What fMRI Can, Can't, and Might Do

Peter A. Bandettini, Ph.D.

Section on Functional Imaging Methods

http://fim.nimh.nih.gov

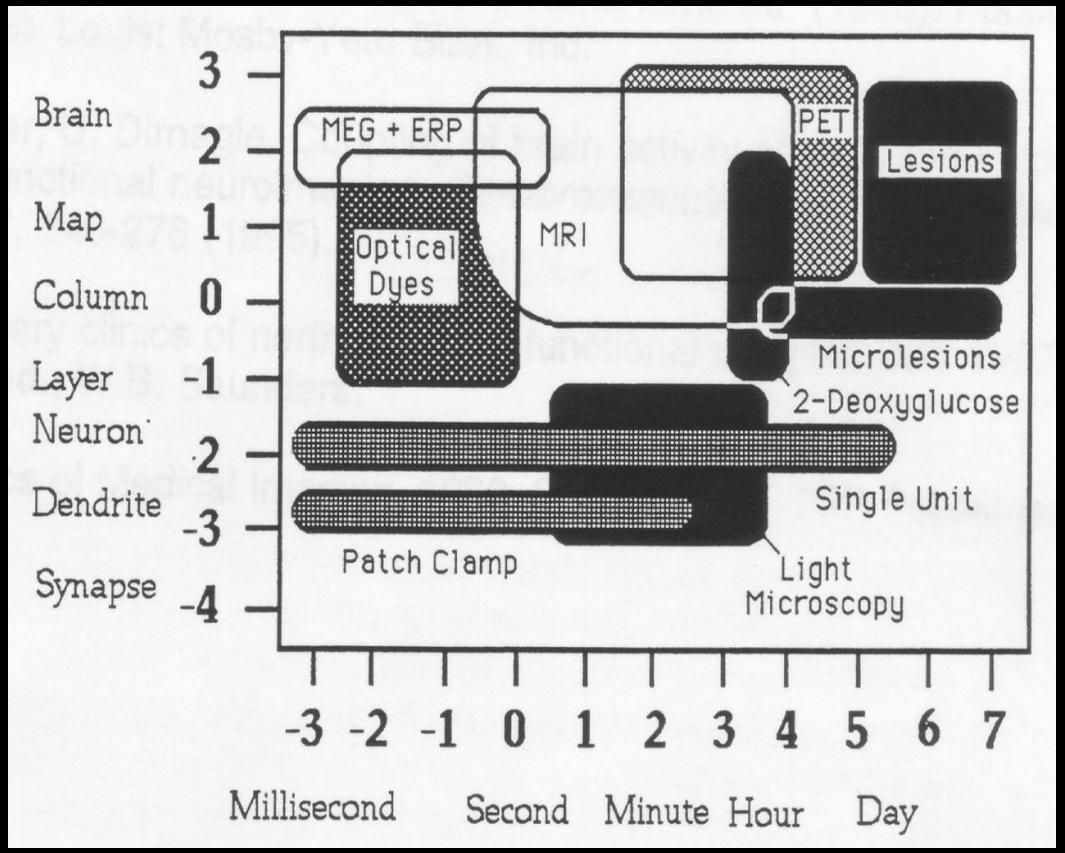
Laboratory of Brain and Cognition

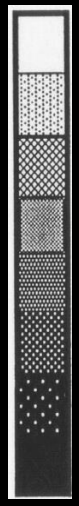
&

Functional MRI Facility

http://fmrif.nimh.nih.gov

Functional Neuroimaging Techniques





1991

A brief overview of the three main types of fMRI contrast

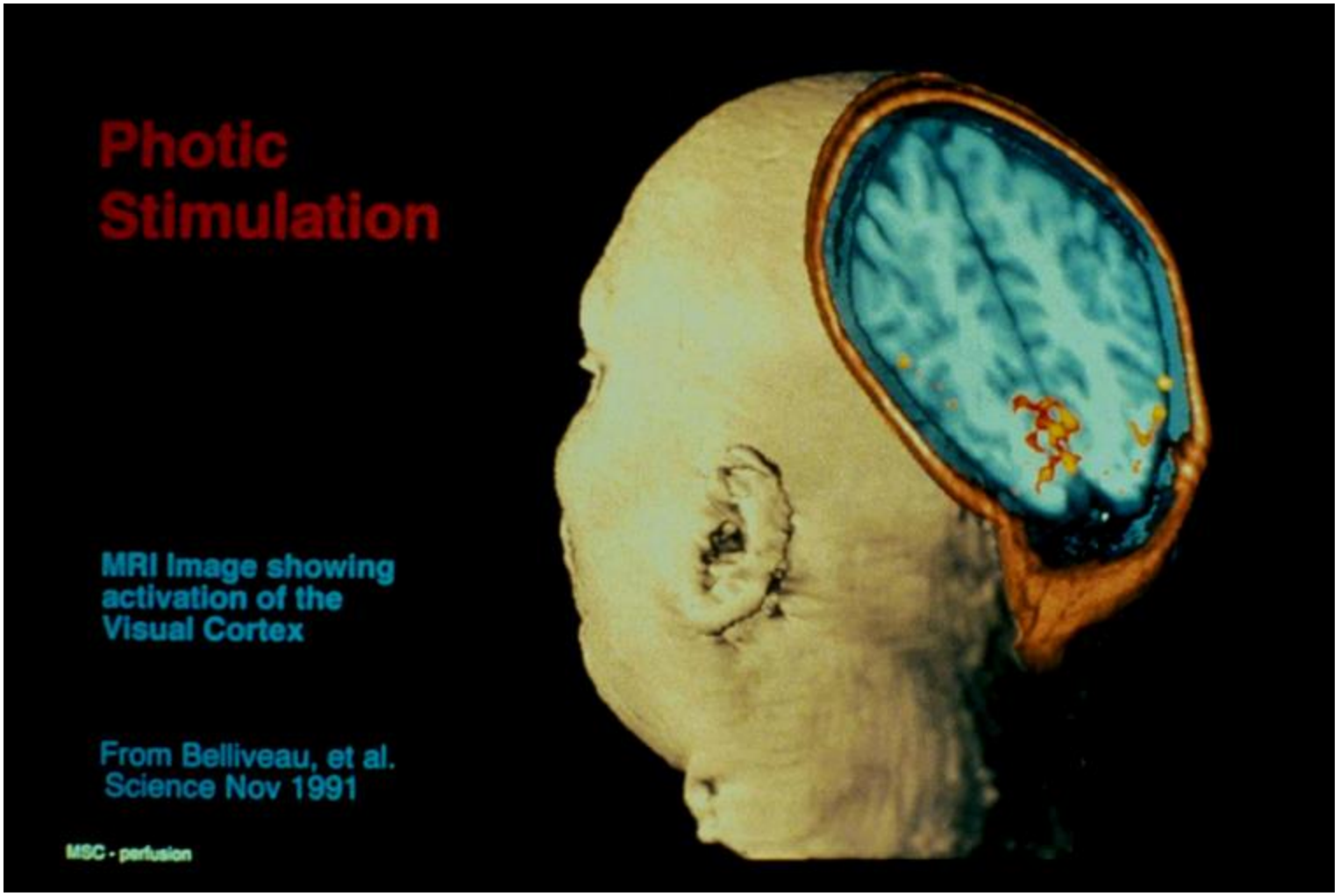
Volume

Flow or Perfusion

Oxygenation

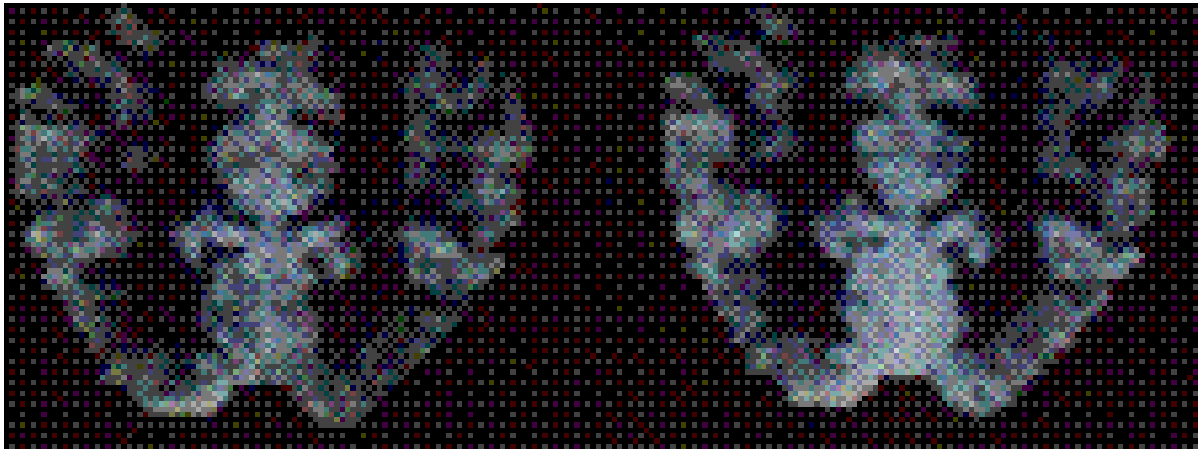
Blood Volume

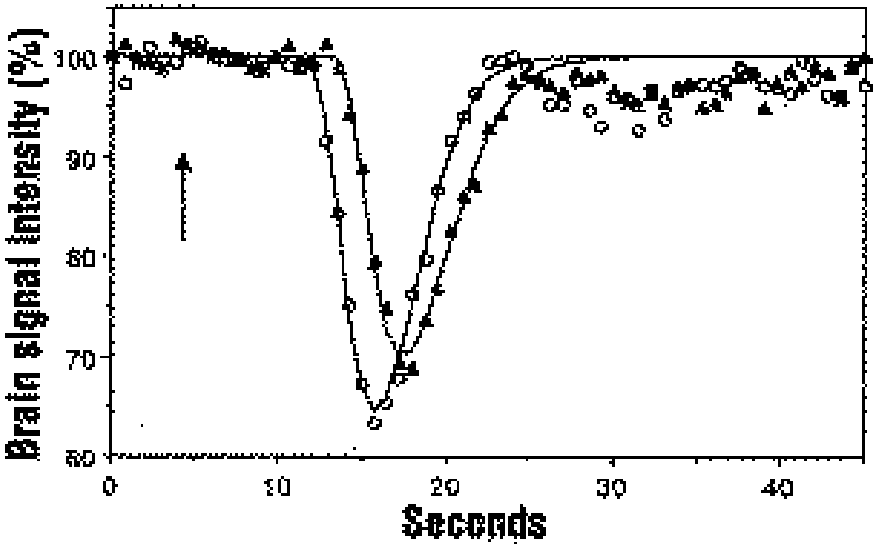
What started it all…

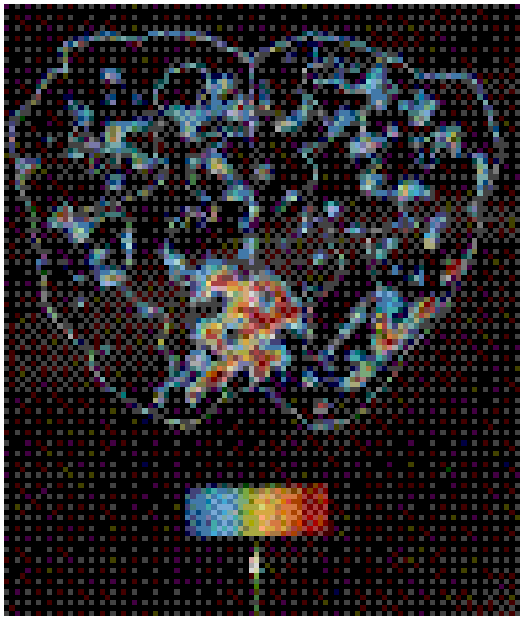


Blood Volume

Resting Active

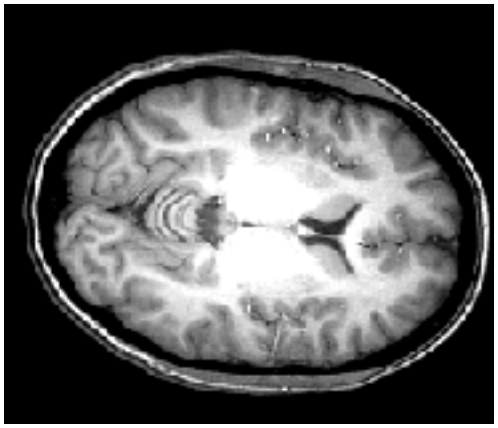






MRI vs. fMRI

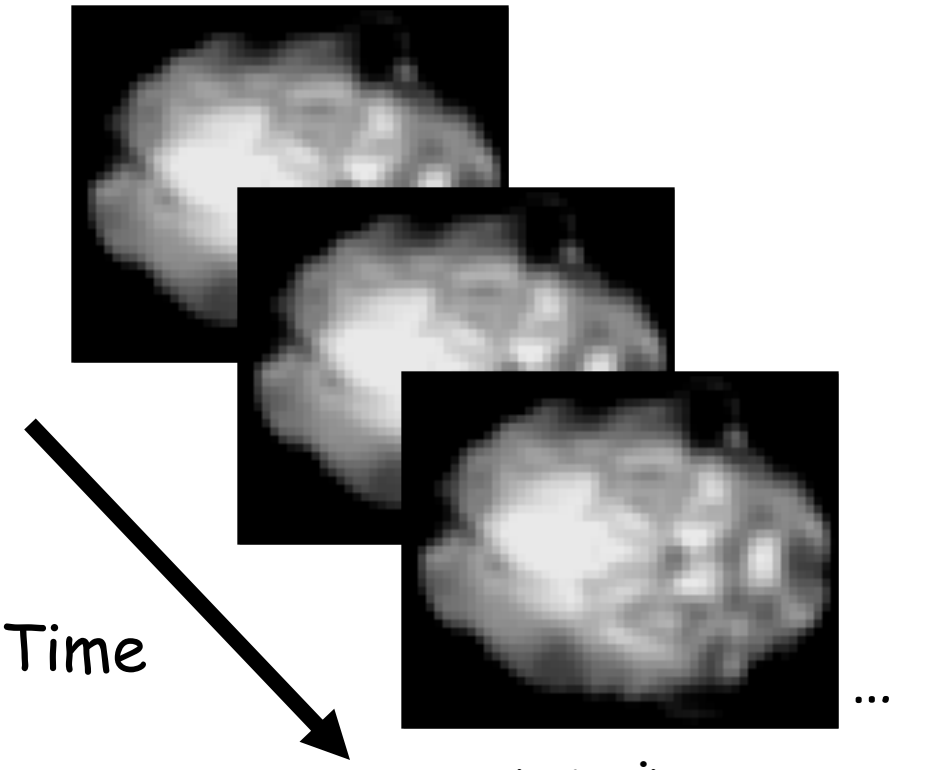
MRI



one image

high resolution
(1 mm or less)

fMRI

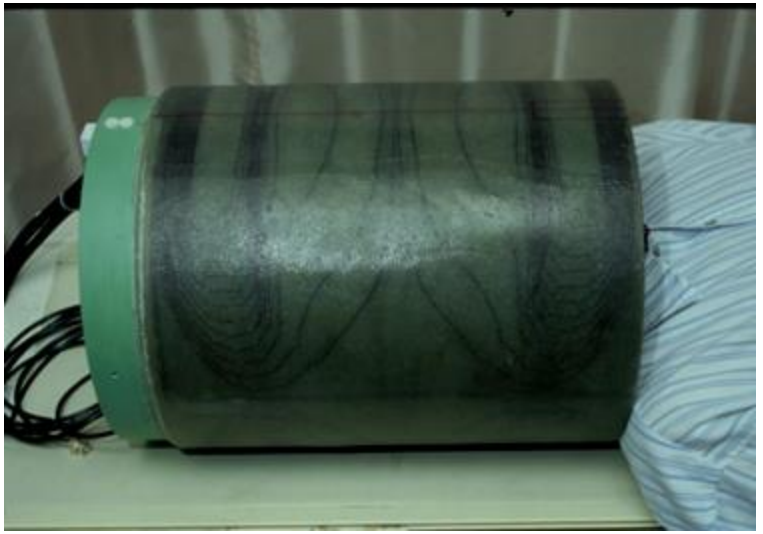


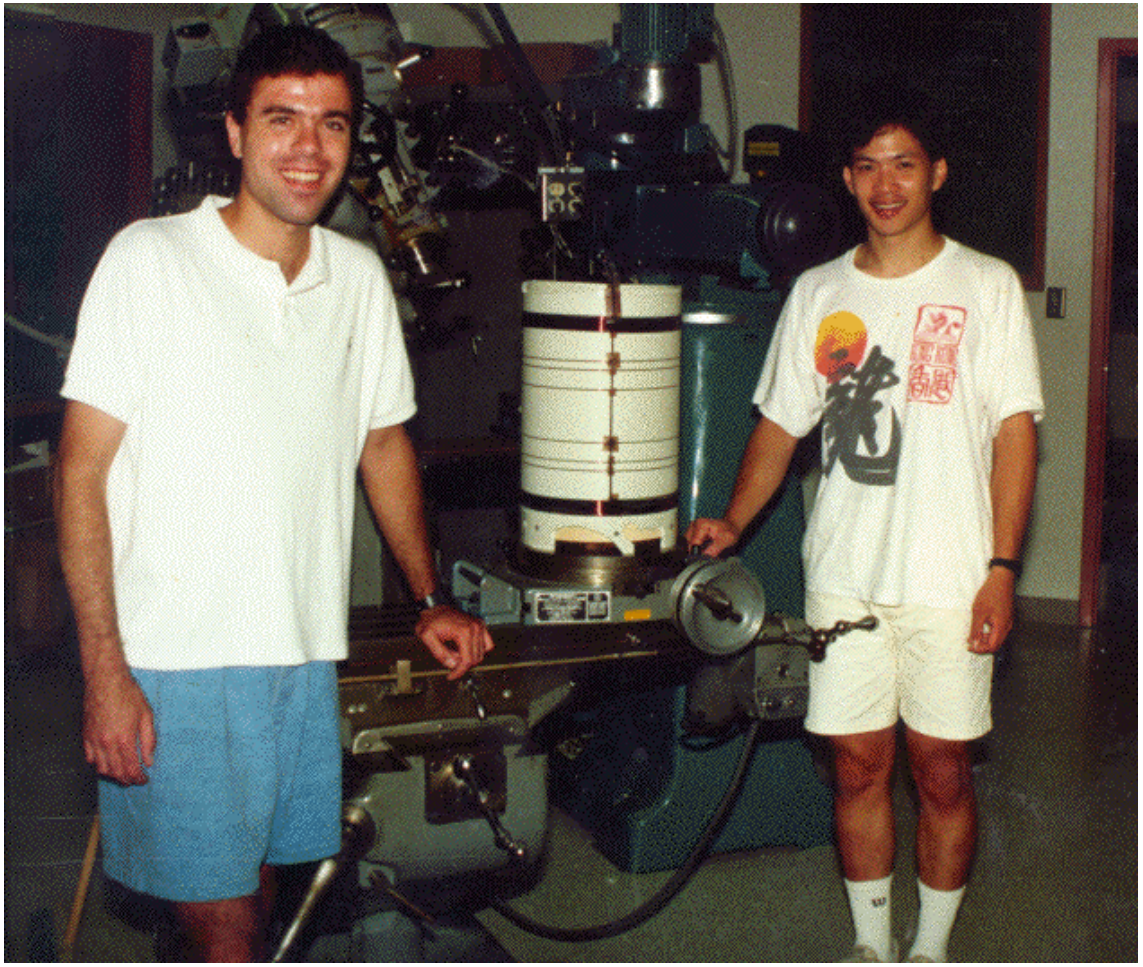
many images
(e.g., every 2 sec for 5 mins)

low resolution
(1.5 to 4 mm)

1991-1992

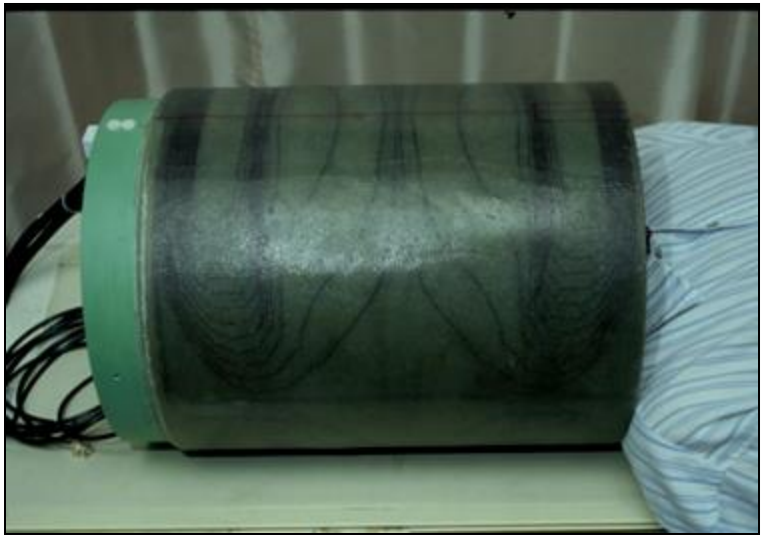
1992-1999



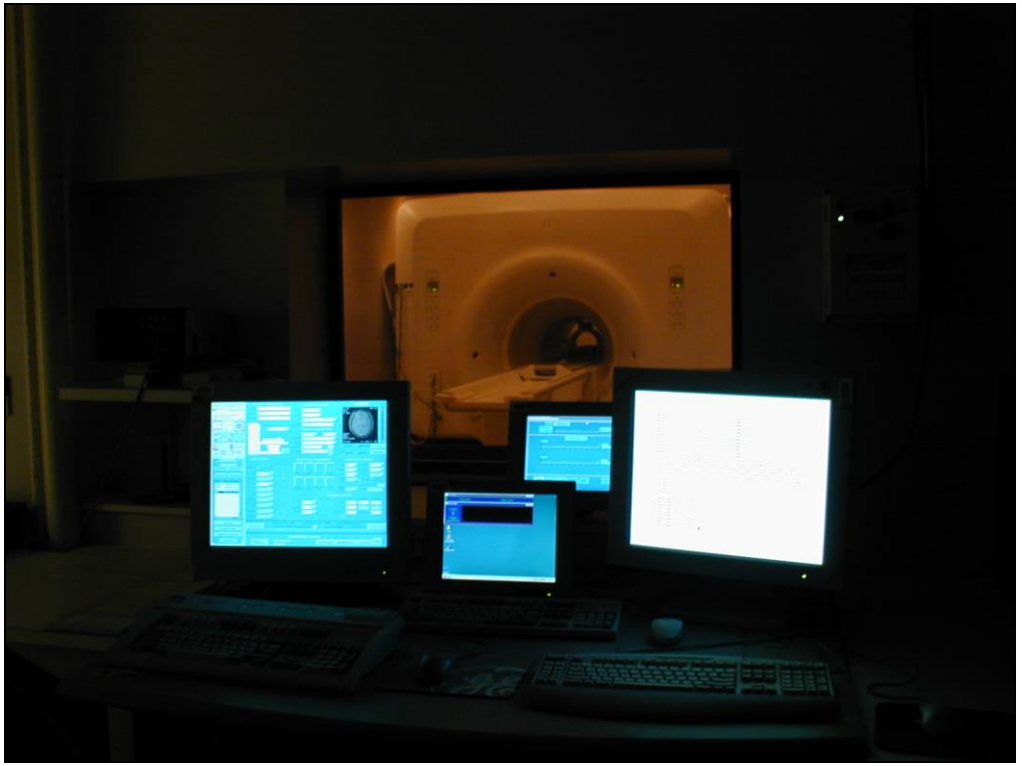


August, 1991

Local Gradient Coil
(low inductance)

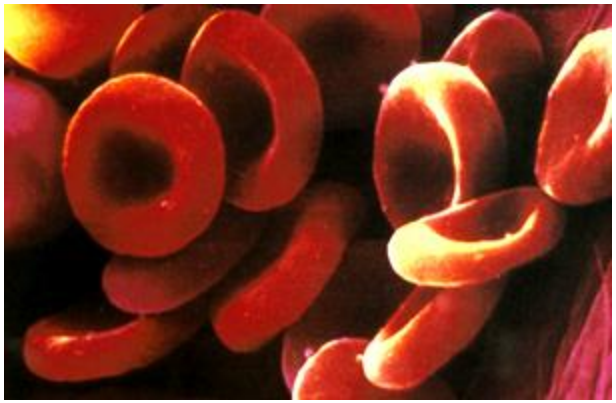


Whole body gradients
(more powerful amplifiers)



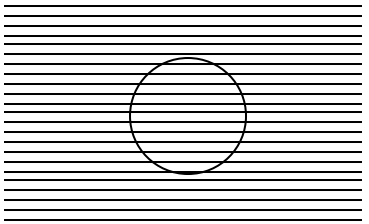
Blood Oxygenation

Oxygenated and deoxygenated red blood cells have different magnetic properties

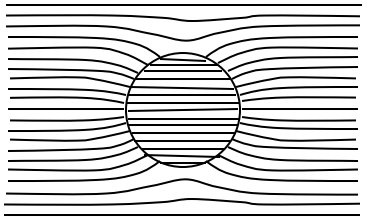


red blood cells

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**.

Blood Oxygenation

Cerebral Tissue Activation

↓

Local Vasodilatation

↓

Increase in Cerebral Blood Flow and Volume → Oxygen Delivery Exceeds Metabolic Need

↓

Increase in Capillary and Venous Blood Oxygenation

↓

Decrease in Deoxy-hemoglobin

Deoxy-hemoglobin: paramagnetic
Oxy-hemoglobin: diamagnetic

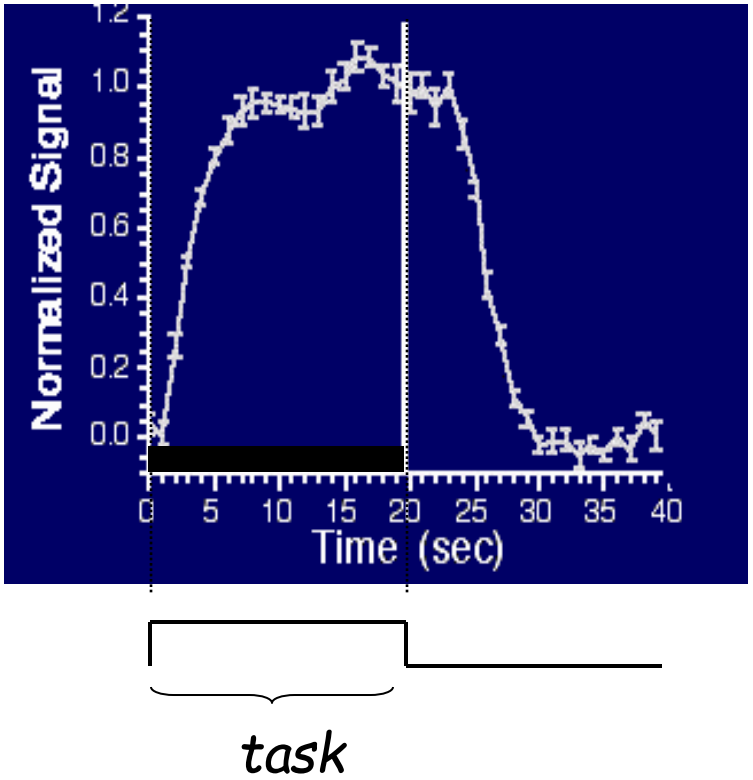
↓

Decrease in susceptibility-related intravoxel dephasing → Increase in T2 and T2*

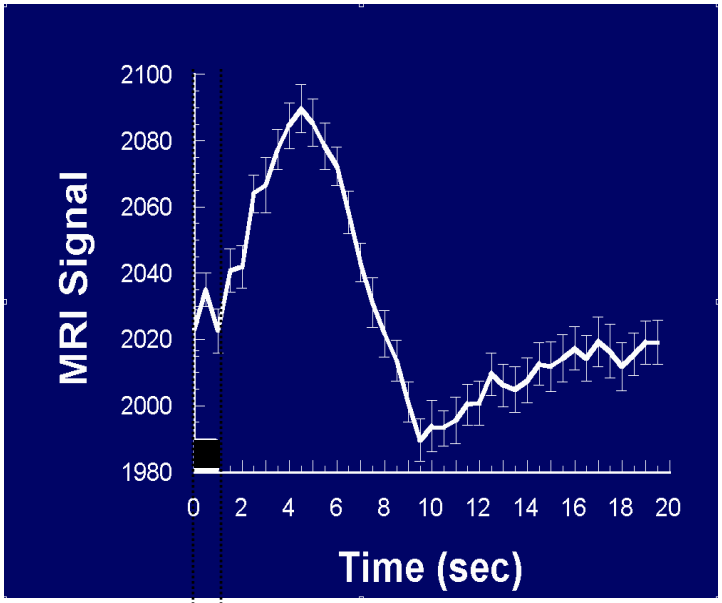
↓

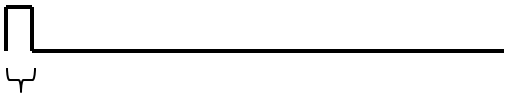
Local Signal Increase in T2 and T2* - weighted sequences

Blood Oxygenation



task

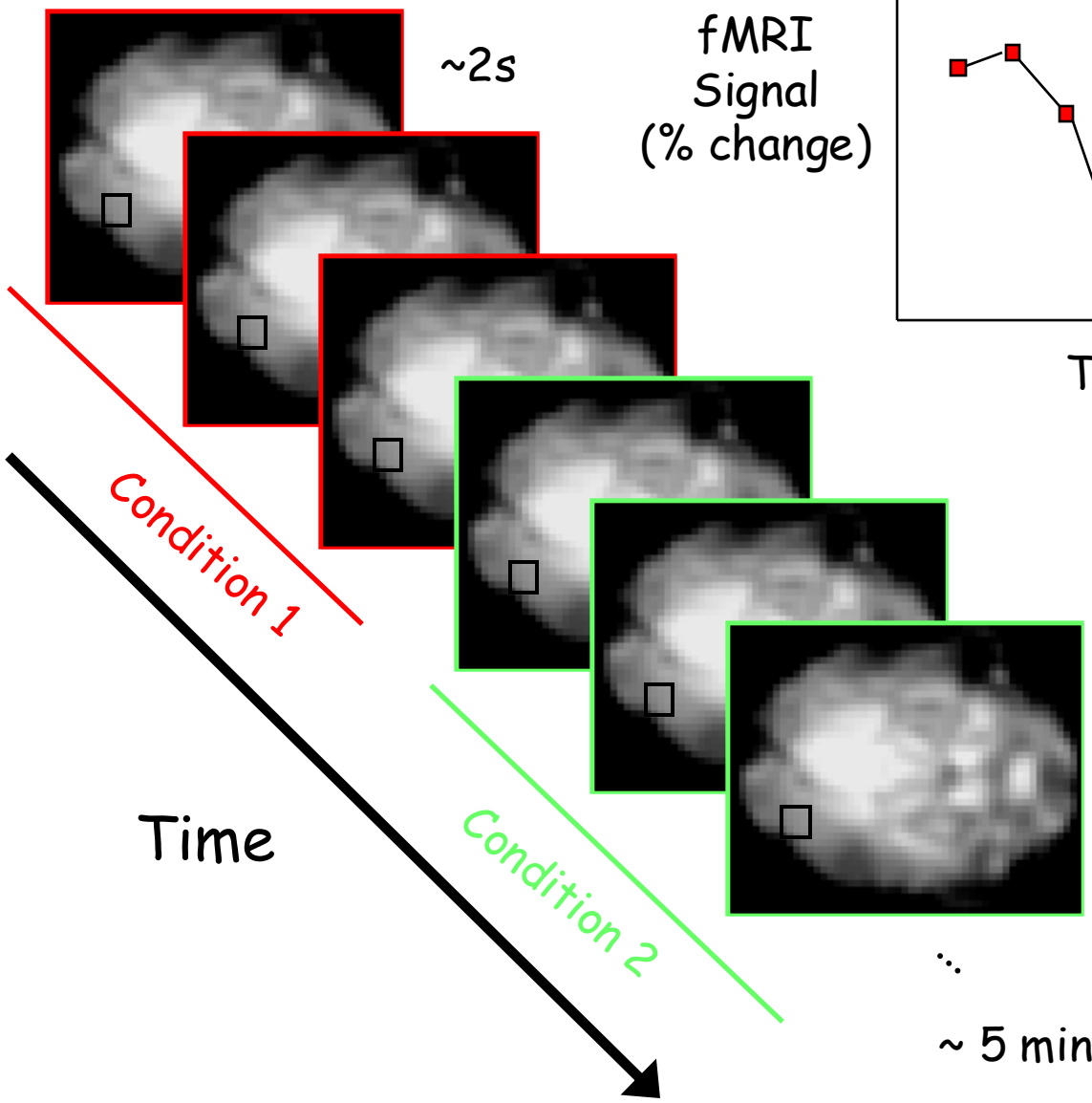




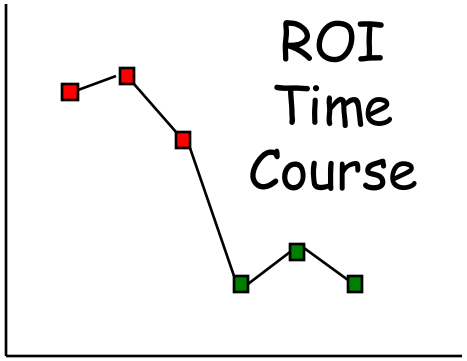
task

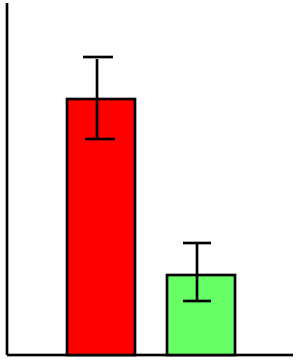
Activation Statistics

Functional images

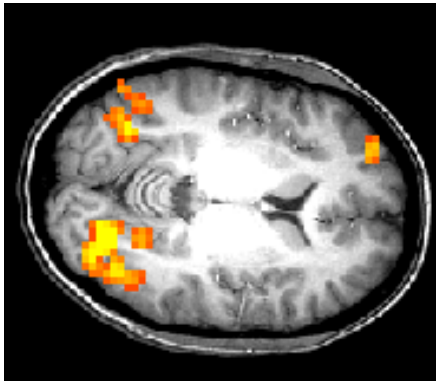


fMRI Signal (% change)



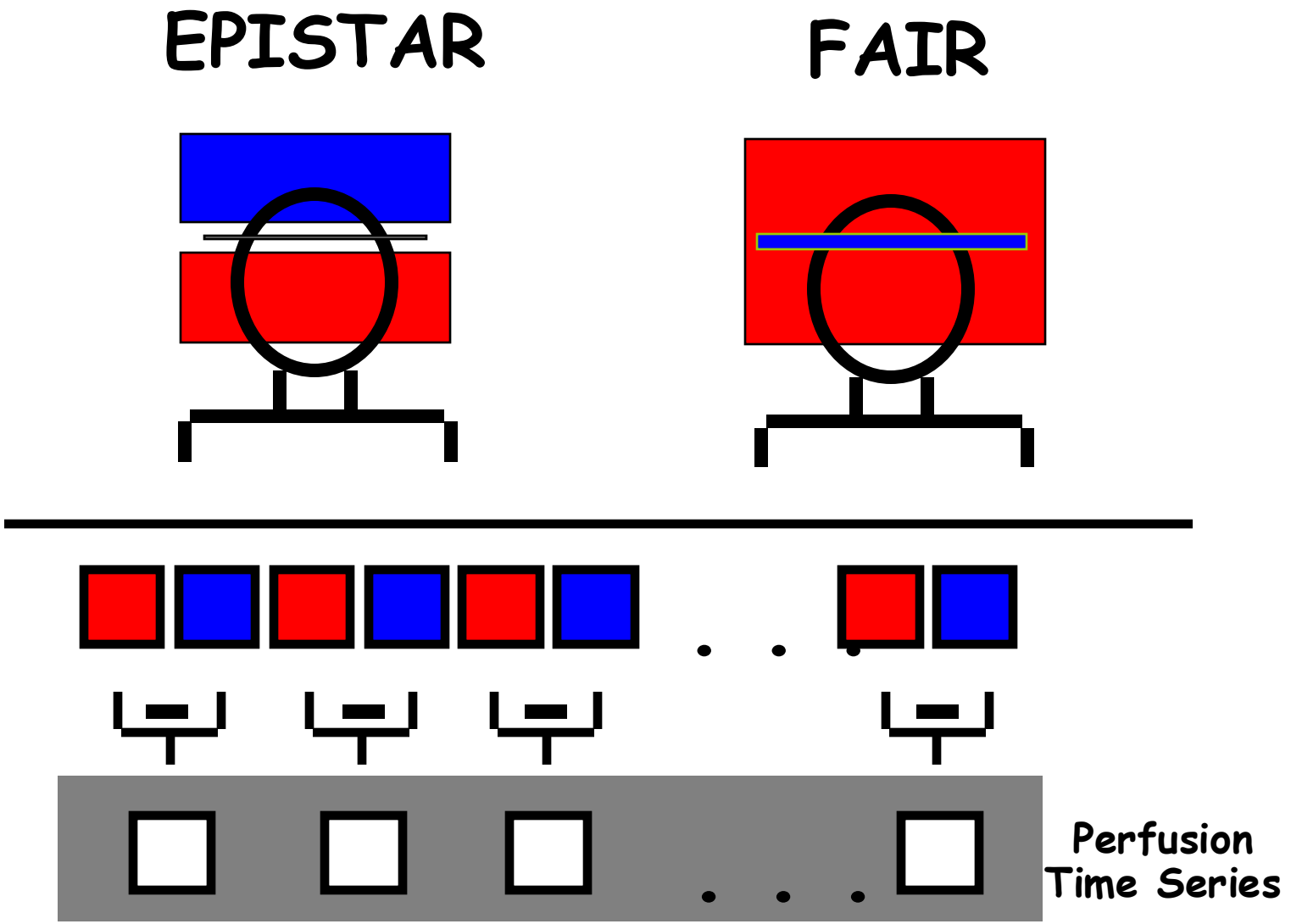


Statistical Map
superimposed on anatomical MRI image

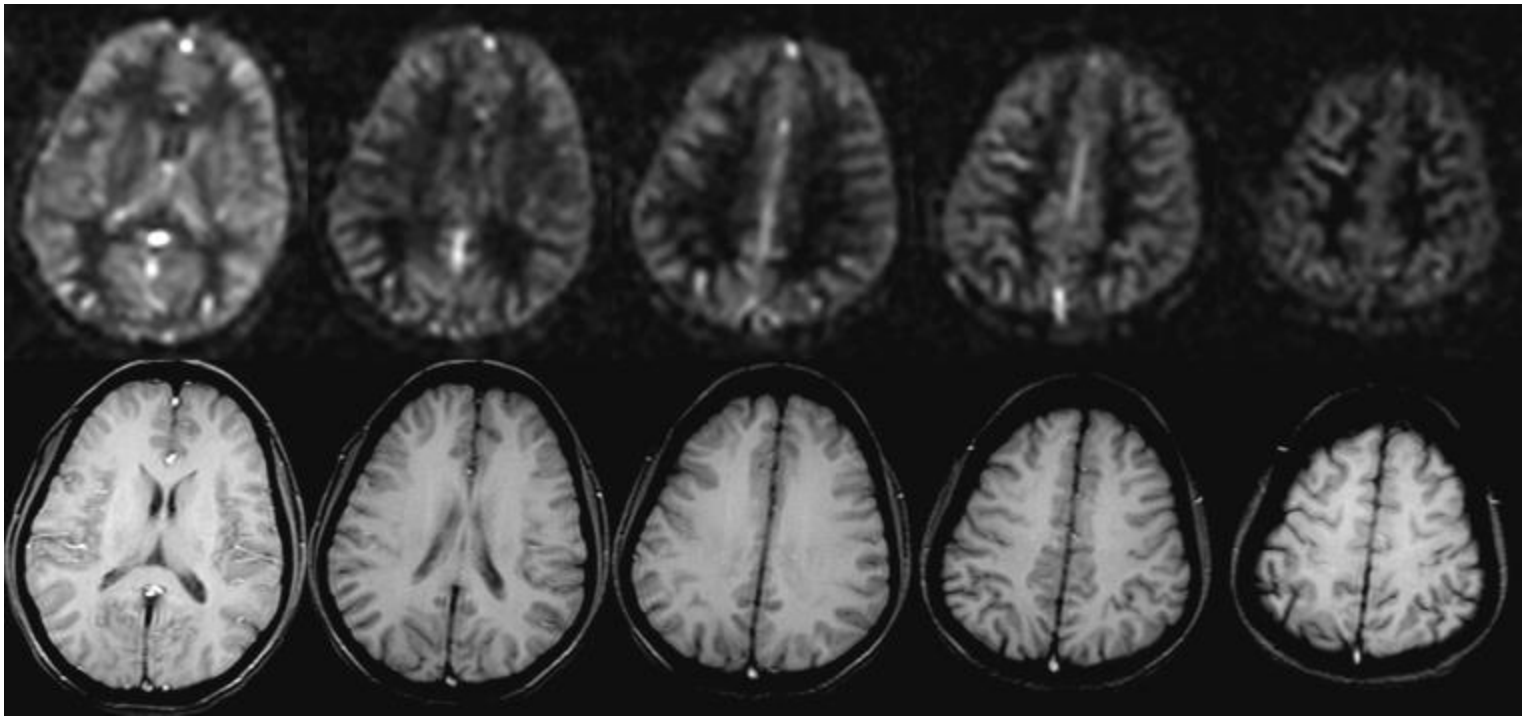


Courtesy, Robert Cox

Perfusion



Perfusion



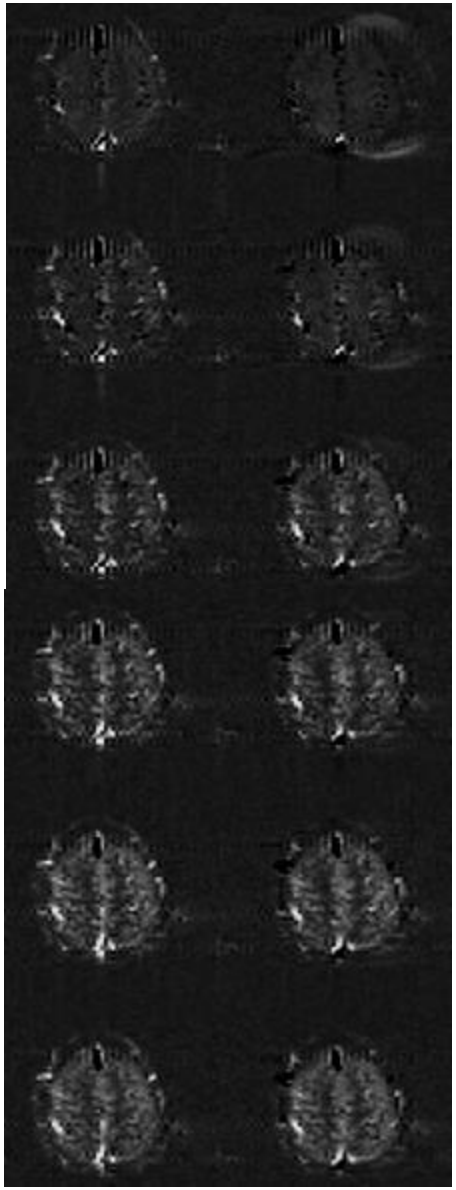
Williams, D. S., Detre, J. A., Leigh, J. S. & Koretsky, A. S. (1992) "Magnetic resonance imaging of perfusion using spin-inversion of arterial water." Proc. Natl. Acad. Sci. USA 89, 212-216.

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.

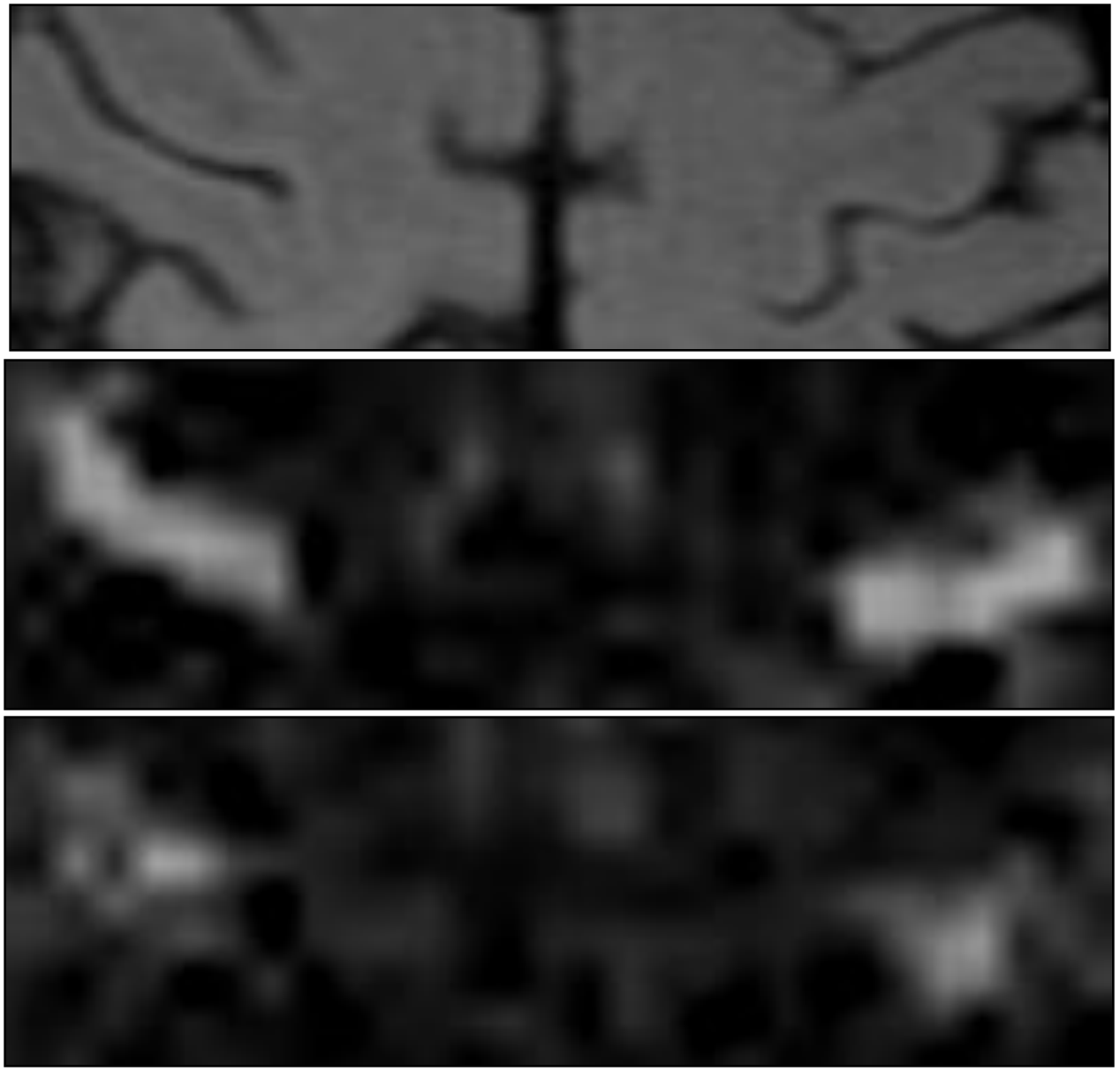
Kwong, K. K. et al. (1995) "MR perfusion studies with T1-weighted echo planar imaging."Magn. Reson. Med. **34**, 878-887.

Perfusion

TI (ms)	FAIR	EPISTAR
200		
400		
600		
800		
1000		
1200		

Perfusion

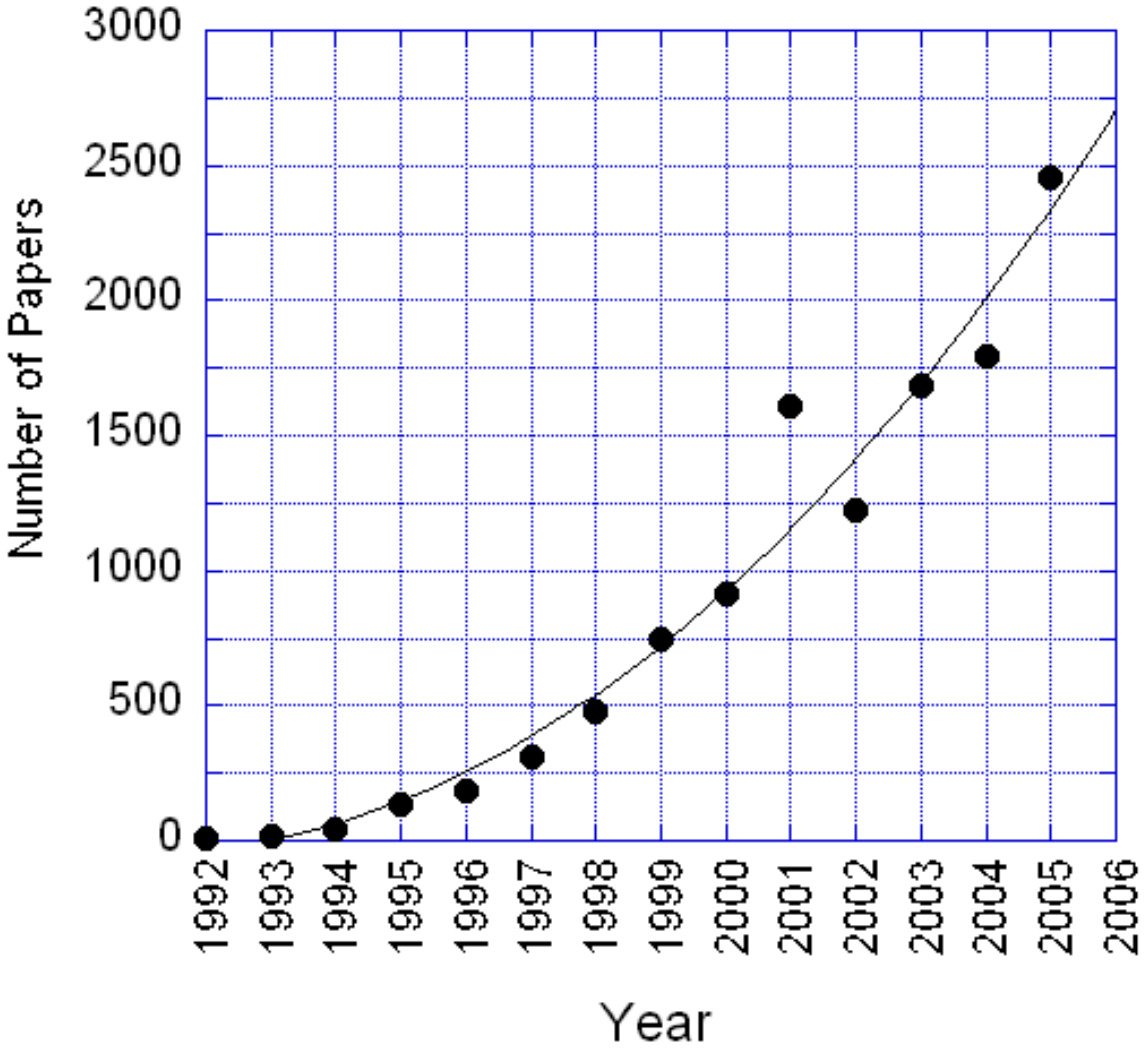
Simultaneous BOLD and Perfusion



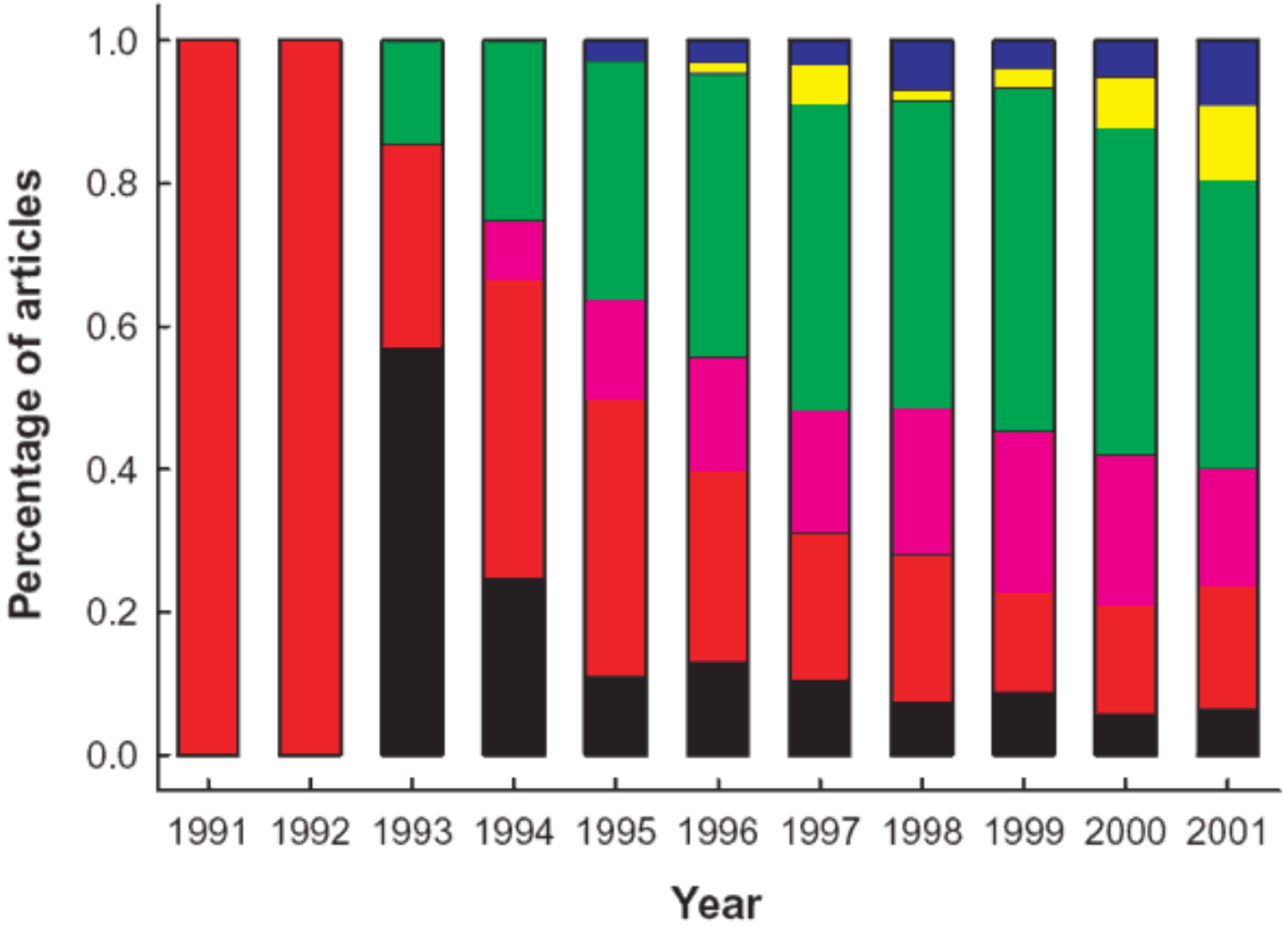
BOLD

Perfusion

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

Technology

Coil arrays
High field strength
High resolution
Novel functional contrast

Methodology

Connectivity assessment
Multi-modal integration
Pattern classification
Task design

Interpretation

Fluctuations
Dynamics
Cross - modal comparison

Applications

Basic Neuroscience
Behavior correlation/prediction
Pathology correlation

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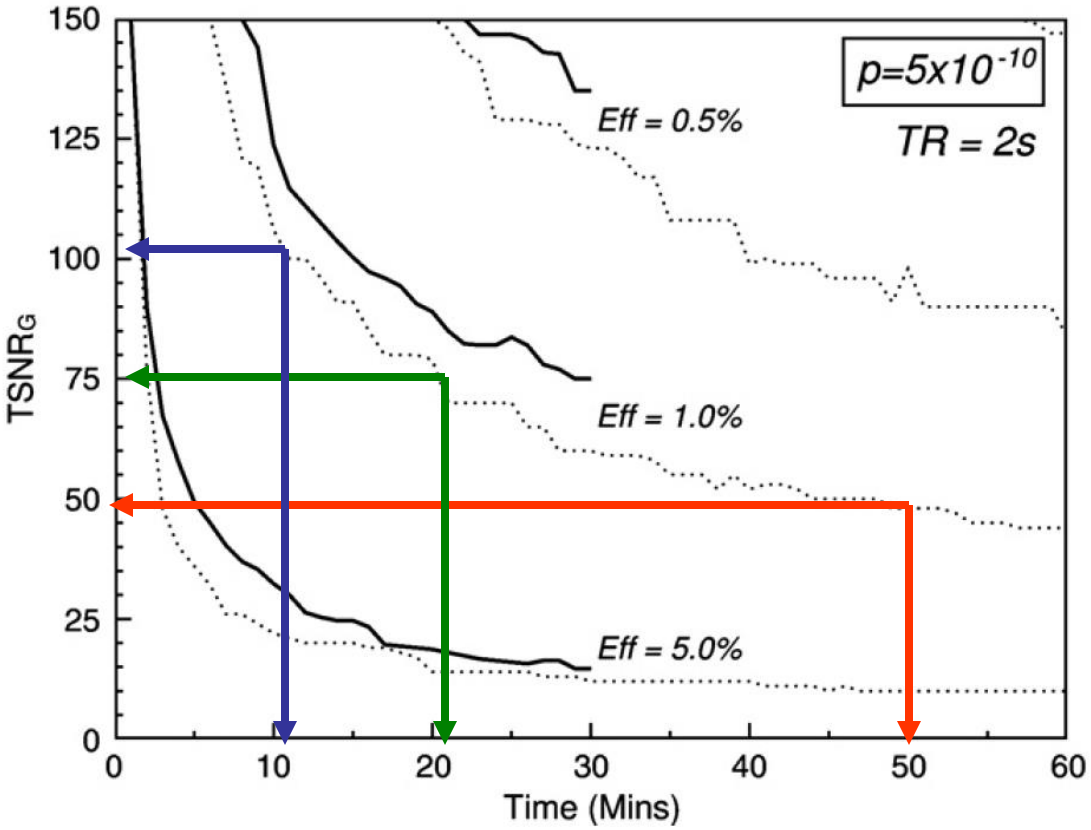
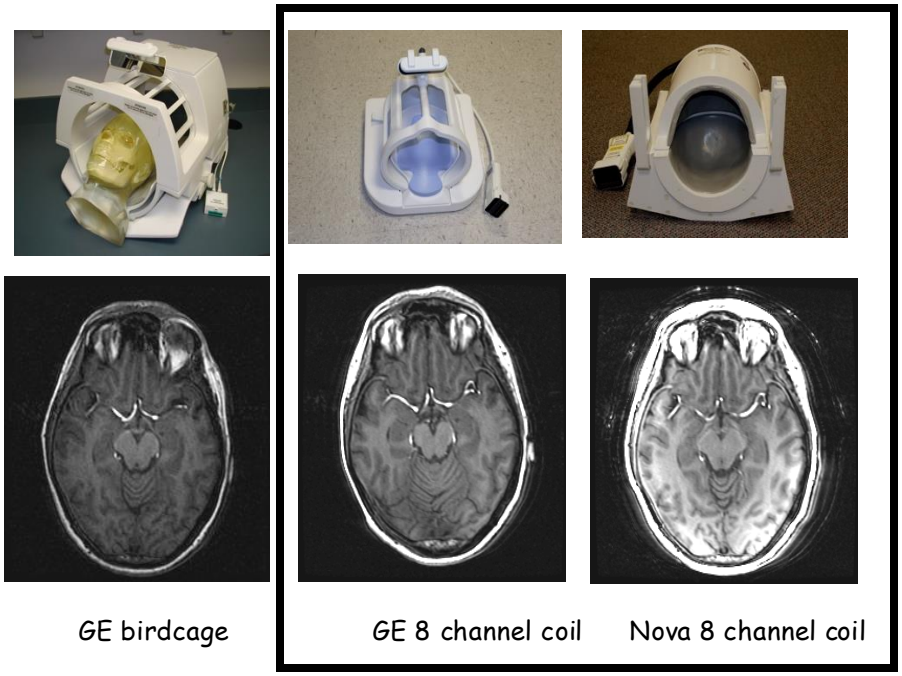


K. Murphy, J. Bodurka, P. A. Bandettini, How long to scan? The relationship between fMRI temporal signal to noise and the necessary scan duration. *NeuroImage*, 34, 565-574 (2007)

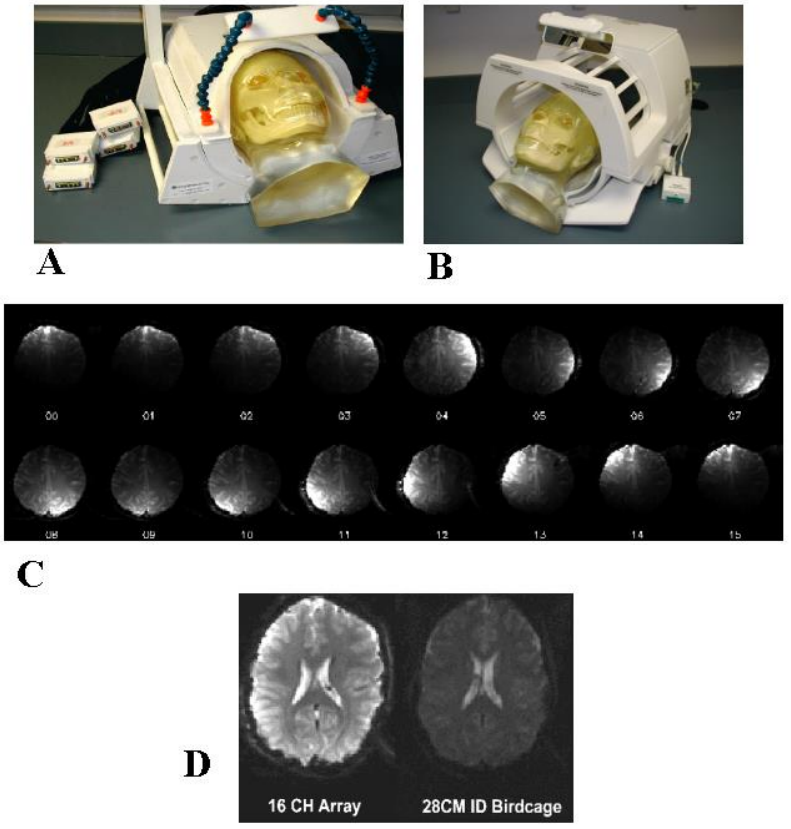
Technology

8 channel parallel receiver coil



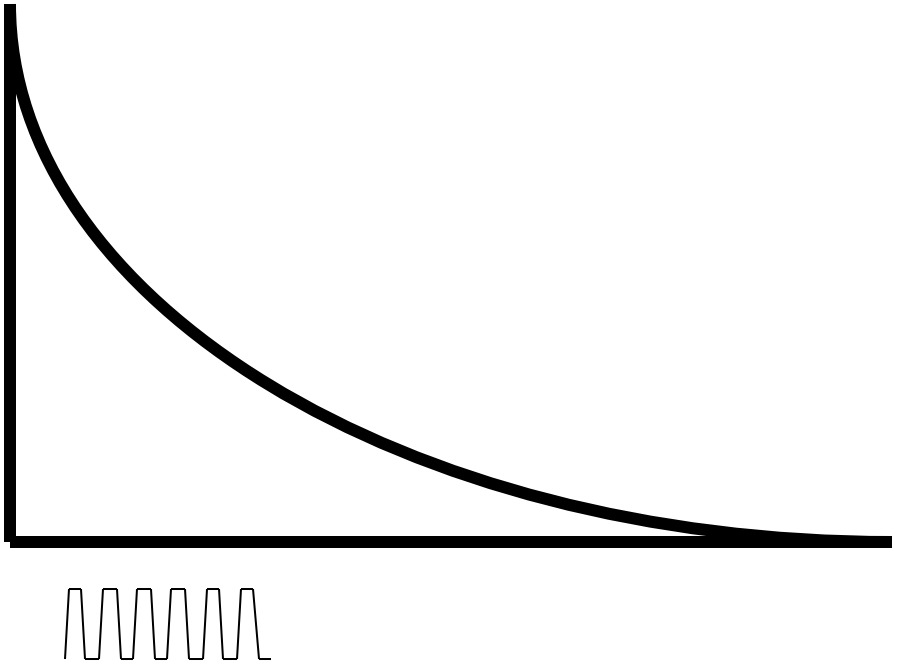
GE birdcage | GE 8 channel coil | Nova 8 channel coil

16 channel parallel receiver coil

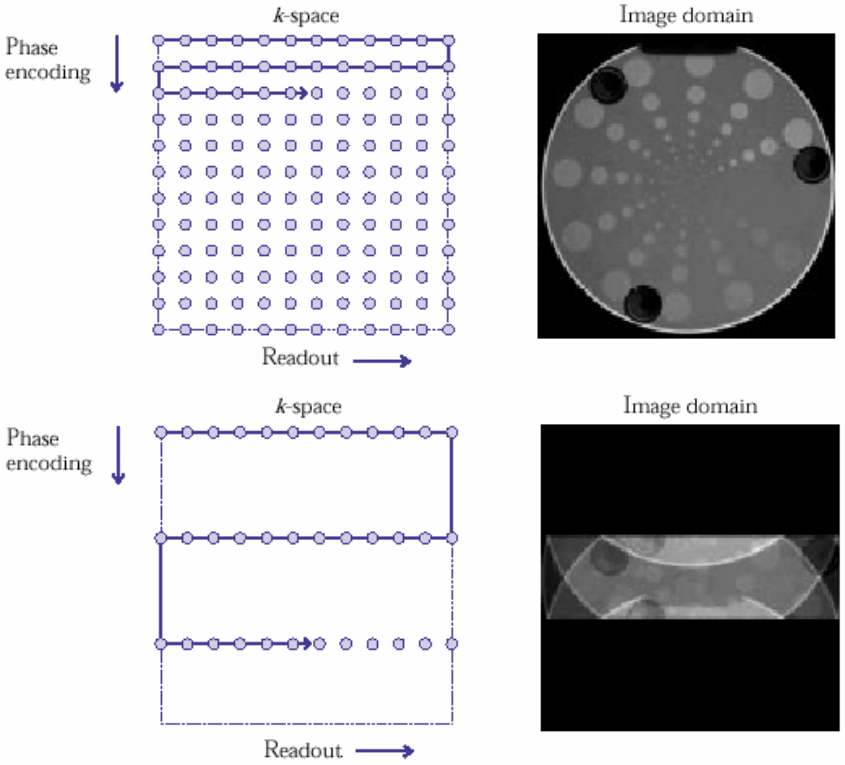


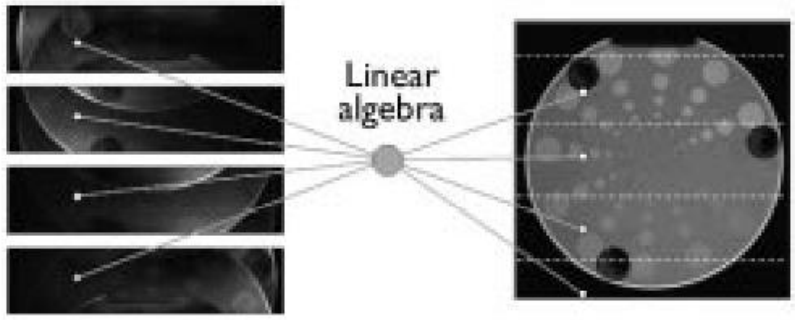
J. Bodurka, et al, Magnetic Resonance in Medicine 51 (2004) 165-171.

Technology



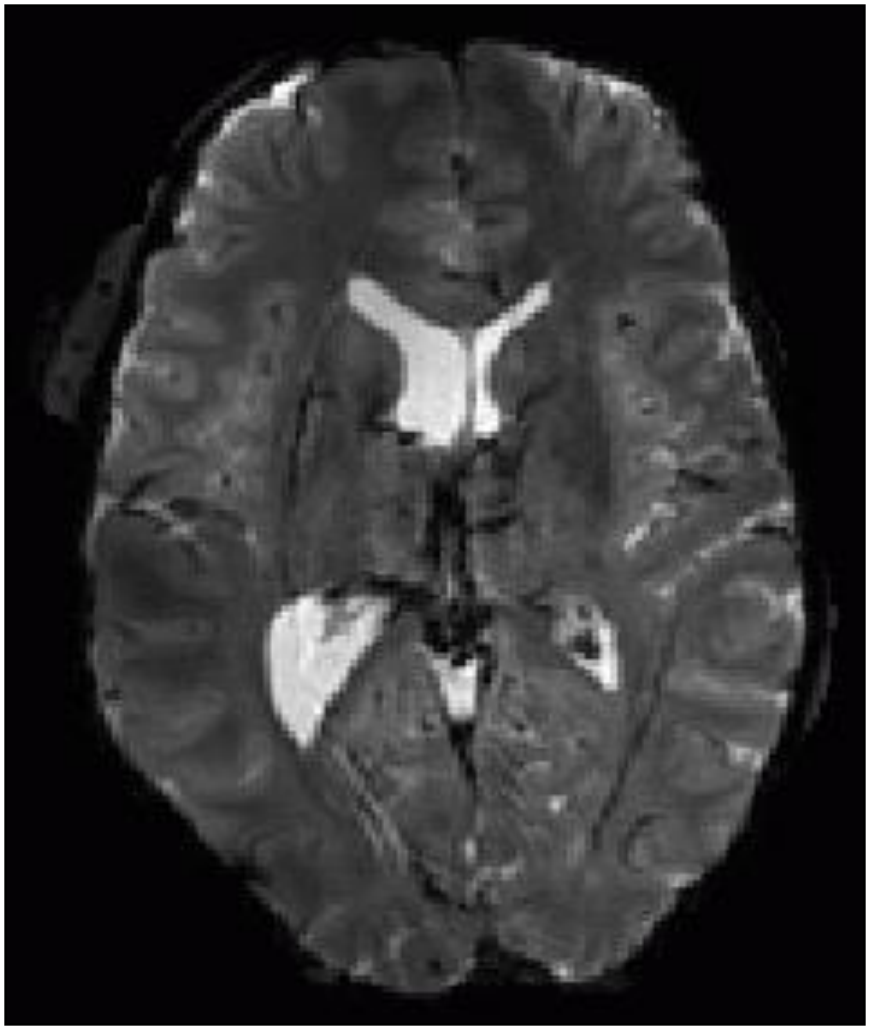
≈ 5 to 30 ms





Pruessmann, et al.

Technology

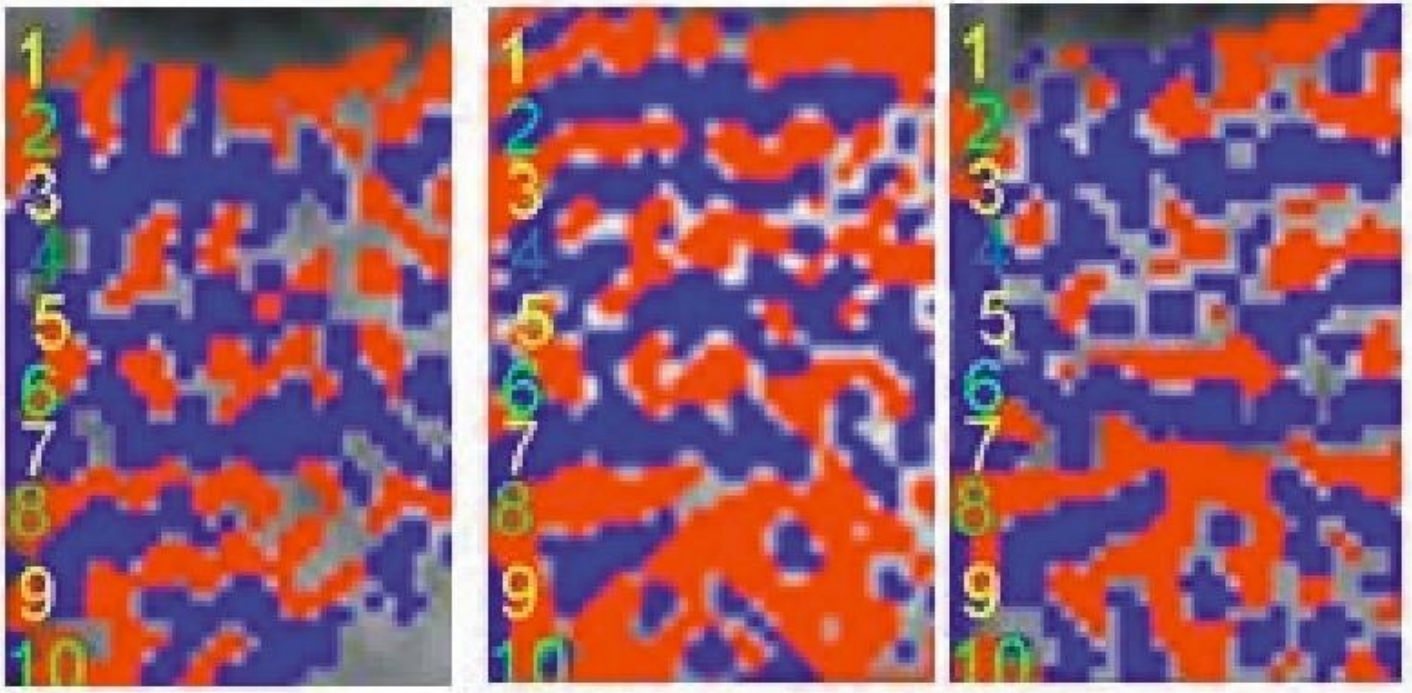


3T single-shot SENSE EPI using 16 channels: 1.25x1.25x2mm

Technology

HSE-BOLD demonstration of ocular dominance columns

human, 7T, 0.5×0.5×3 mm^3

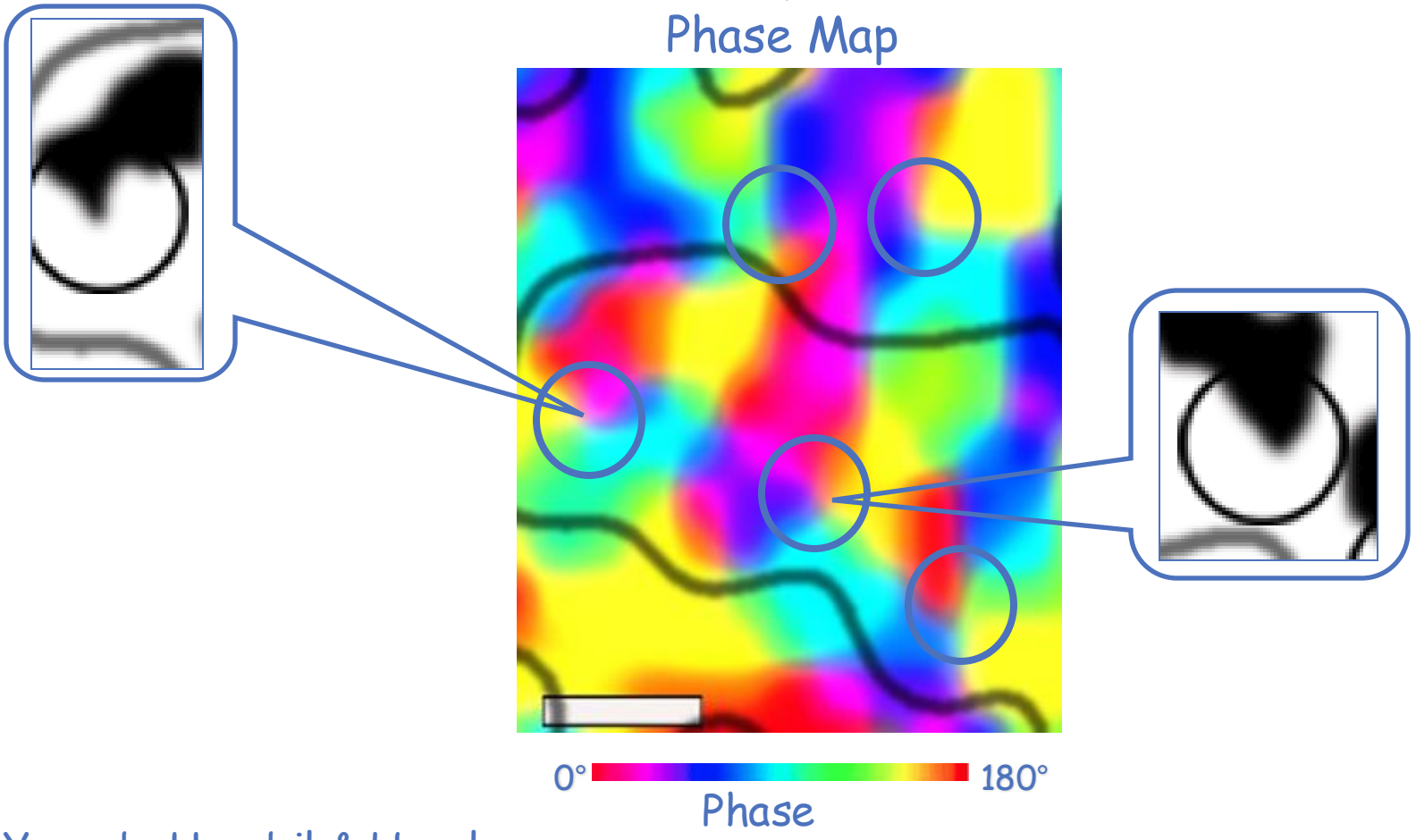


day 1 **day 2** **day 3**

Yacoub et al: differential maps contrasting stimulation of the left and right eye

Technology

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



Yacoub, Ugurbil & Harel
University of Minnesota / CMRR
HBM 2006

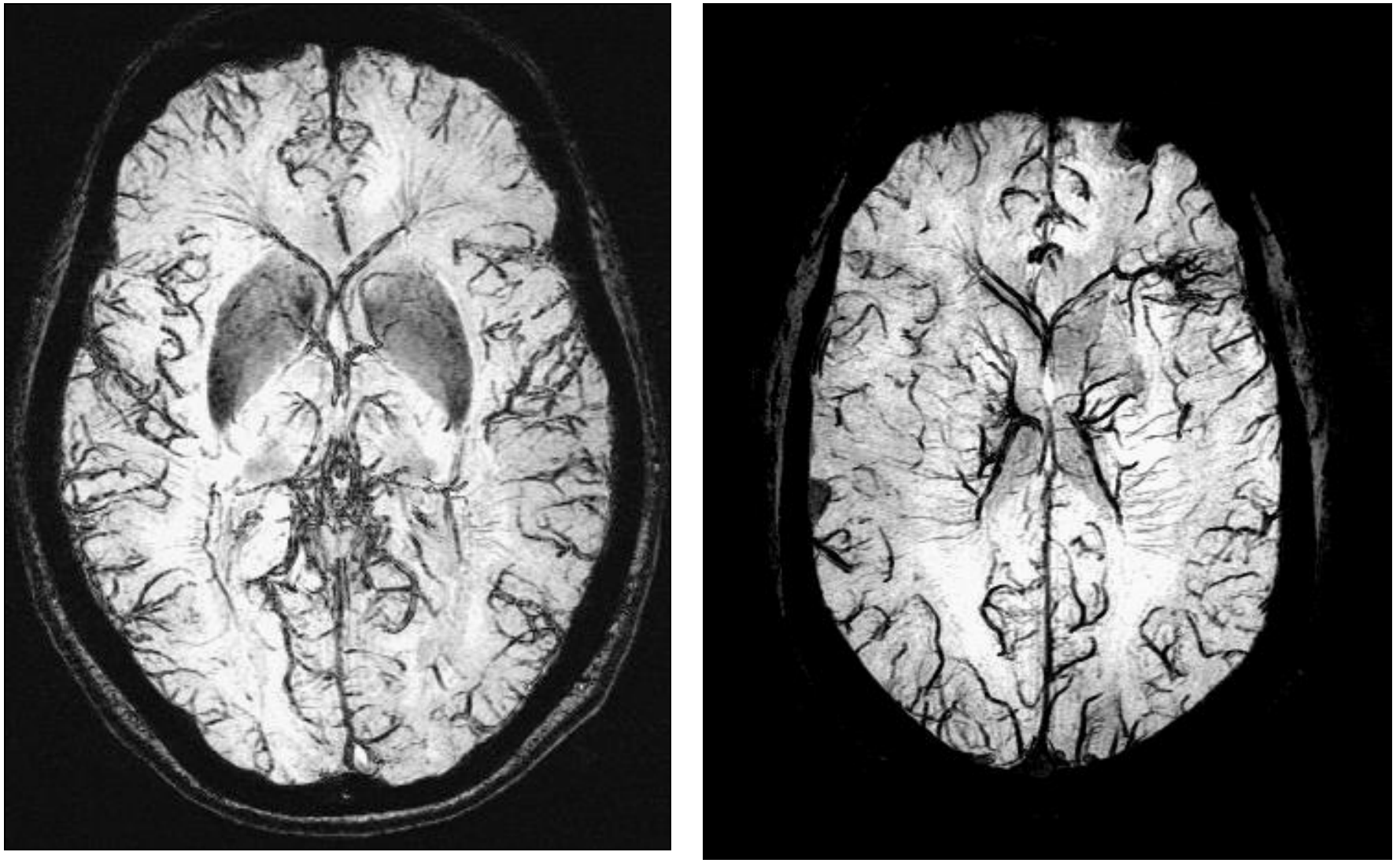
Scalebar = 0.5 mm

fMRI Contrast

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

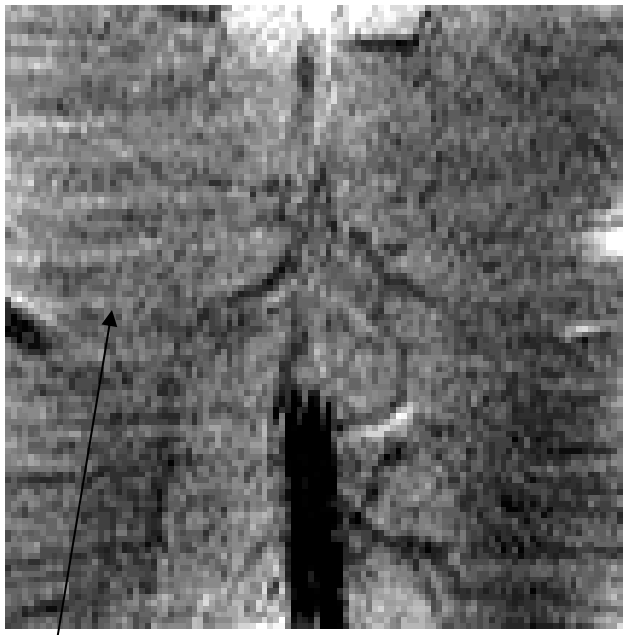
Technology

BOLD effect to highlight veins: 3 Tesla



Bove-Bettis, et al (2004), SMRT

Technology



fiber bundles?

Courtesy Tie-Qiang Li, NINDS

Technology

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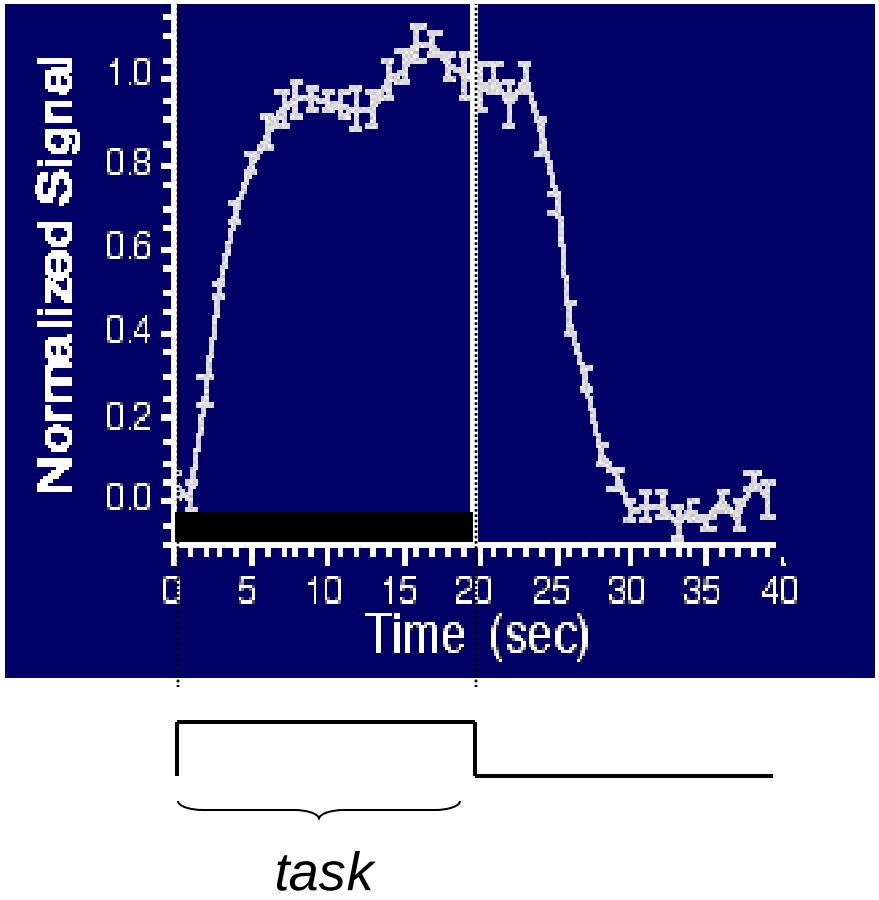
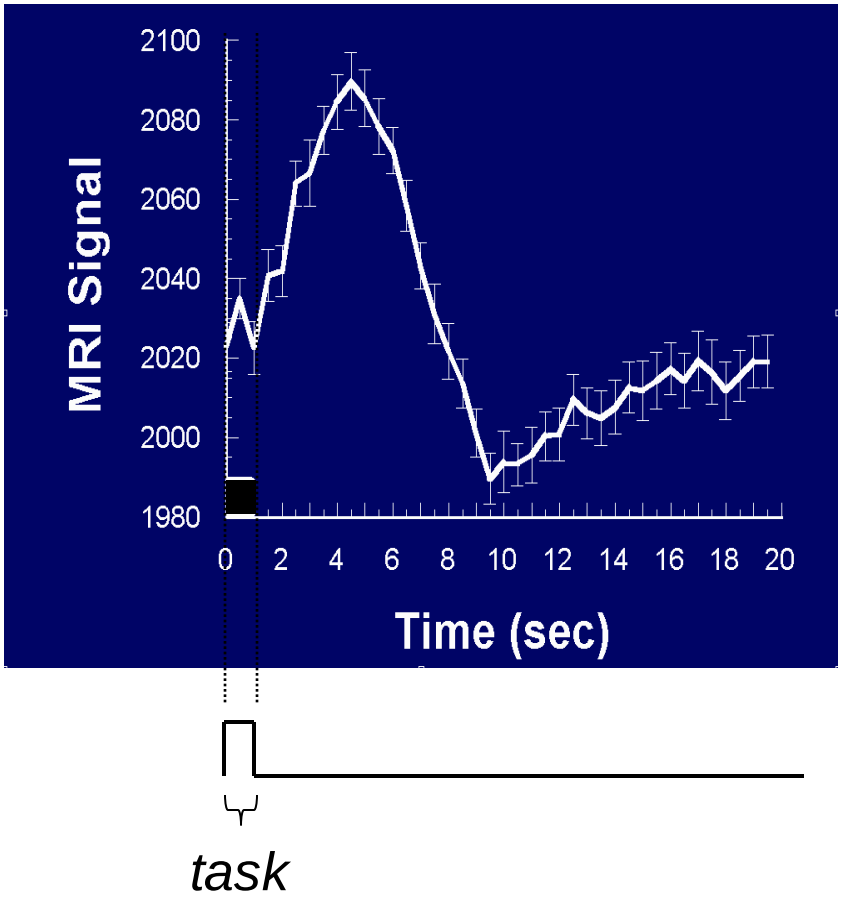
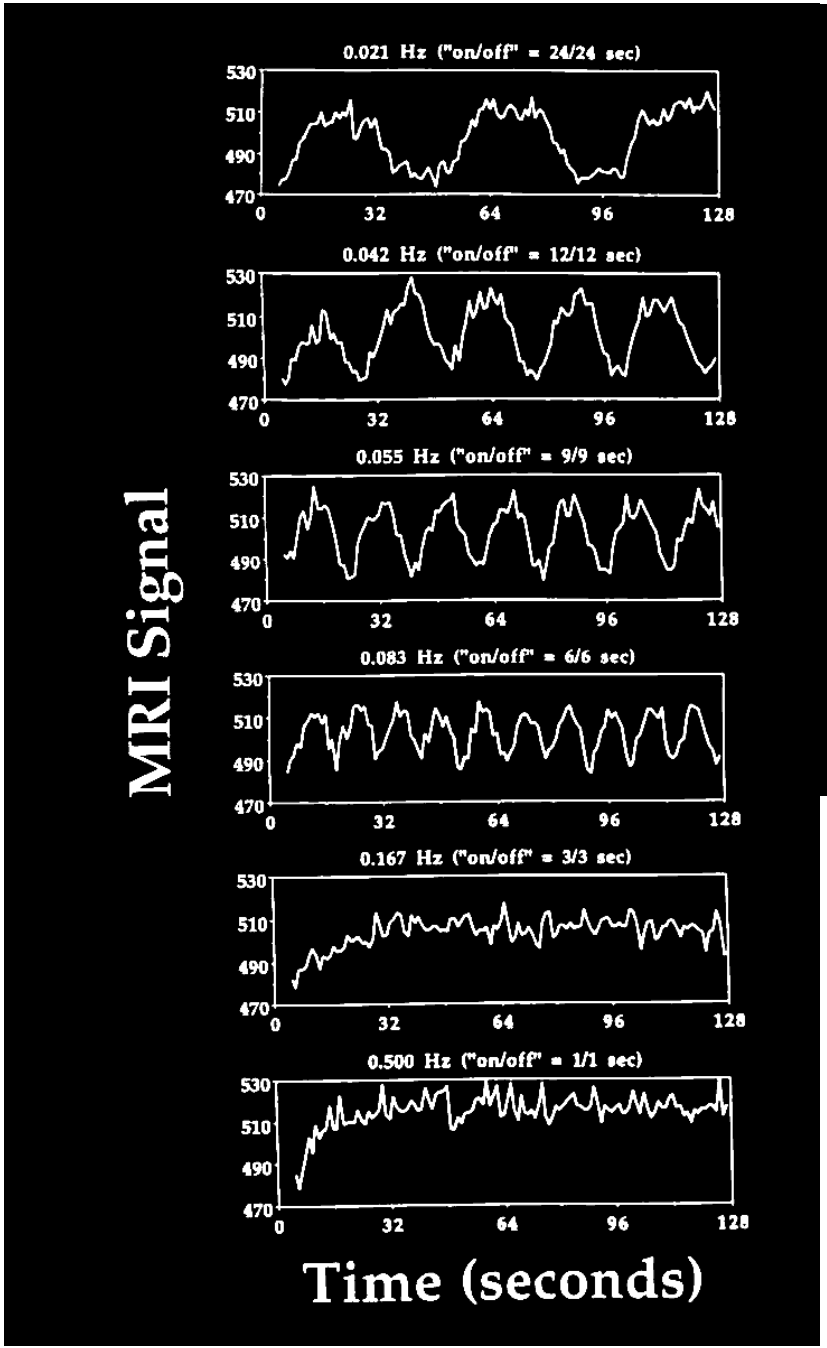
Temporal Resolution

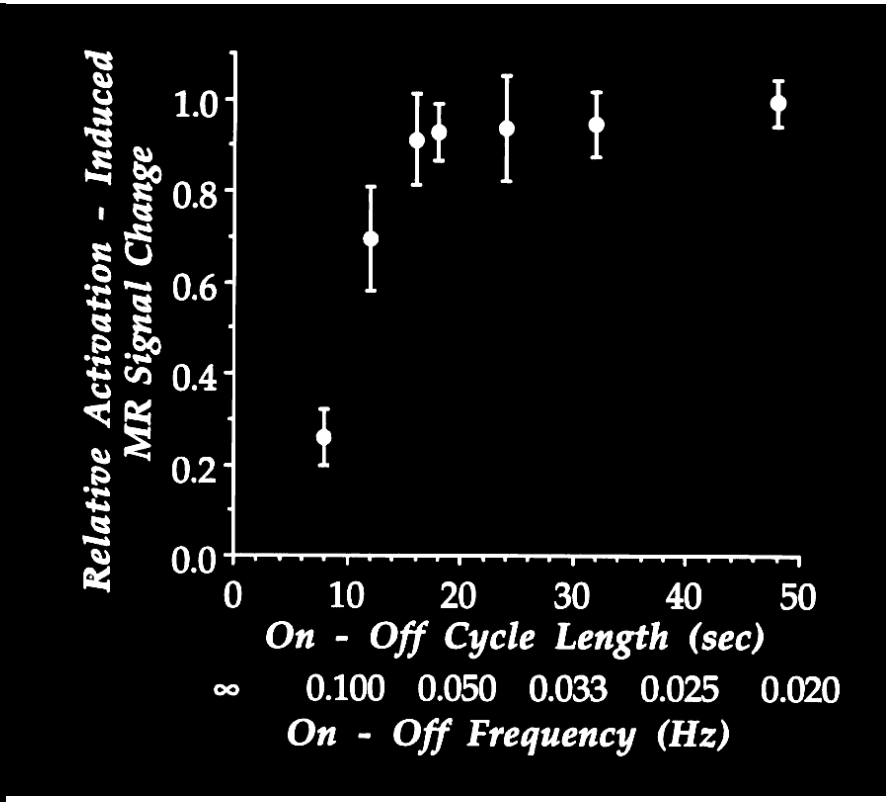




Methodology

Temporal Resolution



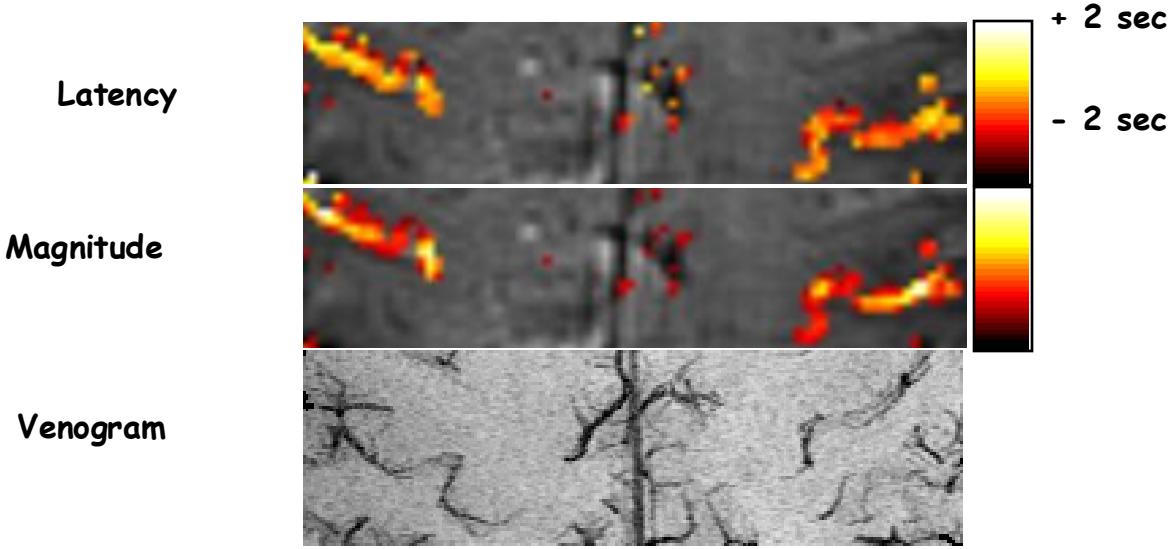


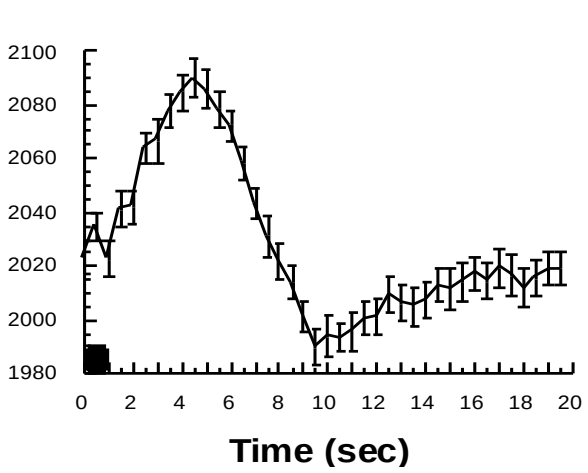
P. A. Bandettini, Functional MRI temporal resolution *in* "Functional MRI" (C. Moonen, and P. Bandettini., Eds.), p. 205-220, Springer - Verlag,. 1999.

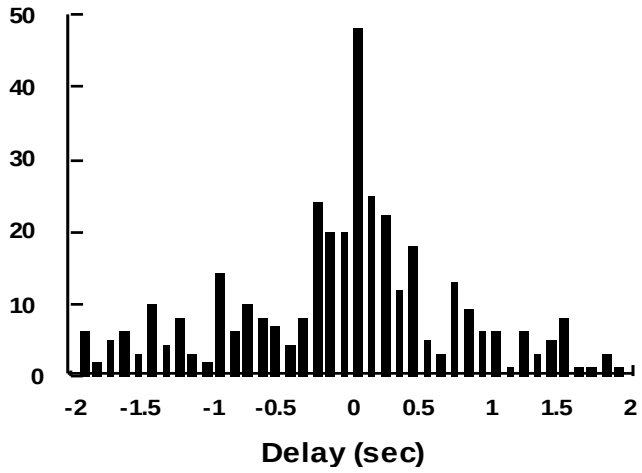
Methodology

Temporal Resolution

Latency Variation…



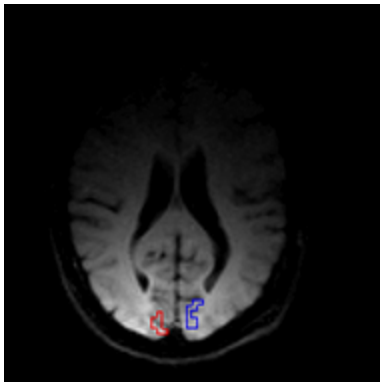




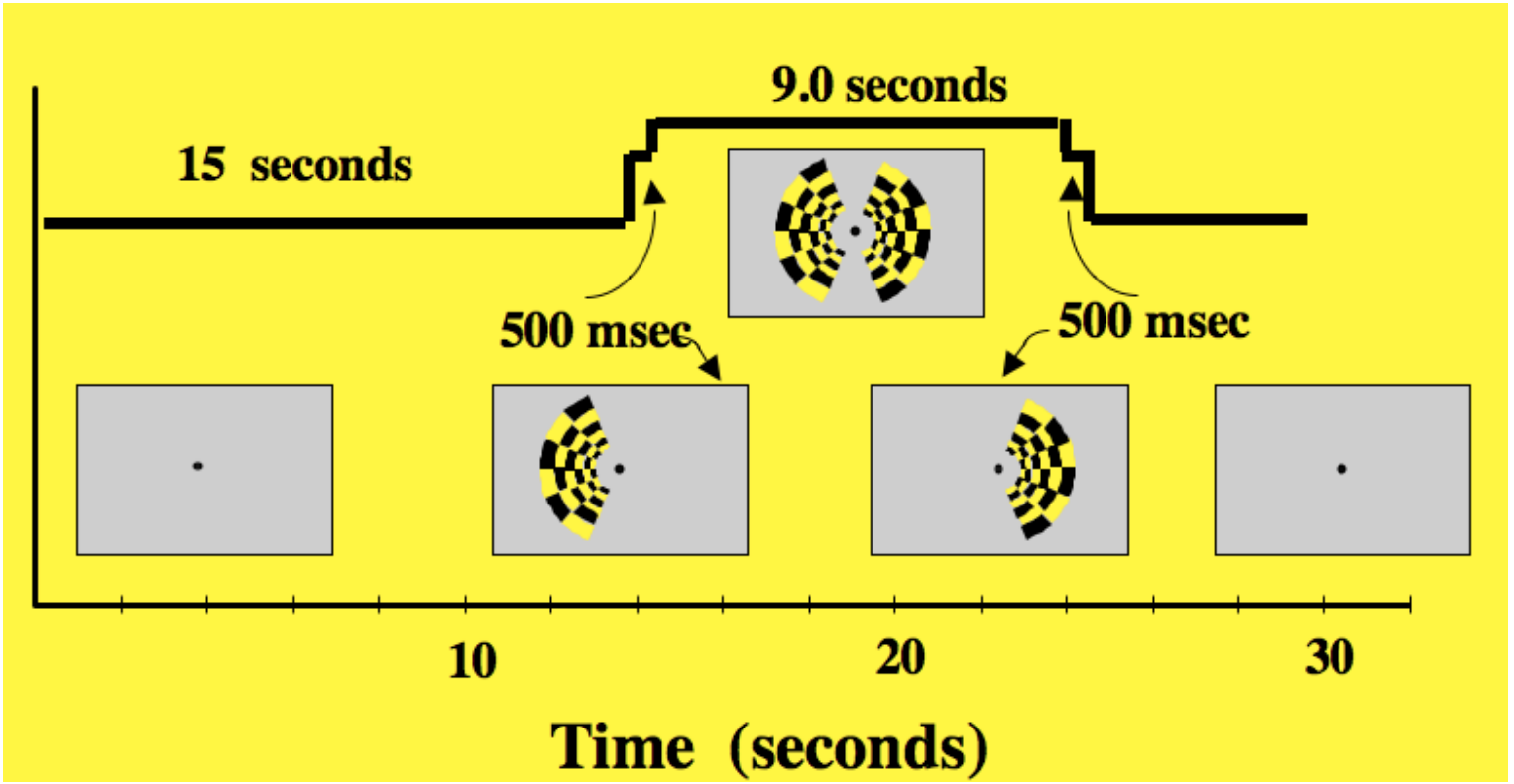
P. A. Bandettini, (1999) "Functional MRI" 205-220.

Hemi-Field Experiment

Right Hemisphere

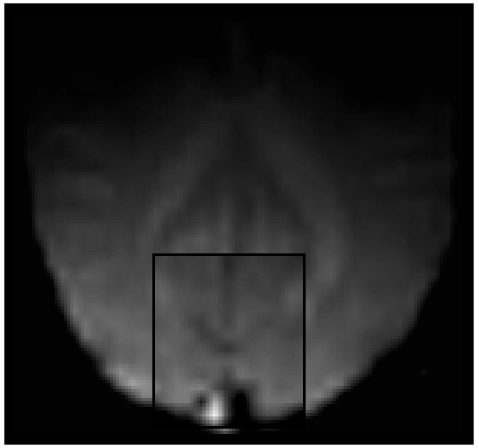


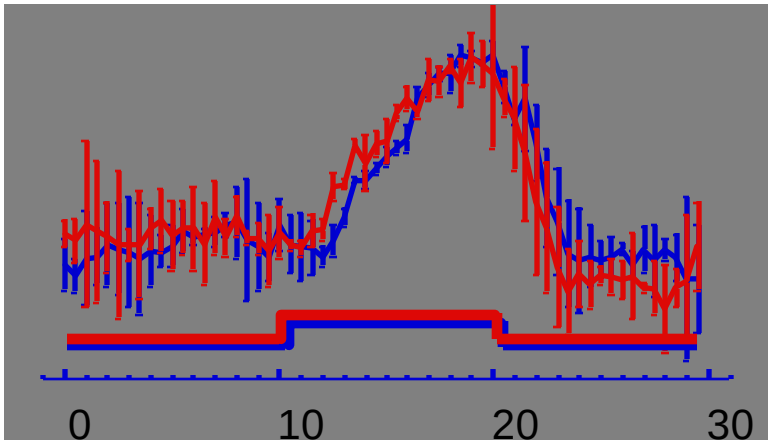
Left Hemisphere



Methodology

Temporal Resolution



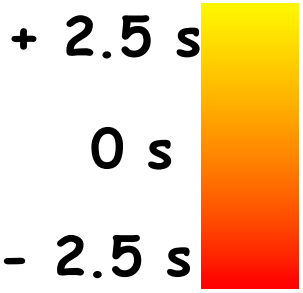


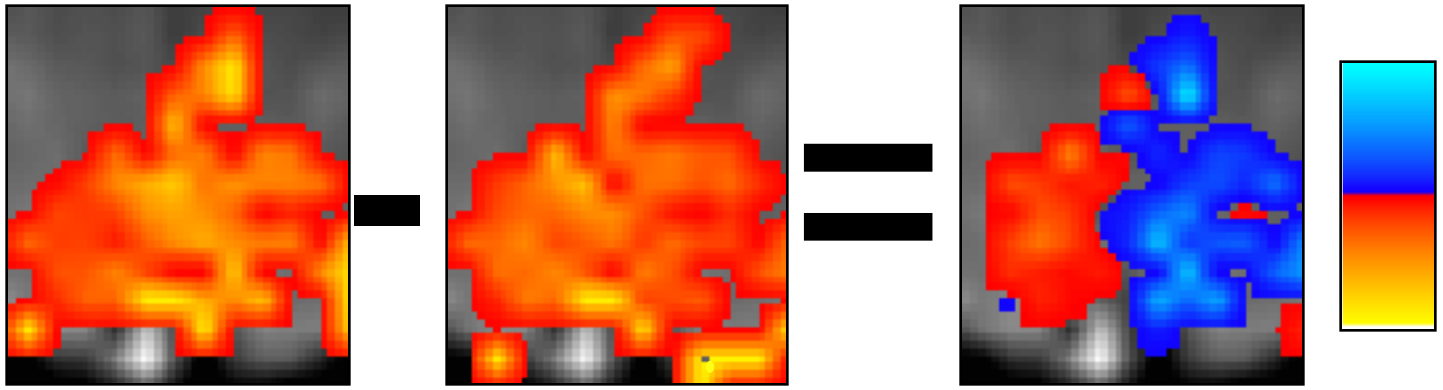
500 ms

500 ms

Right Hemifield

Left Hemifield

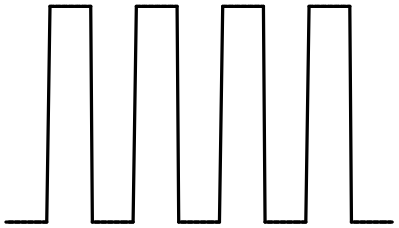




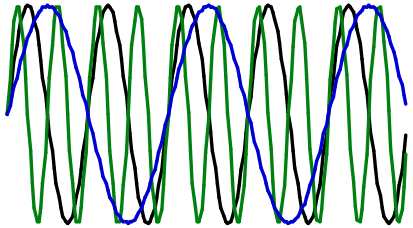
Methodology

Neuronal Activation Input Strategies

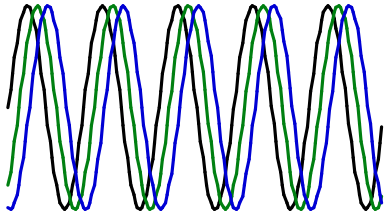
1. Block Design



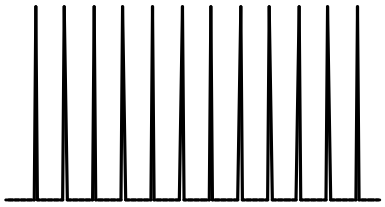
2. Frequency Encoding



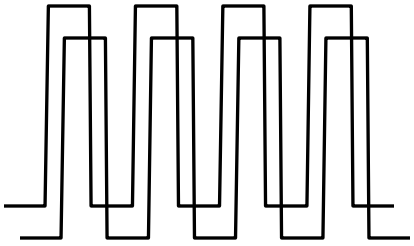
3. Phase Encoding



4. Event-Related



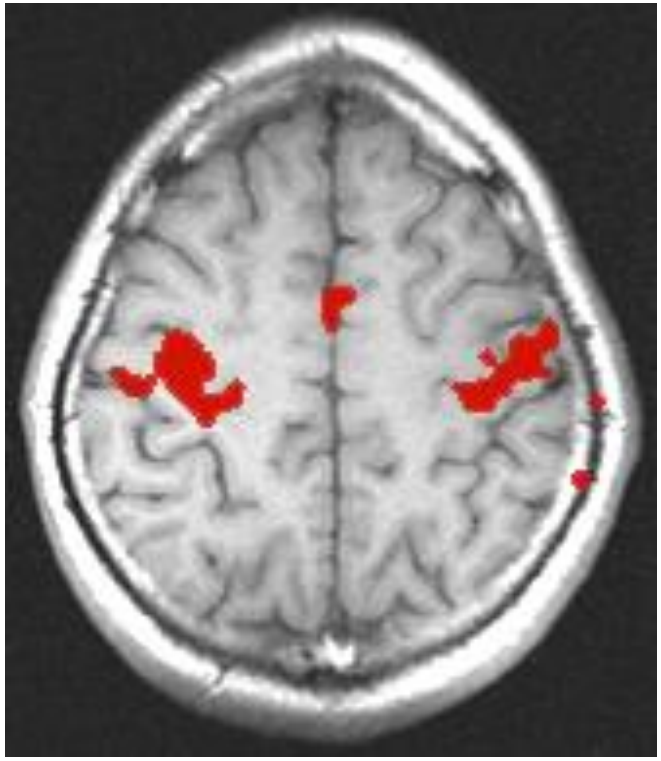
5. Orthogonal Block Design



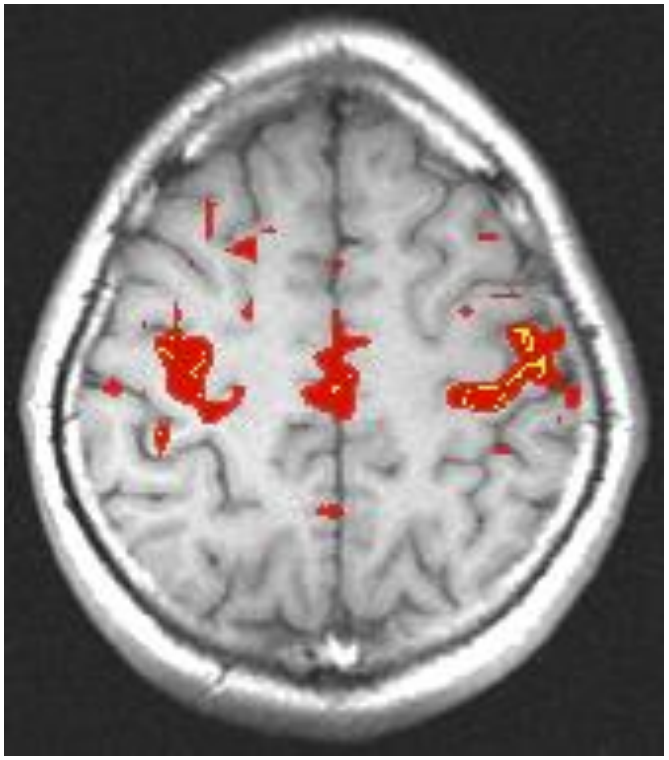
6. Free Behavior Design.

Methodology

Resting State Correlations



Activation:
correlation with reference function



Rest:
seed voxel in motor cortex

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

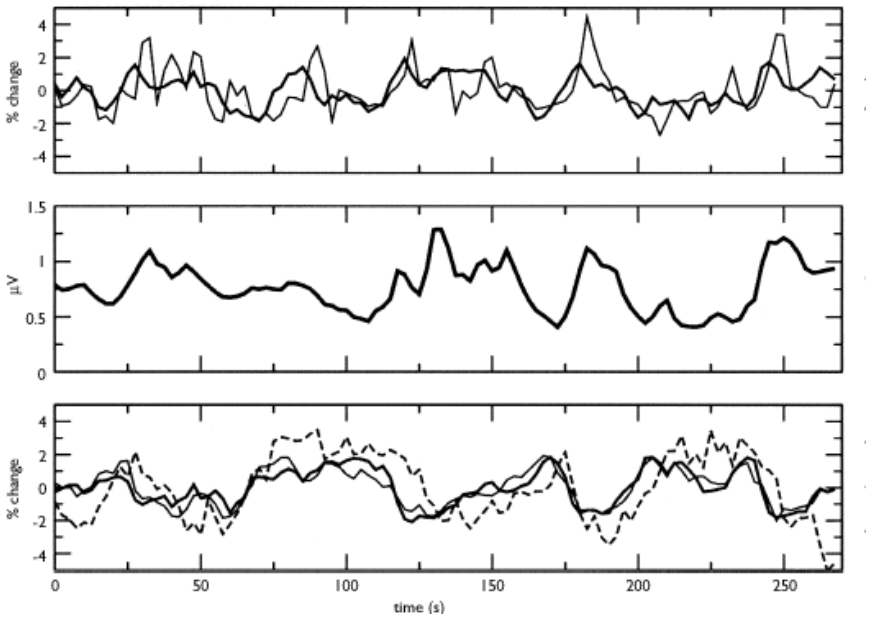
Methodology

BOLD correlated with 10 Hz power during "Rest"

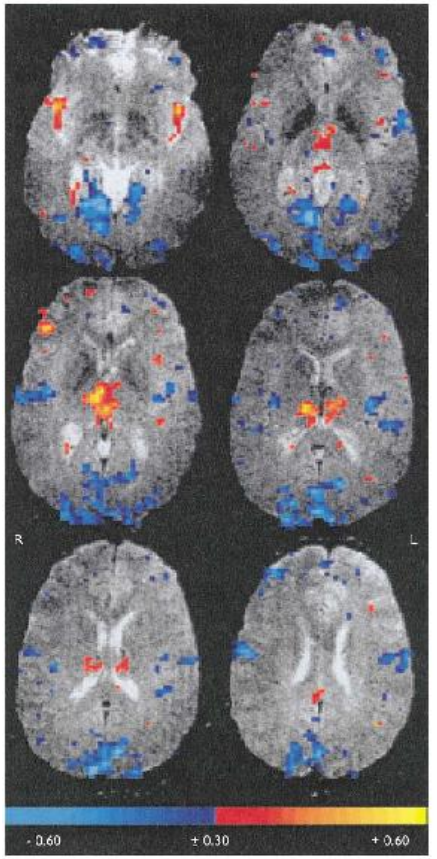
Positive

10 Hz power

Negative

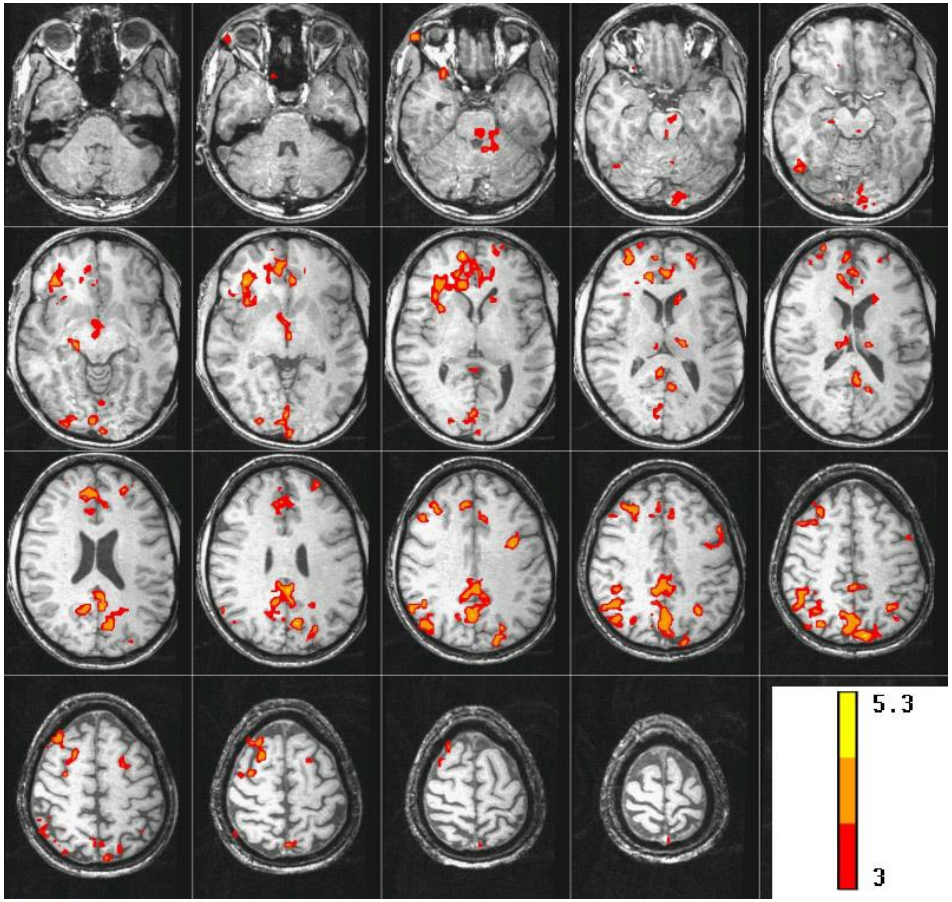


Goldman, et al (2002), Neuroreport



Methodology

BOLD correlated with SCR during "Rest"

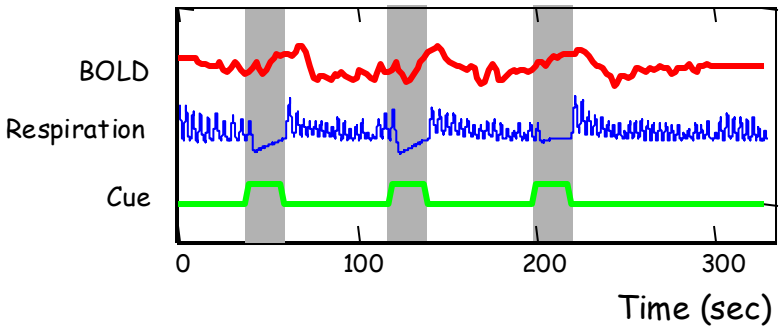


J. C. Patterson II, L. G. Ungerleider, and P. A Bandettini, *NeuroImage* ***17***: *1787-1806, (2002).*

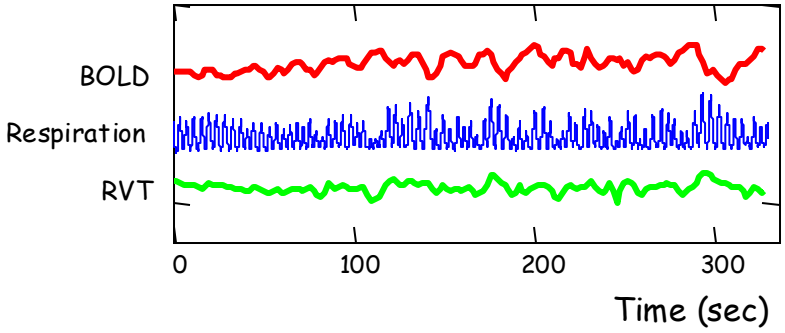
Methodology

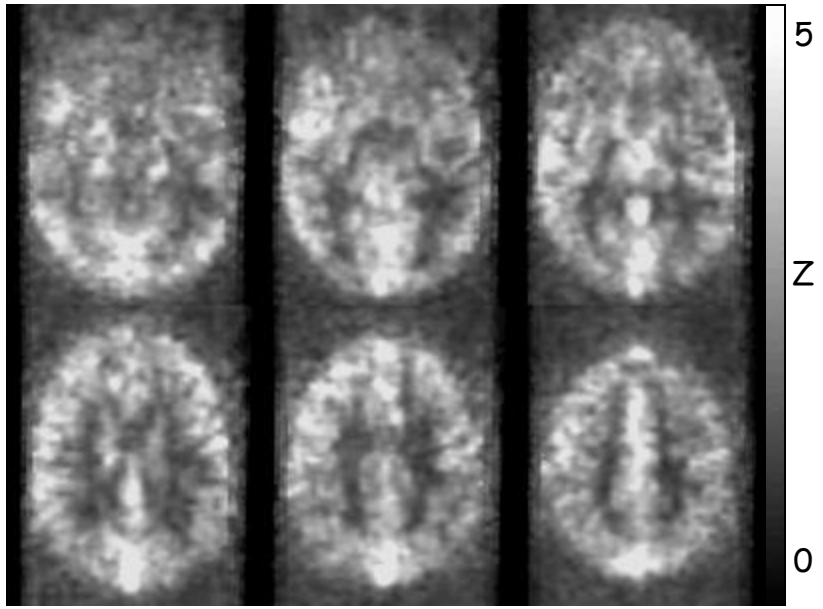
Respiration induced signal changes

Breath-holding

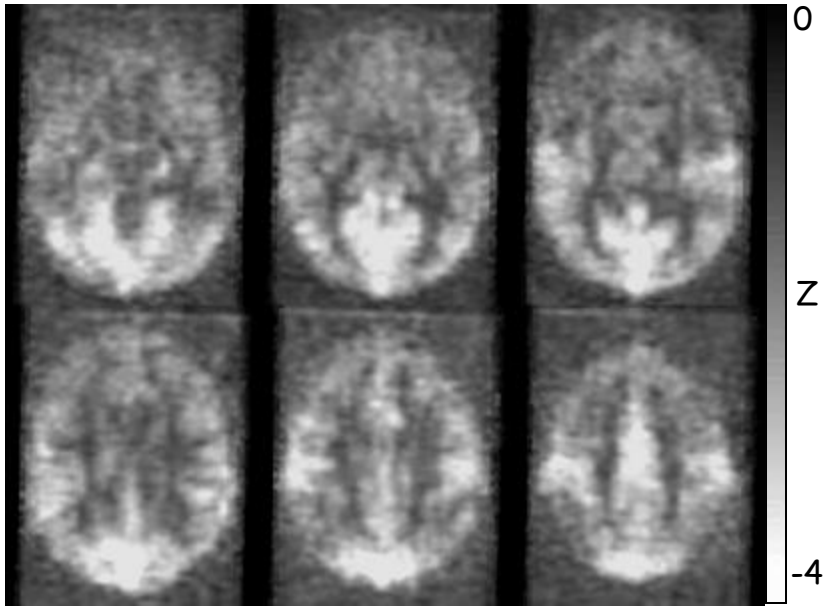


Rest





(N=7)



R. M. Birn, J. B. Diamond, M. A. Smith, P. A. Bandettini, Separating respiratory variation-related fluctuations from neuronal activity-related fluctuations in fMRI, NeuroImage 31, 1536-1548 (2006)

Methodology

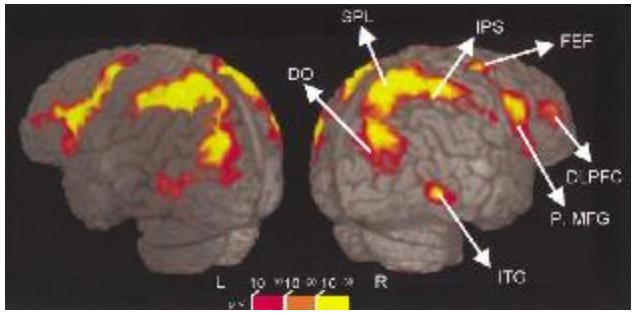
Mapping ⟷ "Reading"

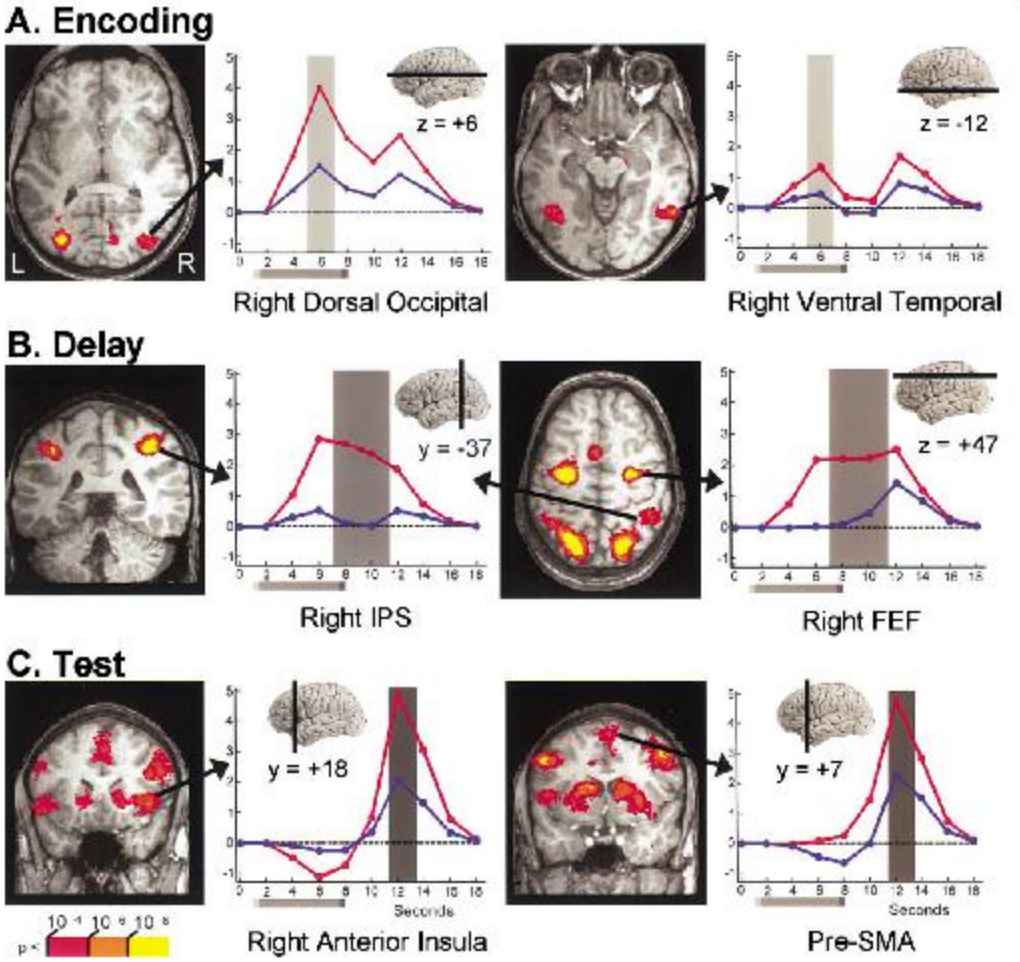
Methodology

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

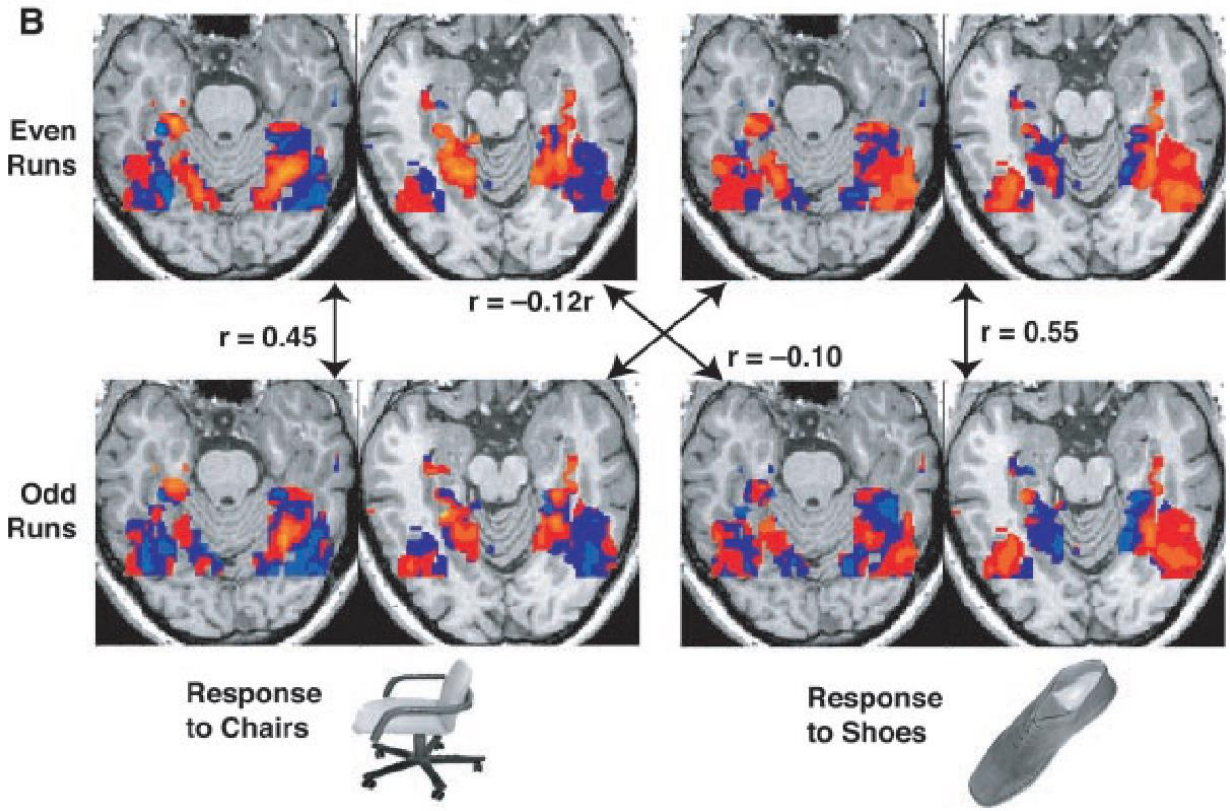




Methodology

Ventral temporal category representations

Object categories are associated with distributed representations in ventral temporal cortex



Haxby et al. 2001

Methodology

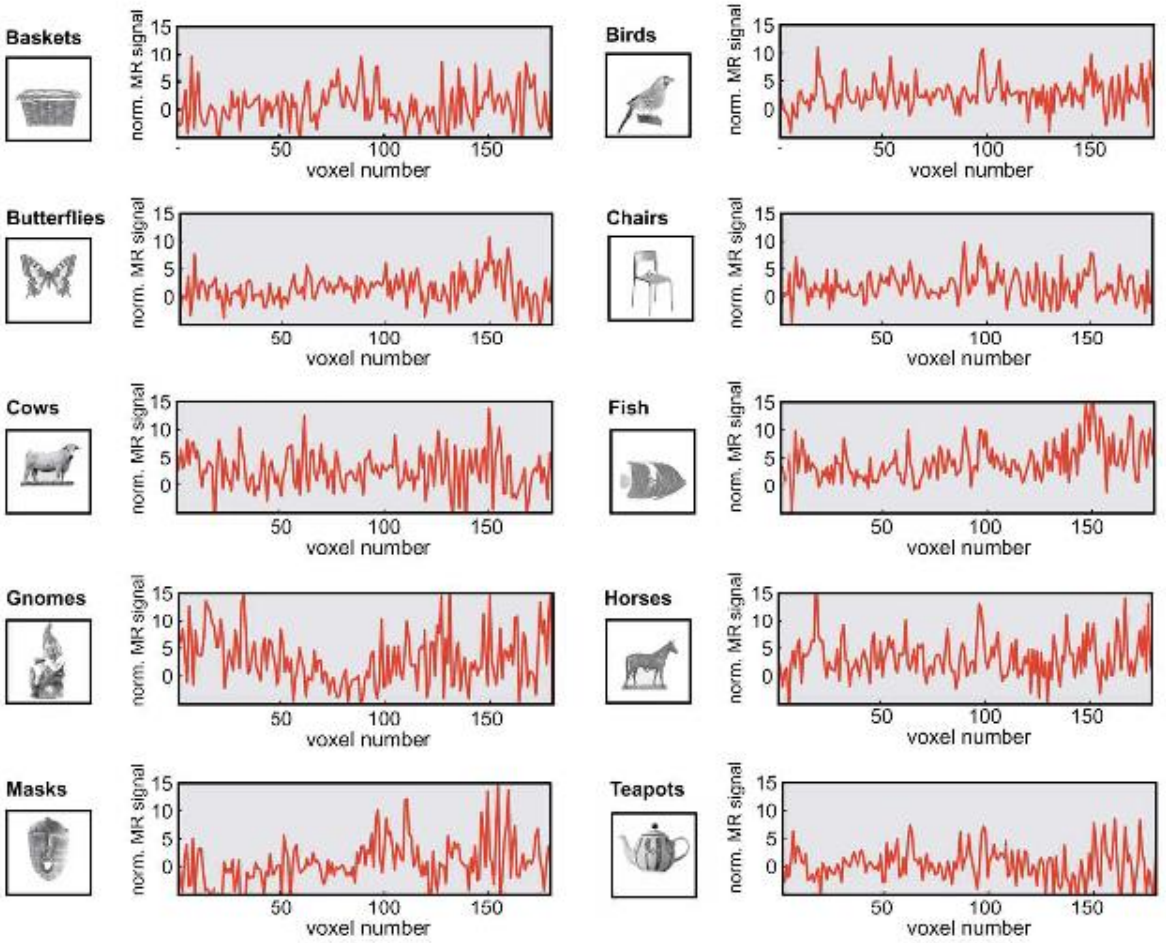
Functional magnetic resonance imaging (fMRI) "brain reading": detecting and classifying distributed patterns of fMRI activity in human visual cortex

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 Structural and Functional Biomedical Imaging, Charlestown, MA 02129, USA
[c] HyperVision, Inc., P.O. Box 158, Lexington, MA 02420, USA

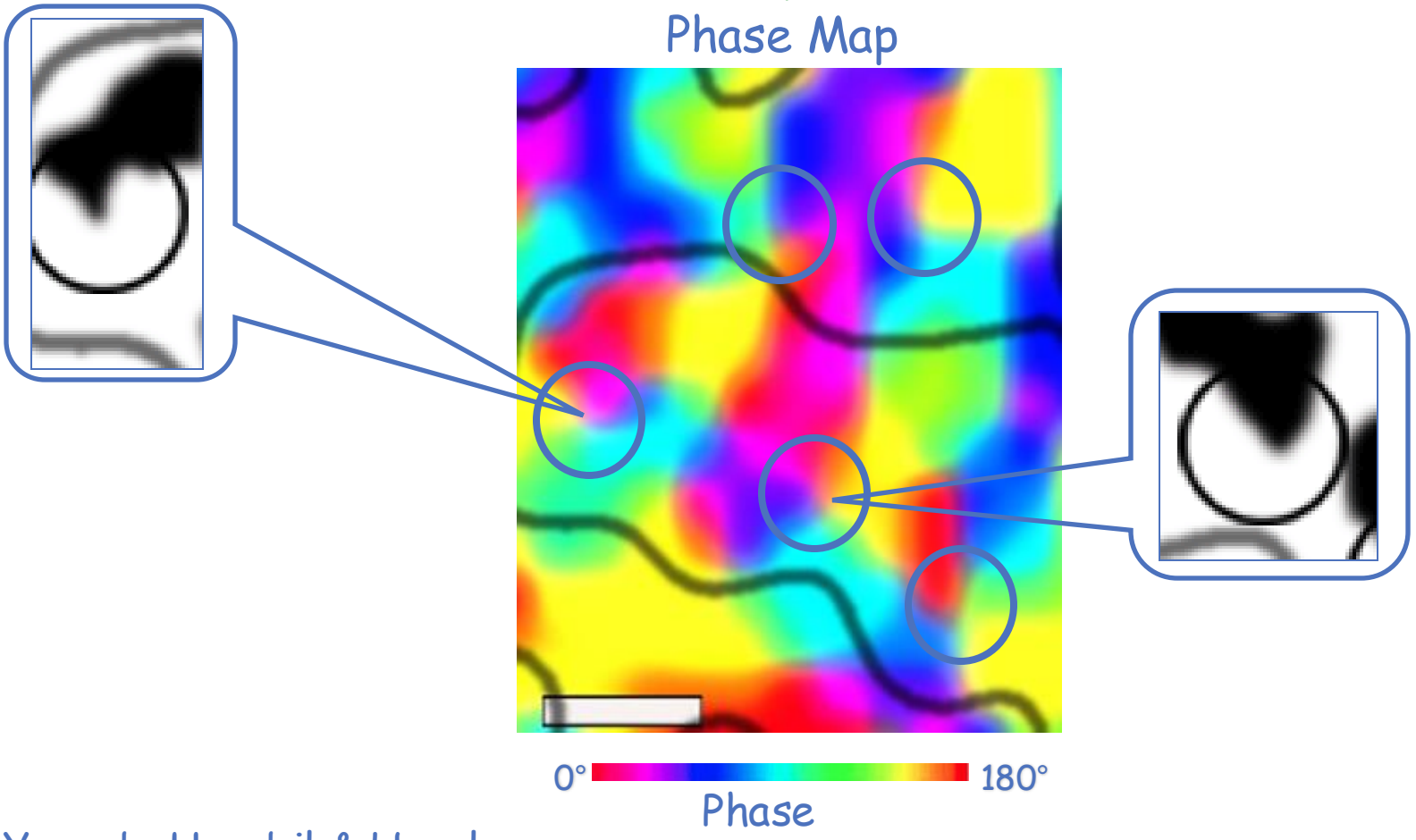
Received 15 July 2002; accepted 10 December 2002

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



Methodology

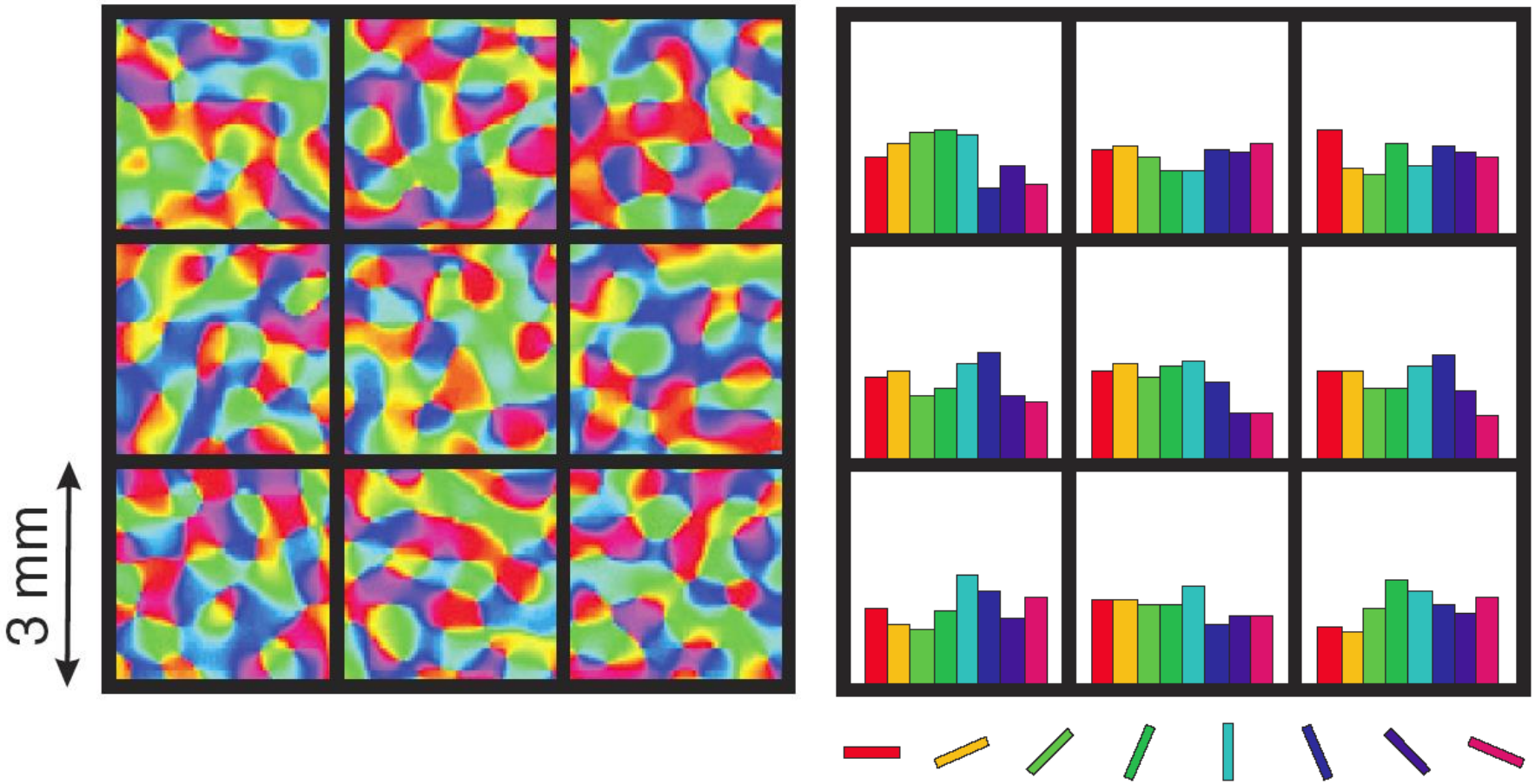
Orientation Columns in Human V1 as Revealed by fMRI at 7T



Yacoub, Ugurbil & Harel
University of Minnesota / CMRR
HBM 2006

Scalebar = 0.5 mm

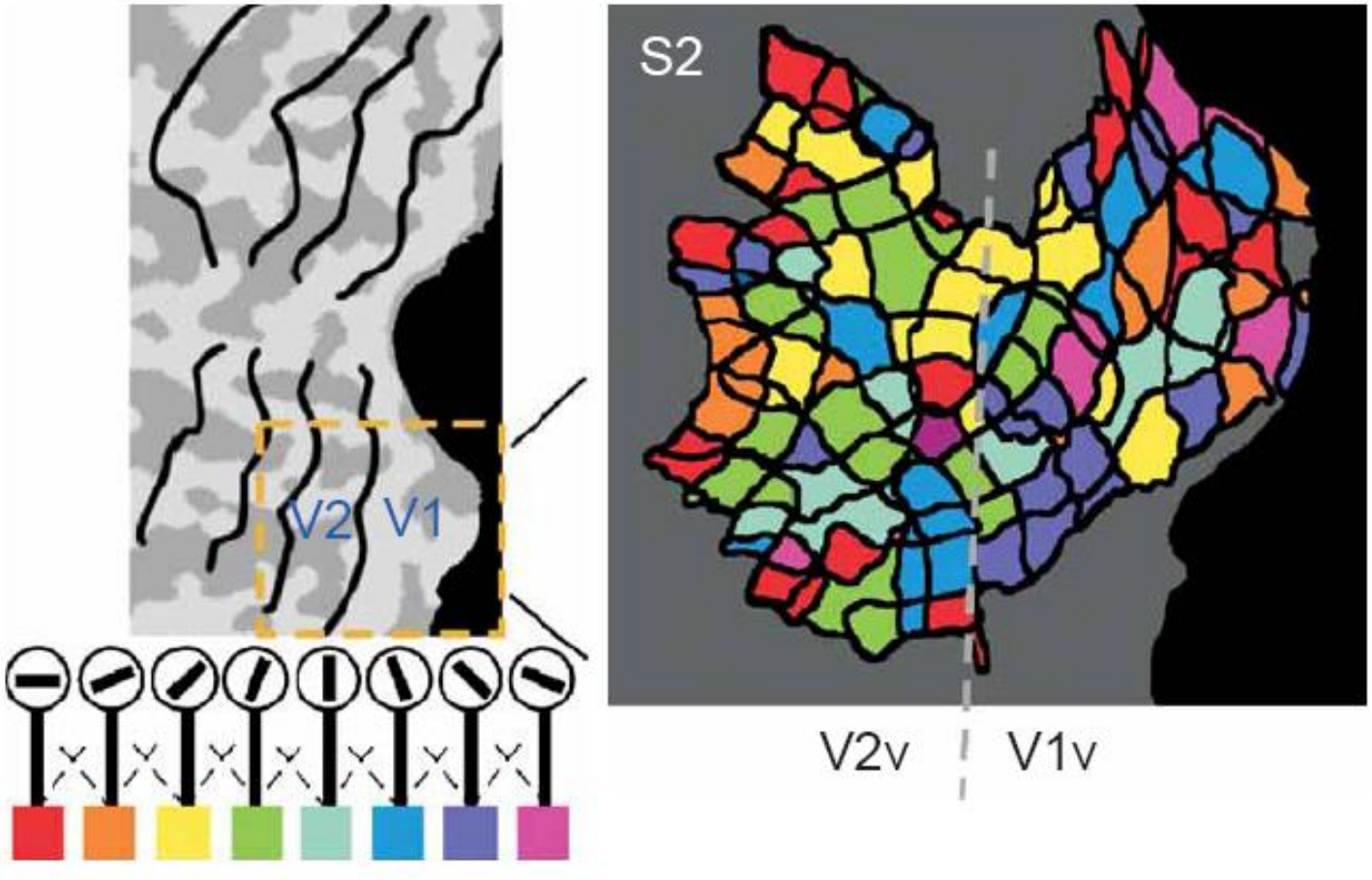
Methodology



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

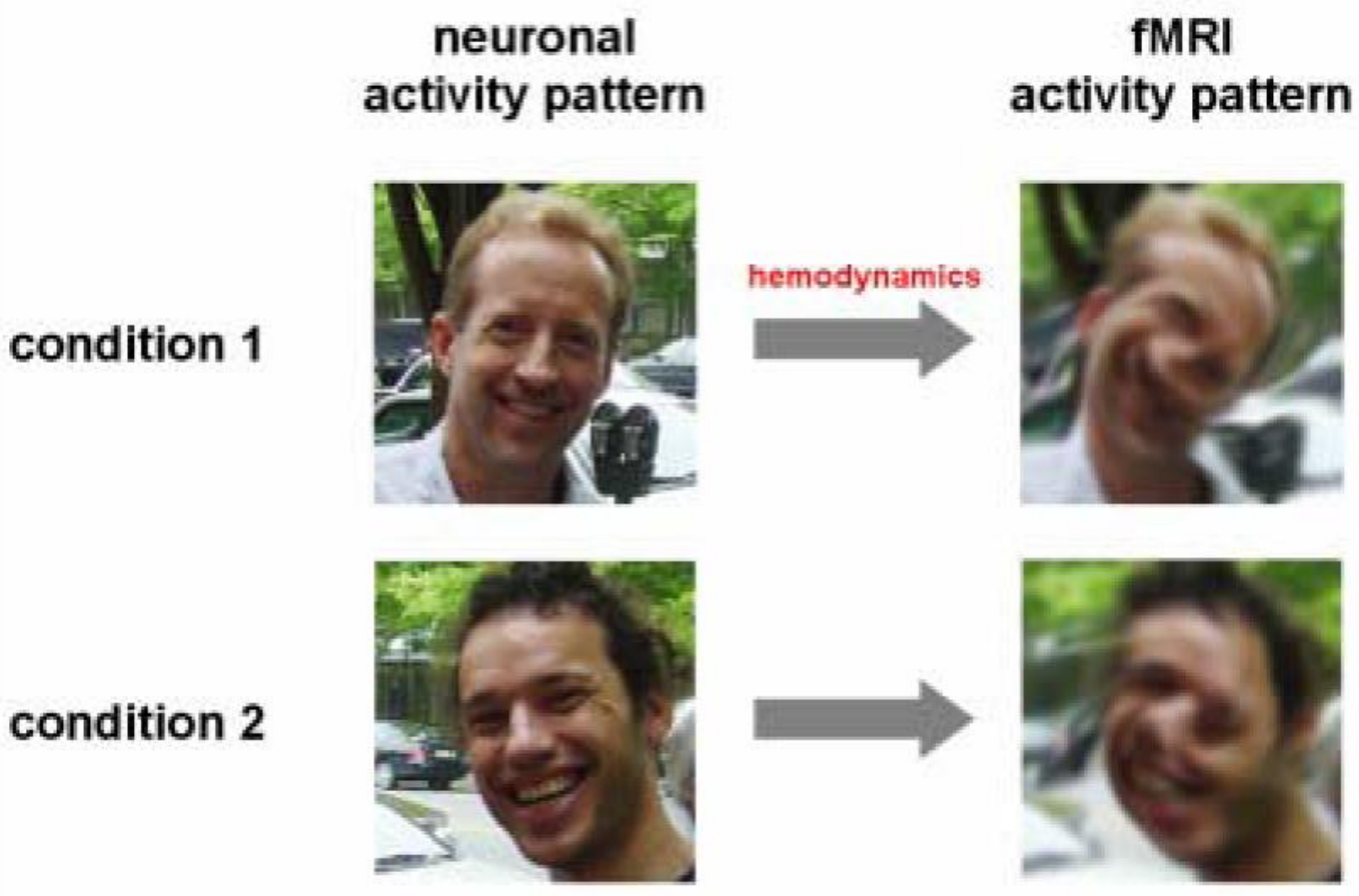
Methodology

Lower spatial frequency clumping

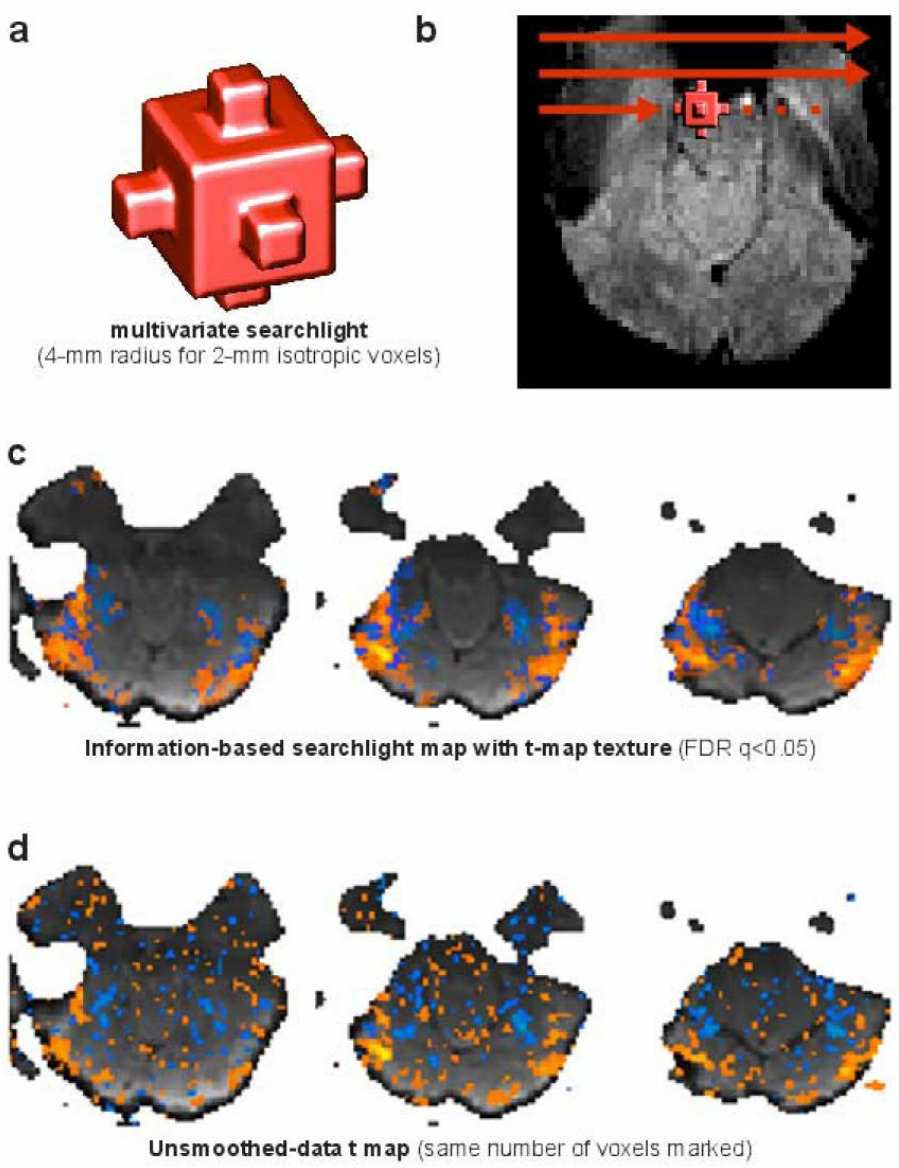


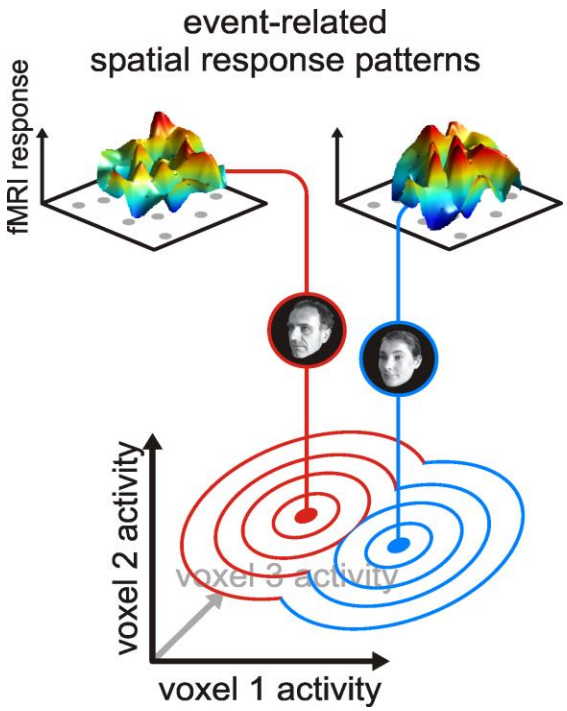
Kamitani & Tong (2005)

Methodology



Methodology





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

Technology

Coil arrays
High field strength
High resolution
Novel functional contrast

Methodology

Connectivity assessment
Multi-modal integration
Pattern classification
Task design

Interpretation

Fluctuations
Dynamics
Cross - modal comparison

Applications

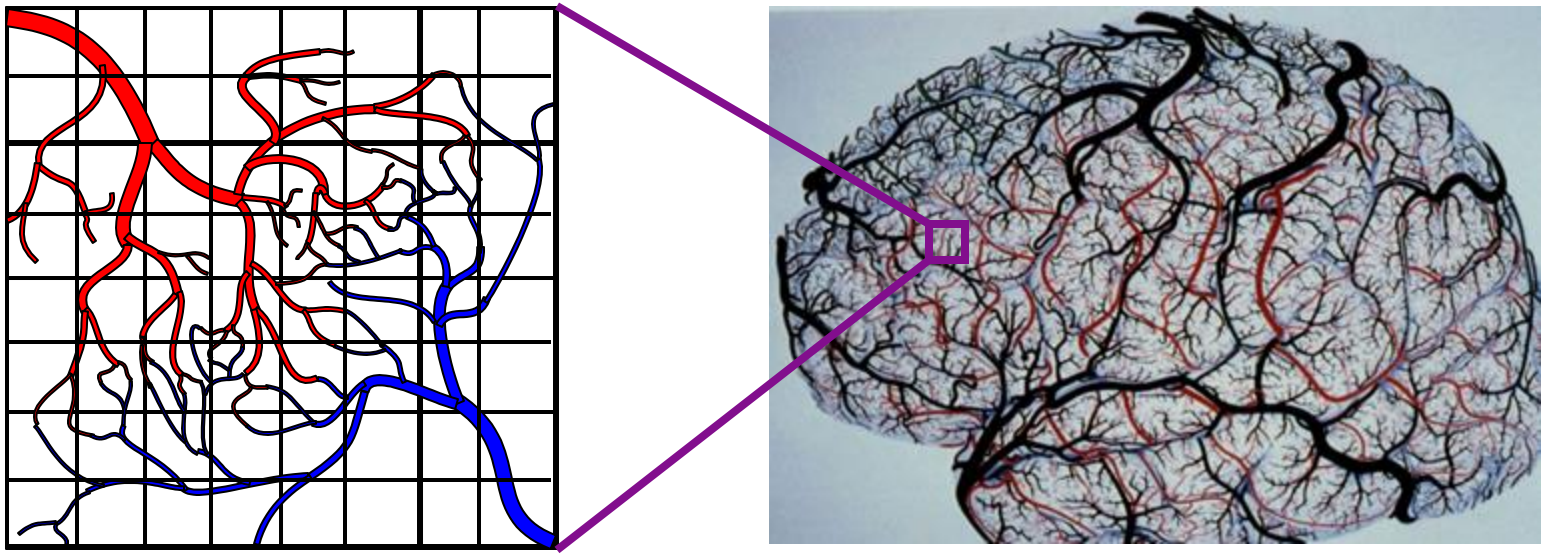
Basic Neuroscience
Behavior correlation/prediction
Pathology correlation

Interpretation

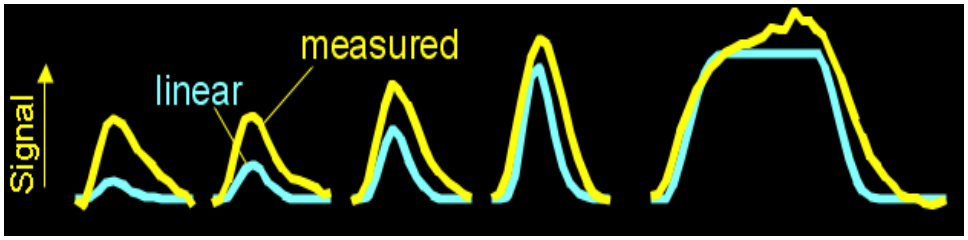
Neuronal Activation ?⟶ Measured Signal

Neuronal Activation ↘? Hemodynamics ↗? Measured Signal

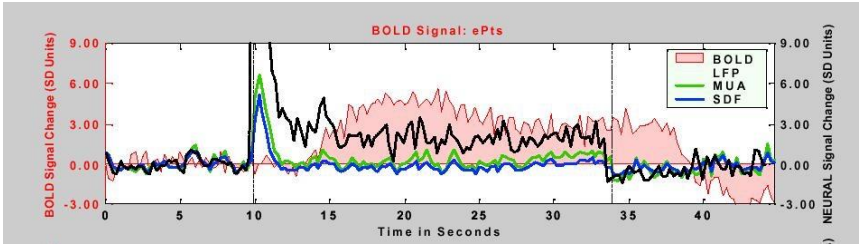
Noise ↑?



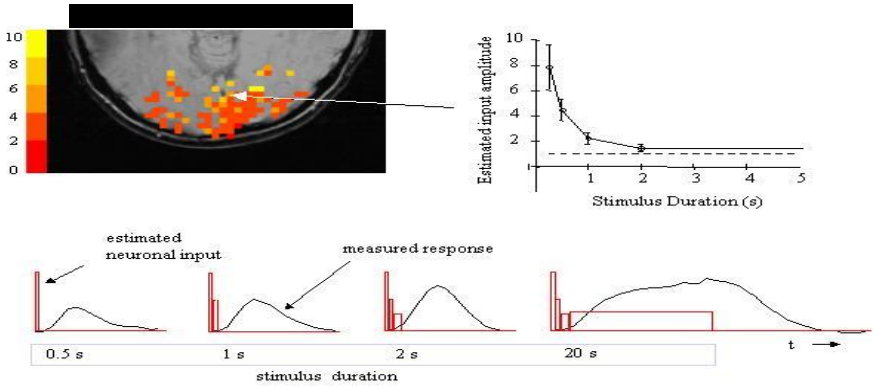
Interpretation



R. M. Birn, (2001) NeuroImage, 14: 817-826.



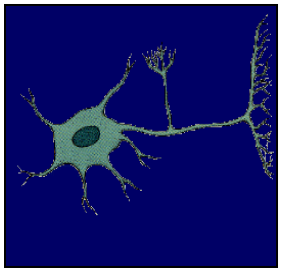
Logothetis et al. (2001) Nature, 412, 150-157.

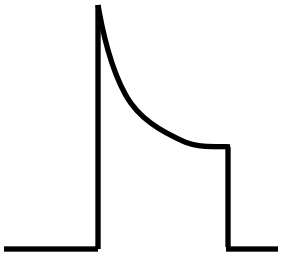


P. A. Bandettini et al, (2001) Nature Neuroscience, 4: 864-866.

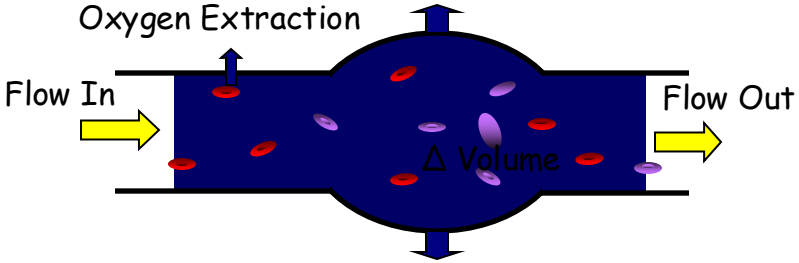
Sources of this Nonlinearity

- Neuronal





- Hemodynamic
  - -Oxygen extraction
  - -Blood volume dynamics



Technology

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Task design

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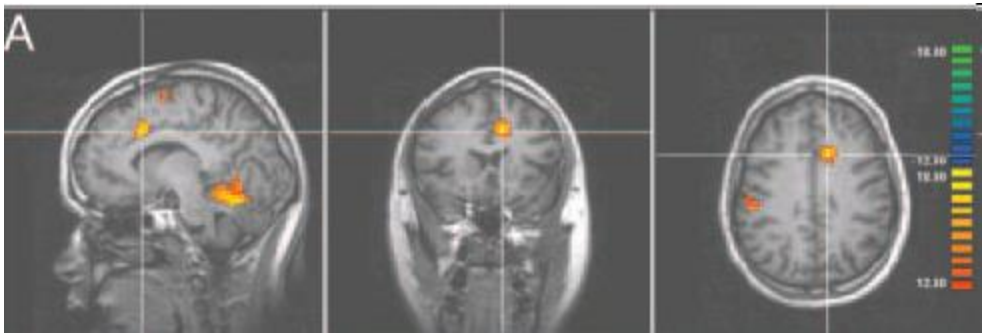
Dynamics
Cross - modal comparison

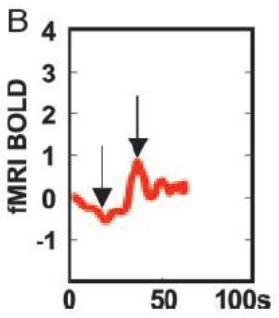
Applications

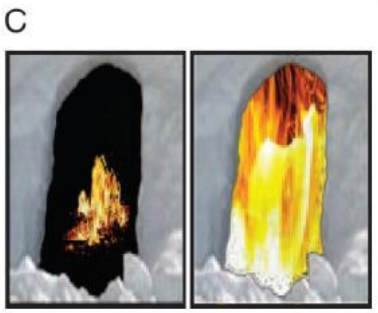
Basic Neuroscience
Behavior correlation/prediction
Pathology correlation

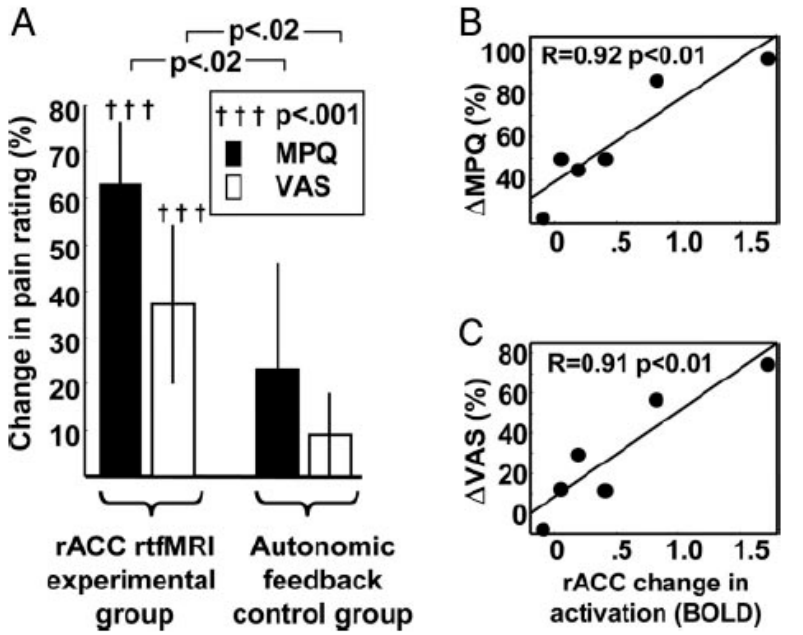
Applications

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)

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

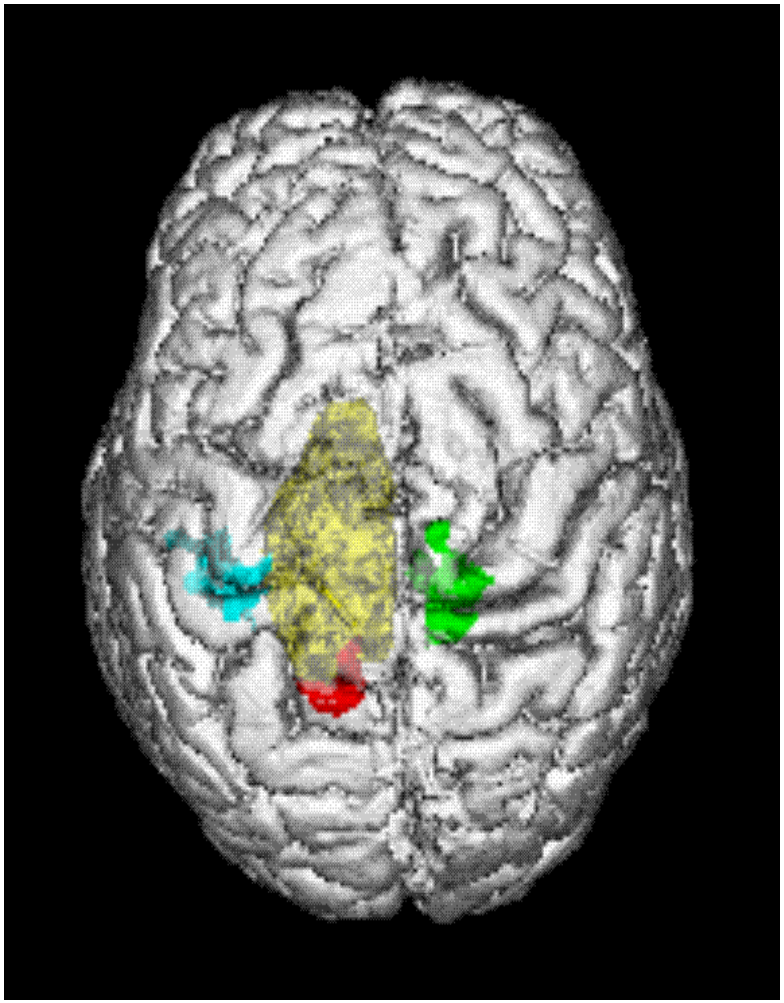
Presurgical Mapping

Left Foot

Tumor

Right Foot

Right Hand



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.

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

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