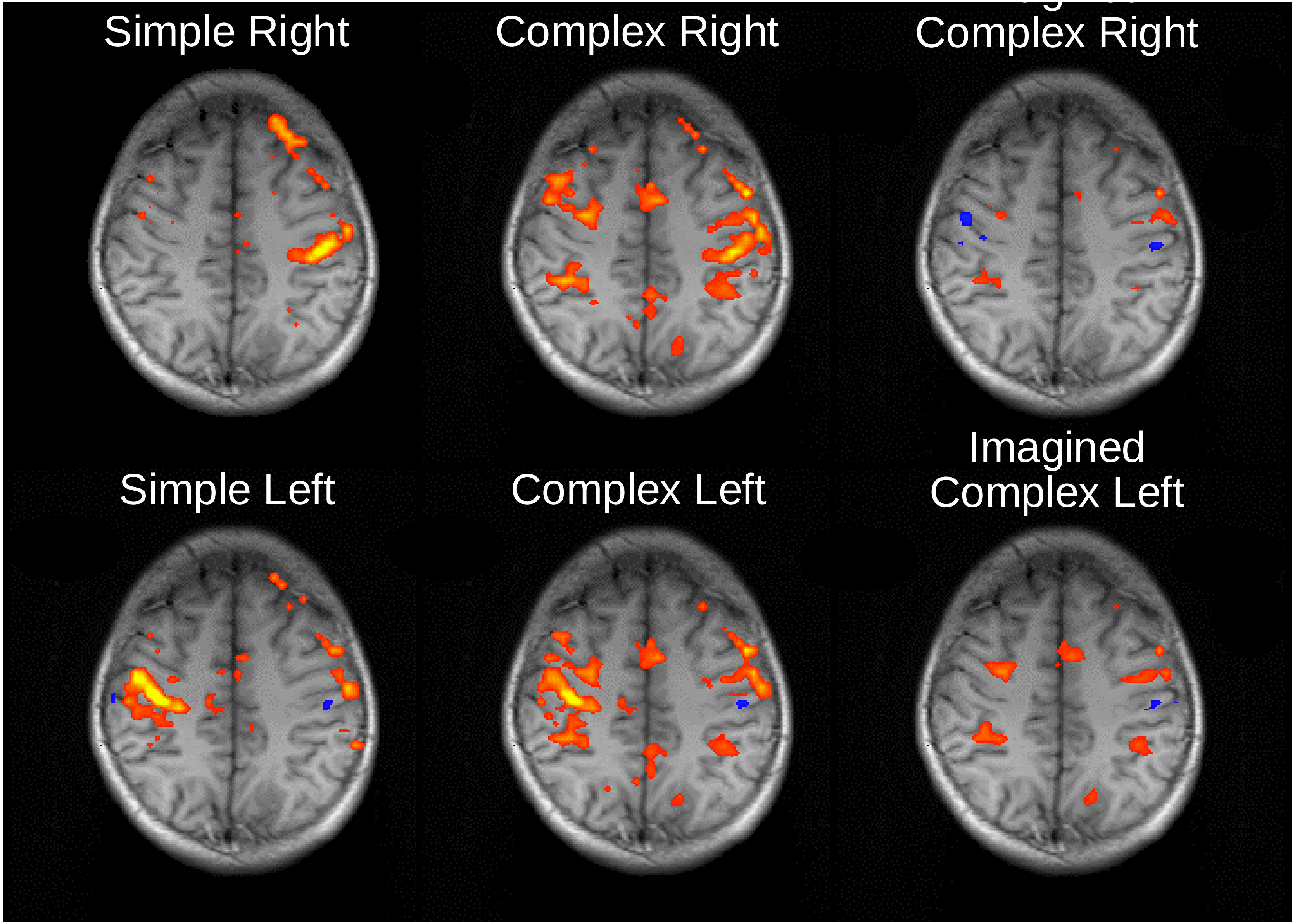

Lips
Jaw
Swallowing
Genitals
Toes
Lower lip
Teeth, gums and jaw
Tongue
Intra-abdominal
(b)

Toe movement

Finger moveme

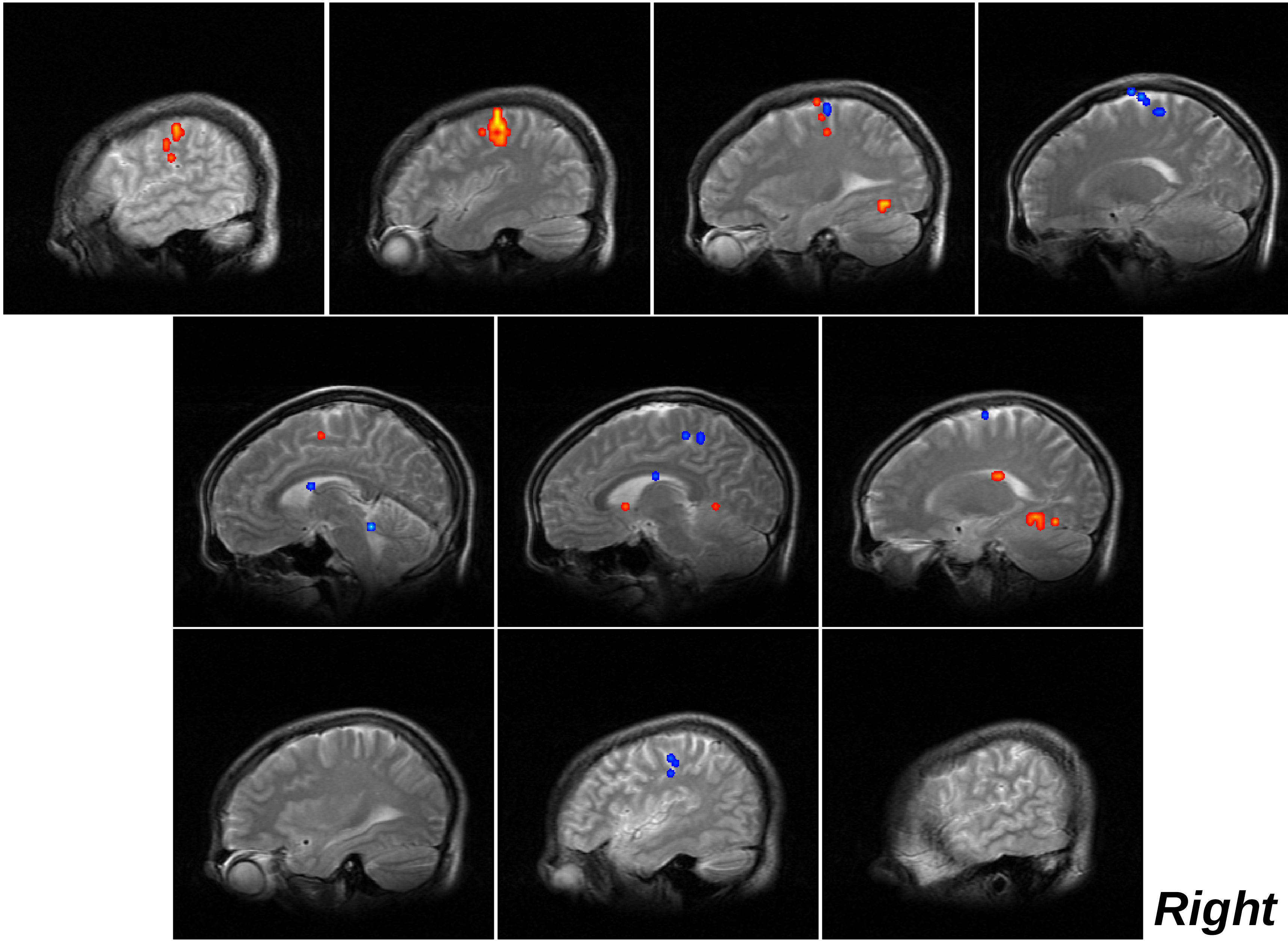





Simple Right
Complex Right
Complex Right
Simple Left
Complex Left
Imagined
Complex Left

Left

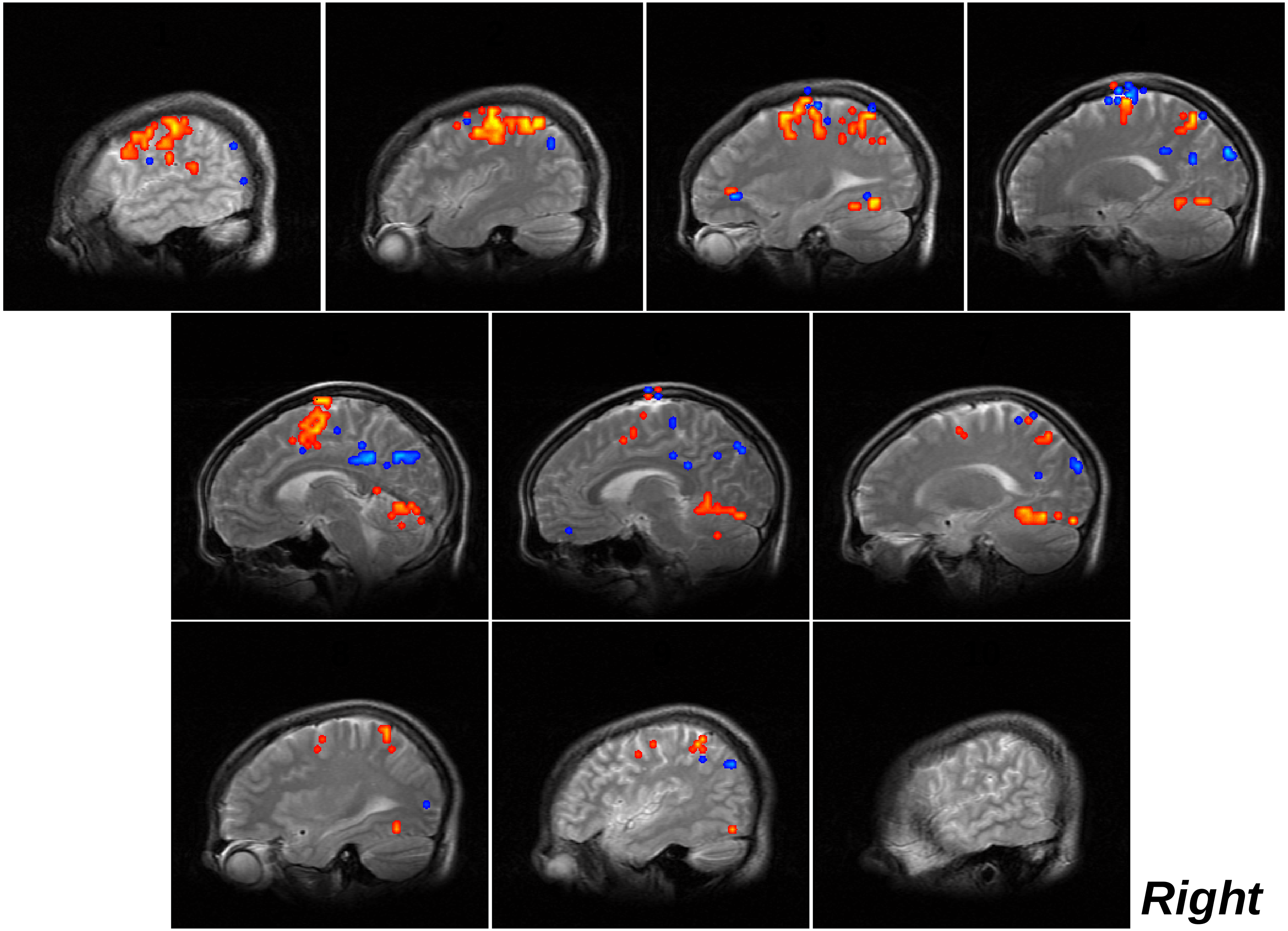
Simple Finger Movement on the RIght Hand



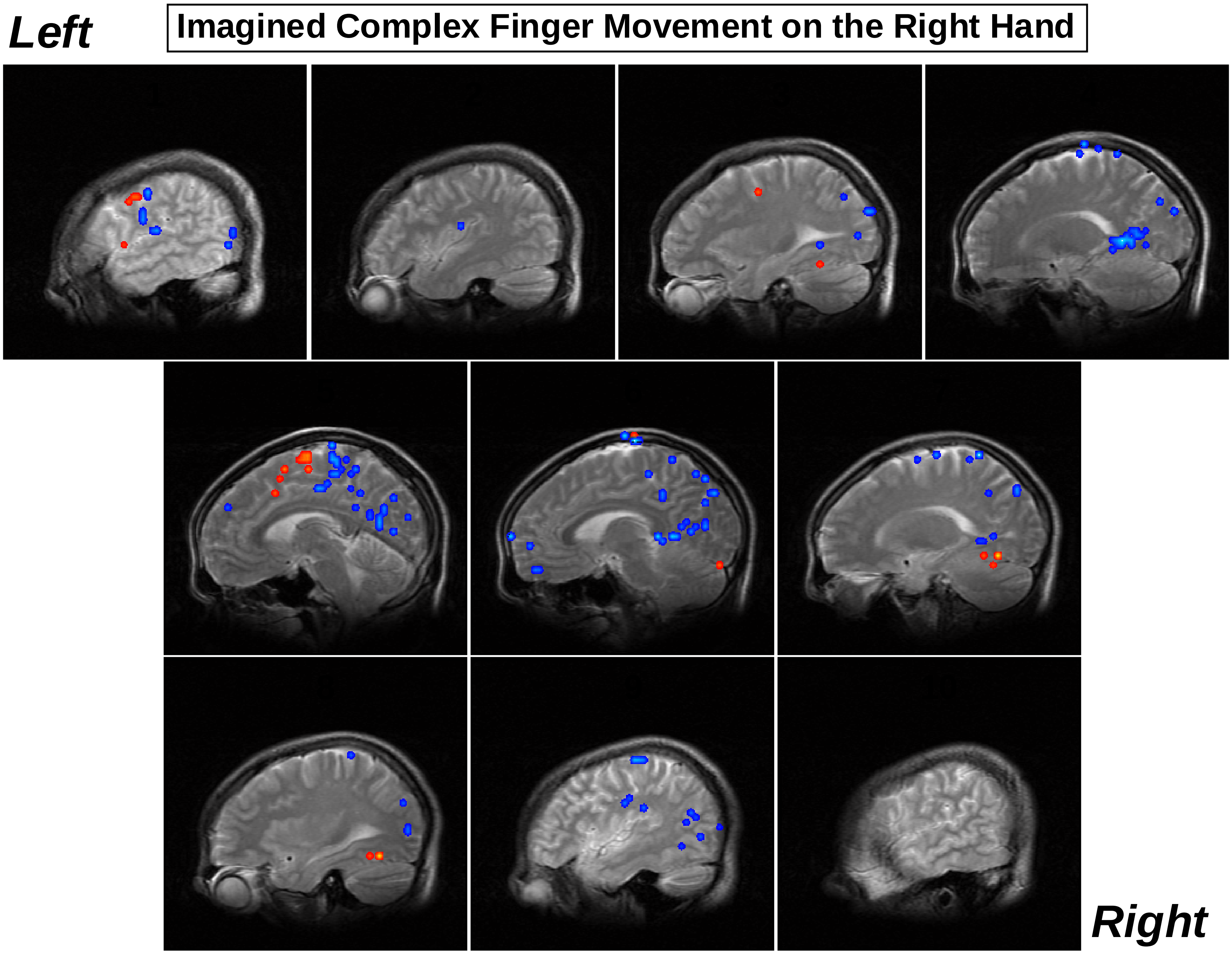
Right

Left

Complex Finger Movement on the Right Hand

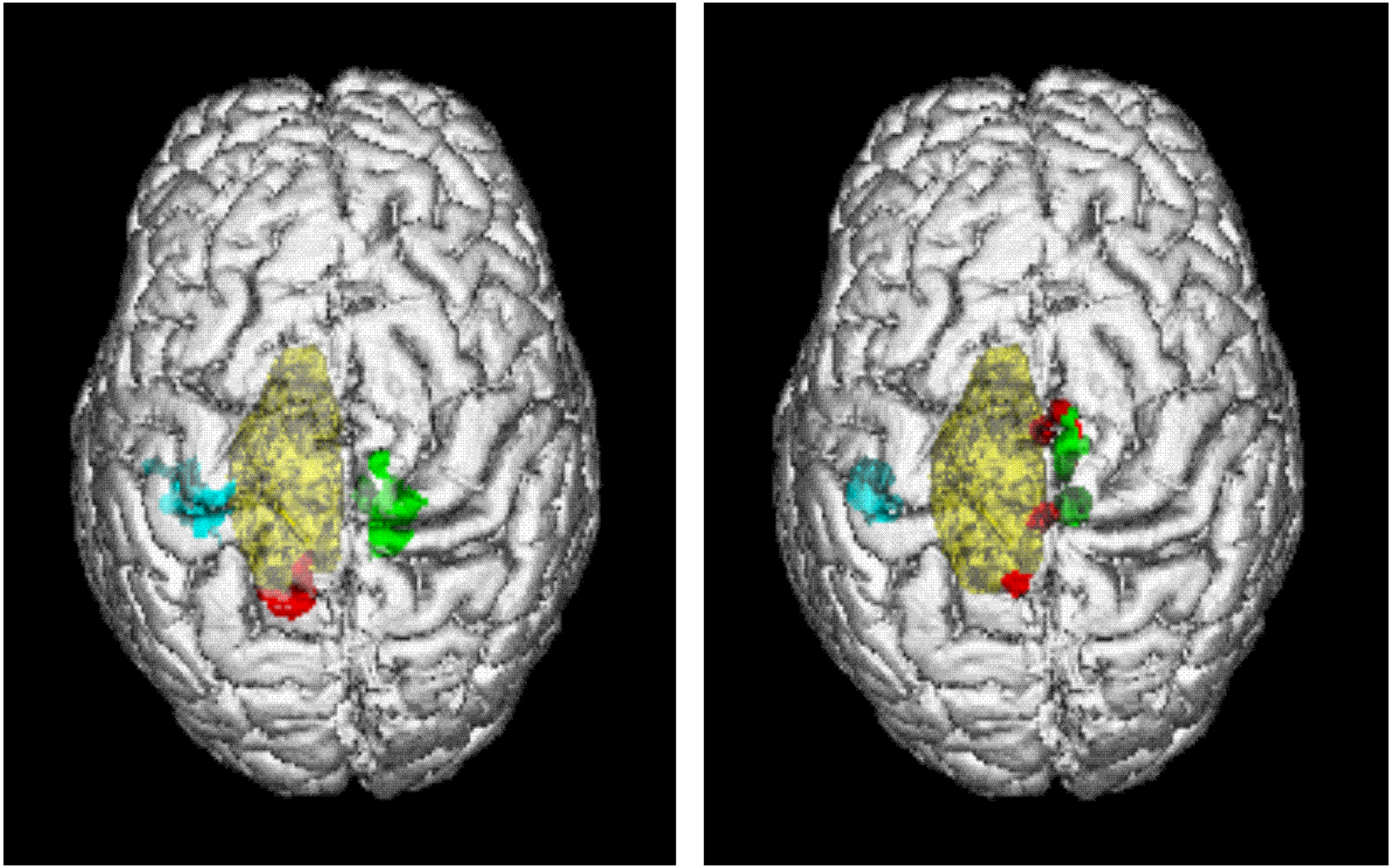


Right


Left
Imagined Complex Finger Movement on the Right Hand
Right

Presurgical Mapping

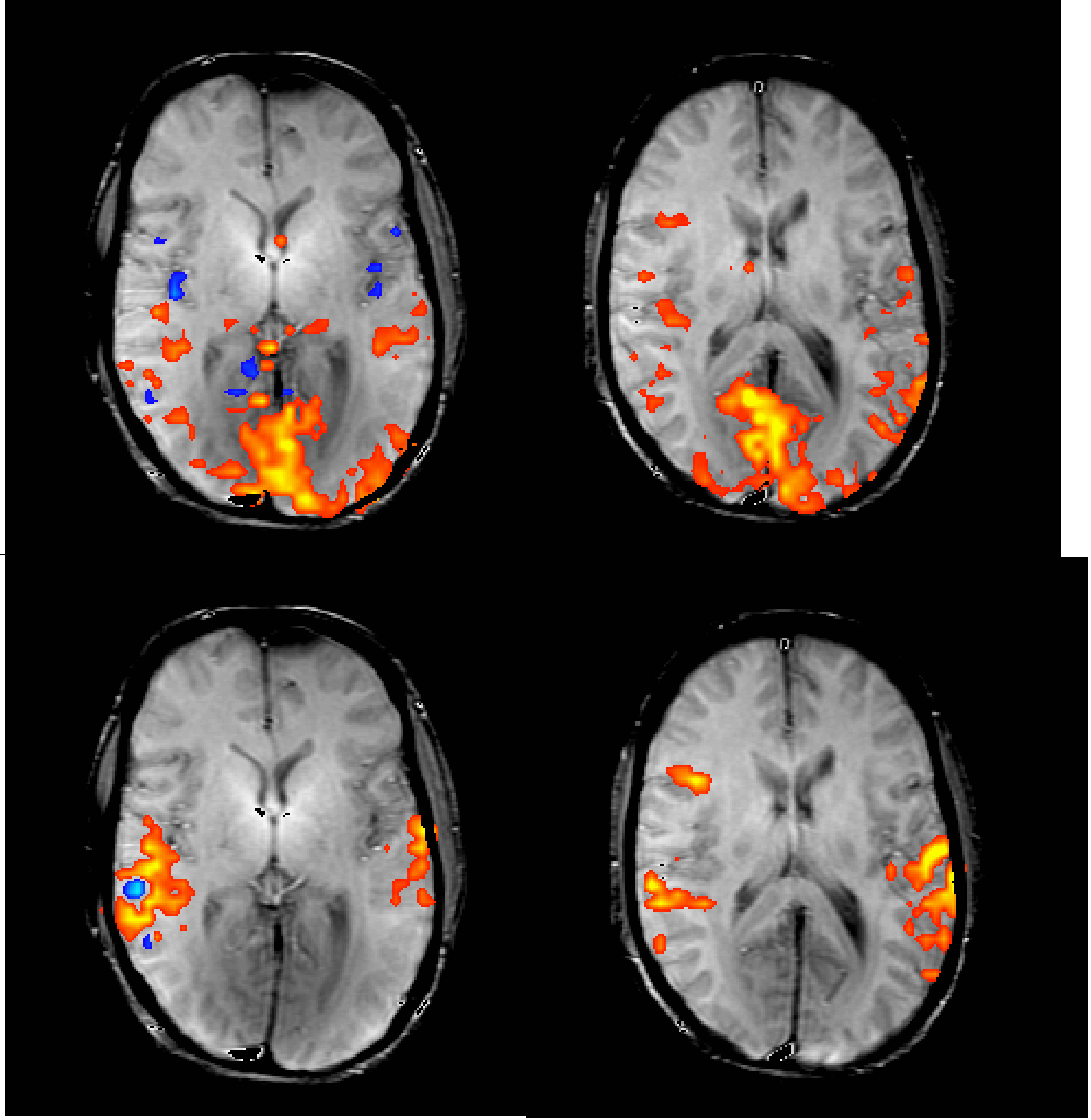
Left Foot Tumor Right Foot Right Hand



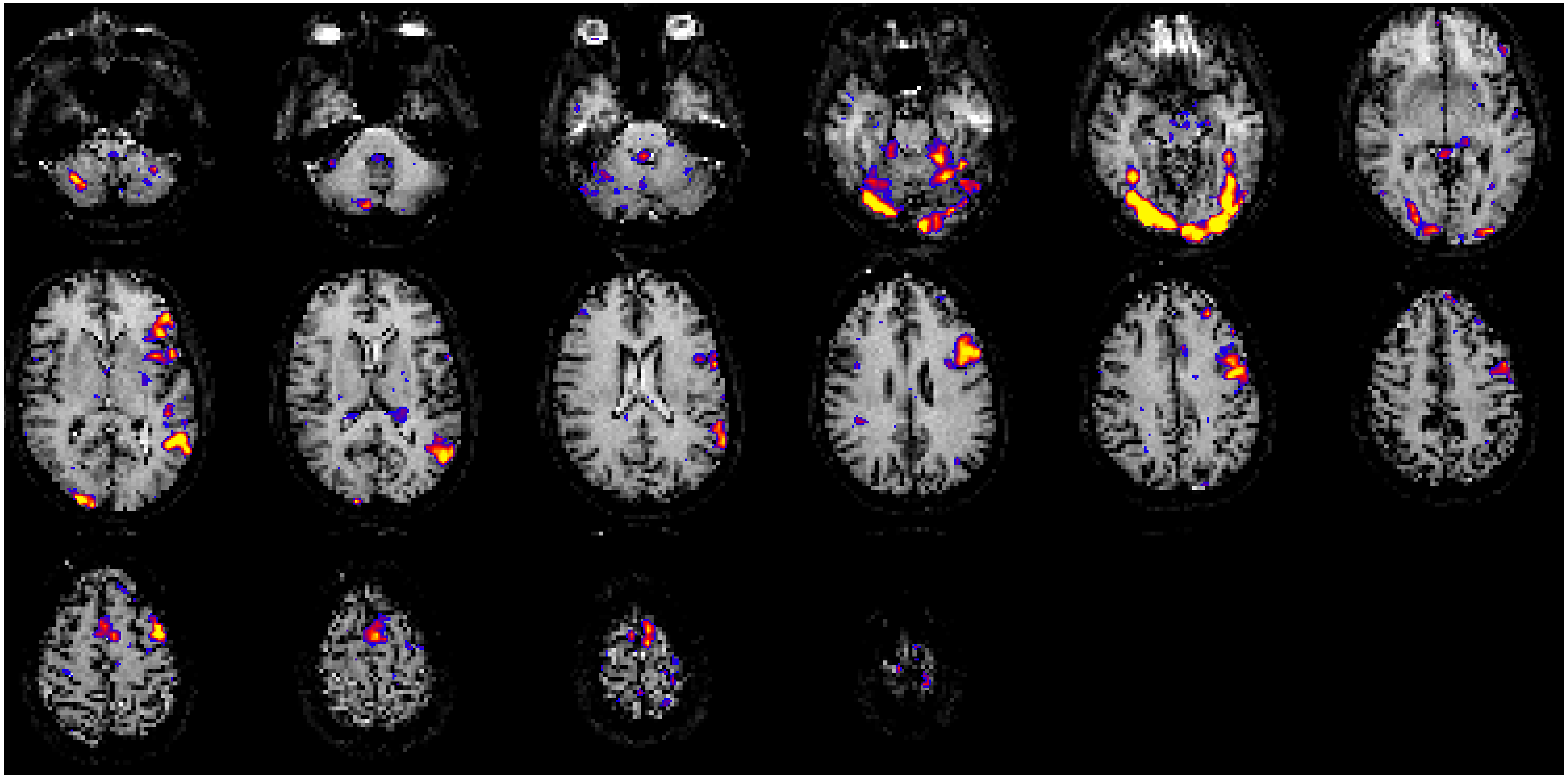
fMRI O-15 PET

Reading

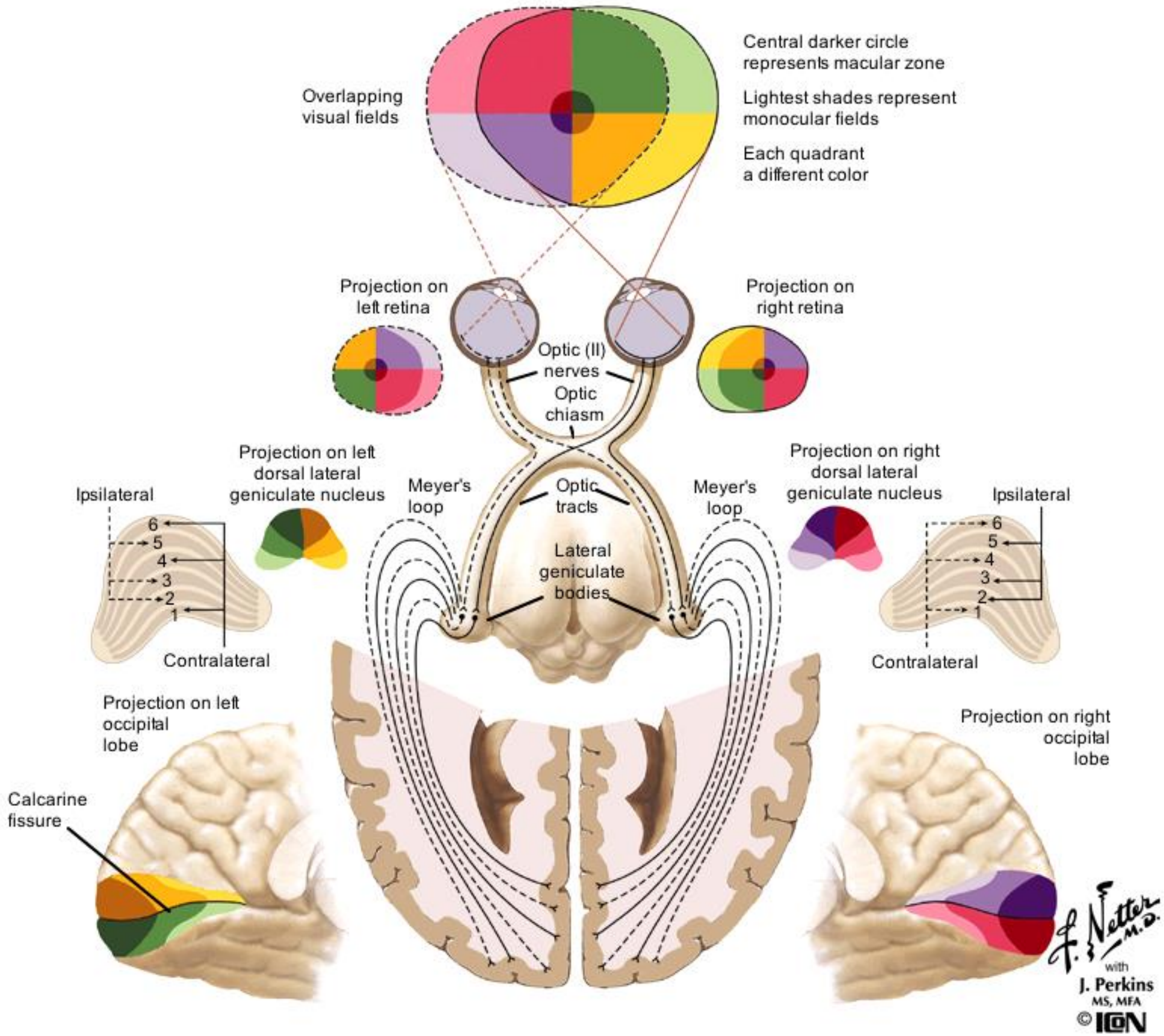
Listening

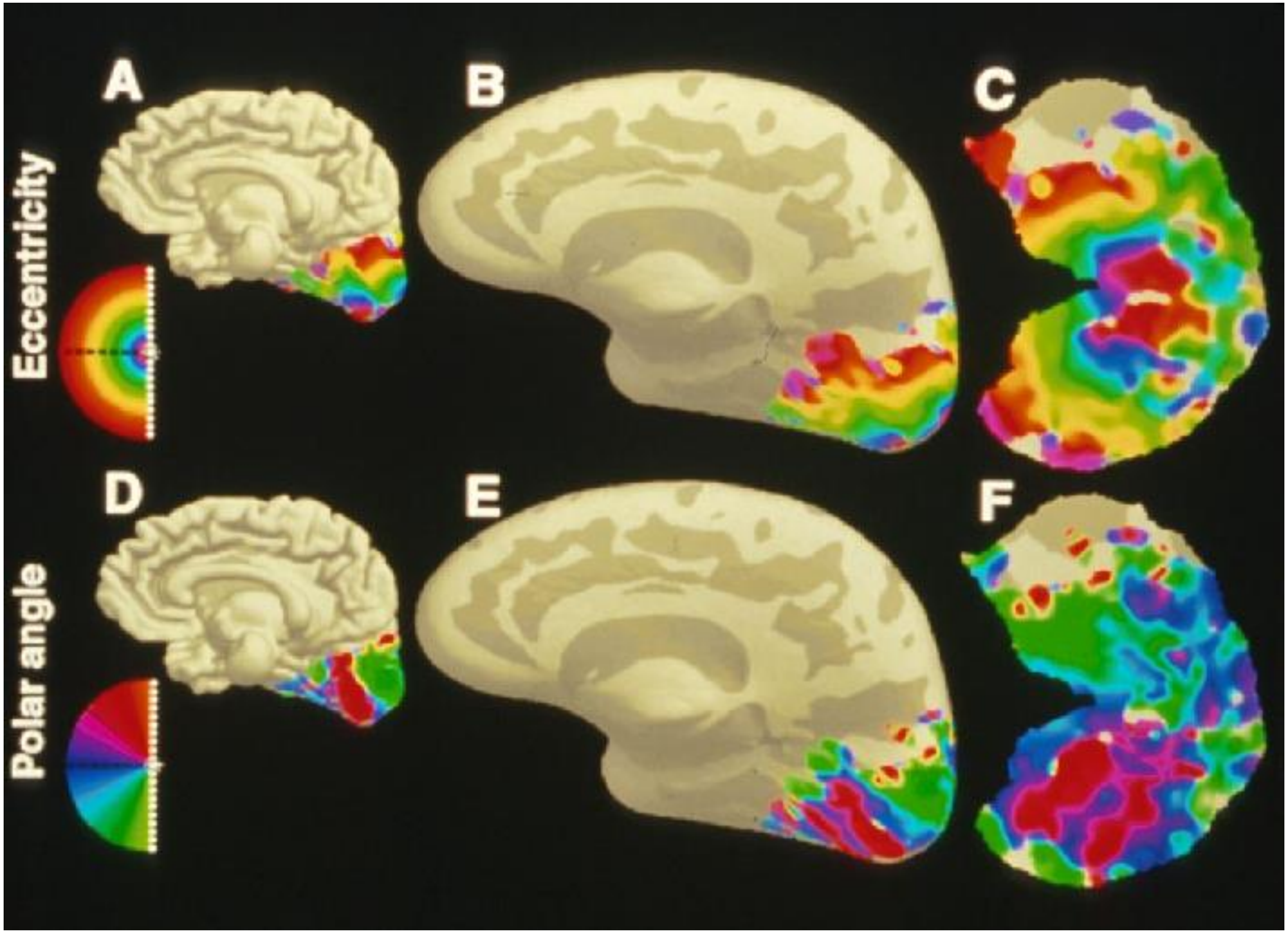


Word stem completion

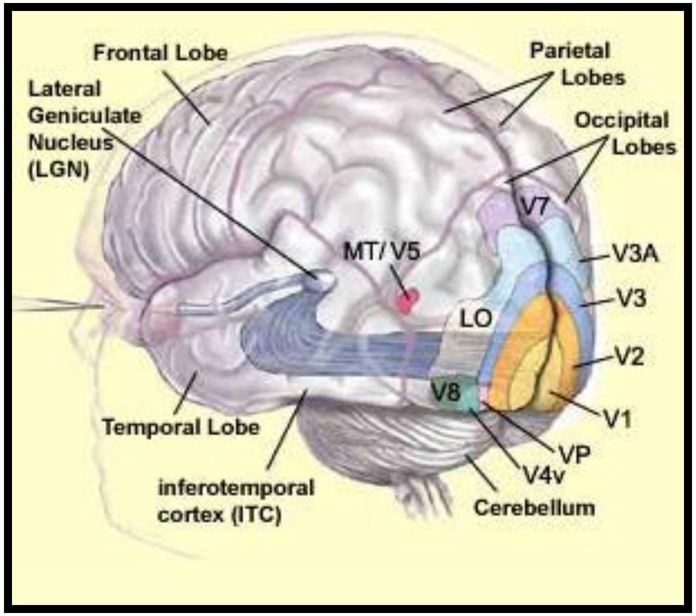


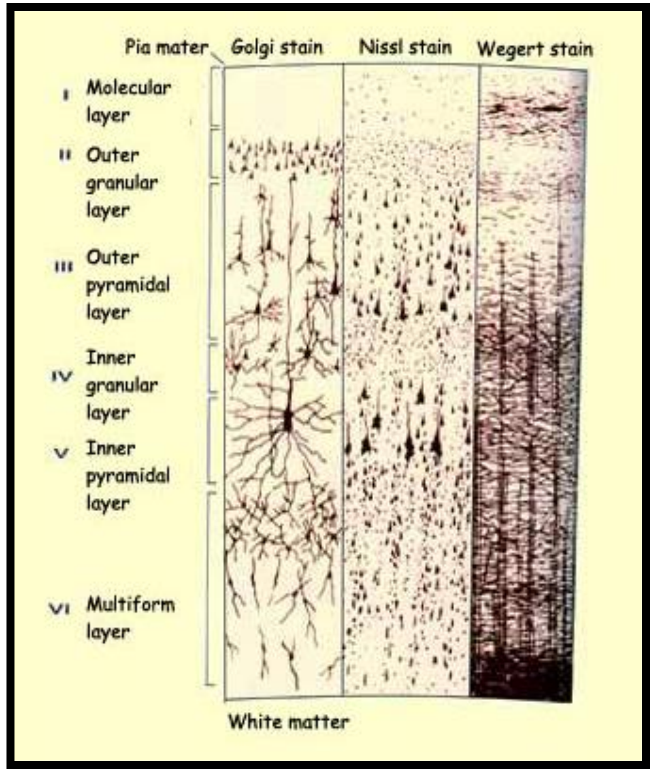
Visual Pathways: The Retino-Geniculo-Calcarine Pathway

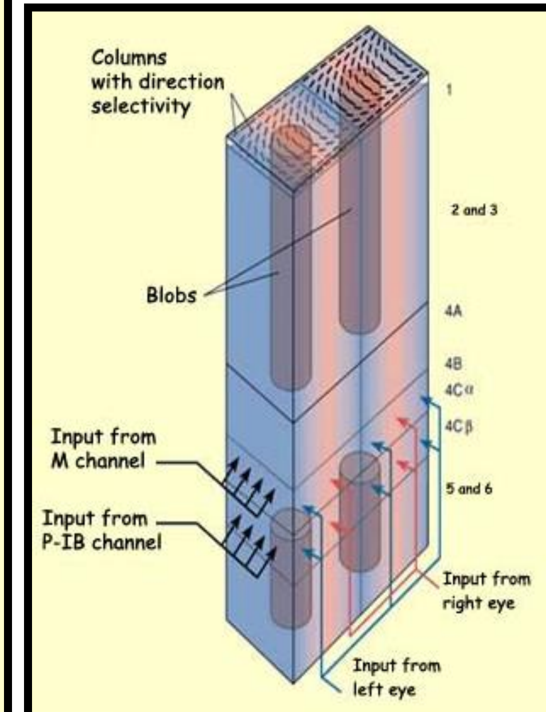


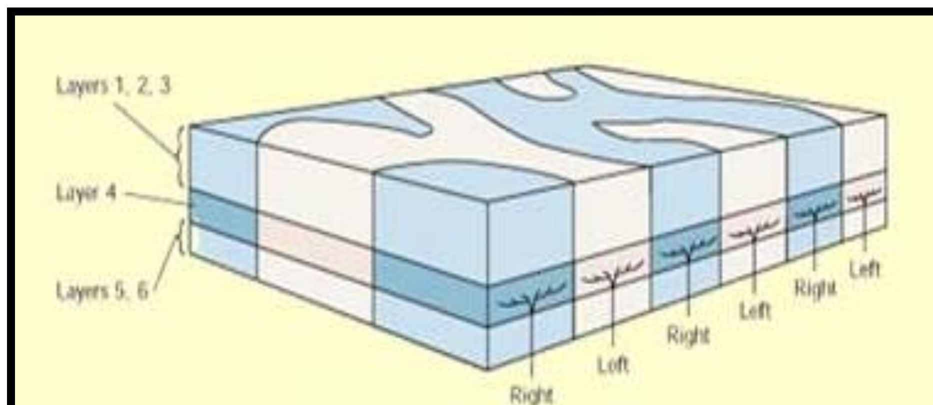

A
B
C
D
E
F
Eccentricity
Polar angle

Visual Cortex Organization



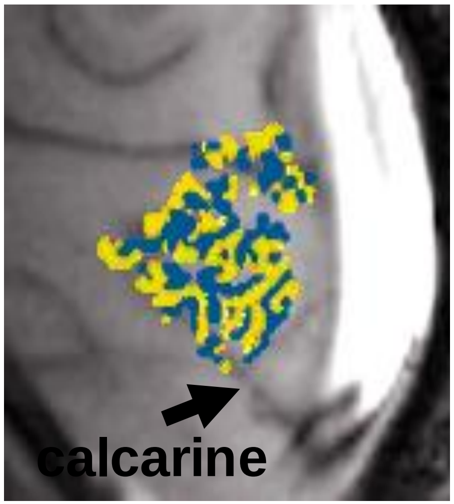


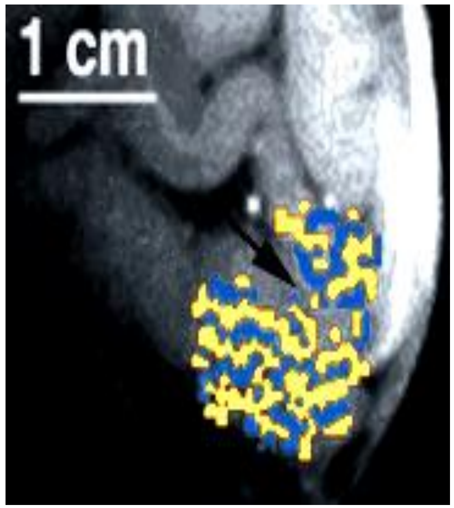


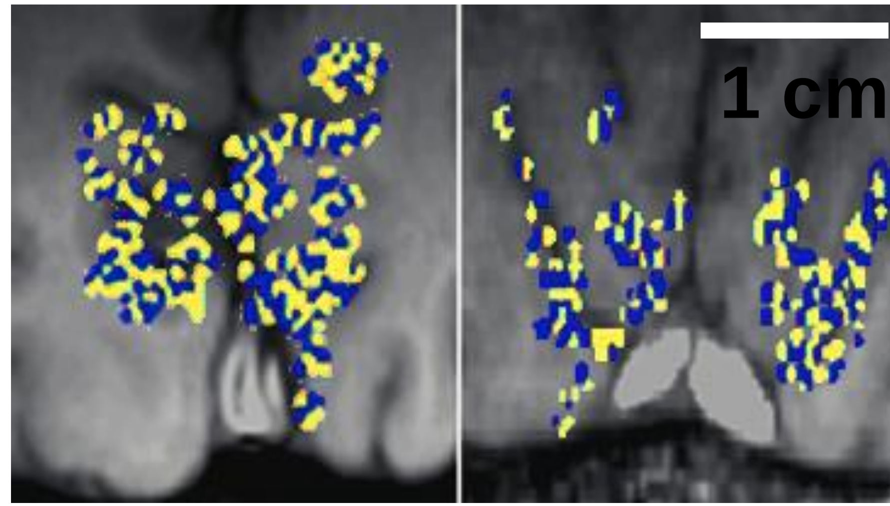


http://www.thebrain.mcgill.ca

ODC Maps using fMRI







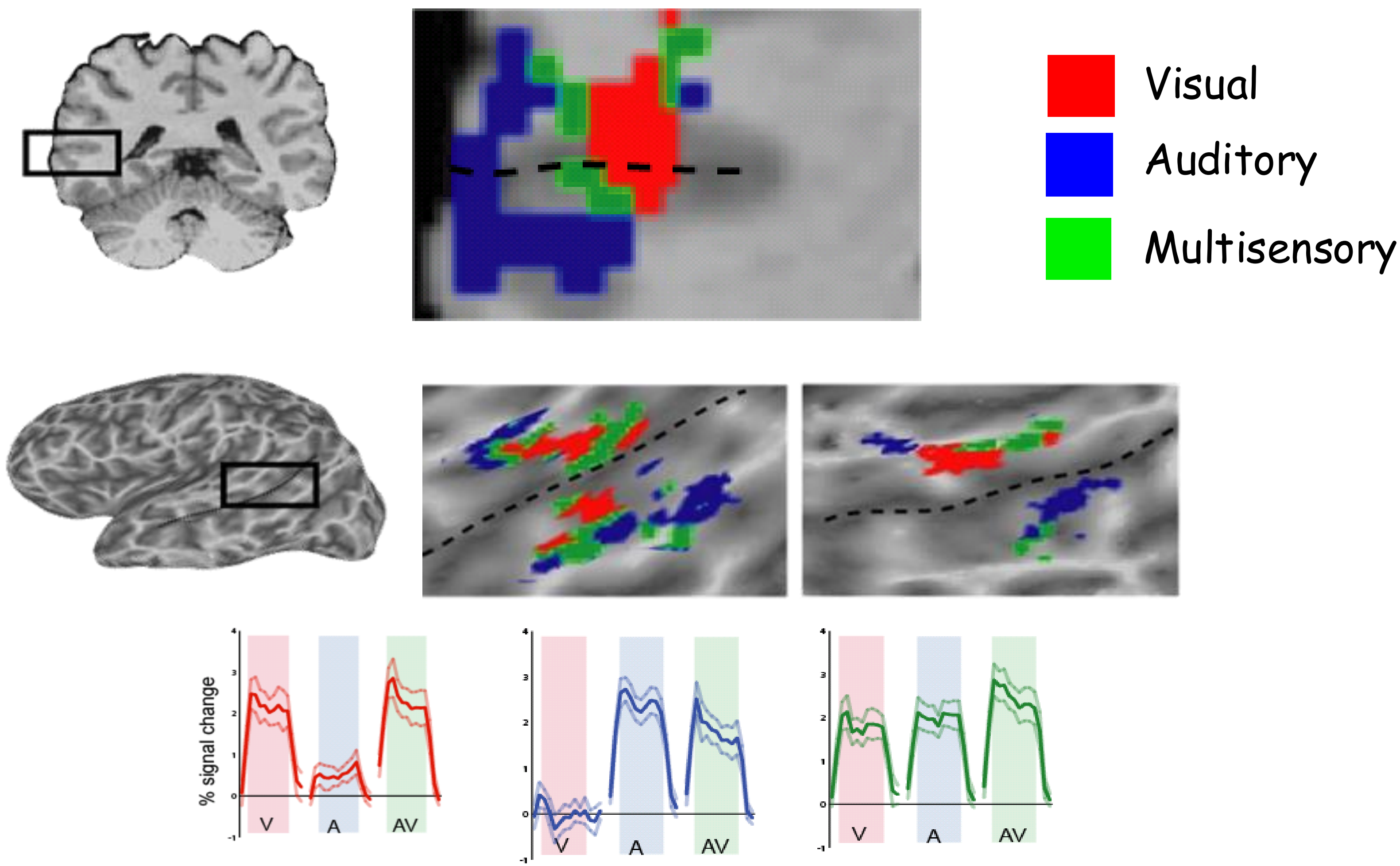
- Identical in size, orientation, and appearance to those obtained by optical imaging[1] and histology[3,4].

Menon et al.

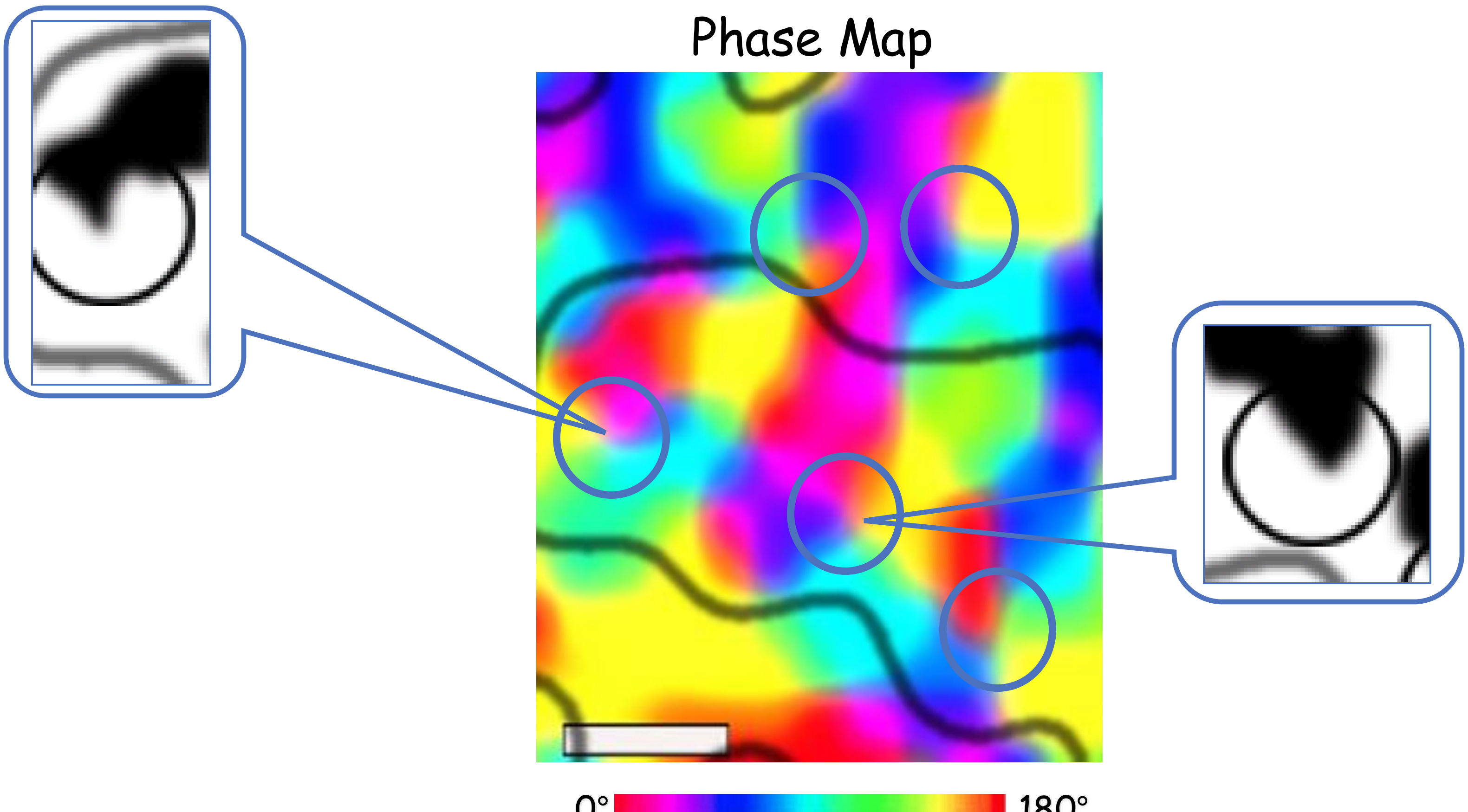
[1]Malonek D, Grinvald A. *Science* 272, 551-4 (1996).
[3]Horton JC, Hocking DR. *J Neurosci* 16, 7228-39 (1996).
[4]Horton JC, et al. *Arch Ophthalmol* 108, 1025-31 (1990).

Multi-sensory integration

M.S. Beauchamp et al.,

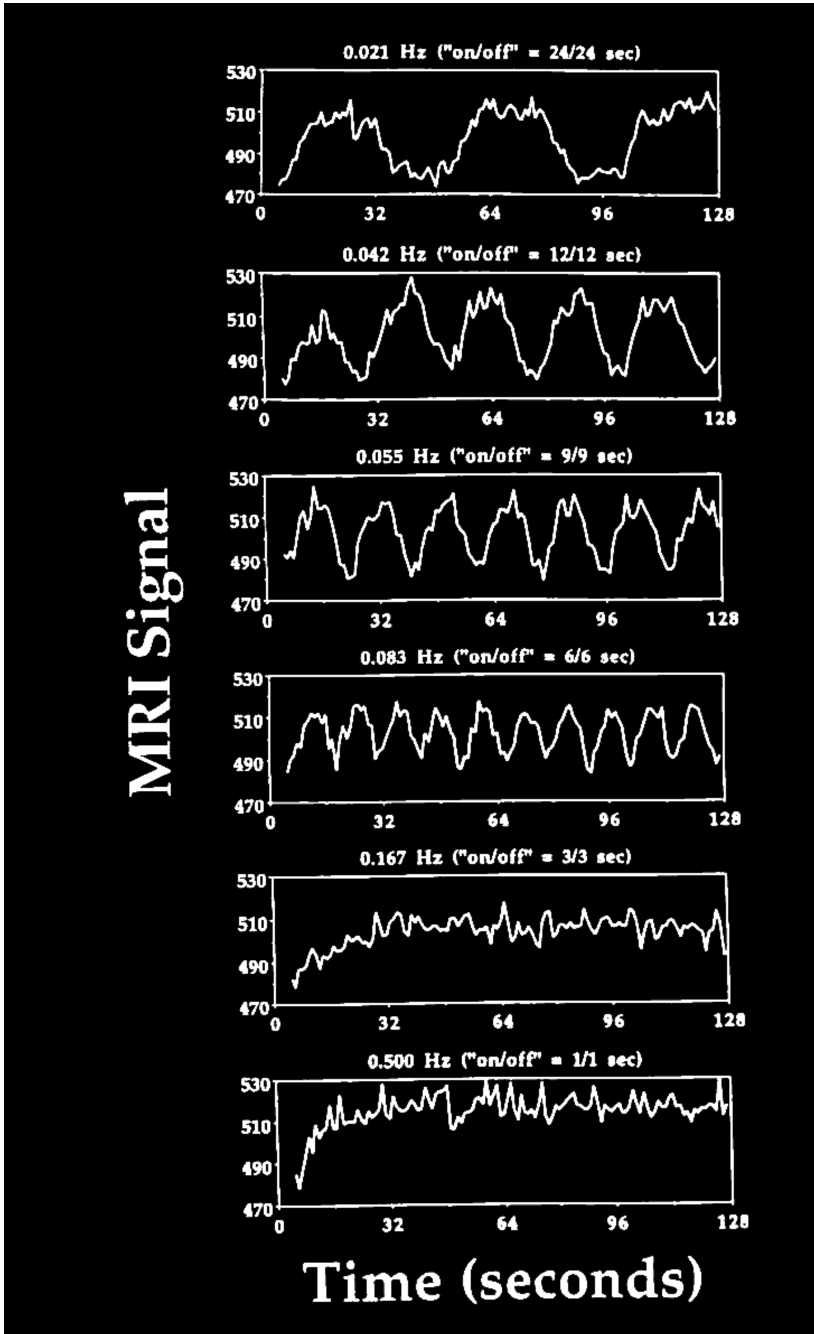


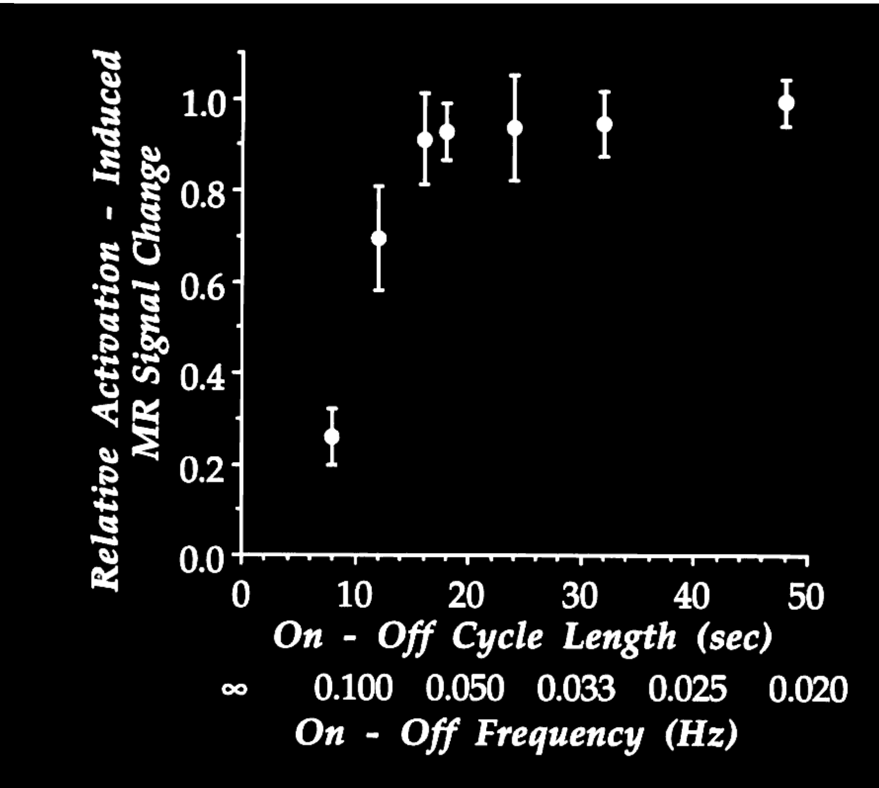
Orientation Columns in Human V1 as Revealed by fMRI at 7T



Yacoub, Ugurbil & Harel
University of Minnesota / CMRR
HBM 2006: Thursday, June 15, 2006 at 9:30

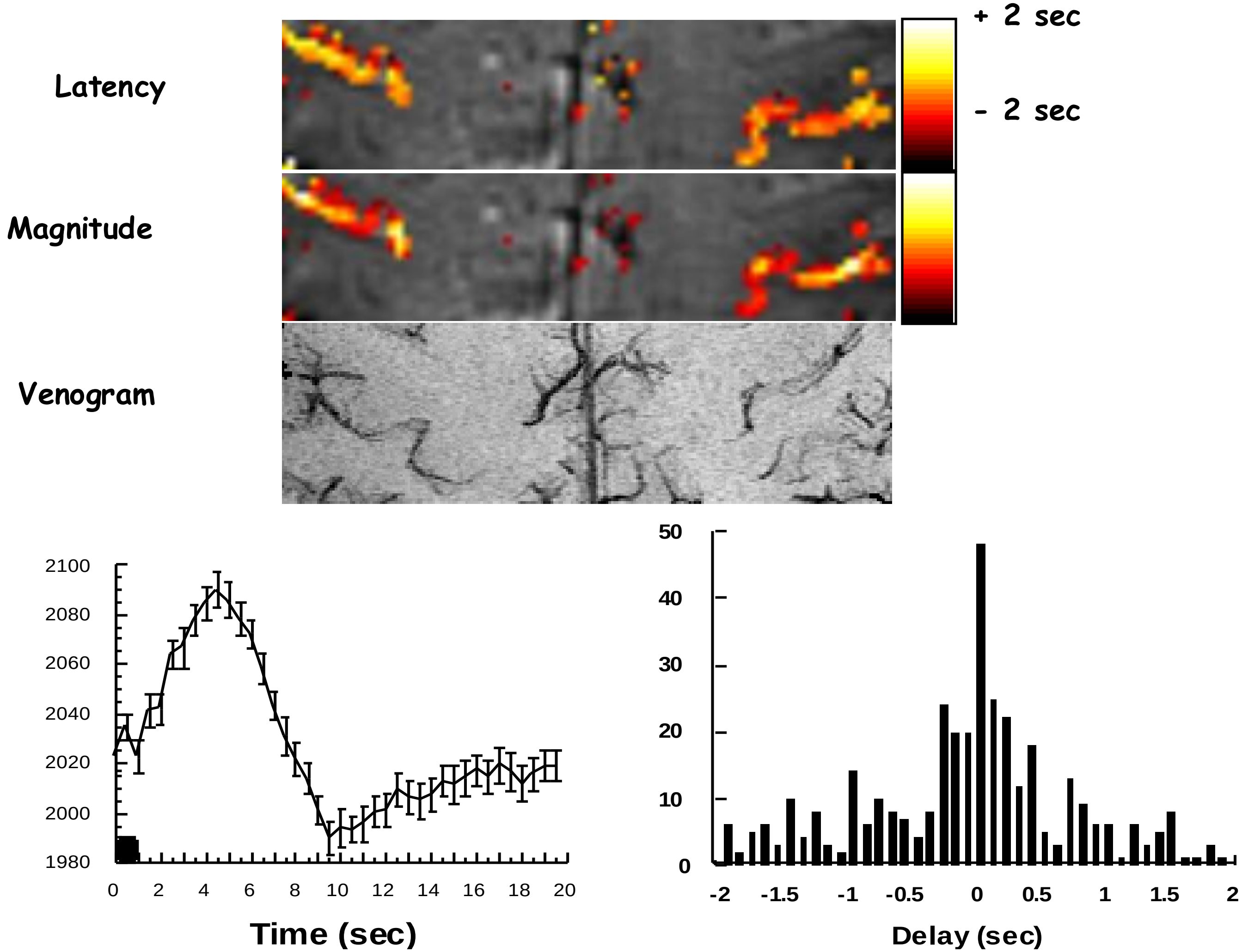
Scalebar = 0.5 mm





P. A. Bandettini, Functional MRI temporal resolution *in* "Functional MRI" (C. Moonen, and P. Bandettini., Eds.), p. 205-220, Springer - Verlag,. 1999.

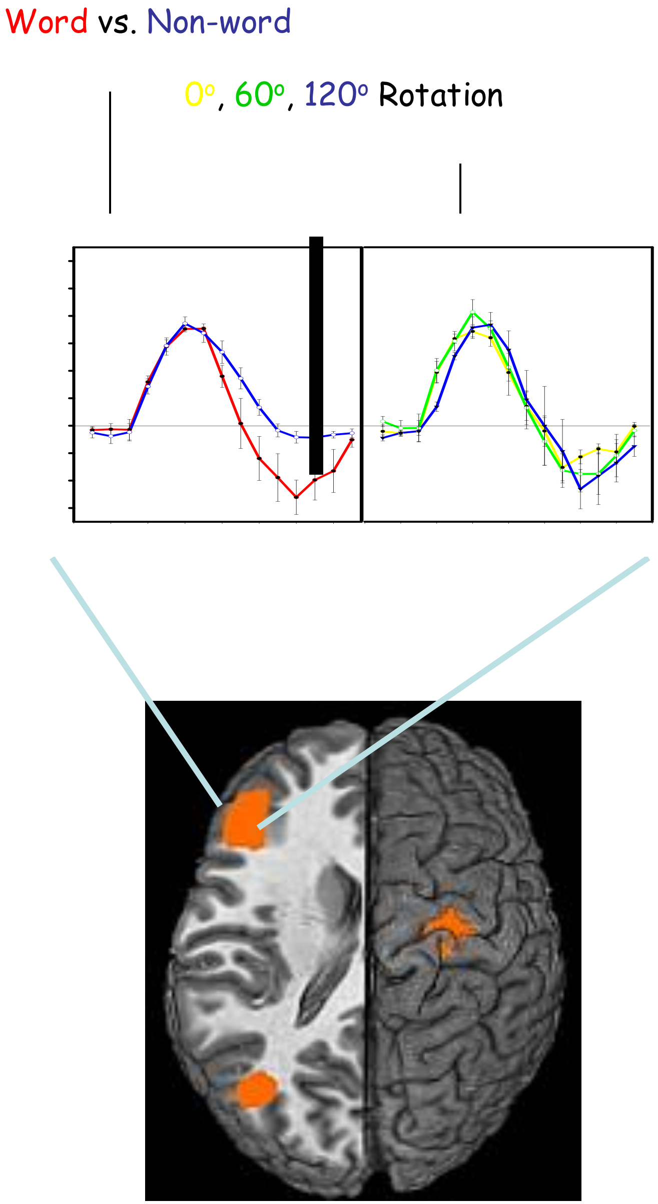
Latency Variation...



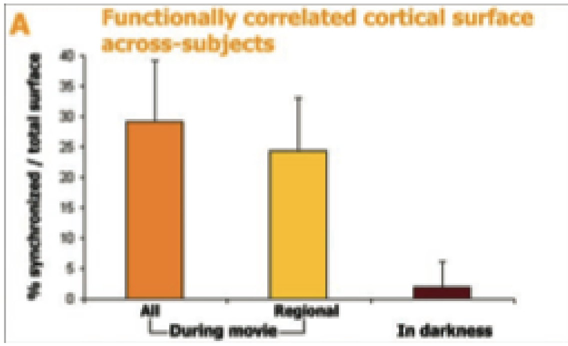
P. A. Bandettini, (1999) "Functional MRI" 205-220.

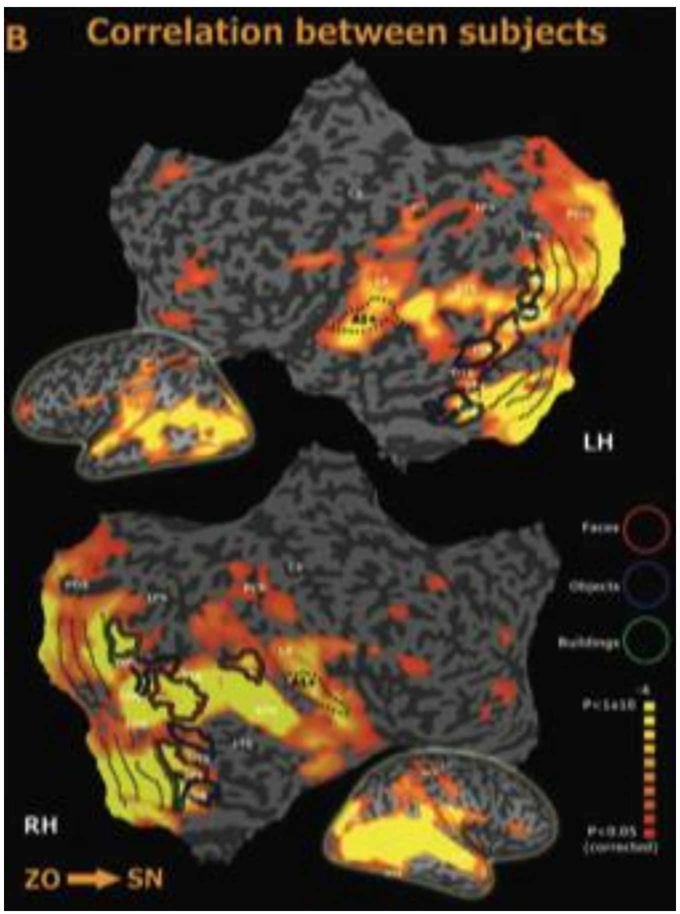
Lexical Delay

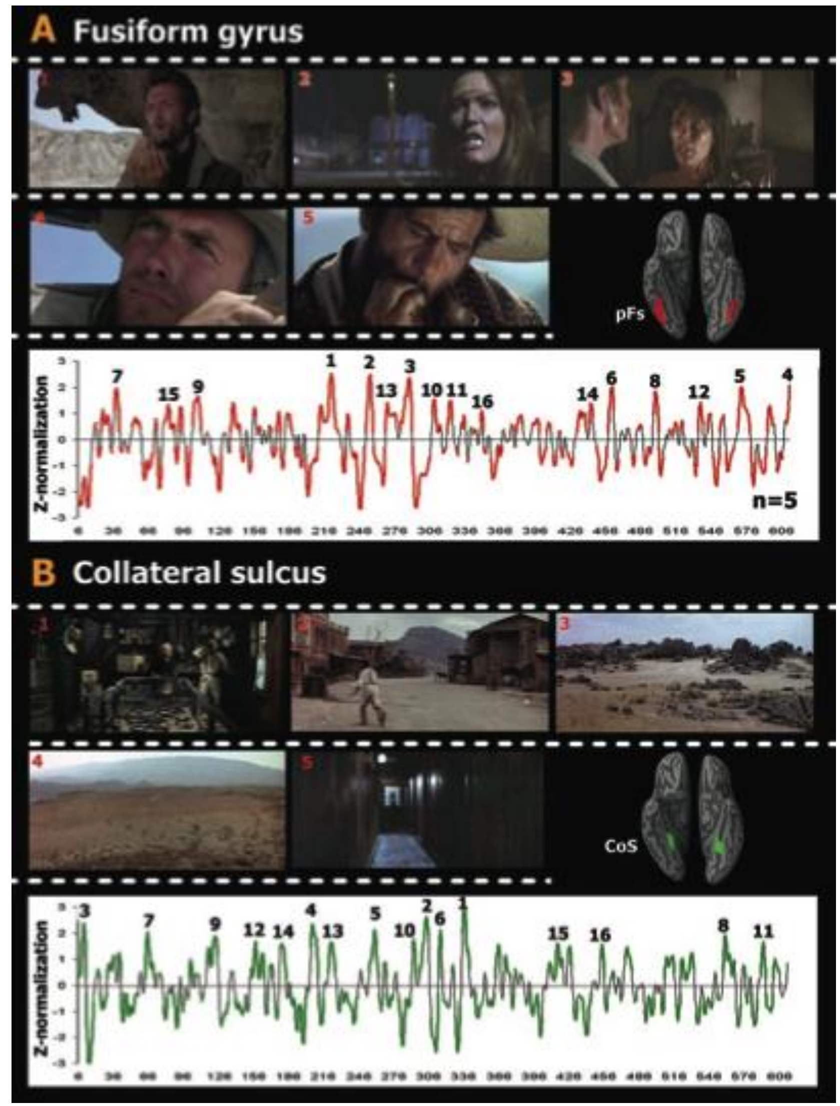
Rotational Delay	Words	Non-Words	Mean Reaction Time
0°	smudge	dierts	823 ms
60°	frolic	cuhlos	891 ms
120°	slouch	gedmus	1446 ms
Mean Reaction Time	986 ms	1219 ms	



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

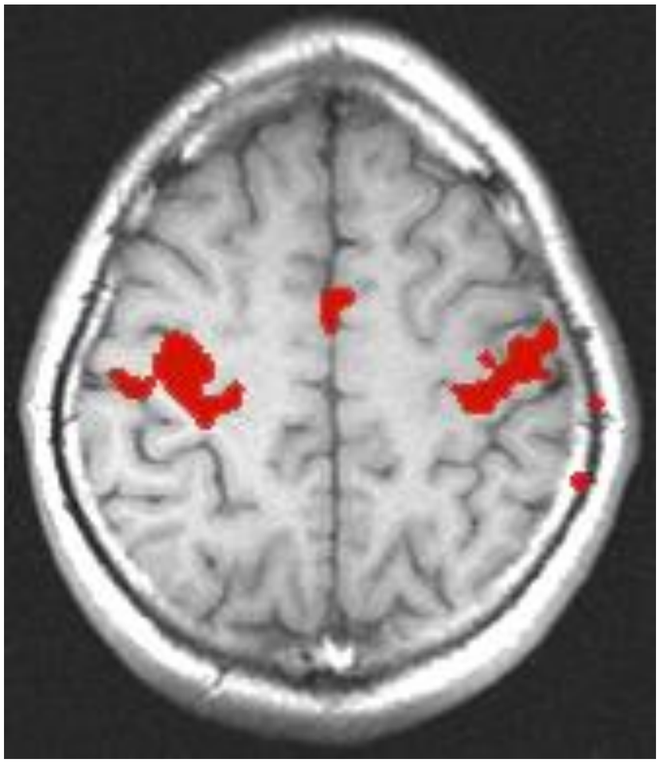




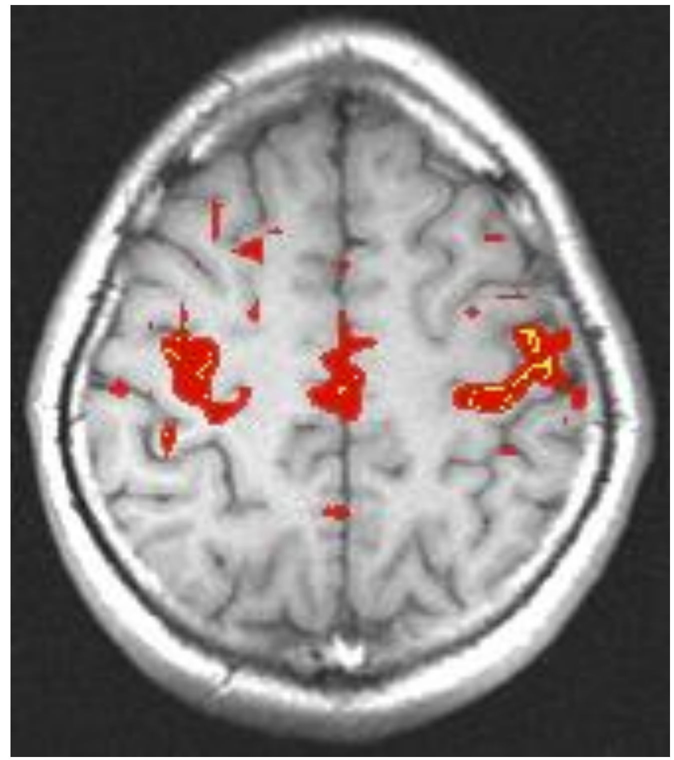


Hasson, et al (2004), Science, 303, 1634-1640

Resting State Correlations



Activation:
correlation with reference function



Rest:
seed voxel in motor cortex

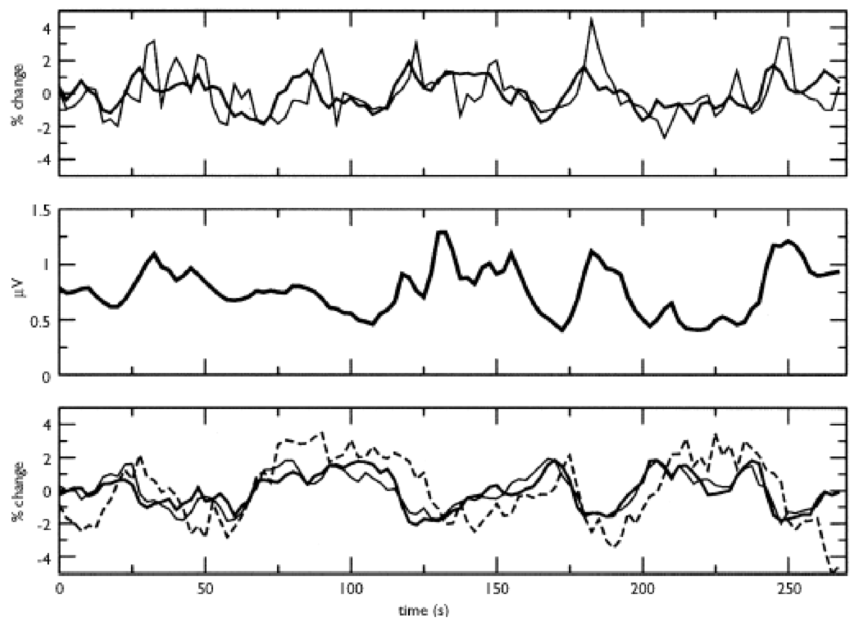
B. Biswal *et al.*, MRM, 34:537 (1995)

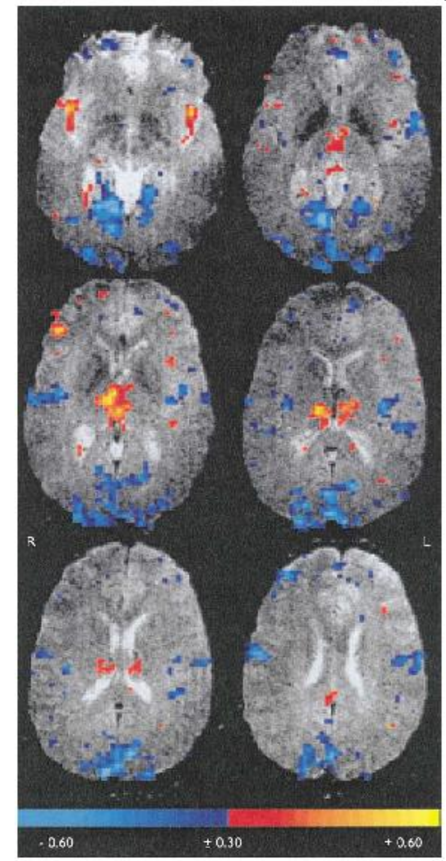
BOLD correlated with 10 Hz power during "Rest"

Positive

10 Hz power

Negative

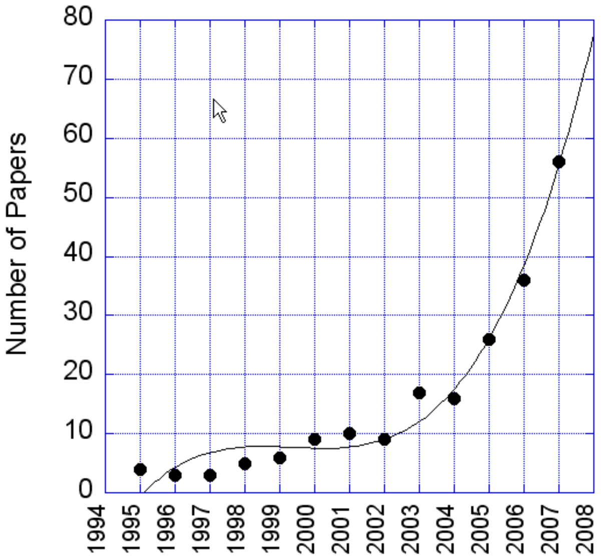


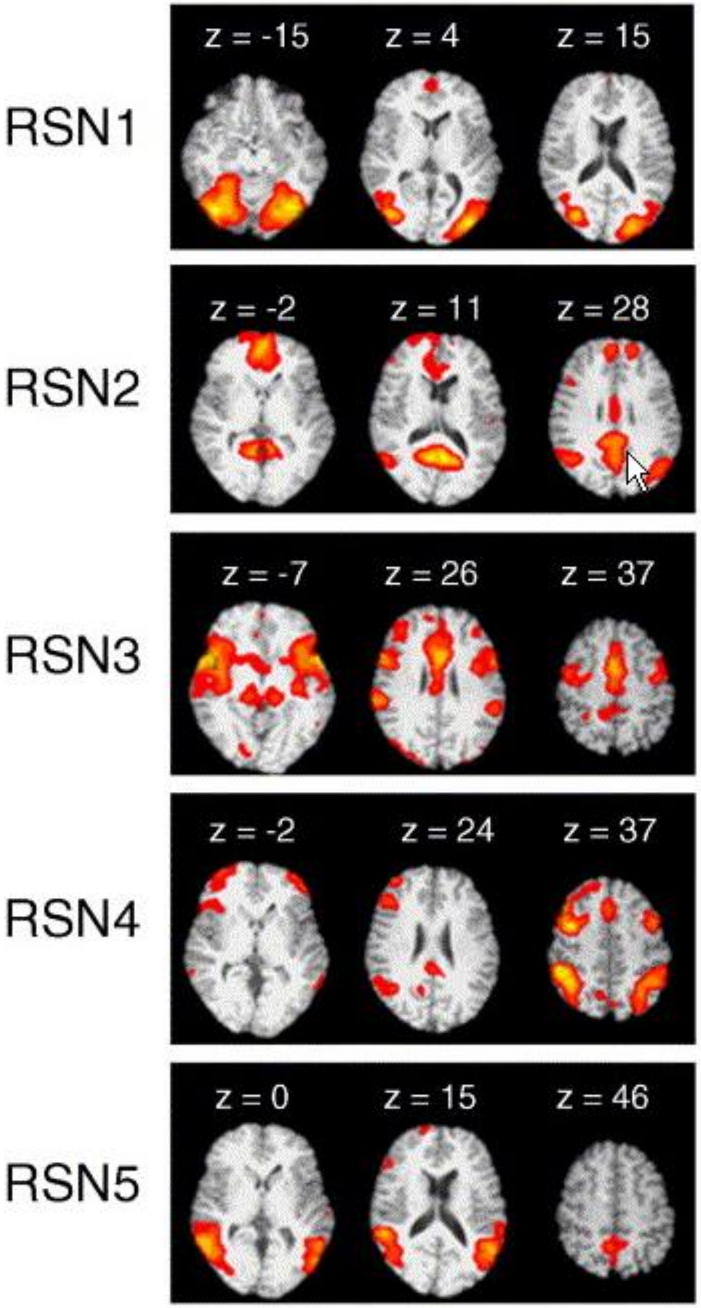


Goldman, et al (2002), Neuroreport

Resting state networks identified with ICA

M. DeLuca, C.F. Beckmann, N. De Stefano, P.M. Matthews, S.M. Smith, fMRI resting state networks define distinct modes of long-distance interactions in the human brain. NeuroImage, 29, 1359-1367





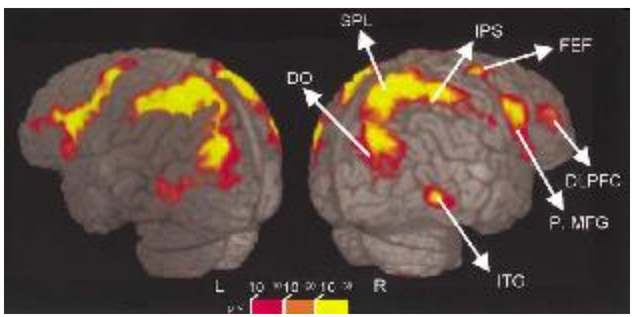
"Brain Reading"

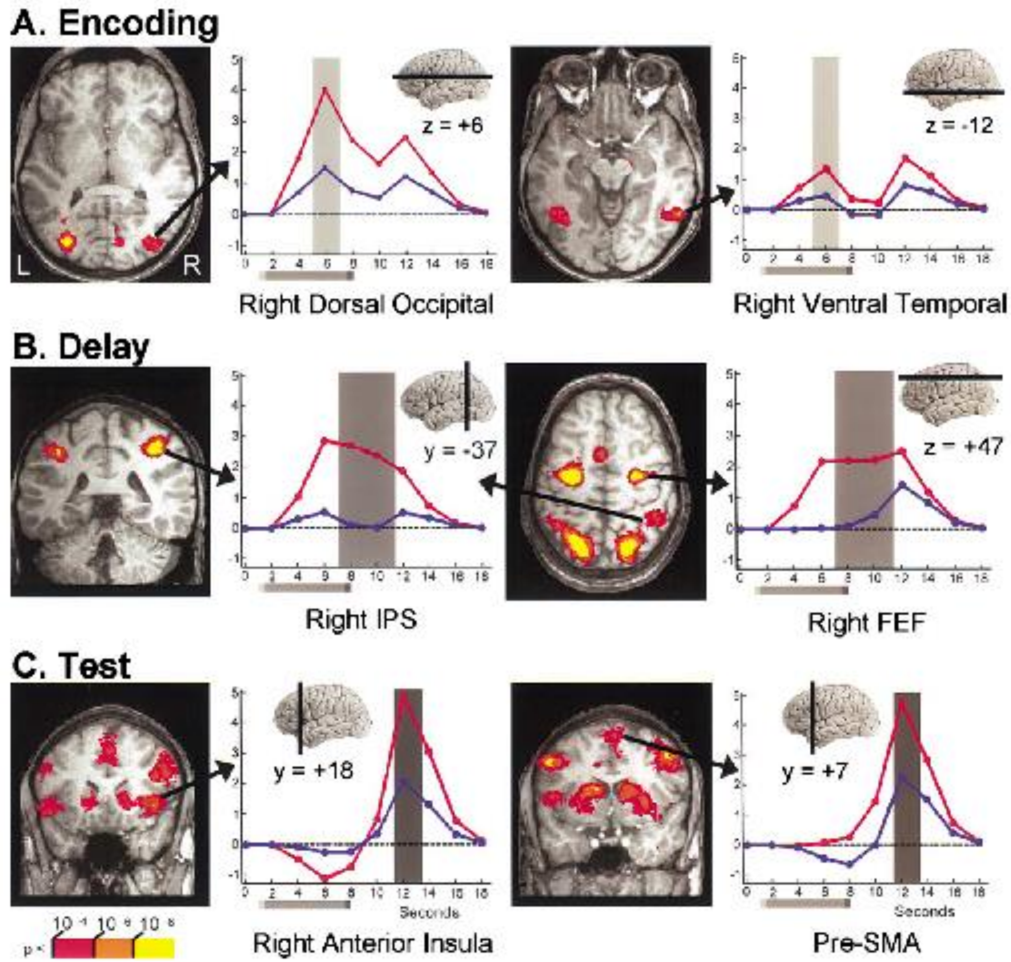
Mapping ⟷ "Reading"

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

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

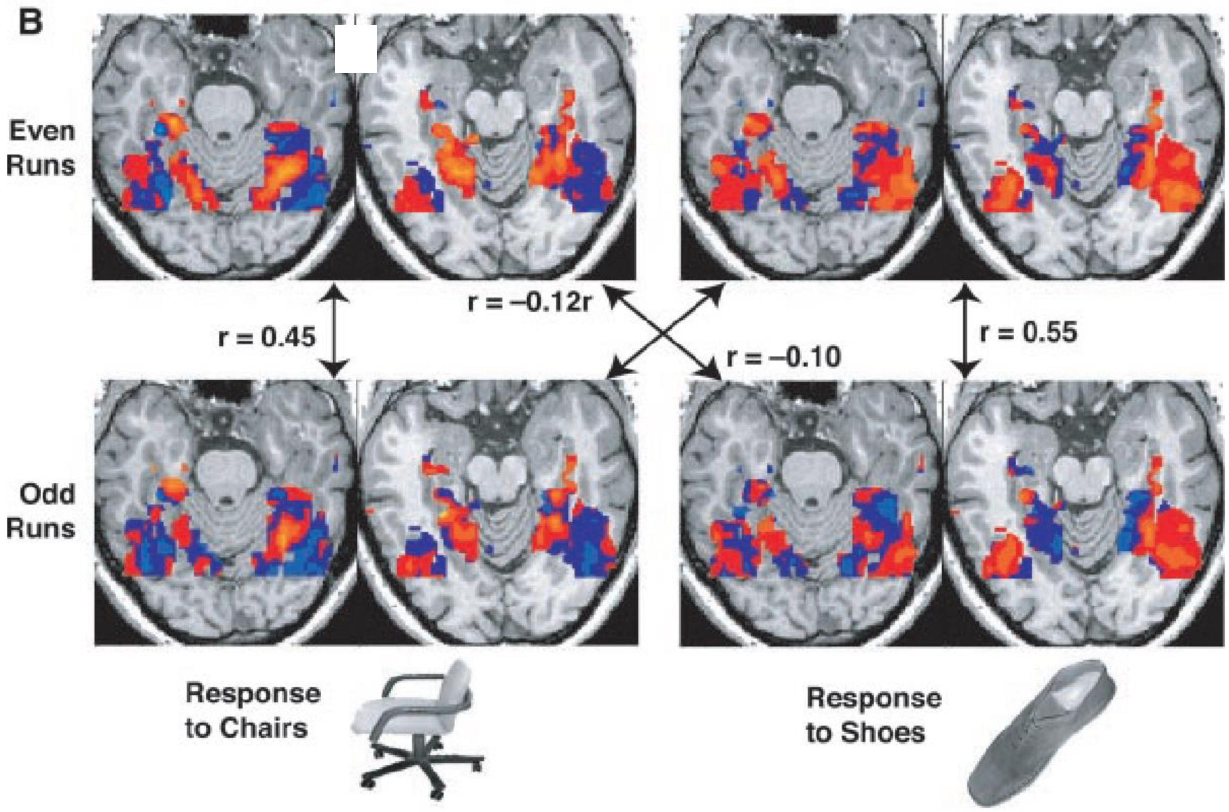
Luiz Pessoa,[1] Eva Gutierrez, Peter A. Bandettini, and Leslie G. Ungerleider
Laboratory of Brain and Cognition
National Institute of Mental Health
National Institutes of Health
Bethesda, Maryland 20892





Ventral temporal category representations

Object categories are associated with distributed representations in ventral temporal cortex



Haxby et al. Science, 2001

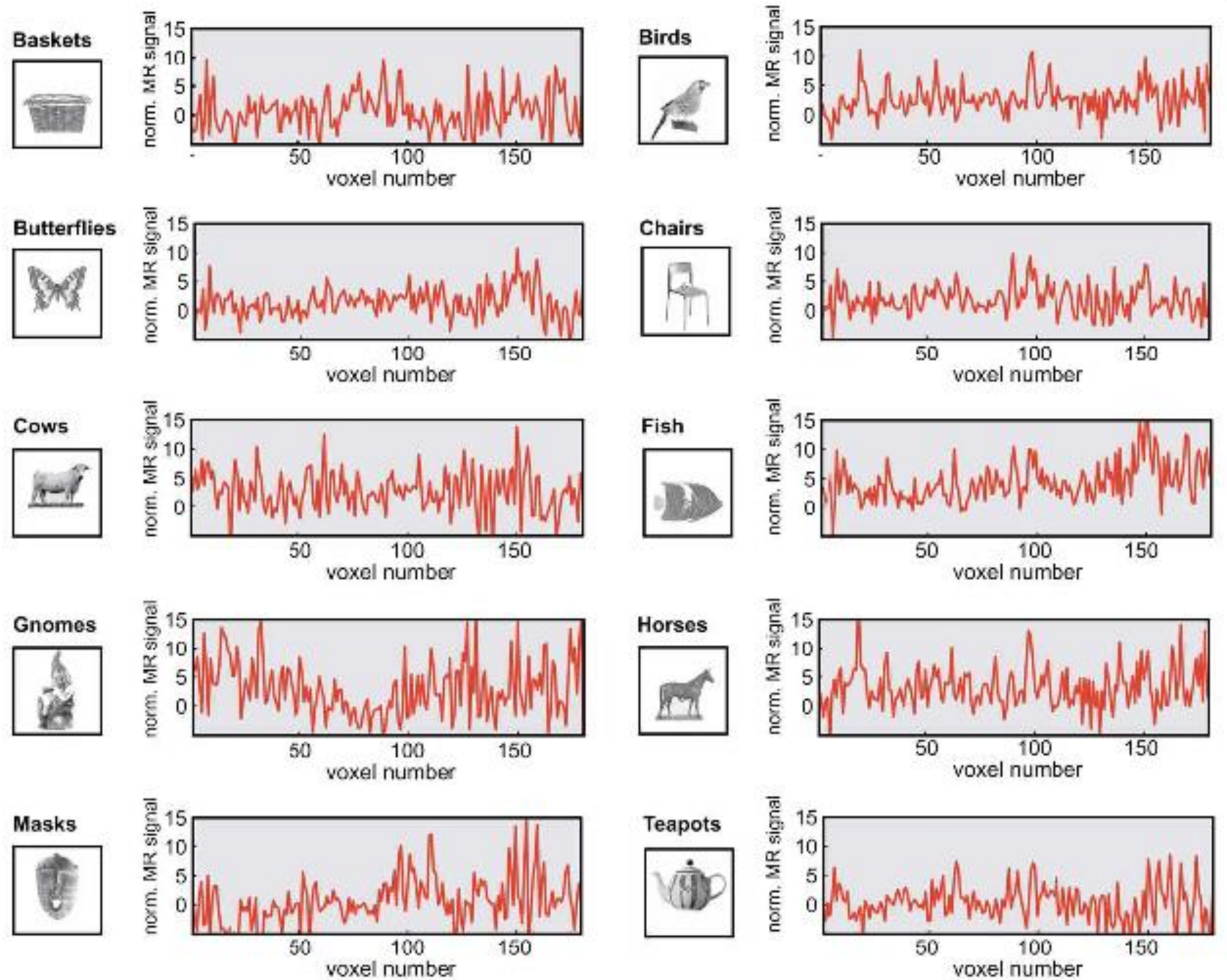
Functional magnetic resonance imaging (fMRI) "brain reading": detecting and classifying distributed patterns of fMRI activity in human visual cortex

David D. Cox[a,b,*] and Robert L. Savoy[a,b,c]

[a] Rowland Institute for Science, Cambridge, MA 02142, USA
[b] Athinoula A. Martinos Center for Structural and Functional Biomedical Imaging, Charlestown, MA 02129, USA
[c] HyperVision, Inc., P.O. Box 158, Lexington, MA 02420, USA

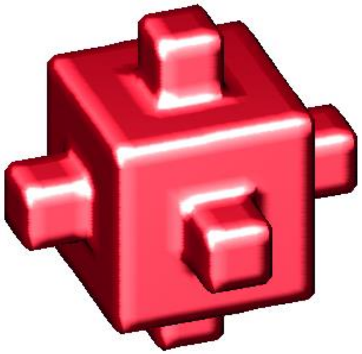
Received 15 July 2002; accepted 10 December 2002

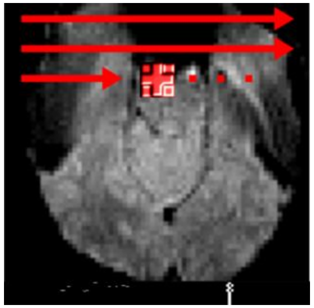
NEUROIMAGE 19 (2): 261-270 Part 1 JUN 2003

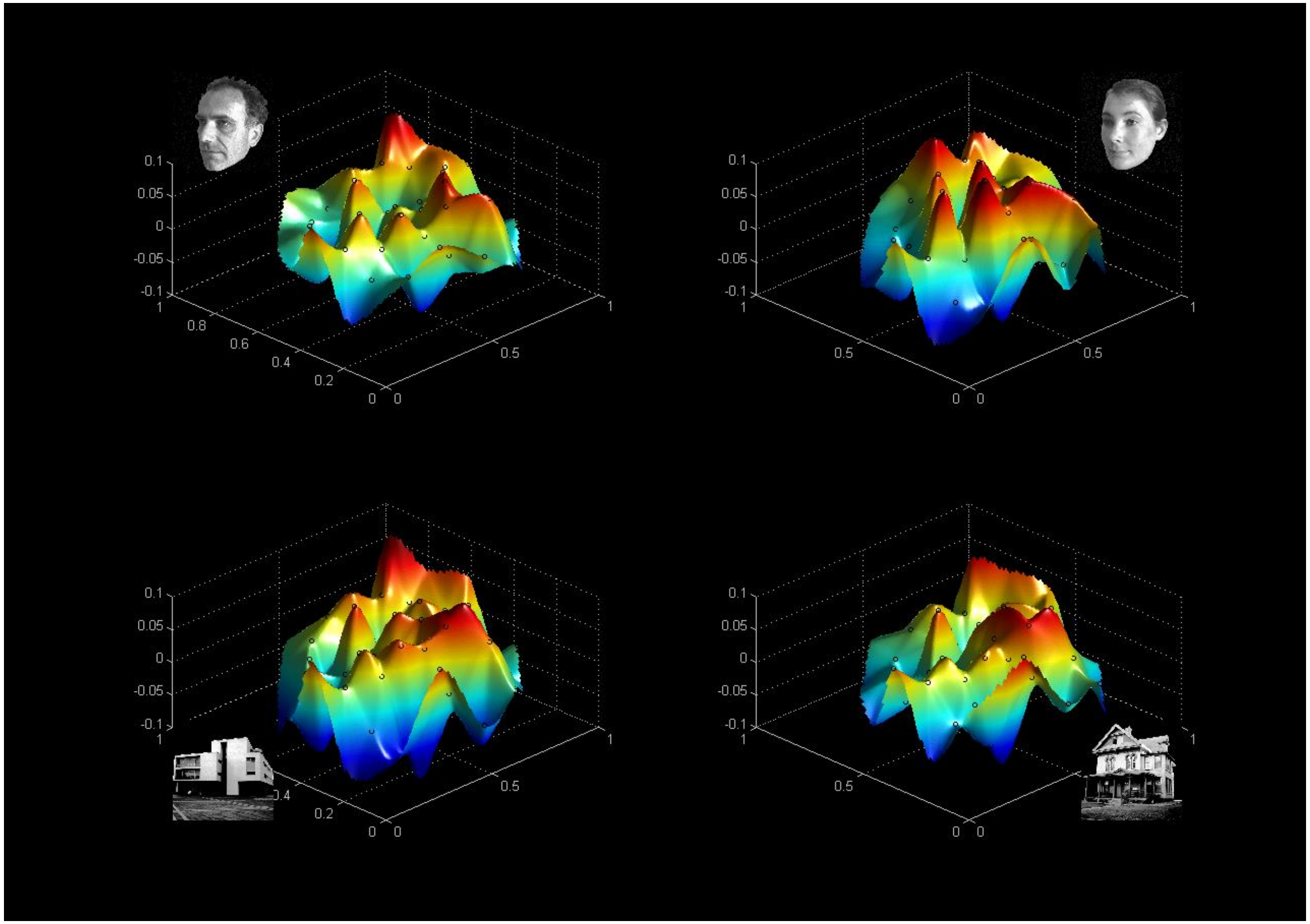


"searchlight" ROI

Mulitvariate analysis







N. Kriegeskorte, R. Goebel, P. Bandettini, *Proc. Nat'l. Acad. Sci. USA*, 103, 3863-3868 (2006)

◆ 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]

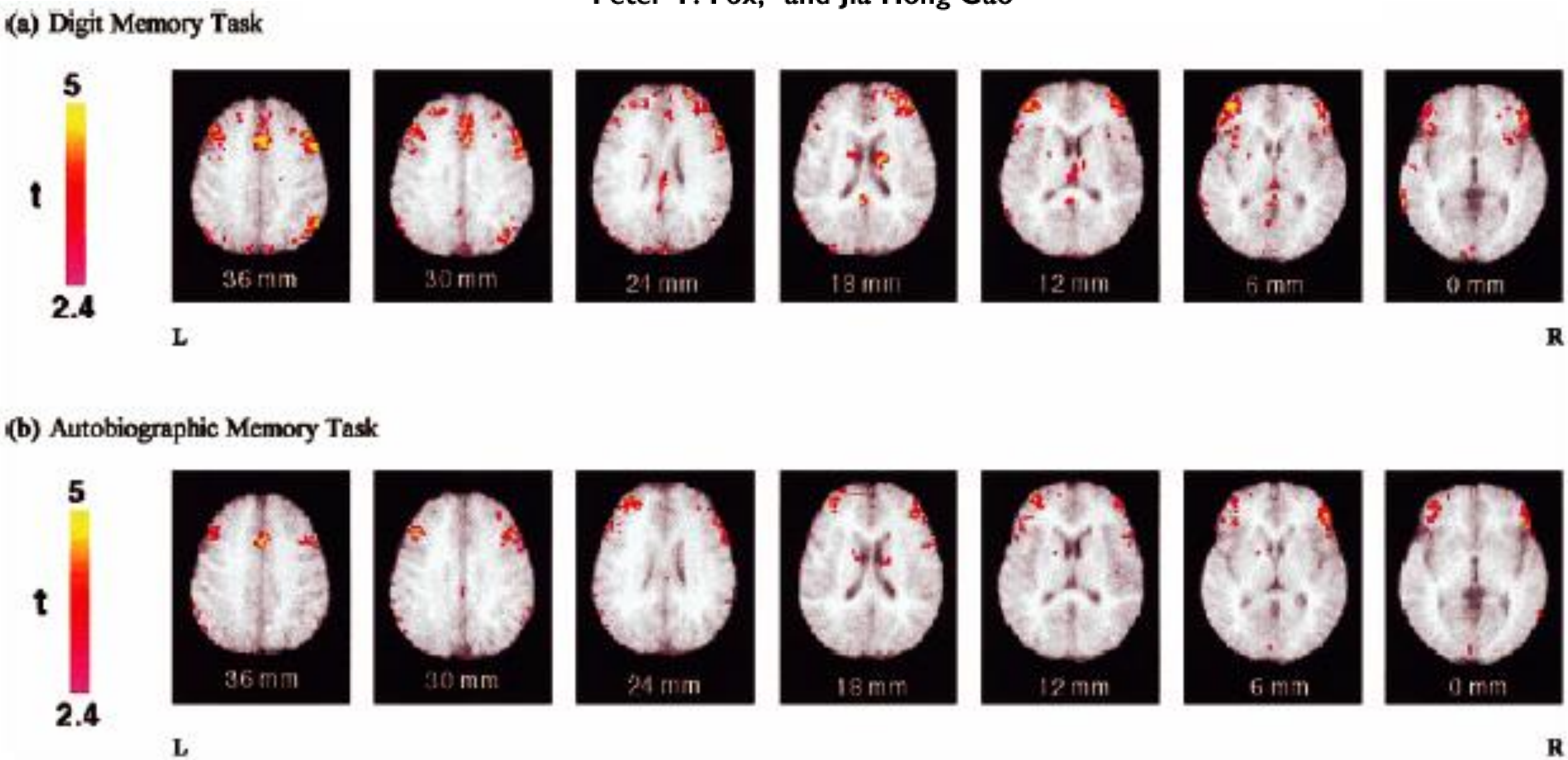
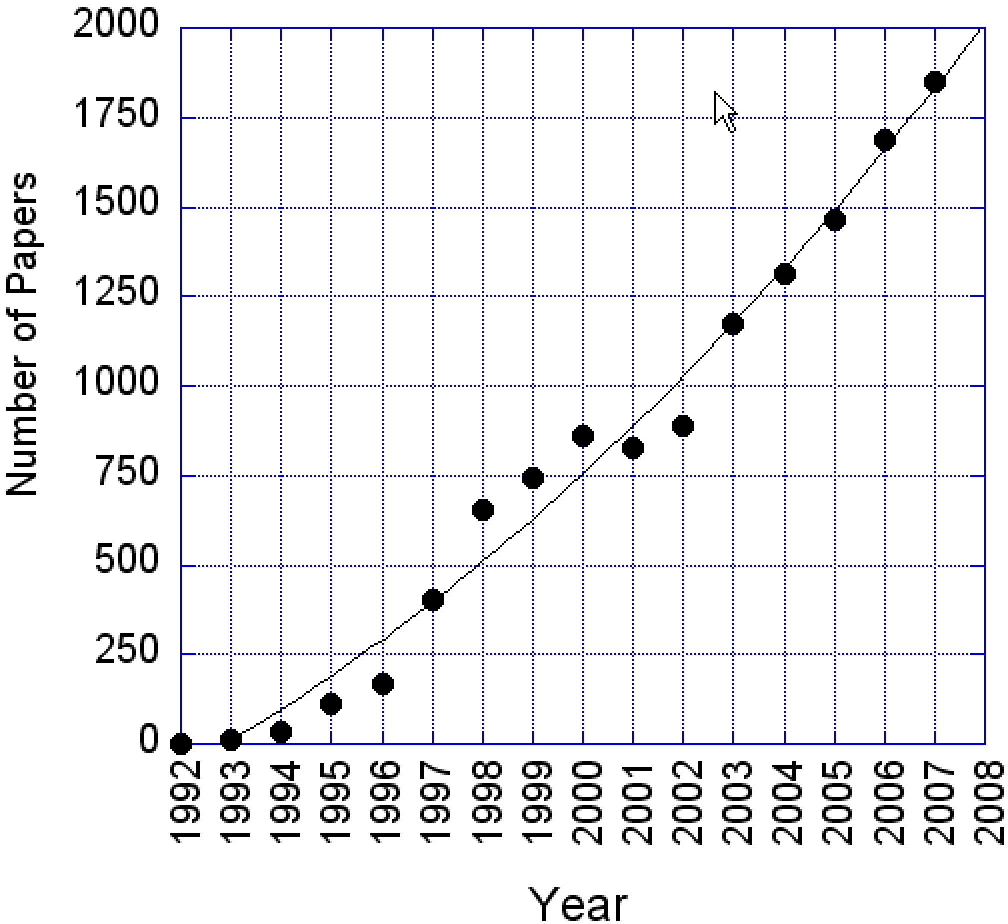


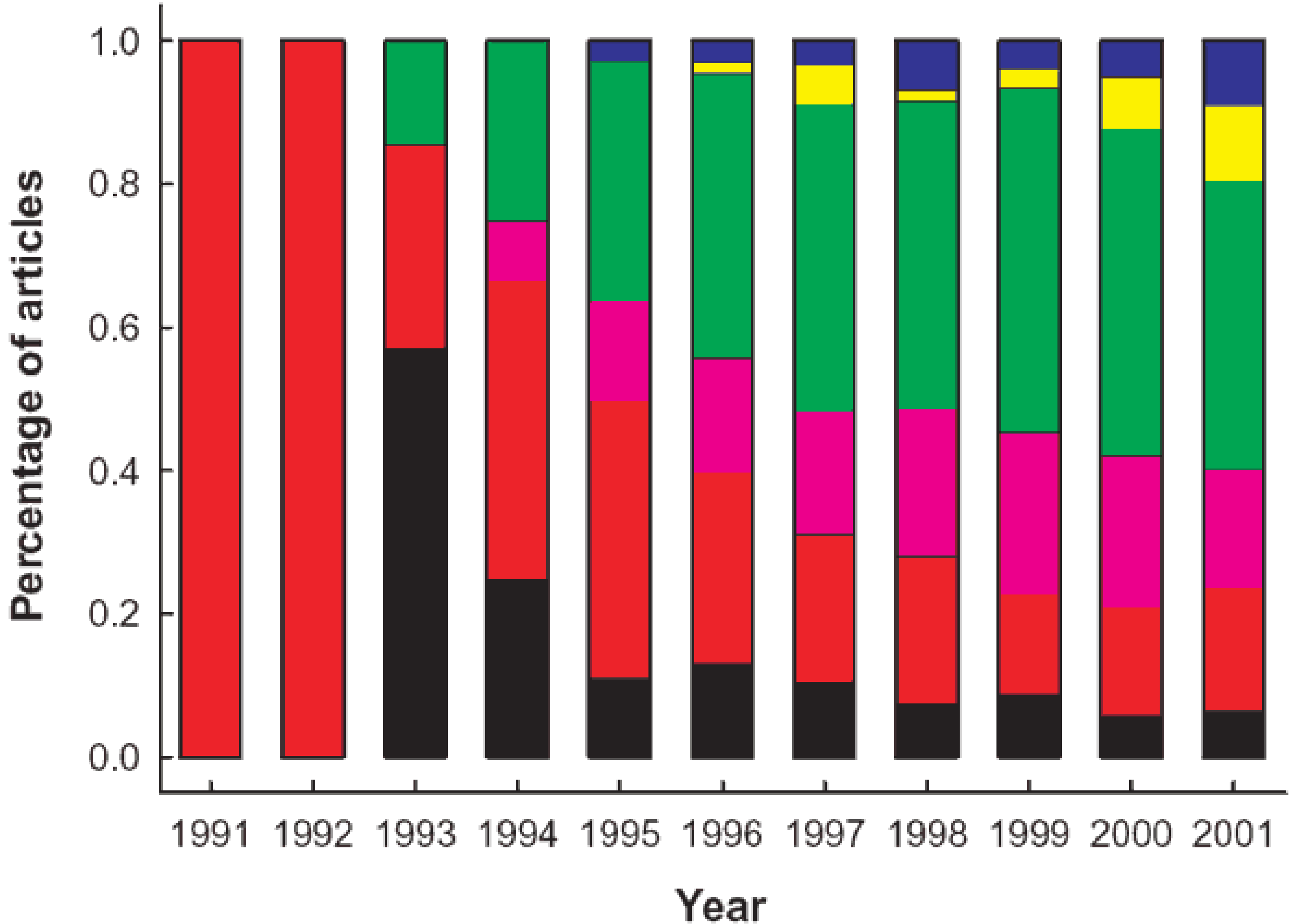
Figure 1.

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.

Scopus: Articles or Reviews Published per Year

"fMRI" or "functional MRI"





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

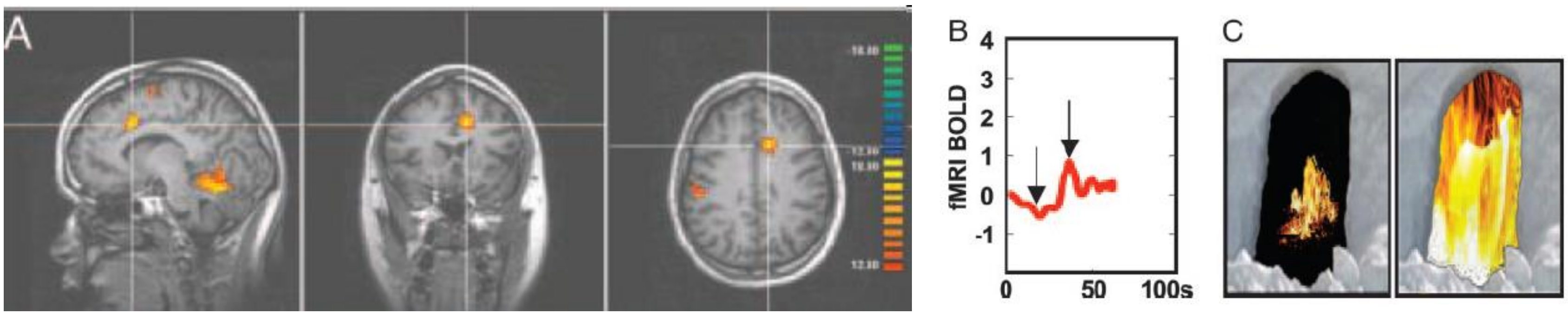
J. Illes, M. P. Kirschen, J. D. E. Gabrielli,
Nature Neuroscience, 6 (3)m p.205

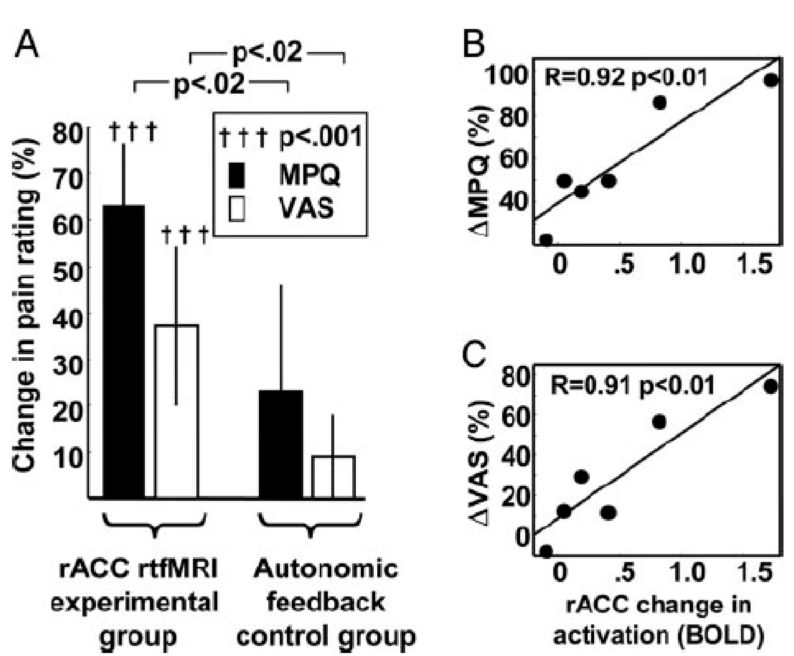
Topics Studied with fMRI at the NIH

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

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)

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

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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