Functional MRI: Current and Potential Capabilities

Peter A. Bandettini, Ph.D.

Section on Functional Imaging Methods

http://fim.nimh.nih.gov

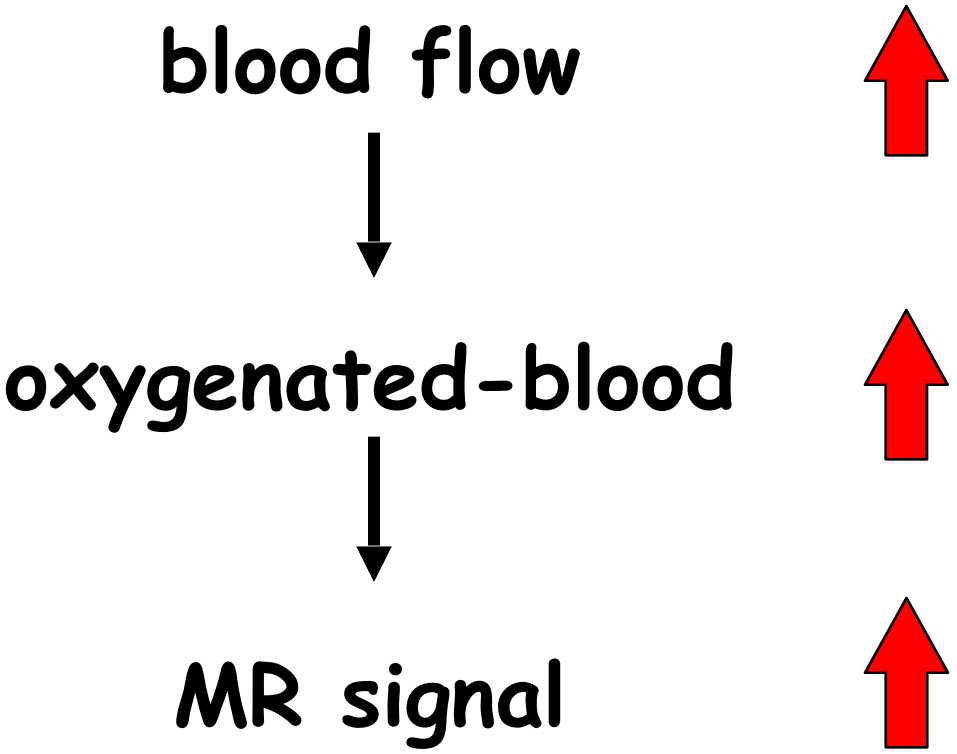
Laboratory of Brain and Cognition

&

Functional MRI Facility

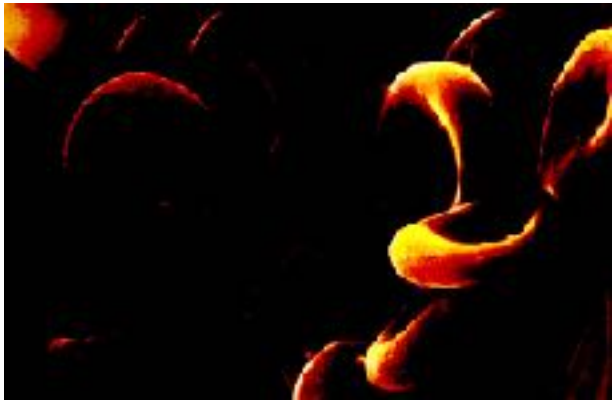
http://fmrif.nimh.nih.gov

BOLD (Blood Oxygen Level Dependent) Contrast



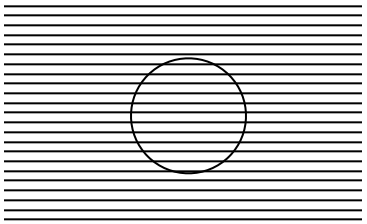
Basis of BOLD Contrast

Oxygenated and deoxygenated red blood cells have different magnetic properties

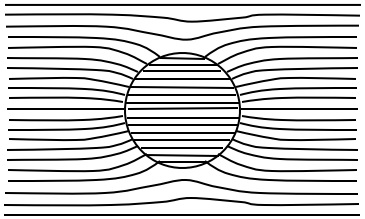


red blood cells

oxygenated



deoxygenated

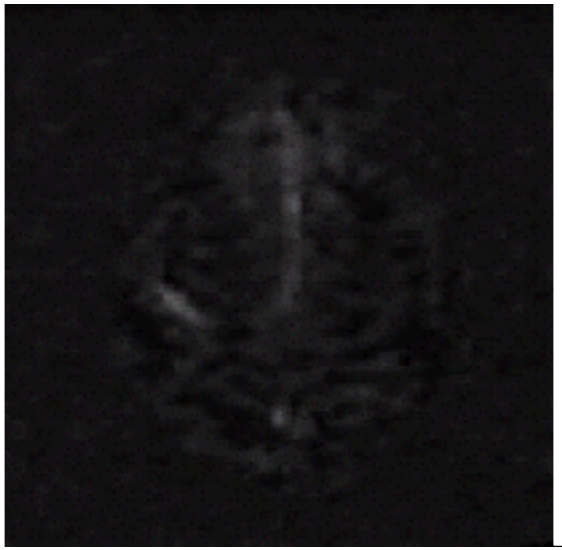


L. Pauling, C. D. Coryell, Proc.Natl. Acad. Sci. USA 22, 210-216, **1936**.

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 Contrast Imaging

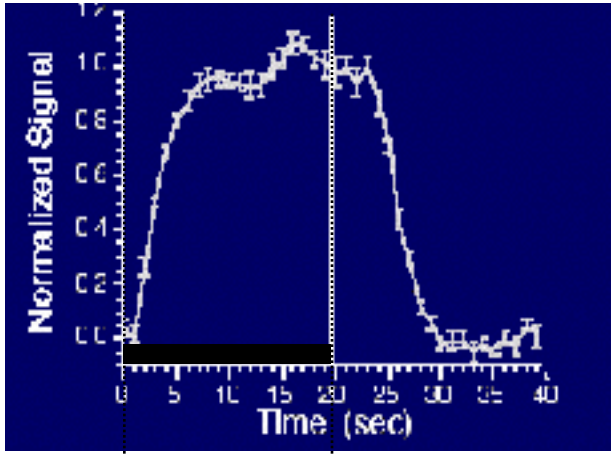


•K. K. Kwong, et al, (1992) "Dynamic magnetic resonance imaging of human brain activity during primary sensory stimulation." Proc. Natl. Acad. Sci. USA. 89, 5675-5679.

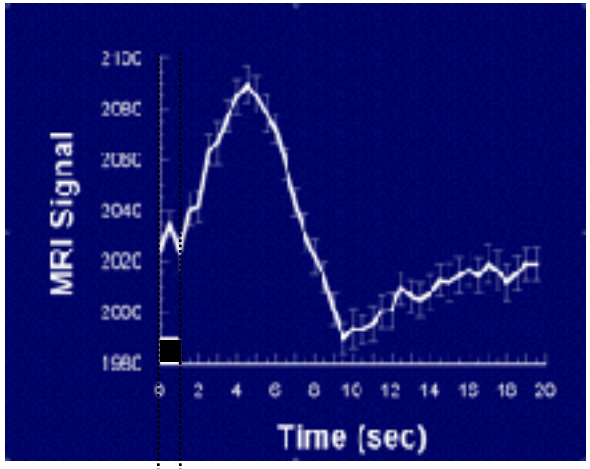
•S. Ogawa, et al., (1992) "Intrinsic signal changes accompanying sensory stimulation: functional brain mapping with magnetic resonance imaging. Proc. Natl. Acad. Sci. USA." 89, 5951-5955.

•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.

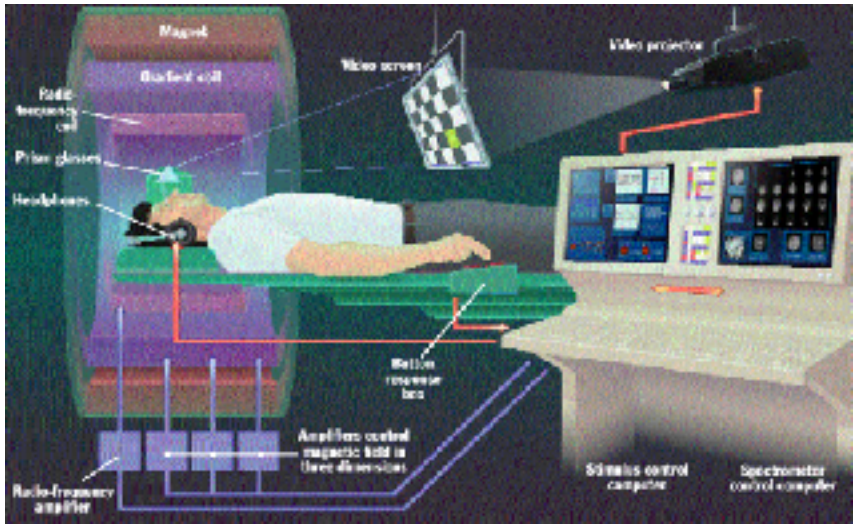


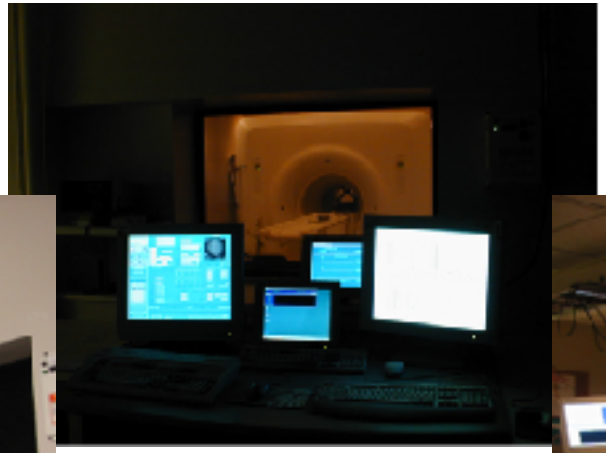
task



task

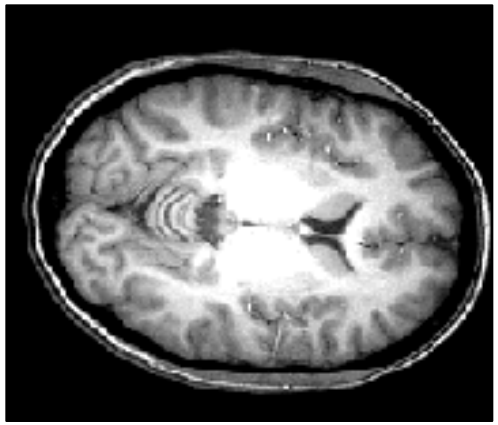
fMRI Setup


Magnet
Video screen
Video projector
Prism glasses
Headphones
Amplifies control magnetic field in three dimensions
Radio-frequency amplifier
Stimulus control computer
Spectrometer control computer



MRI vs. fMRI

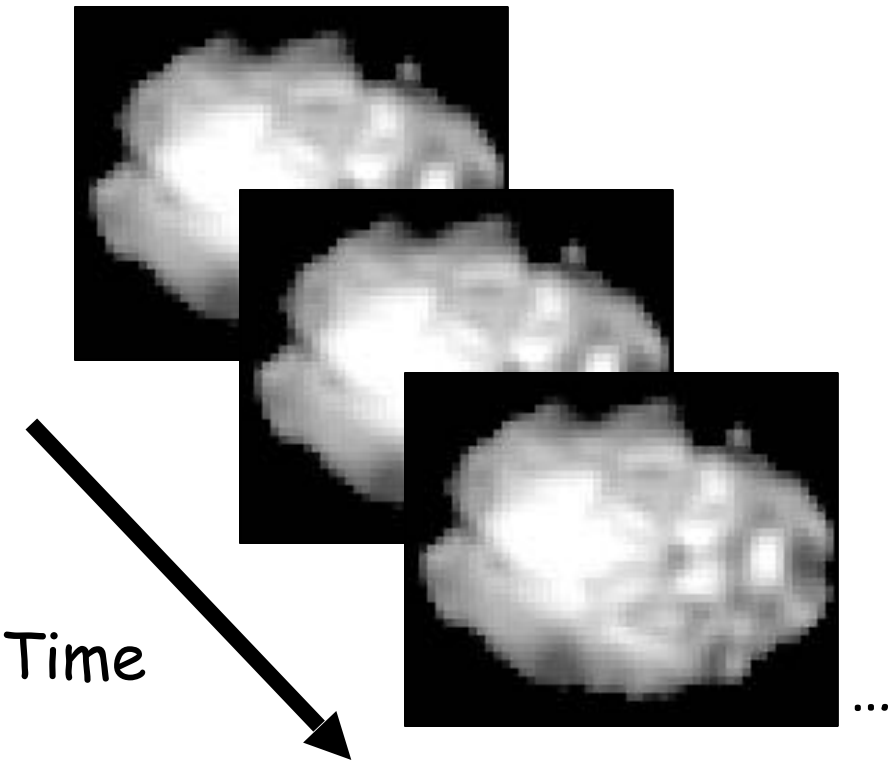
MRI



one image

high resolution
(1 mm or less)

fMRI

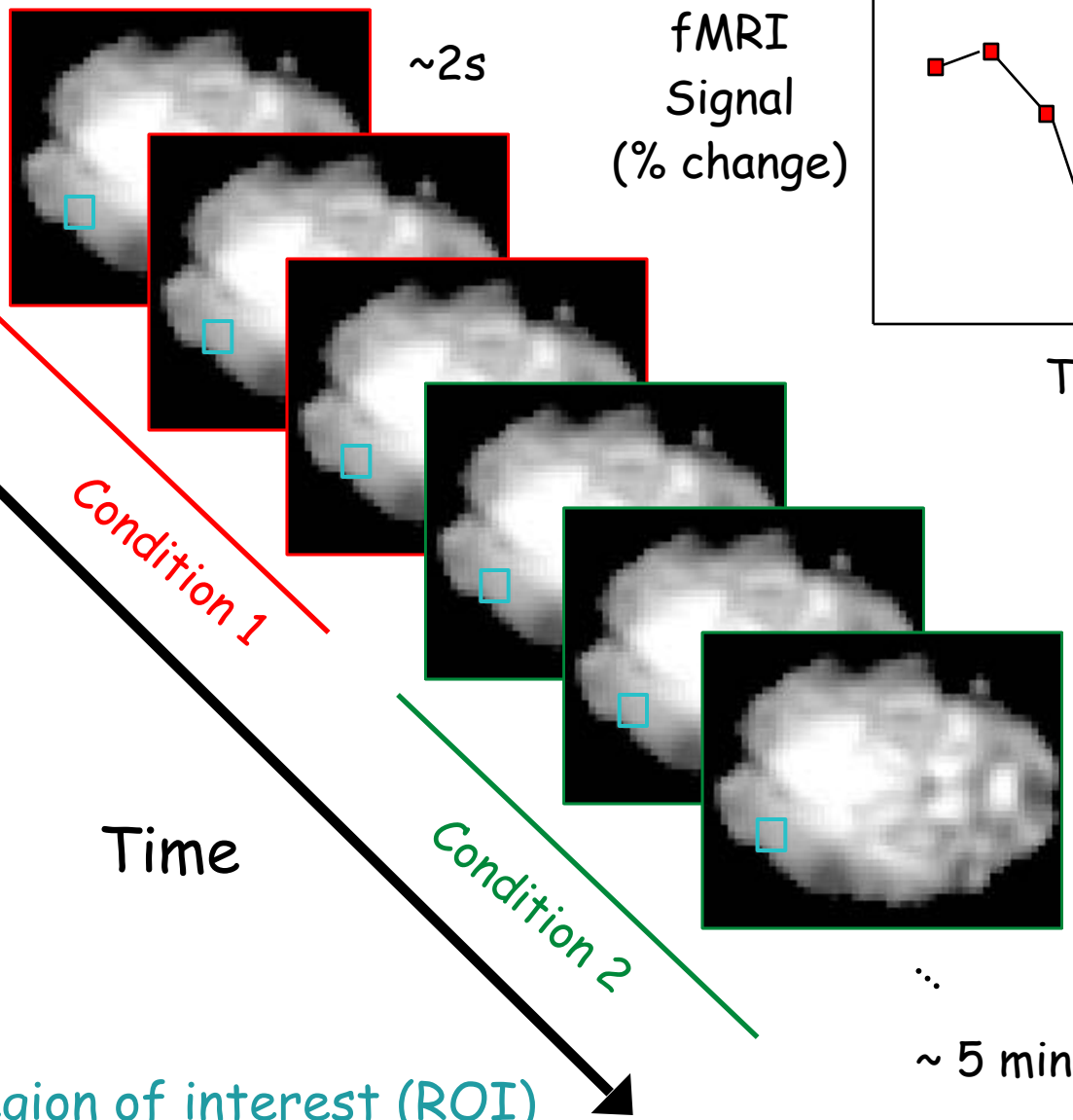


many images
(e.g., every 2 sec for 5 mins)

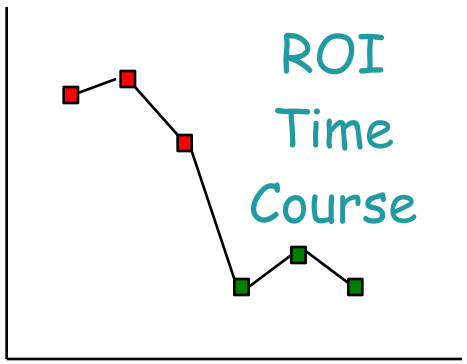
low resolution
(1.5 to 4 mm)

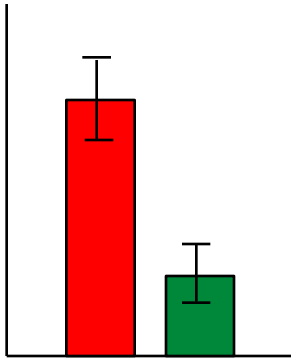
Activation Statistics

Functional images



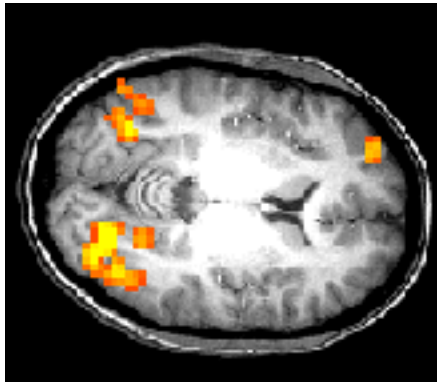
fMRI Signal (% change)

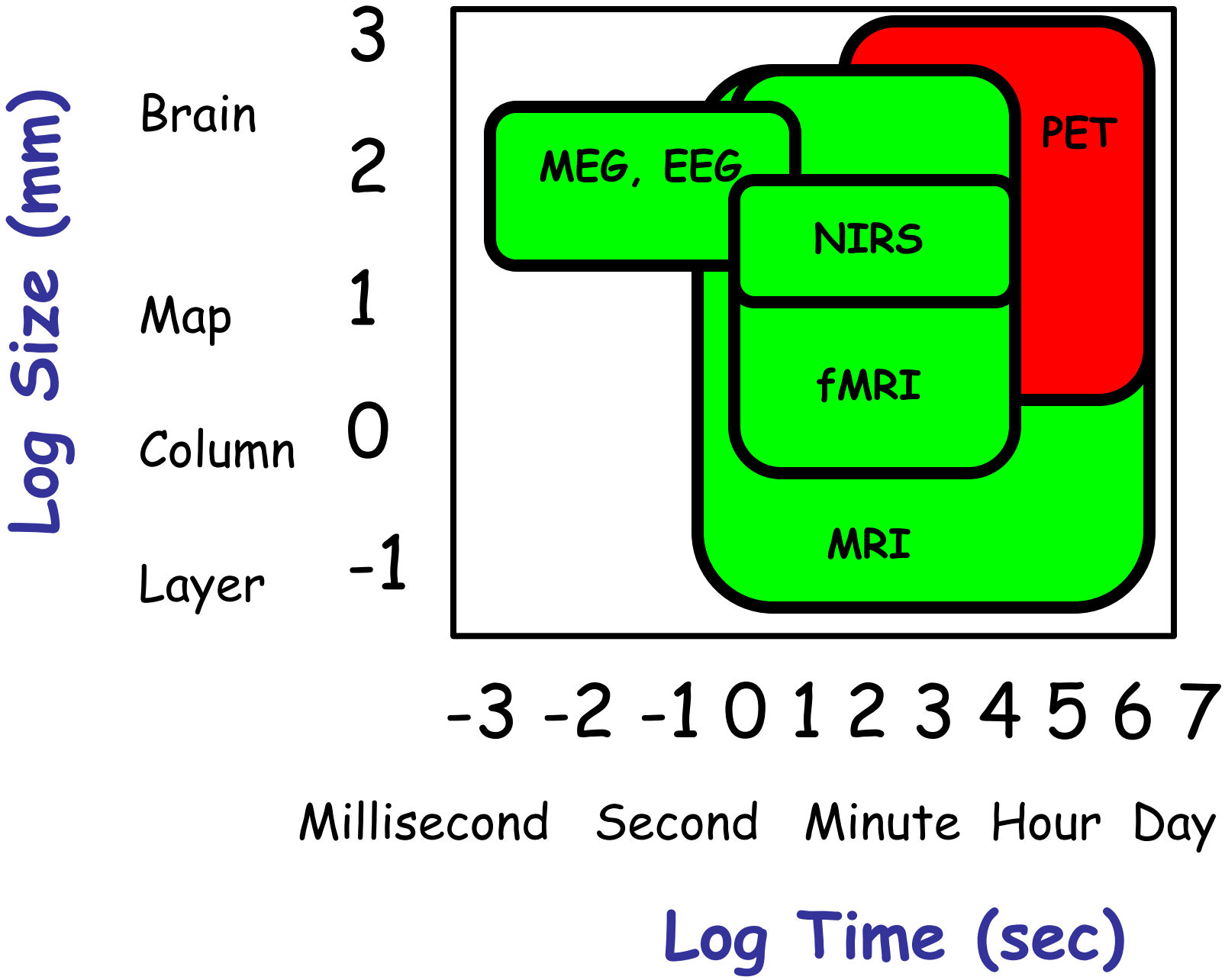




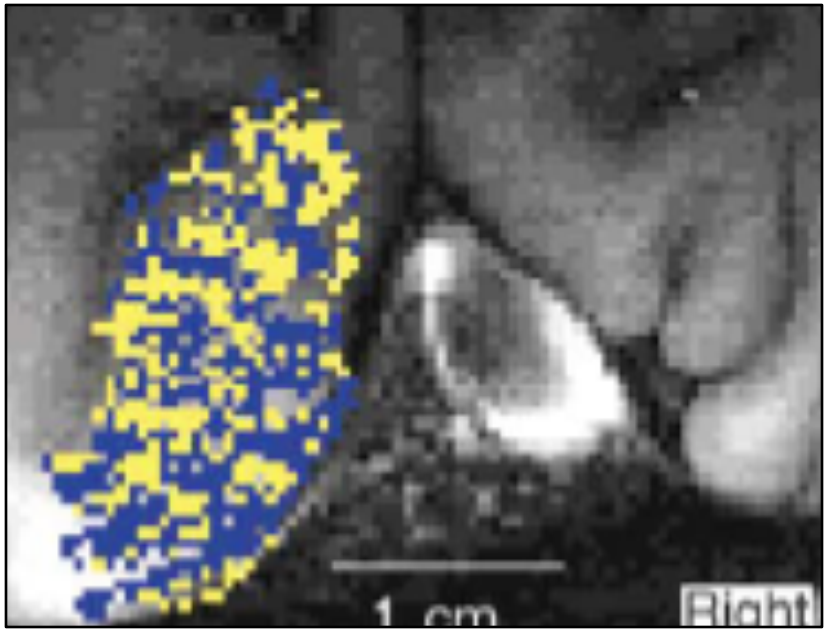
Statistical Map

superimposed on anatomical MRI image

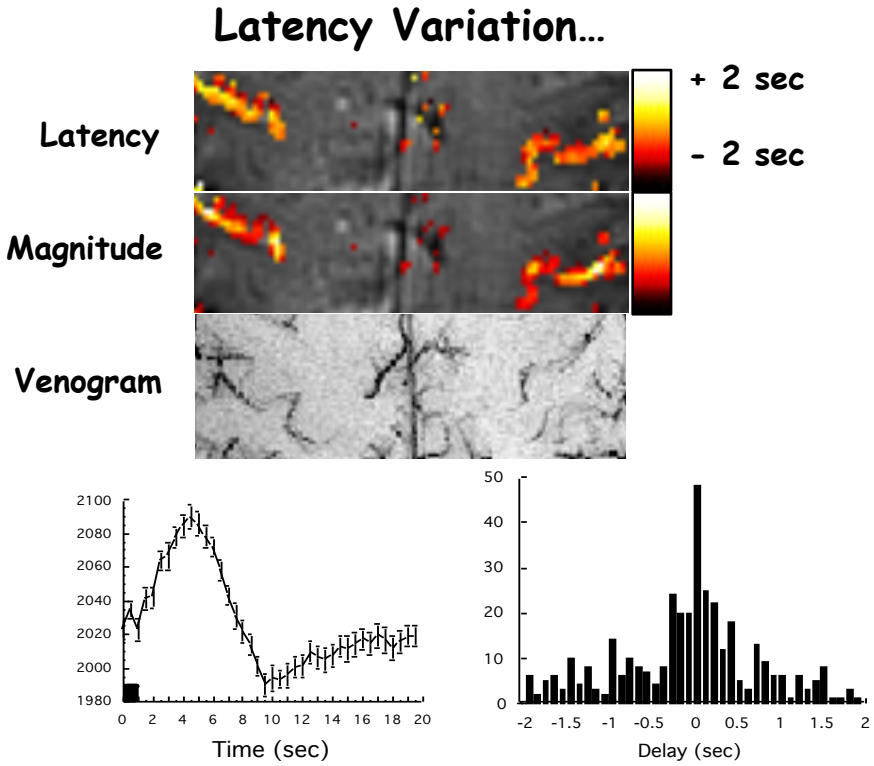



Log Size (mm)
3
Brain
2
Map
1
Column
0
Layer
-1
MEG, EEG
PET
NIRS
fMRI
MRI
-3 -2 -1 0 1 2 3 4 5 6 7
Millisecond Second Minute Hour Day
Log Time (sec)

Spatial and Temporal Resolution



Cheng, et al. (2001) Neuron,32:359-374



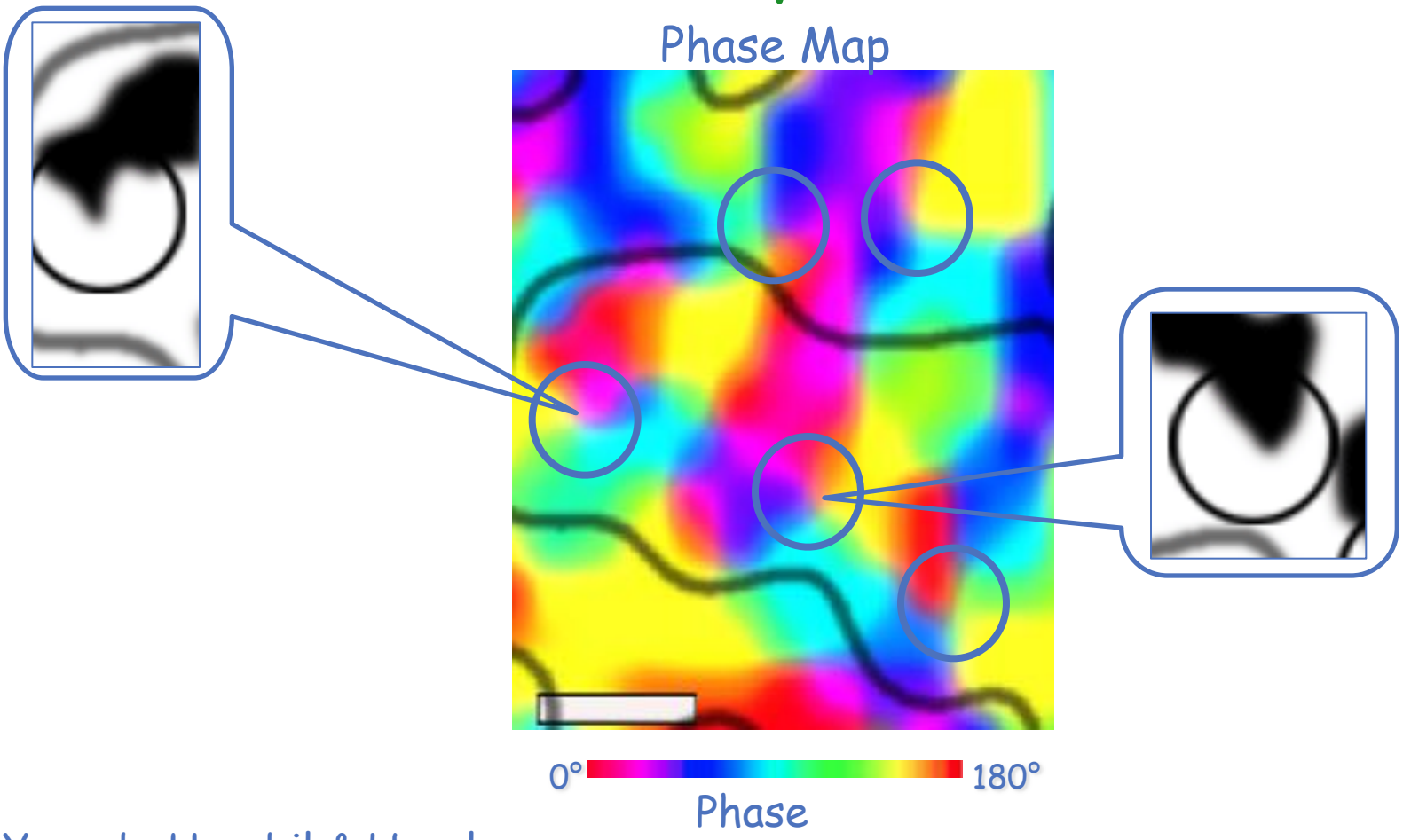
P. A. Bandettini, (1999) "Functional MRI" 205-220.

Spatial

Temporal

Methodology

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



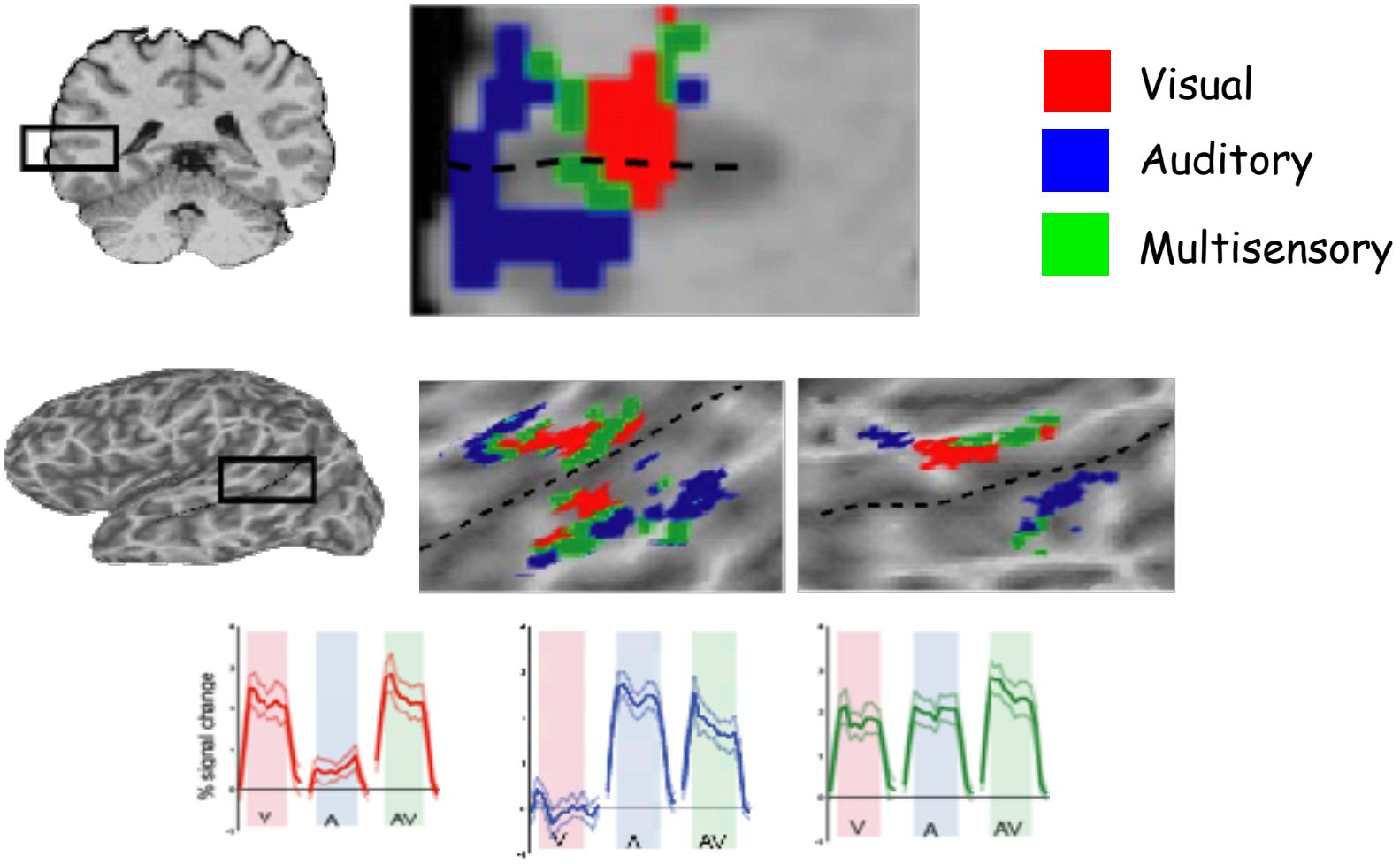
Yacoub, Ugurbil & Harel
University of Minnesota / CMRR

HBM 2006: Thursday, June 15, 2006 at 9:30

Scalebar = 0.5 mm

Multi-sensory integration

M.S. Beauchamp et al.,



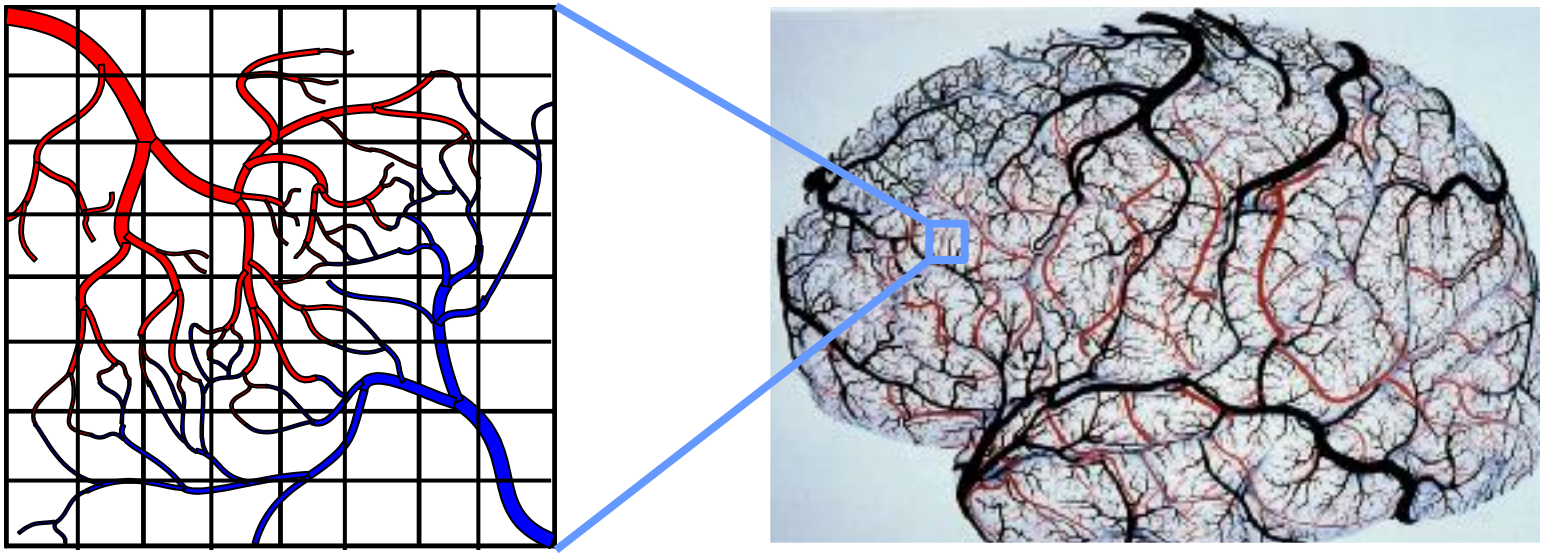
Interpretation

Neuronal Activation ? Measured Signal

? ? ? ?

Hemodynamics

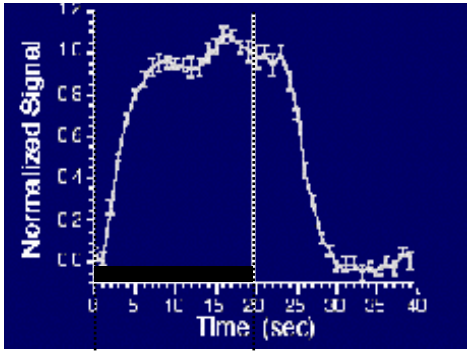
Noise

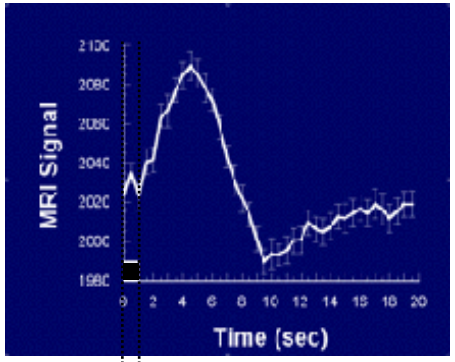


Overview of fMRI

Functional Contrast:

- Blood volume
- Blood flow/perfusion
- Blood oxygenation

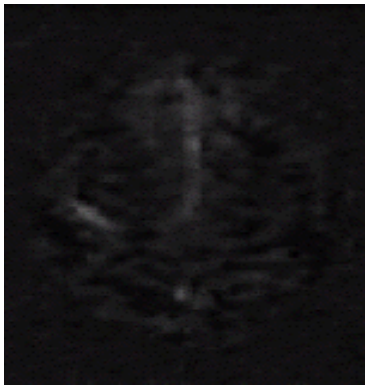




task task

Spatial resolution:

- Typical: 3 mm^3
- Upper: 0.5 mm^3



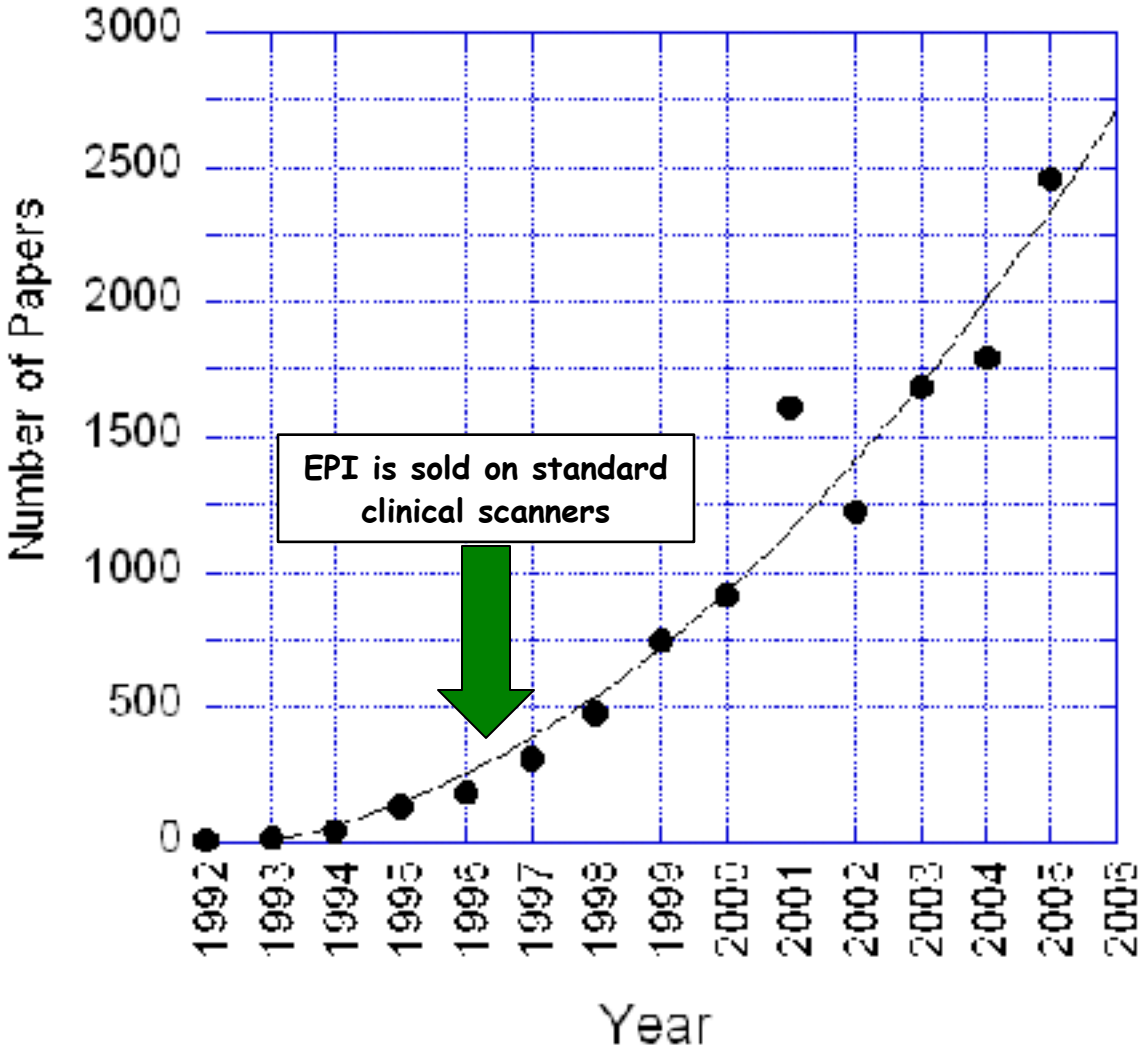
Temporal resolution:

- Minimum duration: < 16 ms
- Minimum onset diff: 100 ms to 2 sec

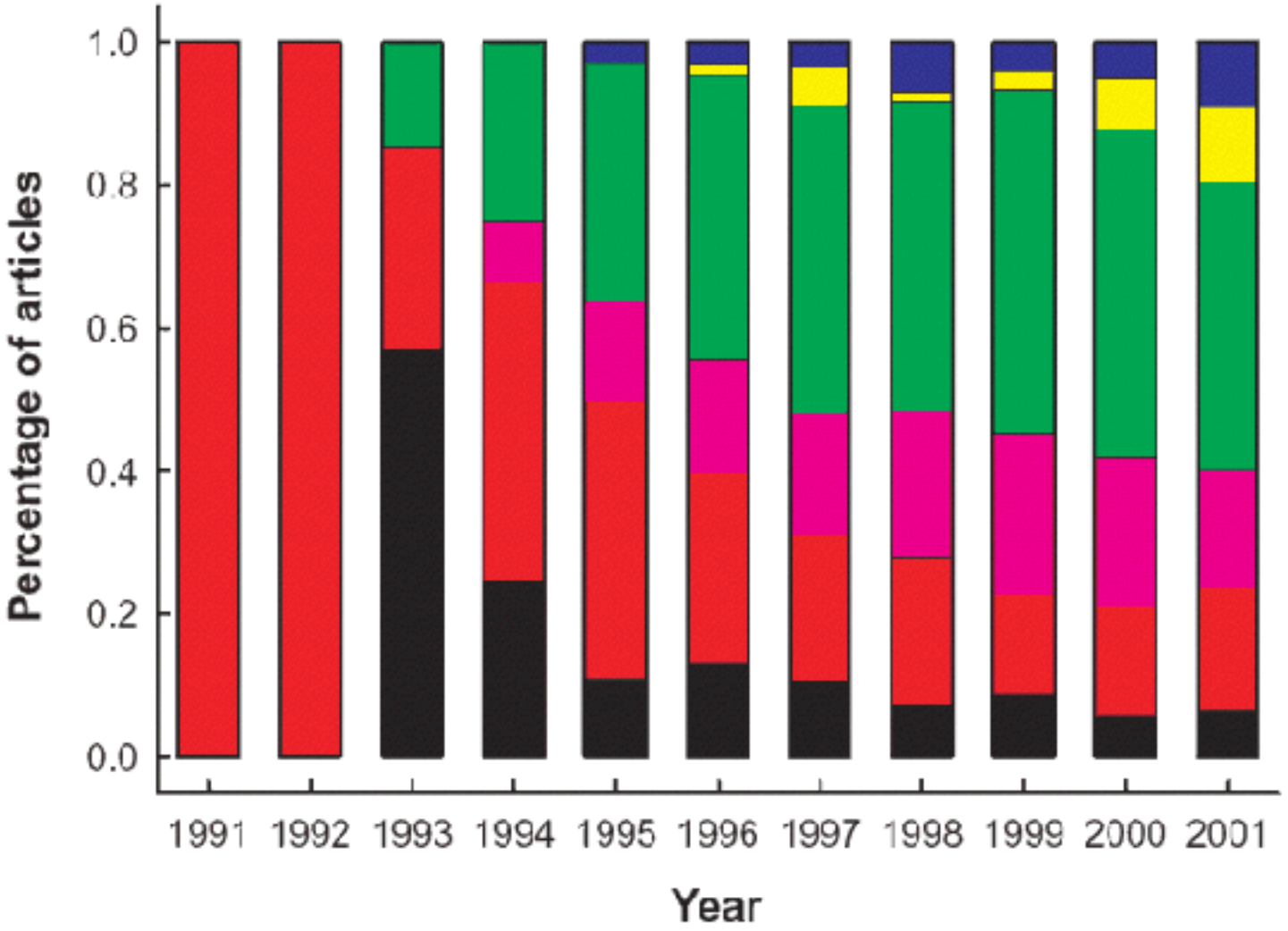
Interpretability:

- Neurovascular coupling, vascular sampling, blood, physiologic noise, motion and other artifacts, etc..

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

What fMRI Can Do (routine fMRI)

Help in understanding healthy brain organization

- -map networks involved with specific behavior, stimulus, or performance
- -characterize changes over time (seconds to years)
- -determine correlates of behavior (response accuracy, etc…)

Current Clinical Applications

- -presurgical mapping (CPT code in place as of Jan, 2007)

Current Clinical Research

- -assessment of recovery and plasticity
- -clinical population characterization with probe task or resting state

What fMRI Can't Do
(what are the problems with fMRI?)

- Too low SNR for routine clinical use (takes too long)
- Requires patient cooperation (too sensitive to motion)
- Too low spatial resolution (each voxel has several million neurons)
- Too low temporal resolution (hemodynamics are variable and sluggish)
- Too indirectly related to neuronal activity
- Too many physiologic variables influence signal
- Requires a task (BOLD cannot look at baseline maps)
- Too confined space and high acoustic noise.

Technology

Coil arrays
High field strength
High resolution
Novel functional contrast

Methodology

Functional Connectivity Assessment
Multi-modal integration
Pattern classification
Real time feedback
Task design

Fluctuations
Dynamics
Cross - modal comparison

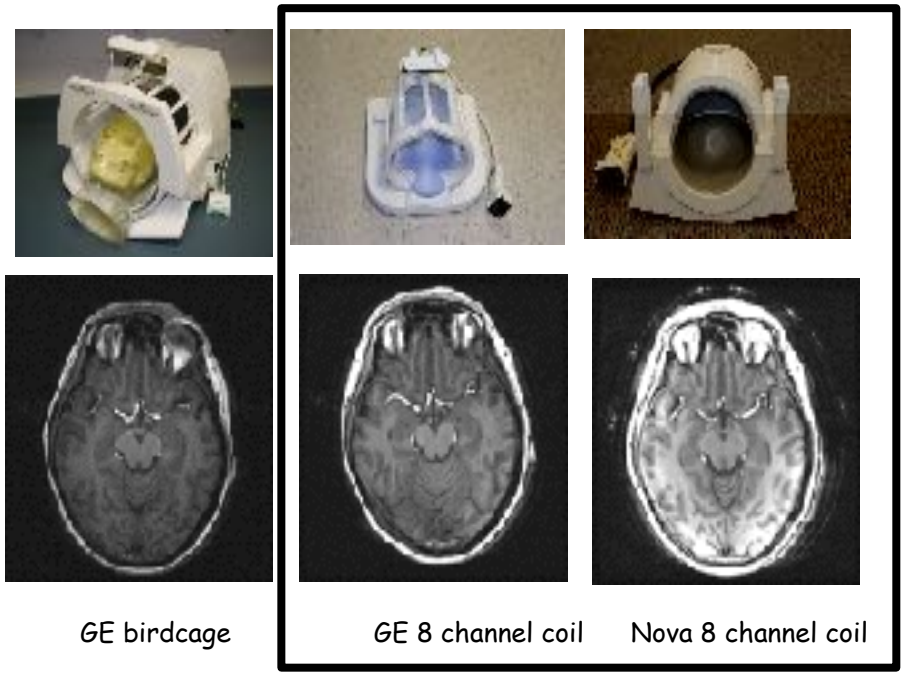
Interpretation

Basic Neuroscience
Behavior correlation/prediction
Pathology assessment

Applications

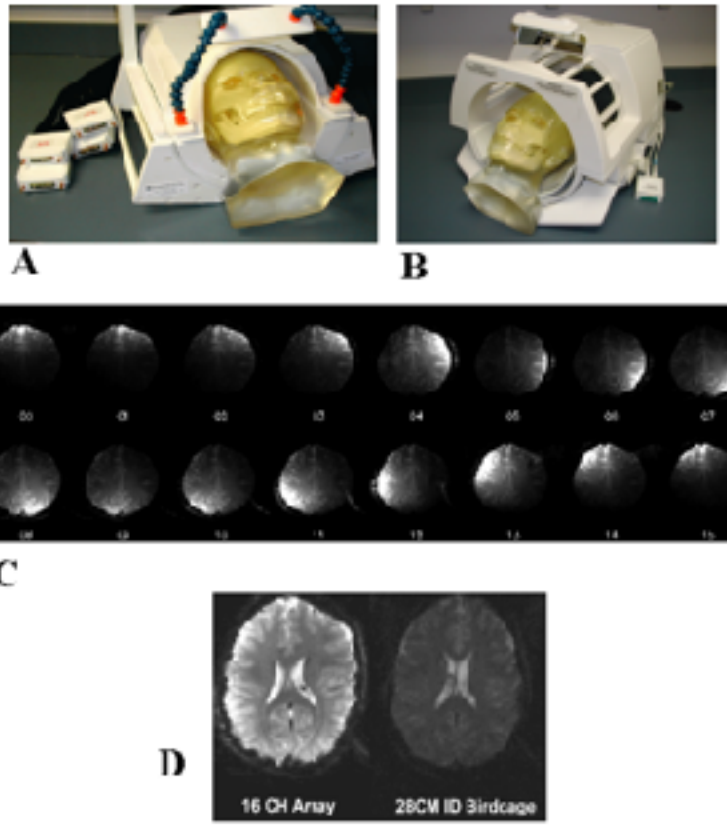
Technology

8 channel parallel receiver coil



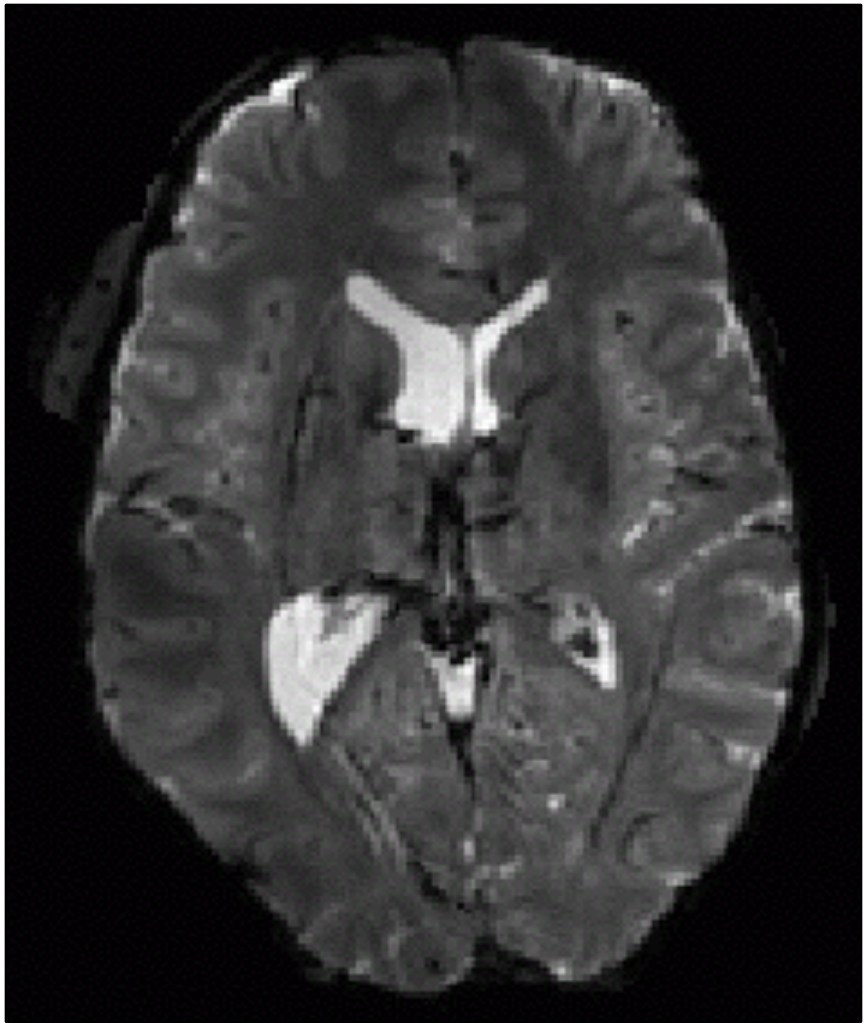
GE birdcage | GE 8 channel coil | Nova 8 channel coil

16 channel parallel receiver coil



J. Bodurka, et al, Magnetic Resonance in Medicine 51 (2004) 165-171.

Technology

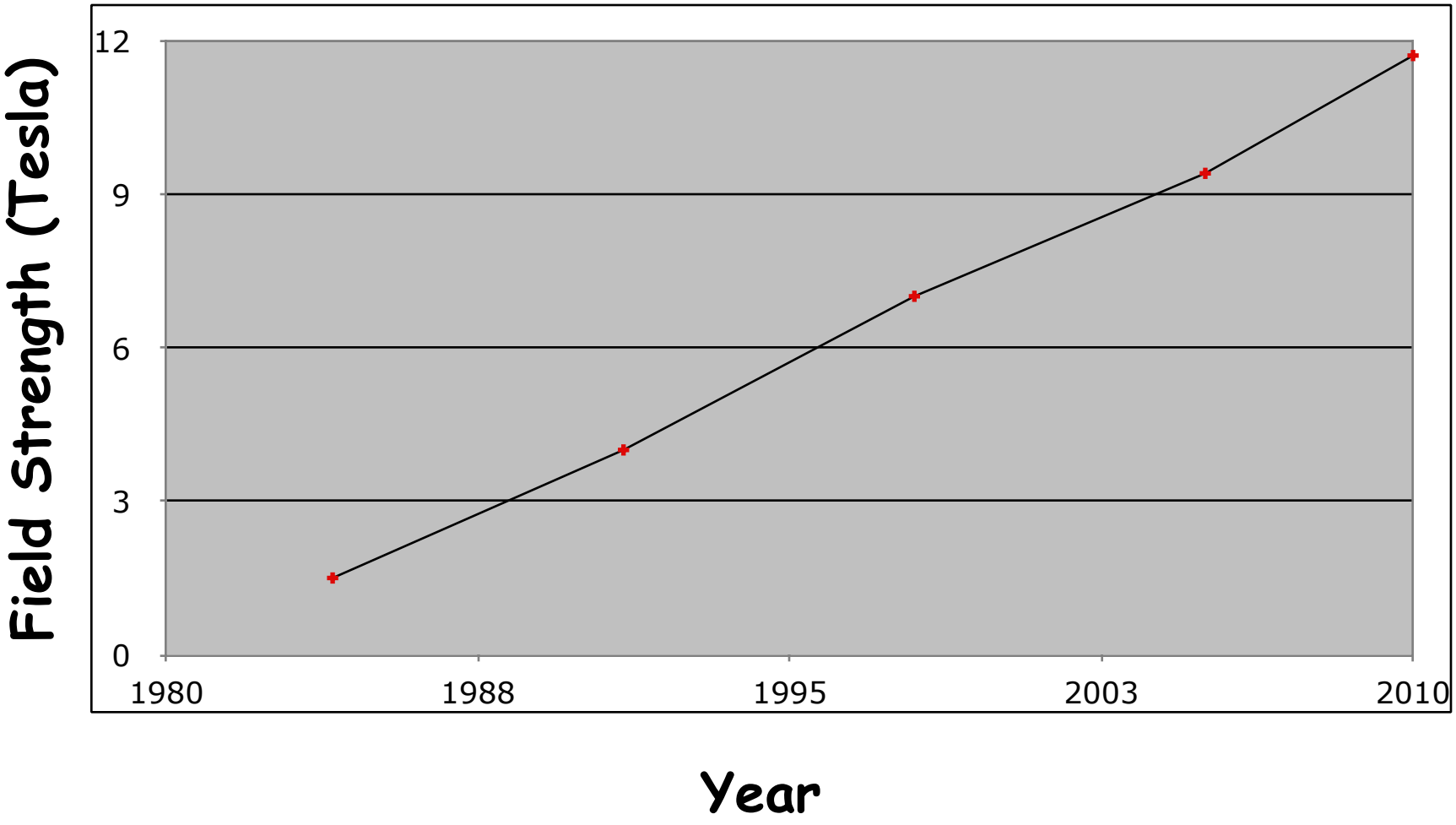


3T single-shot SENSE EPI using 16 channels: 1.25x1.25x2mm

fMRI Contrast

- Volume (gadolinium)
- BOLD
- Perfusion (ASL)
- $\Delta CMRO_2$
- ΔVolume (VASO)
- Neuronal Currents
- Diffusion coefficient
- Temperature

Progression of Human MRI Scanner Field Strength



Technology

Coil arrays
High field strength
High resolution
Novel functional contrast

Methodology

Functional Connectivity Assessment
Multi-modal integration
Pattern classification
Real time feedback
Task design

Fluctuations
Dynamics
Cross - modal comparison

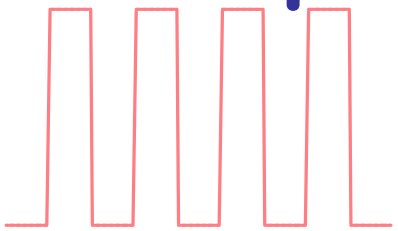
Interpretation

Basic Neuroscience
Behavior correlation/prediction
Pathology assessment

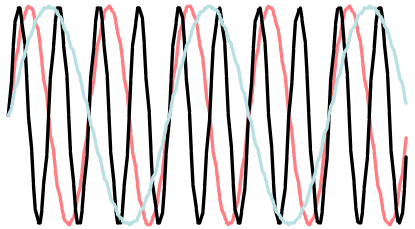
Applications

Neuronal Activation Input Strategies

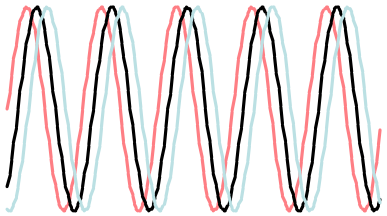
1. Block Design



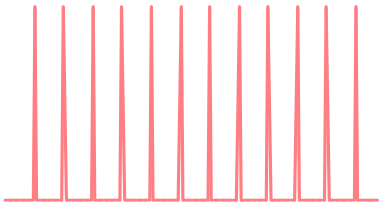
2. Frequency Encoding



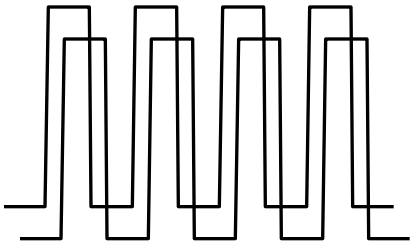
3. Phase Encoding



4. Event-Related



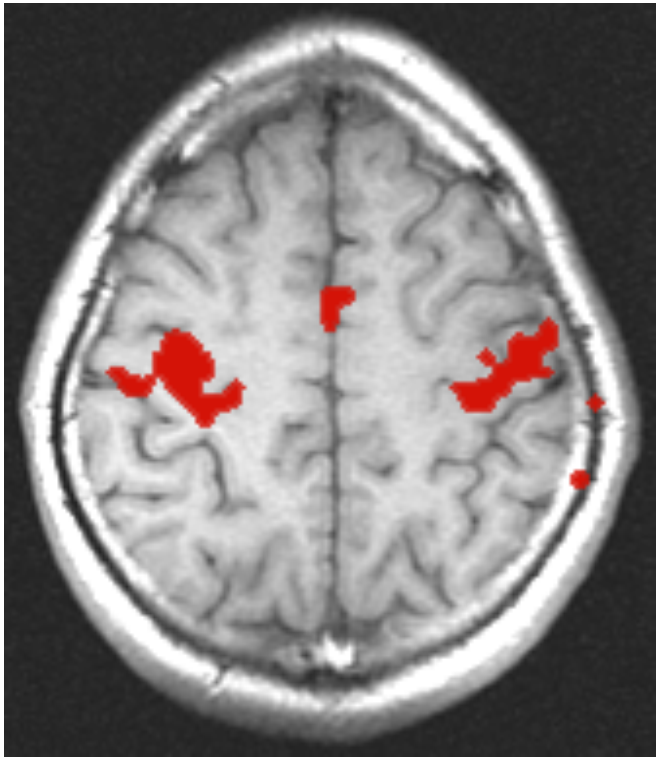
5. Orthogonal Block Design



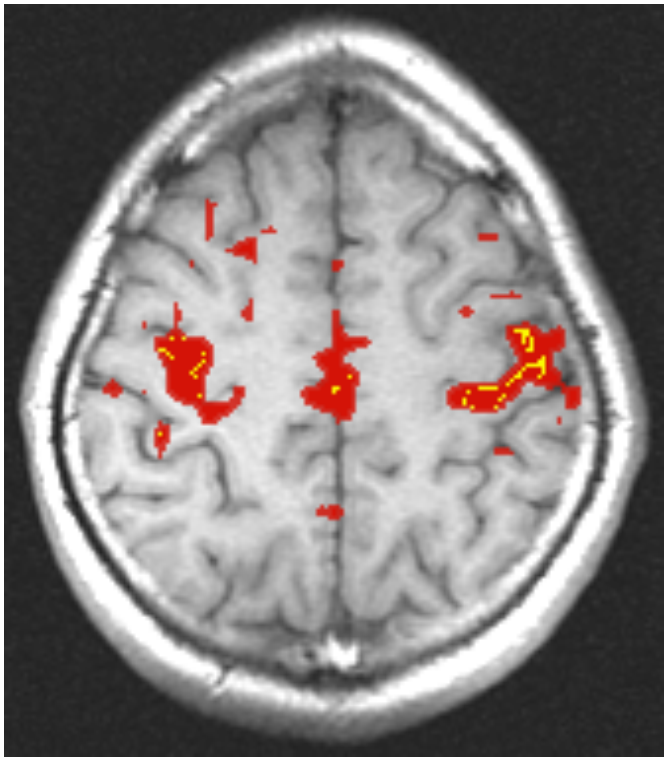
6. Free Behavior Design.

Methodology

Resting State Correlations



Activation:
correlation with reference function

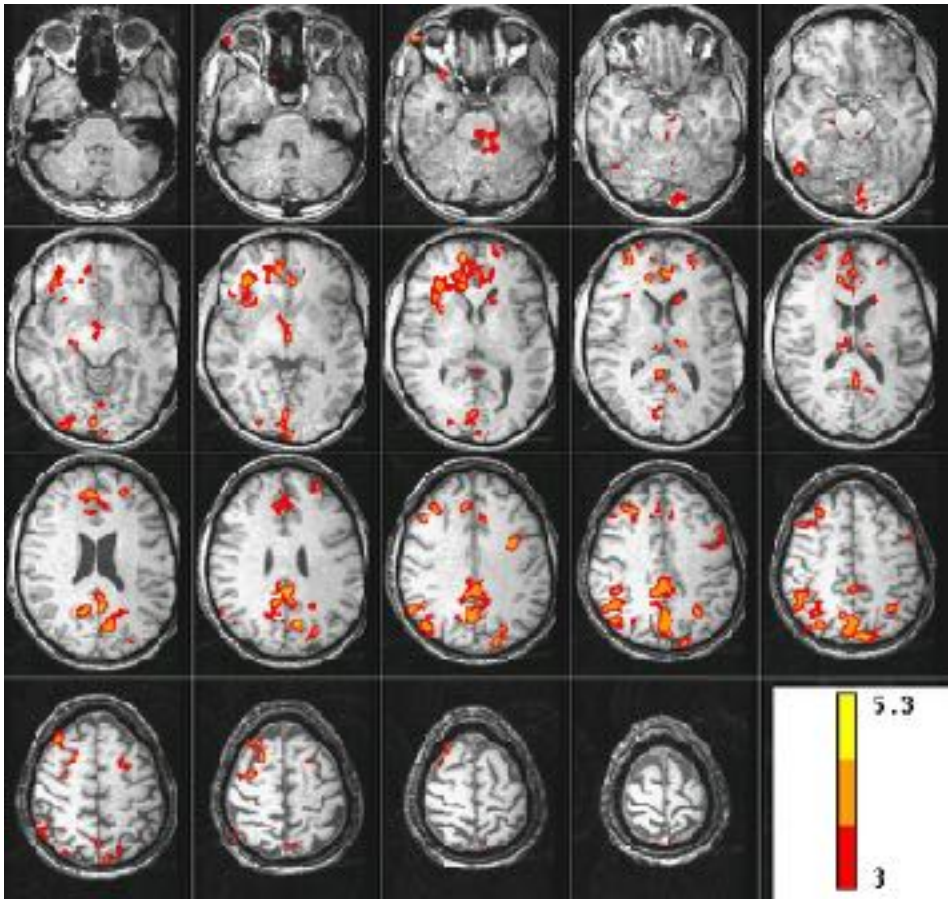


Rest:
seed voxel in motor cortex

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

Methodology

BOLD correlated with SCR during "Rest"



J. C. Patterson II, L. G. Ungerleider, and P. A Bandettini, NeuroImage 17: 1787-1806, (2002).

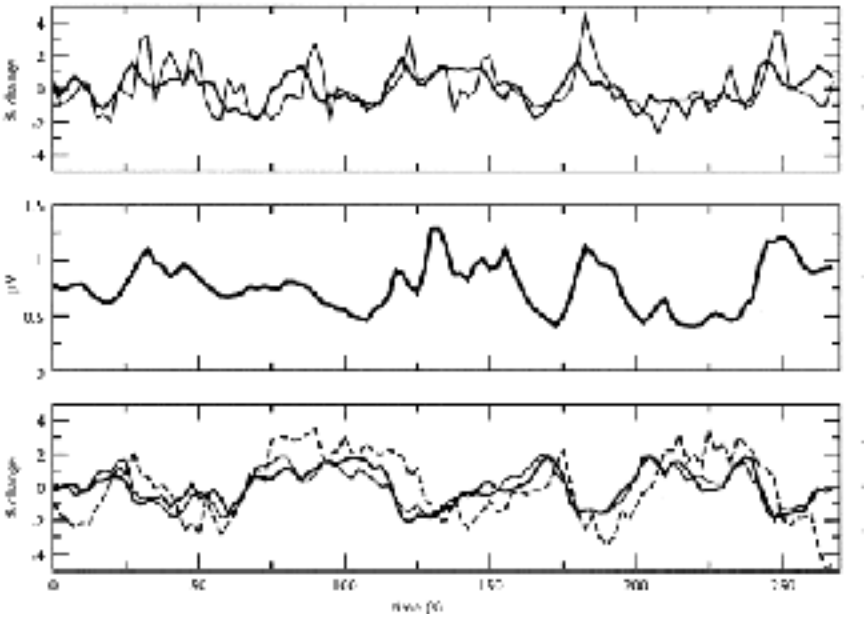
Methodology

BOLD correlated with 10 Hz power during "Rest"

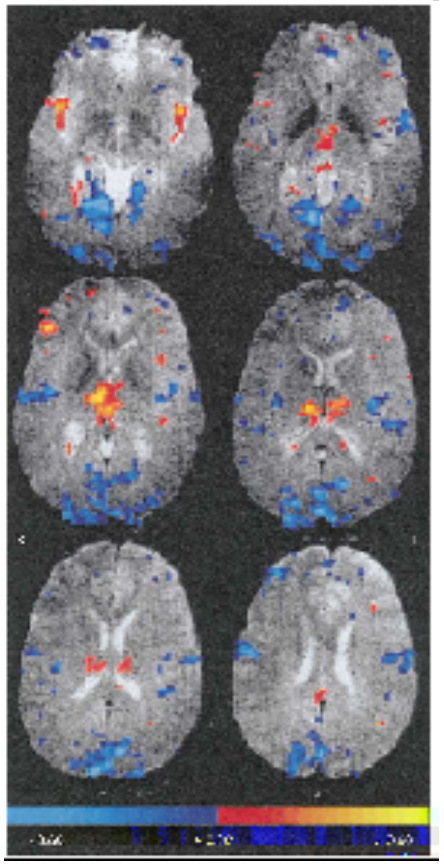
Positive

10 Hz power

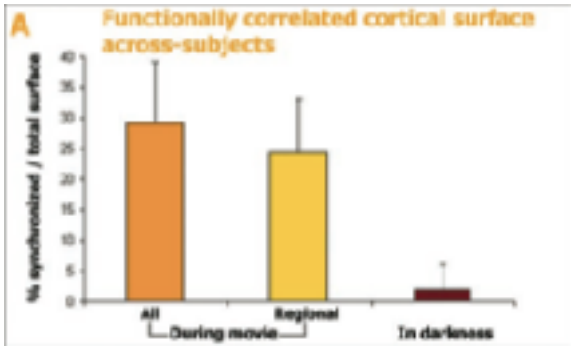
Negative

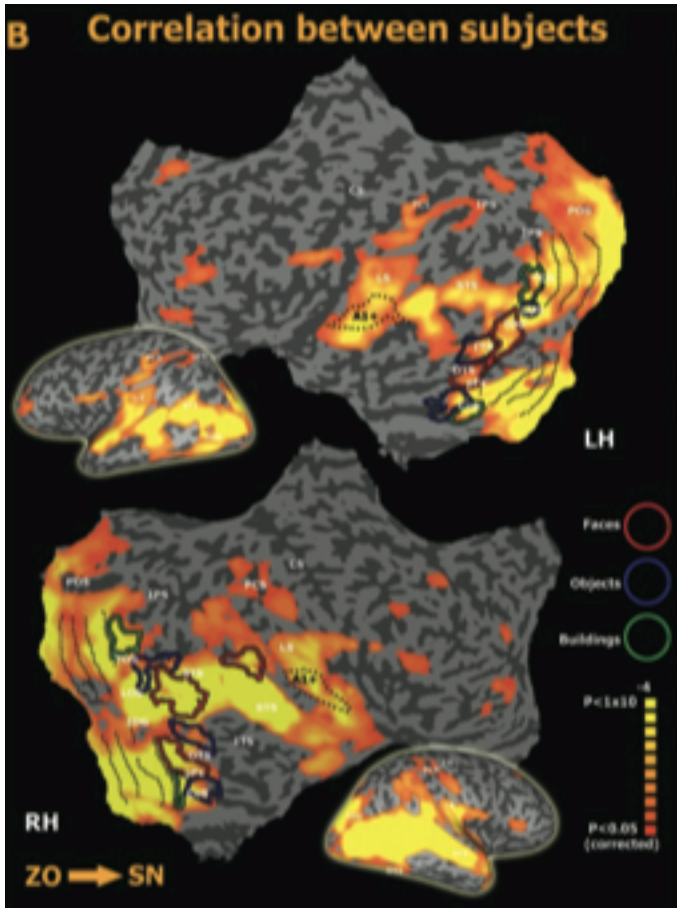


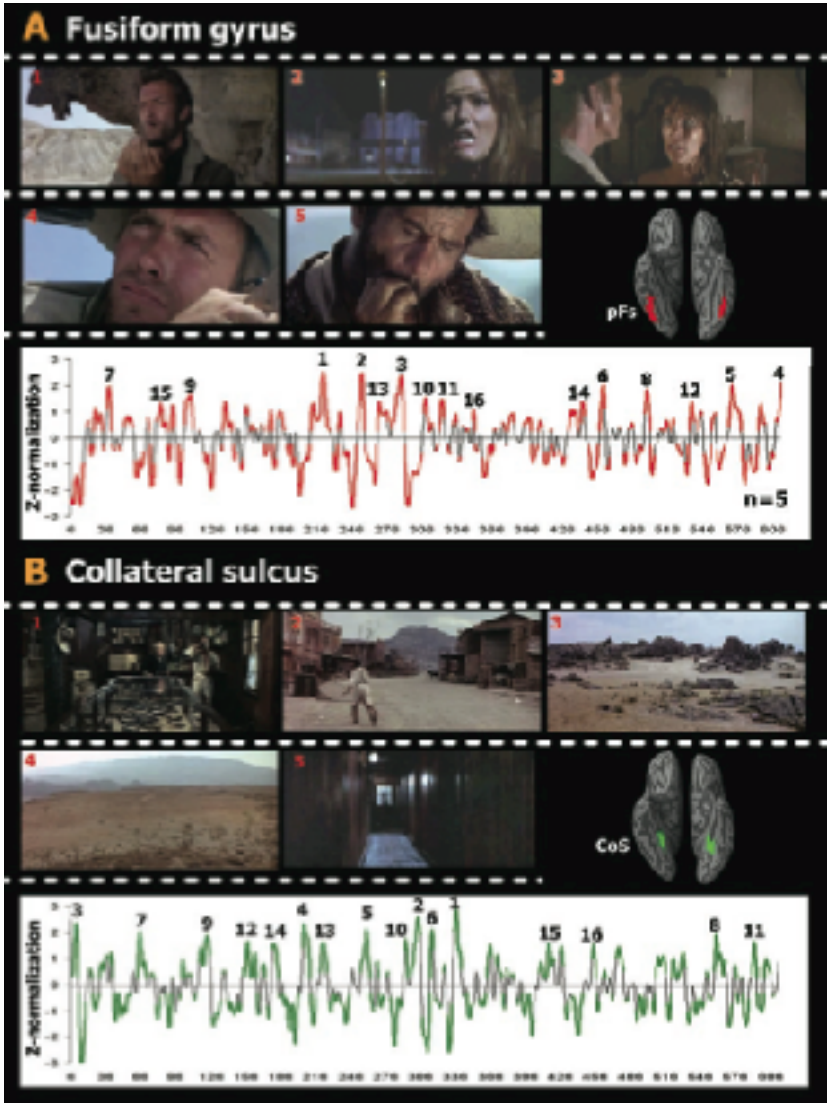
Goldman, et al (2002), Neuroreport



Methodology

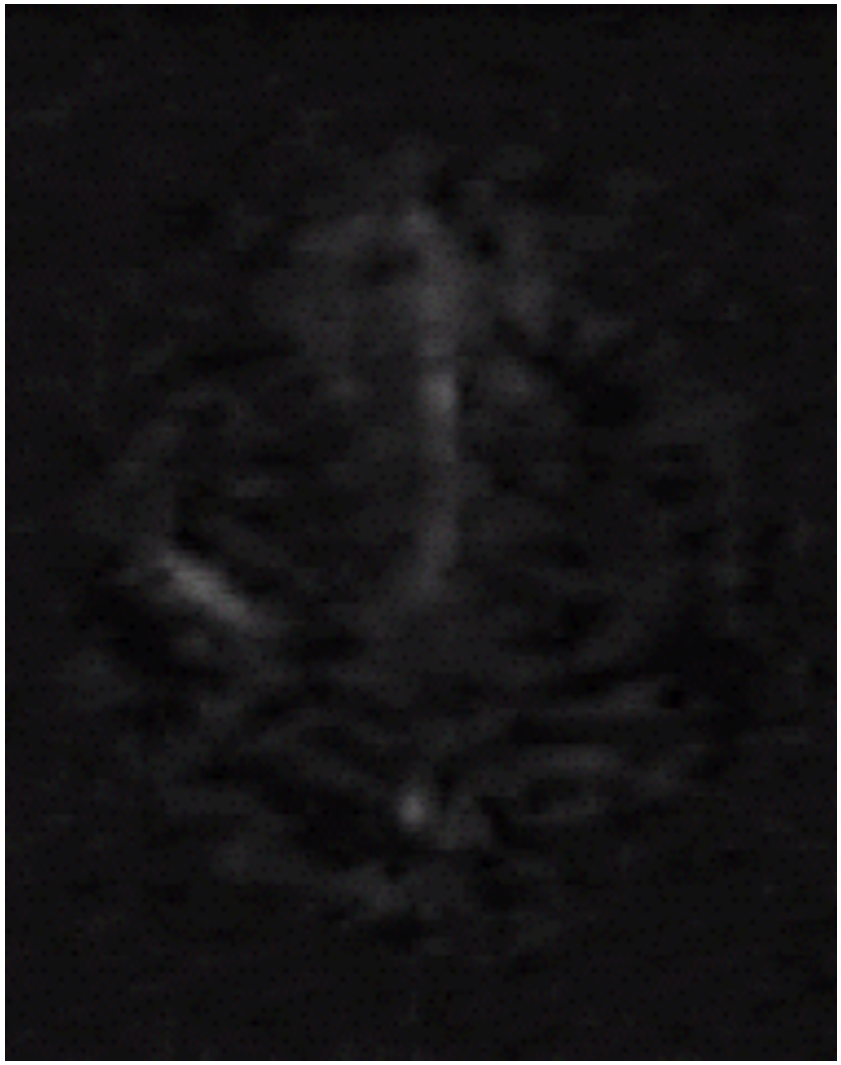






Hasson, et al (2004), Science, 303, 1634-1640

Methodology



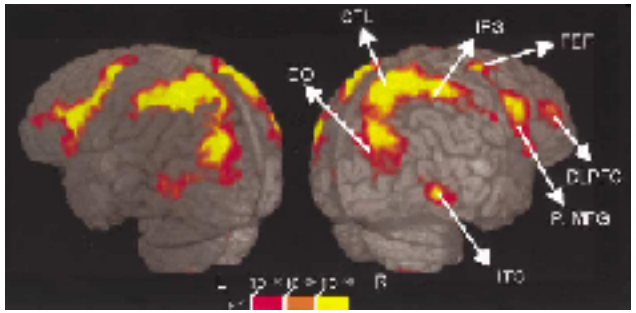
Mapping ⟷ "Reading"

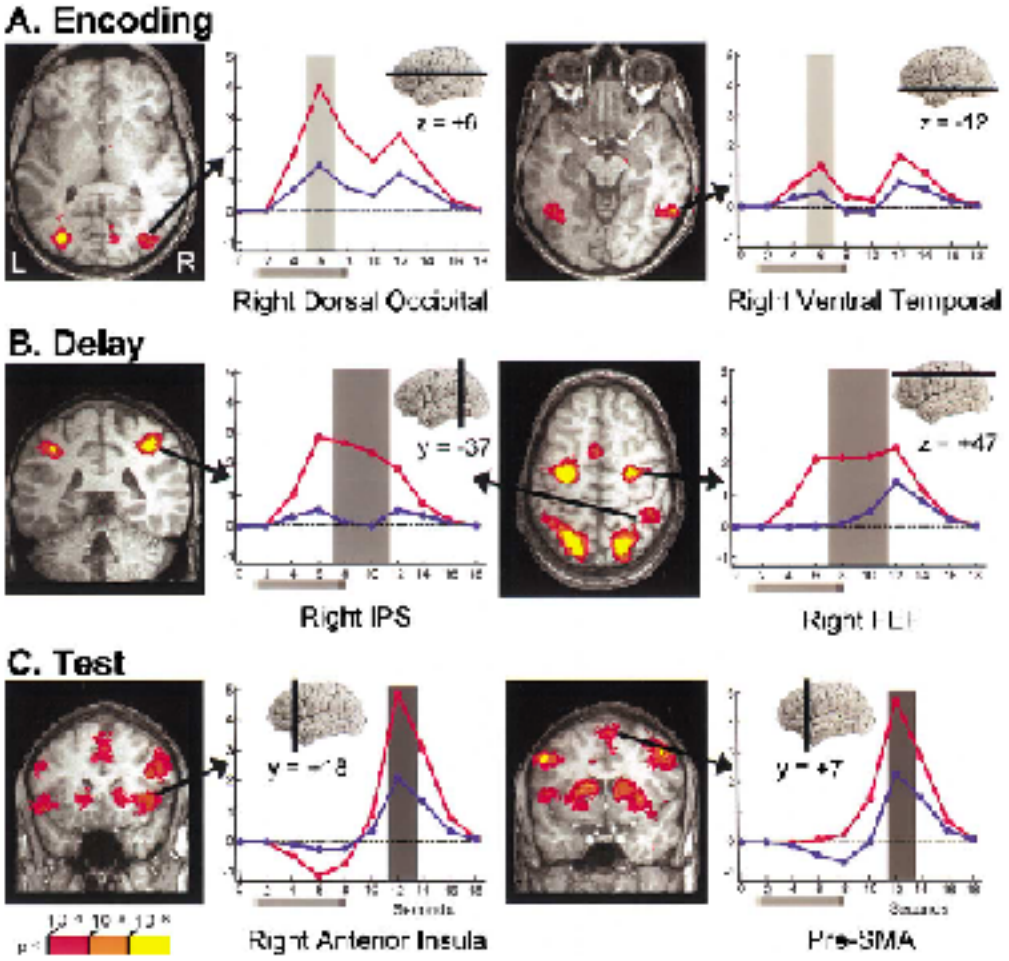
Methodology

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

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

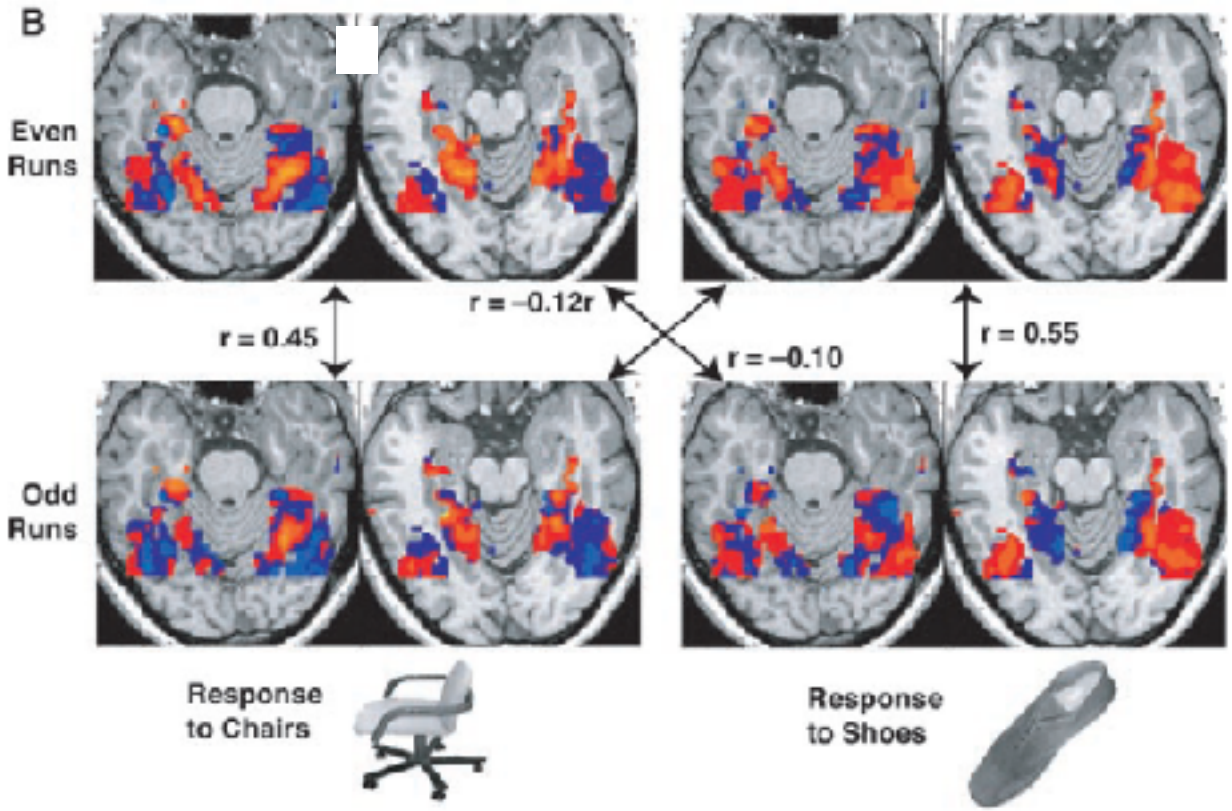
Luiz Pessoa,[1] Eva Gutierrez, Peter A. Bandettini, and Leslie G. Ungerleider
Laboratory of Brain and Cognition
National Institute of Mental Health
National Institutes of Health
Bethesda, Maryland 20892





Methodology

Ventral temporal category representations



Haxby et al. 2001

Methodology

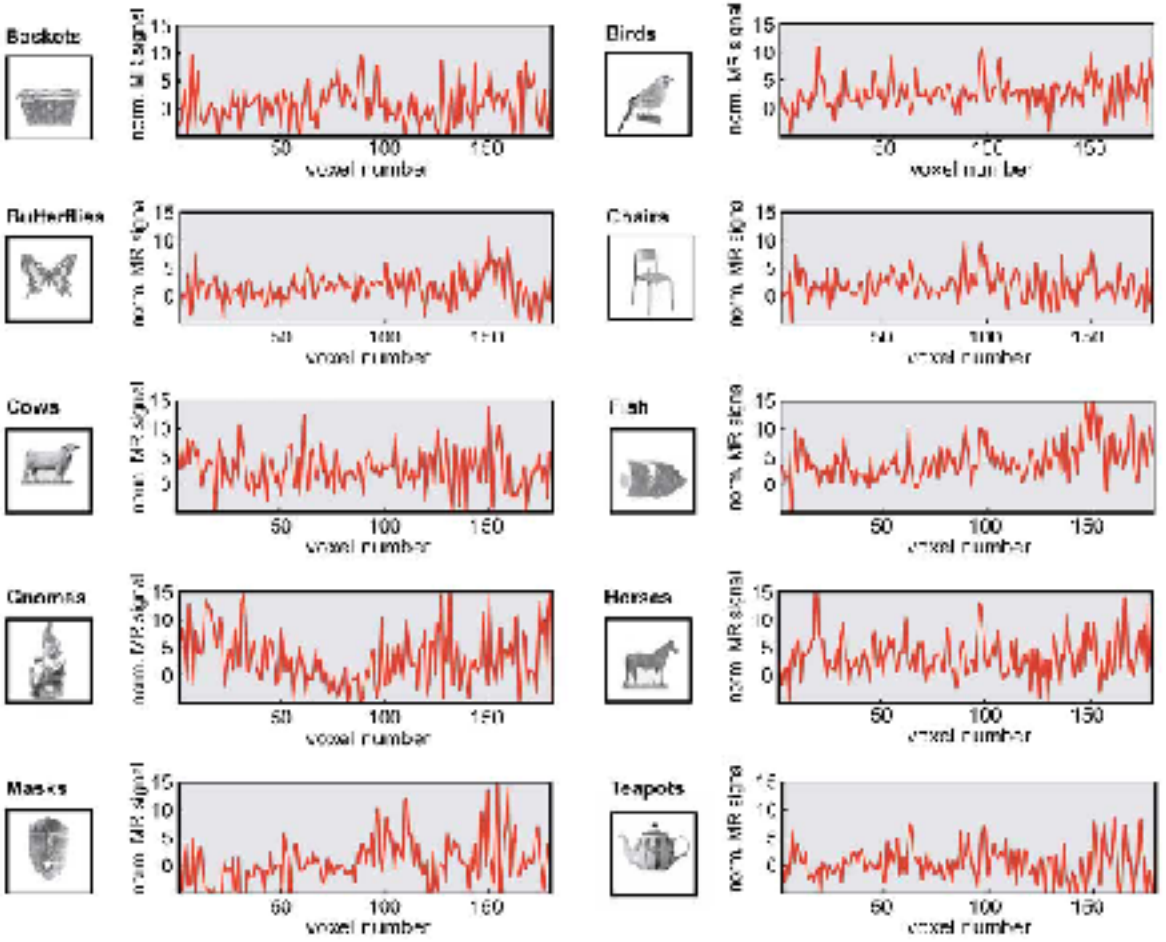
Functional magnetic resonance imaging (fMRI) "brain reading": detecting and classifying distributed patterns of fMRI activity in human visual cortex

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

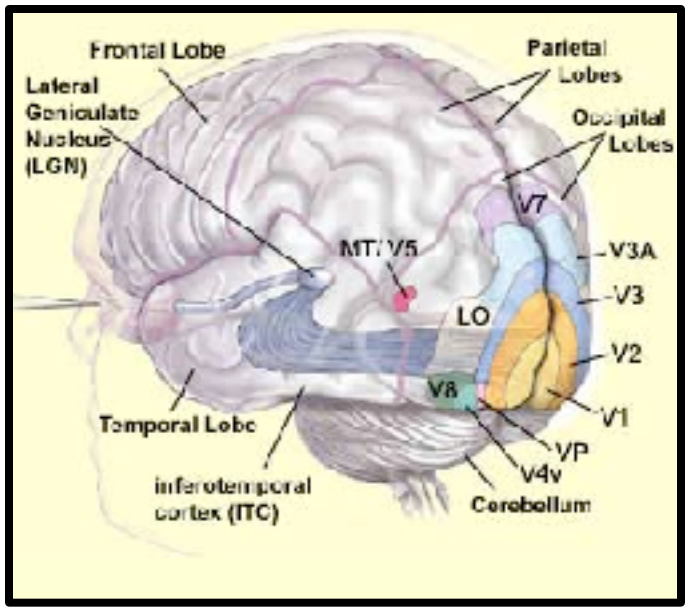
[a]Rowland Institute for Science, Cambridge, MA 02142, USA
[b]Athinoula A. Martinos Center for Biomedical Imaging, Charlestown, MA 02129, USA
[c]MyoVision, Inc., P.O. Box 152, Lexington, MA 02420, USA

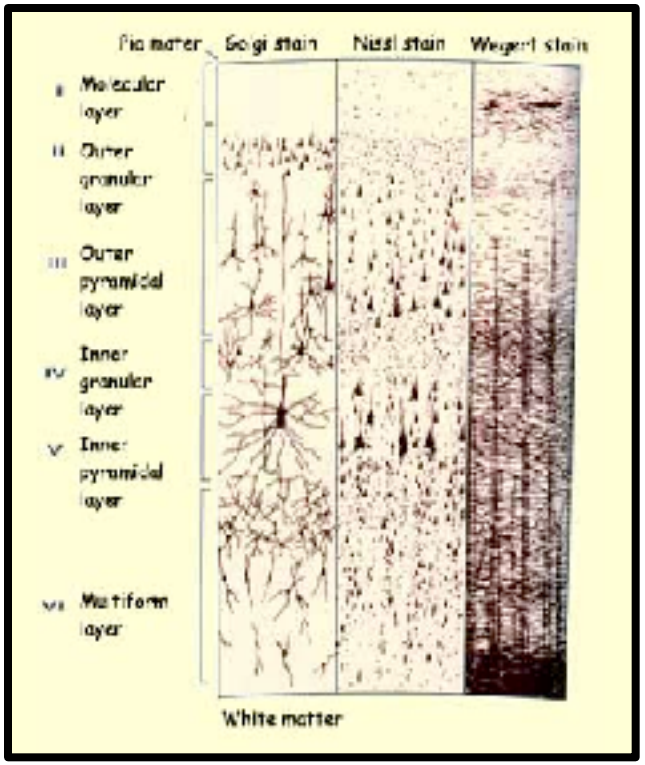
Received 15 July 2002; accepted 10 December 2002

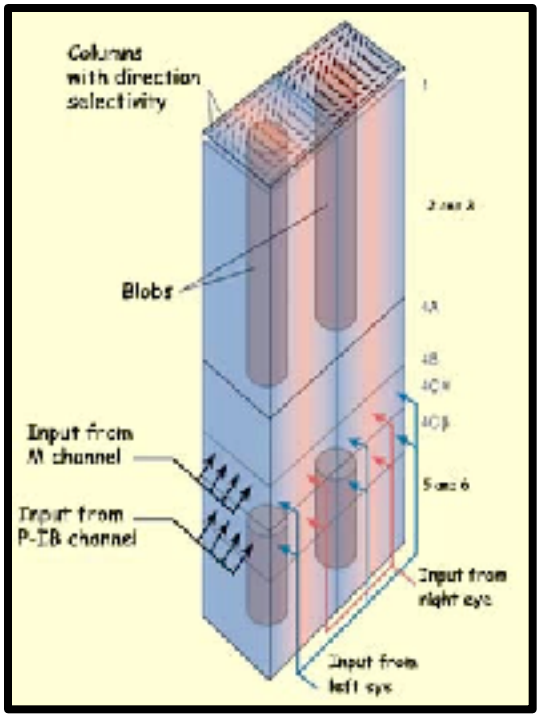
NEUROIMAGE 19 (2): 261-270 Part 1 JUN 2003



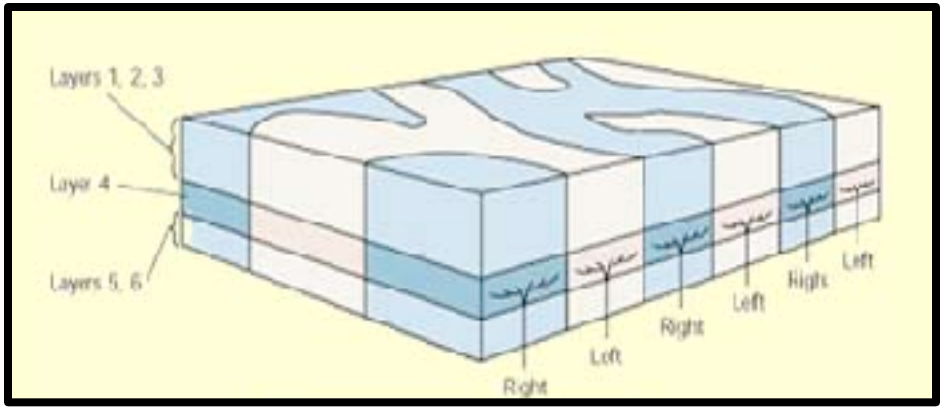
Visual Cortex Organization



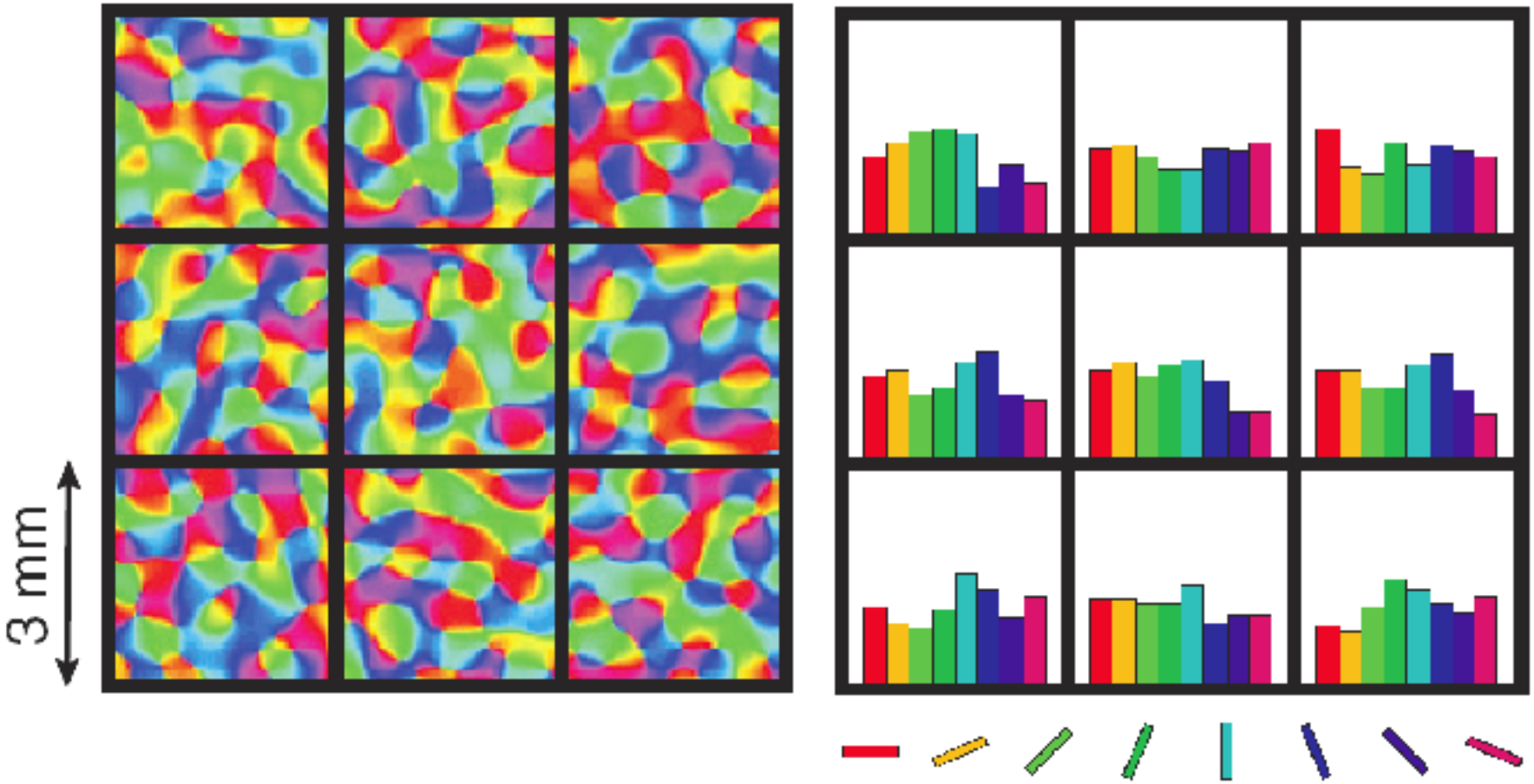




http://www.thebrain.mcgill.ca



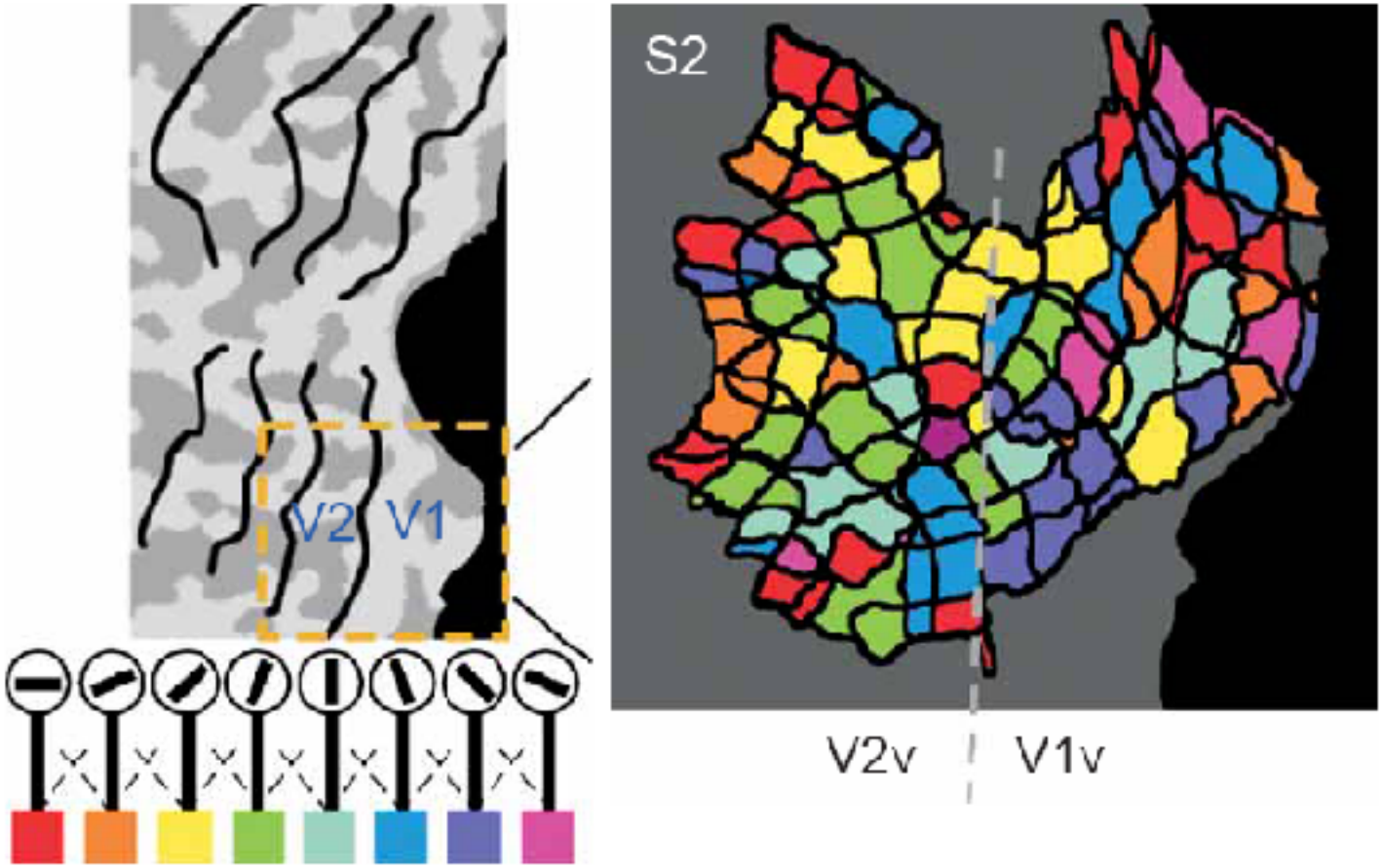
Methodology



Boynton (2005), News & Views on Kamitani & Tong (2005) and Haynes & Rees (2005)

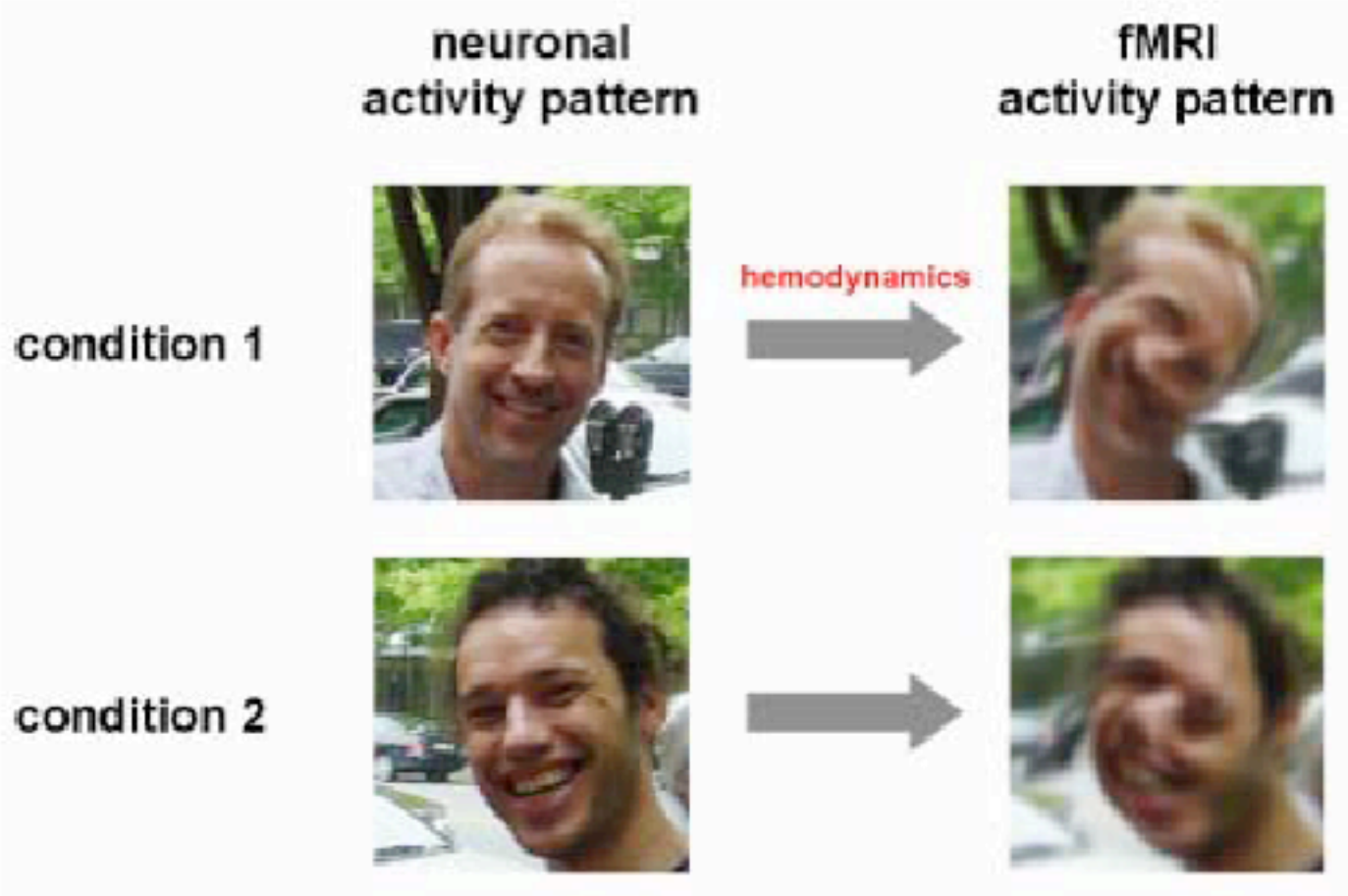
Methodology

Lower spatial frequency clumping



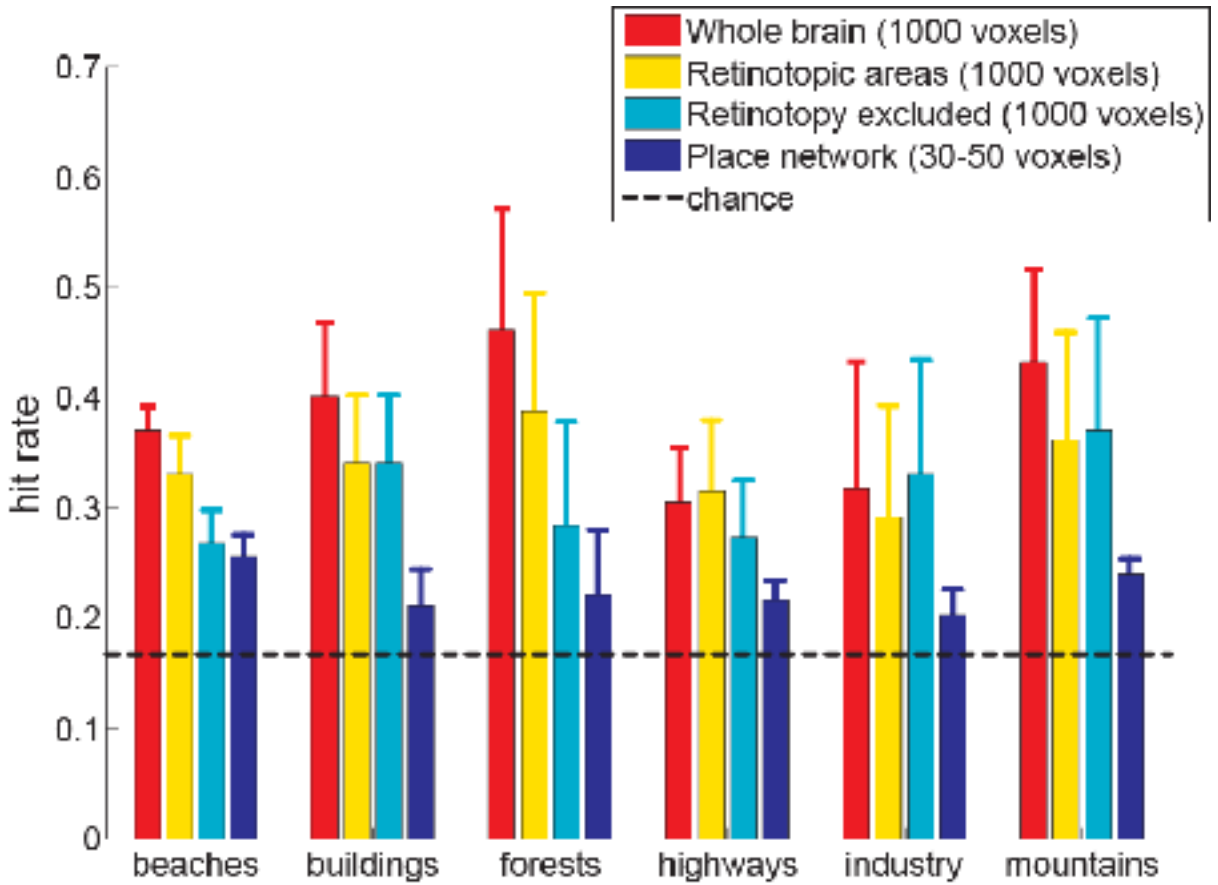
Kamitani & Tong (2005)

Methodology



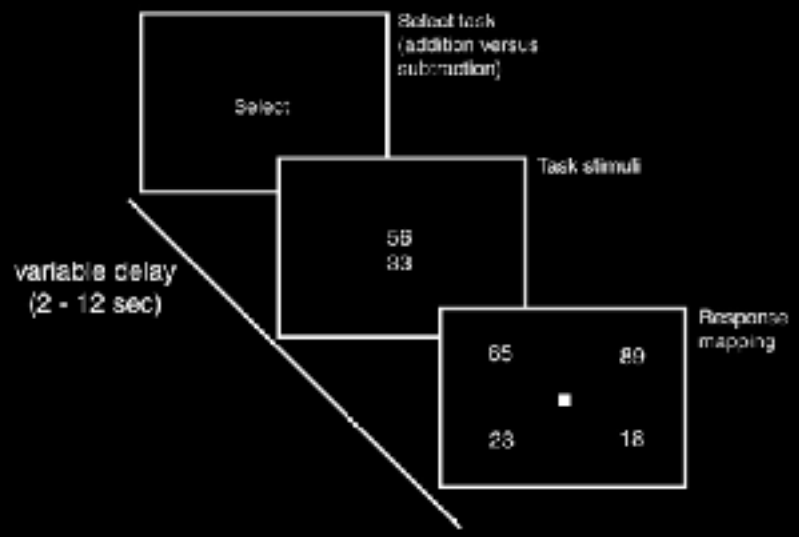
Predicting perceived natural scene categories from distributed patterns of fMRI activity

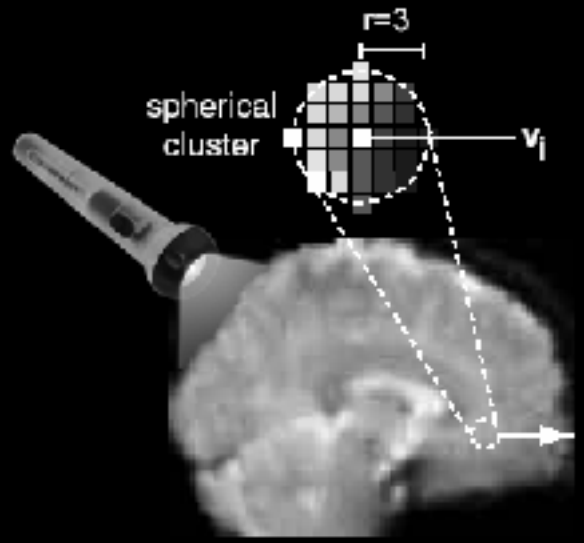
Dirk B. Walther, Eamon Caddigan,
Justas Birgiolas, Li Fei-Fei, Diane Beck

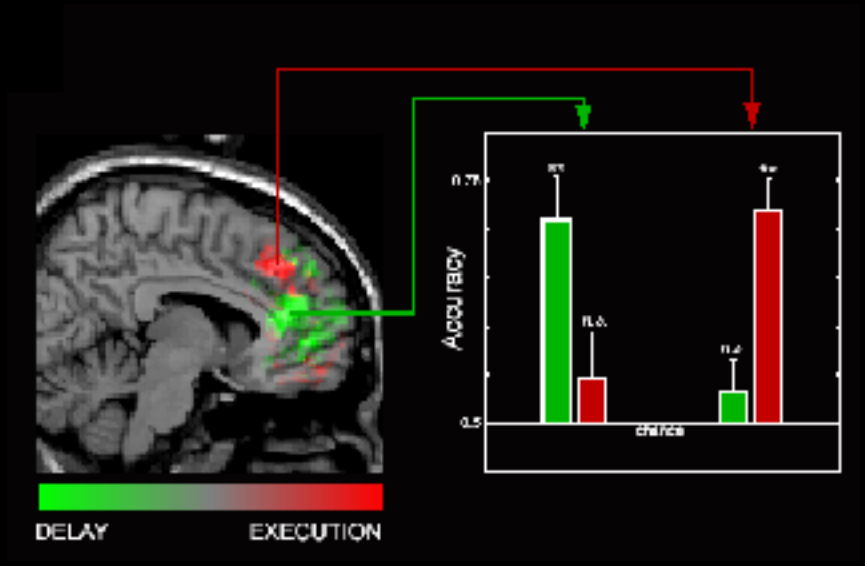


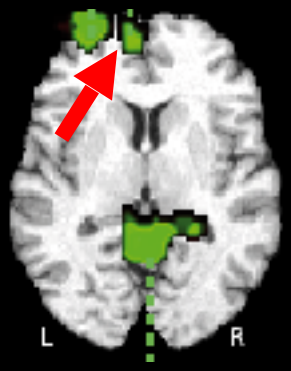
Reading hidden intentions in the human brain

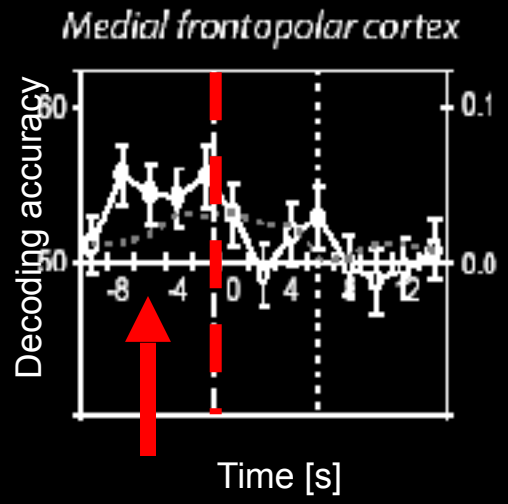
Thu 9.45: Cognition – Representation and Processes





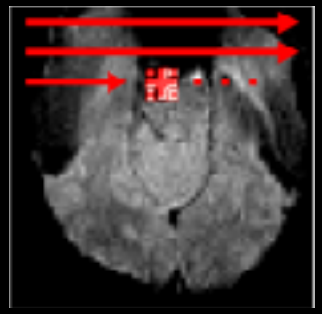


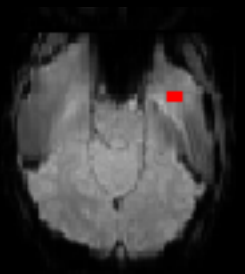


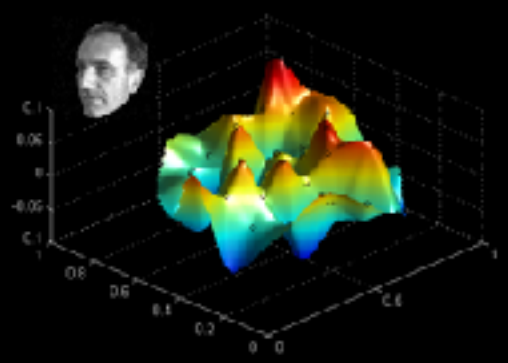


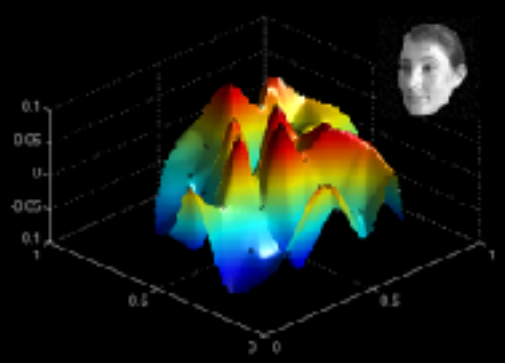
Haynes, Sakai, Rees, Gilbert, Frith & Passingham (Current Biology,2007)

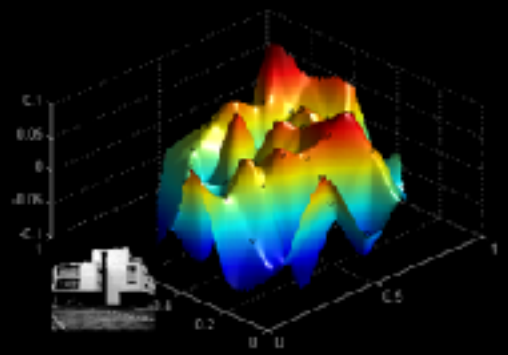
Multivariate Analysis:
looking for differences in pattern

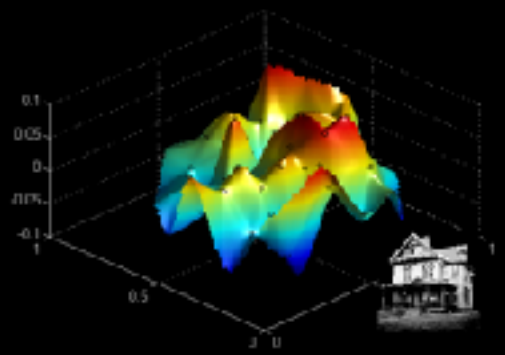






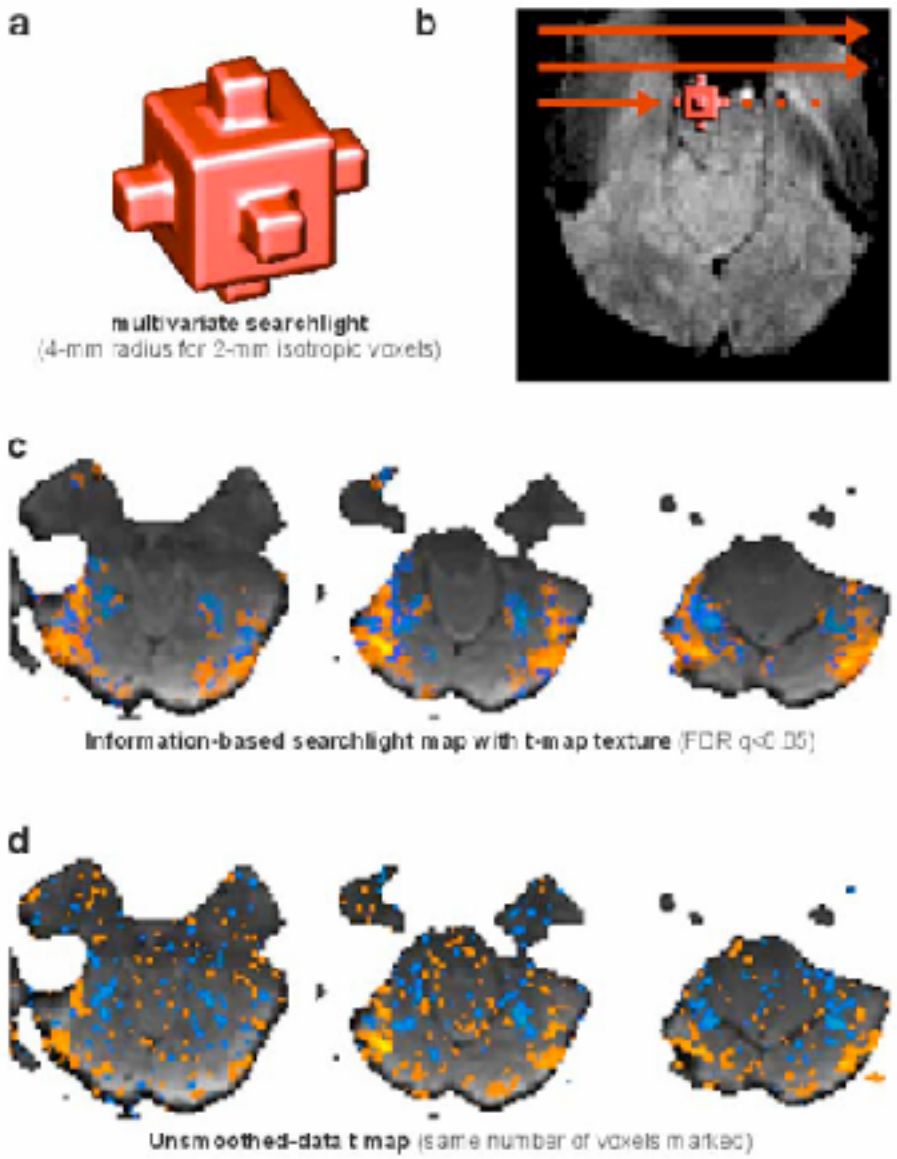


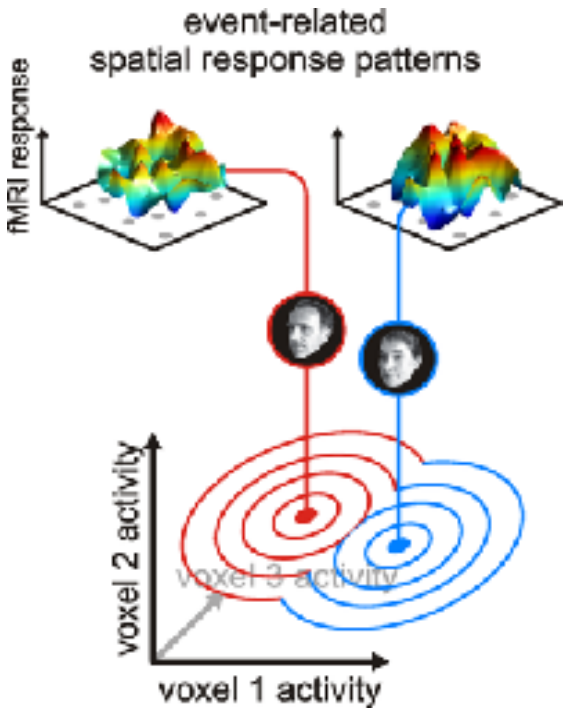




Niko Kriegeskorte, NIH

Methodology

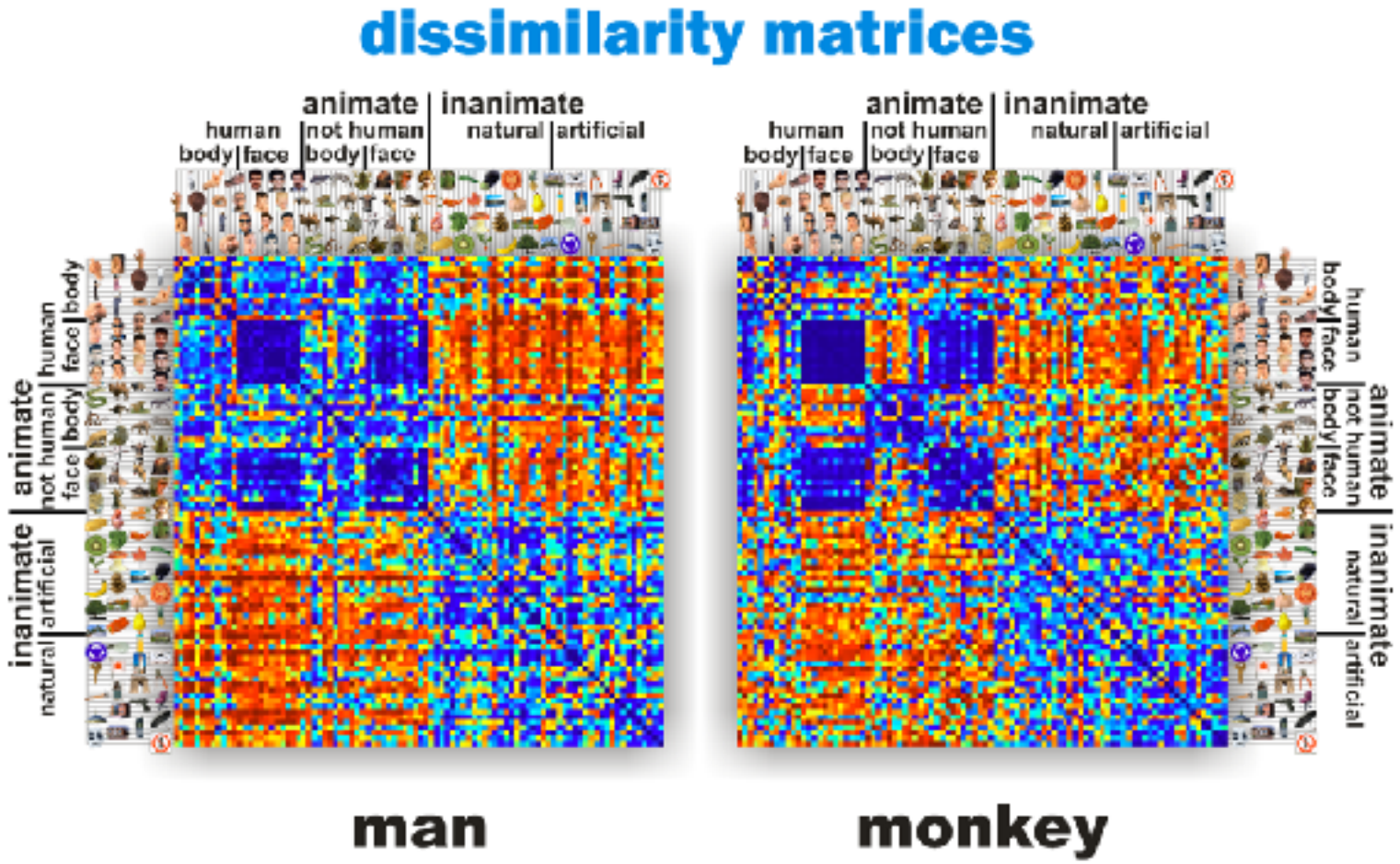




N. Kriegeskorte, R. Goebel, P. Bandettini, Information-based functional brain mapping. Proc. Nat'l. Acad. Sci. USA, 103, 3863-3868 (2006).

Matching categorical object representations in IT cortex of man & monkey

Kriegeskorte N, Mur M, Ruff D, Kiani R, Bodurka J, Bandettini P



Technology

Coil arrays
High field strength
High resolution
Novel functional contrast

Methodology

Functional Connectivity Assessment
Multi-modal integration
Pattern classification
Real time feedback
Task design

Interpretation

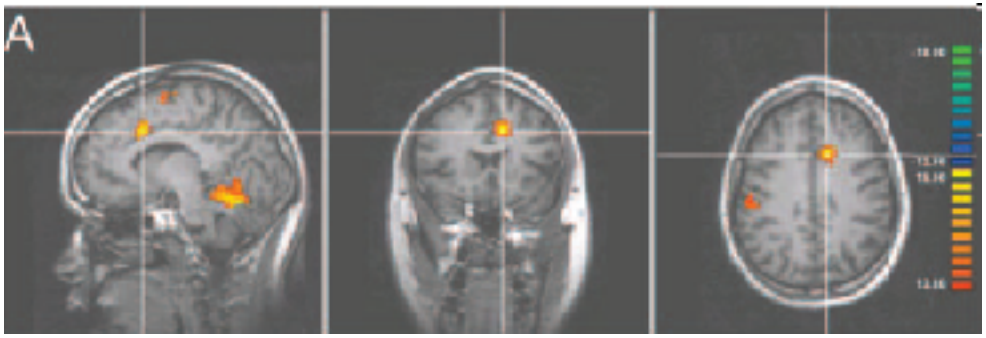
Fluctuations
Dynamics
Cross - modal comparison

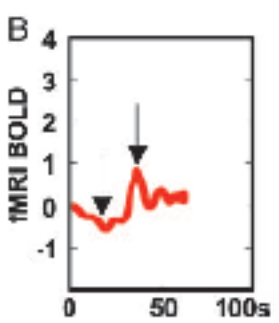
Applications

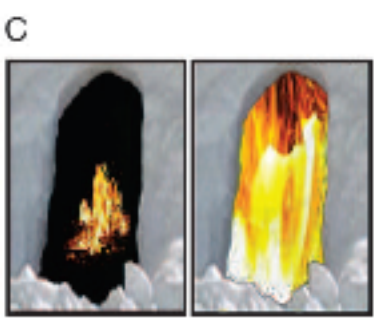
Basic Neuroscience
Behavior correlation/prediction
Pathology assessment

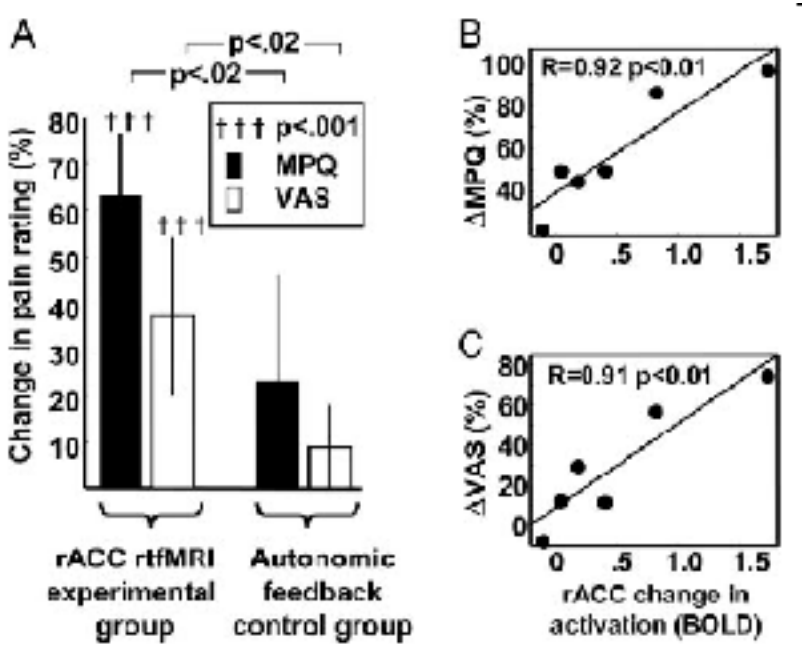
Applications

Real time fMRI feedback from Anterior Cingulate Cortex 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)

What fMRI Might Do

Complementary use for clinical diagnoses

- -utilization of clinical research results for diagnoses
- -prediction of pathology

Clinical treatment and assessment of therapy

- -better understanding mechanism of pathology for focused therapy
- -drug effect assessment
- -assessment of therapy progress, biofeedback
- -epileptic foci mapping
- -neurovascular physiology assessment

Non clinical uses

- -lie detection
- -prediction of behavior tendencies
- -brain/computer interface

What fMRI Can Do

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

What fMRI Might Do

Complementary use for clinical diagnosis

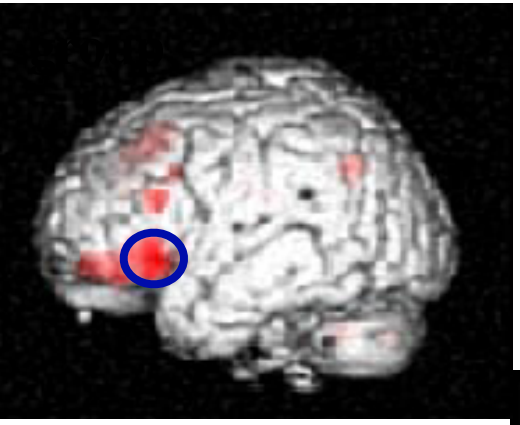
- -utilization of clinical research results
- -prediction of pathology

Clinical treatment and assessment

- -drug, therapy, rehabilitation, biofeedback
- -epileptic foci mapping
- -drug effects

Non clinical uses

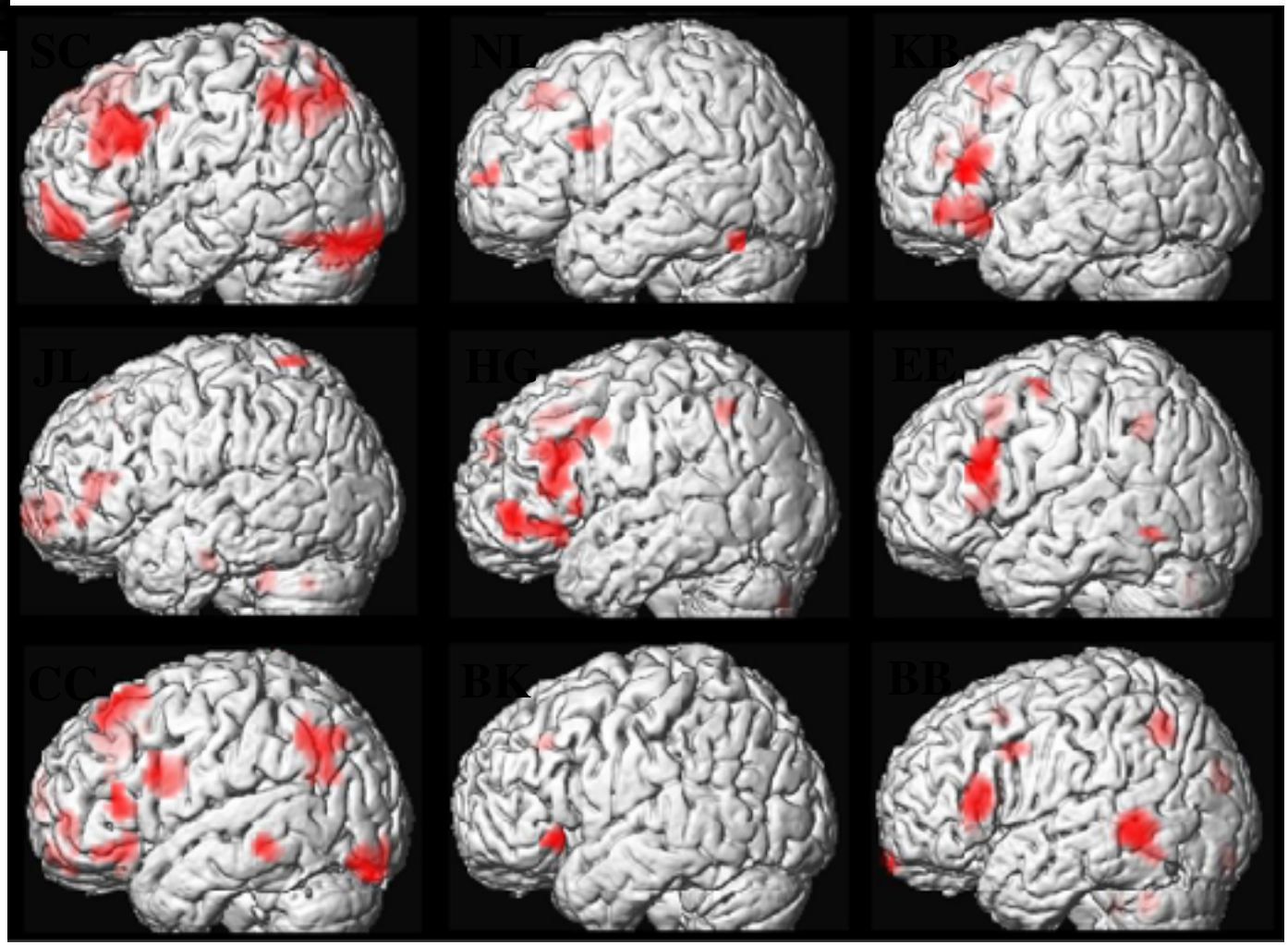
- -complementary use with behavioral, anatomical, other modality results
- -lie detection
- -prediction of behavior tendencies
- -brain/computer interface



Extensive Individual Differences in Brain Activations During Episodic Retrieval

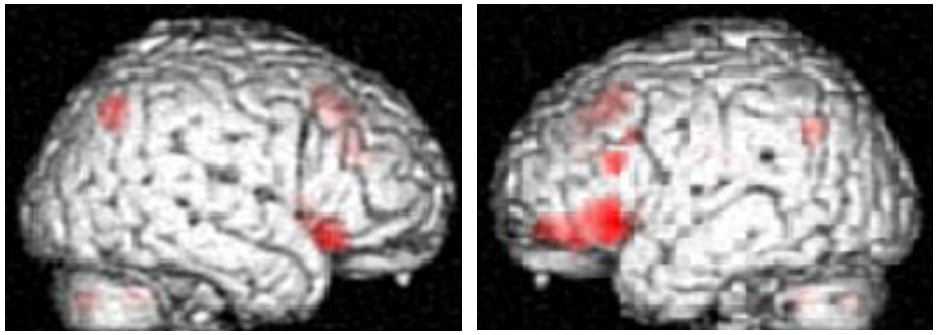
Miller et al., 2002

Individual activations from the left hemisphere of the 9 subjects

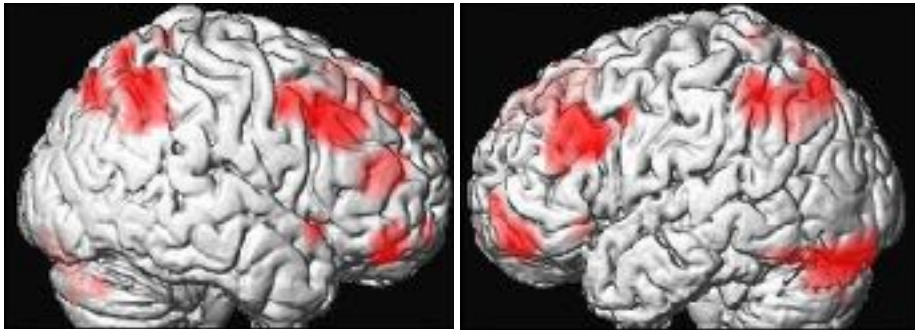


Courtesy, Mike Miler, UC Santa Barbara and Jack Van Horn, fMRI Data Center, Dartmouth University

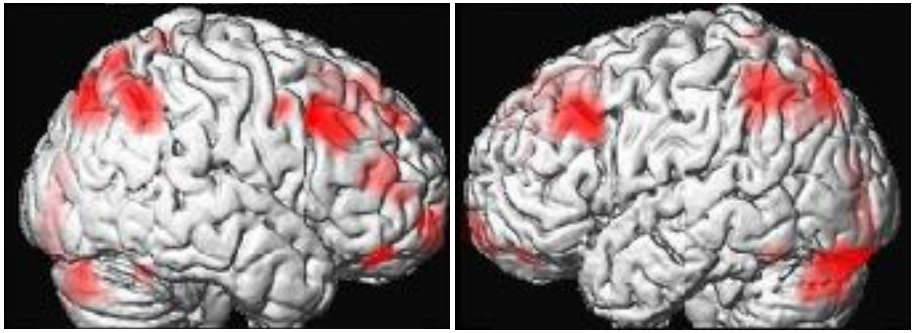
These individual patterns of activations are stable over time



Group Analysis of Episodic Retrieval



Subject SC



Subject SC 6 months later

Courtesy, Mike Miler, UC Santa Barbara and Jack Van Horn, fMRI Data Center, Dartmouth University