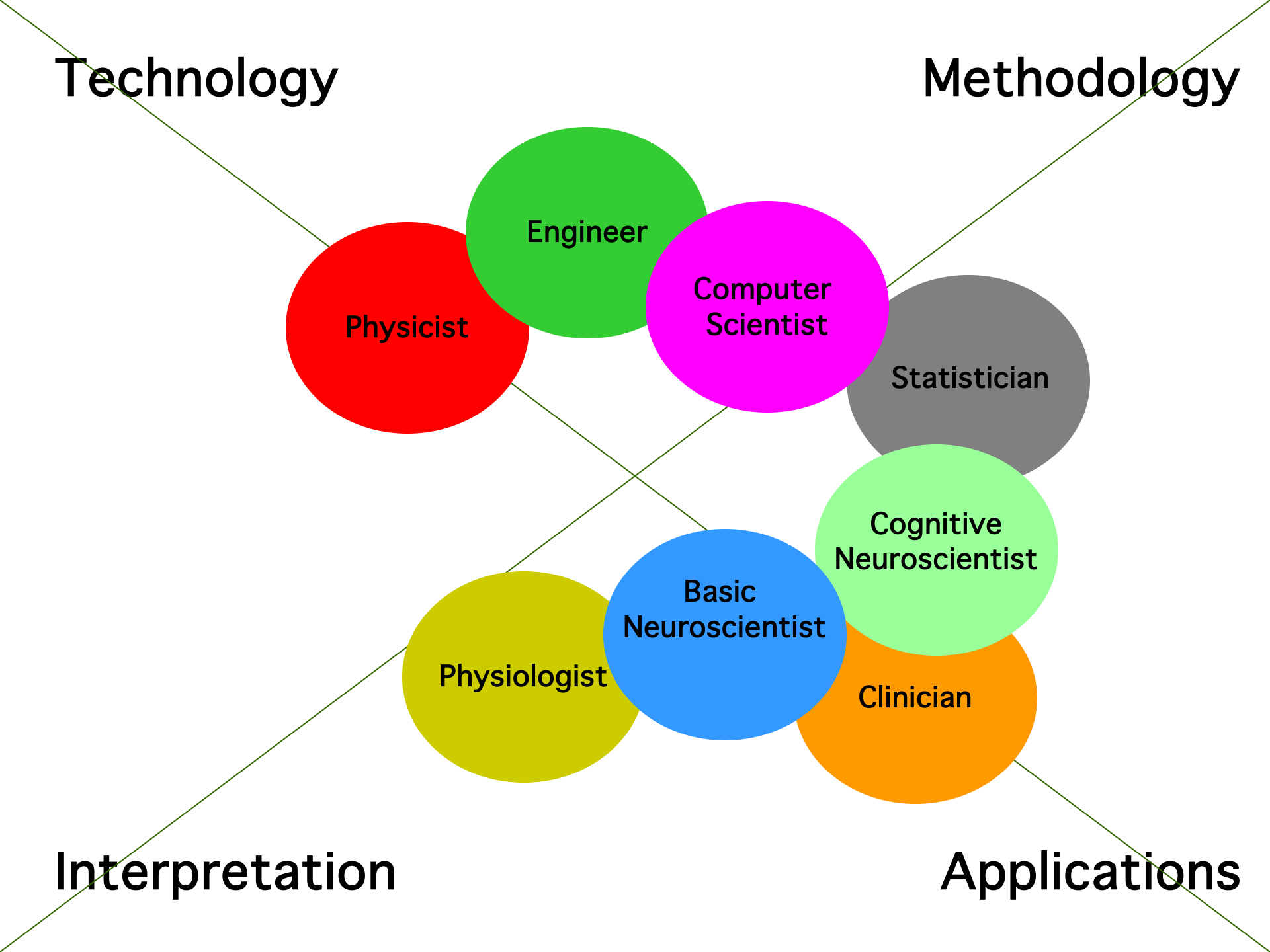
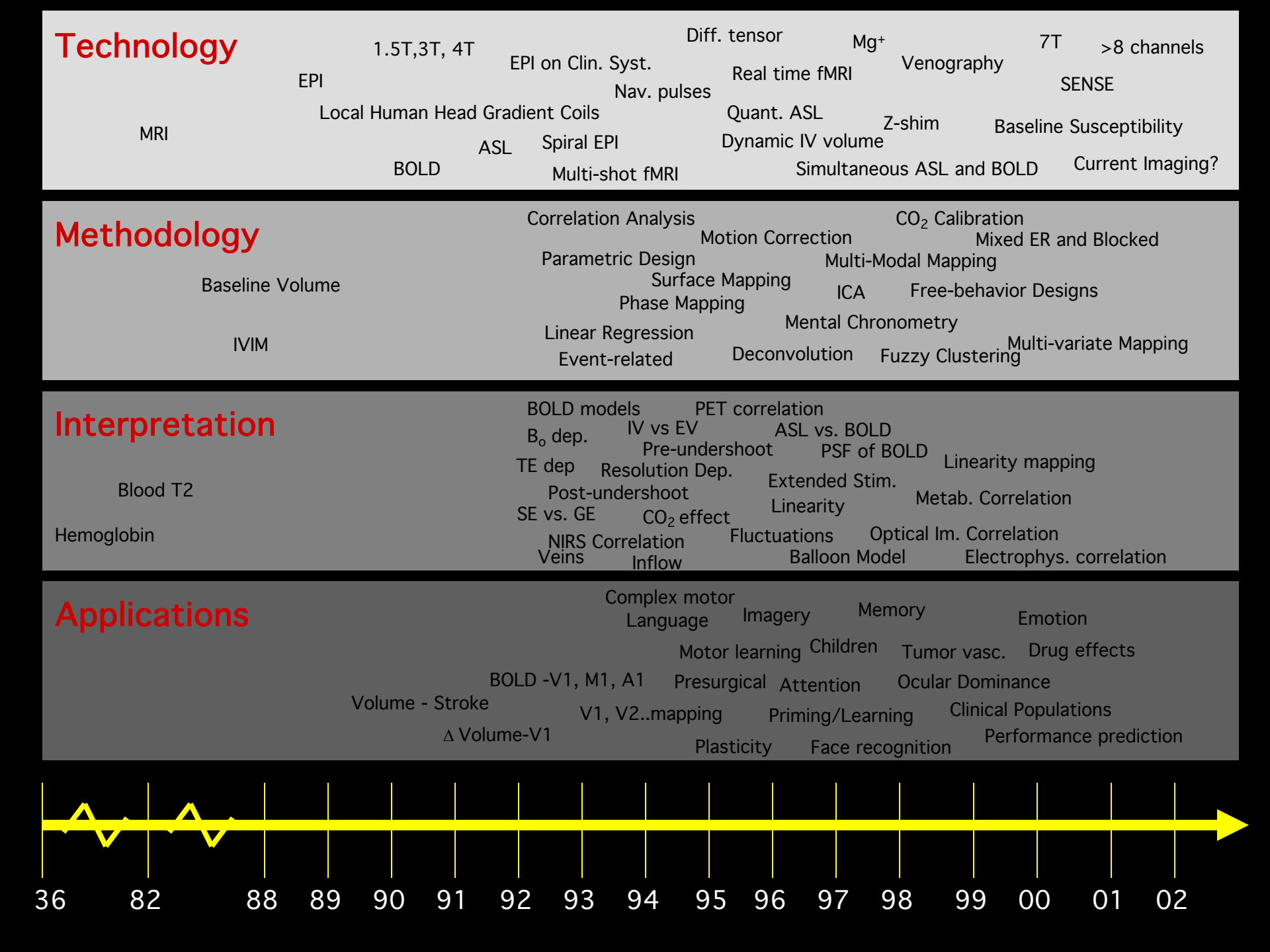
Latest Developments in fMRI

Peter A. Bandettini, Ph.D

Unit on Functional Imaging Methods
&
3T Neuroimaging Core Facility

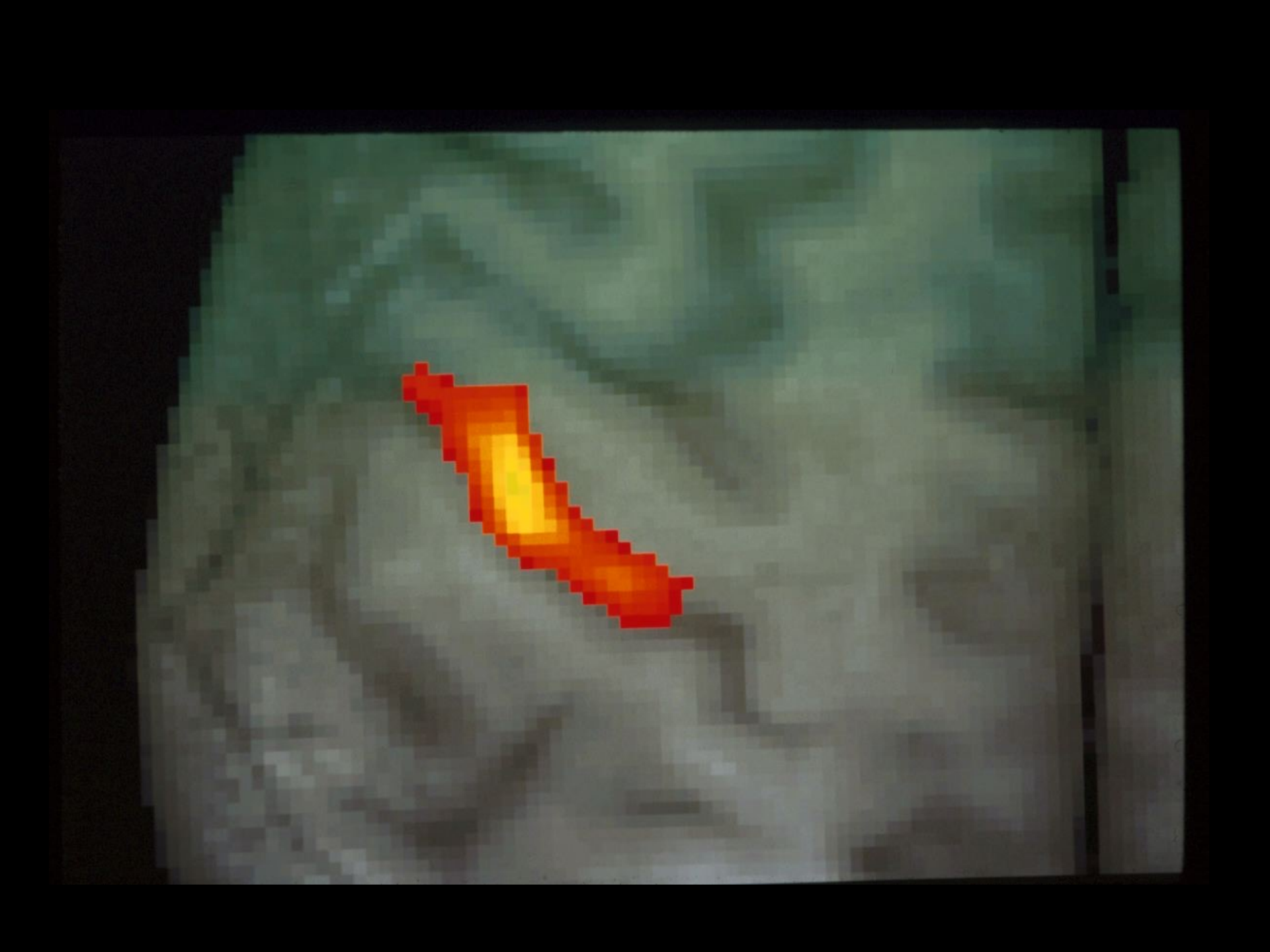
Laboratory of Brain and Cognition
National Institute of Mental Health


Technology
Methodology
Engineer
Physicist
Computer Scientist
Statistician
Cognitive Neuroscientist
Basic Neuroscientist
Physiologist
Clinician
Interpretation
Applications


Technology
1.5T,3T, 4T
Diff. tensor
Mg+
7T
>8 channels
EPI on Clin. Syst.
Venography
EPI
Real time fMRI
SENSE
Nav. pulses
Local Human Head Gradient Coils
Quant. ASL
Z-shim
Baseline Susceptibility
MRI
Dynamic IV volume
ASL
Spiral EPI
BOLD
Multi-shot fMRI
Simultaneous ASL and BOLD
Current Imaging?
Methodology
Correlation Analysis
CO2 Calibration
Motion Correction
Mixed ER and Blocked
Parametric Design
Multi-Modal Mapping
Surface Mapping
Baseline Volume
ICA
Free-behavior Designs
Phase Mapping
Mental Chronometry
Linear Regression
IVIM
Multi-variate Mapping
Event-related
Deconvolution
Fuzzy Clustering
Interpretation
BOLD models
PET correlation
IV vs EV
B0 dep.
ASL vs. BOLD
Pre-undershoot
PSF of BOLD
TE dep
Linearity mapping
Resolution Dep.
Extended Stim.
Blood T2
Post-undershoot
Metab. Correlation
Linearity
SE vs. GE
CO2 effect
Hemoglobin
Fluctuations
Optical Im. Correlation
NIRS Correlation
Veins
Balloon Model
Electrophys. correlation
Inflow
Applications
Complex motor
Language
Imagery
Memory
Emotion
Motor learning
Children
Tumor vasc.
Drug effects
BOLD -V1, M1, A1
Presurgical
Attention
Ocular Dominance
Volume - Stroke
V1, V2..mapping
Priming/Learning
Clinical Populations
Δ Volume-V1
Performance prediction
Plasticity
Face recognition
36
82
88
89
90
91
92
93
94
95
96
97
98
99
00
01
02

Alternating Left and Right Finger Tapping

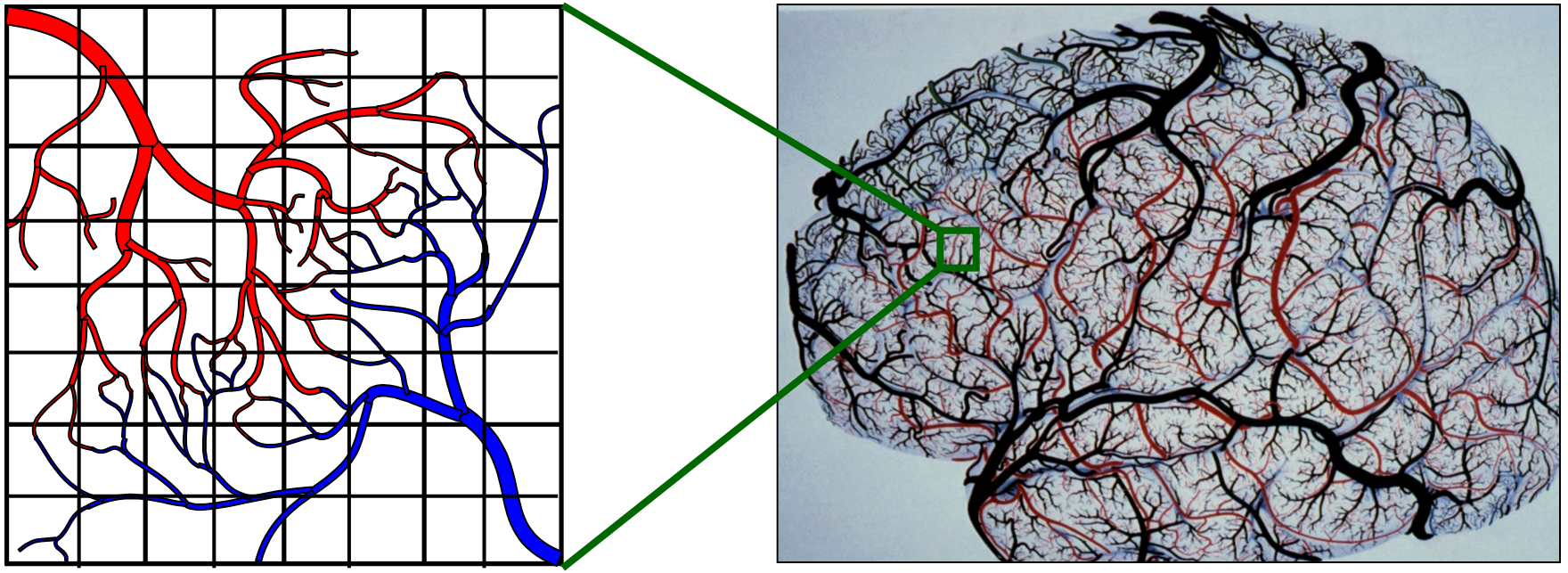
~ 1992



Neuronal Activation ? Measured Signal

? Hemodynamics ? ?

Noise



Latest Developments...

1. Temporal Resolution
2. Spatial Resolution
3. Sensitivity and Noise
4. Information Content
5. Implementation

Latest Developments...

1. Temporal Resolution
2. Spatial Resolution
3. Sensitivity and Noise
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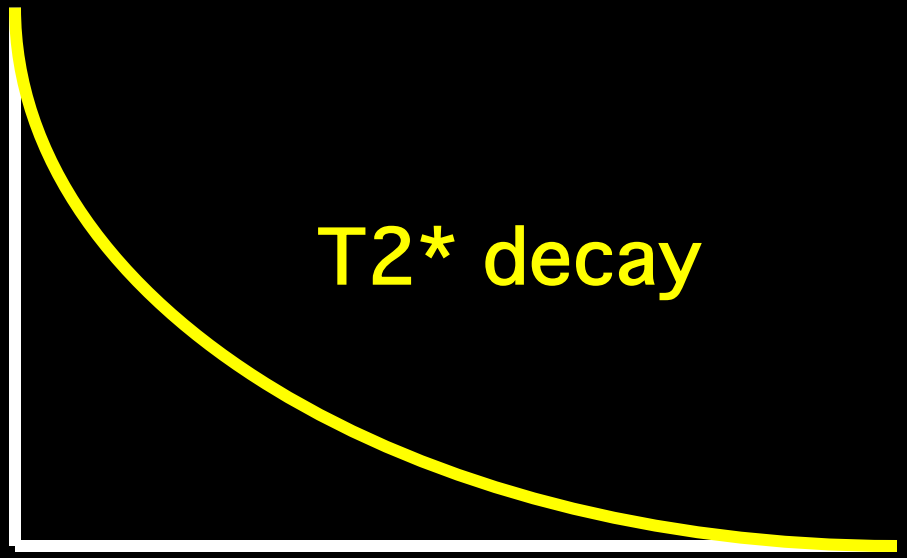
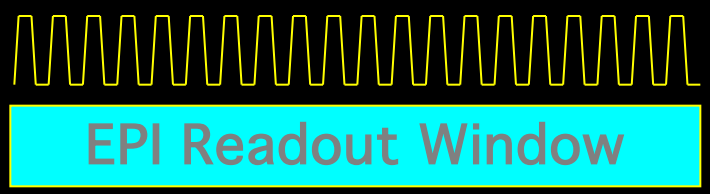
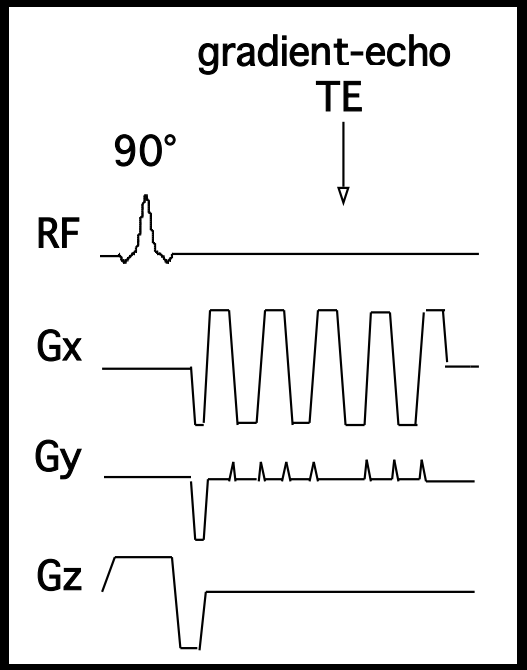
5. Implementation

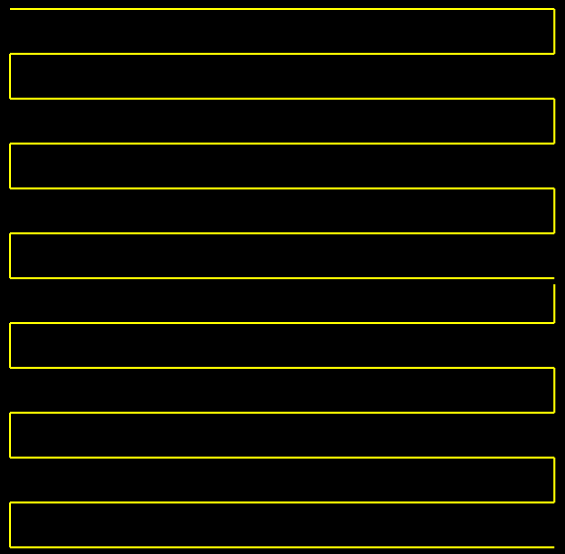
Single Shot EPI

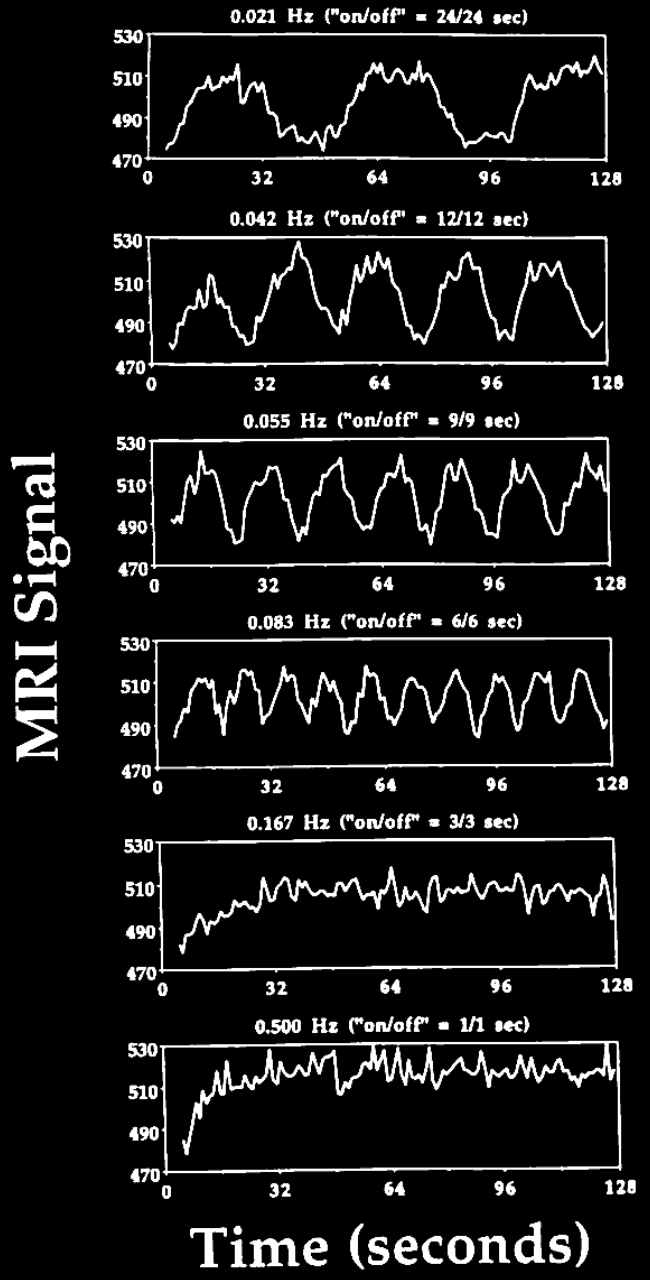


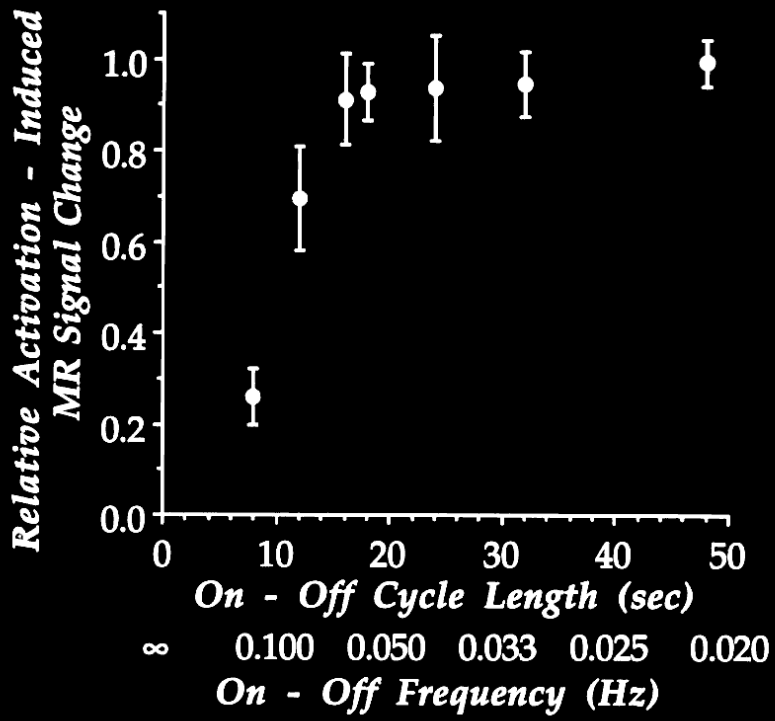


≈ 20 to 40 ms



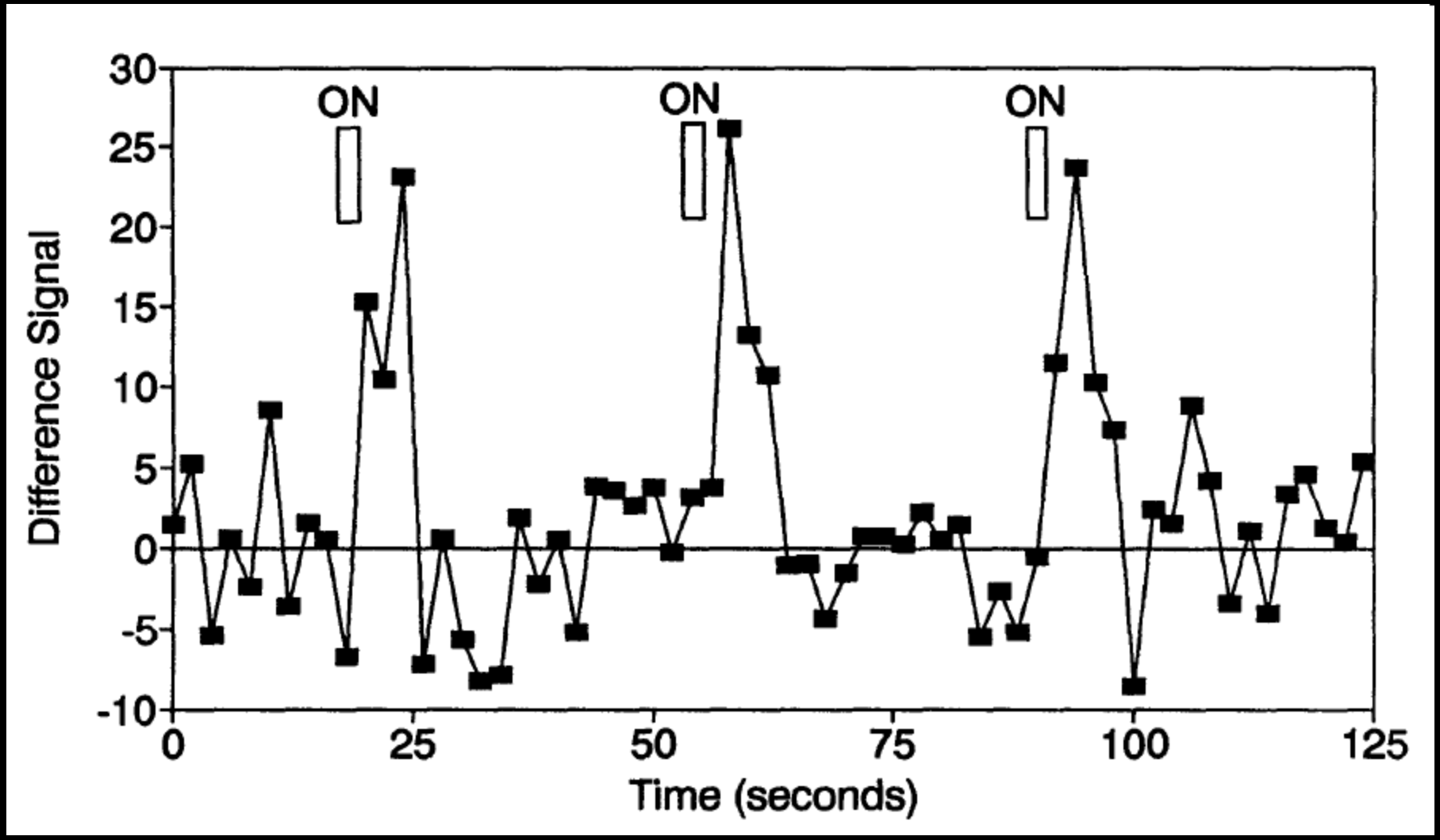






P. A. Bandettini, Functional MRI temporal resolution *in* "Functional MRI" (C. Moonen, and P. Bandettini., Eds.), p. 205-220, Springer - Verlag,. 1999.

First Event-related fMRI Results



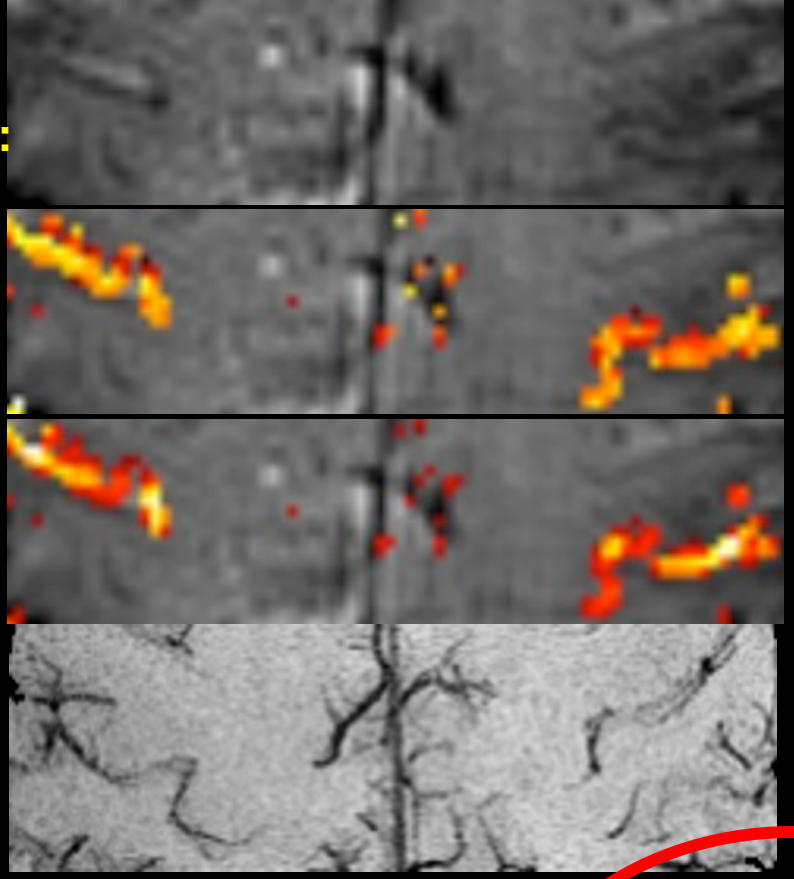
Blamire, A. M., et al. (1992). "Dynamic mapping of the human visual cortex by high-speed magnetic resonance imaging." Proc. Natl. Acad. Sci. USA 89: 11069-11073.

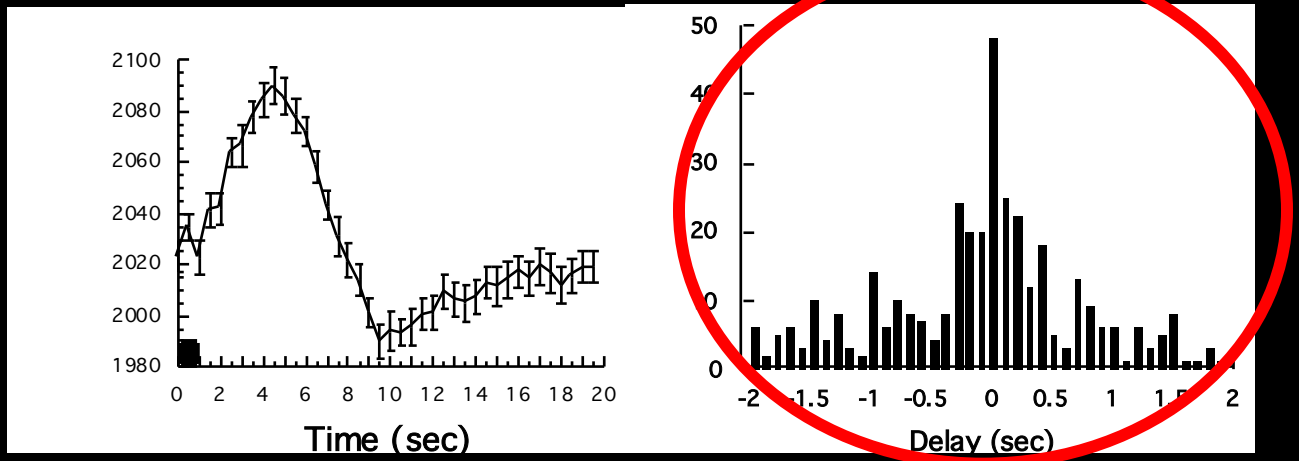
The major obstacle in BOLD contrast temporal resolution:

Latency

Magnitude

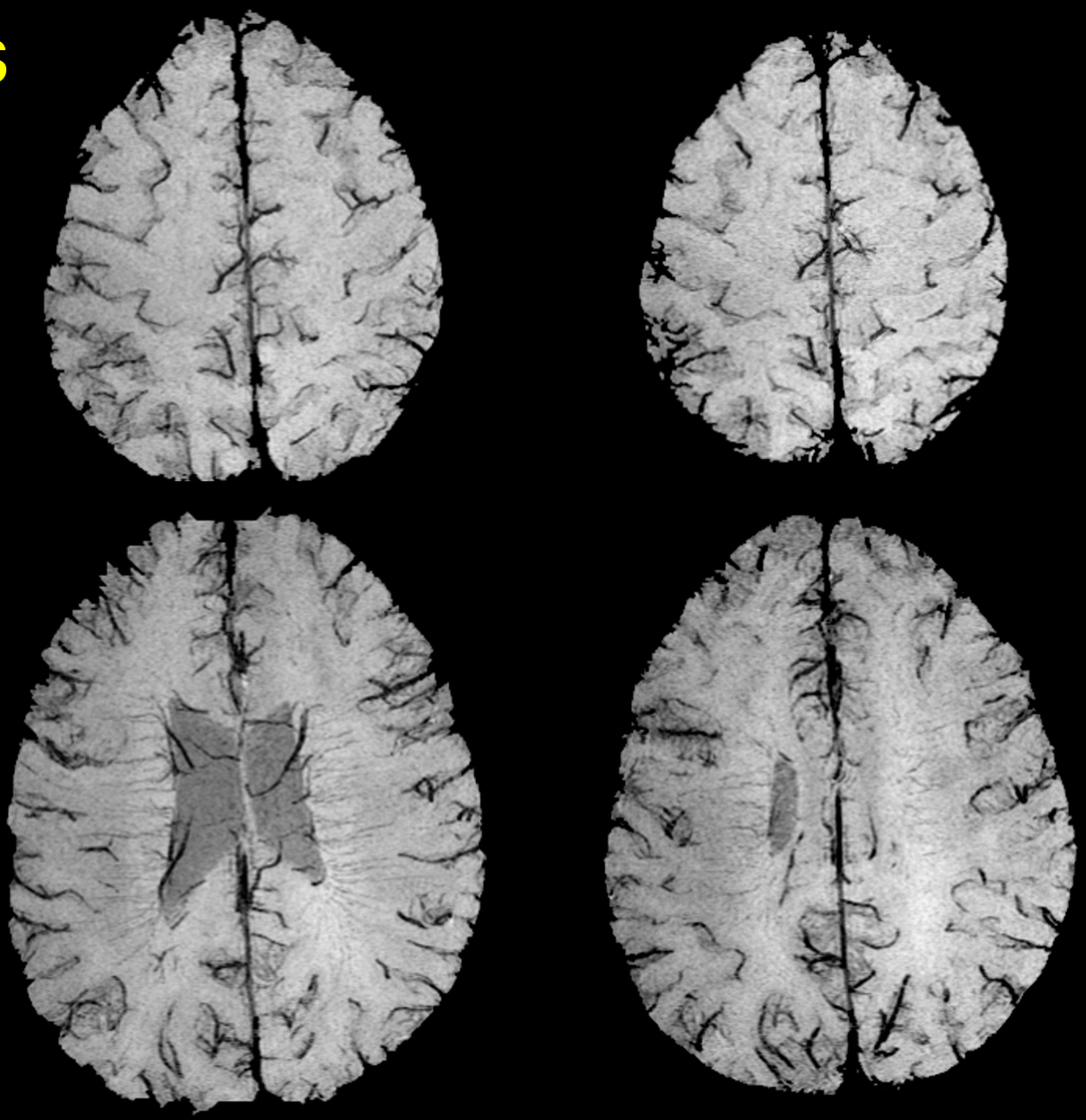
Venogram

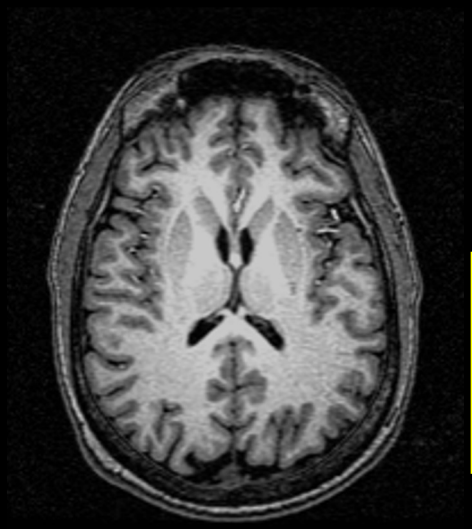




P. A. Bandettini, The temporal resolution of Functional MRI *in* "Functional MRI" (C. Moonen, and P. Bandettini., Eds.), p. 205-220, Springer - Verlag,. 1999.

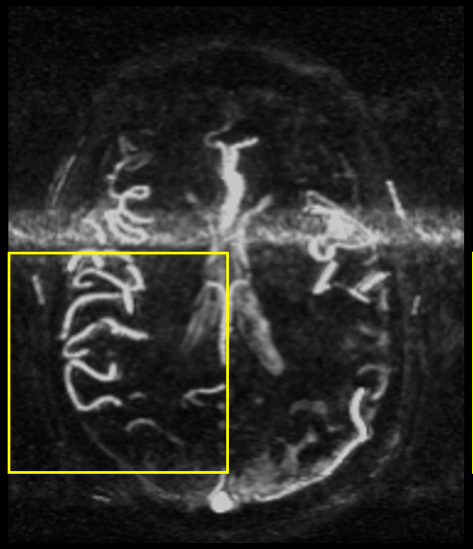
A tangent into venograms
(3 Tesla)



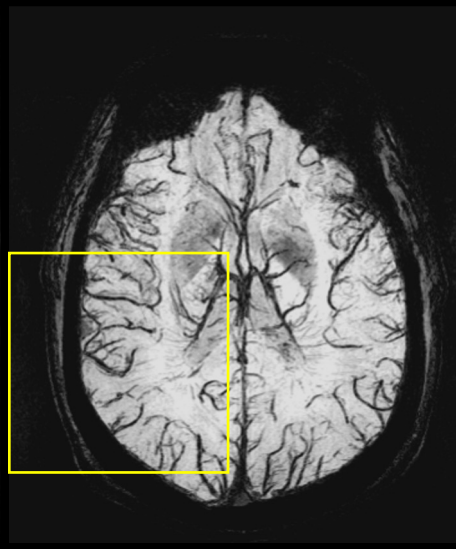


MP-RAGE

3D T-O-F MRA



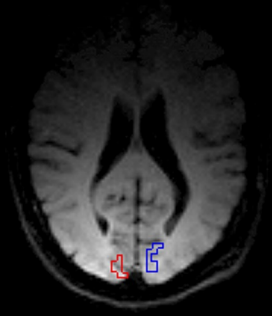
3D Venous PC



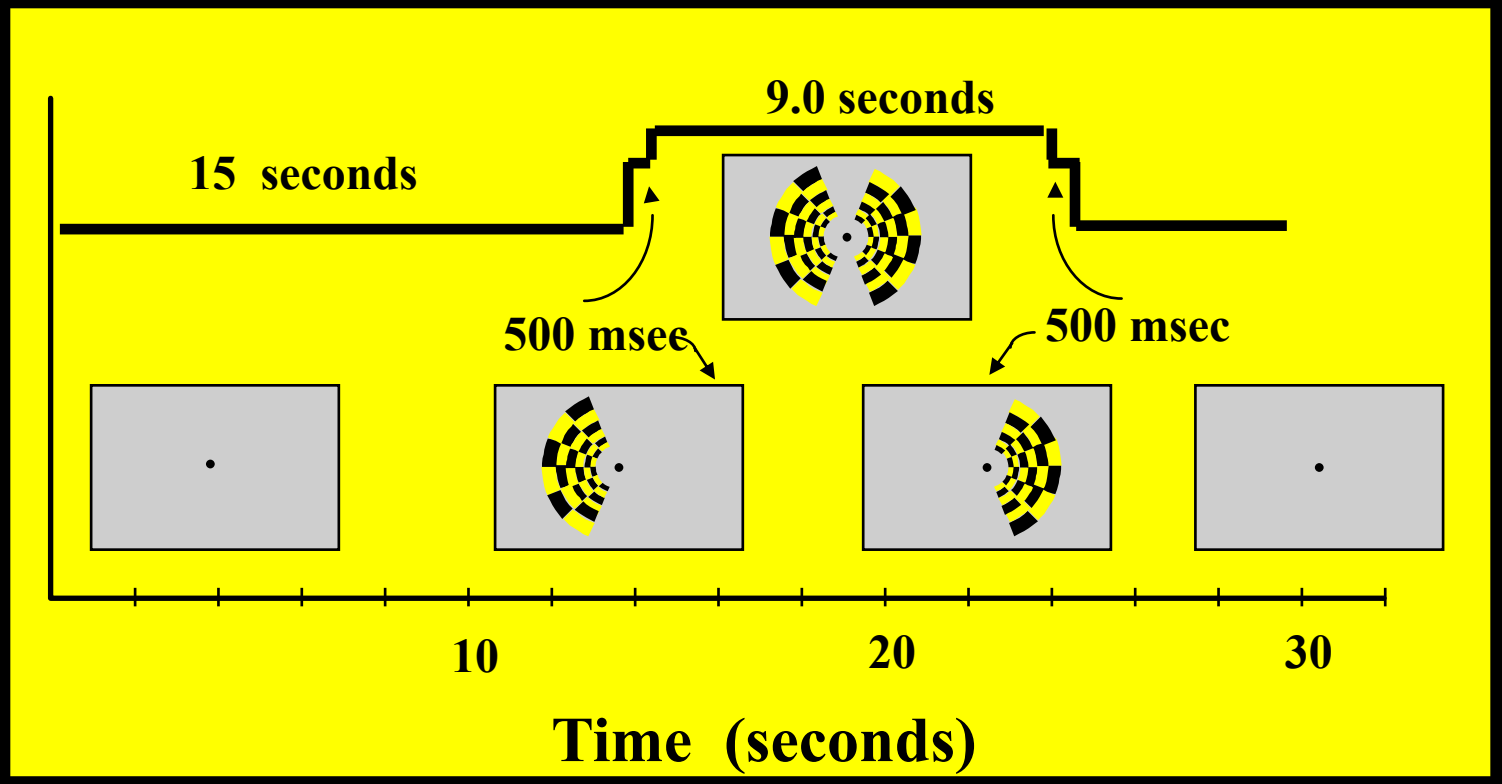
MR Venogram

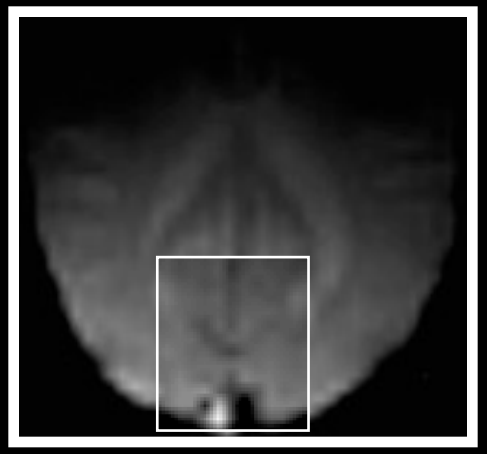
Hemi-Field Experiment

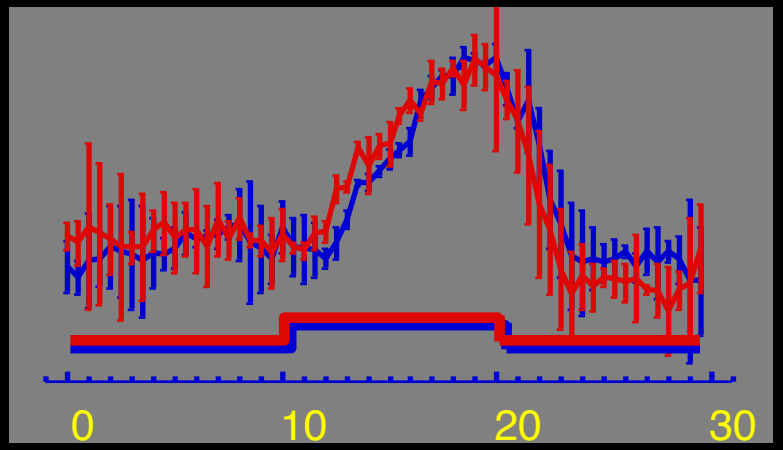
Right Hemisphere



Left Hemisphere







500 ms

500 ms

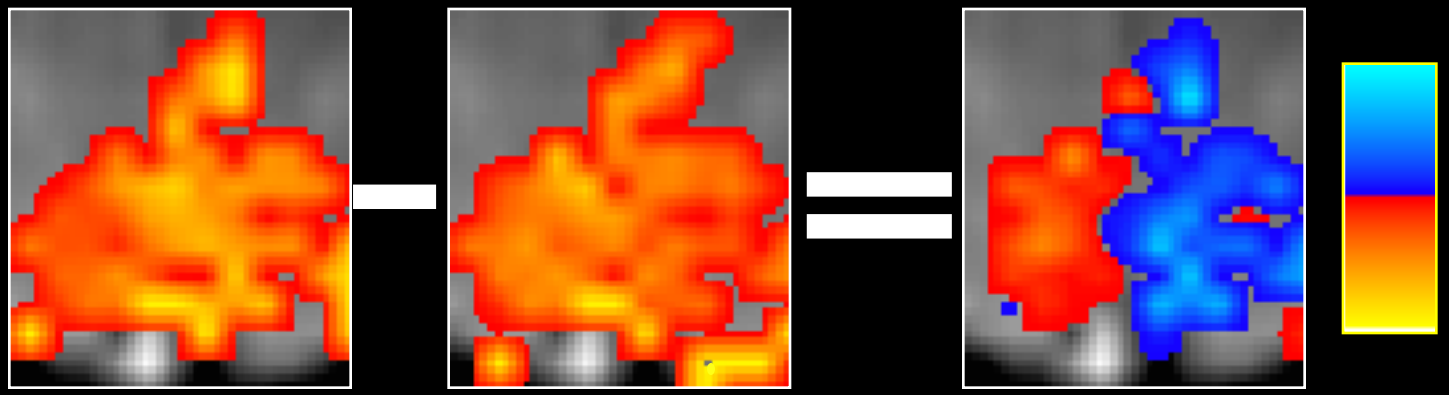
Right Hemifield

Left Hemifield

+ 2.5 s

0 s

- 2.5 s



Cognitive Neuroscience Application:

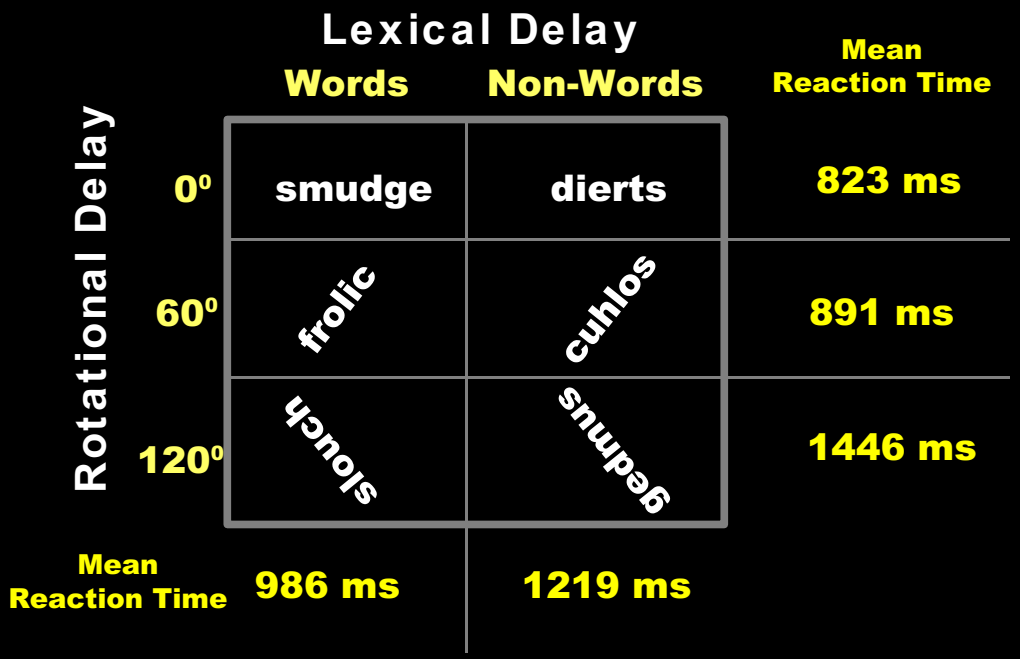
Understanding neural system dynamics through task modulation and measurement of functional MRI amplitude, latency, and width

PNAS

P. S. F. Bellgowan*†, Z. S. Saad‡, and P. A. Bandettini*

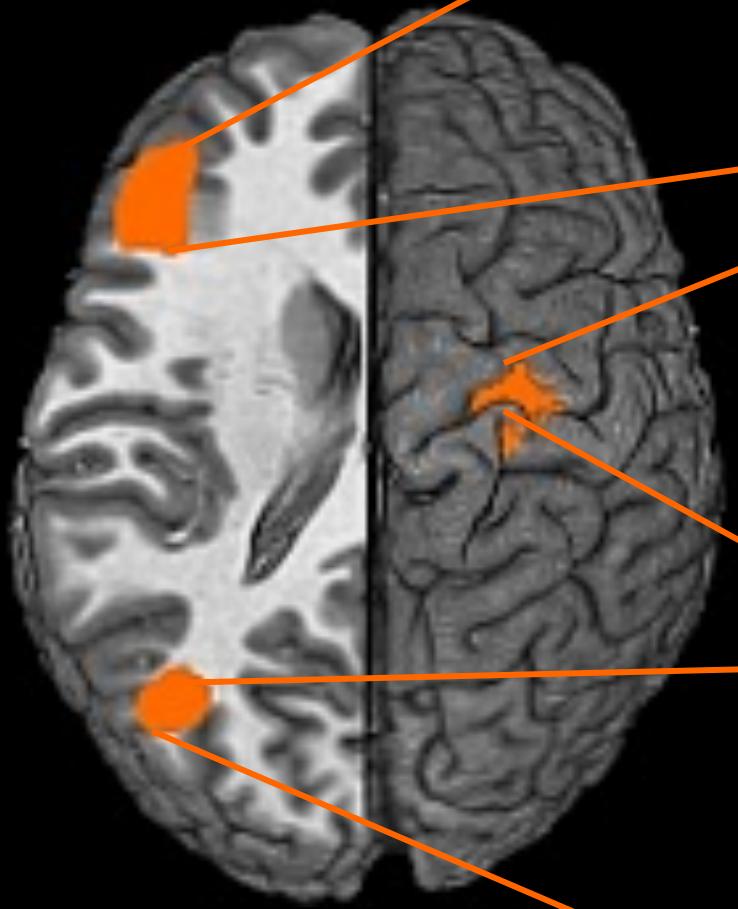
*Laboratory of Brain and Cognition and ‡Scientific and Statistical Computing Core, National Institute of Mental Health, Bethesda, MD 20892

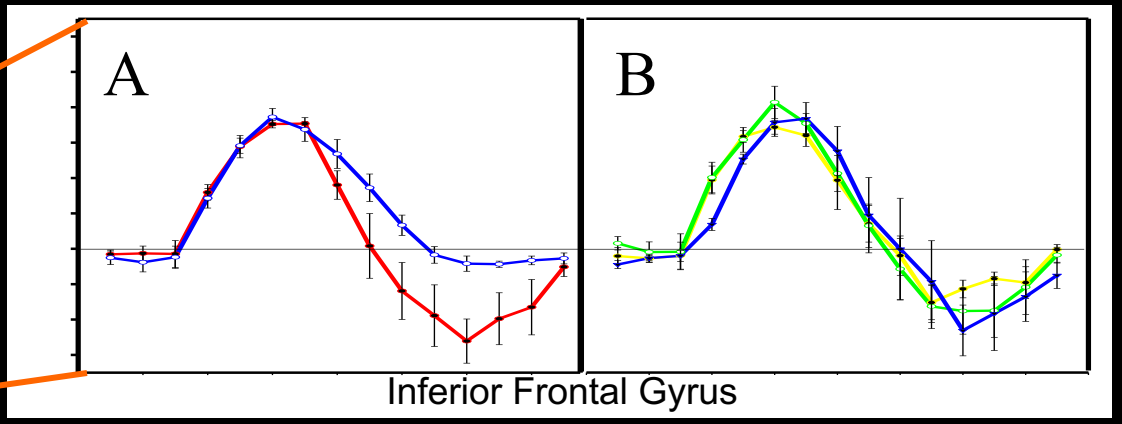
Communicated by Leslie G. Ungerleider, National Institutes of Health, Bethesda, MD, December 19, 2002 (received for review October 31, 2002)



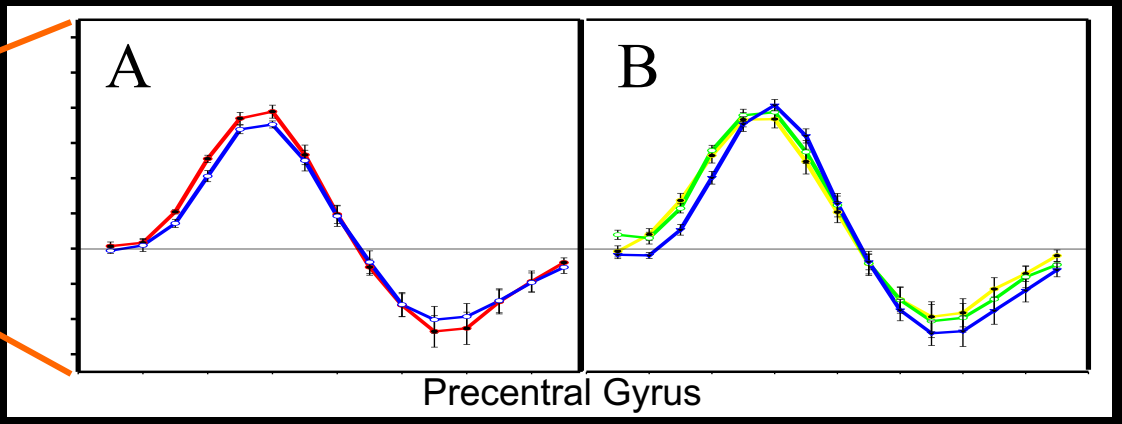
Word vs. Non-word 0°, 60°, 120° Rotation

Regions of Interest

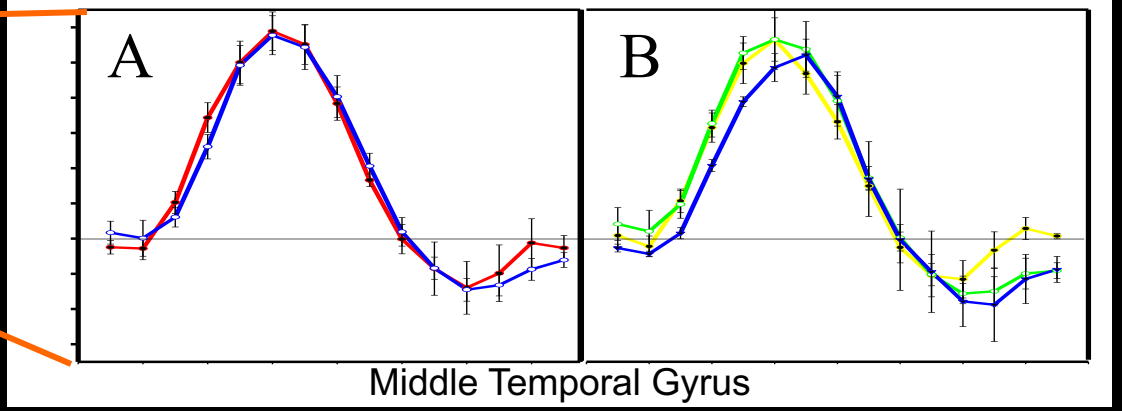




Inferior Frontal Gyrus

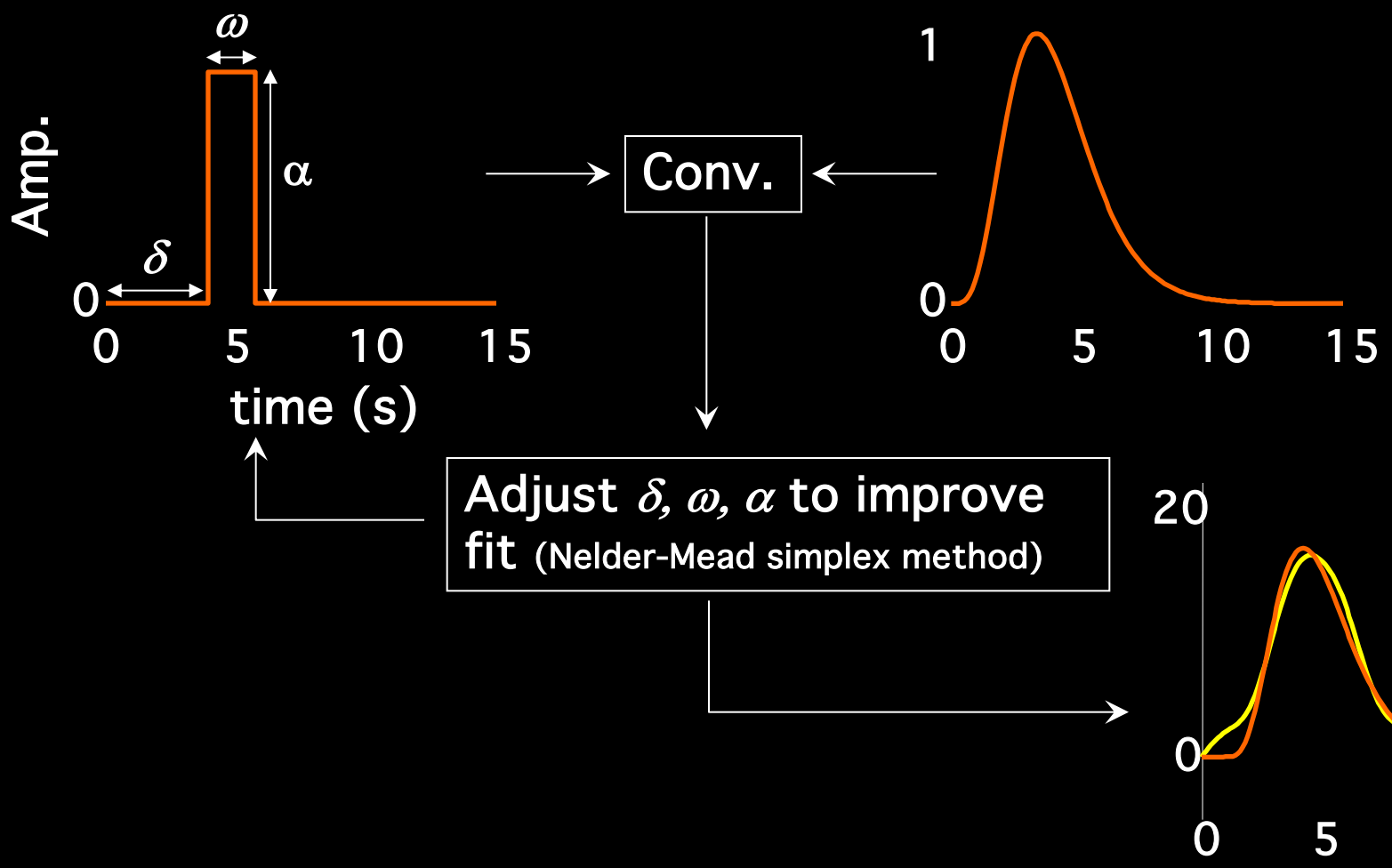


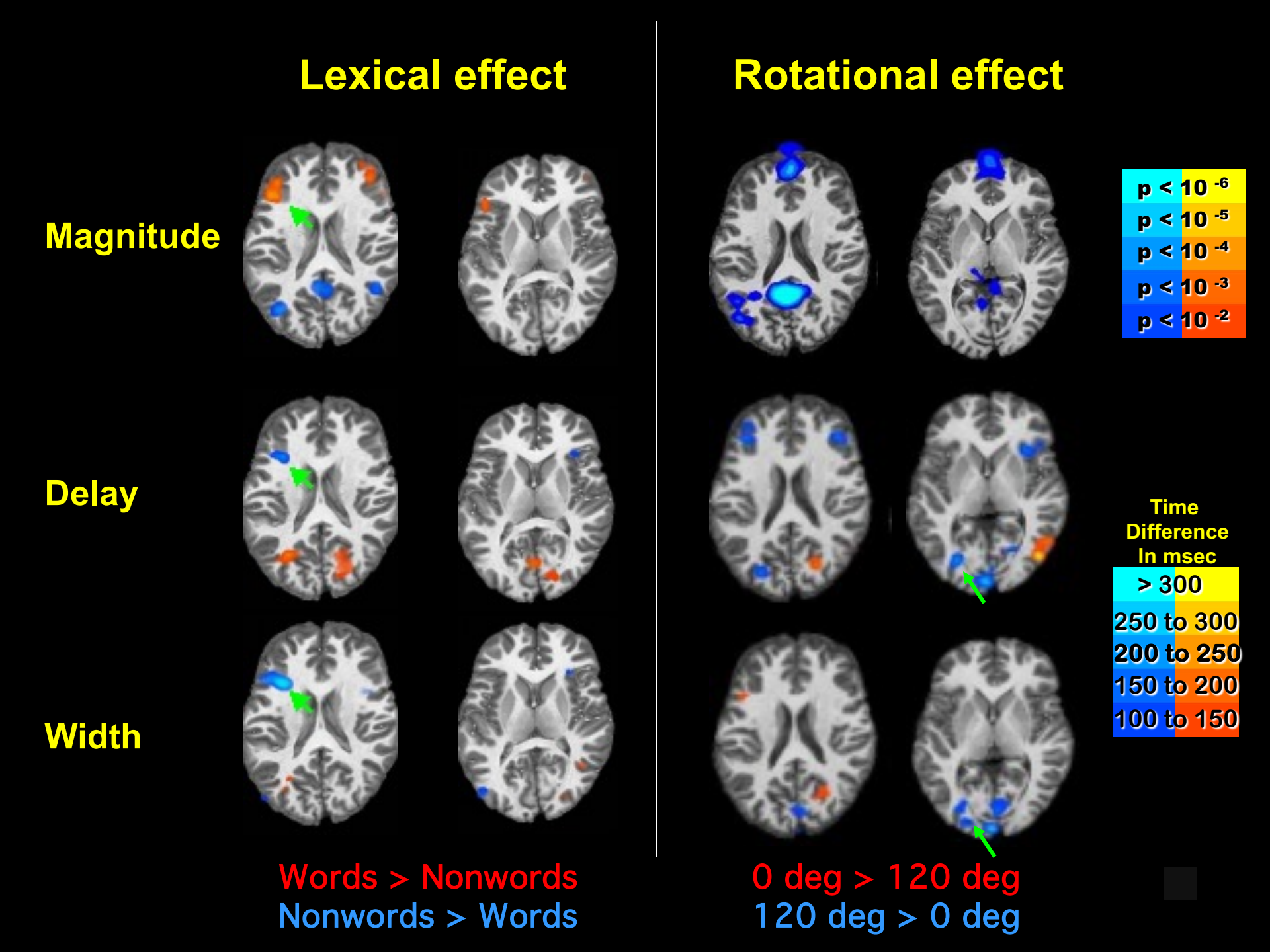
Precentral Gyrus



Middle Temporal Gyrus

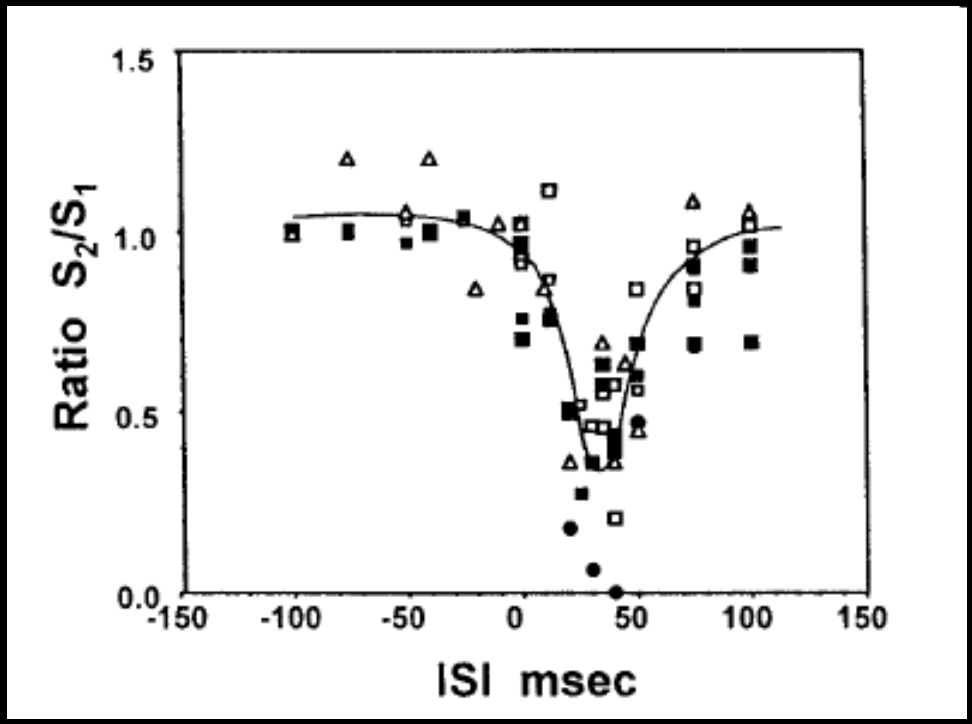
Estimation of Delay, Width & Amplitude




Lexical effect
Rotational effect
Magnitude
Delay
Width
p < 10 -6
p < 10 -5
p < 10 -4
p < 10 -3
p < 10 -2
Time Difference In msec
> 300
250 to 300
200 to 250
150 to 200
100 to 150
Words > Nonwords
Nonwords > Words
0 deg > 120 deg
120 deg > 0 deg

An approach to probe some neural systems interaction by functional MRI at neural time scale down to milliseconds

Seiji Ogawa[†‡], Tso-Ming Lee[†], Ray Stepnoski[†], Wei Chen[§], Xiao-Hong Zhu[§], and Kamil Ugurbil[§]

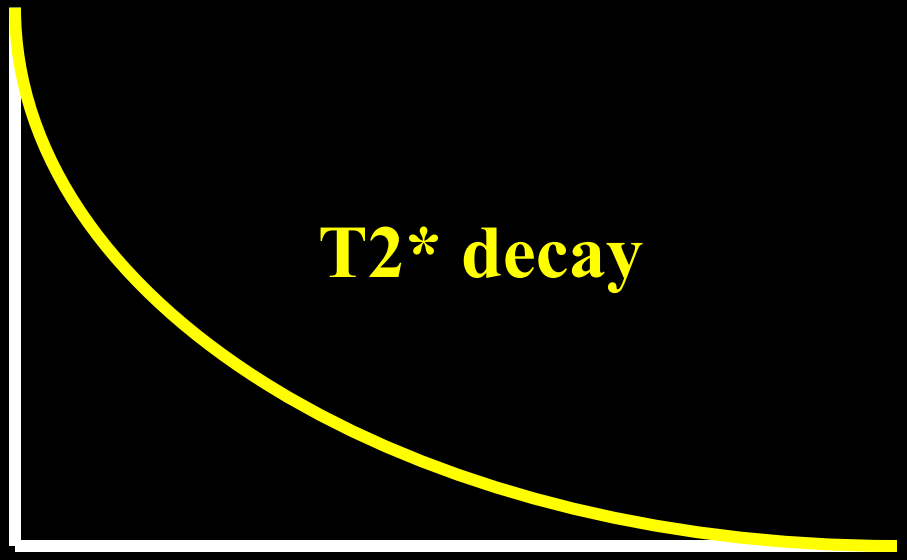


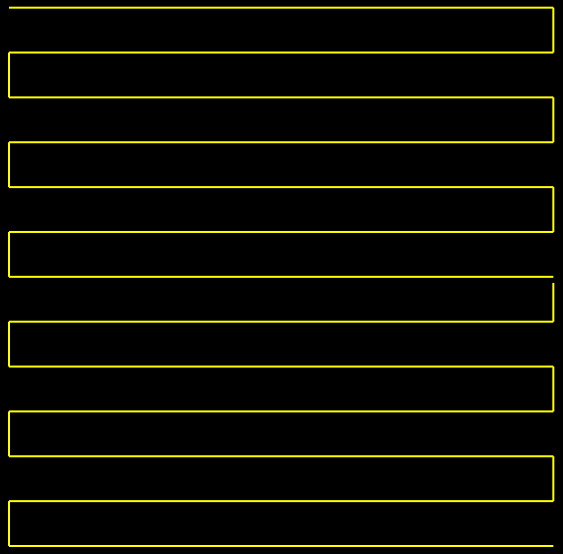
11026–11031 PNAS **September 26, 2000** vol. 97 no. 20

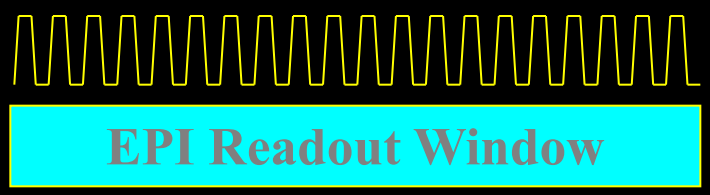
Latest Developments...

1. Temporal Resolution
2. Spatial Resolution
3. Sensitivity and Noise
4. Information Content
5. Implementation

Single Shot Imaging

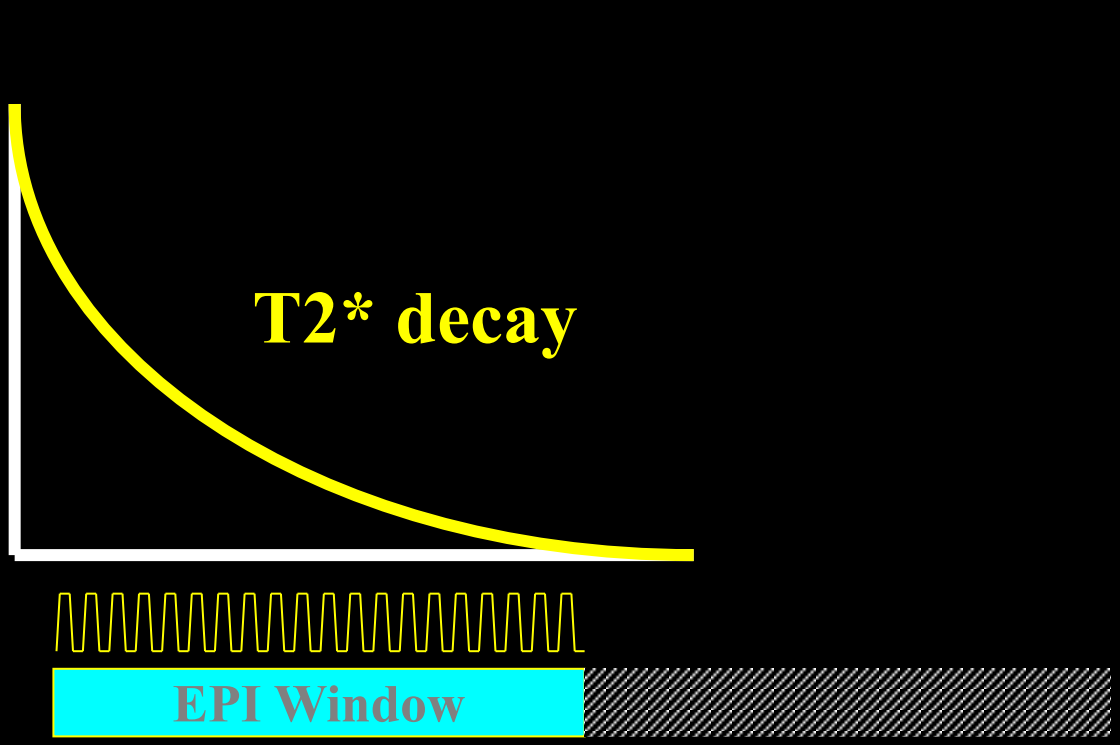


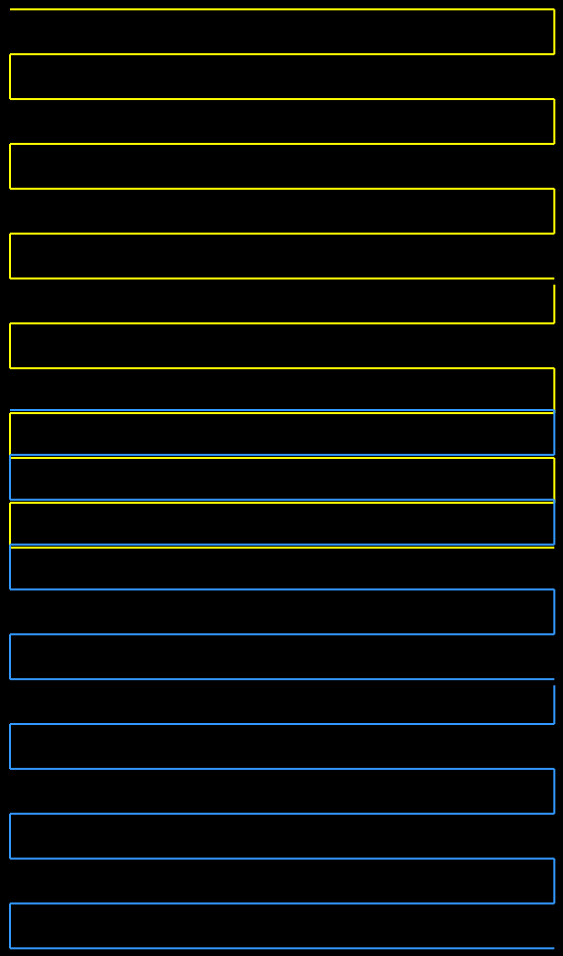




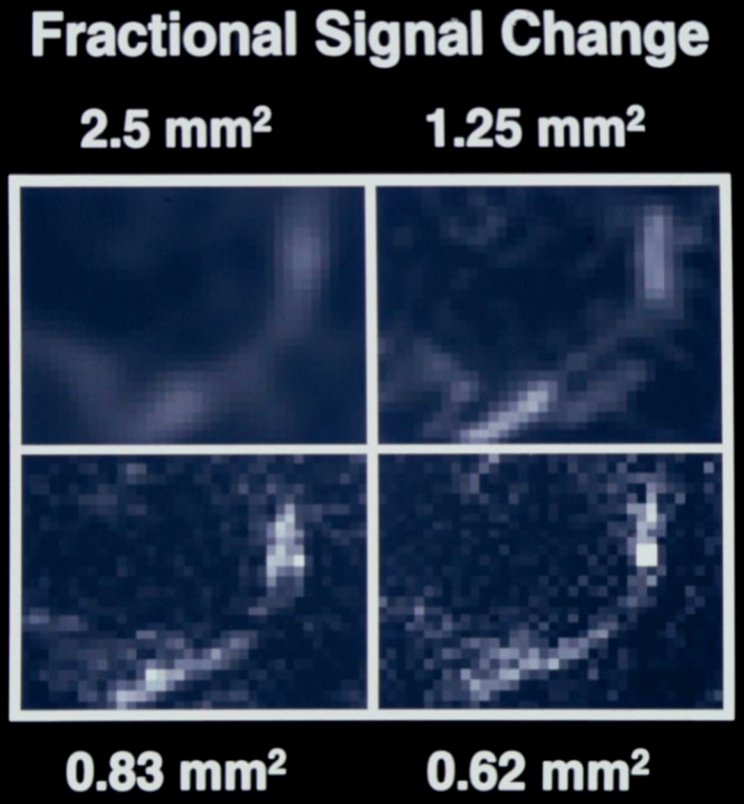
≈ 20 to 40 ms

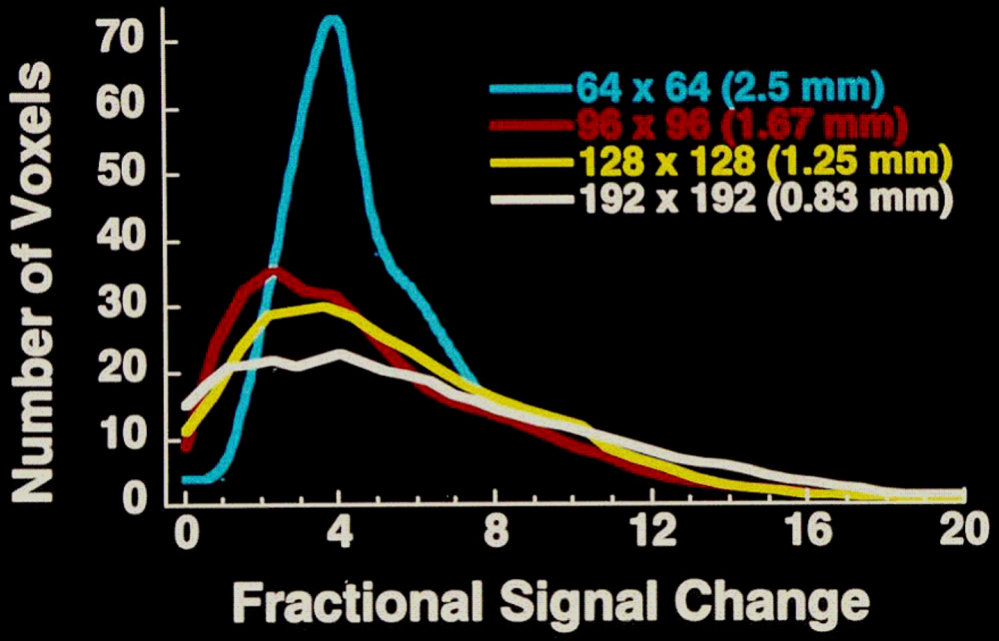
Partial k-space imaging





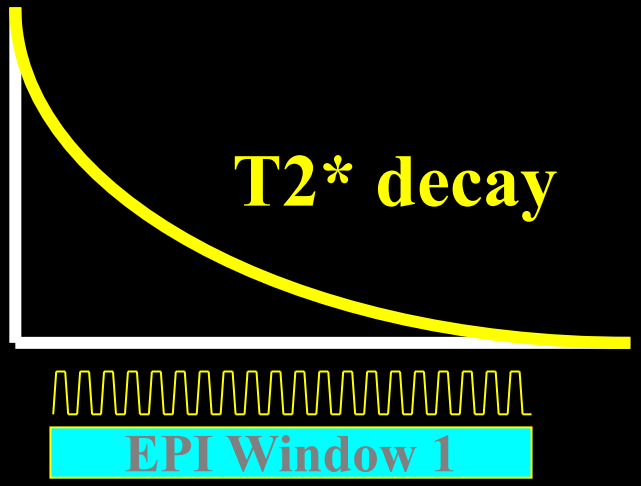
Partial k-space imaging

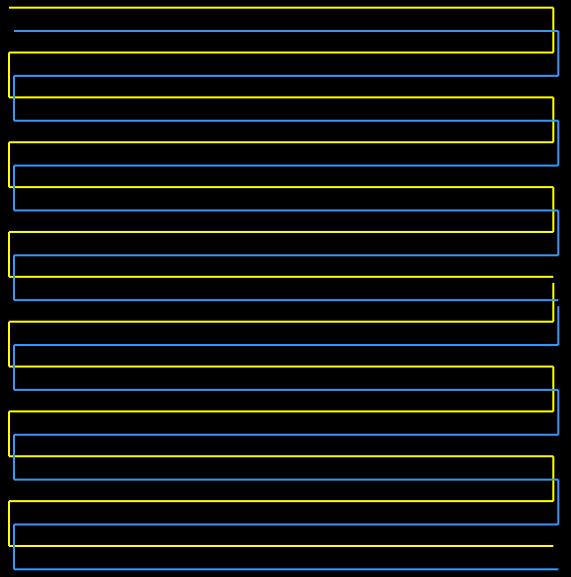


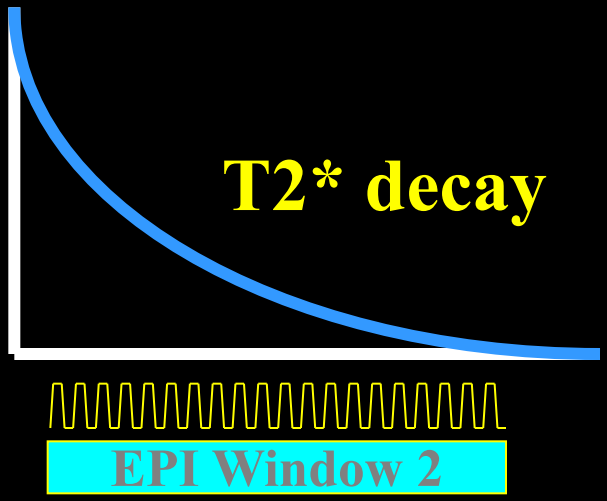


Jesmanowicz, P. A. Bandettini, J. S. Hyde, (1998) "Single shot half k-space high resolution EPI for fMRI at 3T." *Magn. Reson. Med.* 40, 754-762.

Multishot Imaging

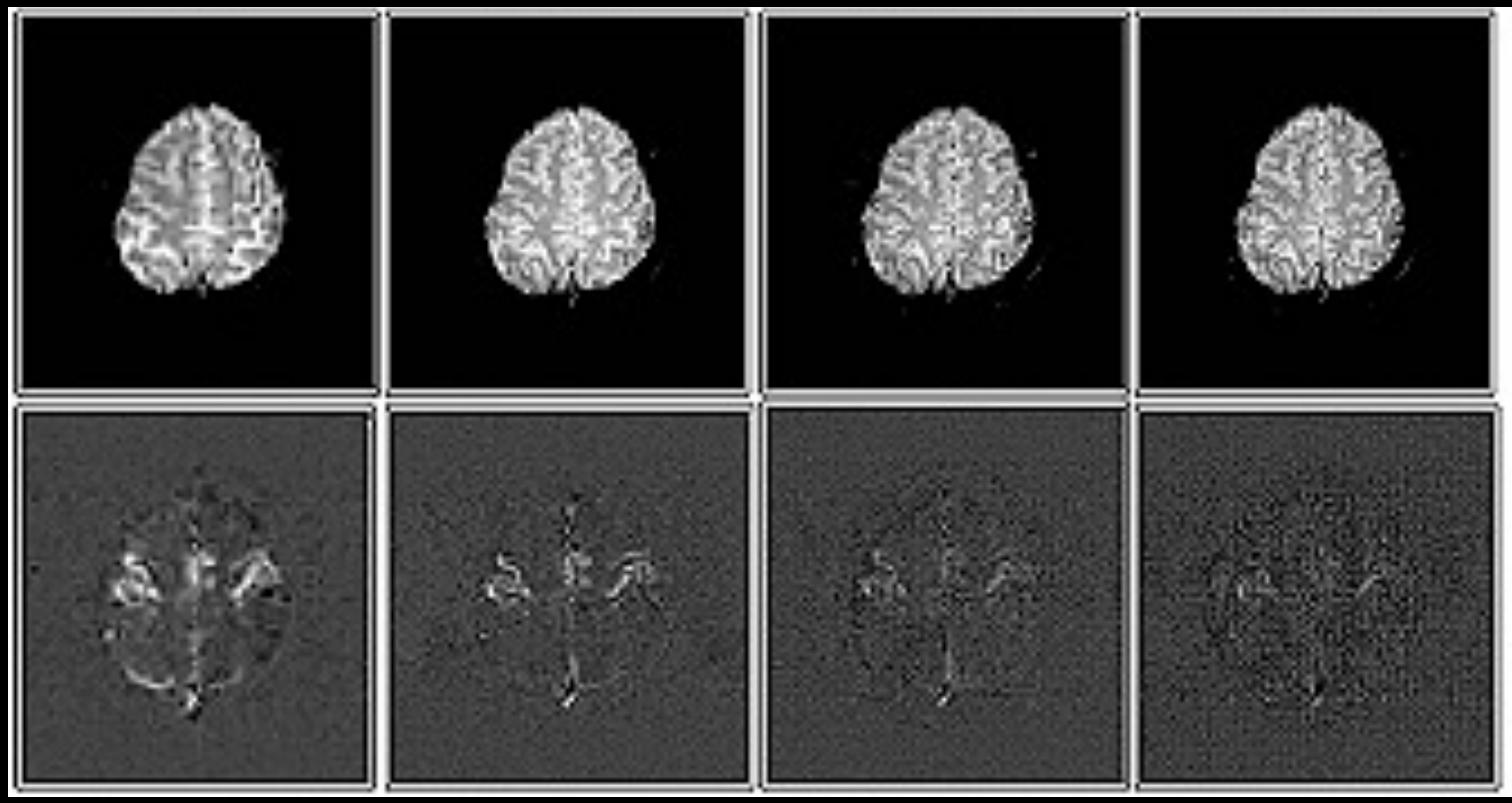




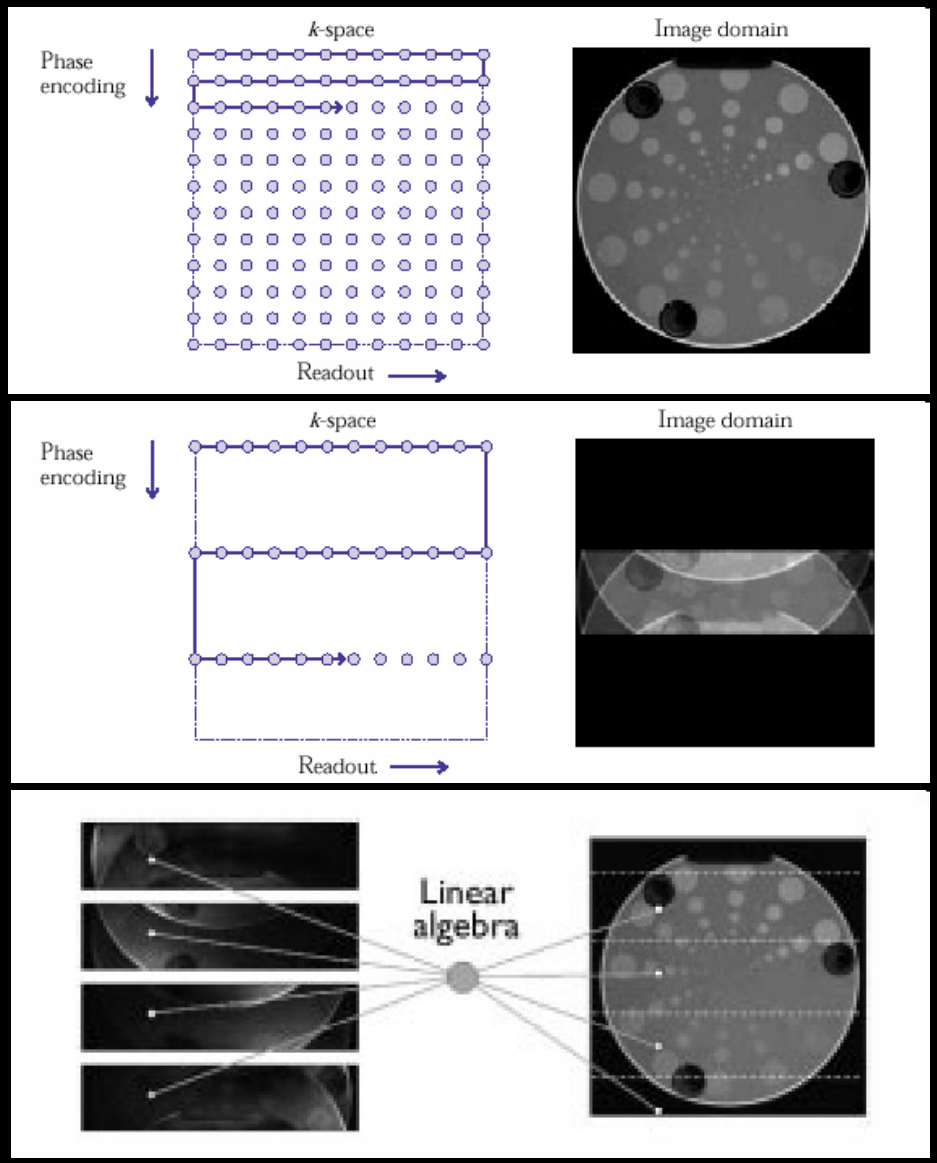


Multi Shot EPI

Excitations	1	2	4	8	
Matrix Size	64 x 64		128 x 128	256 x 128	256



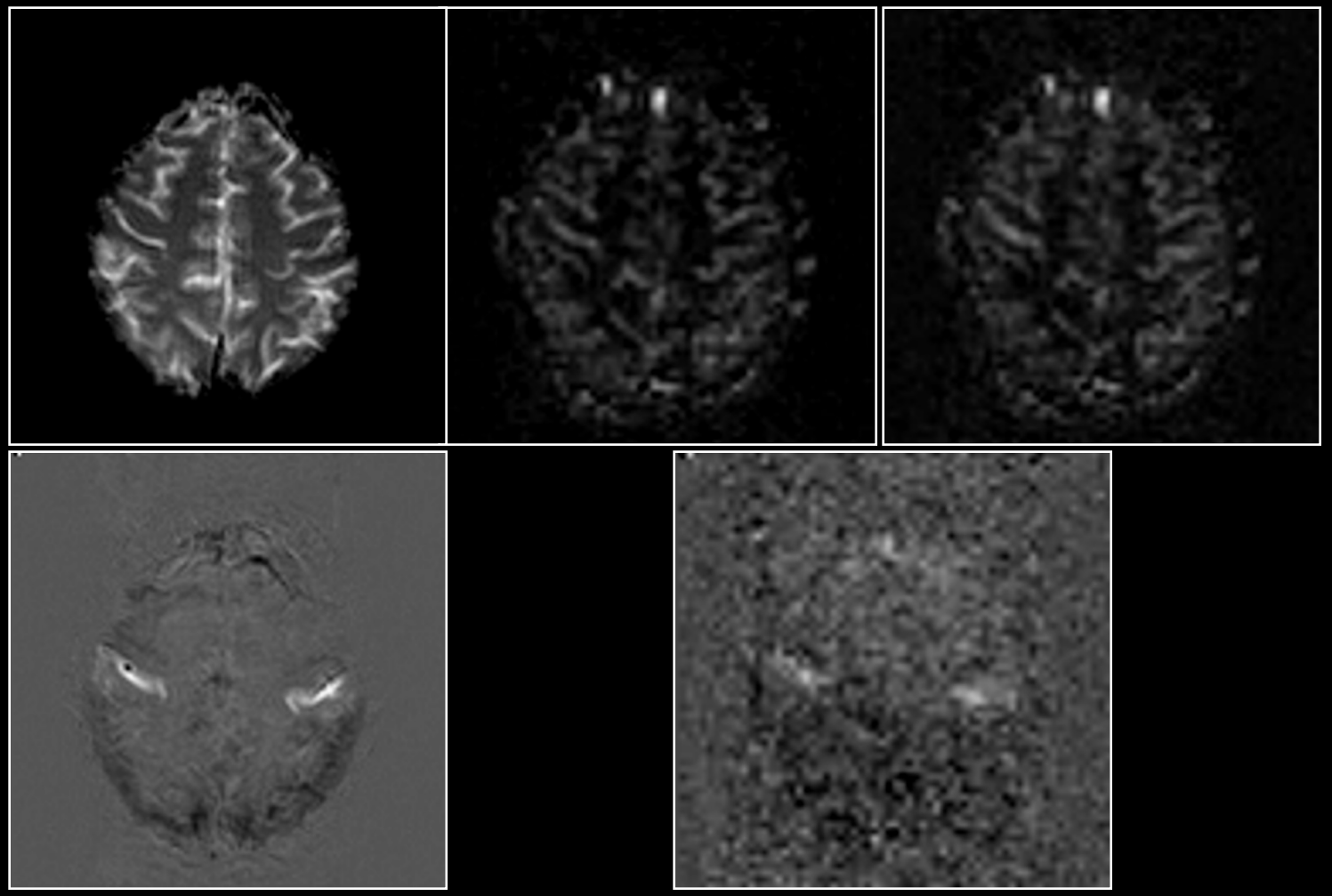
SENSE Imaging



Pruessmann, et al.

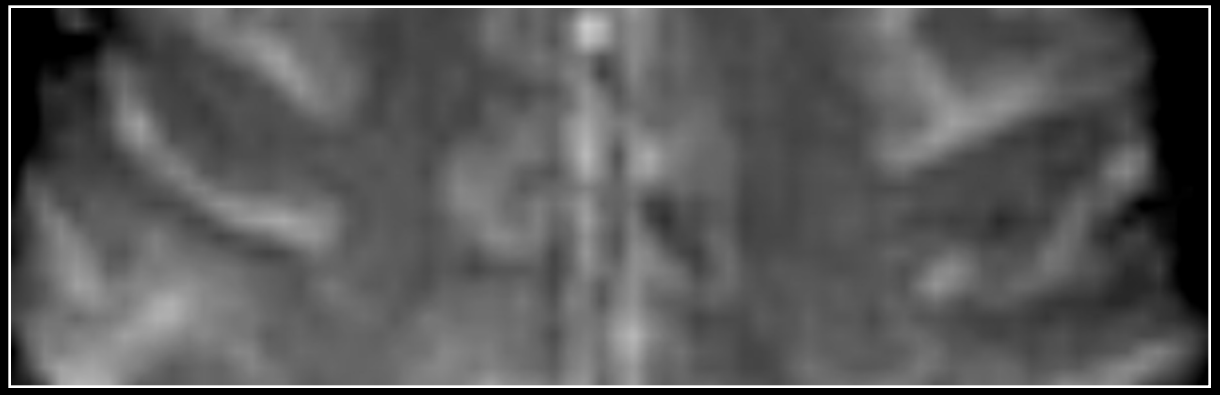
Perfusion

BOLD *Rest* *Activation*

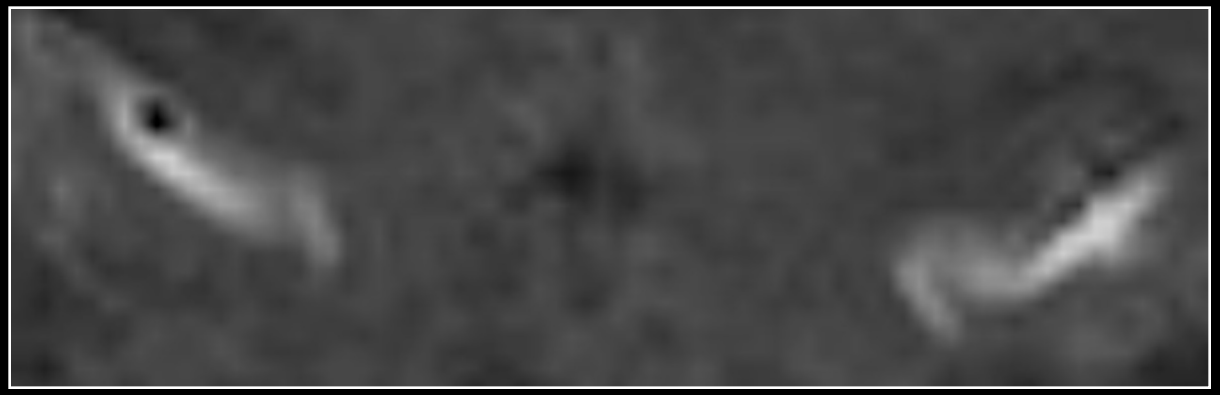


P. A. Bandettini, E. C. Wong, Magnetic resonance imaging of human brain function: principles, practicalities, and possibilities, *in* "Neurosurgery Clinics of North America: Functional Imaging" (M. Haglund, Ed.), p.345-371, W. B. Saunders Co., 1997.

Anatomy

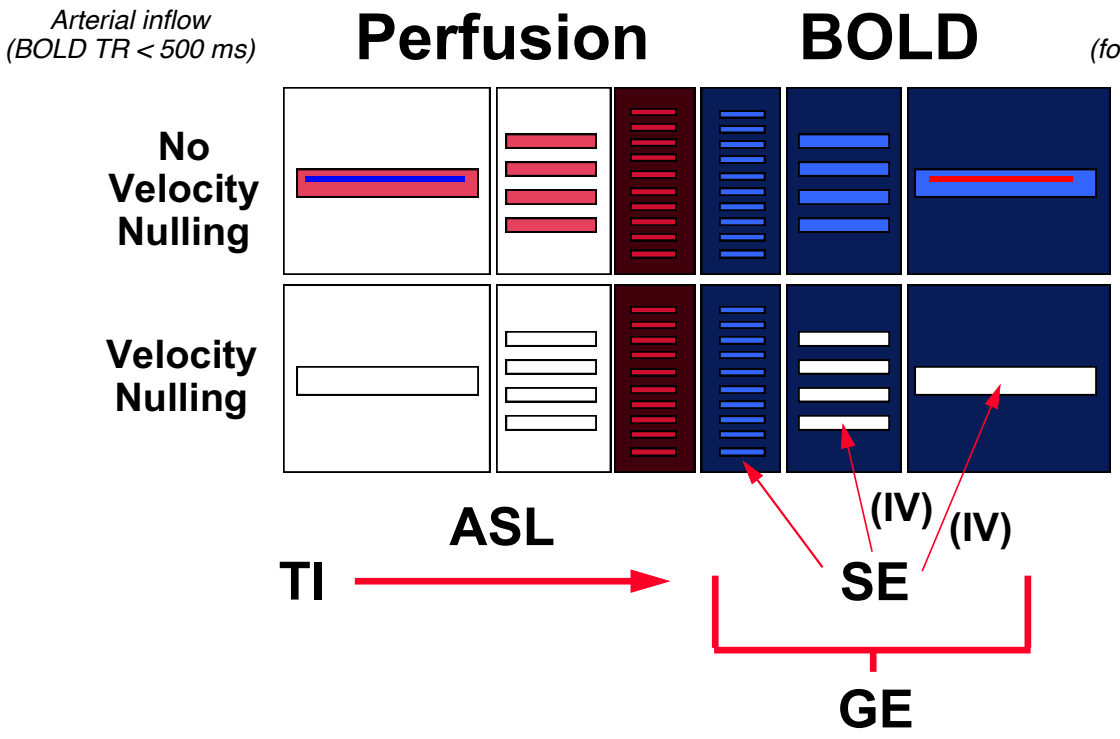


BOLD



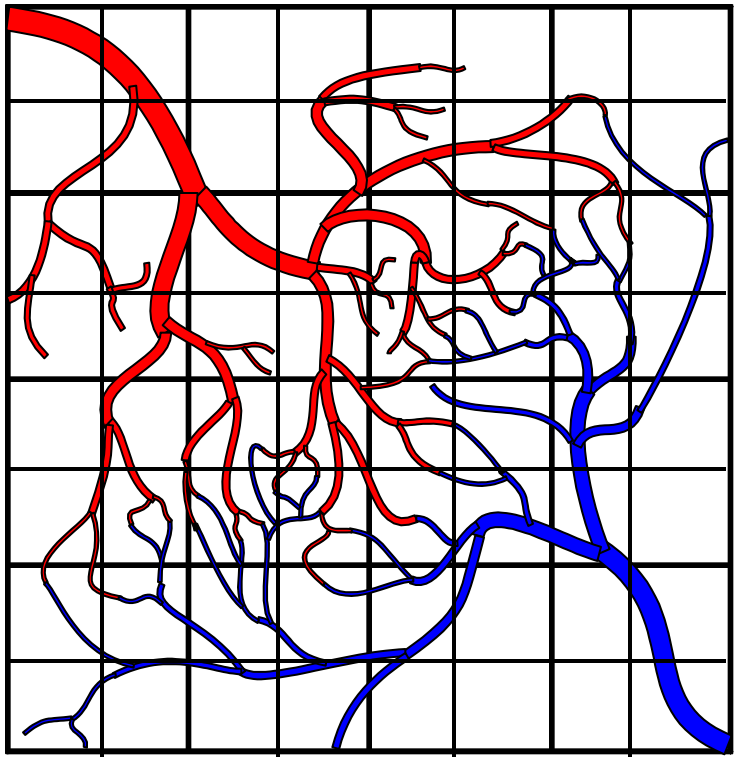
Perfusion

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.



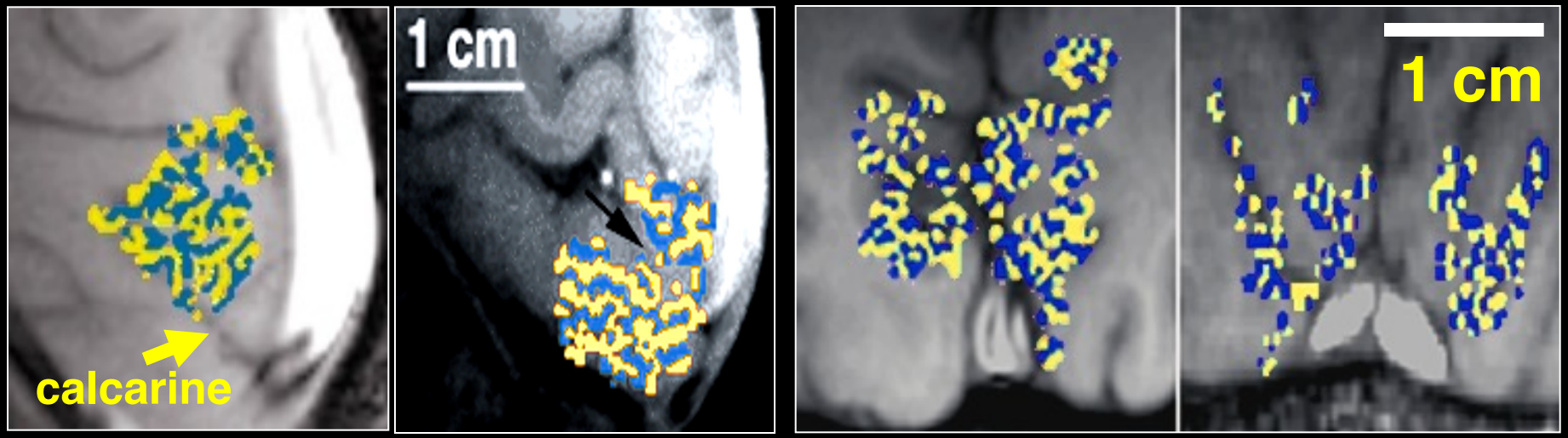
Pulse Sequence Sensitivity

Spatial Heterogeneity



Menon, et al

ODC Maps using fMRI



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

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

Latest Developments...

1. Temporal Resolution
2. Spatial Resolution
3. Sensitivity and Noise
4. Information Content
5. Implementation

The spatial extent of the BOLD response

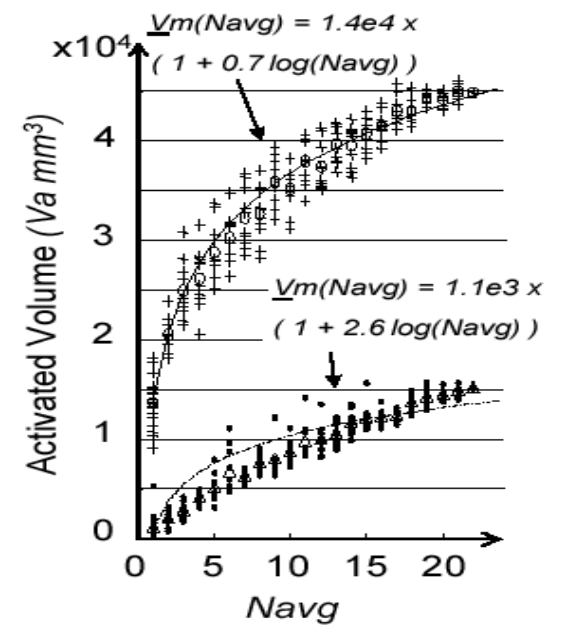
Ziad S. Saad,[a,b,*] Kristina M. Ropella,[b] Edgar A. DeYoe,[c] and Peter A. Bandettini[a]

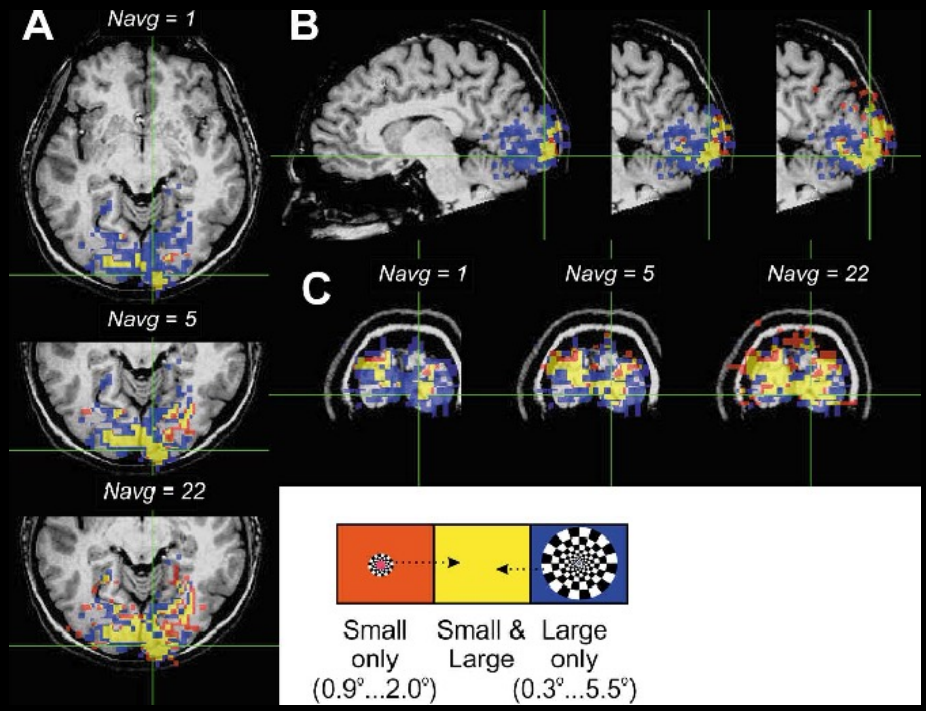
[a] Laboratory of Brain and Cognition, National Institute of Mental Health, NIH, Bethesda, MD 20892-1148, USA
[b] Department of Biomedical Engineering Marquette University, Milwaukee, WI 53233, USA
[c] Department of Cell Biology, Neurobiology and Anatomy, Medical College of Wisconsin, Milwaukee, WI 53226, USA

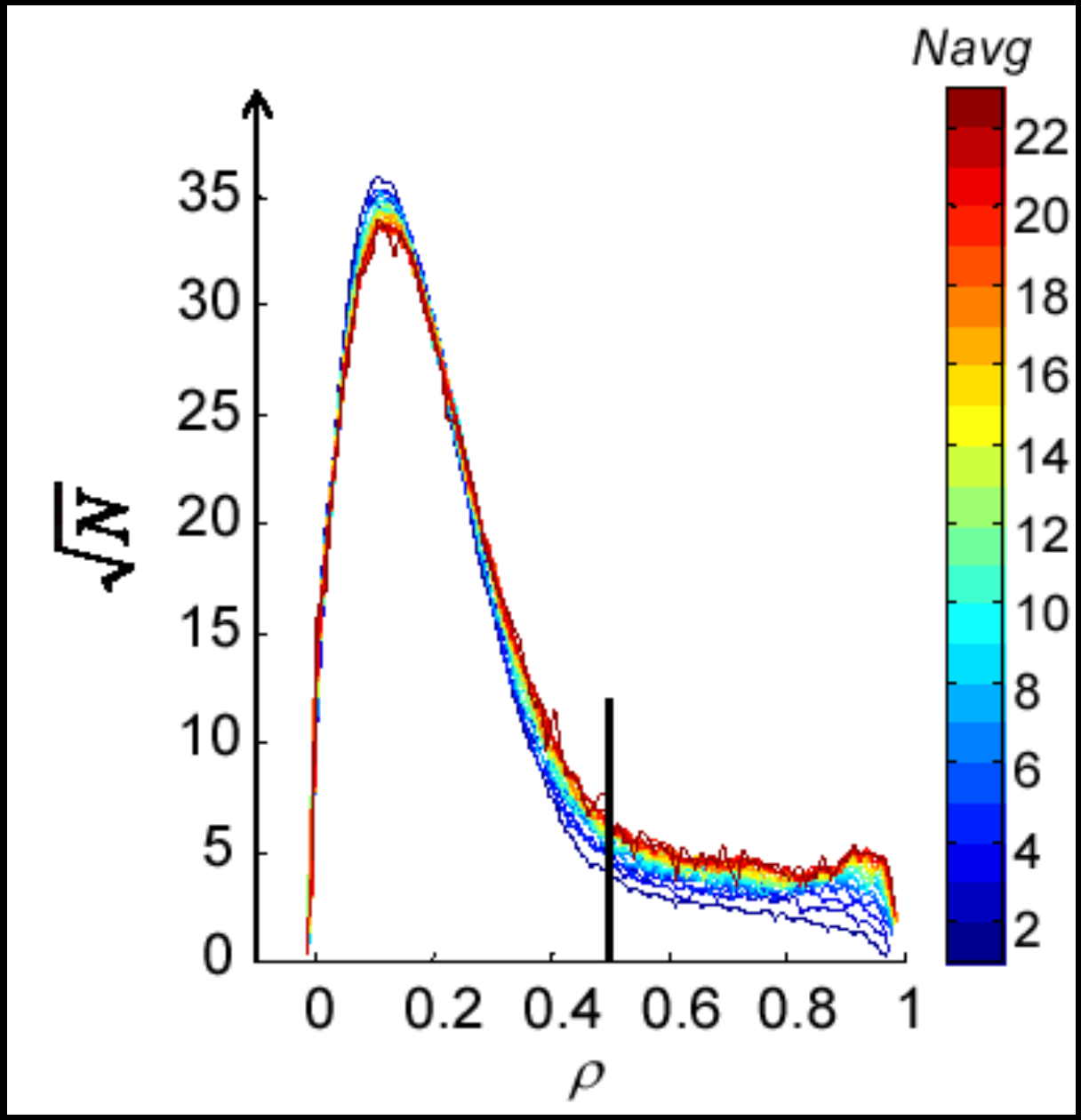
Received 16 August 2002; revised 29 October 2002; accepted 21 November 2002

NeuroImage

Question: What is the "true" spatial extent of BOLD contrast?
Paradigm: Repeated averaging of simple visual task






Navg
22
20
18
16
14
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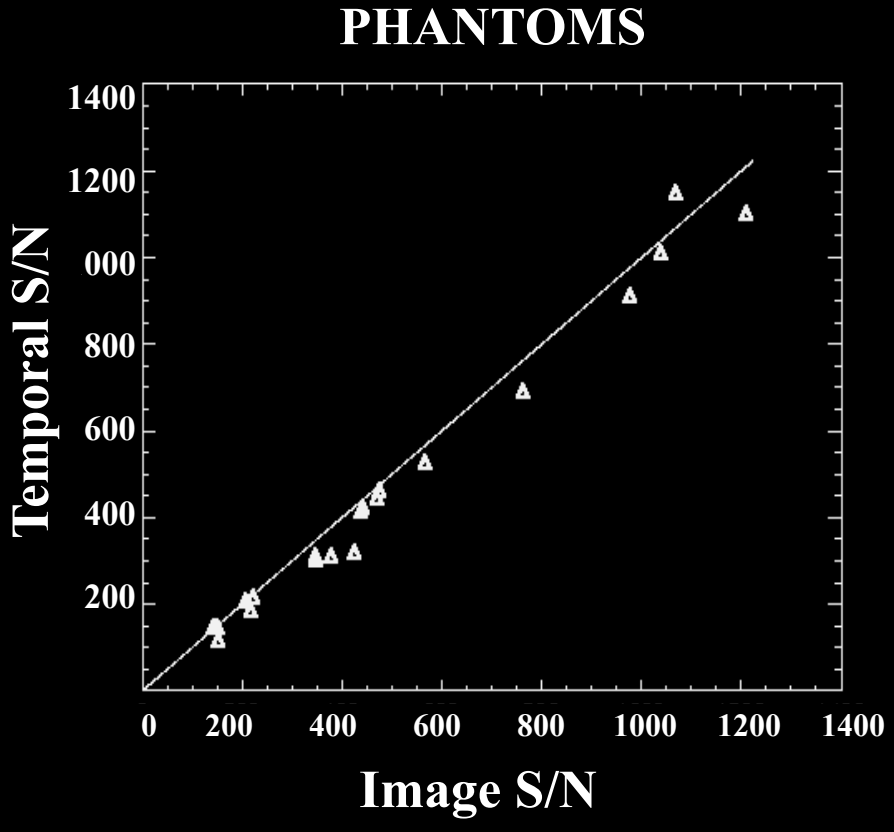
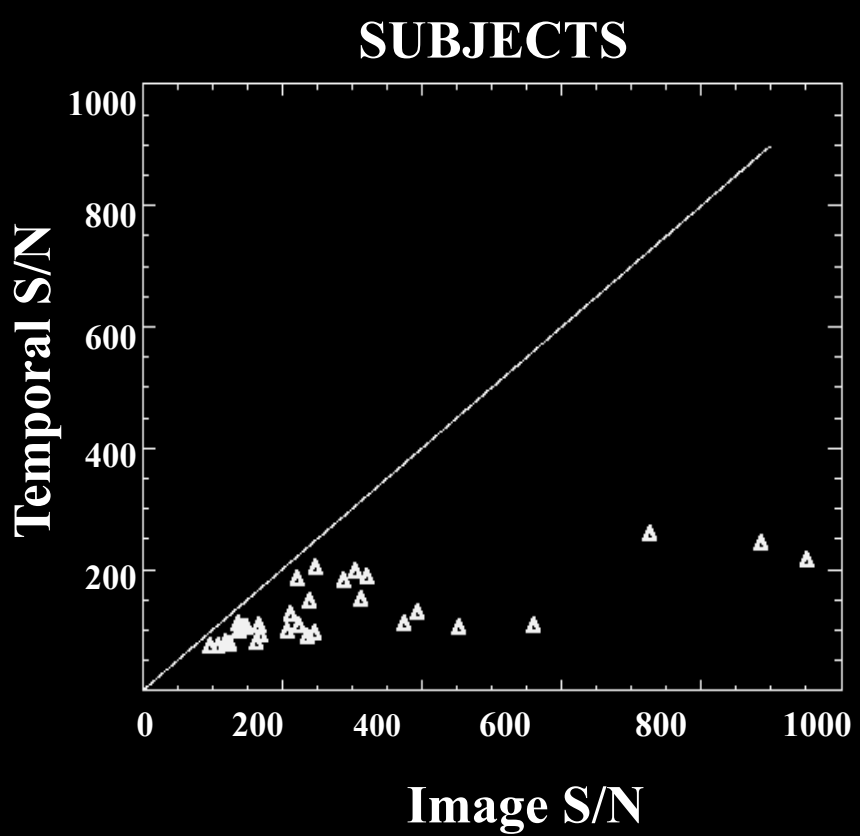
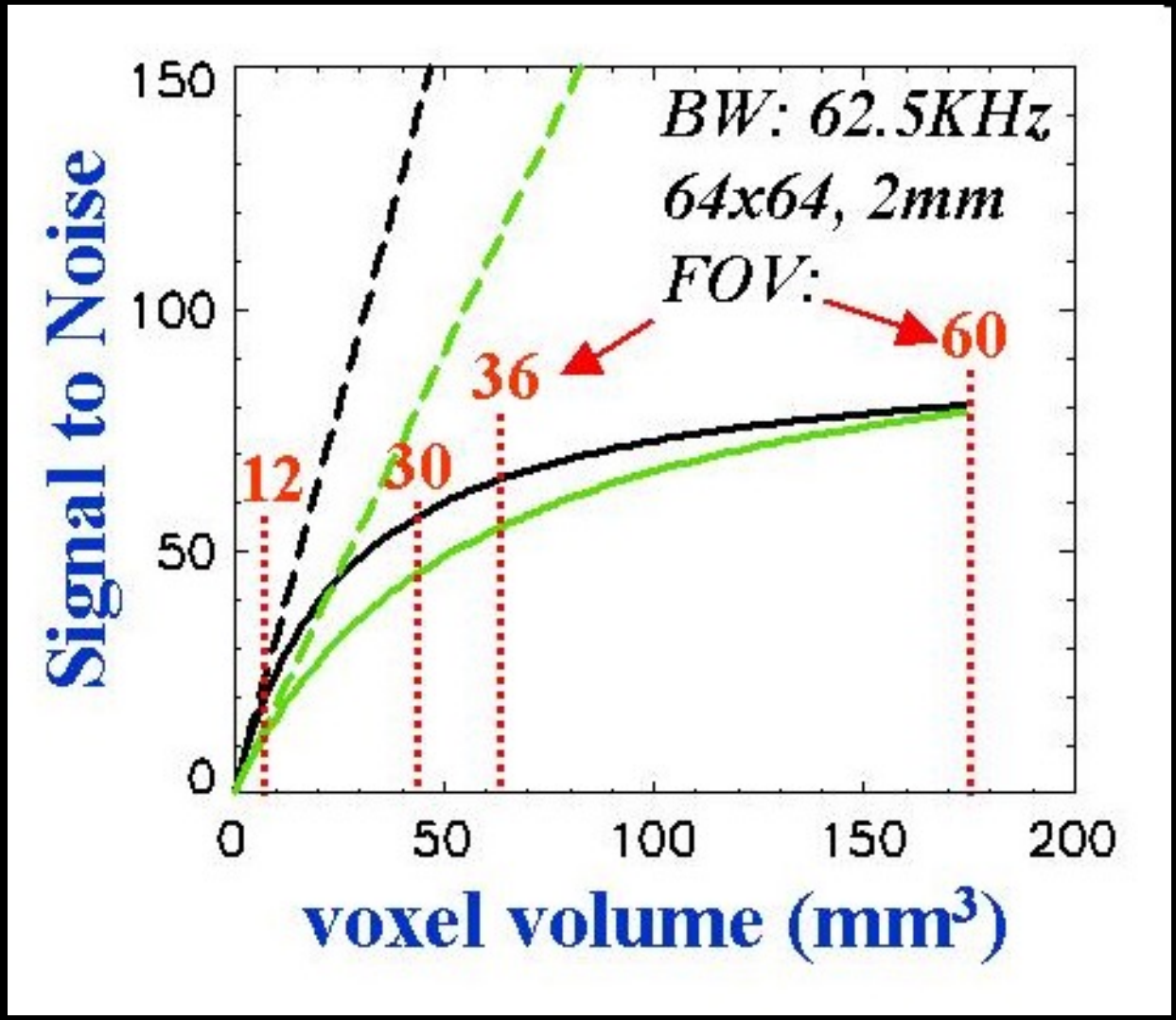
8
6
4
2
35
30
25
20
15
10
5
0
$\sqrt{N}$
0
0.2
0.4
0.6
0.8
1
ρ

Temporal S/N vs. Image S/N





N. Petridou


BW: 62.5KHz
64x64, 2mm
FOV:
60
36
30
12
Signal to Noise
voxel volume (mm3)
150
100
50
0
0
50
100
150
200

Single shot full k-space echo-planar-imaging with an eight-channel phase array coil at 3T.

Jerzy Bodurka[1], Peter van Gelderen[2], Patrick Ledden[3], Peter Bandettini[1], Jeff Duyn[2]
[1]Functional MRI Facility NIMH/NIH, [2]Advance MRI NINDS/NIH, [3]Nova Medical Inc.

Quadrature Head Coil

8 Channel Array

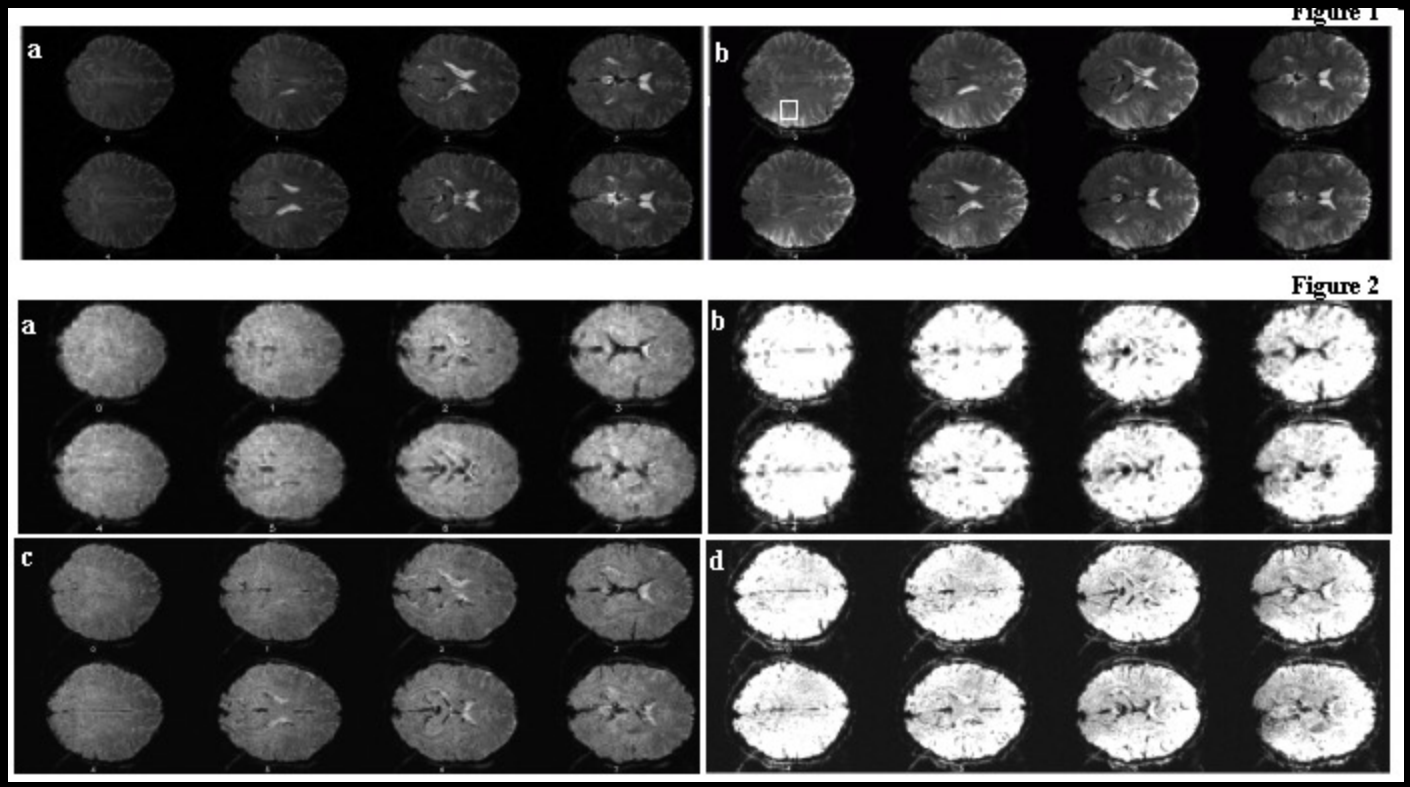
128 x 96

64 x 48

128 x 96

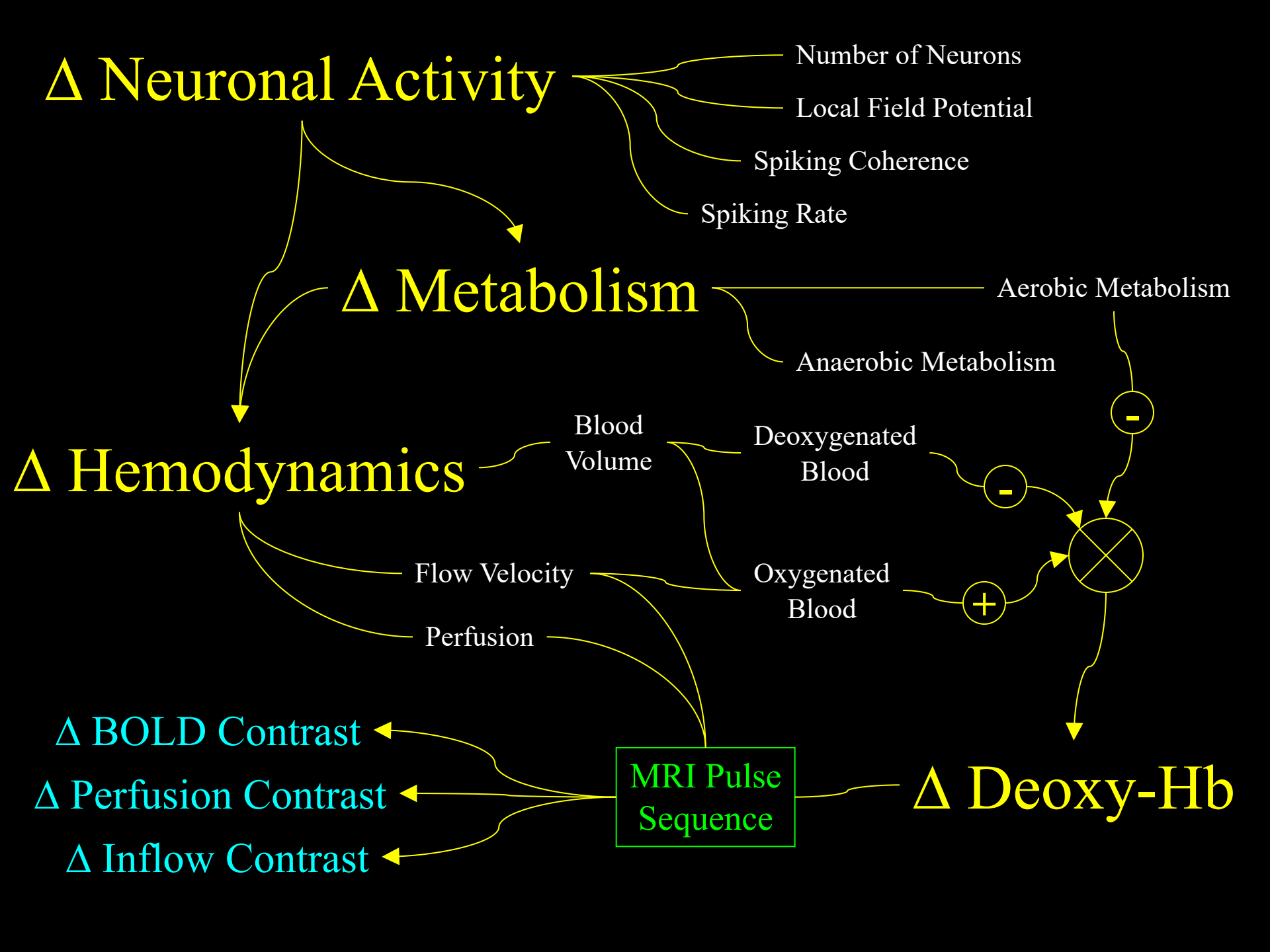
SNR

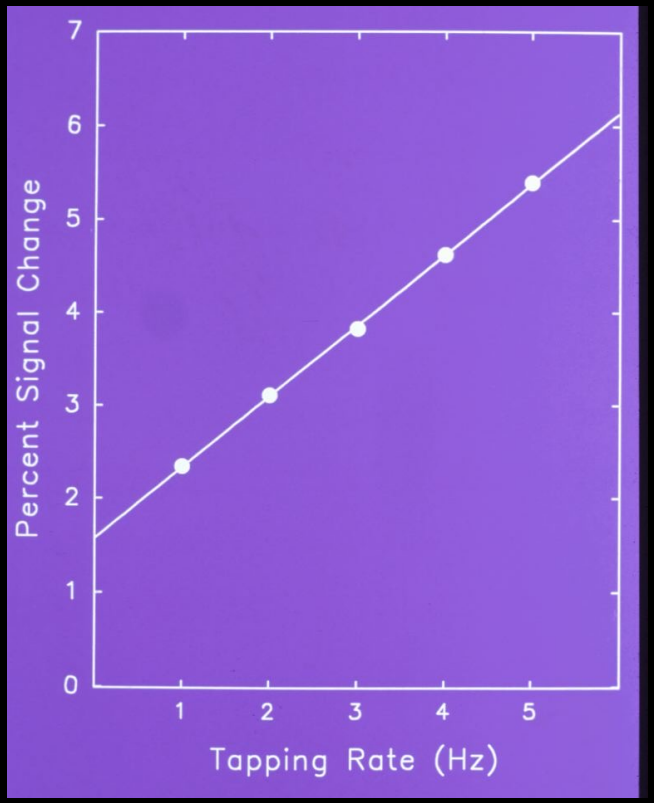
TSNR



Latest Developments...

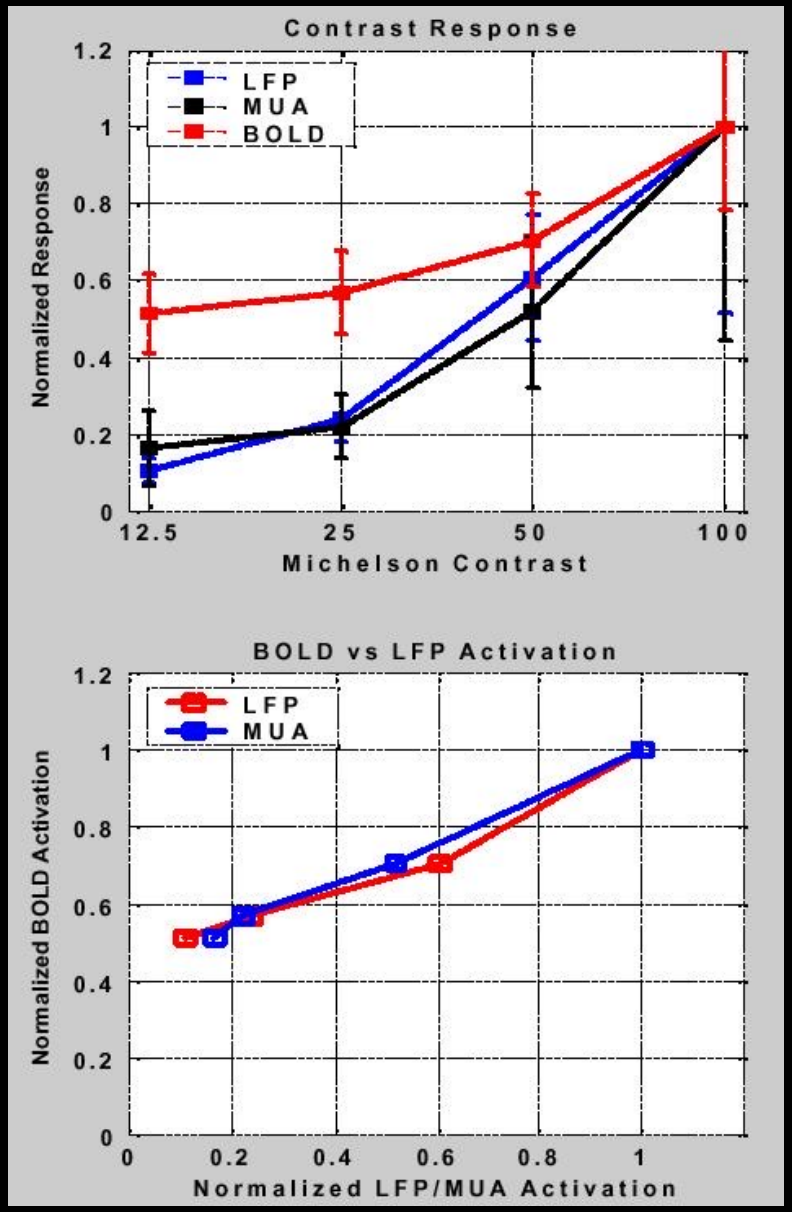
1. Temporal Resolution
2. Spatial Resolution
3. Sensitivity and Noise
4. Information Content
5. Implementation


Δ Neuronal Activity
Number of Neurons
Local Field Potential
Spiking Coherence
Spiking Rate
Δ Metabolism
Aerobic Metabolism
Anaerobic Metabolism
Δ Hemodynamics
Blood Volume
Deoxygenated Blood
Flow Velocity
Oxygenated Blood
Perfusion
-
-
+
Δ BOLD Contrast
Δ Perfusion Contrast
Δ Inflow Contrast
MRI Pulse Sequence
Δ Deoxy-Hb



S. M. Rao et al, (1996) "Relationship between finger movement rate and functional magnetic resonance signal change in human primary motor cortex." *J. Cereb. Blood Flow and Met.* 16, 1250-1254.

Logothetis et al. (2001) "Neurophysiological investigation of the basis of the fMRI signal" Nature, 412, 150-157



Spatial Heterogeneity of the Nonlinear Dynamics in the FMRI BOLD Response

Rasmus M. Birn, Ziad S. Saad, and Peter A. Bandettini

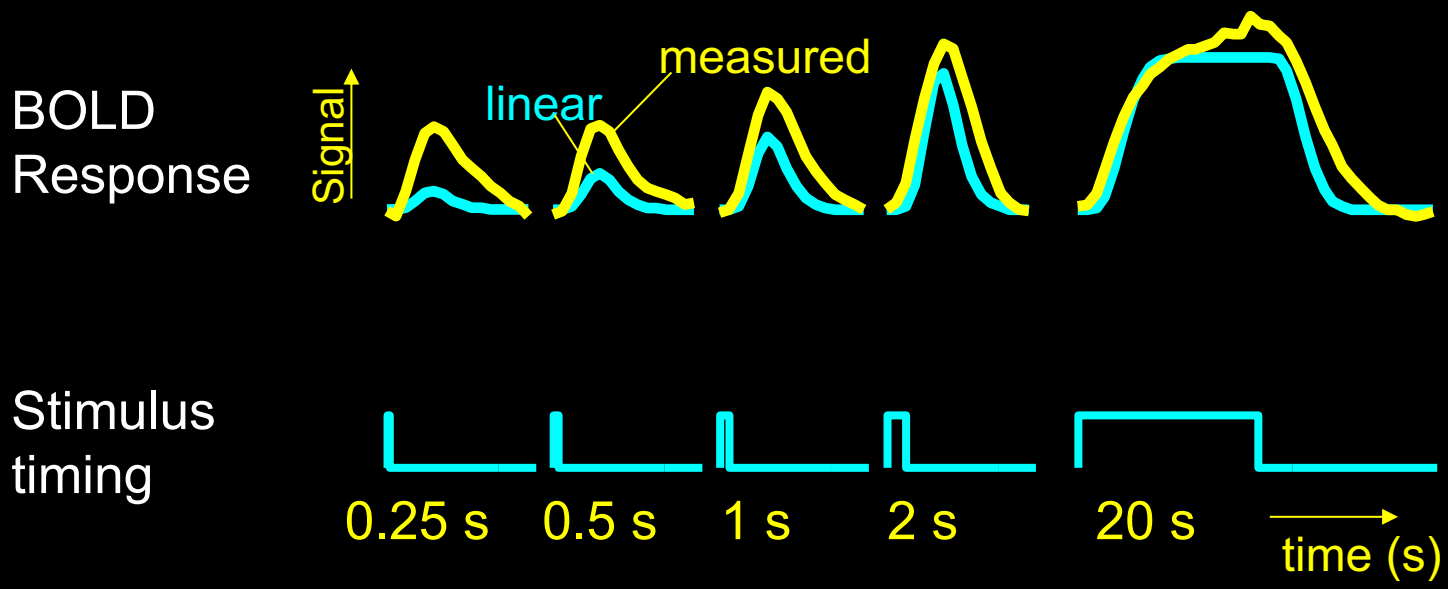
Laboratory of Brain and Cognition, National Institute of Mental Health, NIH Bethesda, Maryland

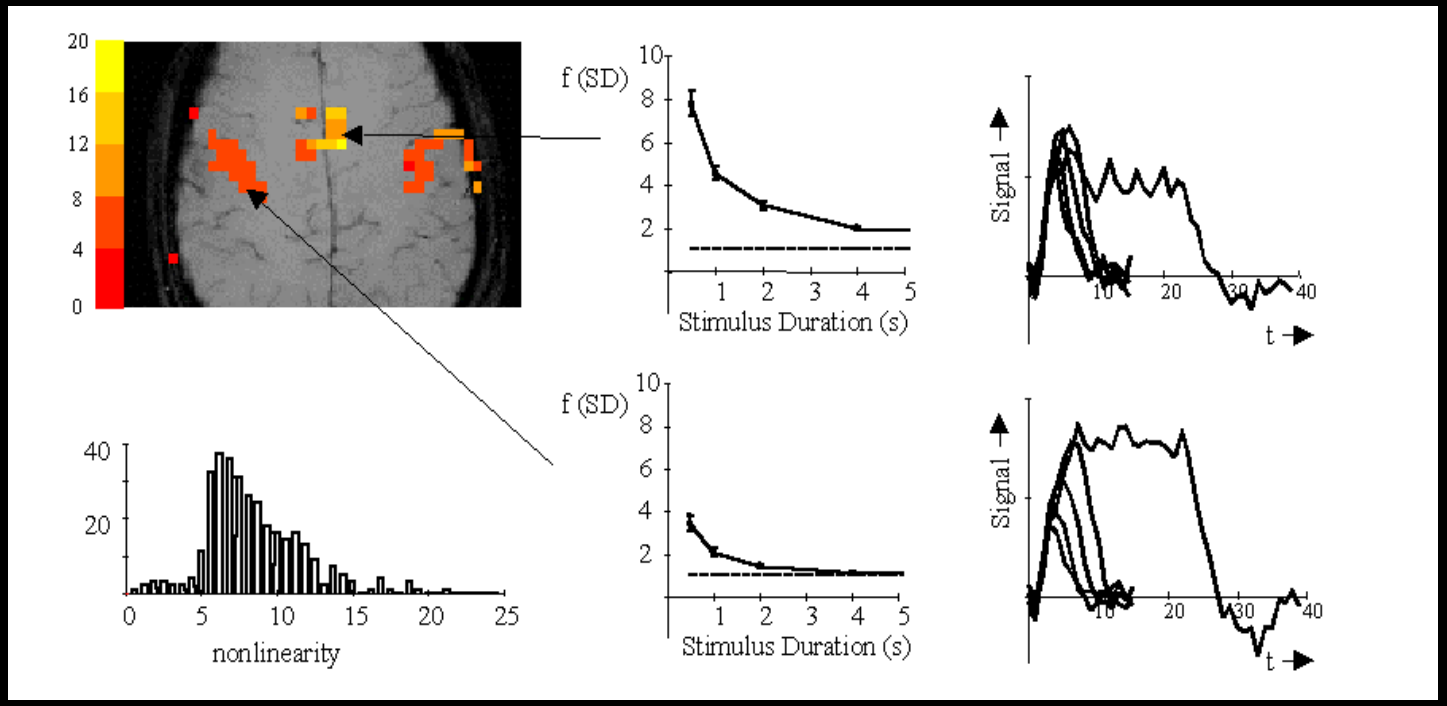
Received October 18, 2000

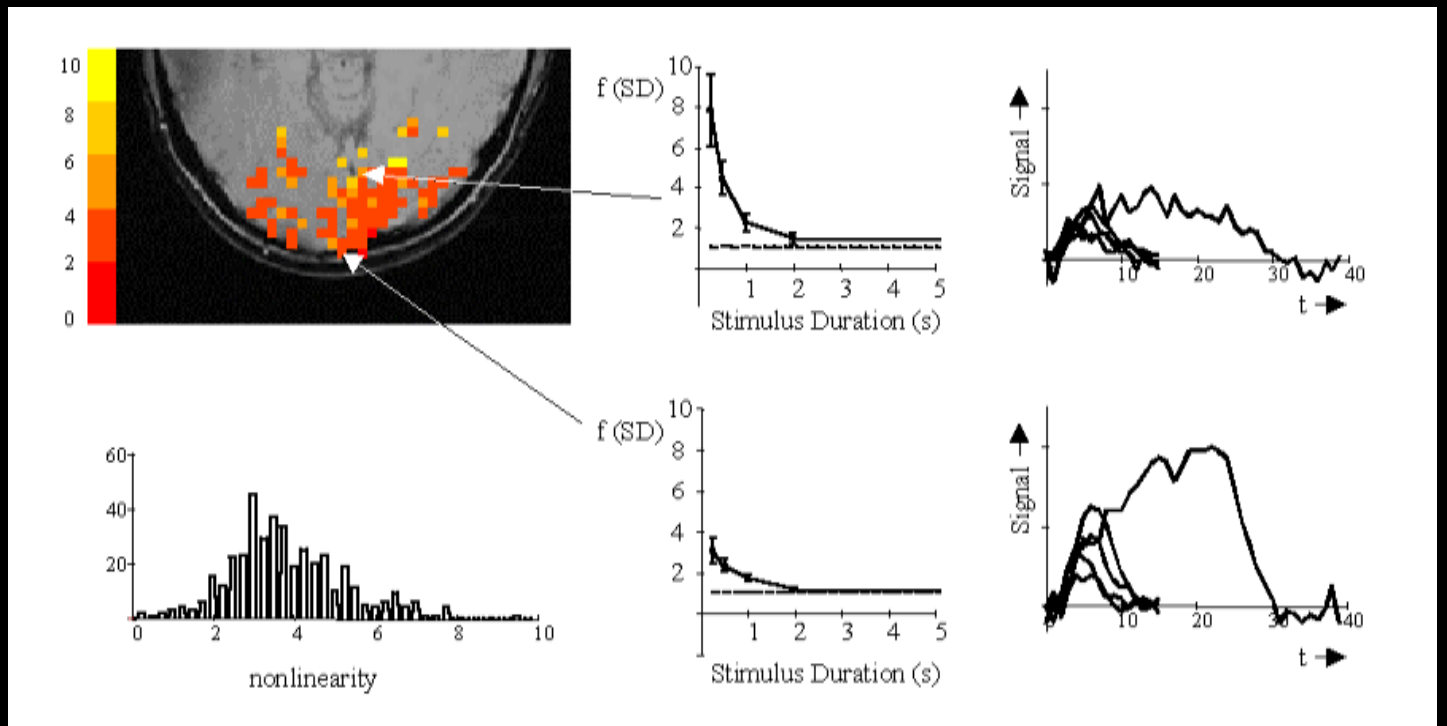
NeuroImage

Question: Do BOLD nonlinearities exhibit spatial heterogeneity?

Paradigm: Stimulus duration modulation from 50 ms to 20 sec.




20
16
12
8
4
0
f (SD)
10
8
6
4
2
1 2 3 4 5
Stimulus Duration (s)
Signal
10 20 30 40
t
40
20
0 5 10 15 20 25
nonlinearity
f (SD)
Stimulus Duration (s)
Signal
t

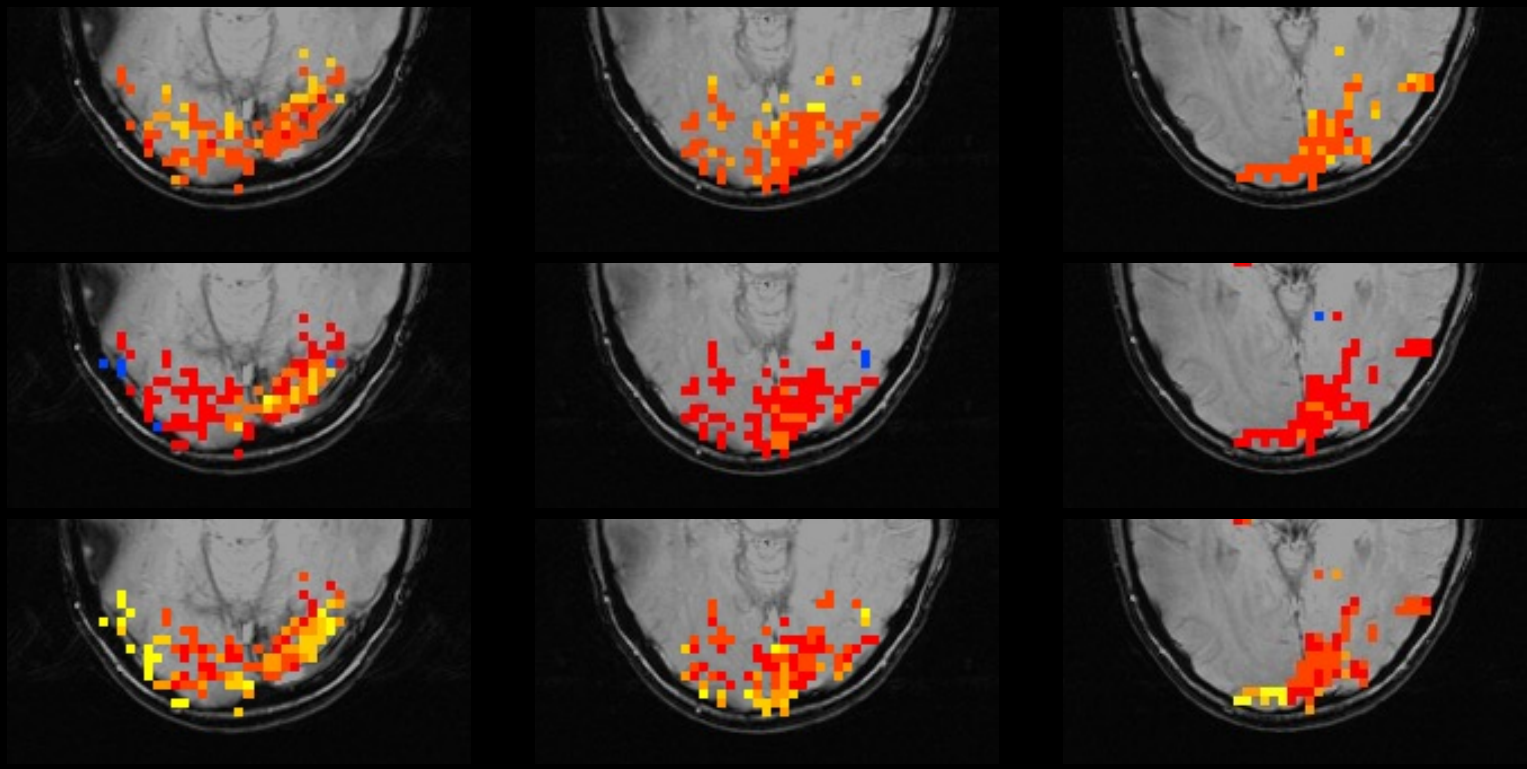

10
8
6
4
2
0
f (SD)
1 2 3 4 5
Stimulus Duration (s)
Signal
10 20 30 40
t
60
40
20
0 2 4 6 8 10
nonlinearity
f (SD)
Stimulus Duration (s)
Signal
t

Results – visual task

Nonlinearity

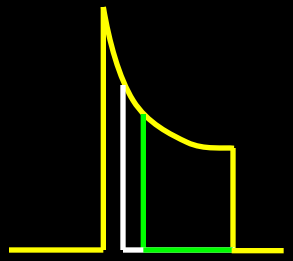
Magnitude

Latency

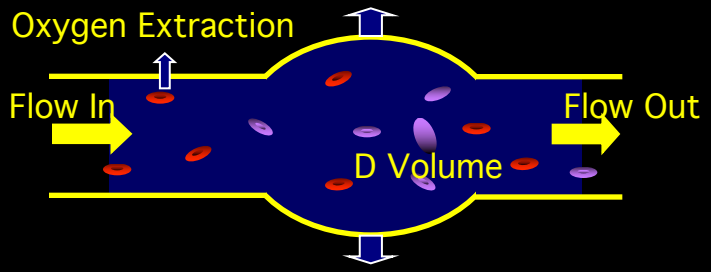


Sources of this Nonlinearity

- Neuronal

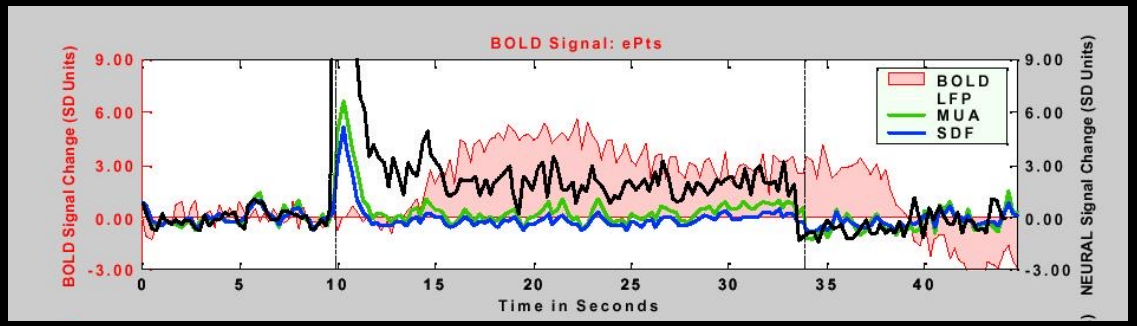


- Hemodynamic
  - Oxygen extraction
  - Blood volume dynamics

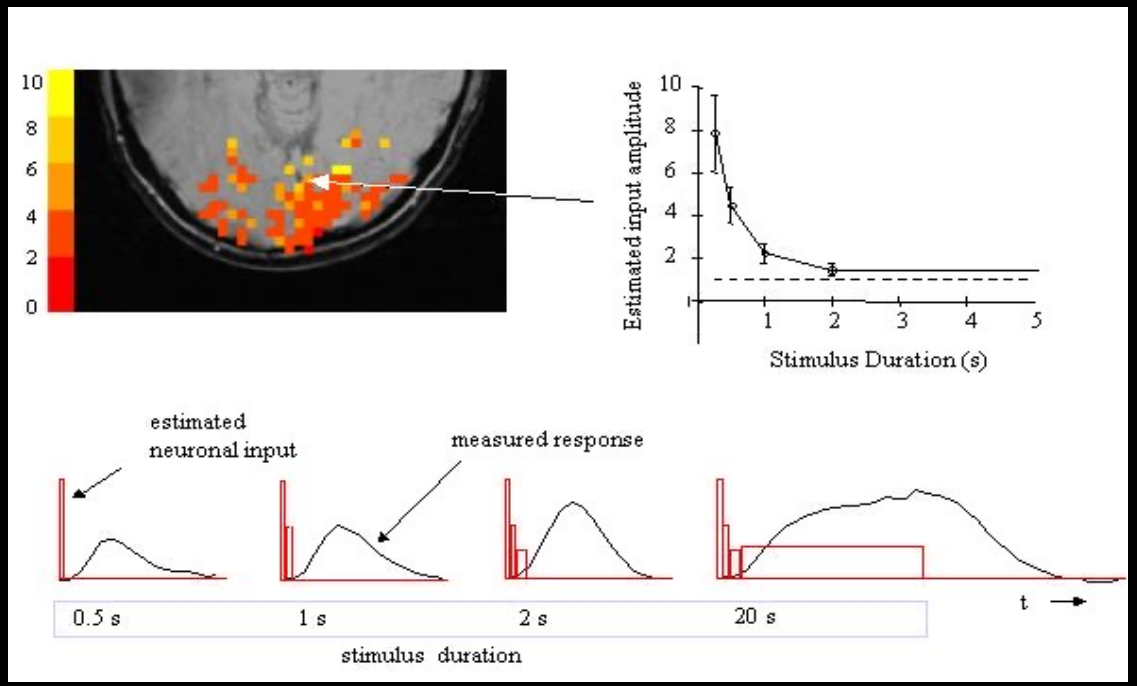


BOLD Correlation with Neuronal Activity

Logothetis et al. (2001) "Neurophysiological investigation of the basis of the fMRI signal" Nature, 412, 150-157.



P. A. Bandettini and L. G. Ungerleider, (2001) "From neuron to BOLD: new connections." Nature Neuroscience, 4: 864-866.



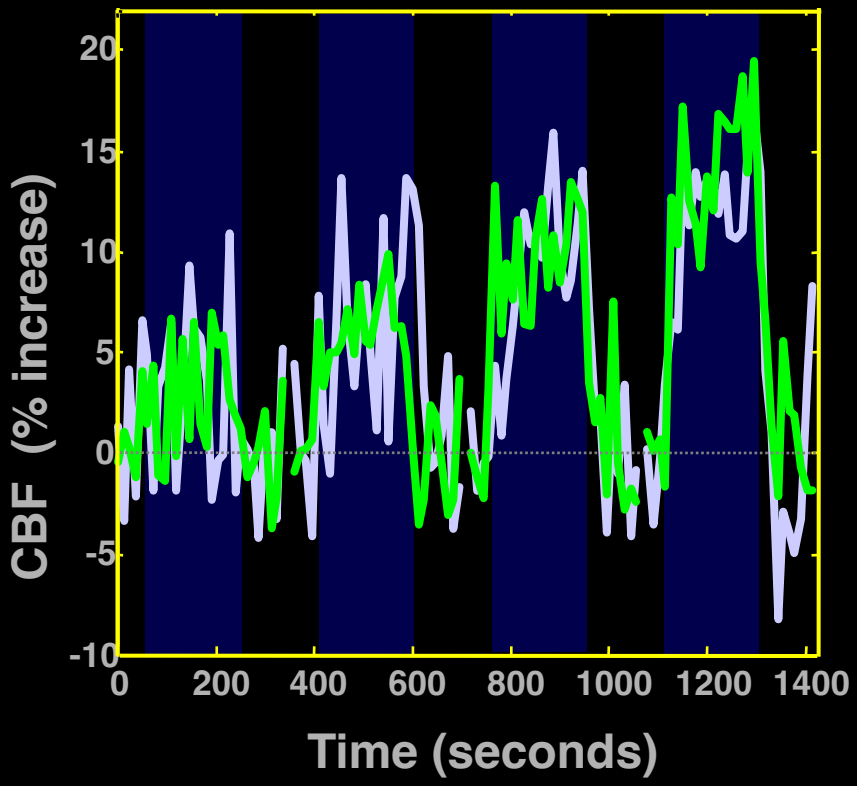
Proc. Natl. Acad. Sci. USA
Vol. 96, pp. 9403–9408, August 1999
Neurobiology

Linear coupling between cerebral blood flow and oxygen consumption in activated human cortex

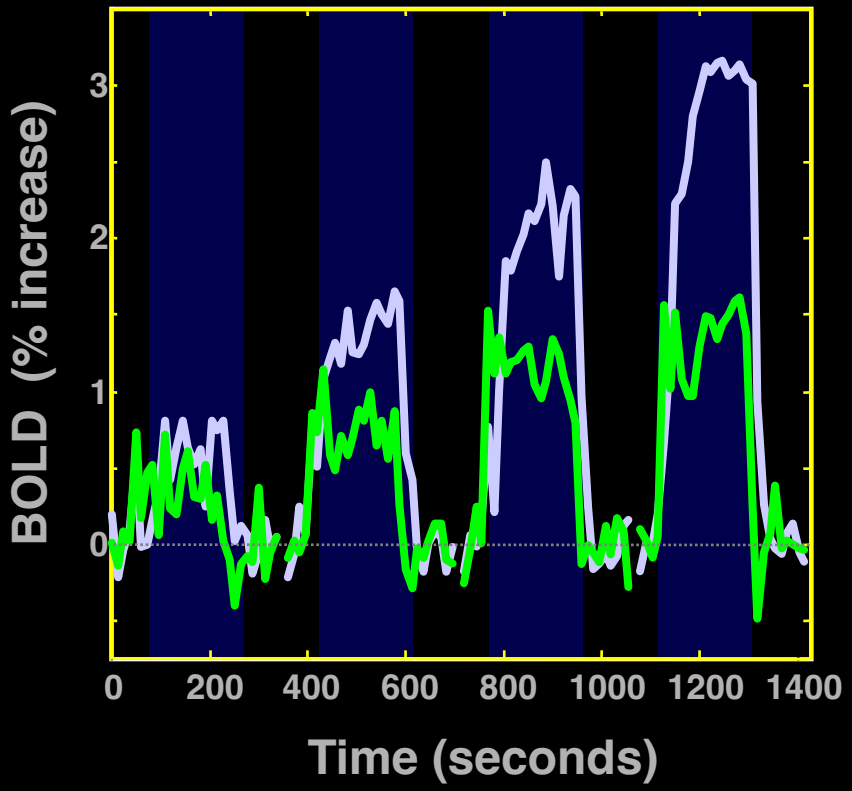
RICHARD D. HOGE*†, JEFF ATKINSON*, BRAD GILL*, GÉRARD R. CRELIER*, SEAN MARRETT‡, AND G. BRUCE PIKE*

*Room WB325, McConnell Brain Imaging Centre, Montreal Neurological Institute, Quebec, Canada H3A 2B4; and ‡Nuclear Magnetic Resonance Center, Massachusetts General Hospital, Building 149, 13th Street, Charlestown, MA 02129

CBF



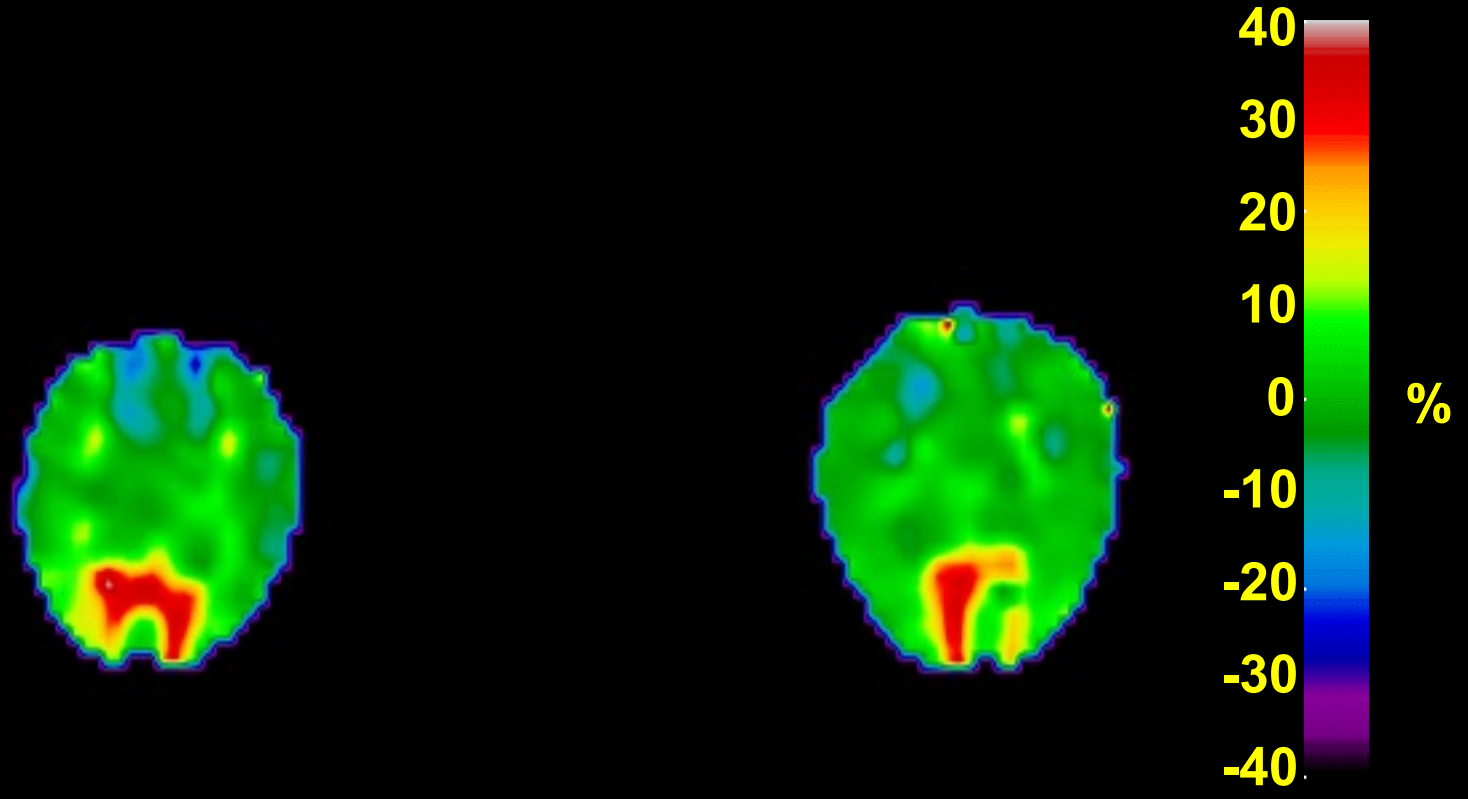
BOLD



Simultaneous Perfusion and BOLD imaging during graded visual activation and hypercapnia

N=12

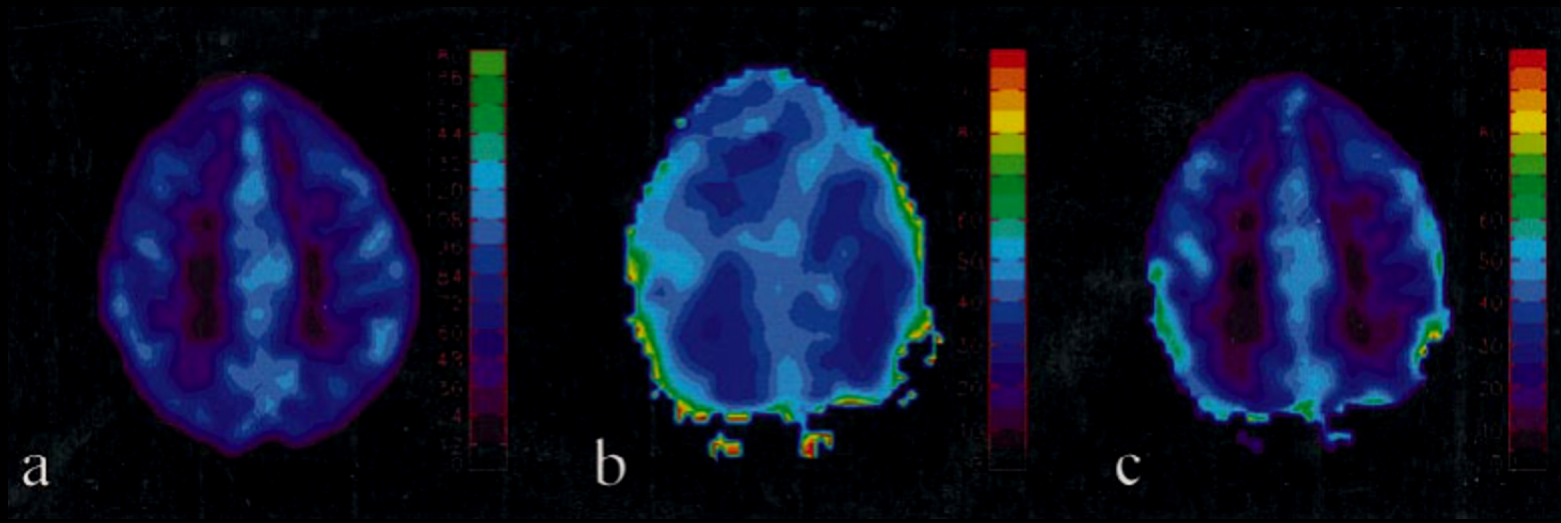
Computed $CMRO_2$ Changes



NMR IN BIOMEDICINE
NMR Biomed. 2001;**14**:441–447
DOI:10.1002/nbm.717

Quantitative measurements of cerebral metabolic rate of oxygen utilization using MRI: a volunteer study

Hongyu An,[1] Weili Lin,[2]* Azim Celik[3] and Yueh Z. Lee[2]



CBF OEF $CMRO_2$

Latest Developments...

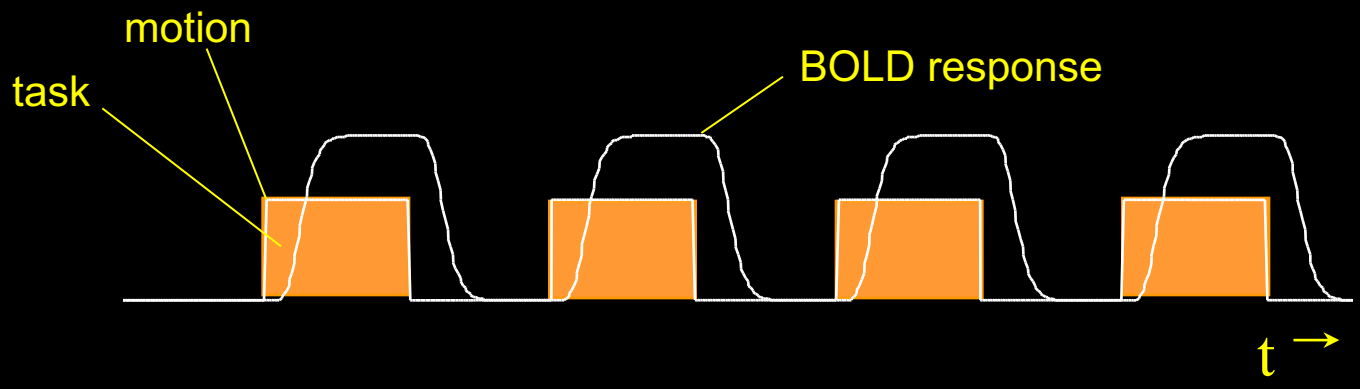
1. Temporal Resolution
2. Spatial Resolution
3. Sensitivity and Noise
4. Information Content
5. Implementation

Neuronal Activation Input Strategies

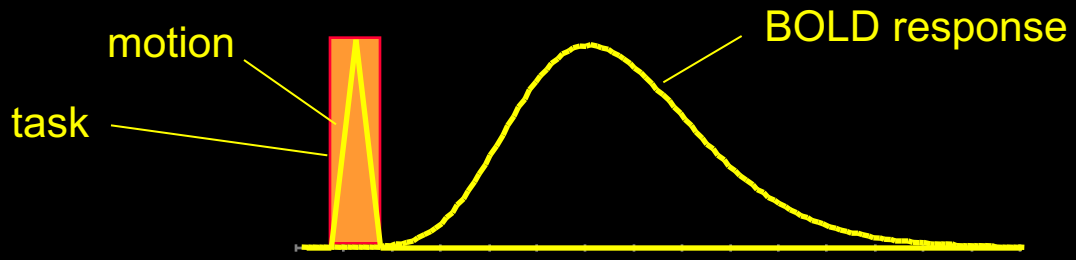
1. Block Design
2. Parametric Design
3. Frequency Encoding
4. Phase Encoding
5. Event Related
6. Orthogonal Design
7. Free Behavior Design

fMRI during tasks that involve brief motion

Blocked Design

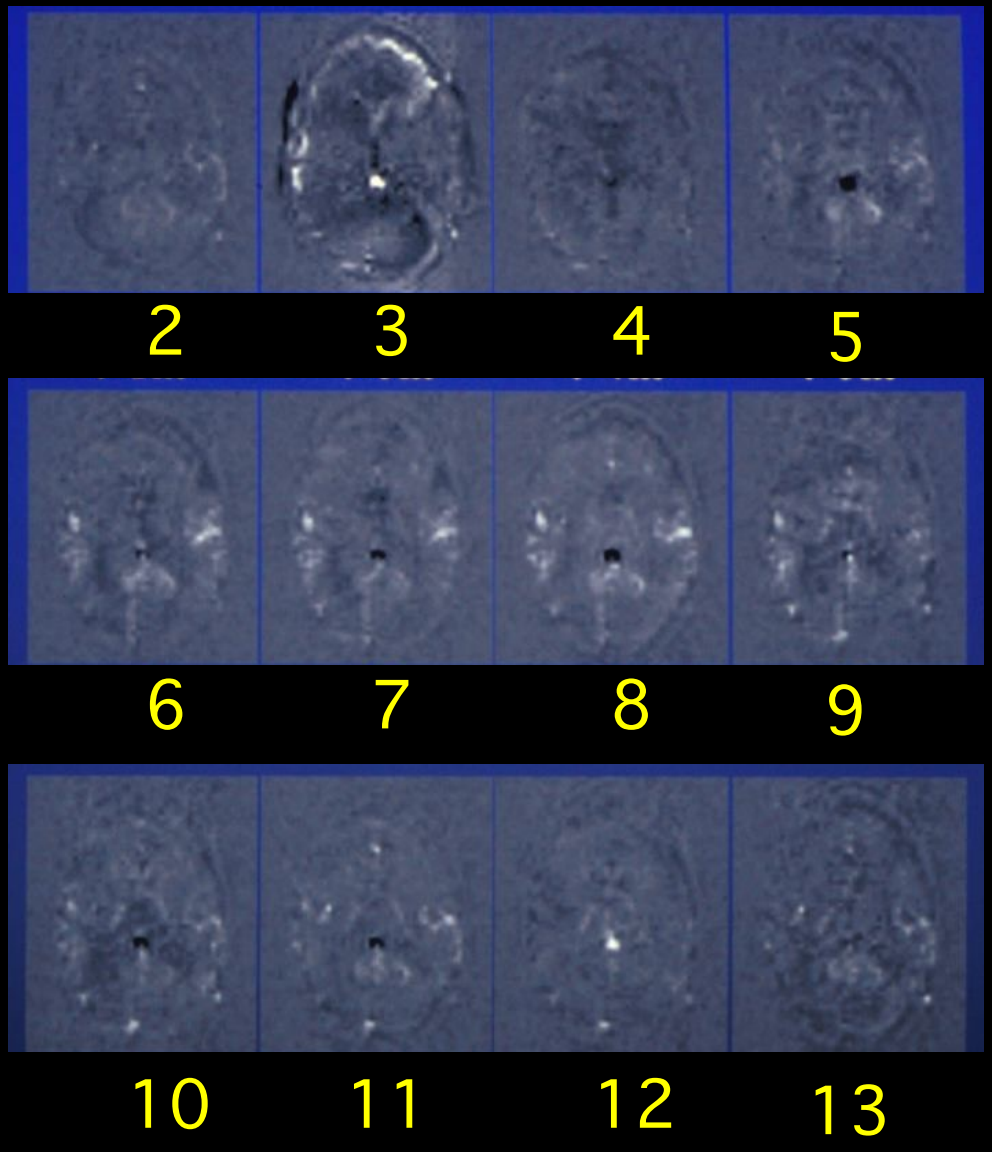


Event-Related Design



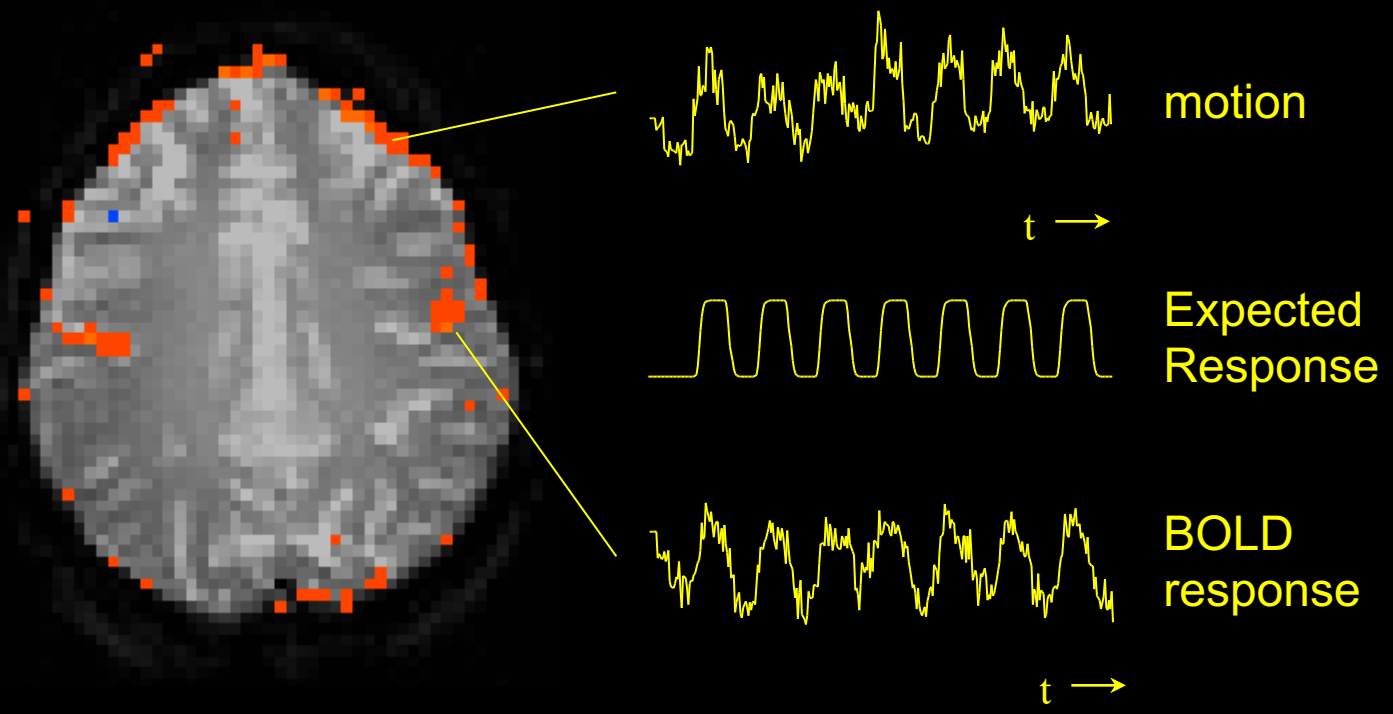
R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

Overt Word Production



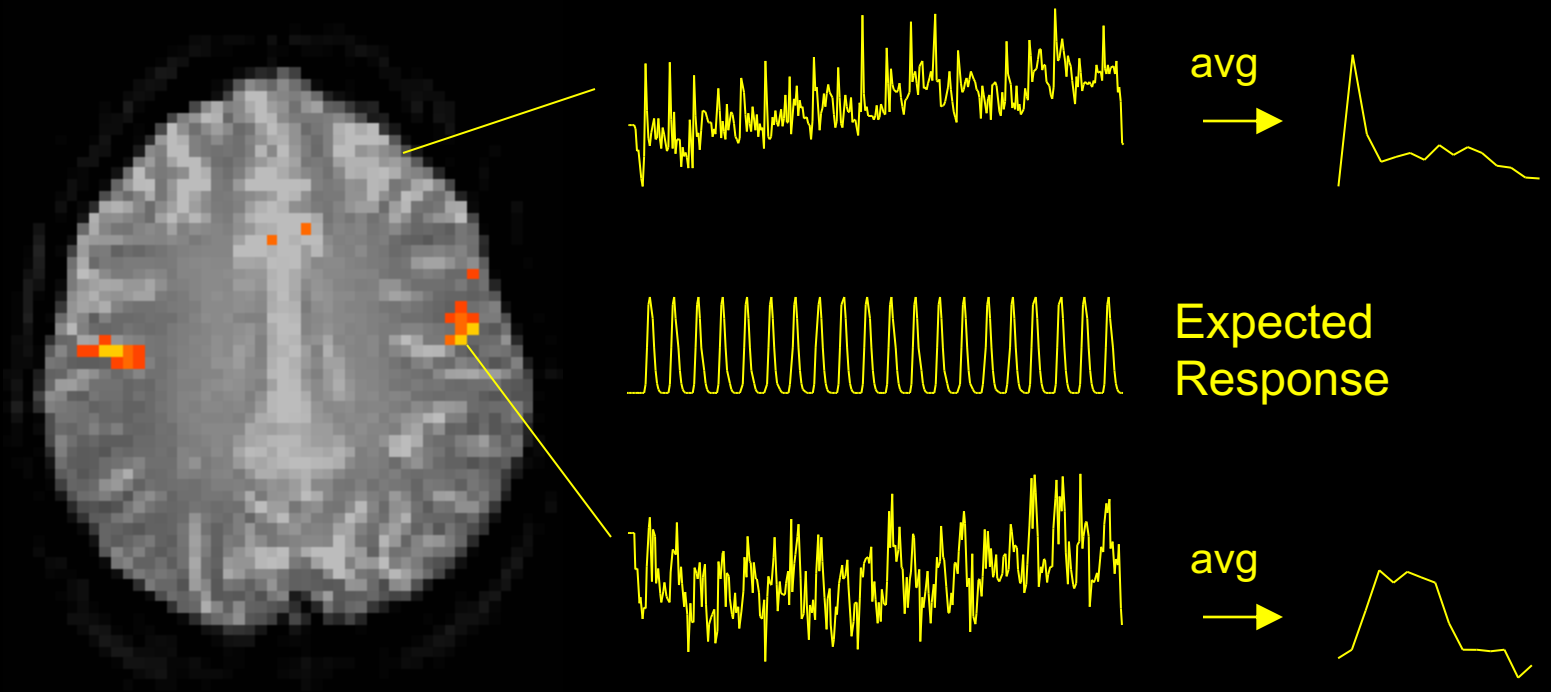
R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

Speaking - Blocked Trial

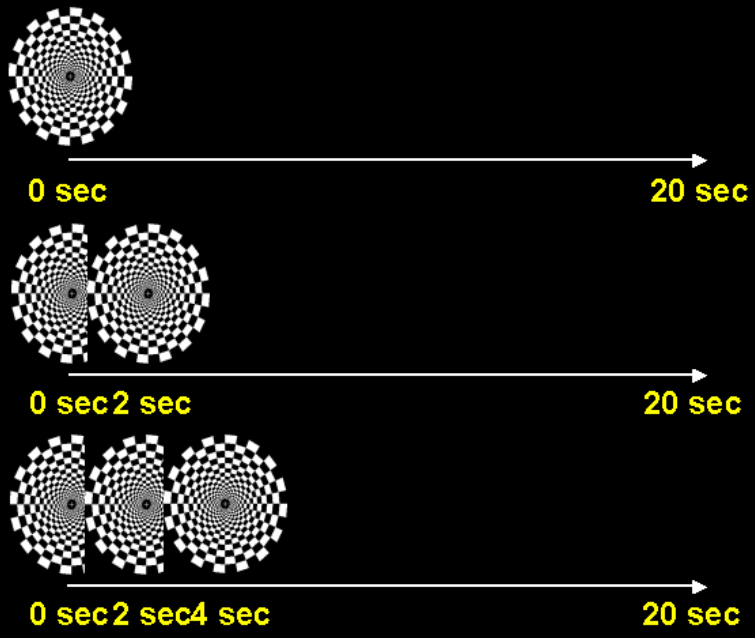


R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

Speaking - ER-fMRI



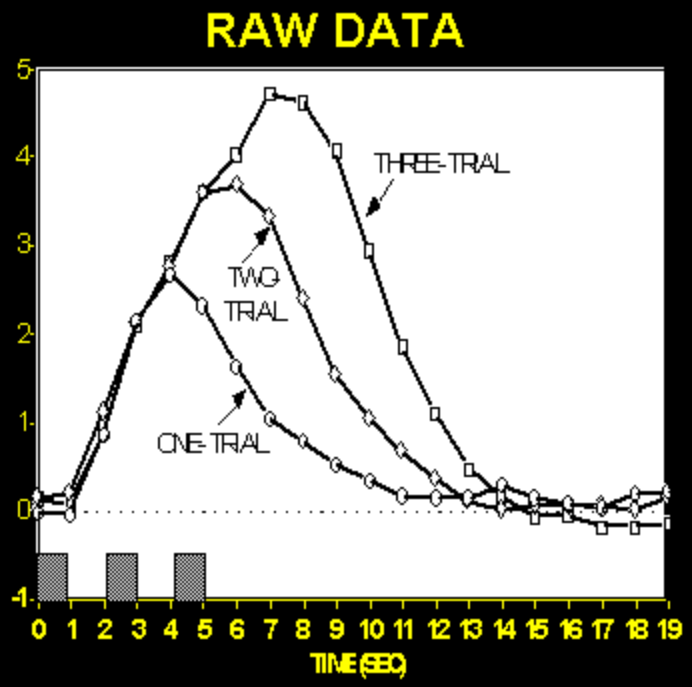
R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

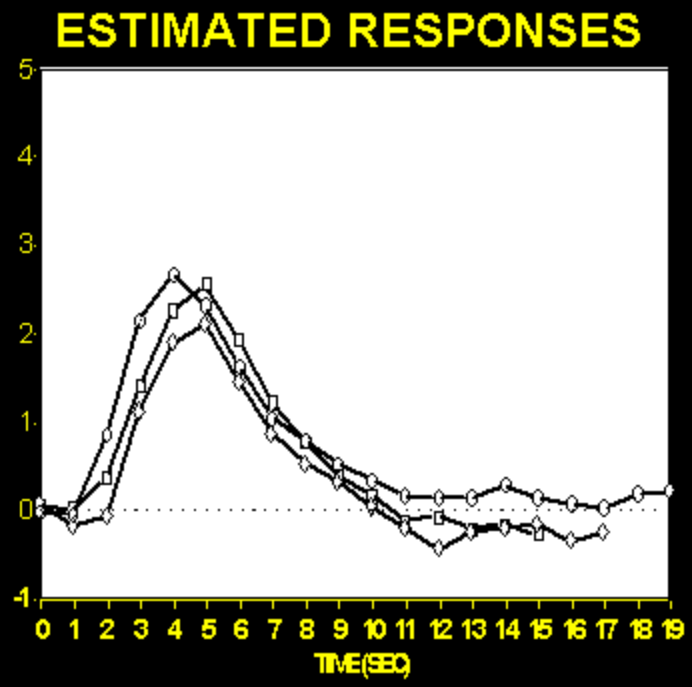


◆ Human Brain Mapping 5:329–340(1997) ◆

Selective Averaging of Rapidly Presented Individual Trials Using fMRI

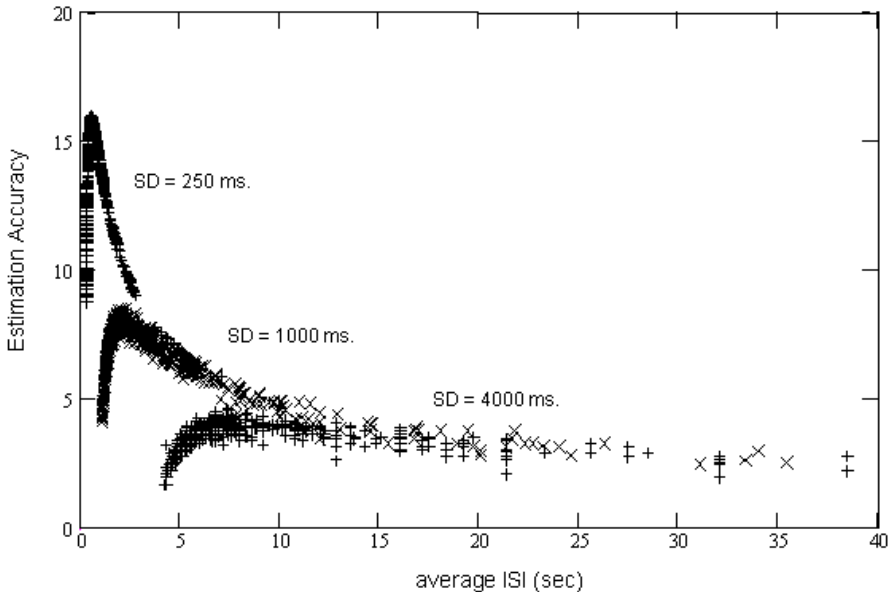
Anders M. Dale* and Randy L. Buckner



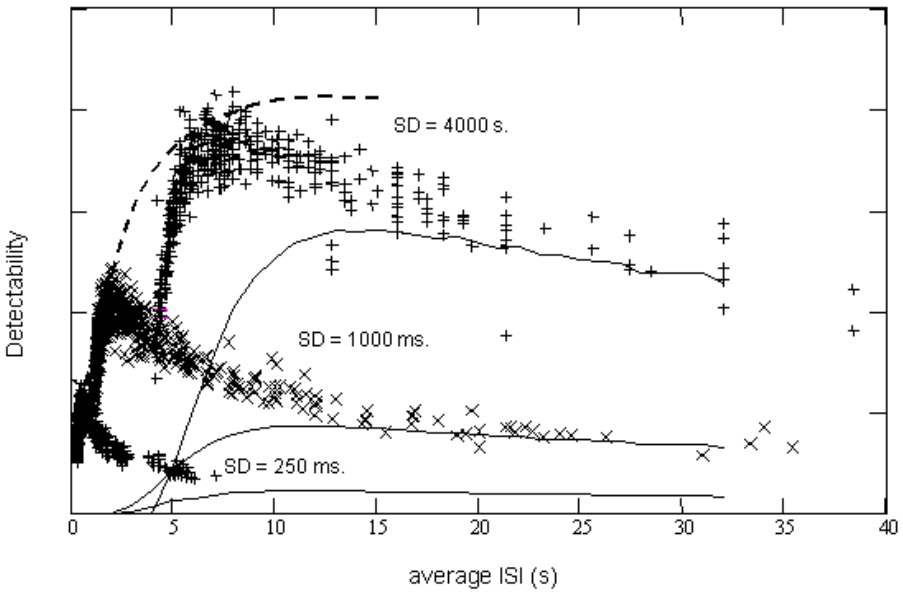


R. M. Birn, R. W. Cox, P. A. Bandettini, Detection versus estimation in Event-Related fMRI: choosing the optimal stimulus timing. *NeuroImage* 15: 262-264, (2002).

Estimation accuracy vs. average ISI



Detectability vs. Average ISI



Neuronal Activation Input Strategies

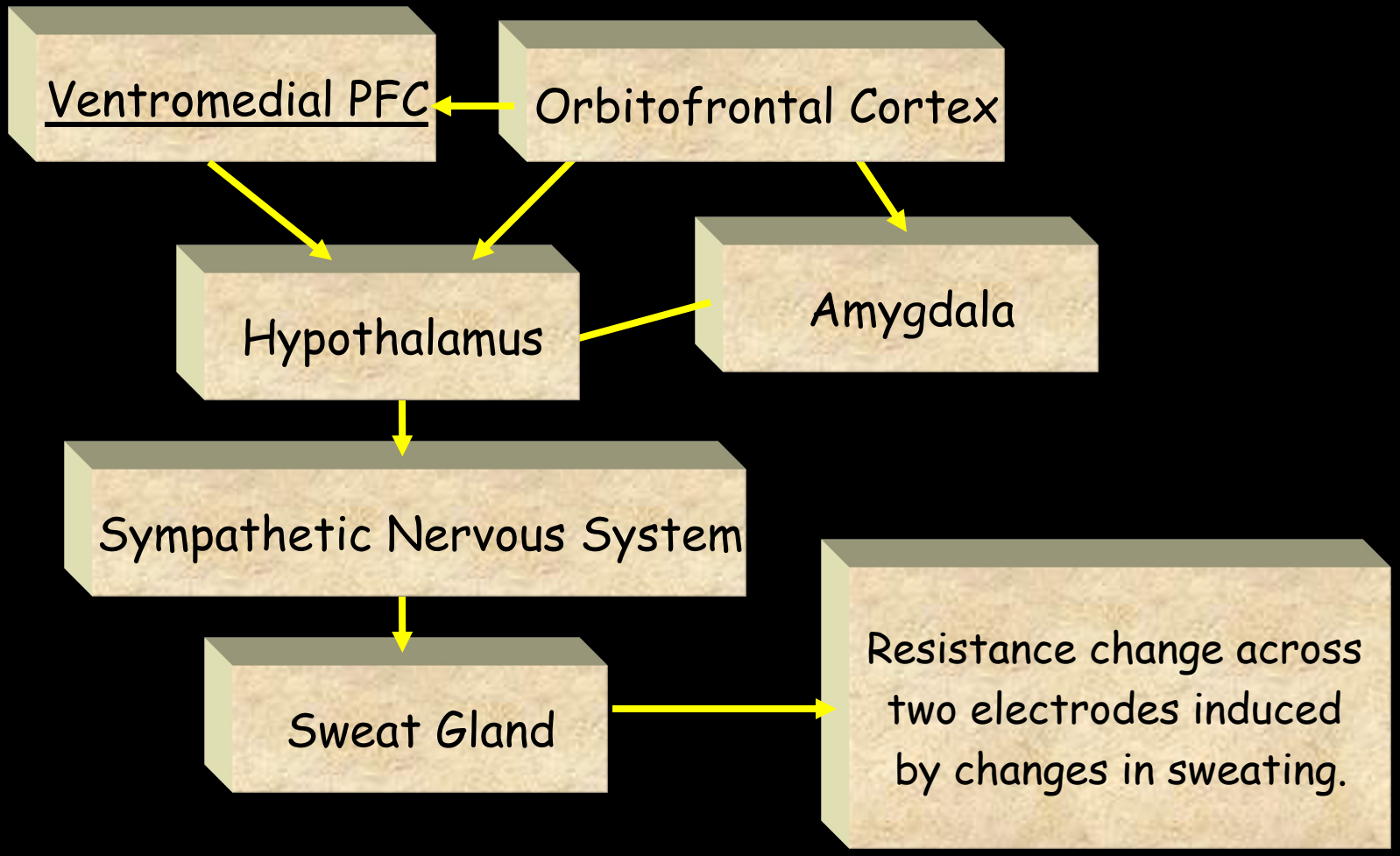
1. Block Design
2. Parametric Design
3. Frequency Encoding
4. Phase Encoding
5. Event Related
6. Orthogonal Design
7. Free Behavior Design

Free Behavior Design

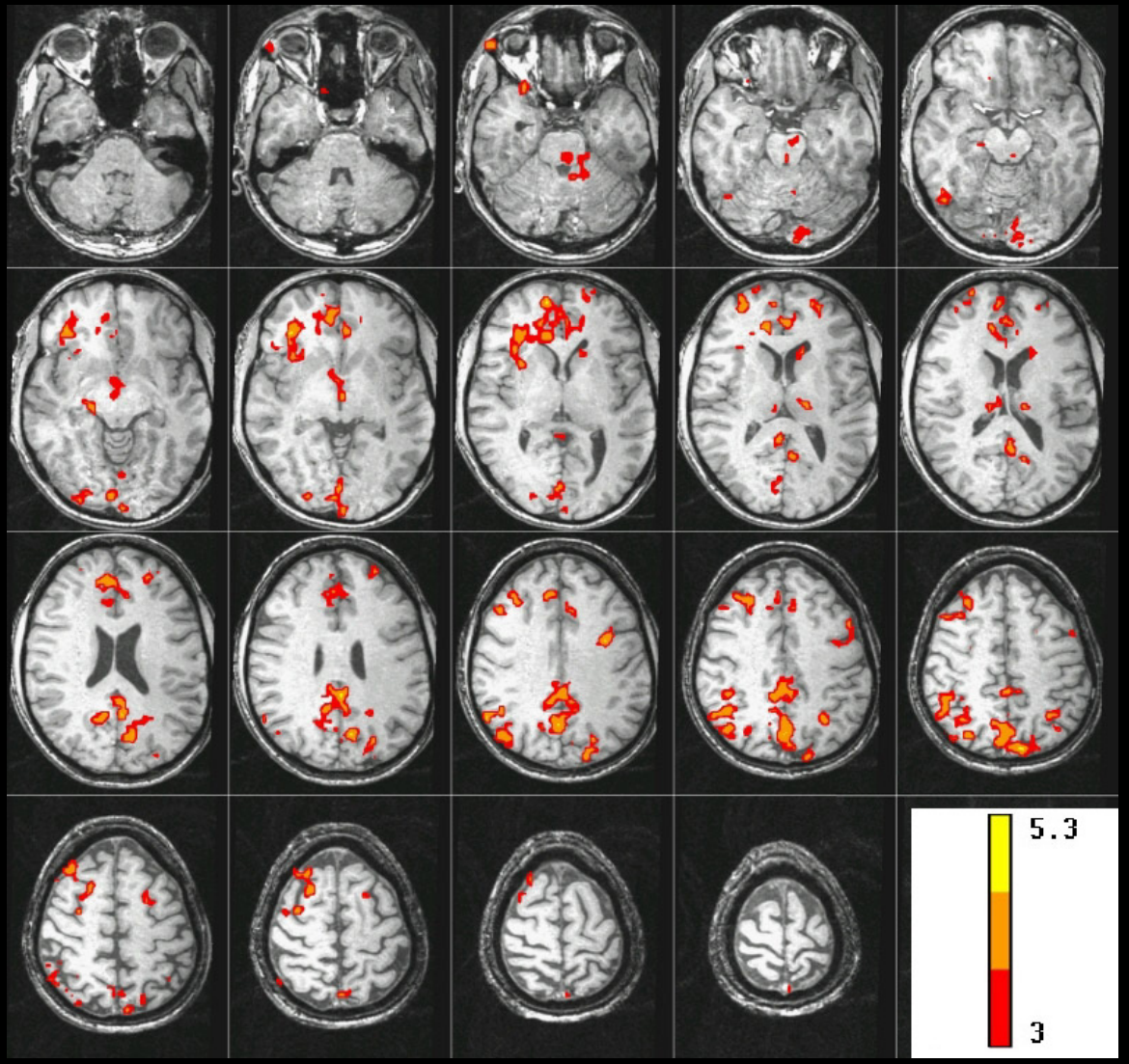
Use a continuous measure as a reference function:

- Task performance
- Skin Conductance
- Heart, respiration rate..
- Eye position
- EEG

The Skin Conductance Response (SCR)



Brain activity correlated with SCR during "Rest"



J. C. Patterson II, L. G. Ungerleider, and P. A Bandettini, Task - independent functional brain activity correlation with skin conductance changes: an fMRI study. *NeuroImage* (in press)

Simultaneous EEG and fMRI of the alpha rhythm

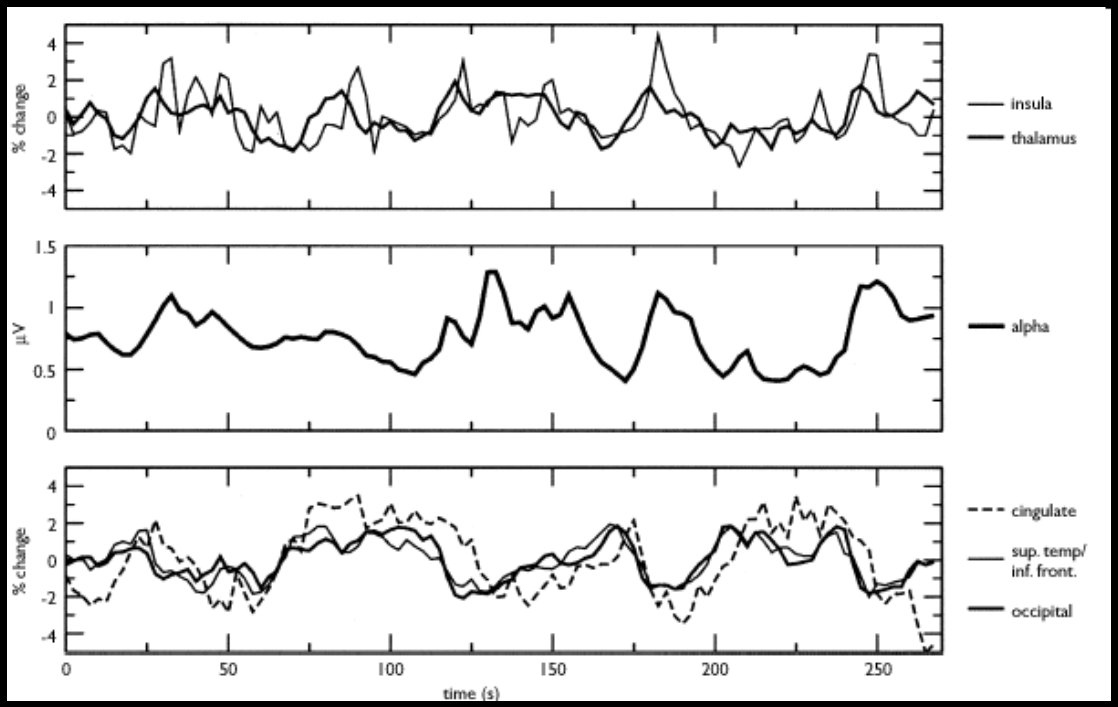
Robin I. Goldman,[2,CA] John M. Stern,[1] Jerome Engel Jr[1] and Mark S. Cohen

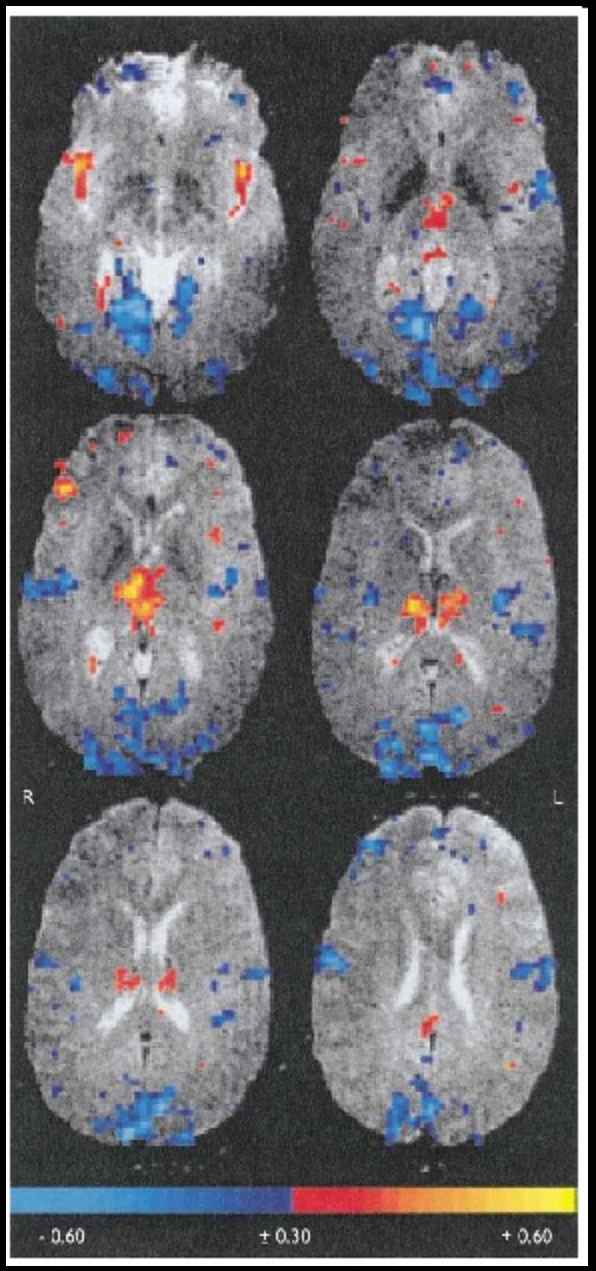
Ahmanson-Lovelace Brain Mapping Center, UCLA, 660 Charles Young Drive South, Los Angeles, CA 90095; [1]Department of Neurology, UCLA School of Medicine, Los Angeles, CA; [2]Hatch Center for MR Research, Columbia University, HSD, 710 W. 168th St., NIB-1, Mailbox 48, NY, NY 10032, USA

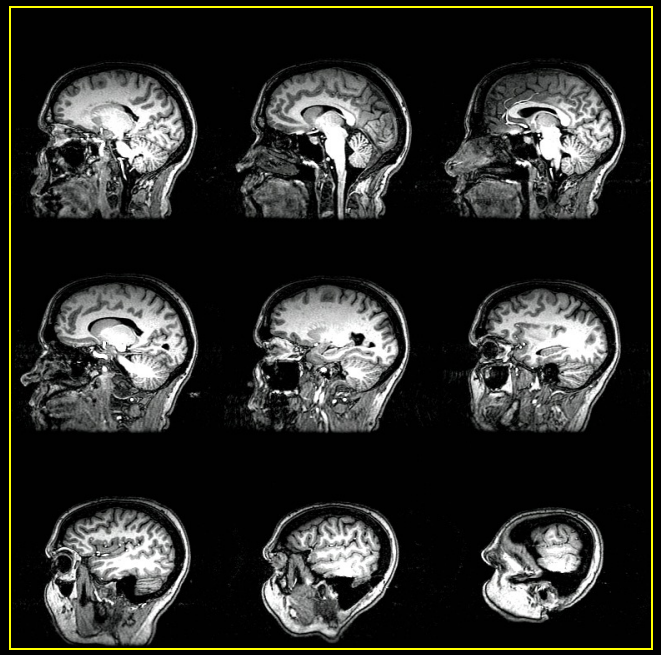
[CA,2]Corresponding Author and Address: rg2146@columbia.edu

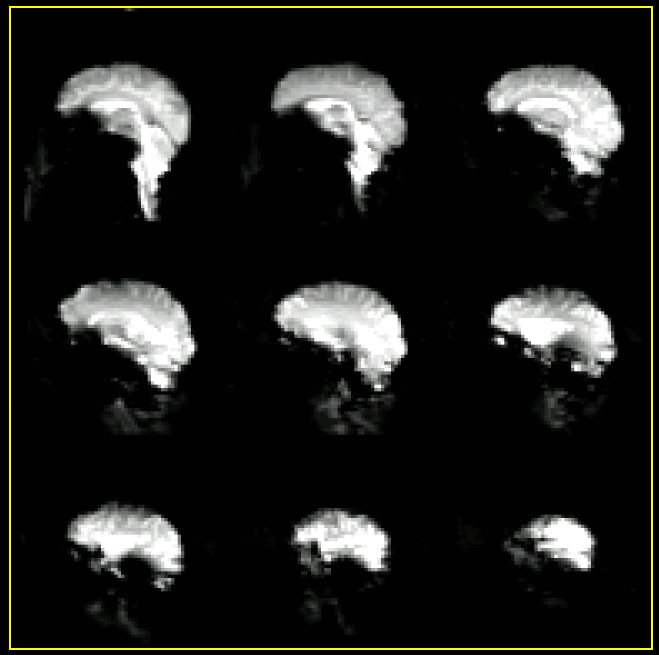
Received 28 October 2002; accepted 30 October 2002

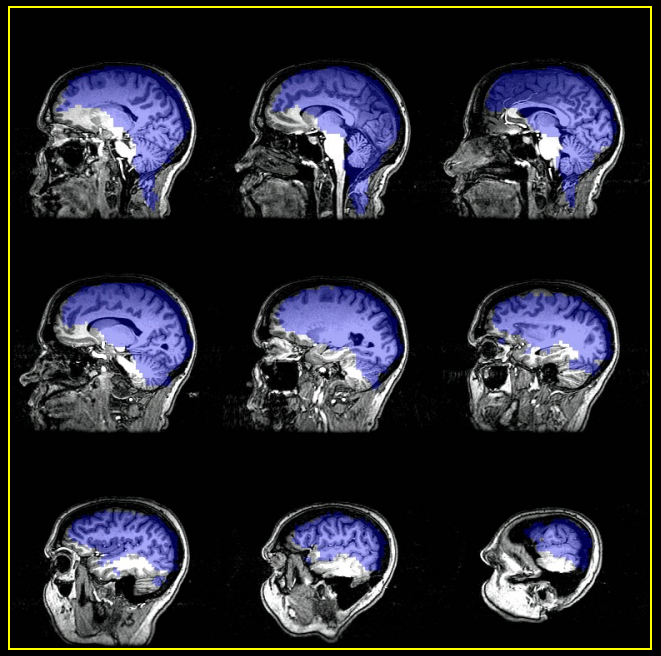
DOI: 10.1097/01.wnr.0000047685.08940.d0







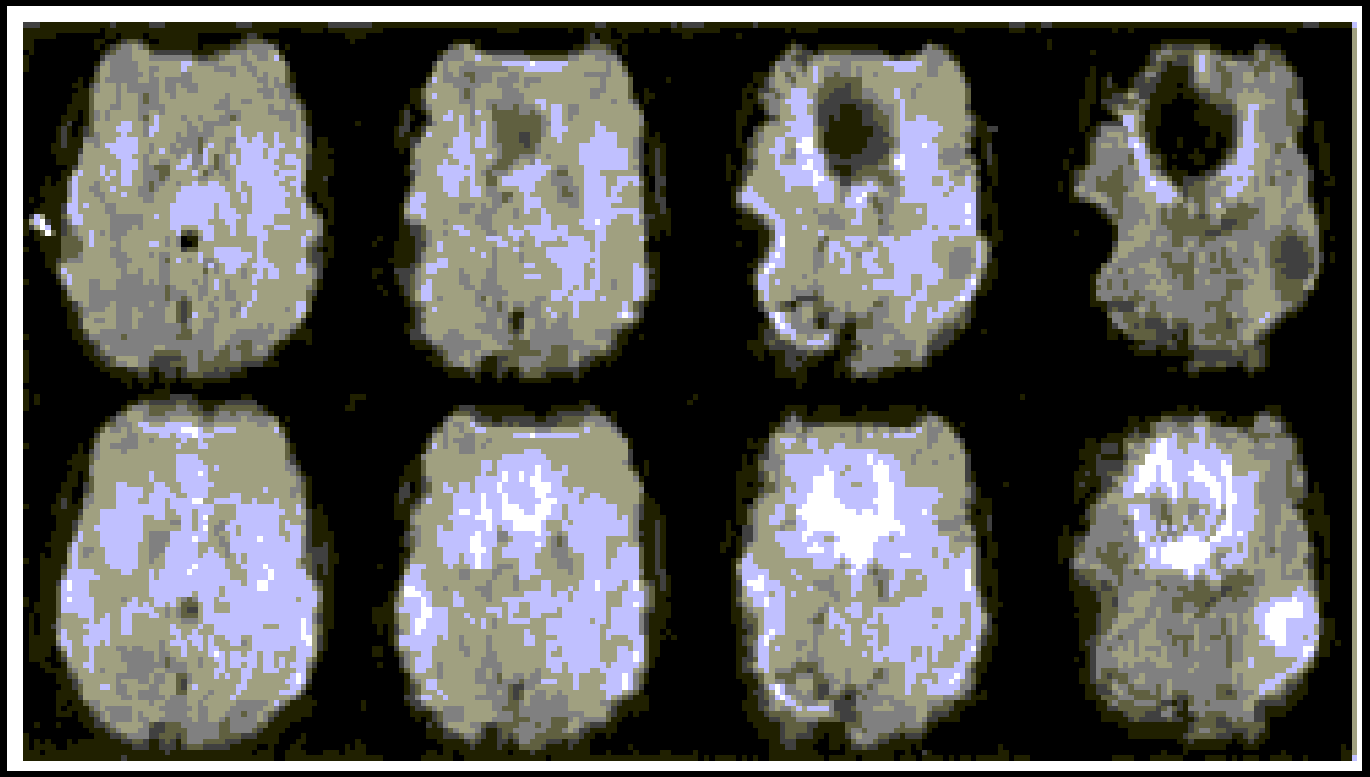




Magnetic Resonance in Medicine 42:290–299 (1999)

3D z-Shim Method for Reduction of Susceptibility Effects in BOLD fMRI

Gary H. Glover*



- Shimming
- Acoustic Noise
- Multishot Techniques
- Increased Gradient Performance
- Higher Field Strengths
- Surface Coil Arrays
- Calibration / Quantification
- Embedded Functional Contrast
- Noise / Fluctuations
- Direct Neuronal Current Imaging
- Clinical Populations
- Neuronal,Vascular, and Metabolic Informatic

UFIM & FMRIF

Director:

Peter Bandettini

Staff Scientists:

Sean Marrett

Jerzy Bodurka

Frank Ye

Wen-Ming Luh

Computer Specialist:

Adam Thomas

Post Docs:

Rasmus Birn

Hauke Heekeren

David Knight

Patrick Bellgowan

Ziad Saad

Graduate Student:

Natalia Petridou

Post-Bac. IRTA Students:

Elisa Kapler

August Tuan

Dan Kelley

Hahn Nguen

Visiting Fellows:

Sergio Casciaro

Marta Maieron

Guosheng Ding

Clinical Fellow:

James Patterson

Psychologist:

Julie Frost

Summer Students:

Hannah Chang

Courtney Kemps

Douglass Ruff

Carla Wettig

Kang-Xing Jin

Program Assistant:

Kay Kuhns

Scanning Technologists:

Karen Bove-Bettis

Paula Rowser