# How Much Information Can We Extract from the fMRI Time Series?

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Laboratory of Brain and Cognition
&
Functional MRI Core Facility

DEPARTMENT OF HEALTH & HUMAN SERVICES · USA

NIMH
National Institute of Mental Health

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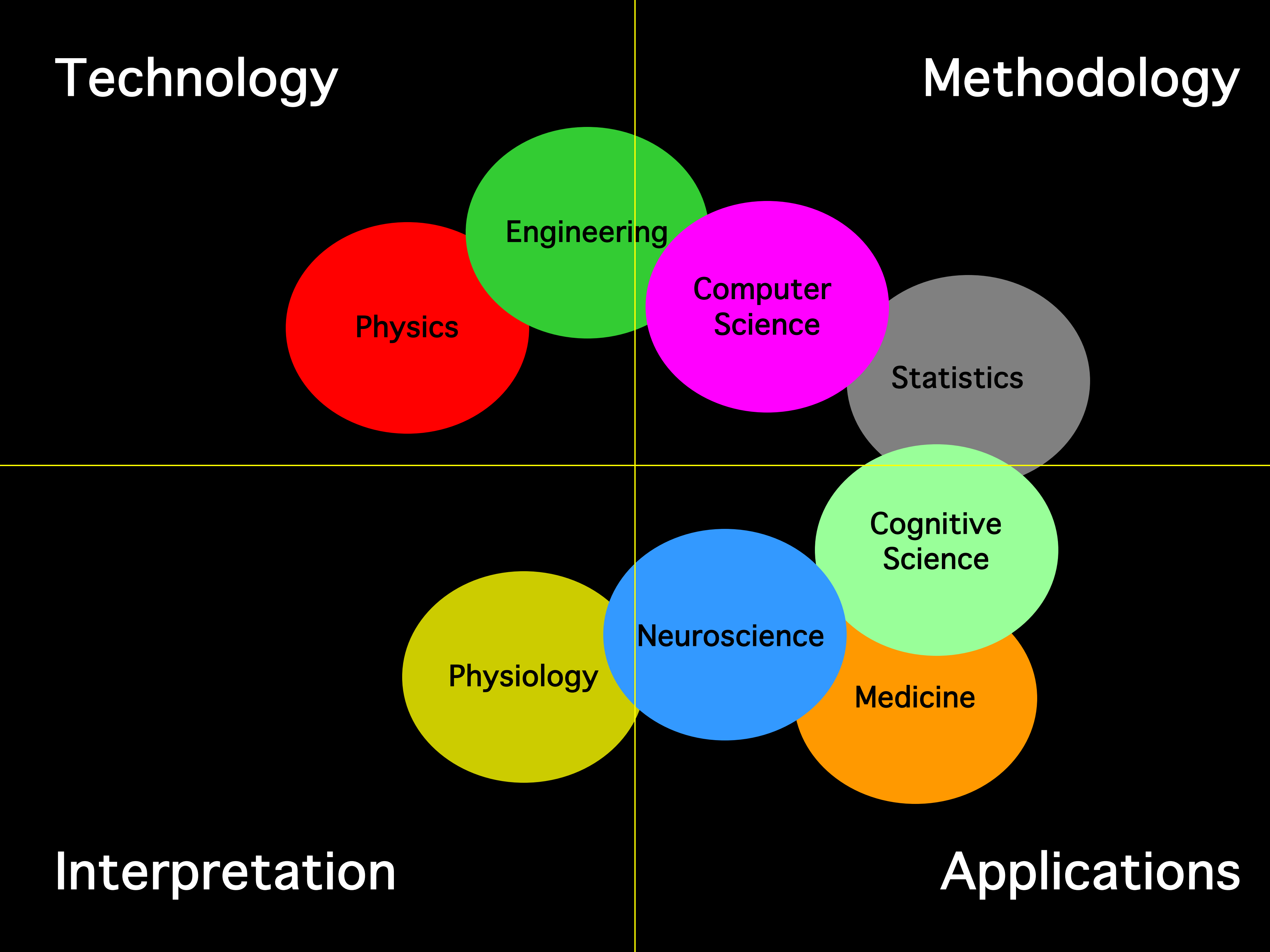
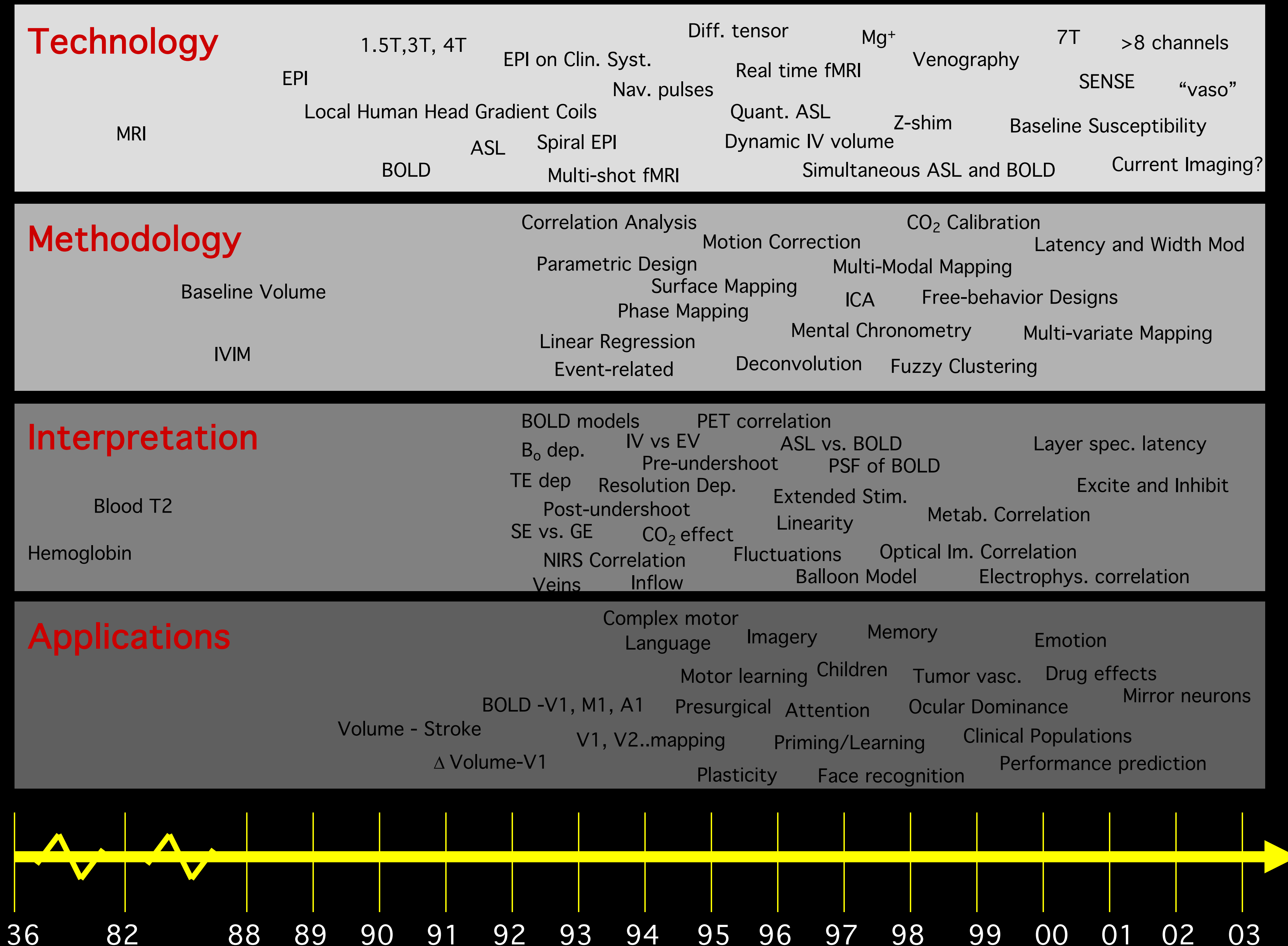

Technology
Methodology
Engineering
Physics
Computer Science
Statistics
Cognitive Science
Neuroscience
Physiology
Medicine
Interpretation
Applications


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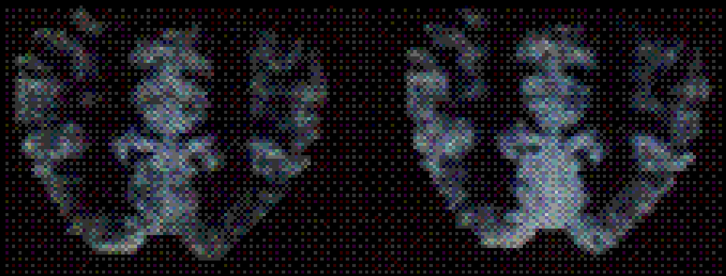
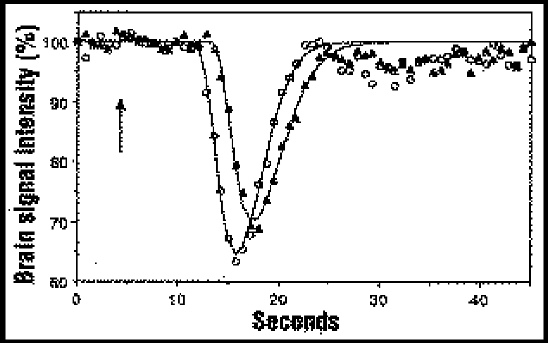
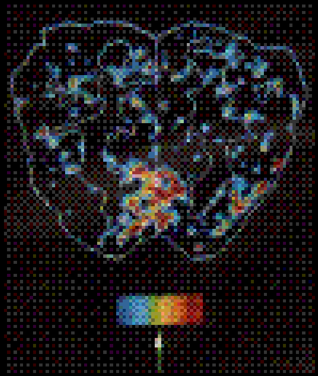
# Blood Volume Imaging

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

Resting Active





Photic Stimulation

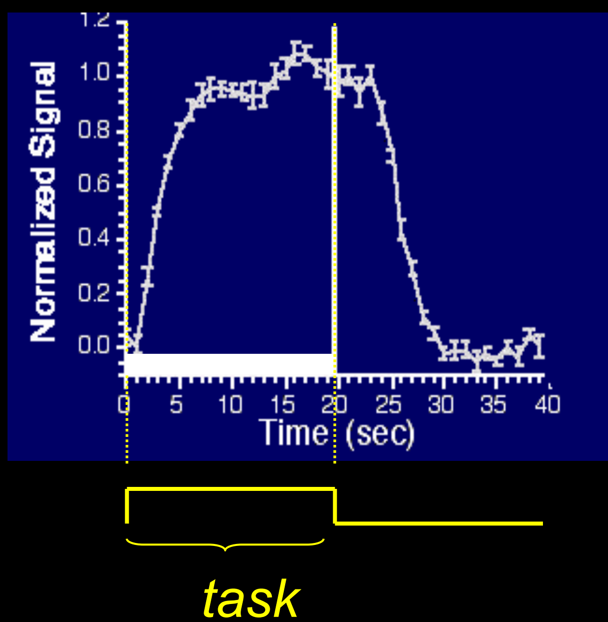
MRI Image showing activation of the Visual Cortex

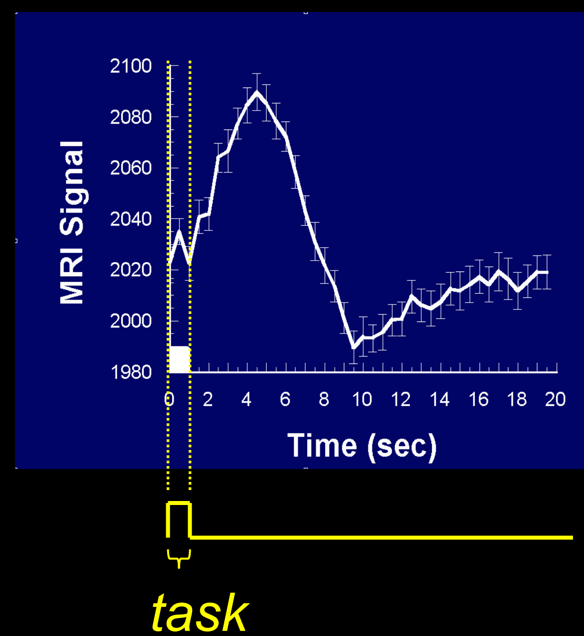
From Belliveau, et al. Science Nov 1991

MSC - perfusion

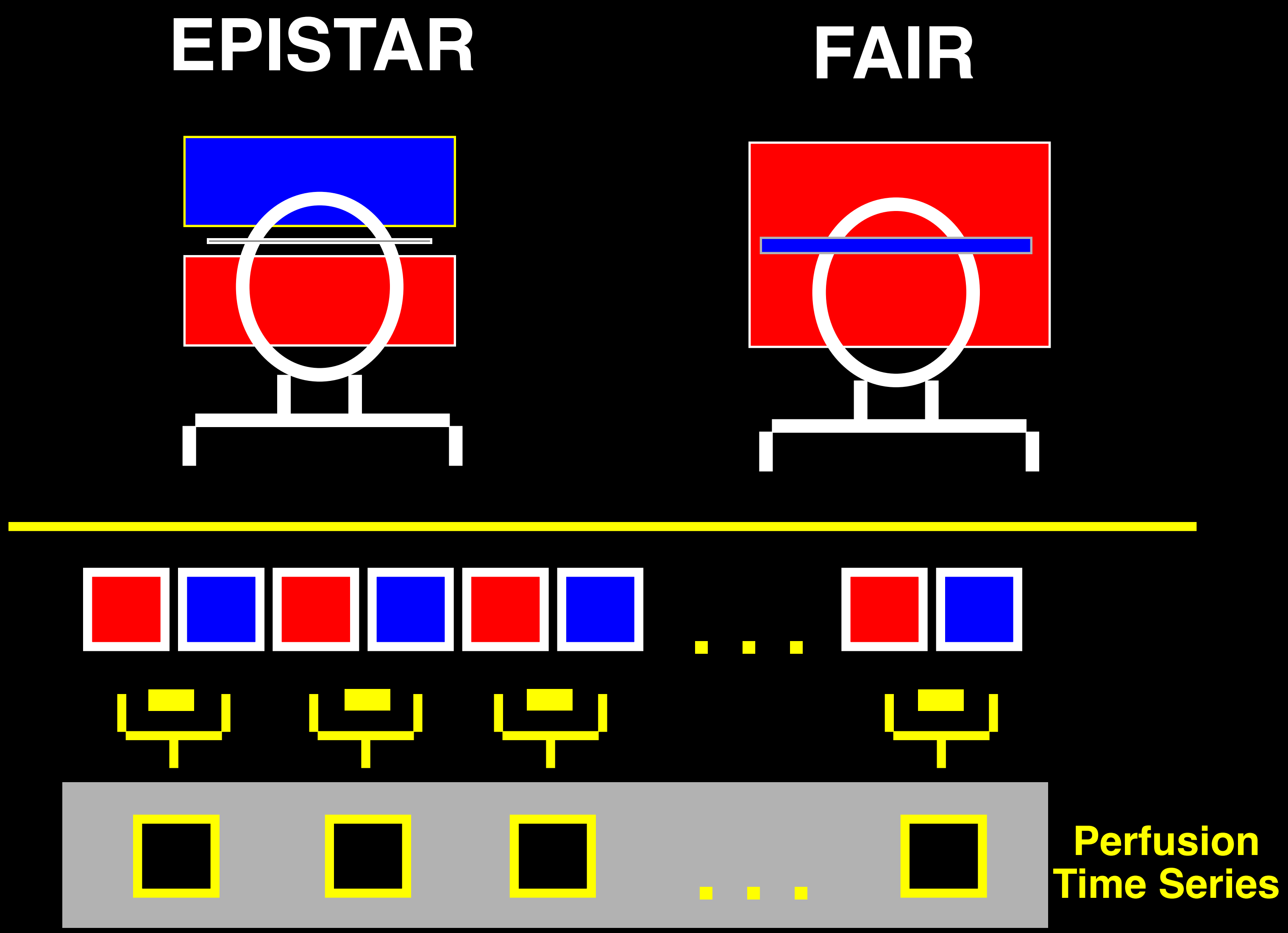
# Blood Oxygenation Imaging

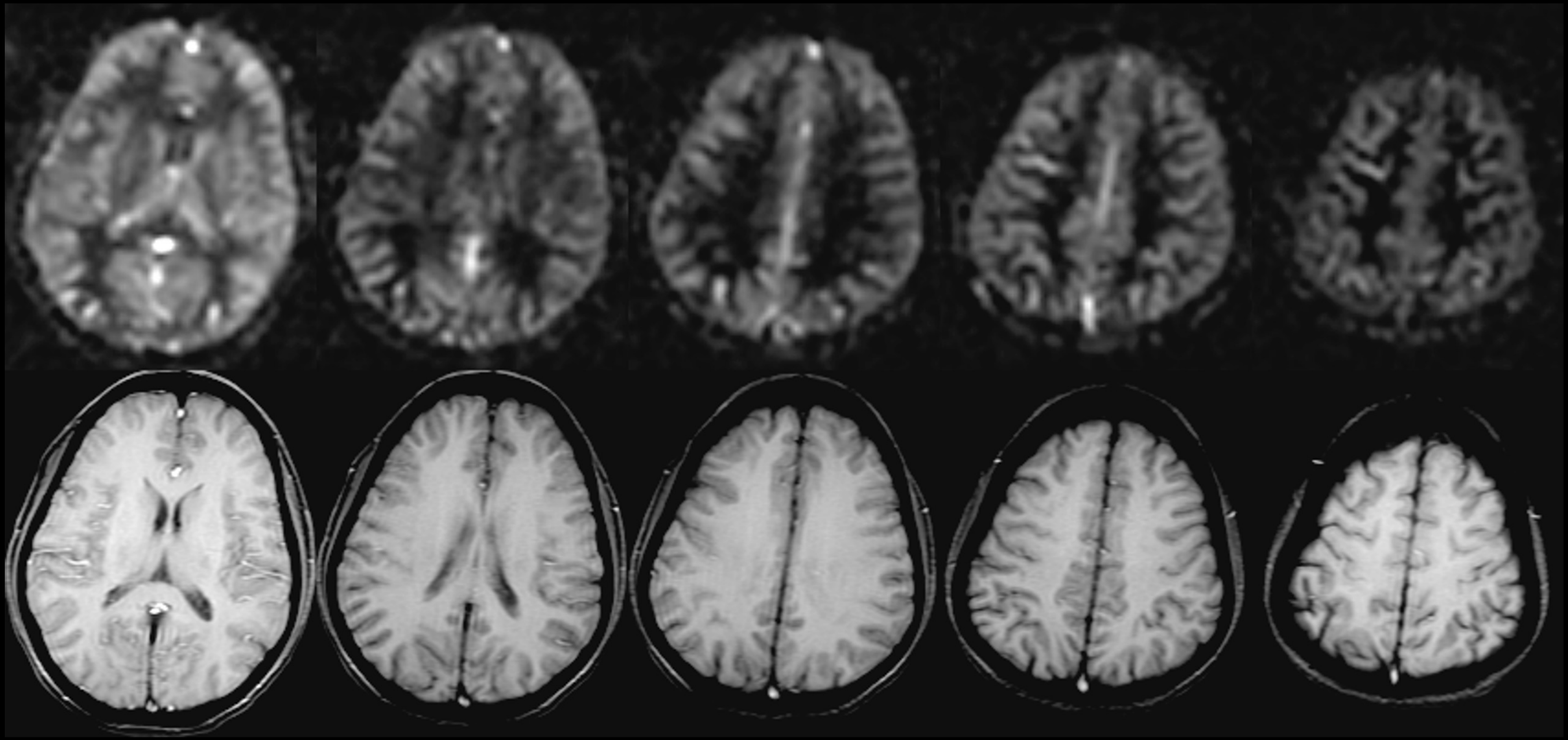
- K. K. Kwong, et al, (1992) "Dynamic magnetic resonance imaging of human brain activity during primary sensory stimulation." Proc. Natl. Acad. Sci. USA. 89, 5675-5679.
- S. Ogawa, et al., (1992) "Intrinsic signal changes accompanying sensory stimulation: functional brain mapping with magnetic resonance 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.



# Blood Perfusion Imaging





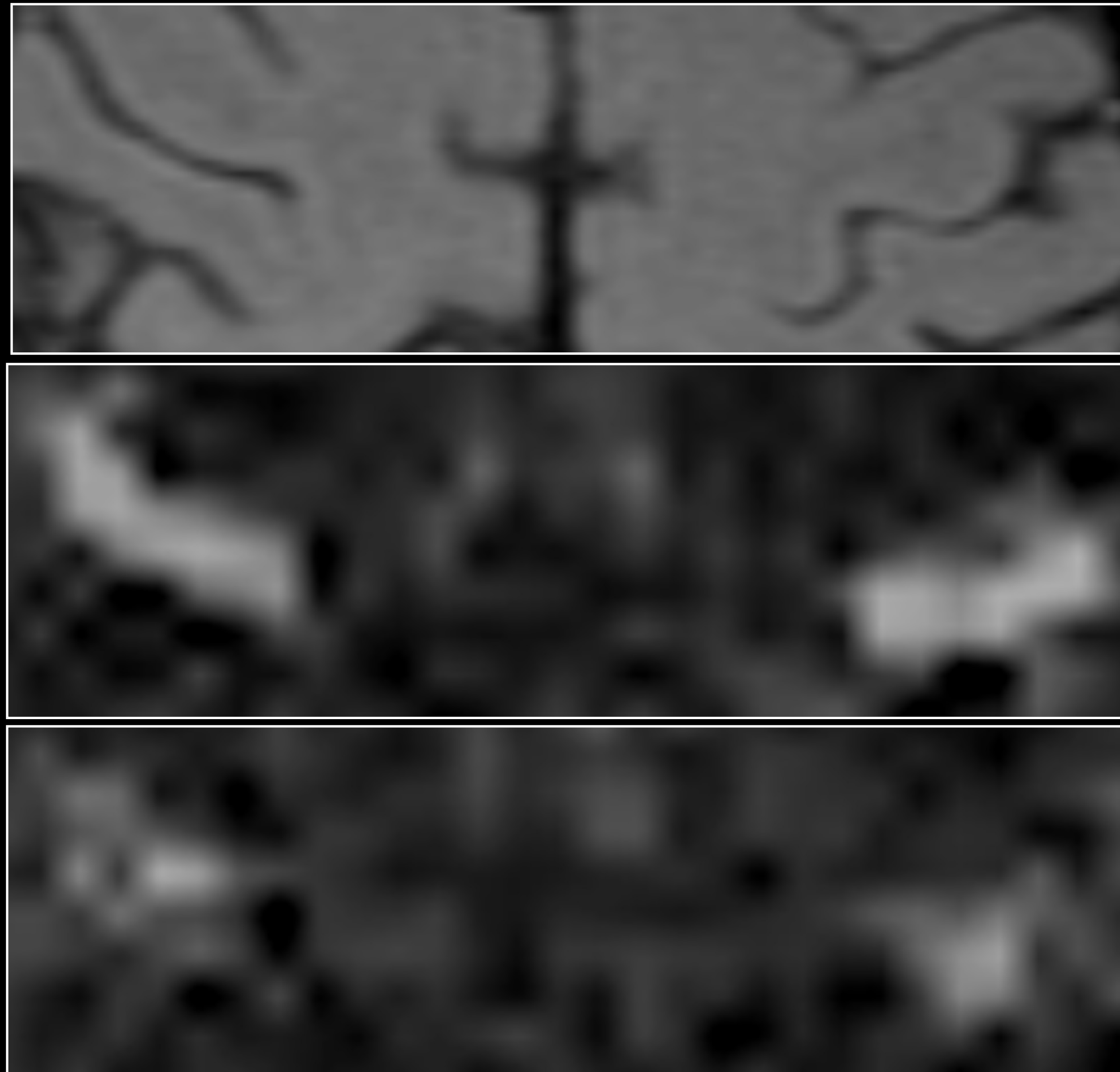

Williams, D. S., Detre, J. A., Leigh, J. S. & Koretsky, A. S. (1992) “Magnetic resonance imaging of perfusion using spin-inversion of arterial water.” Proc. Natl. Acad. Sci. USA 89, 212-216.

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.

## Simultaneous BOLD and Perfusion



**BOLD**

**Perfusion**

*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**

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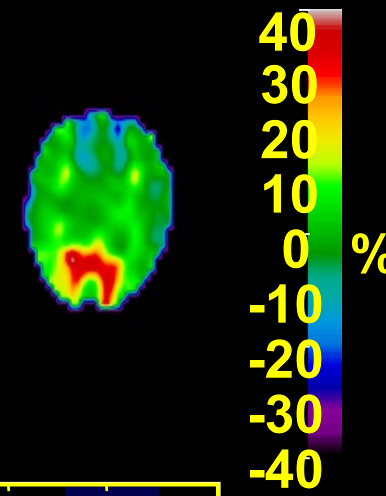
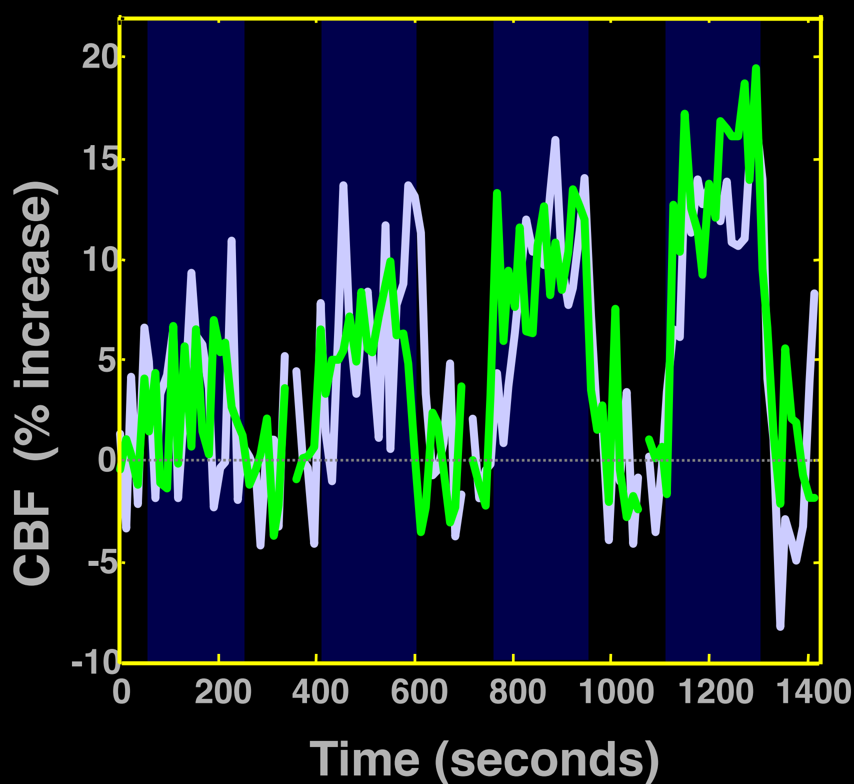
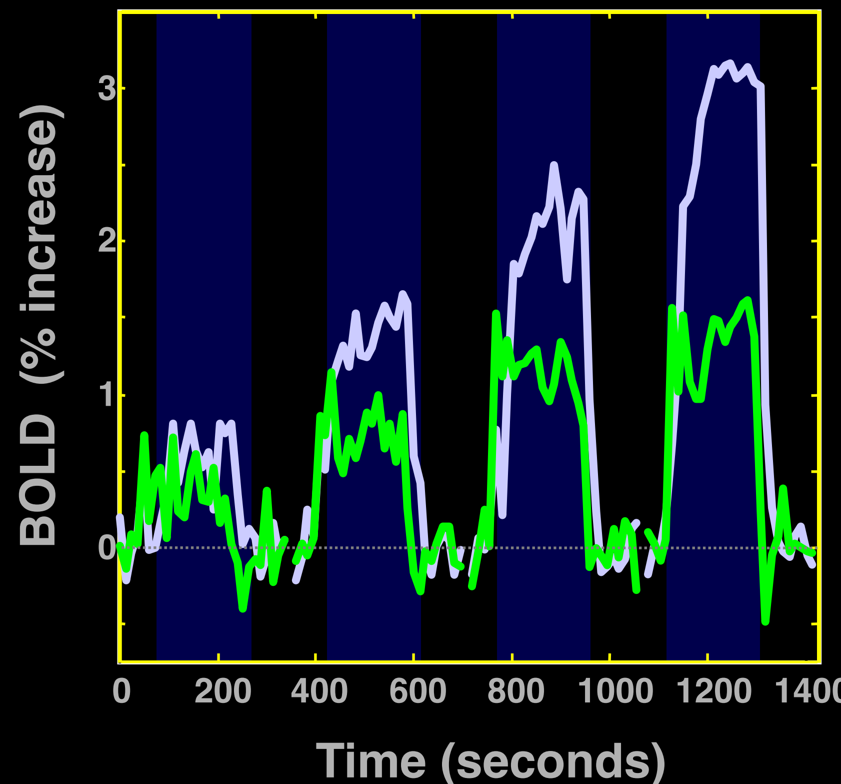
*Room WB325, McConnell Brain Imaging Centre, Montreal Neurological Institute, Quebec, Canada H3A 2B4; and ‡Nuclear Magnetic Resonance Center, Massachusetts General Hospital, Building 149, 13th Street, Charlestown, MA 02129




## CBF




## BOLD

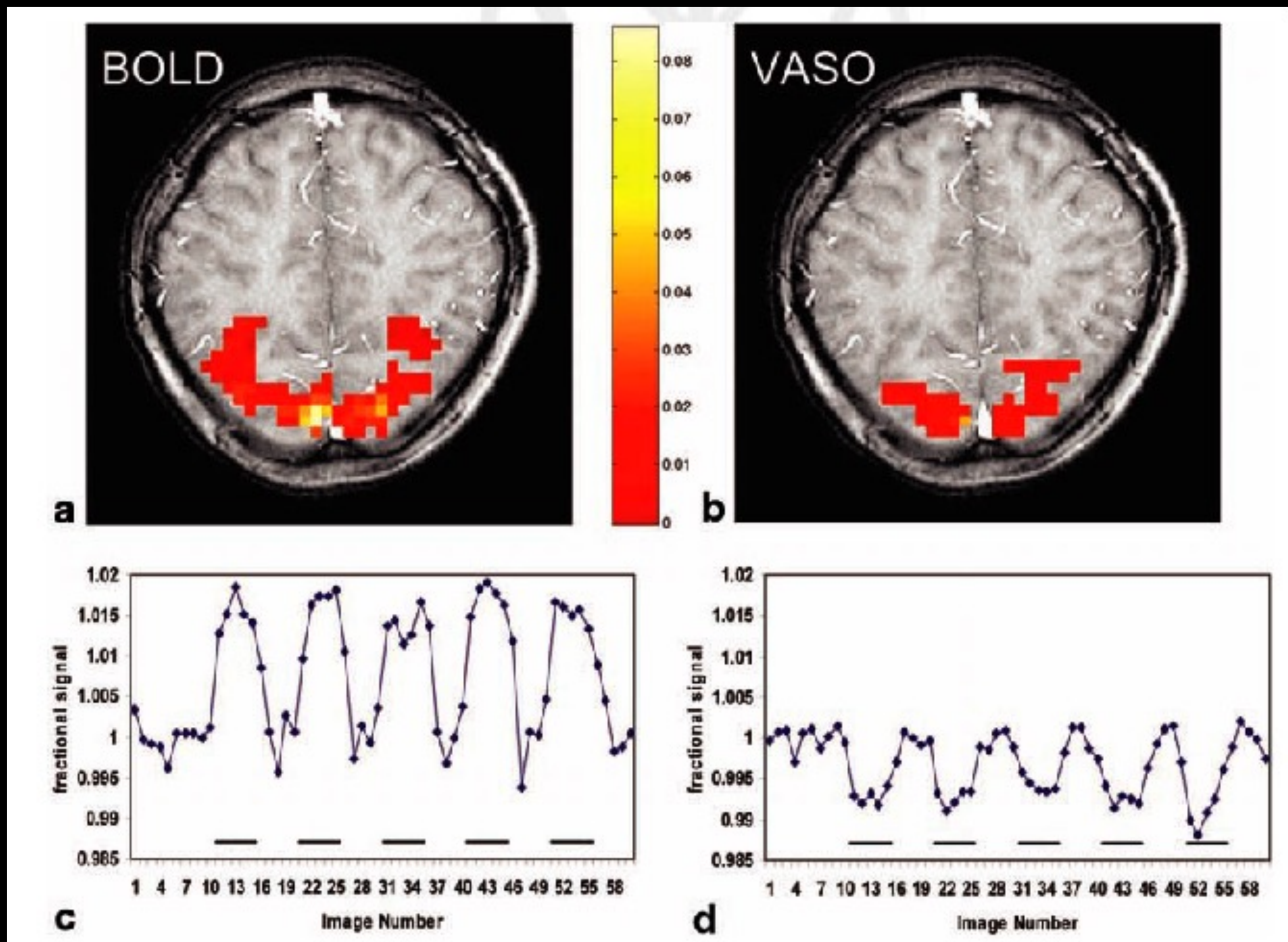



Simultaneous Perfusion and BOLD imaging during graded visual activation and hypercapnia

# Functional Magnetic Resonance Imaging Based on Changes in Vascular Space Occupancy

Hanzhang Lu,[1–3] Xavier Golay,[1,3] James J. Pekar,[1,3] and Peter C.M. van Zijl[1,3*]

MAGNET RESON MED 50 (2): 263-274 AUG 2003



# Where fMRI can improve:

- Sensitivity
- Spatial Resolution
- Temporal Resolution
- Interpretation
- Experimental
  Design/Execution/Analysis
- Other contrast mechanisms

# Why Sensitivity?

- More activated signal is present
- Information in the fluctuations
- Shorter scan times
- More subtle comparisons
- Buys higher resolution

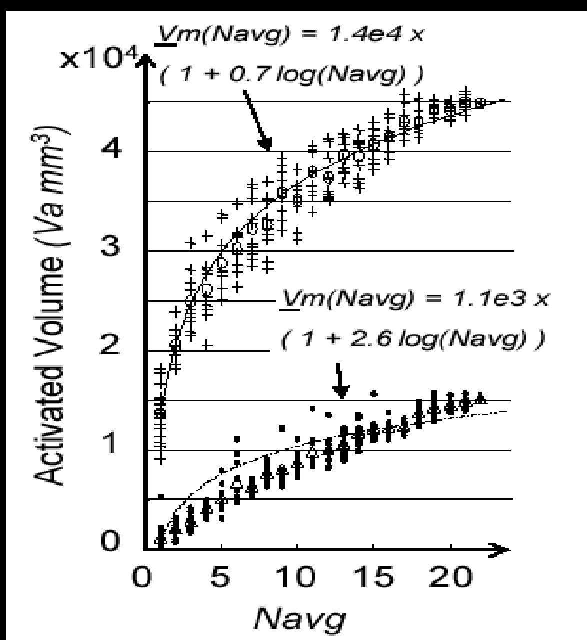
# The spatial extent of the BOLD response

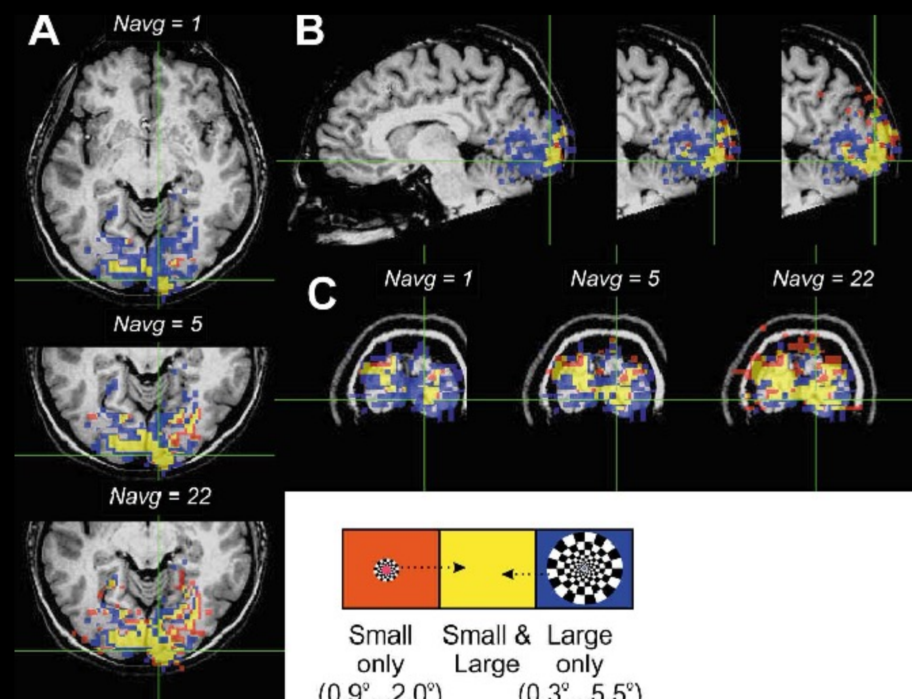
Ziad S. Saad,[a,b,*] Kristina M. Ropella,[b] Edgar A. DeYoe,[c] and Peter A. Bandettini[a]

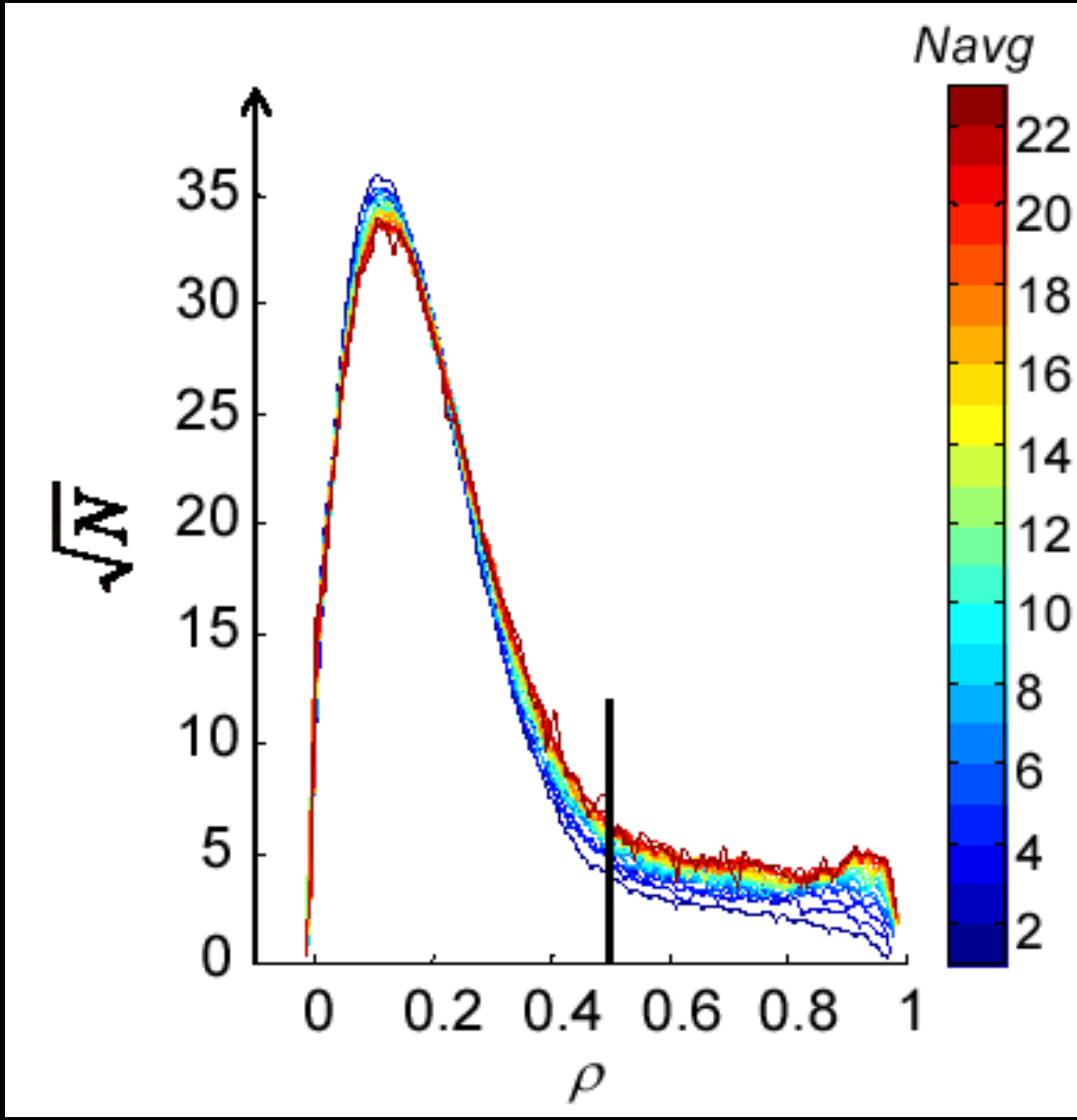
[a] Laboratory of Brain and Cognition, National Institute of Mental Health, NIH, Bethesda, MD 20892-1148, USA
[b] Department of Biomedical Engineering Marquette University, Milwaukee, WI 53233, USA
[c] Department of Cell Biology, Neurobiology and Anatomy, Medical College of Wisconsin, Milwaukee, WI 53226,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

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

NeuroImage





Navg
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12
14
16
18
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22
√N
0
5
10
15
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25
30
35
0
0.2
0.4
0.6
0.8
1
ρ

# Increasing Sensitivity

- Higher field strength
- More and Smaller RF coils
- Reduction of physiological noise

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

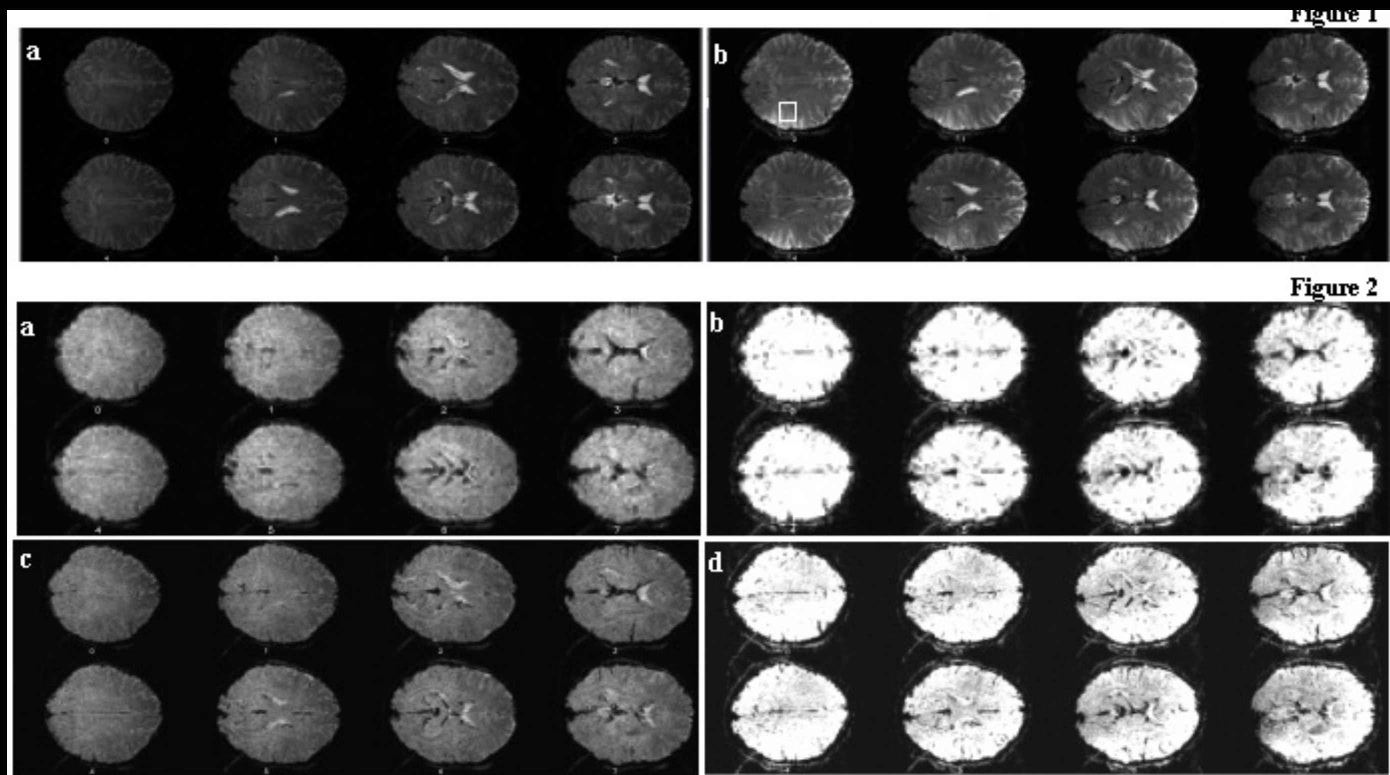
Jerzy Bodurka[1], Peter van Gelderen[2], Patrick Ledden[3], Peter Bandettini[1], Jeff Duyn[2]
[1]Functional MRI Facility NIMH/NIH, [2]Advance MRI NINDS/NIH, [3]Nova Medical Inc.

Quadrature Head Coil | 8 Channel Array

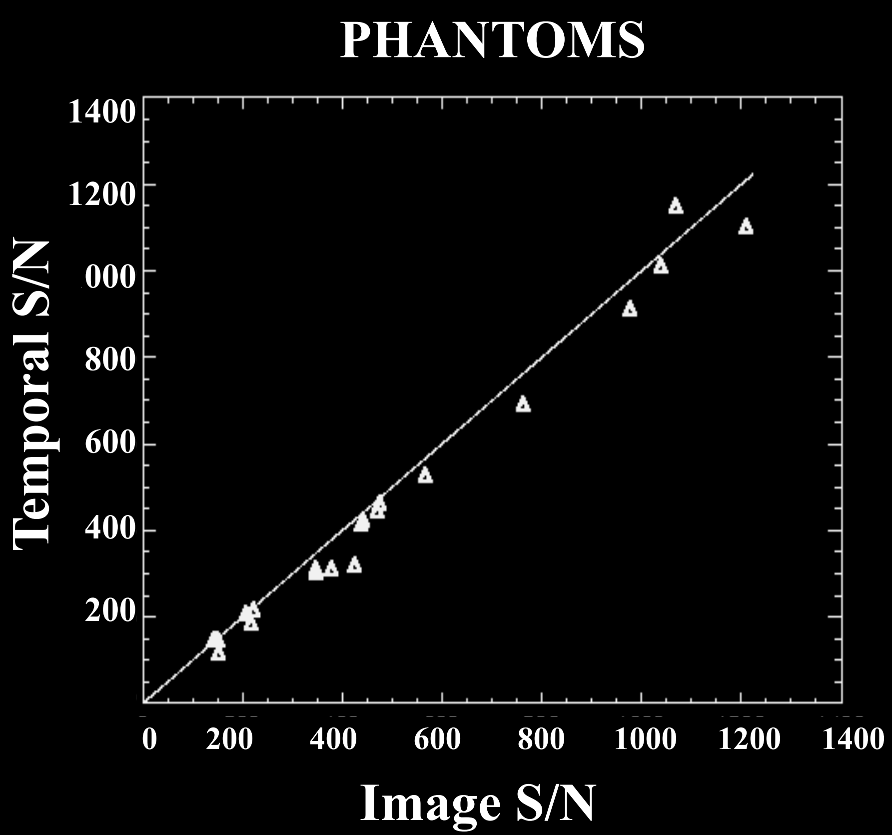
128 x 96 — SNR

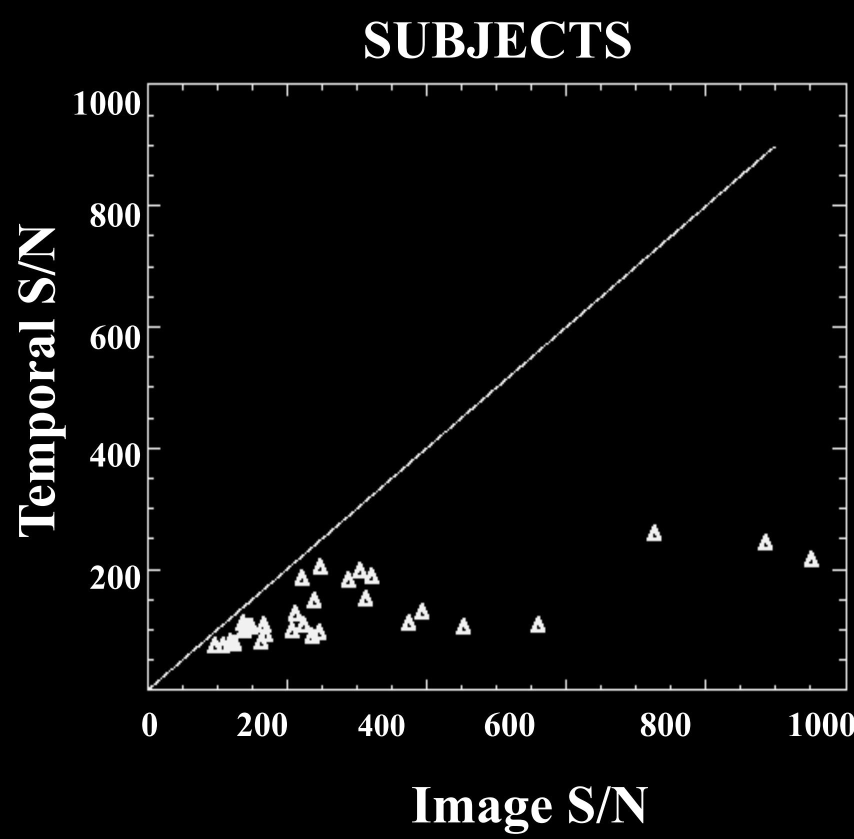
64 x 48 — TSNR

128 x 96

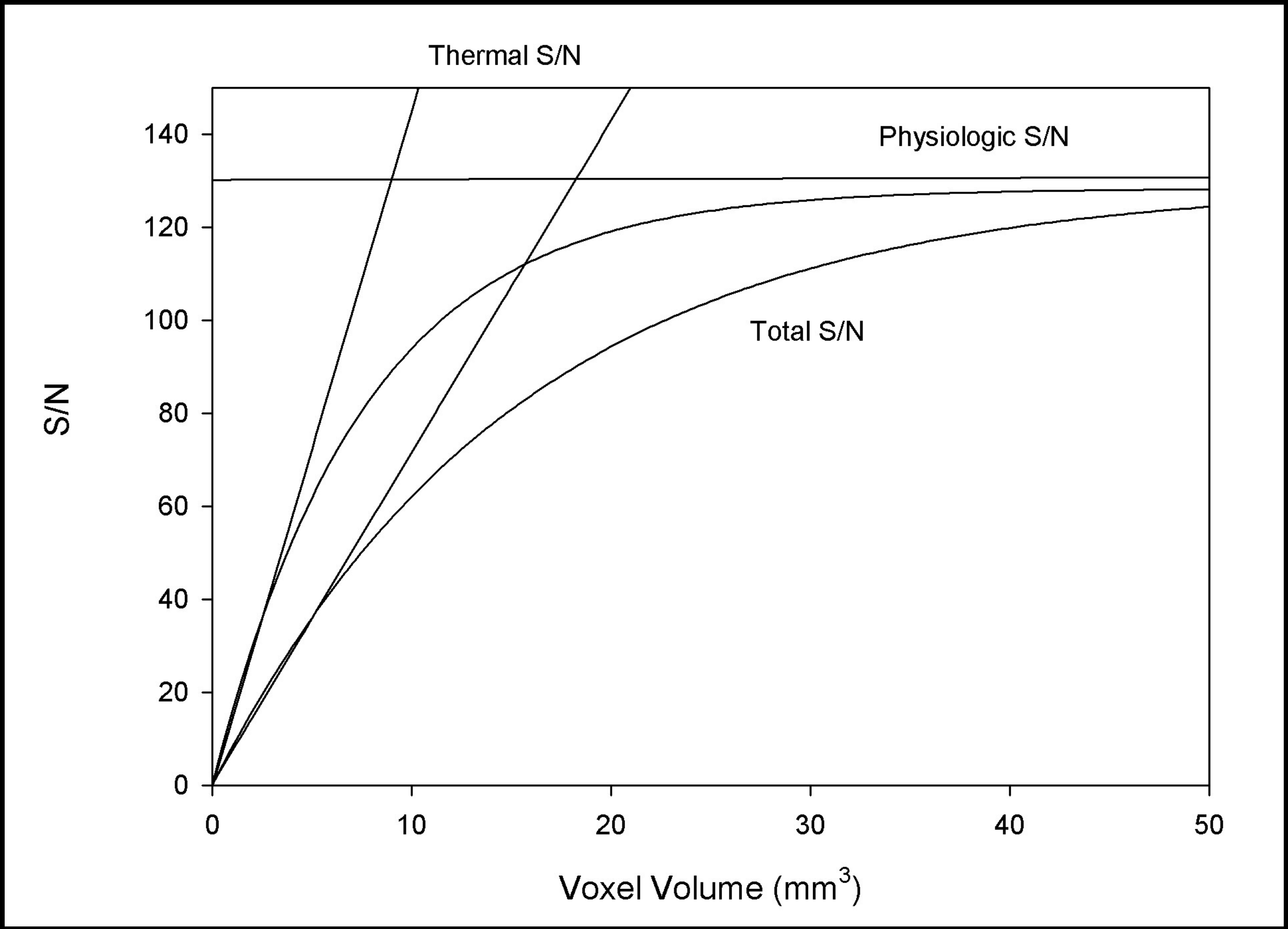


# Temporal S/N vs. Image S/N




N. Petridou

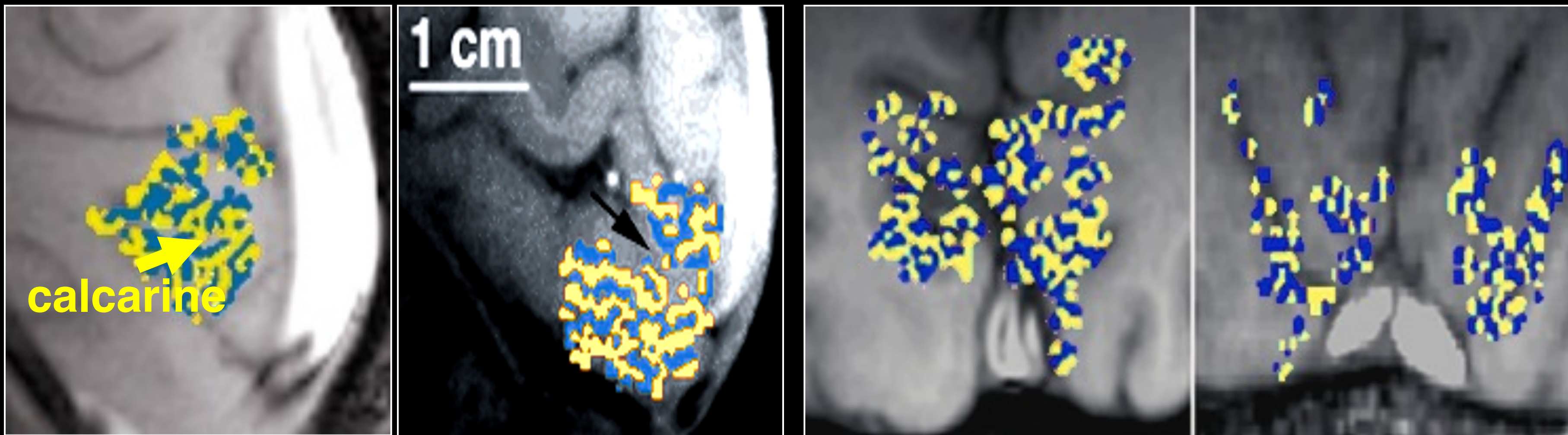


Thermal S/N
Physiologic S/N
Total S/N
S/N
0
20
40
60
80
100
120
140
0
10
20
30
40
50
Voxel Volume (mm3)

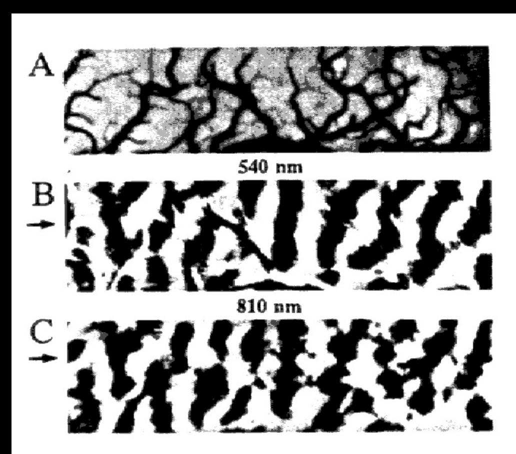
# Why Higher Spatial Resolution?

- Delineation of function
- Possible gain in contrast to noise
- Reduction of signal dropout
- Better registration with high res anatomy

# Ocular Dominance Column Mapping using fMRI




Menon, R. S., S. Ogawa, et al. (1997). "Ocular dominance in human V1 demonstrated by functional magnetic resonance imaging." J Neurophysiol 77(5): 2780-7.




Optical Imaging

R. D. Frostig et. al, PNAS 87: 6082-6086, (1990).

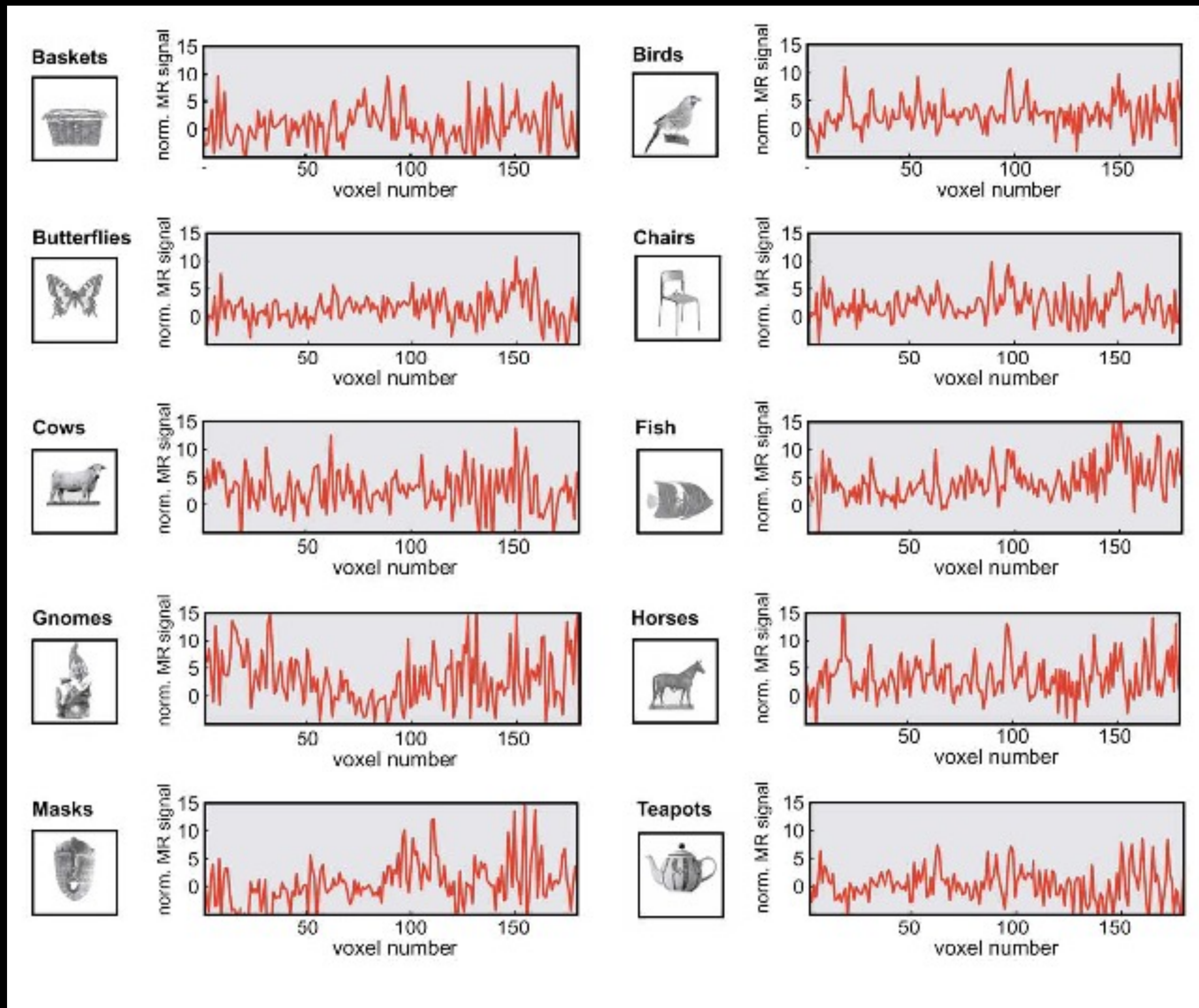
Functional magnetic resonance imaging (fMRI) "brain reading": detecting and classifying distributed patterns of fMRI activity in human visual cortex

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

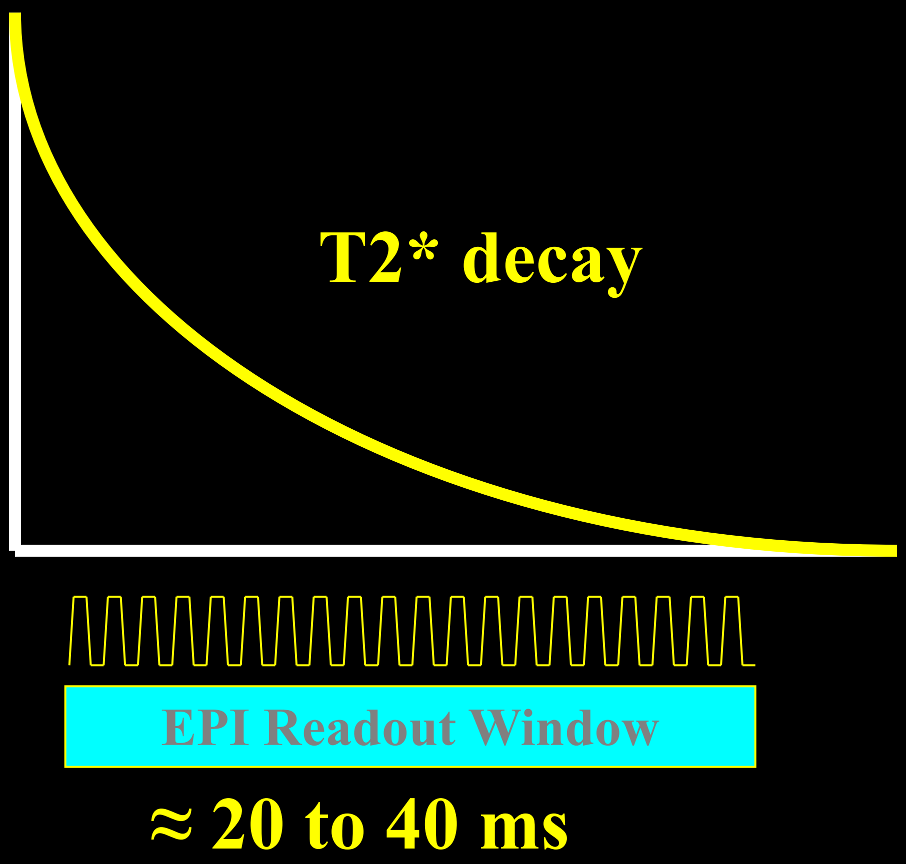
NEUROIMAGE 19 (2): 261-270 Part 1 JUN 2003

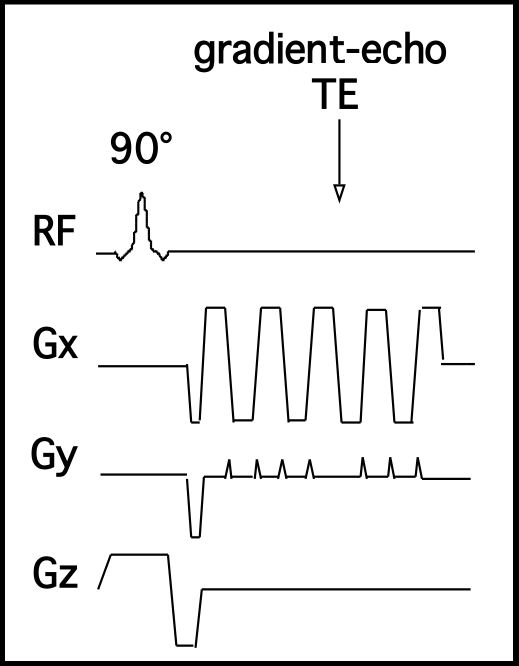


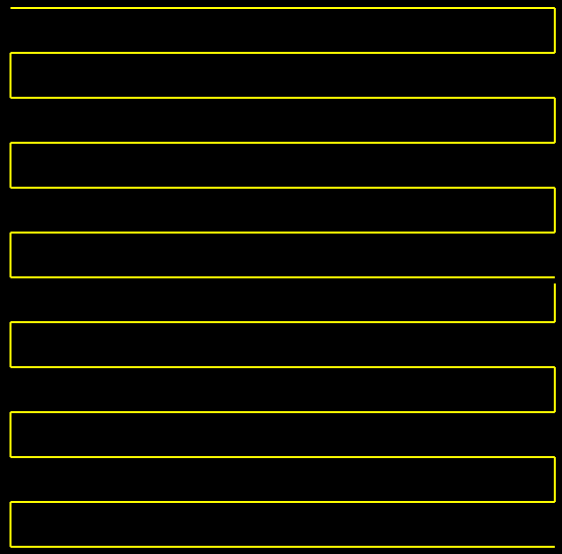
# Increasing Spatial Resolution

- Multi-shot Imaging (with navigators)
- Partial k-space
- Parallel imaging (SENSE, SMASH, etc..)

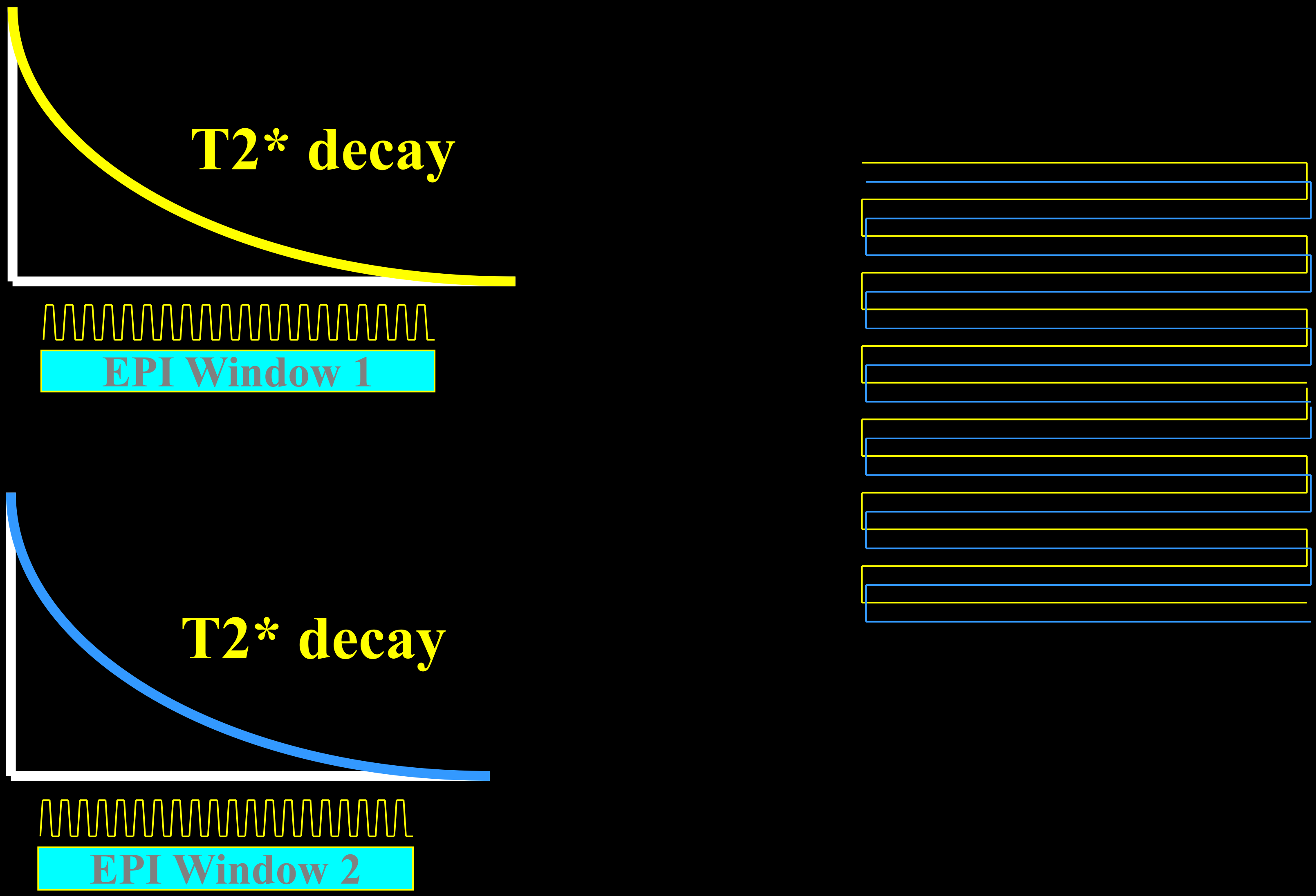
# Single Shot EPI



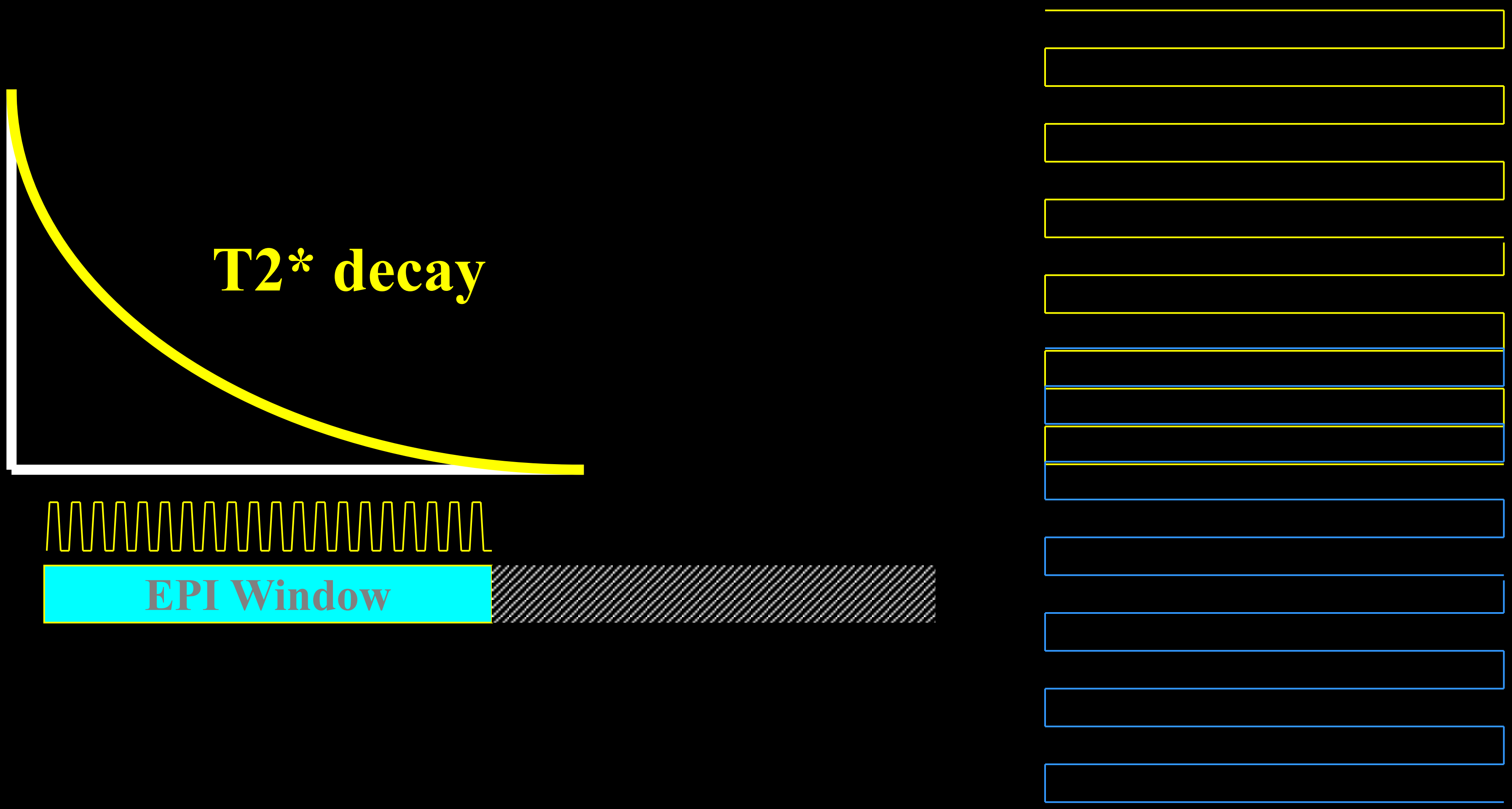



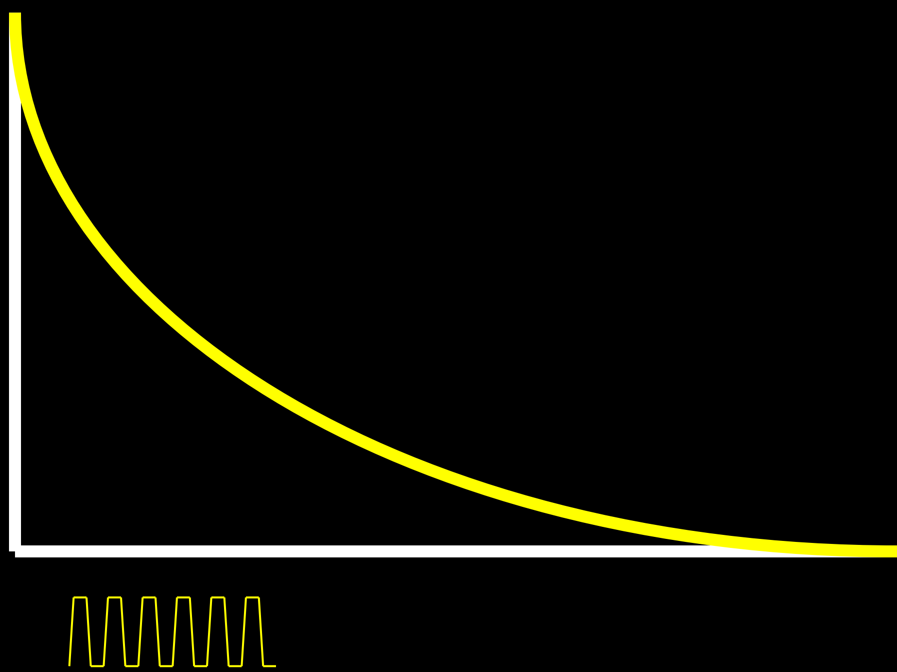
# Multishot Imaging



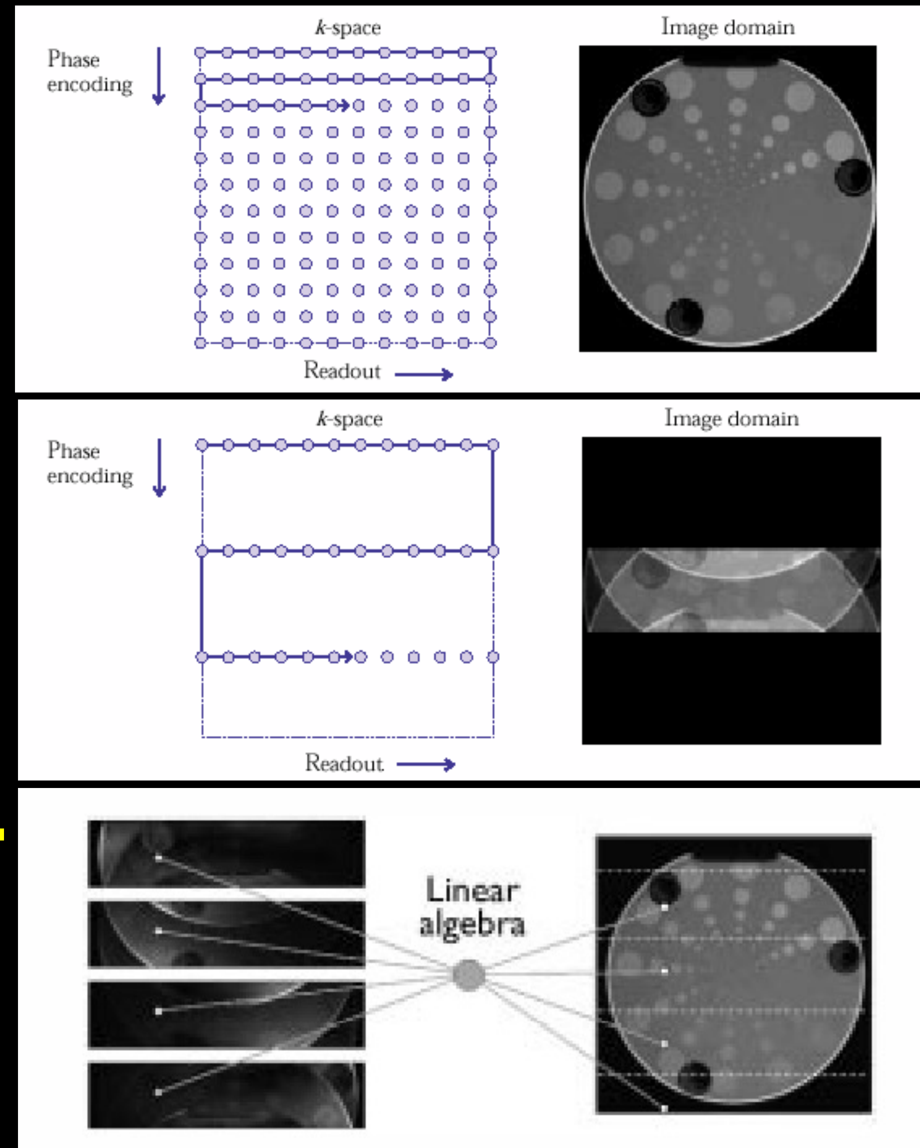
# Partial k-space imaging



# SENSE Imaging



≈ 5 to 30 ms



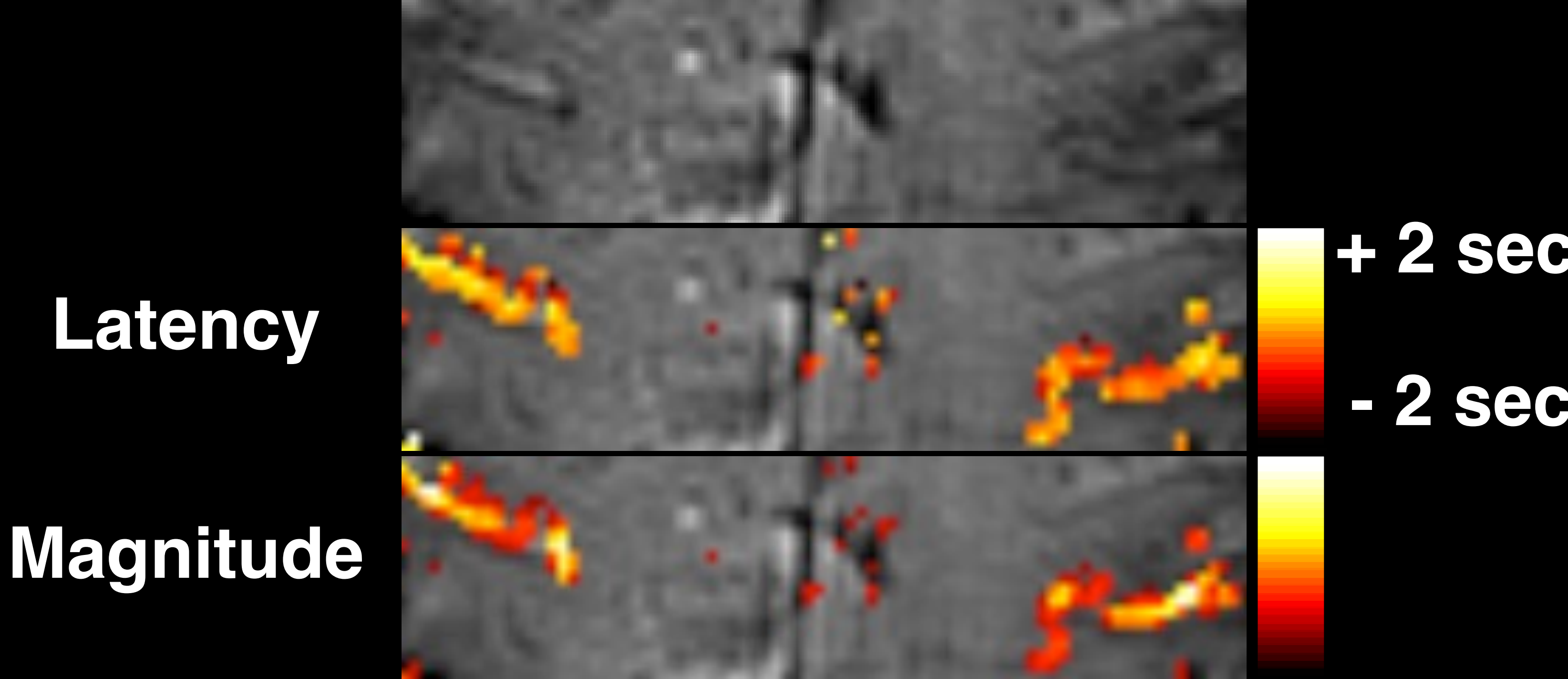

Pruessmann, et al.

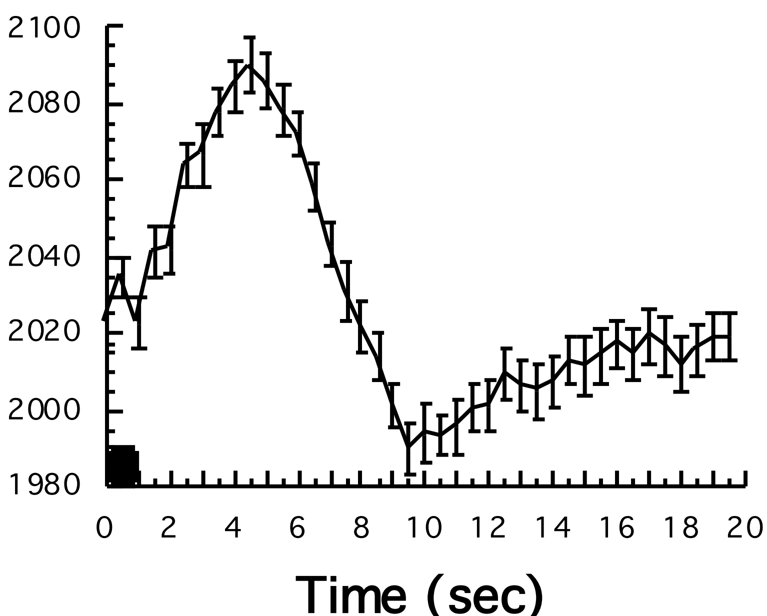
# Why higher temporal resolution?

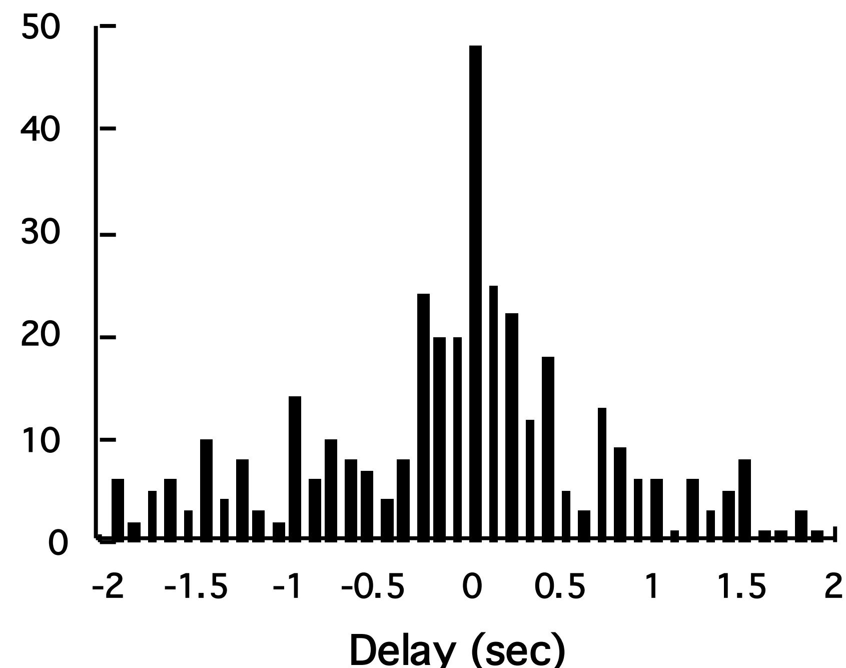
- More slices per volume
- Better delineation of hemodynamic response
- Potentially better delineation neuronal activity timing

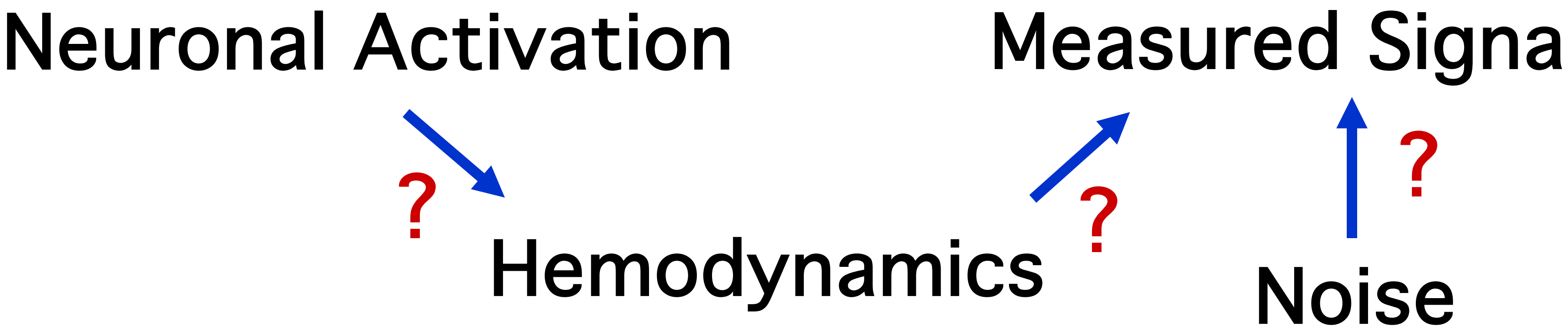
# Increasing temporal resolution

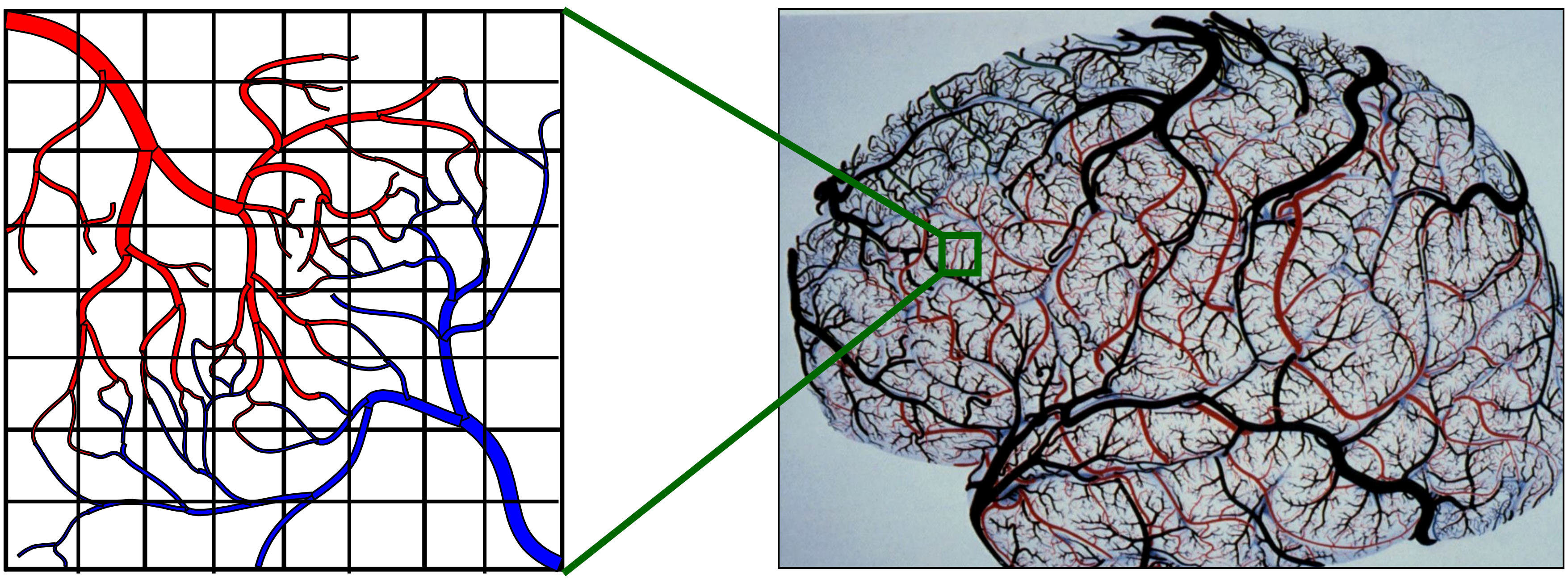
- Asynchronous task and TR timing
- Reduce readout window width
- Increased averaging
- Focus on modulation of task timing
- Calibration?


Latency
Magnitude
+ 2 sec
- 2 sec


2100
2080
2060
2040
2020
2000
1980
0 2 4 6 8 10 12 14 16 18 20
Time (sec)

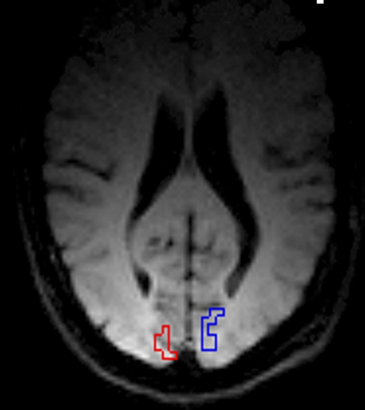

50
40
30
20
10
0
-2 -1.5 -1 -0.5 0 0.5 1 1.5 2
Delay (sec)


Neuronal Activation
Measured Signal
?
?
?
Hemodynamics
Noise

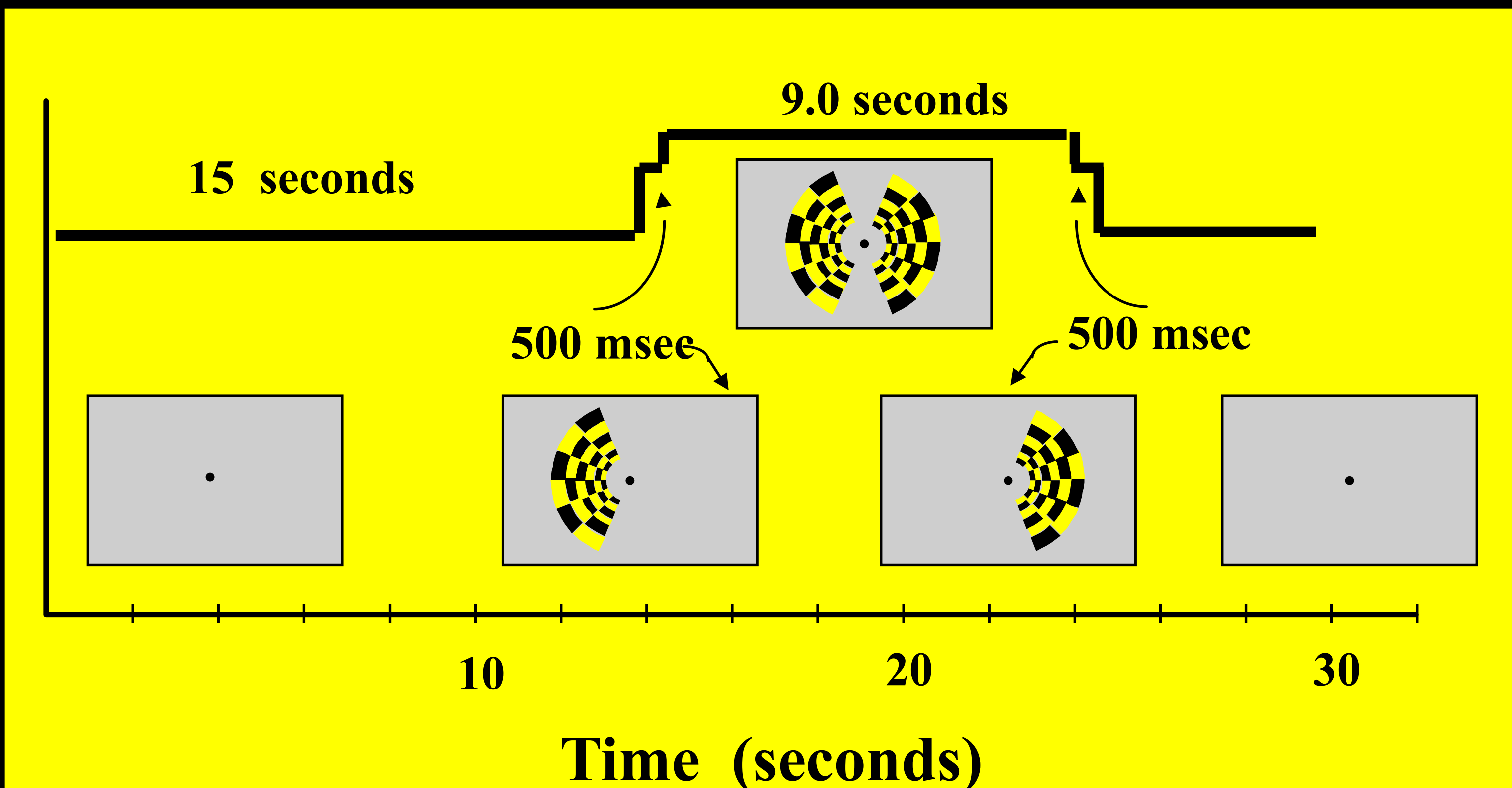


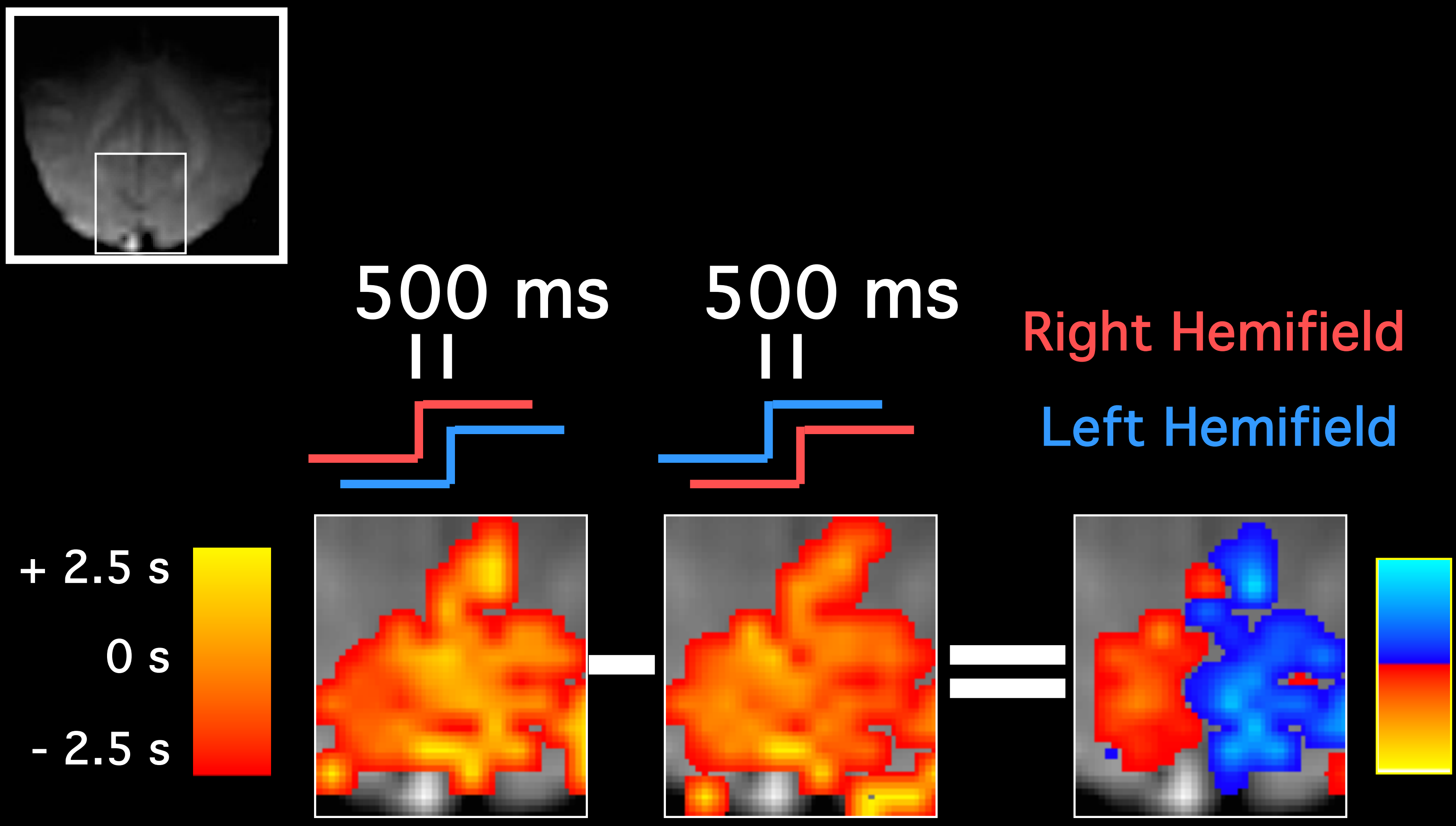
# Hemi-Field Experiment

Left Hemisphere



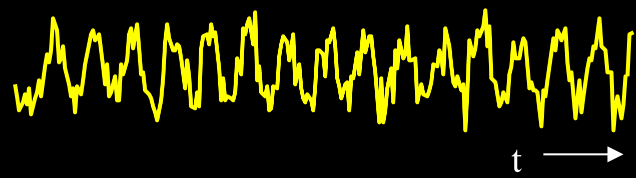
Right Hemisphere

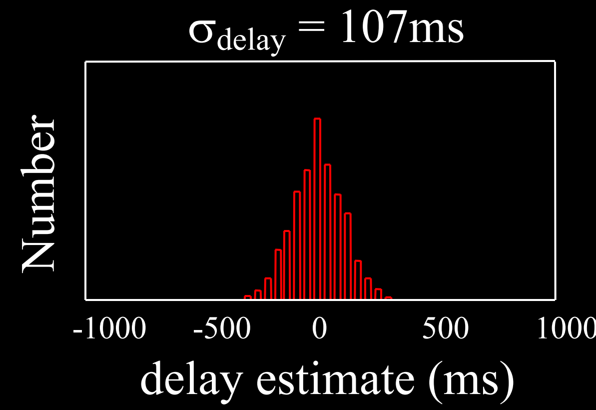



500 ms
500 ms
Right Hemifield
Left Hemifield
+ 2.5 s
0 s
- 2.5 s

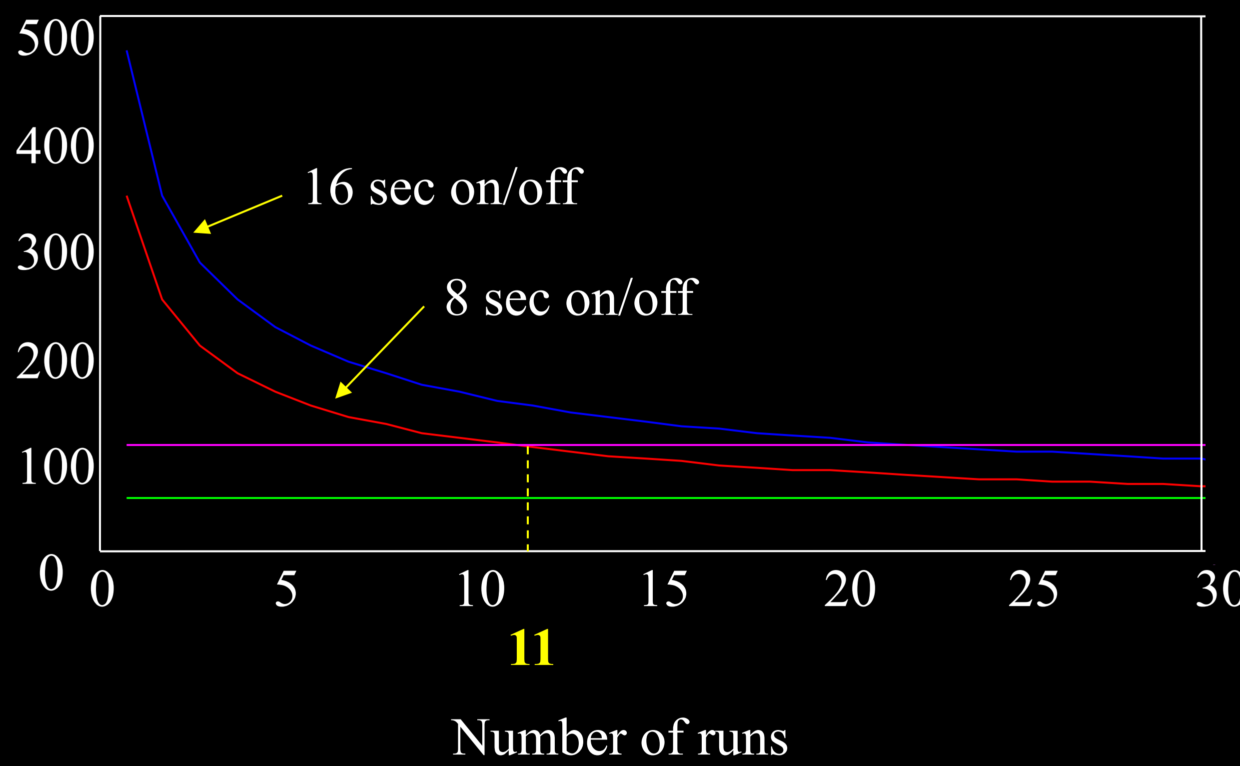
1 run:

1% Noise
4% BOLD
256 time pts /run
1 second TR

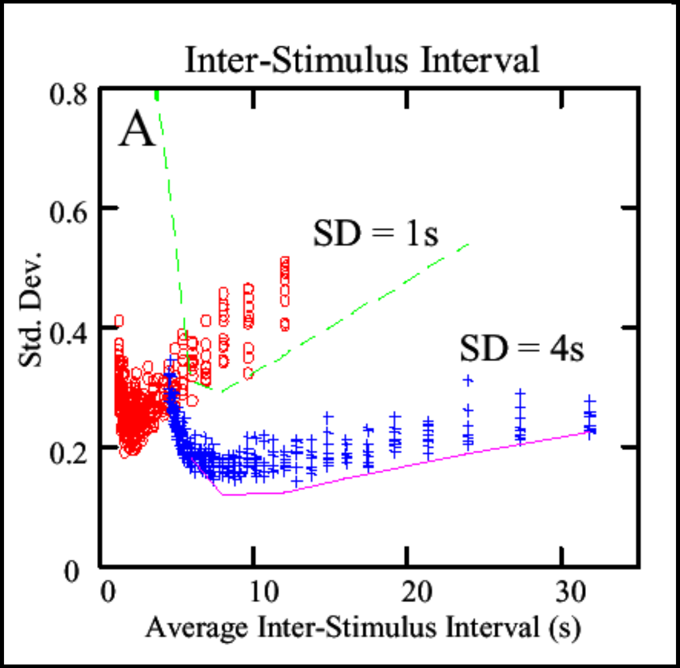


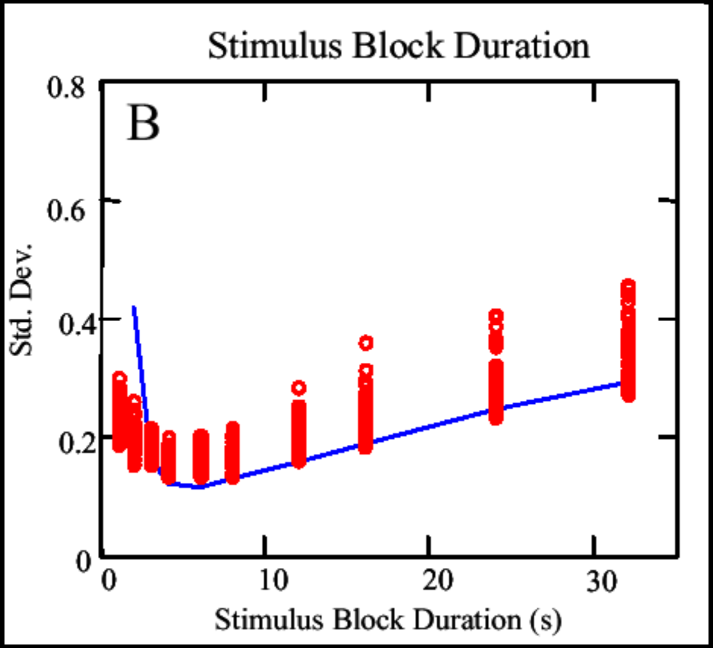




Smallest latency Variation Detectable (ms) ($p < 0.001$)



# Optimal Detection of Hemodynamic Latency



# Cognitive Neuroscience Application:

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

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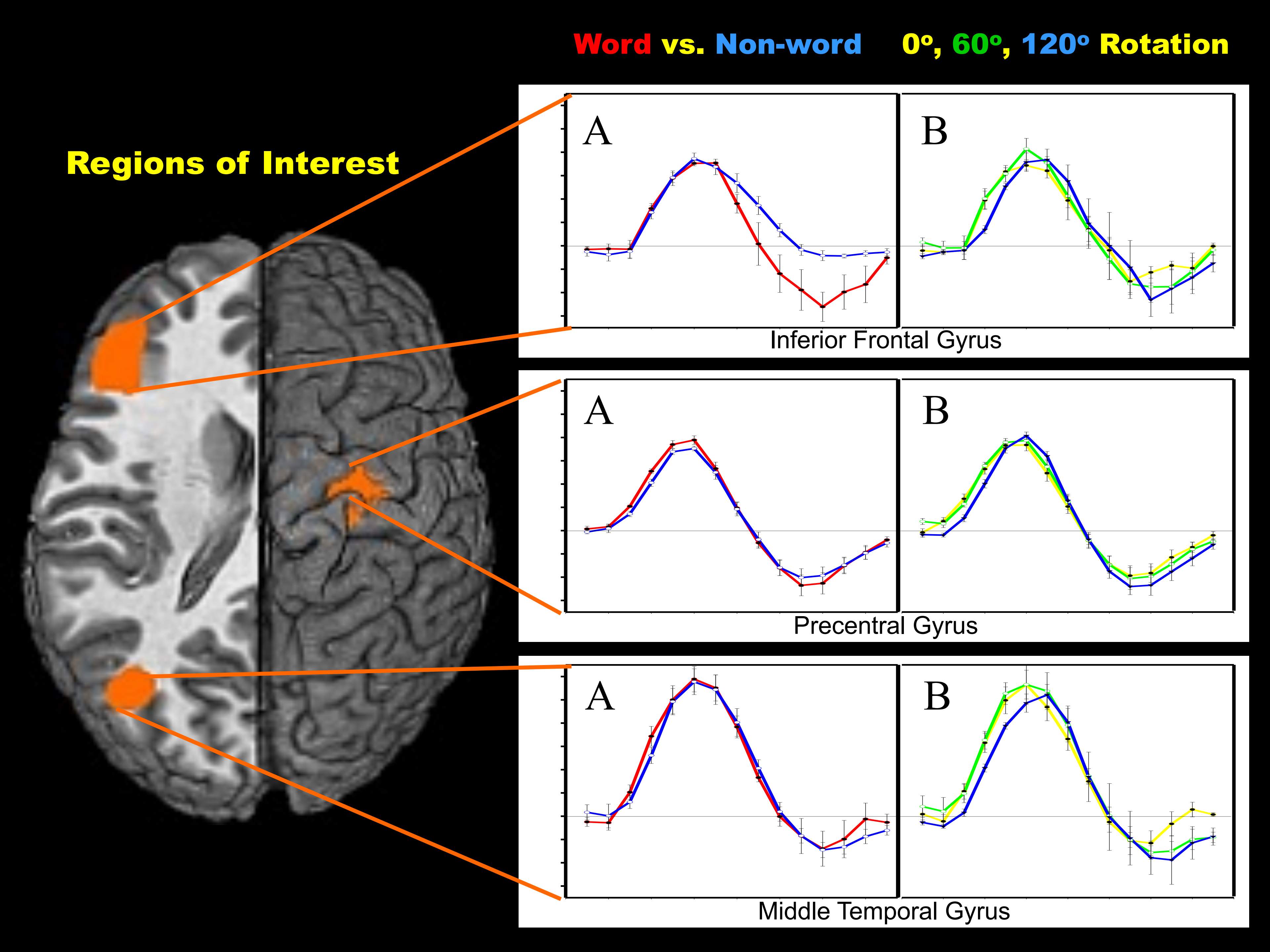
*Laboratory of Brain and Cognition and ‡Scientific and Statistical Computing Core, National Institute of Mental Health, Bethesda, MD 20892

PNAS

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

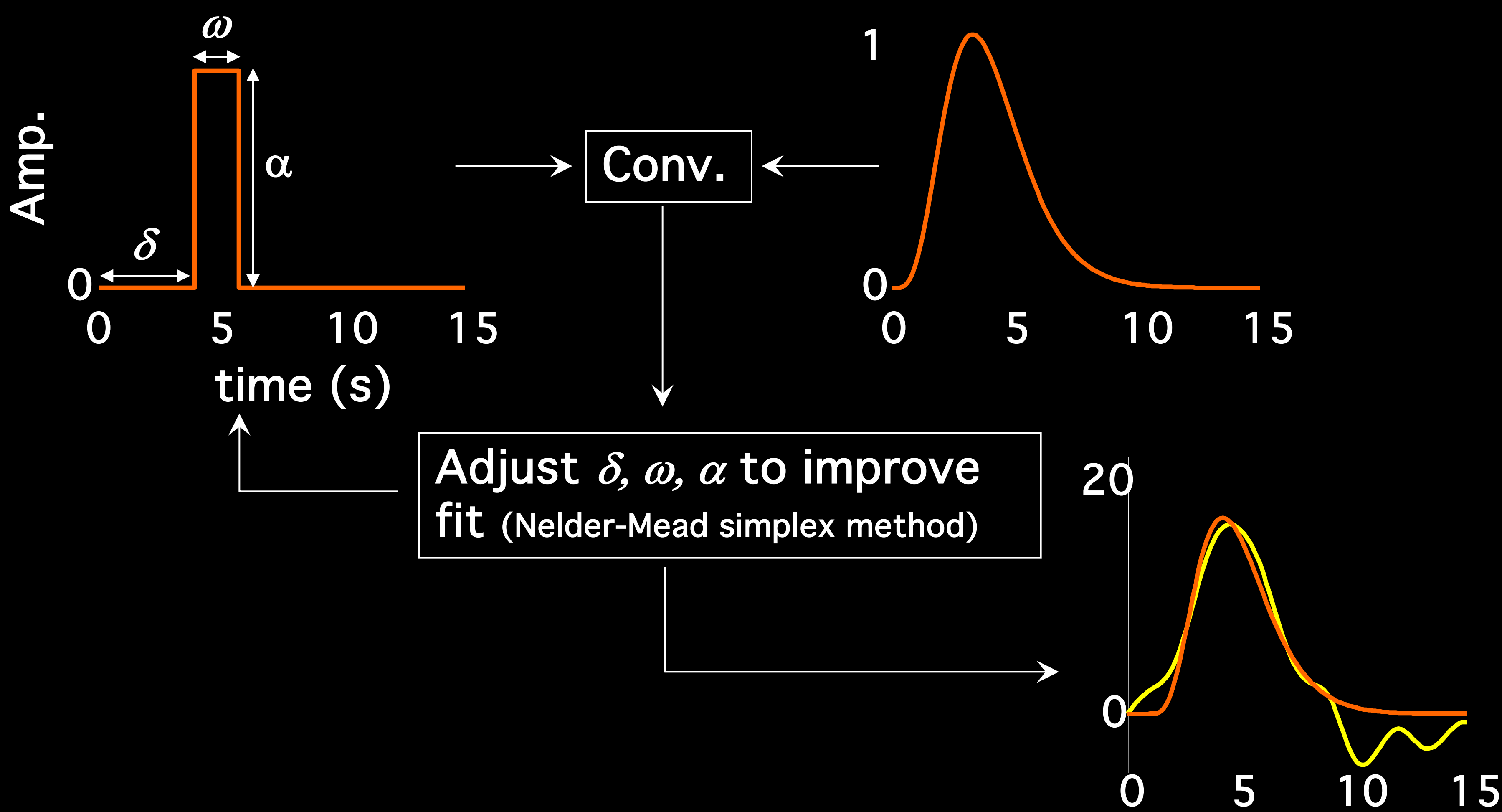
**Lexical Delay**

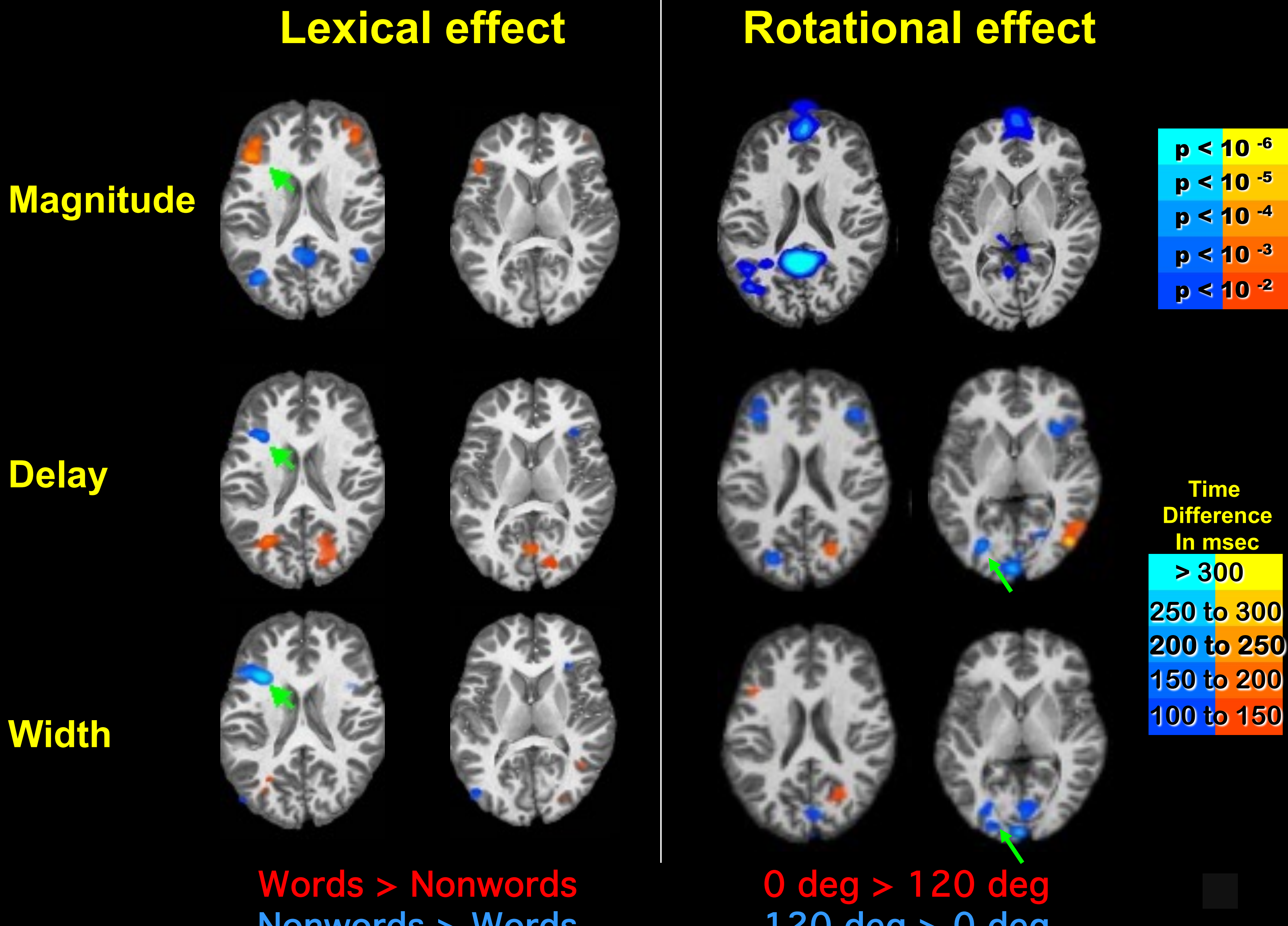
| Rotational Delay | Words | Non-Words | Mean Reaction Time |
|---|---|---|---|
| 0⁰ | smudge | dierts | 823 ms |
| 60⁰ | frolic | cuhlos | 891 ms |
| 120⁰ | slouch | gedmus | 1446 ms |
| Mean Reaction Time | 986 ms | 1219 ms | |



Word vs. Non-word
0º, 60º, 120º Rotation
Regions of Interest
A
B
Inferior Frontal Gyrus
A
B
Precentral Gyrus
A
B
Middle Temporal Gyrus

# Estimation of Delay, Width & Amplitude

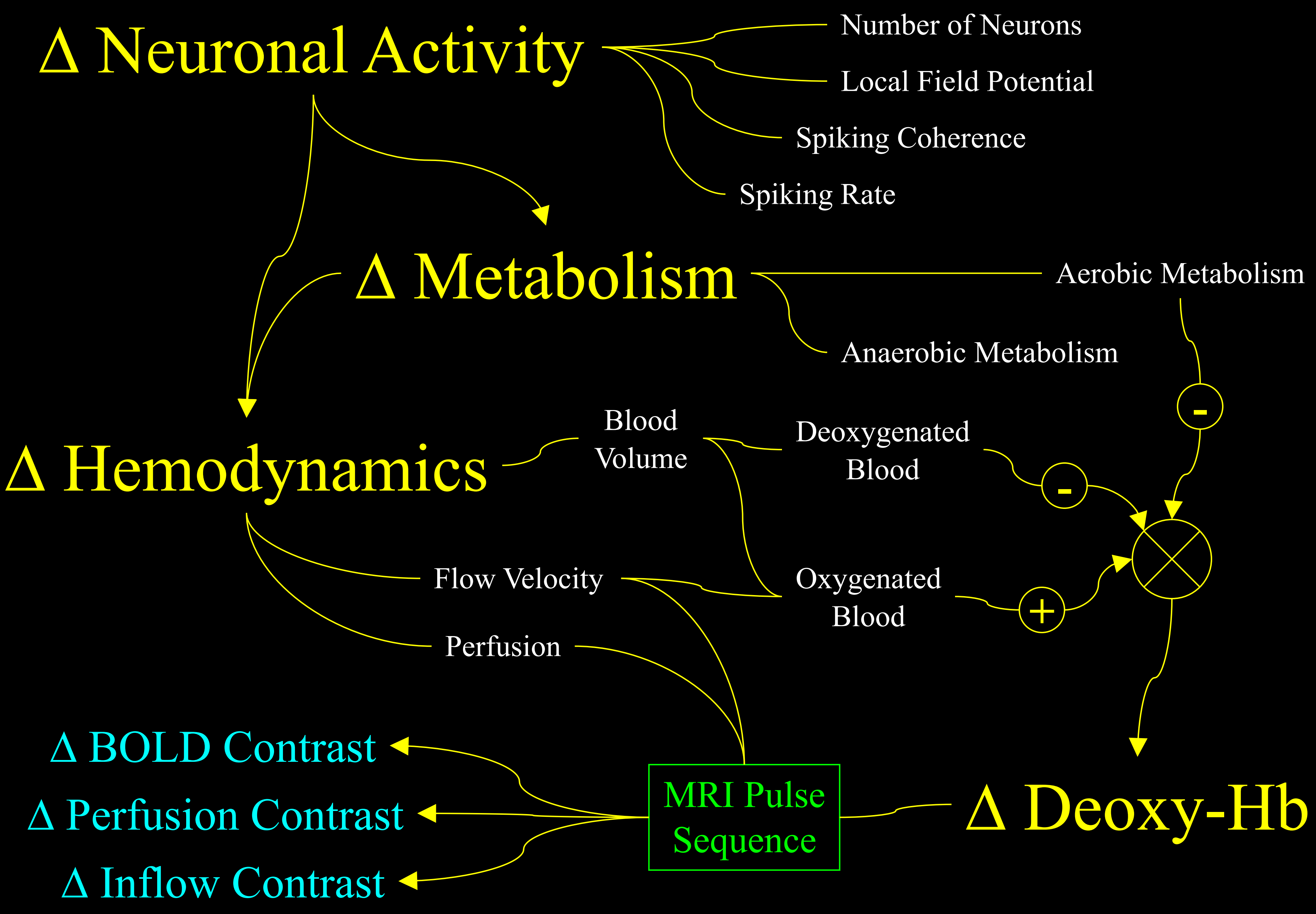


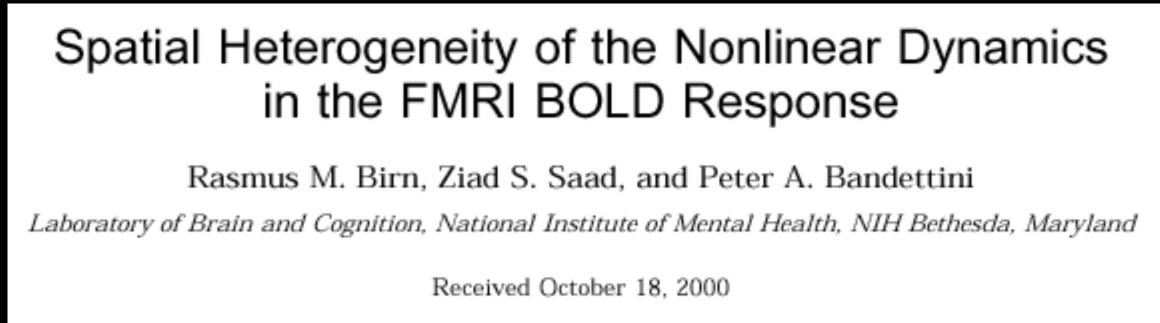


Lexical effect
Rotational effect
Magnitude
Delay
Width
p < 10 -6
p < 10 -5
p < 10 -4
p < 10 -3
p < 10 -2
Time Difference In msec
> 300
250 to 300
200 to 250
150 to 200
100 to 150
Words > Nonwords
Nonwords > Words
0 deg > 120 deg
120 deg > 0 deg

# Interpretation

- More direct neuronal information
- More quantitative physiologic information


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
Oxygenated Blood
Flow Velocity
Perfusion
-
-
+
Δ BOLD Contrast
Δ Perfusion Contrast
Δ Inflow Contrast
MRI Pulse Sequence
Δ Deoxy-Hb



Spatial Heterogeneity of the Nonlinear Dynamics in the FMRI BOLD Response

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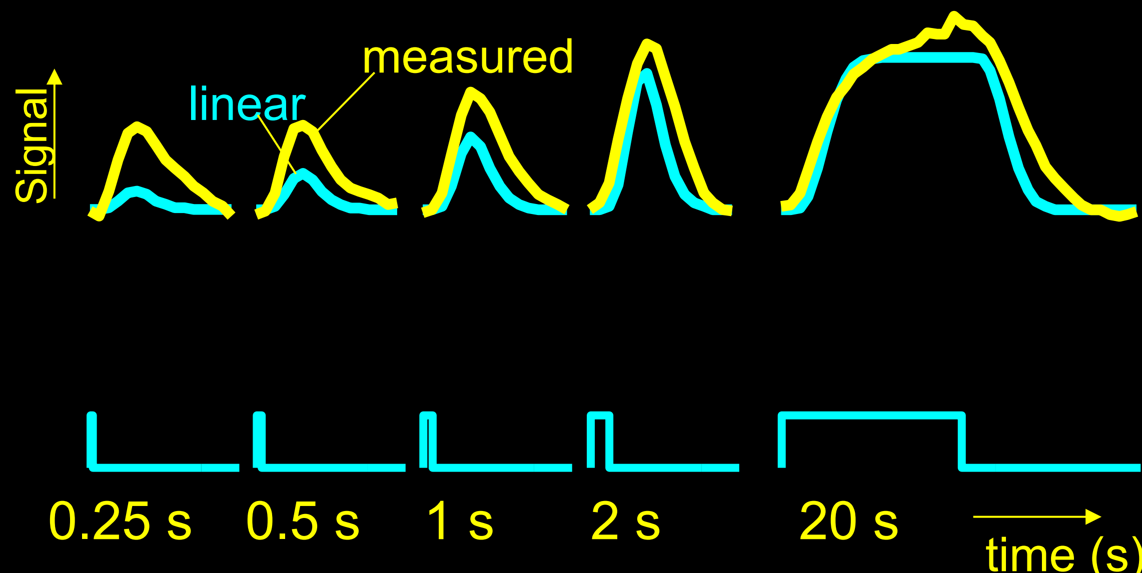
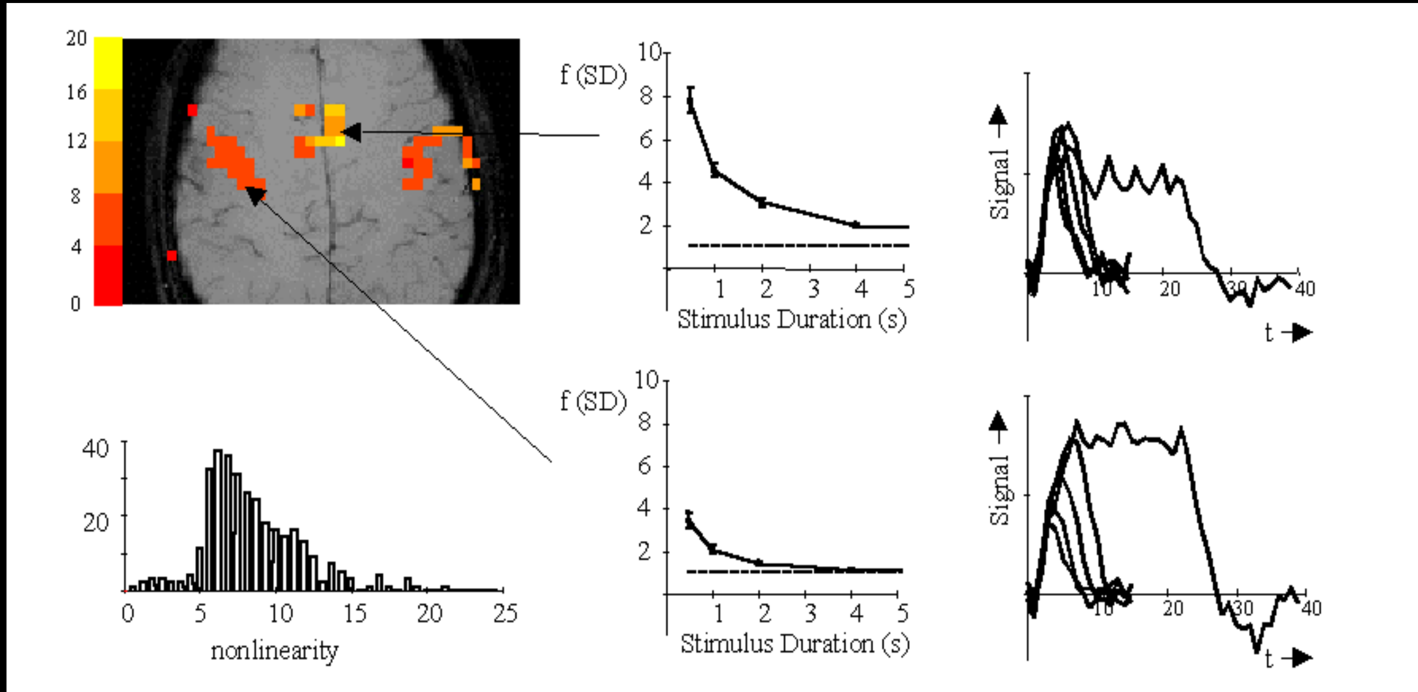
Received October 18, 2000

NeuroImage

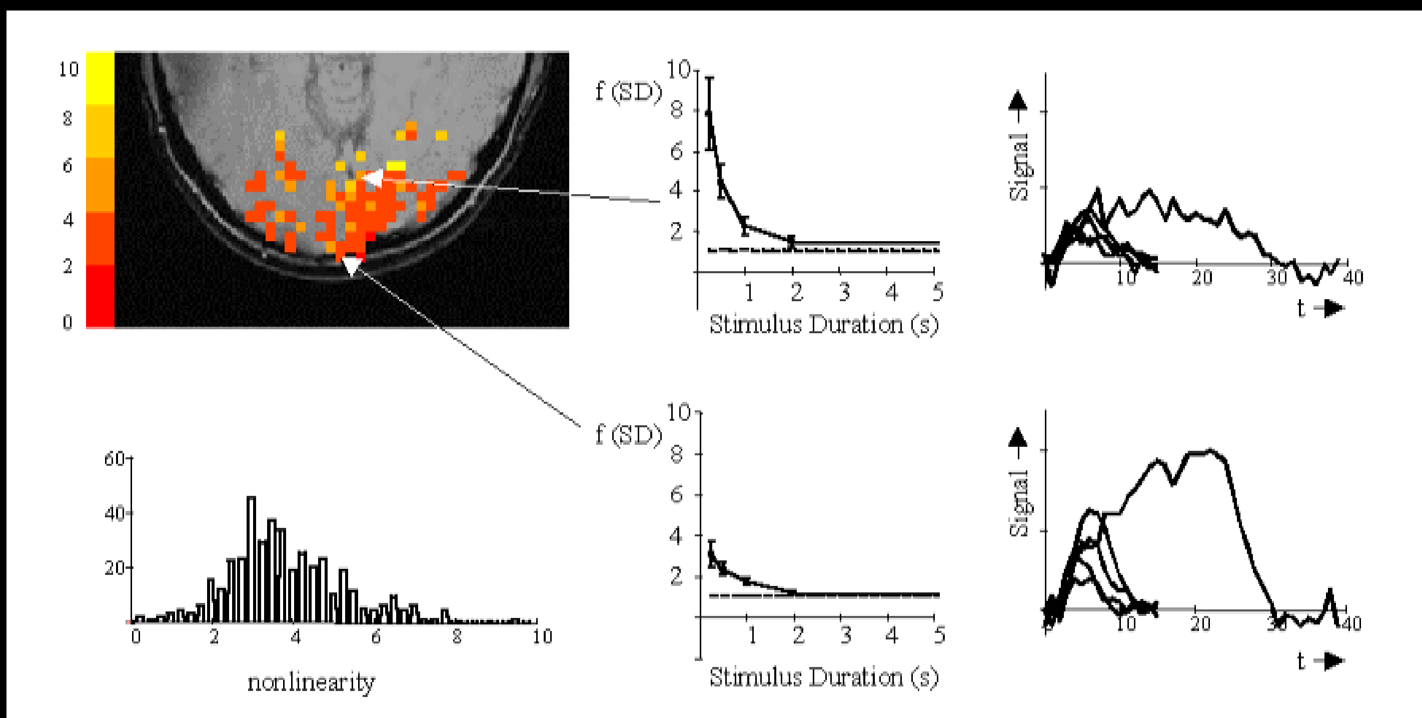
BOLD Response

Stimulus timing





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)
10
8
6
4
2
1 2 3 4 5
Stimulus Duration (s)
Signal
10 20 30 40
t

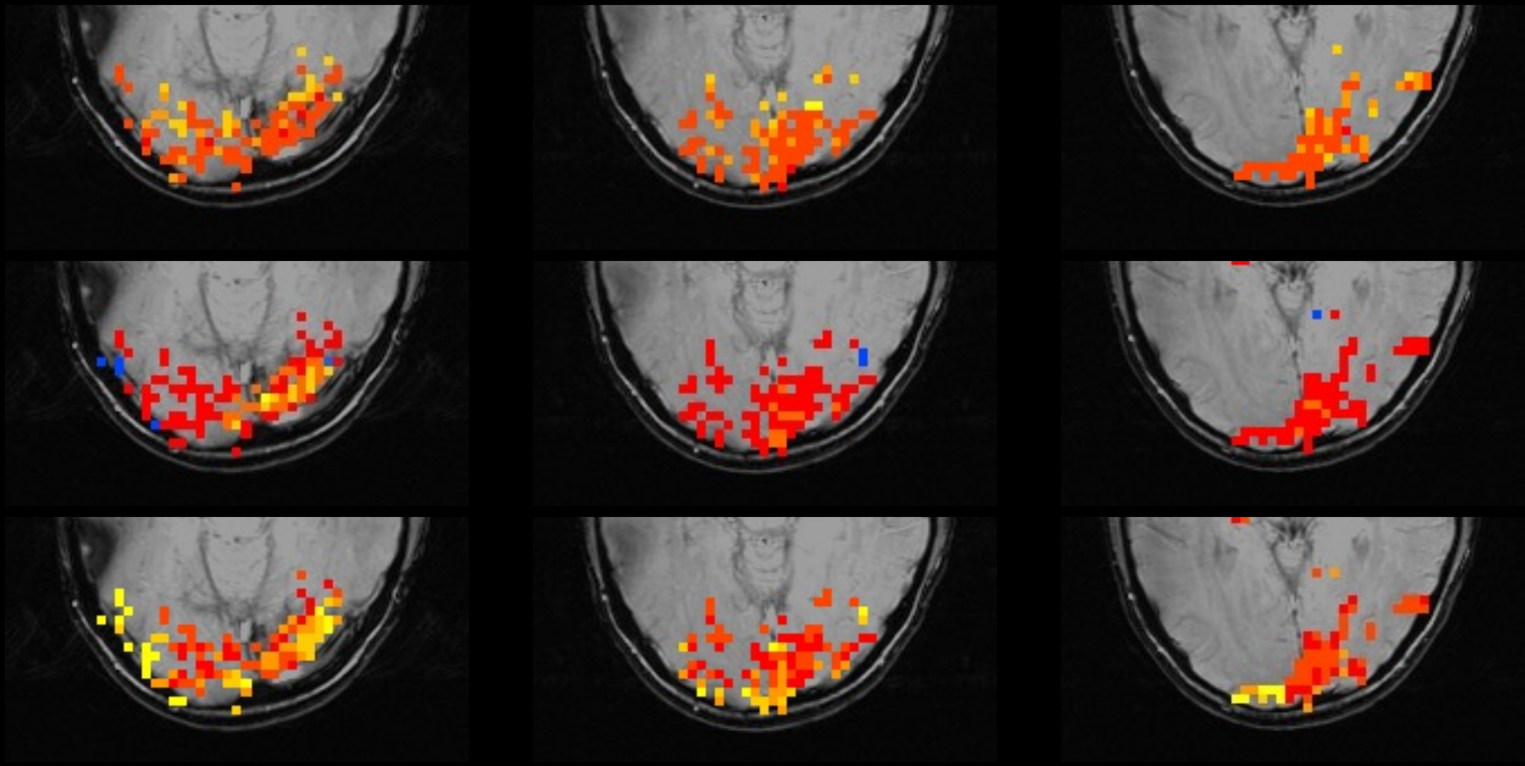
10
8
6
4
2
0
f (SD)
10
8
6
4
2
1 2 3 4 5
Stimulus Duration (s)
Signal
10 20 30 40
t
60
40
20
0 2 4 6 8 10
nonlinearity
f (SD)
10
8
6
4
2
1 2 3 4 5
Stimulus Duration (s)
Signal
10 20 30 40
t

# Hemodynamic Comparisons

Nonlinearity

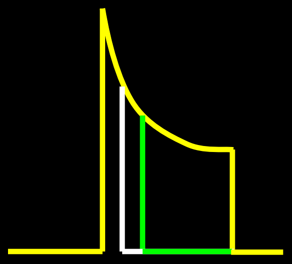
Magnitude

Latency

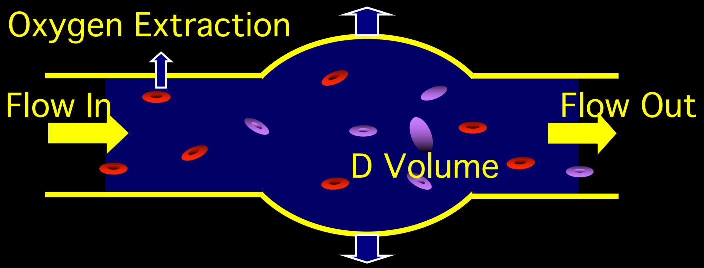


# Sources of this Nonlinearity

- Neuronal

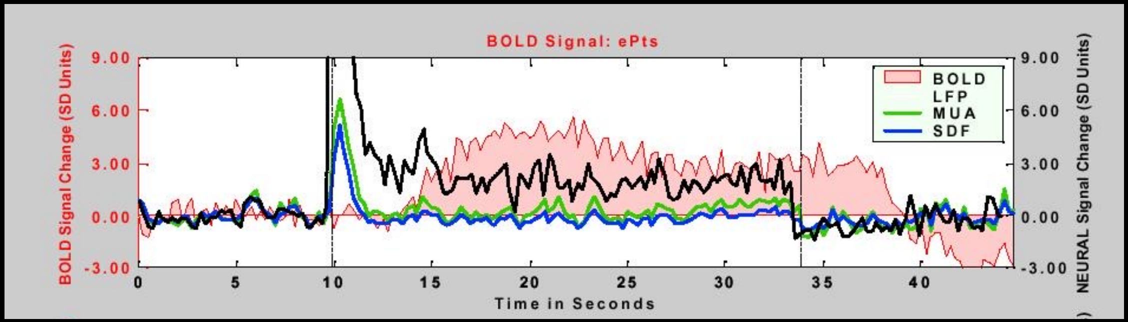


- Hemodynamic
  - Oxygen extraction
  - Blood volume dynamics

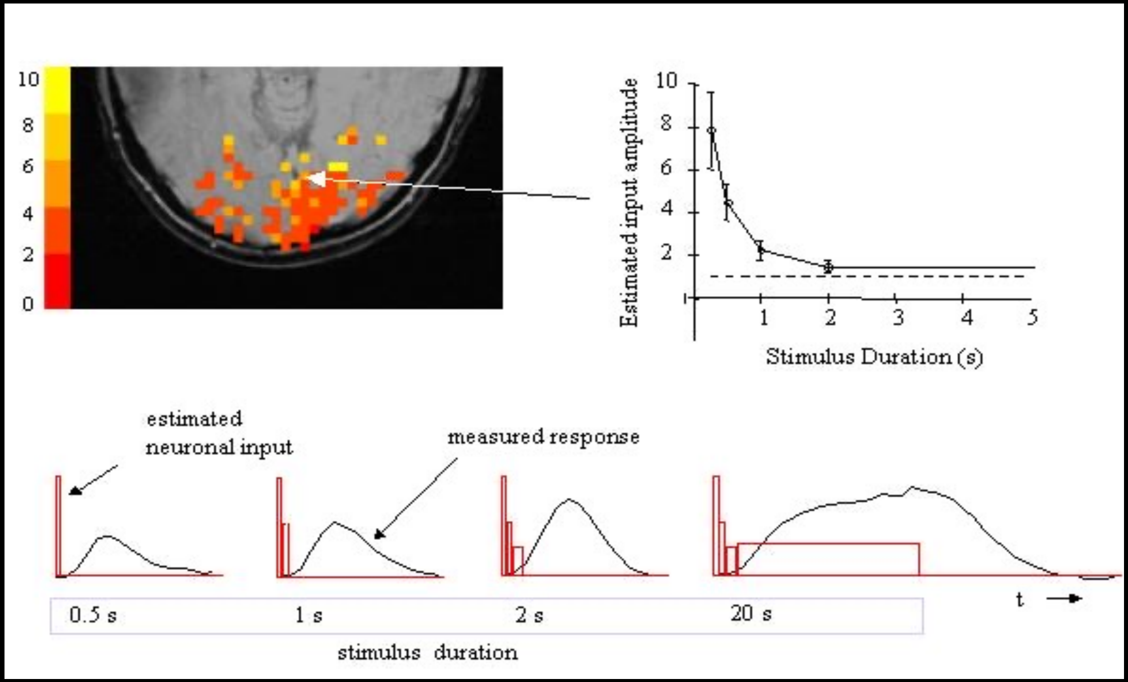


# BOLD Correlation with Neuronal Activity

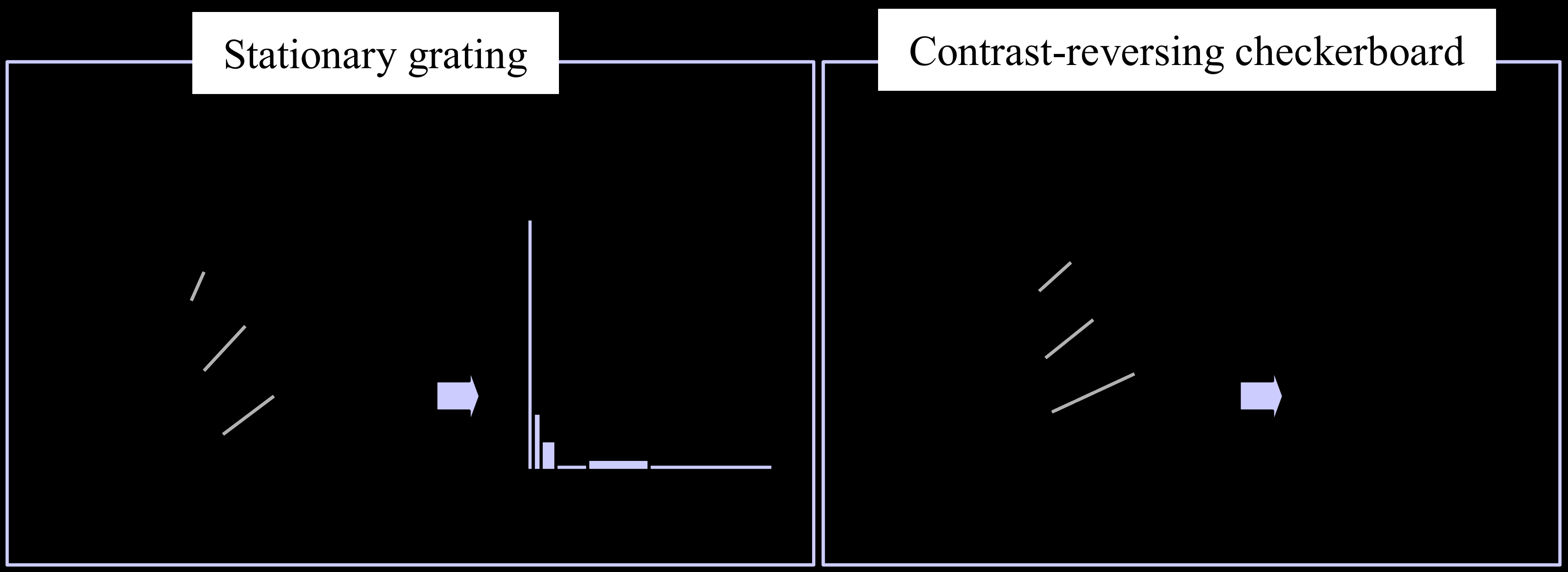
**Logothetis et al. (2001) "Neurophysiological investigation of the basis of the fMRI signal" Nature, 412, 150-157.**




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



## Ongoing work: Modulation of neuronal activation




**Planned work:**

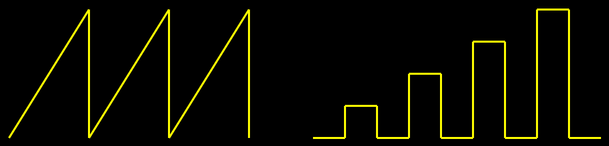
- Single unit monkey recordings with identical stimuli
- Identical experiments with MEG in humans

# Experimental
# Design, Execution, and Analysis

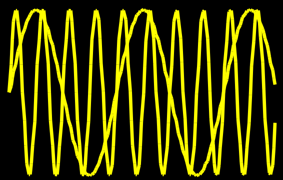
# Neuronal Activation Input Strategies

1. Block Design

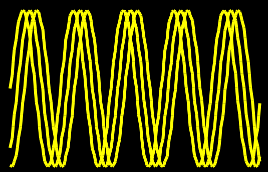
2. Parametric Design



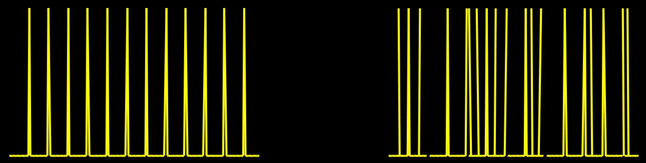
3. Frequency Encoding



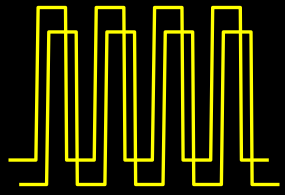
4. Phase Encoding



5. Event Related

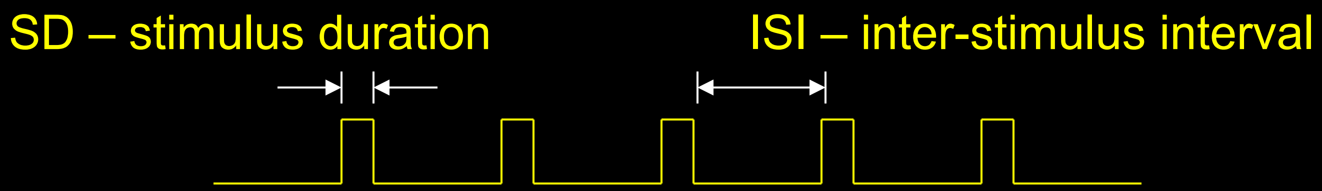


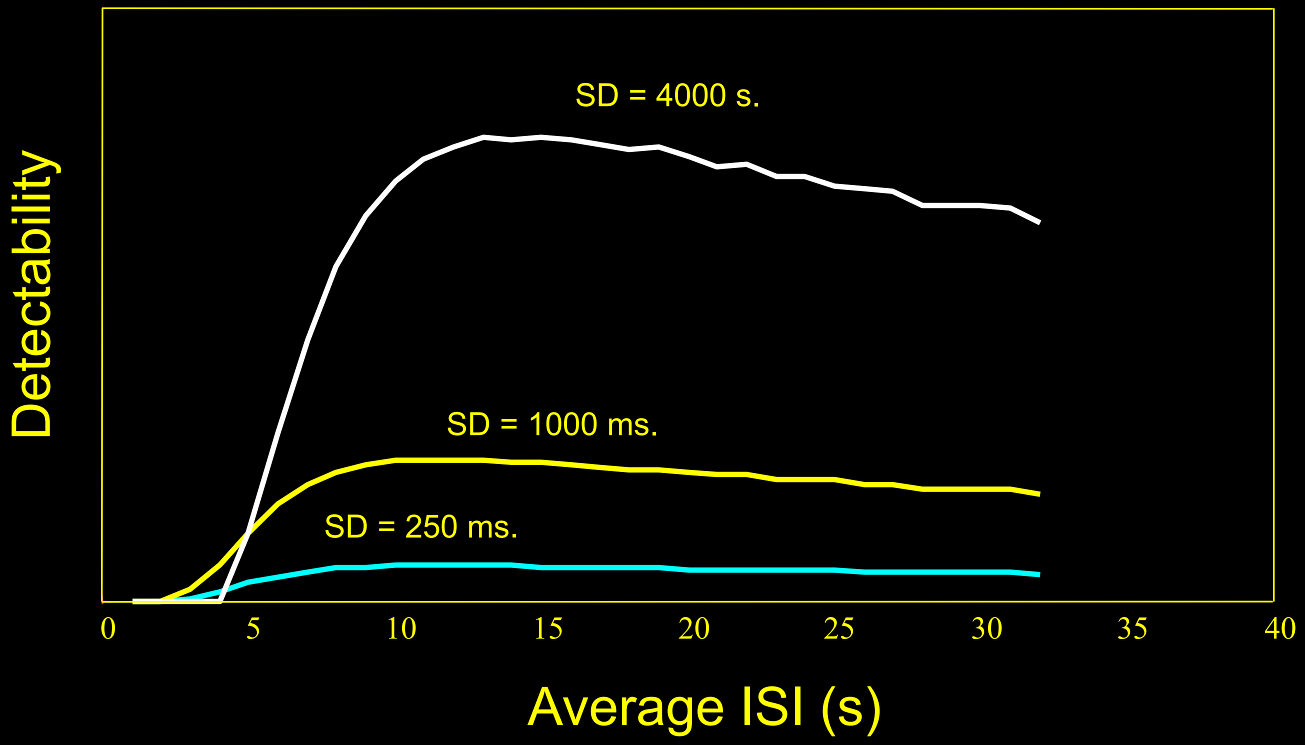
6. Orthogonal Design



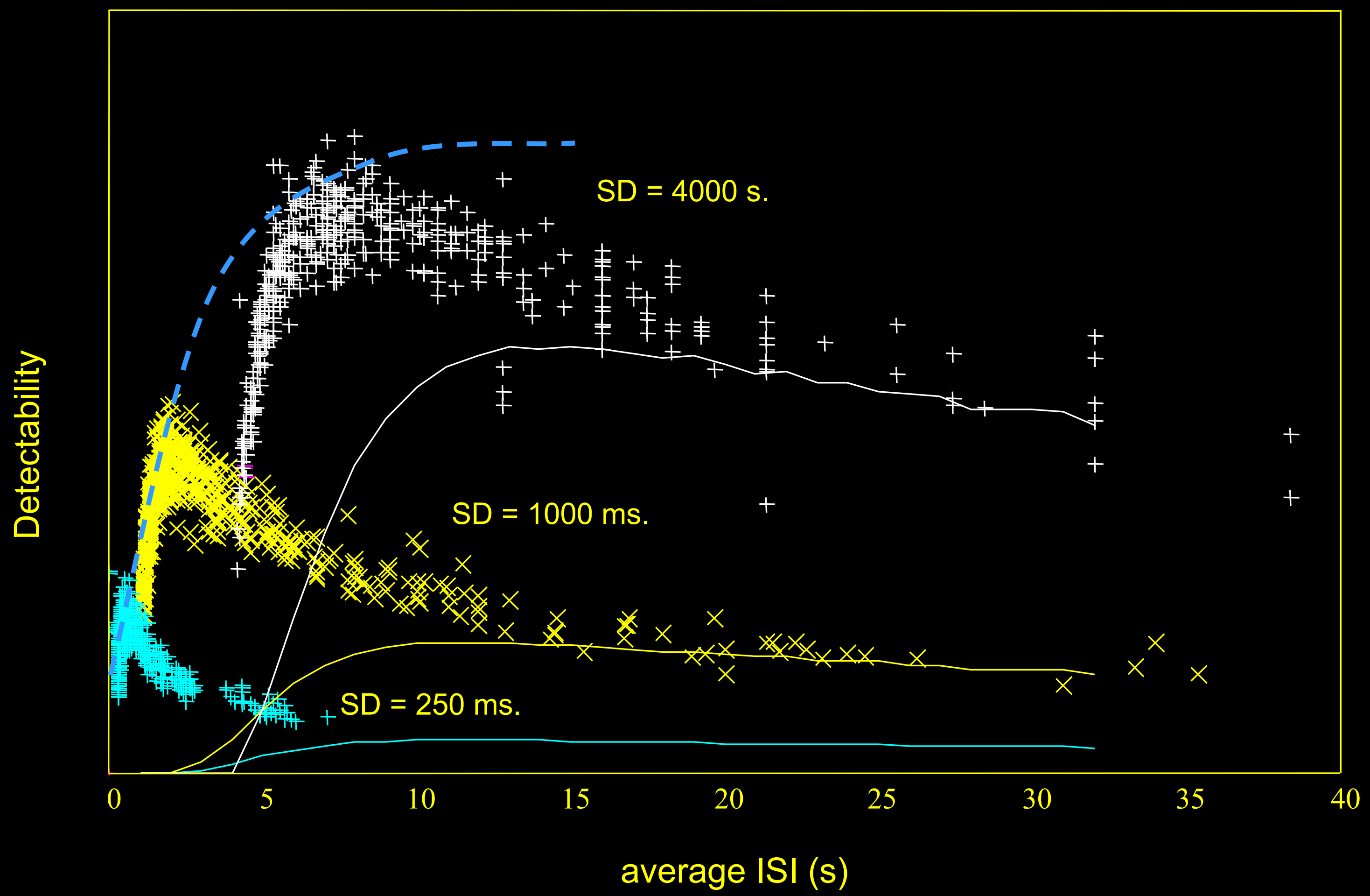
7. Free Behavior Design

# Detectability – constant ISI



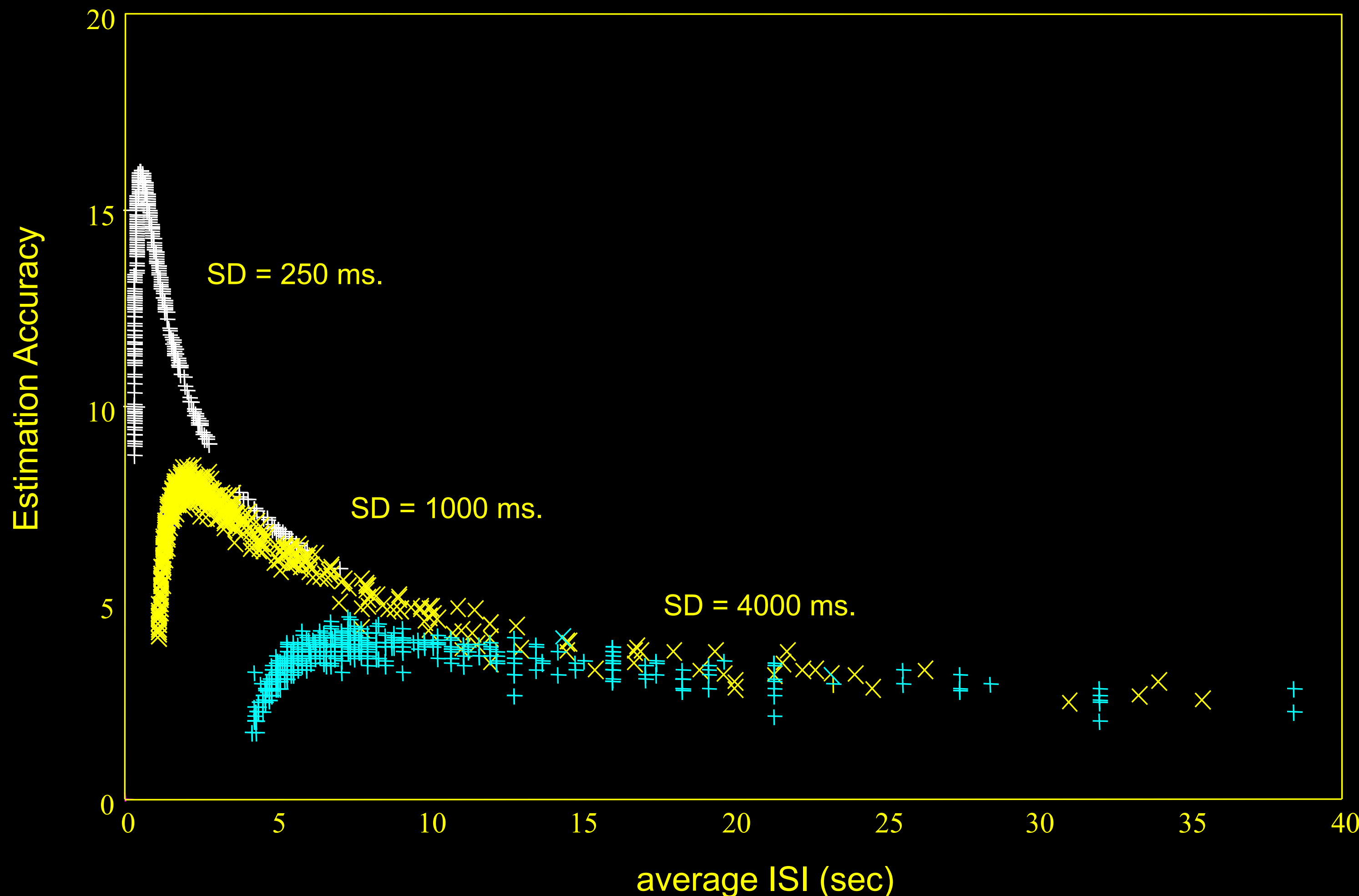



# Detectability vs. Average ISI




**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).**

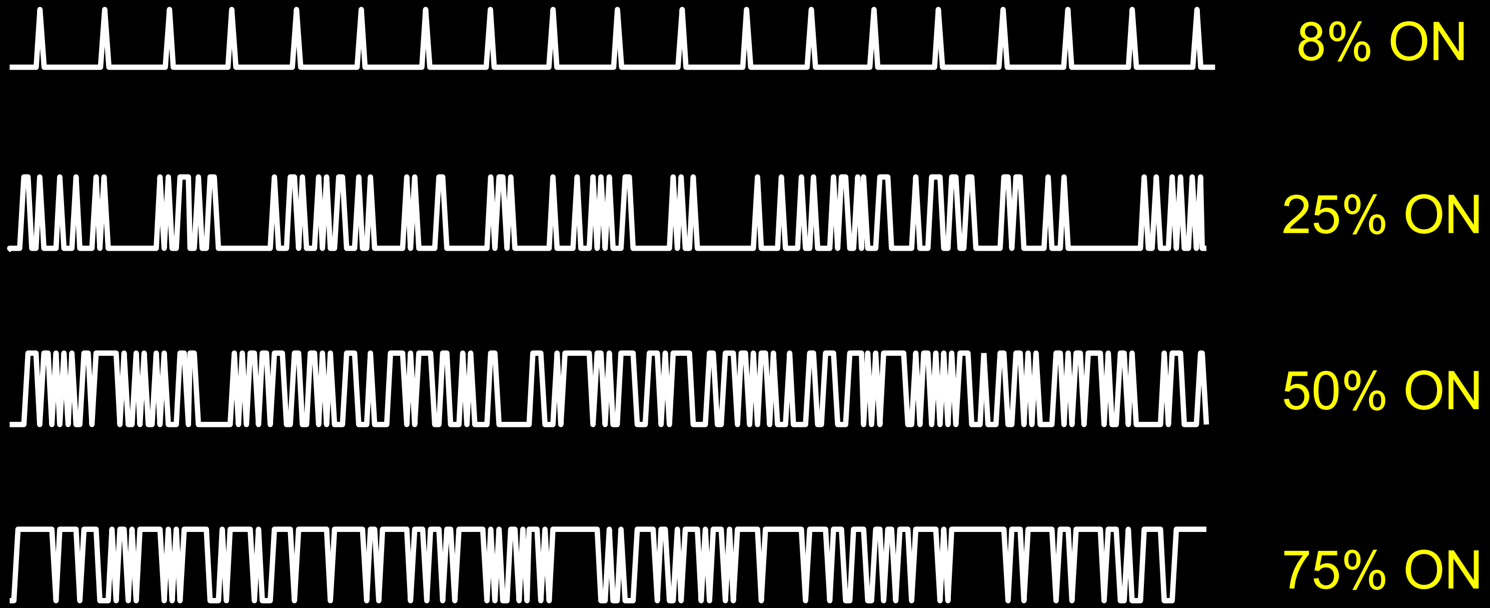
# Estimation accuracy vs. average ISI

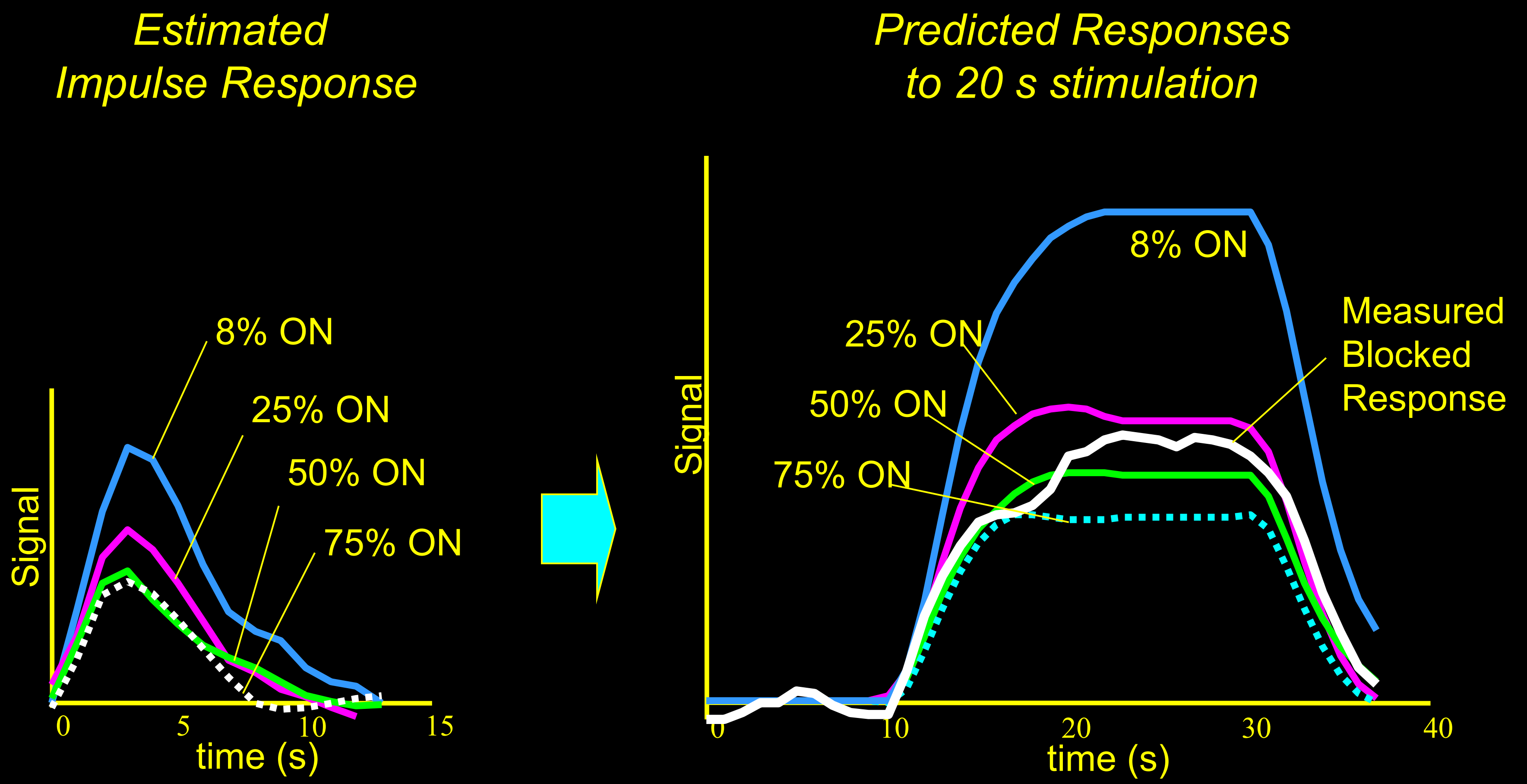



**R. M. Birn, R. W. Cox, P. A. Bandettini, Detection versus estimation in Event-Related fMRI: choosing the optimal stimulus timing. *NeuroImage* 15: 262-264, (2002).**

# A practical implication....

*Rapid event-related design with varying ISI*

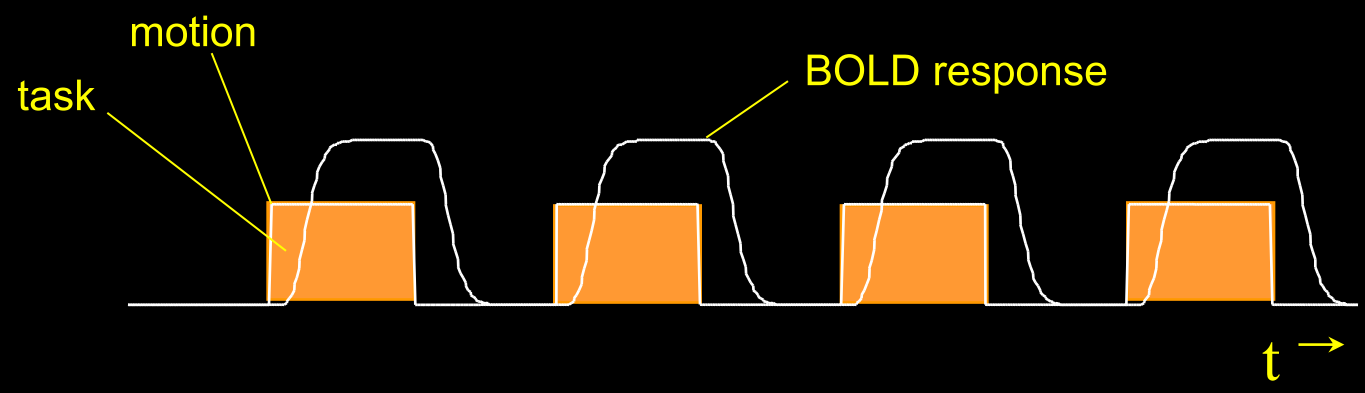




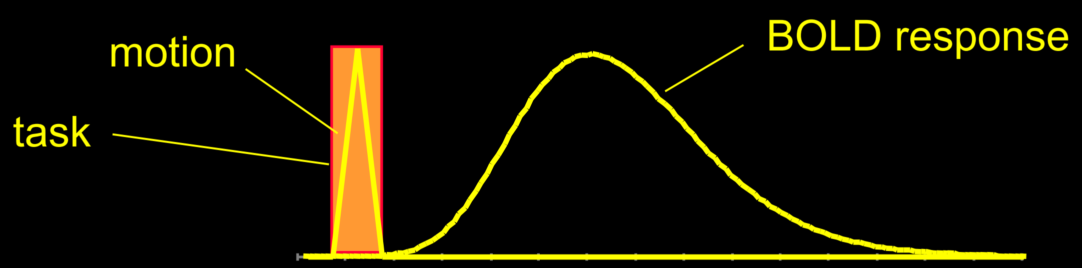
*Estimated Impulse Response*
8% ON
25% ON
50% ON
75% ON
Signal
0
5
10
15
time (s)
*Predicted Responses to 20 s stimulation*
8% ON
25% ON
50% ON
75% ON
Measured Blocked Response
Signal
0
10
20
30
40
time (s)

# fMRI during tasks that involve brief motion

## Blocked Design



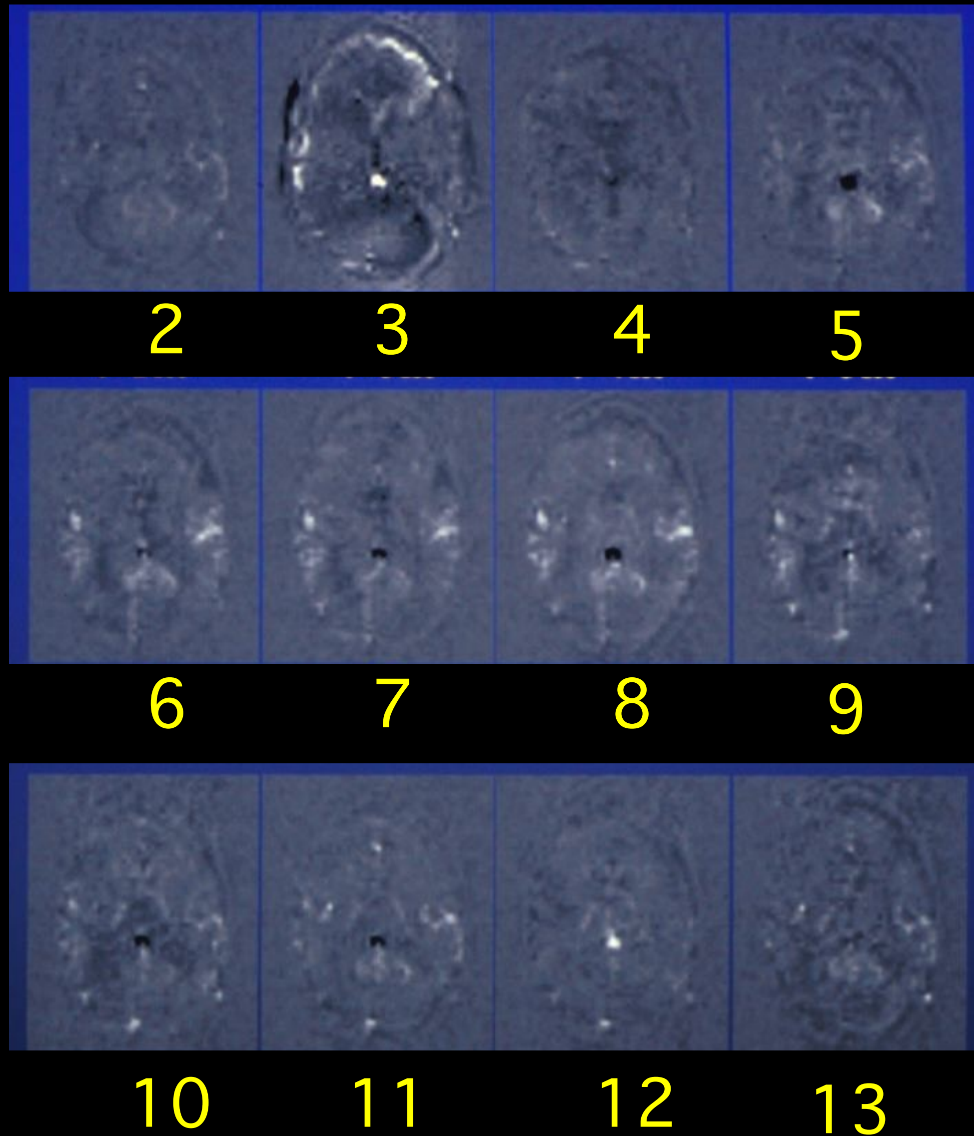

## Event-Related Design





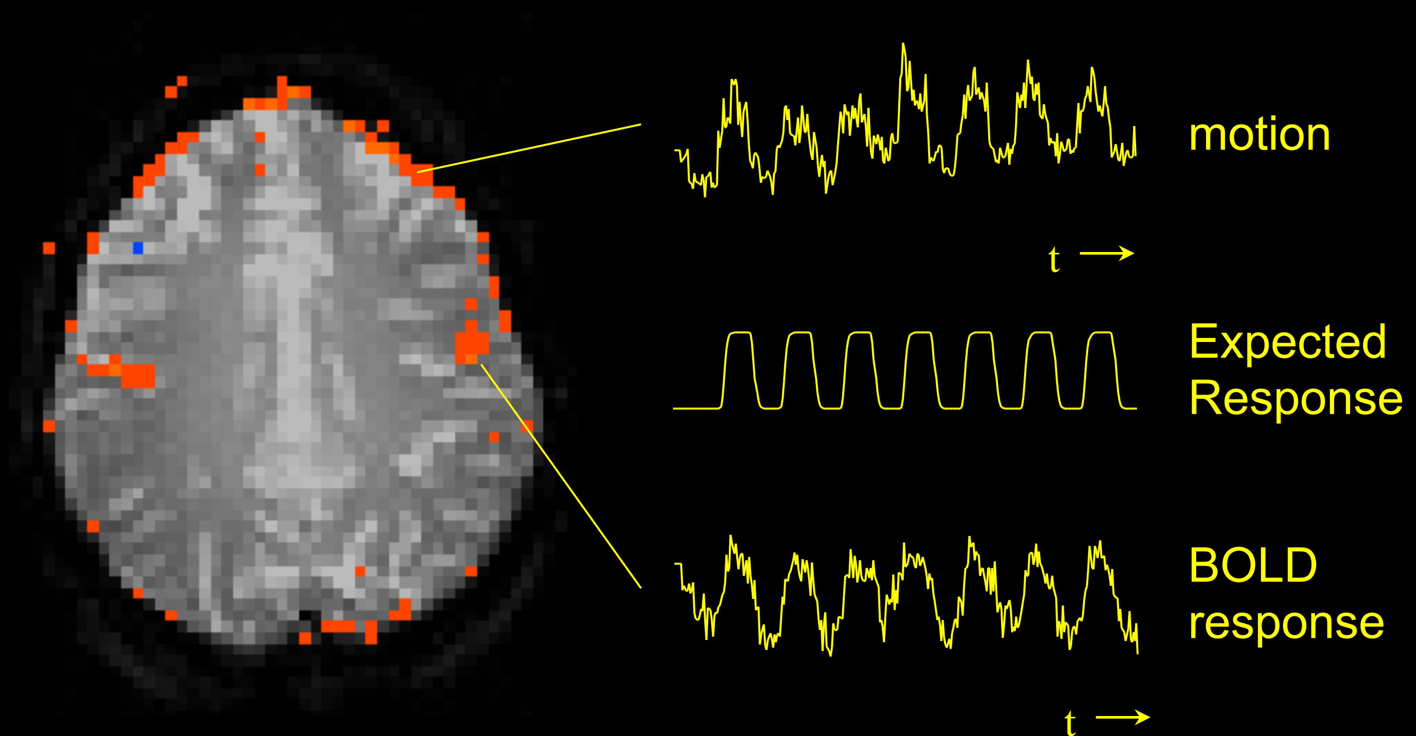
R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

# Overt Word Production



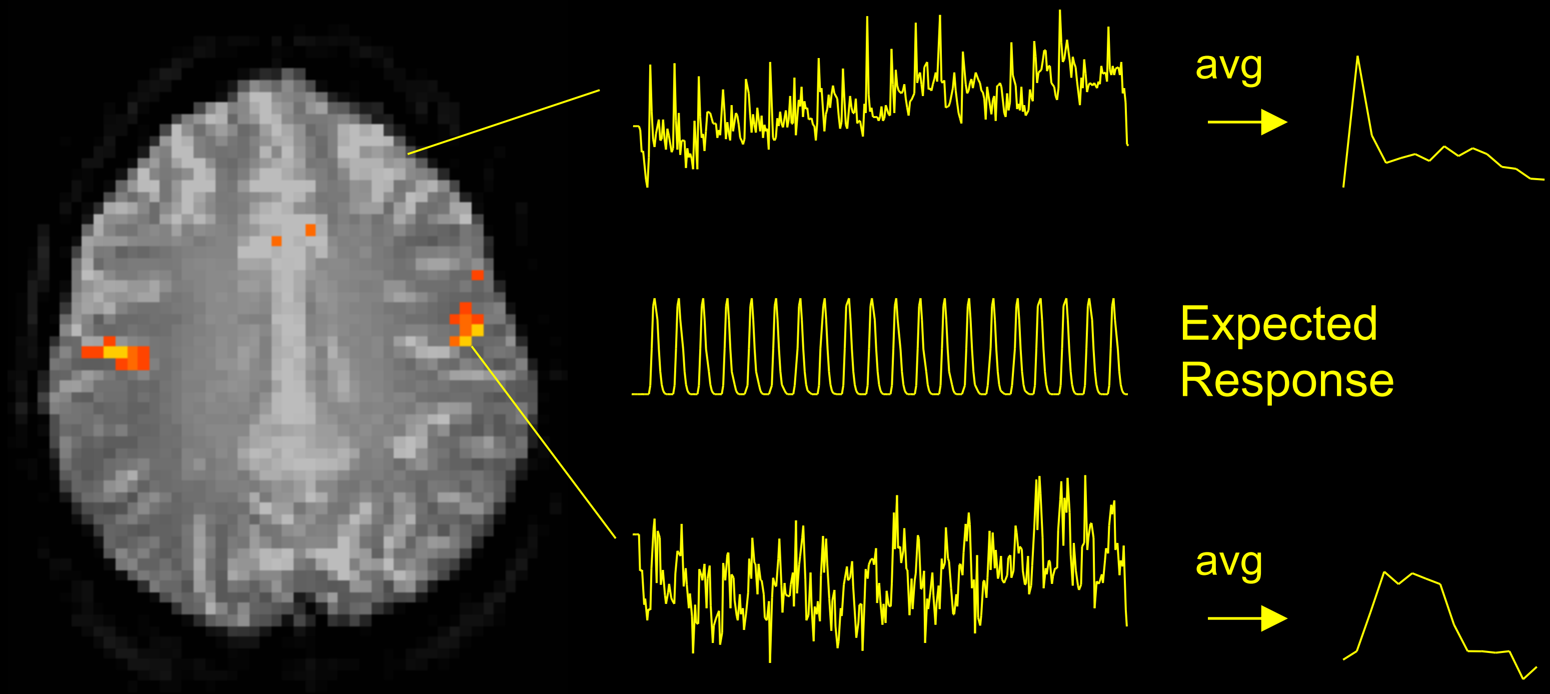

R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

# Speaking - Blocked Trial

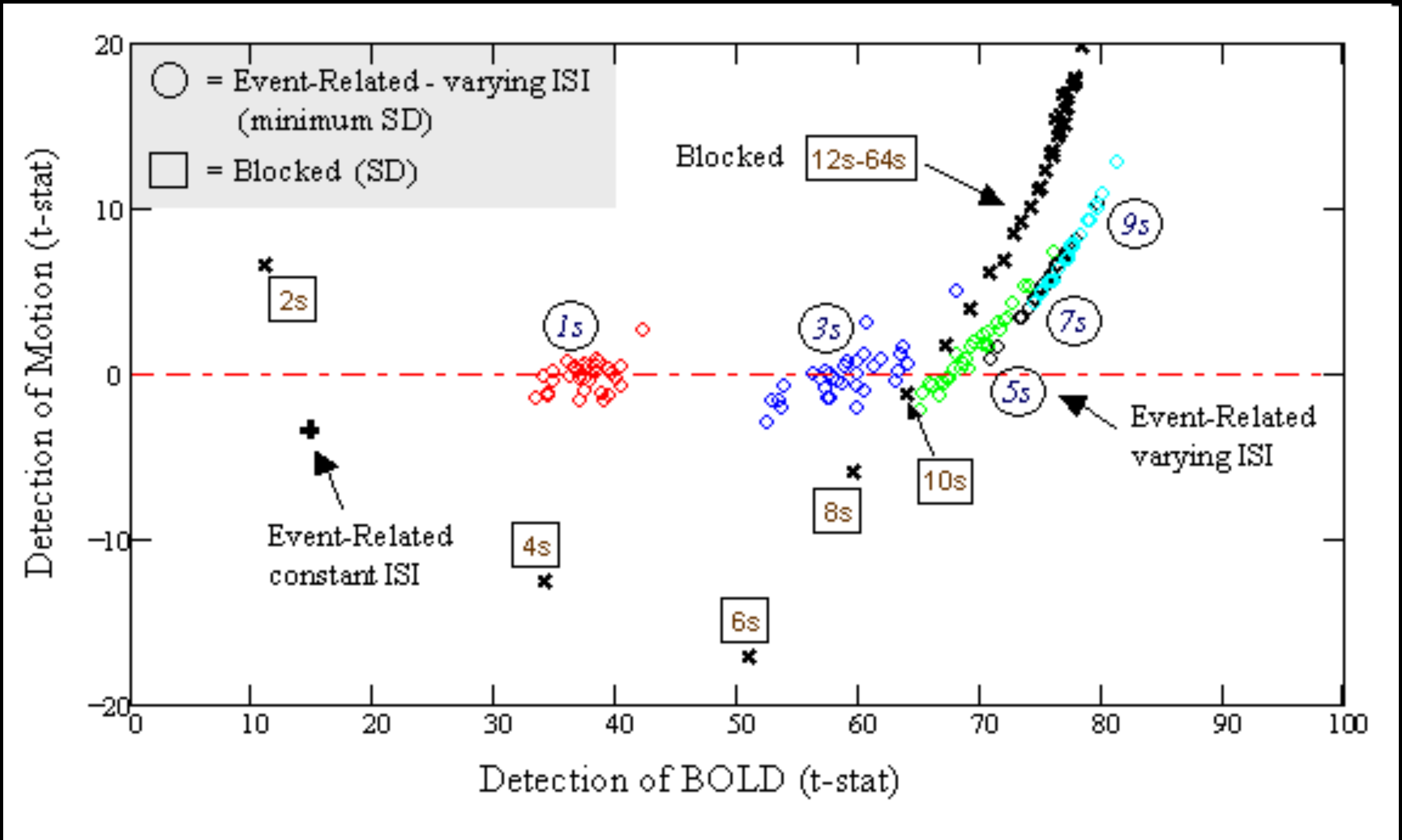



R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

# 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).



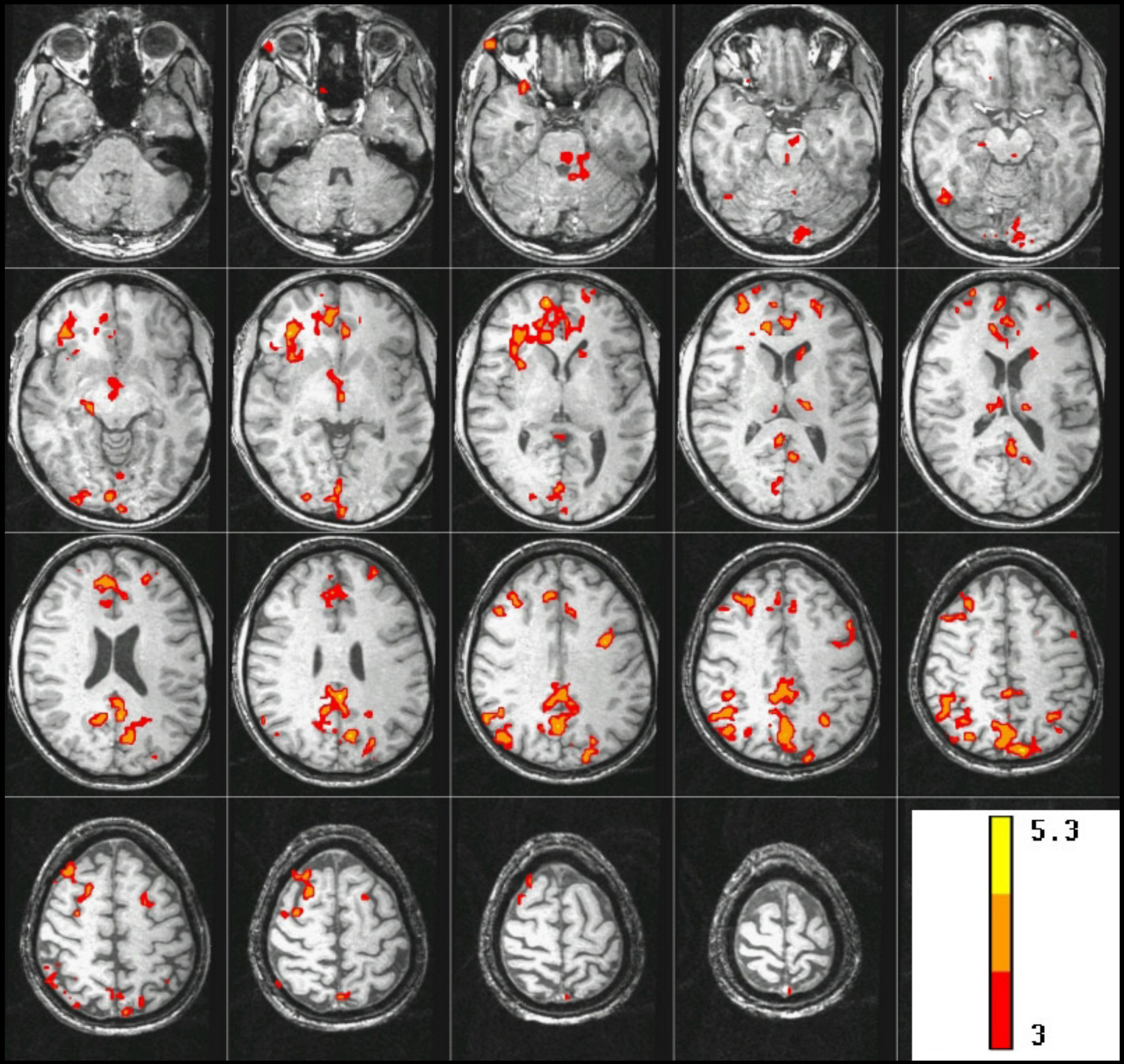
= Event-Related - varying ISI (minimum SD)
= Blocked (SD)
Blocked
12s-64s
9s
7s
5s
3s
1s
2s
4s
6s
8s
10s
Event-Related varying ISI
Event-Related constant ISI
Detection of Motion (t-stat)
Detection of BOLD (t-stat)
20
10
0
-10
-20
0
10
20
30
40
50
60
70
80
90
100

# Free Behavior Design

Use a continuous measure as a reference function:

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

# Brain activity correlated with SCR during "Rest"

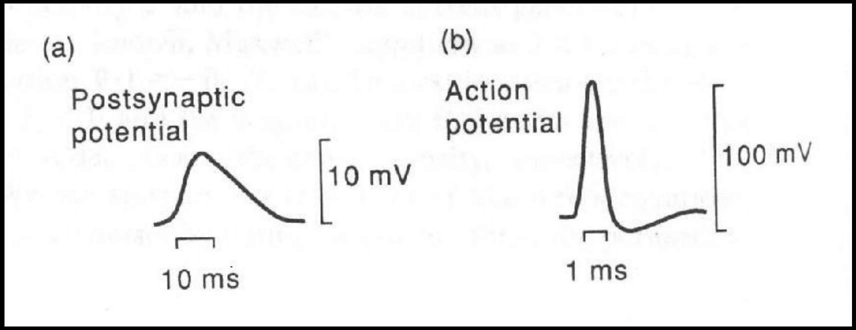


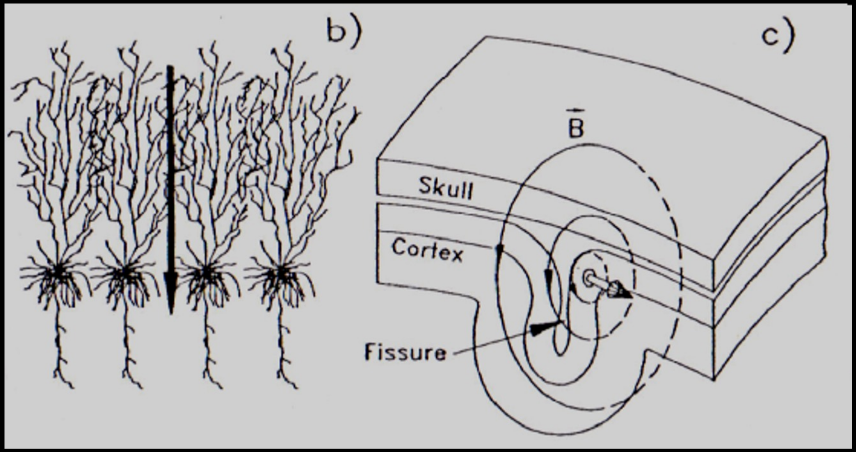

J. C. Patterson II, L. G. Ungerleider, and P. A Bandettini, Task - independent functional brain activity correlation with skin conductance changes: an fMRI study. *NeuroImage*, **17**: 1787-1806, (2002).

## New Contrast?

# Neuronal Current Imaging

# The Basic Idea...




100 fT at on surface of skull

J.P. Wikswo Jr et al. *J Clin Neuronphy* 8(2): 170-188, 1991

# Derivation of B field generated in an MRI voxel by a current dipole

Single dendritic tree having a diameter d, and length L behaves like a conductor with conductivity $\sigma$. Resistance is R=V/I, where $R=4L/(\pi d^2 \sigma)$. From Biot-Savart:

$$B = \frac{\mu_0}{4\pi}\frac{Q}{r^2} = \frac{\mu_0}{16}\frac{d^2 \sigma V}{r^2}$$

by substituting d = 4$\mu$m, $\sigma \approx 0.25\ \Omega^{-1}\ m^{-1}$, V = 10mV and

r = 4cm (measurement distance when using MEG) the resulting value is: **B≈0.002 fT**

Because **$B_{MEG}$=100fT** is measured by MEG on the scalp, (0.002 fT x 50,000 = 100 fT), must coherently act to generate such field. These bundles of neurons produce, within a typical voxel, 1 mm x 1 mm x 1 mm, a field of order:

$$B_{MRI} = B_{MEG}\left(\frac{r_{MEG}}{r_{MRI}}\right)^2 = B_{MEG}\left(\frac{4\,cm}{0.1\,cm}\right)^2 = 1600\,B_{MEG}$$

**$B_{MRI} \approx$0.2nT**

**J. Bodurka, P. A. Bandettini.** *Toward direct mapping of neuronal activity: MRI detection of ultra weak transient magnetic field changes.* **Magn. Reson. Med. 47: 1052-1058, (2002).**

# Some background...

**G. C. Scott, M. L. Joy, R. L. Armstrong, R. M. Henkelman,** *RF current density imaging homogeneous media.* **Magn. Reson. Med. 28: 186-201, (1992).**

**M. Singh,** *Sensitivity of MR phase shift to detect evoked neuromagnetic fields inside the head.* **IEEE Transactions on Nuclear Science. 41: 349-351, (1994).**

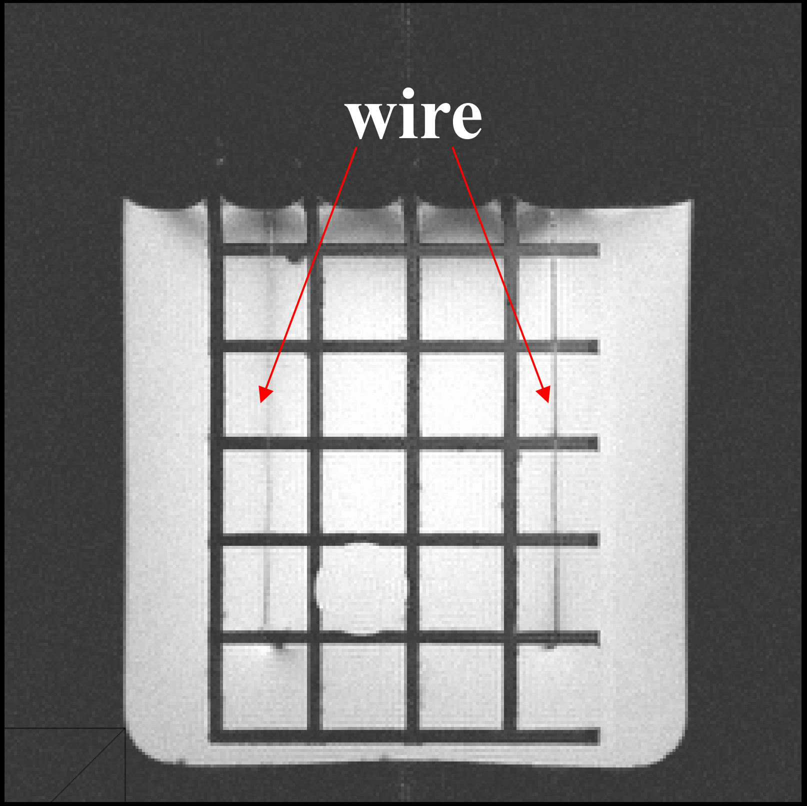
**H. Kamei, J, Iramina, K. Yoshikawa, S. Ueno,** *Neuronal current distribution imaging using MR.* **IEEE Trans. On Magnetics, 35: 4109-4111, (1999)**

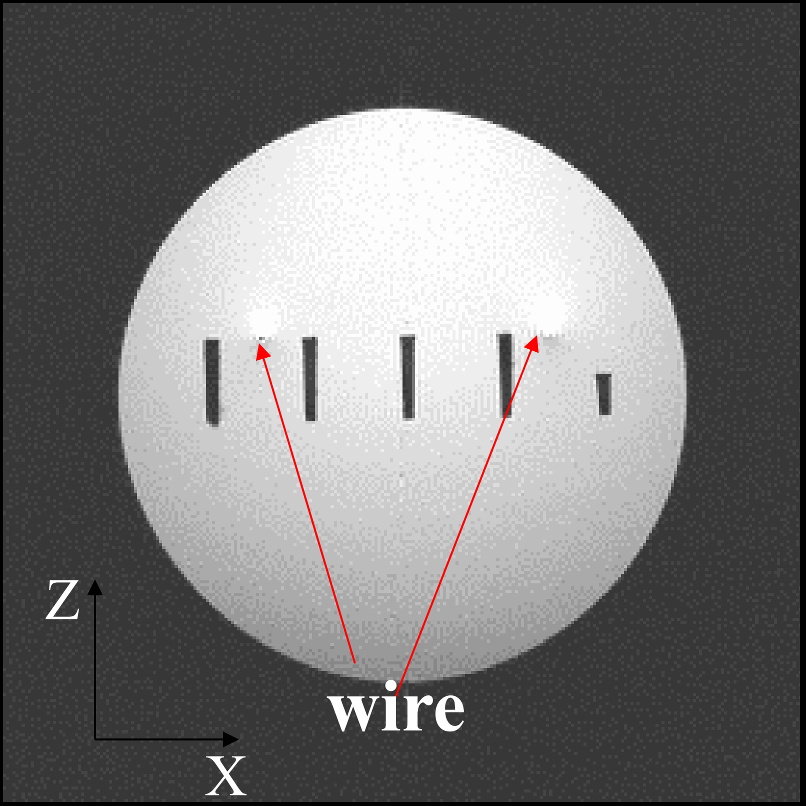
**J. Bodurka, P. A. Bandettini.** *Toward direct mapping of neuronal activity: MRI detection of ultra weak transient magnetic field changes.* **Magn. Reson. Med. 47: 1052-1058, (2002).**

**D. Konn, P. Gowland, R. Bowtell,** *MRI detection of weak magnetic fields due to an extended current dipole in a conducting sphere: a model for direct detection of neuronal currents in the brain.* **Magn. Reson. Med. 50: 40-49, (2003).**

**J. Xiong, P. T. Fox, J.-H. Gao,** *Direct MRI Mapping of neuronal activity.* **Human Brain Mapping, 20: 41-49, (2003)**

# Current Phantom Experiment

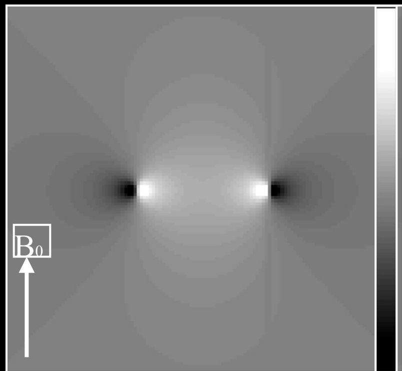


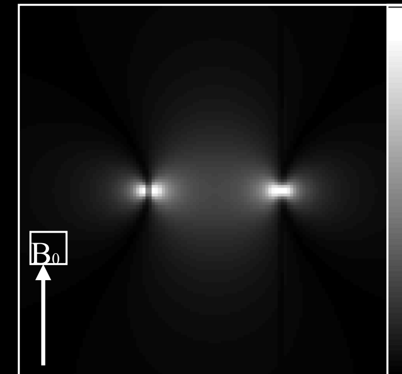



calculated $B_c$ || $B_0$

# Simulation

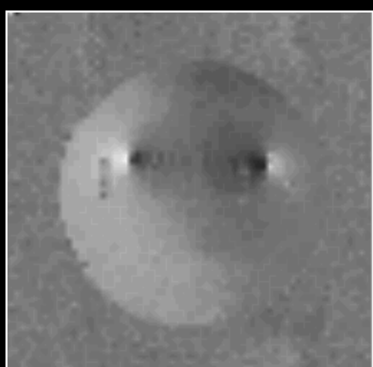
calculated $|\Delta B_c|$ || $B_0$



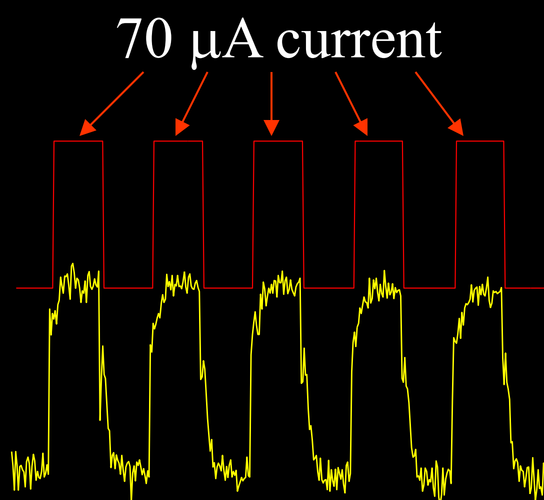



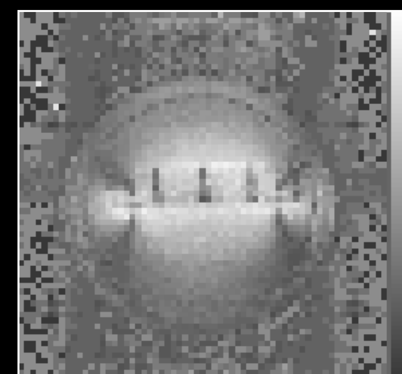

# Measurement

$\Delta\phi \cong 20^0$



Correlation image

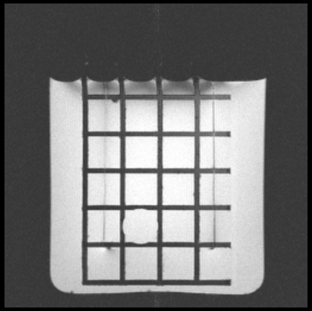


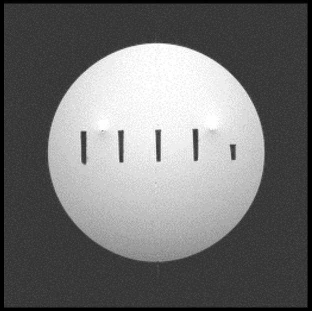



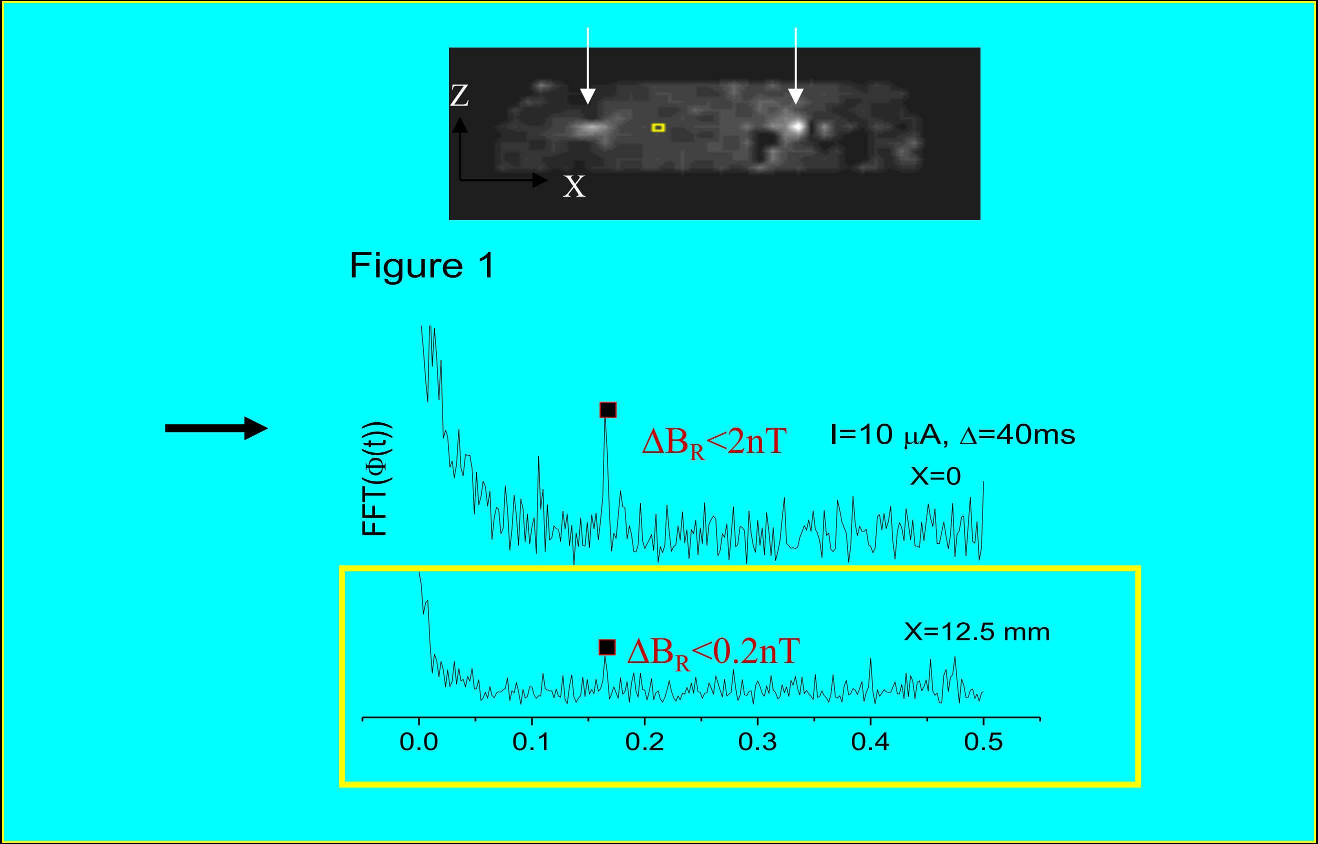
Spectral image

Single shot GE EPI

**J. Bodurka, P. A. Bandettini. Toward direct mapping of neuronal activity: MRI detection of ultra weak transient magnetic field changes, Magn. Reson. Med. 47: 1052-1058, (2002).**

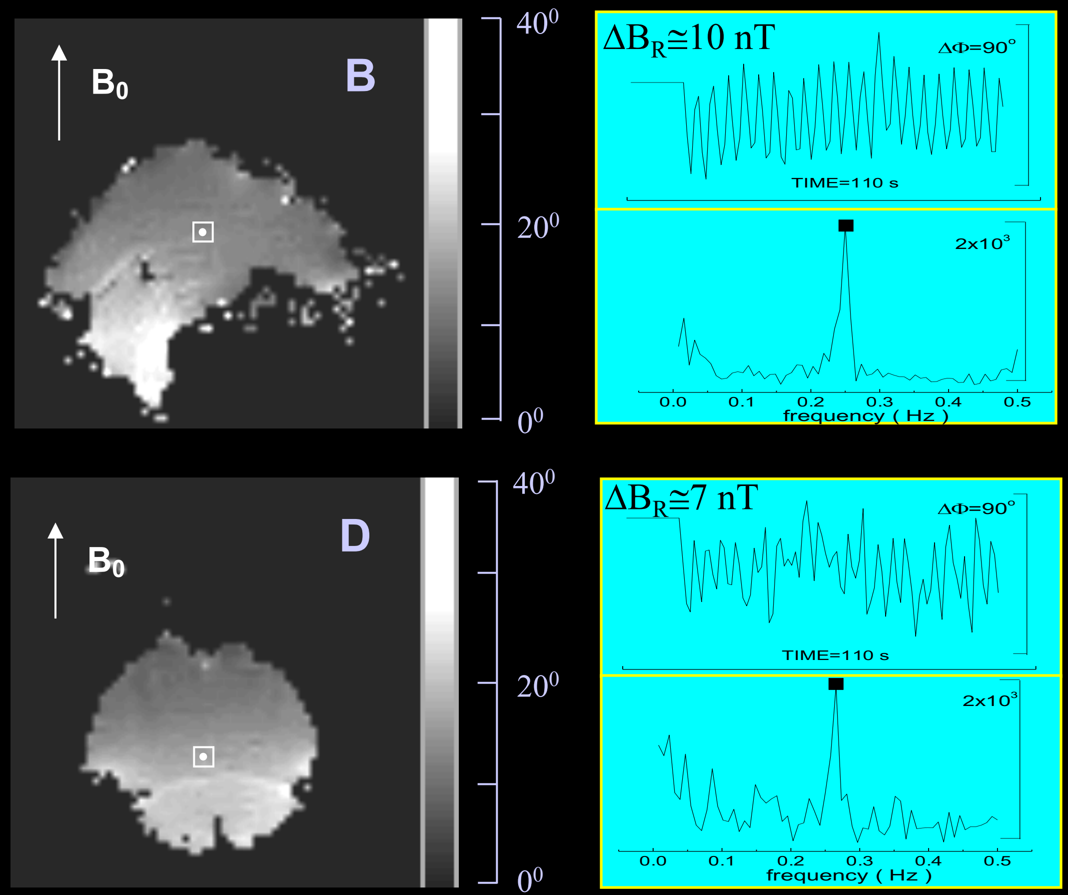




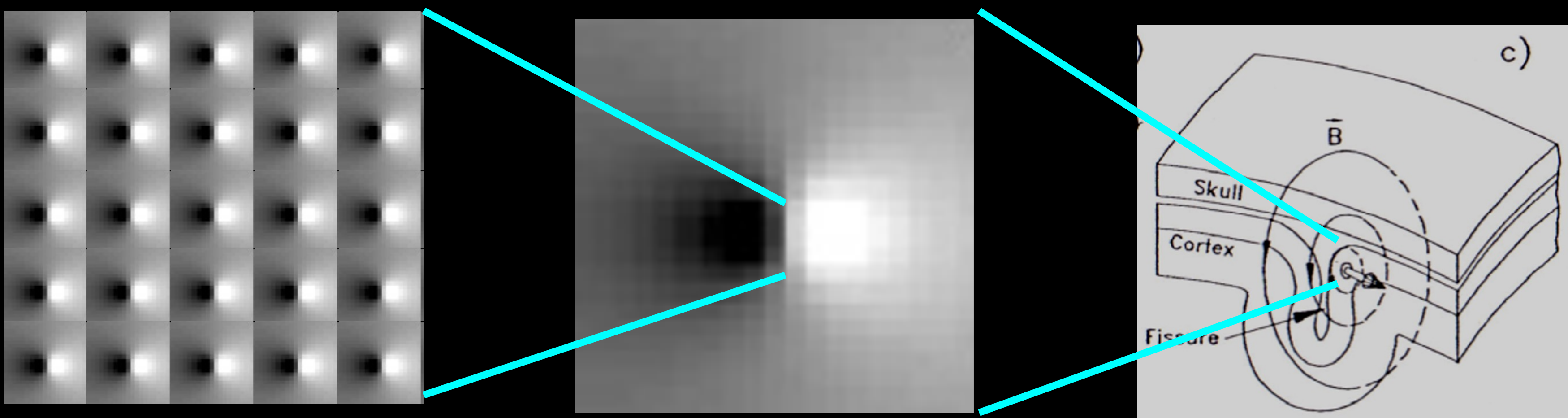



**J. Bodurka, P. A. Bandettini. Toward direct mapping of neuronal activity: MRI detection of ultra weak transient magnetic field changes, Magn. Reson. Med. 47: 1052-1058, (2002).**

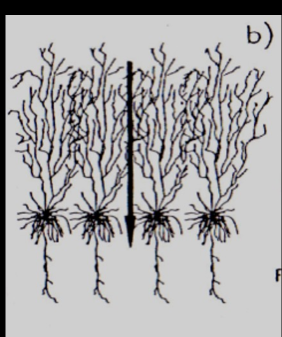
# Human Respiration



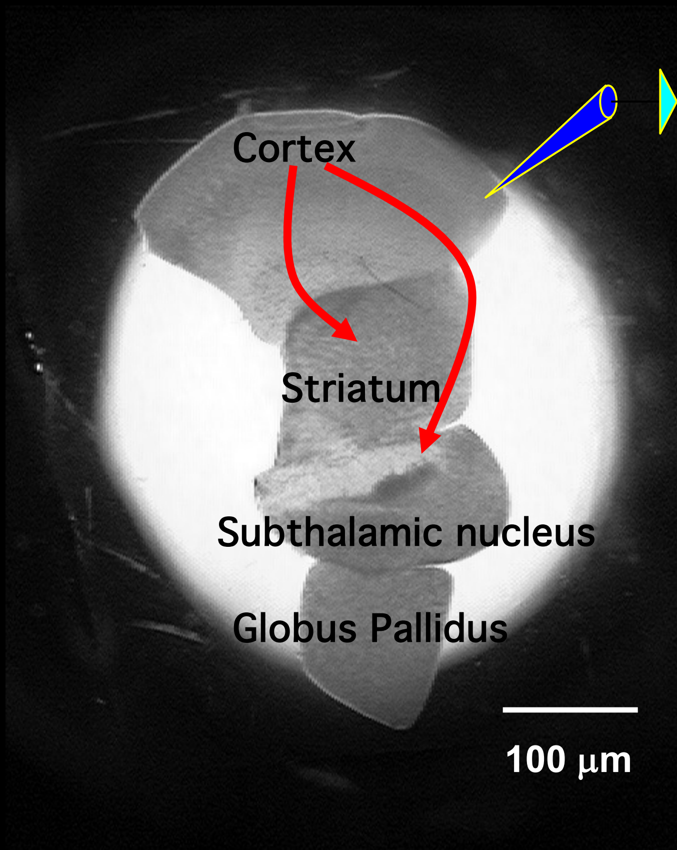
# Phase vs. Magnitude Detection...



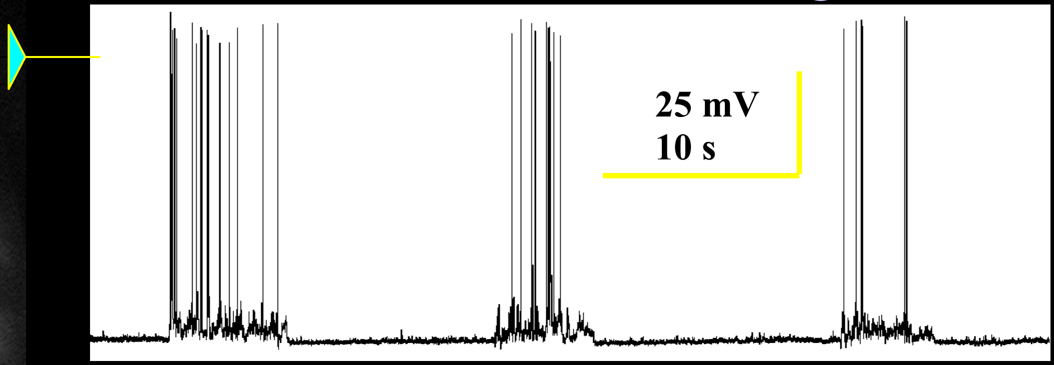

0.1 to 0.3 Deg.



# in vitro model




Patch electrode recording



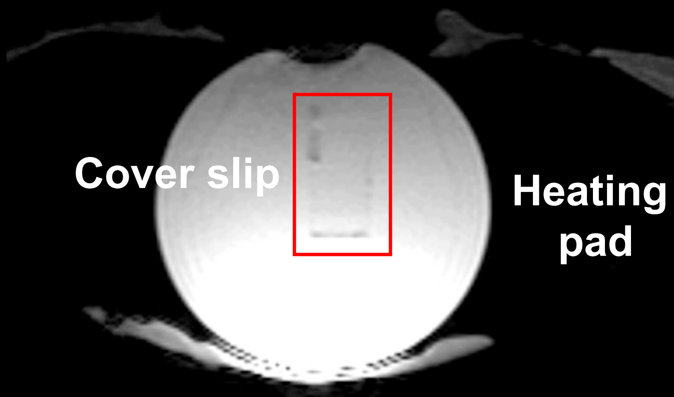

•coronal sections of newborn-rat brains ; in-plane:~1mm$^2$, thickness: ~60-100 μm

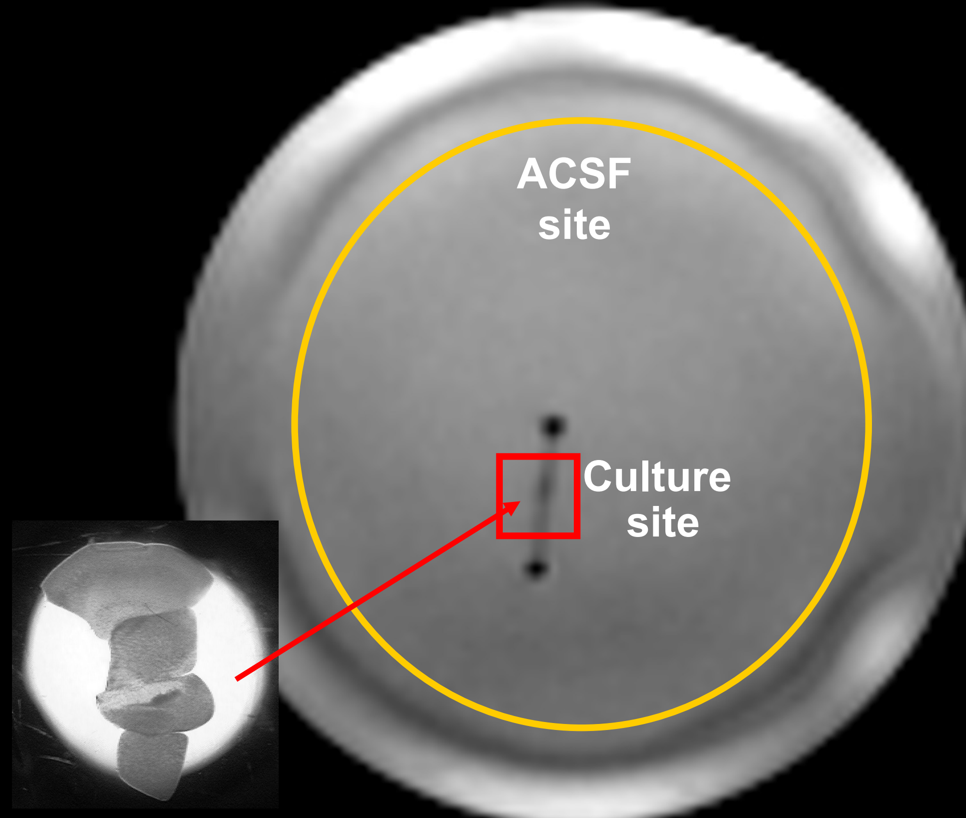
Neuronal Population: 10,000-50,000

- Spontaneous synchronized activity ; current: ~ 180nA-2μA, ΔB: ~ 60pT-0.5nT

Plenz, D. and S.T. Kital. Nature, 1999. **400**: p. 677-682.

# methods - *imaging*




*Imaging*

- 3T, Surface coil receive
- FSE structural images (256x256)
- SE EPI single shot, TE: 60ms, TR:1s, flip angle: $90^0$,

  FOV: 18cm, matrix: 64x64, 4 slices (3mm)

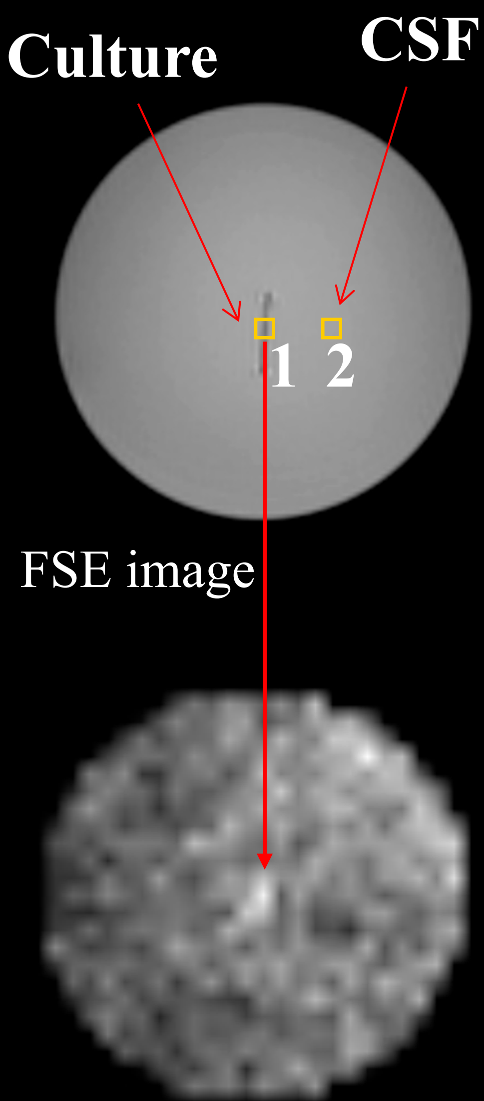
## methods - *imaging*

**Six Experiments**

**two conditions per experiment**

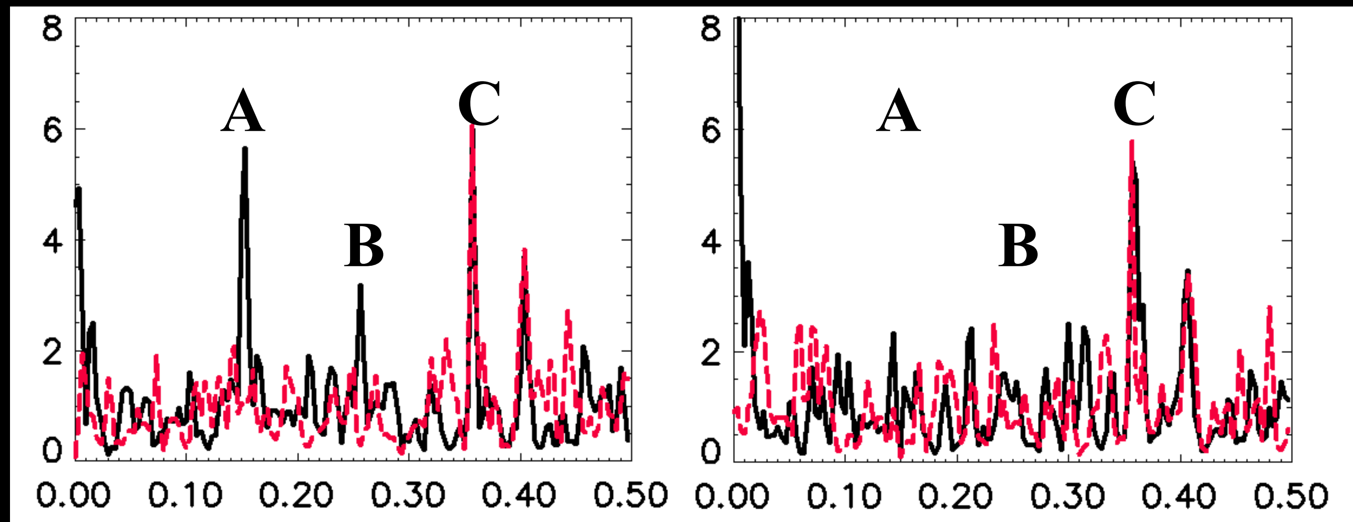
| **Active** | **Inactive** |
|---|---|
| **600 images** | **600 images** |
| **neuronal activity present** | **neuronal activity terminated via TTX administration** |

# results




0.15Hz map

*1: culture* | *2: CSF*




**Active condition: black line**
**Inactive condition: red line**

**A: 0.15 Hz activity, on/off frequency**
**B: activity**
**C: scanner noise (cooling-pump)**

# Strategies for Detection

- Time shifted sampling
- Under sampling

# Time shifted sampling

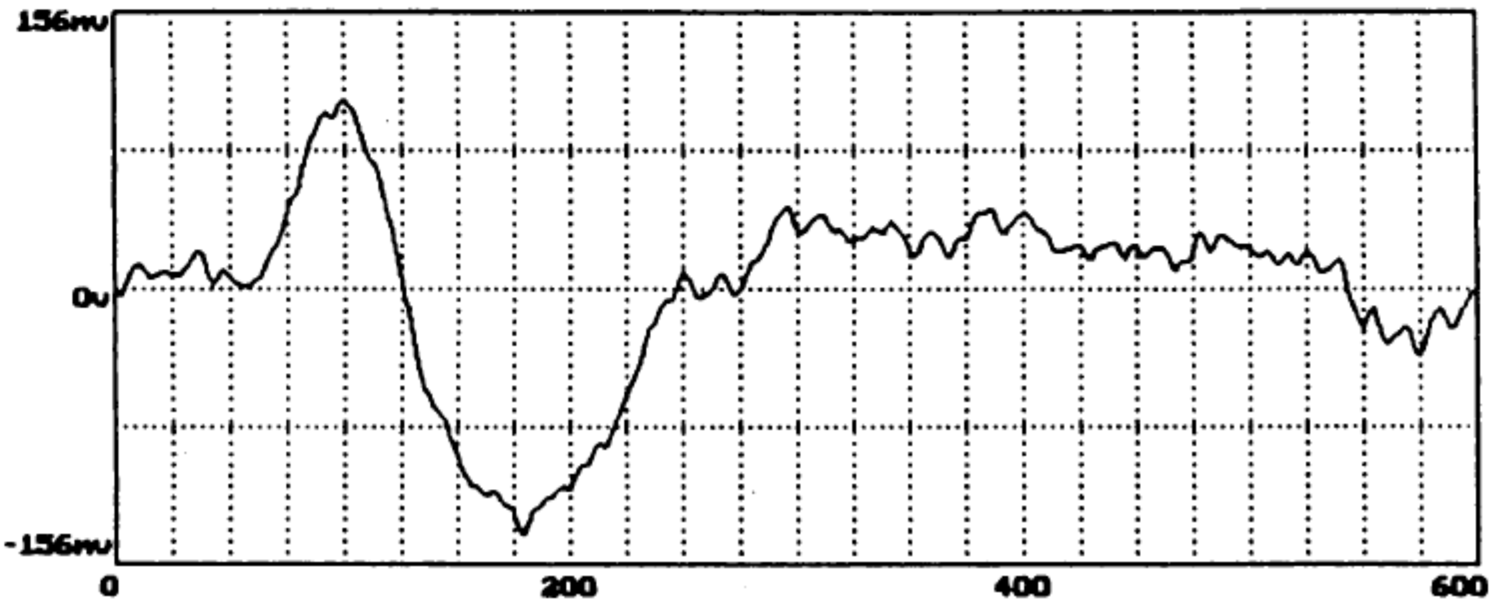



Fig. 4. A typical neuromagnetic field measurement normal to the head in response to auditory stimulation. A 50 ms wide prominent peak is seen at about 100 ms post-stimulus, followed by a wider, polarity reversed peak at about 200 ms.

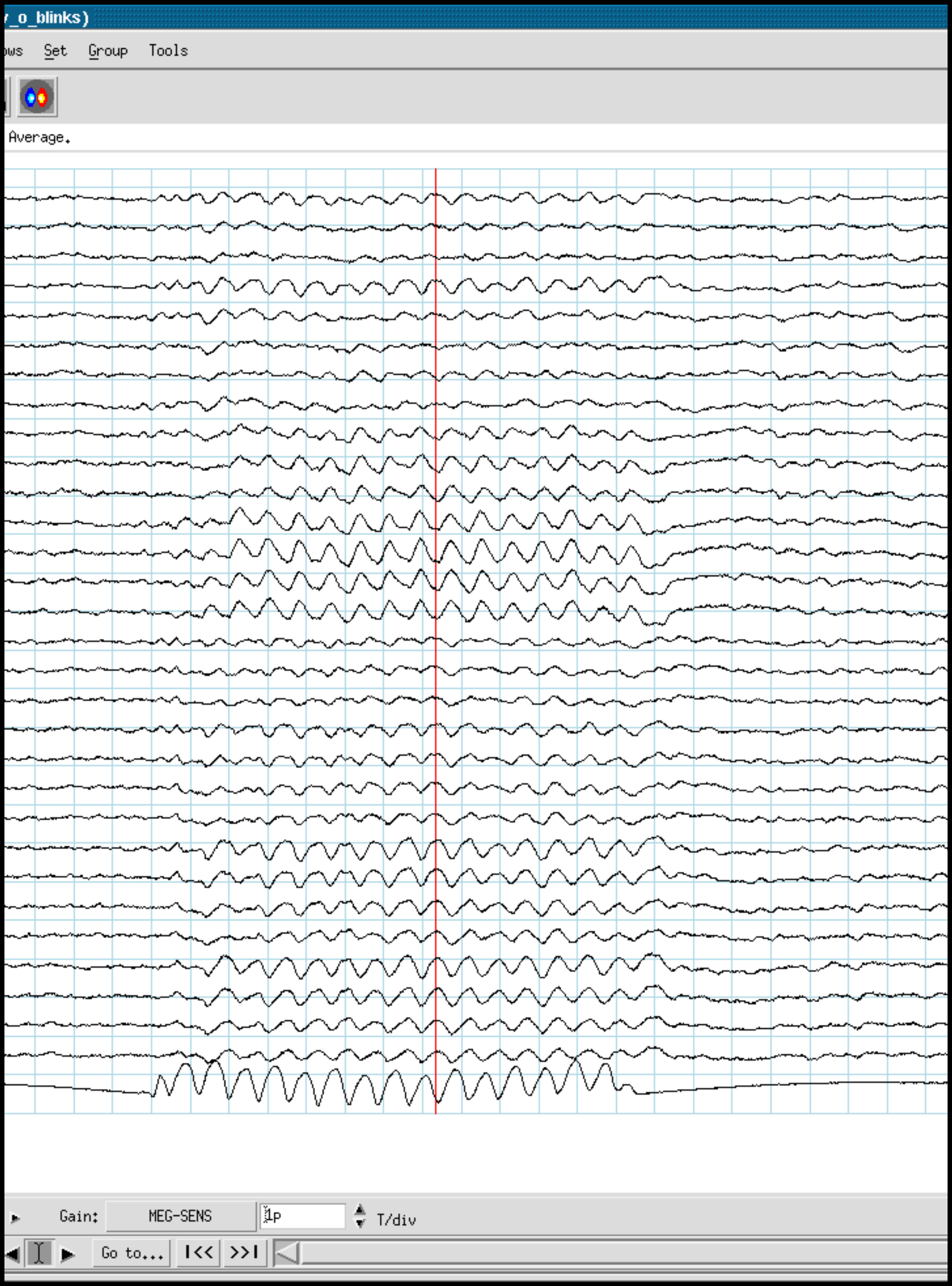
**M. Singh,** *Sensitivity of MR phase shift to detect evoked neuromagnetic fields inside the head.* **IEEE Transactions on Nuclear Science. 41: 349-351, (1994).**

# Undersampling

8 Hz alternating checkerboard

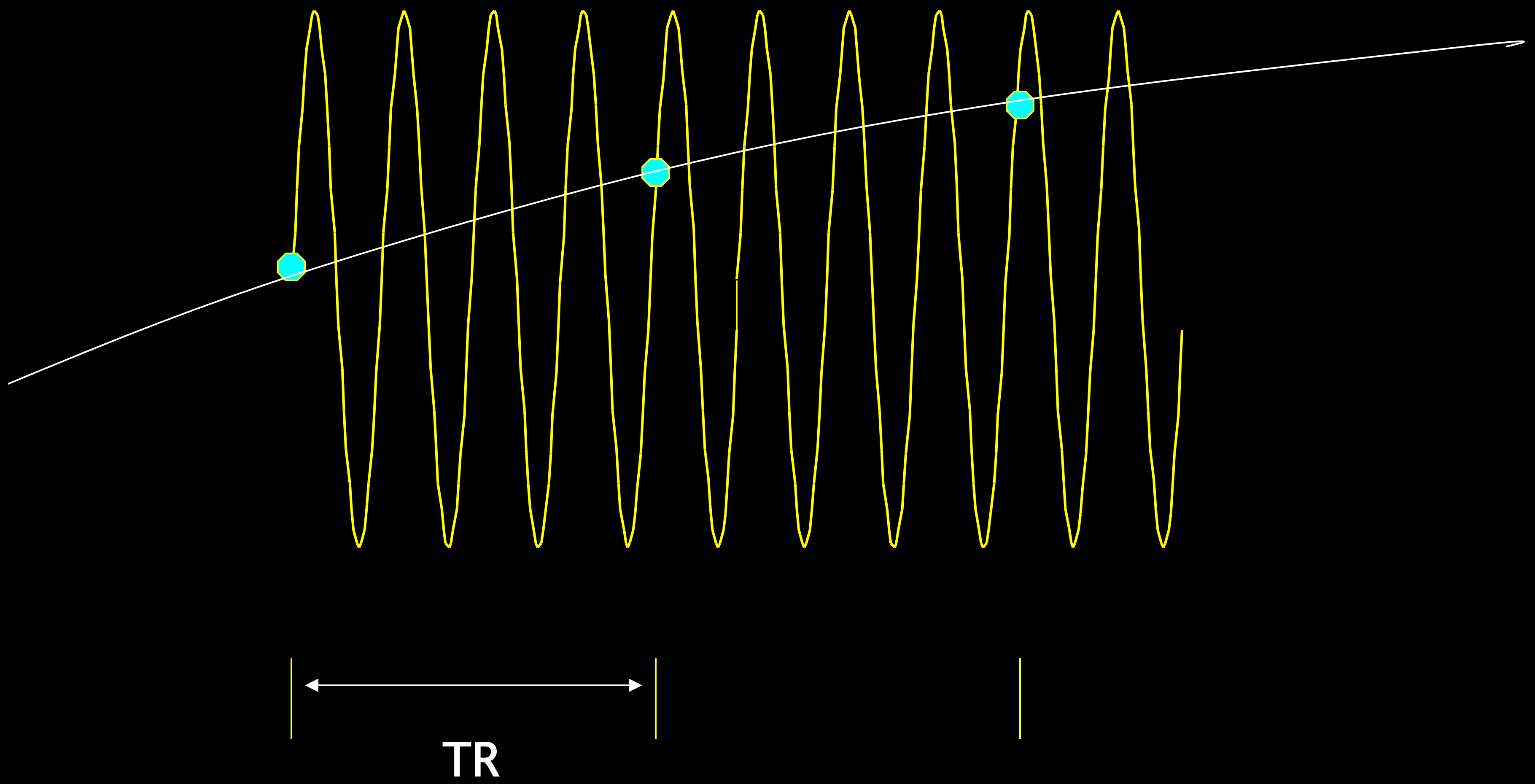
MEG

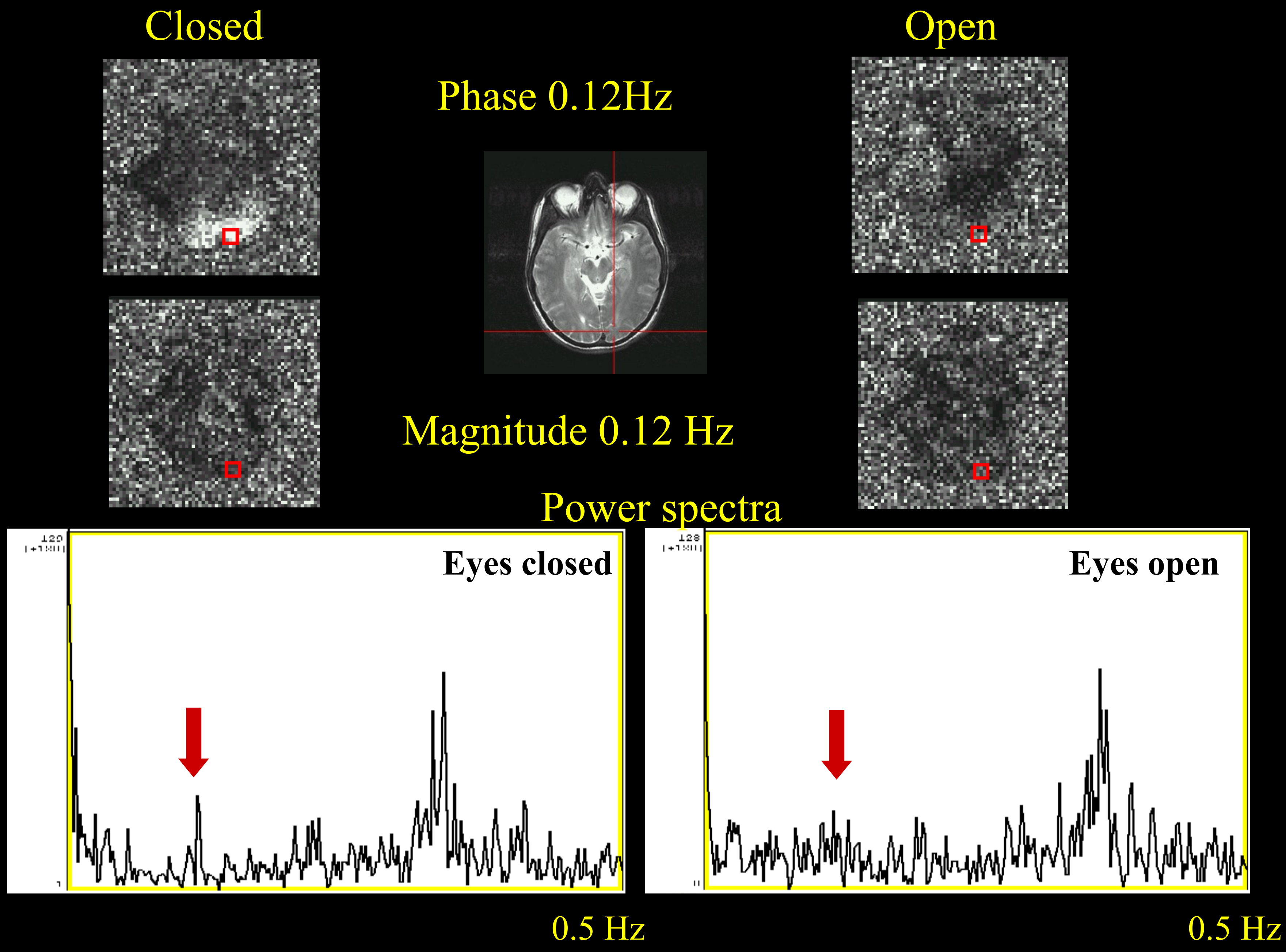
Photodiode



# Undersampling

## Alternating Checkerboard Frequency





Closed
Open
Phase 0.12Hz
Magnitude 0.12 Hz
Power spectra
Eyes closed
Eyes open
0.5 Hz
0.5 Hz

# Caution, Despair, Hope…

- Need to rule out BOLD or other mechanisms

- Noise is larger than effect
- MR sampling rate is slow

- Neuronal activation timing is variable and unspecified
- Models describing spatial distribution and locally induced magnetic fields remain relatively uncharacterized…therefore could be off by up to an order of magnitude.

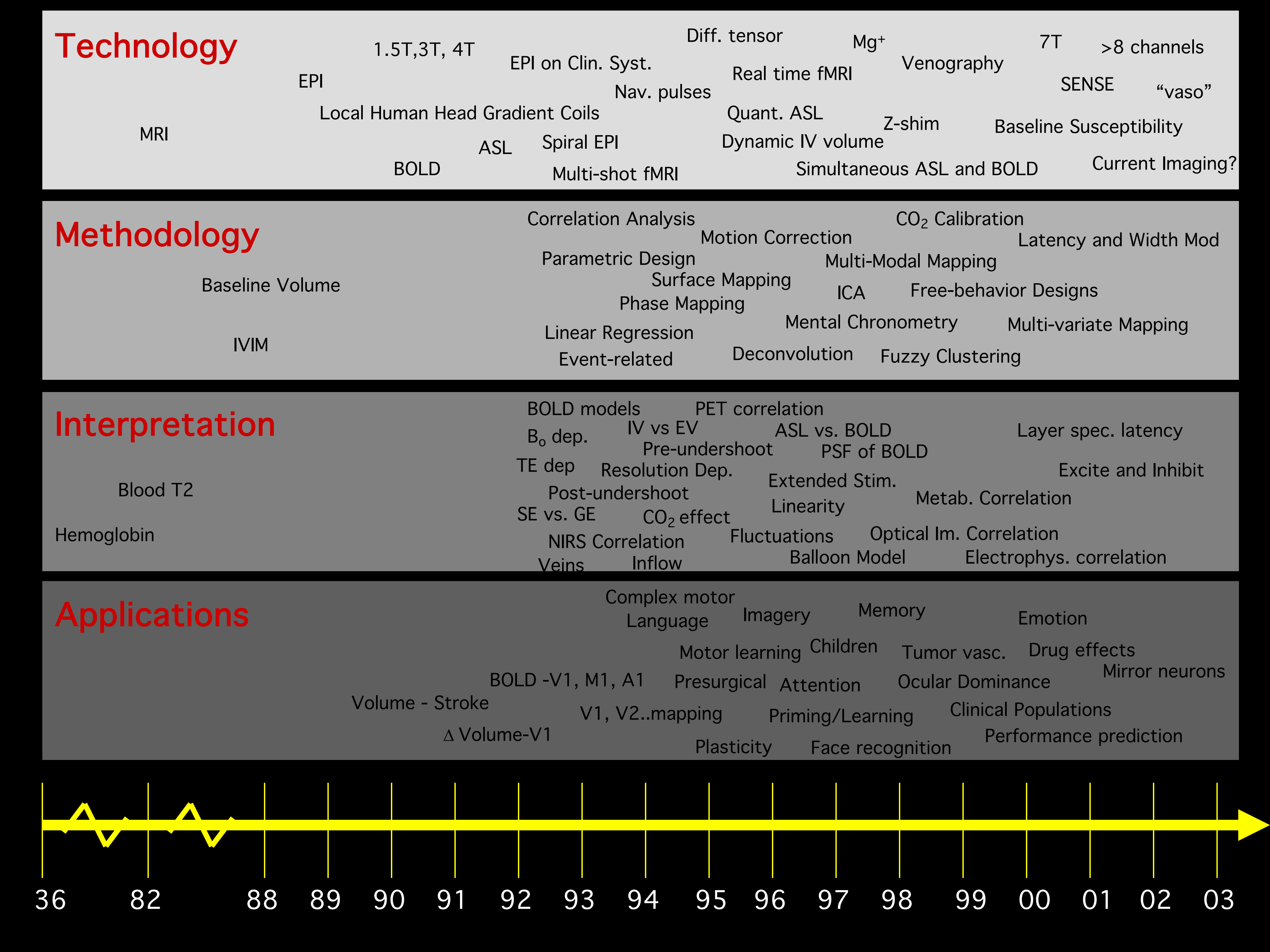
- Well characterized stimuli
- "Transient-tuned" pulse sequences (spin-echo, multi-echo)
- Sensitivity and/or resolution improvements
- Simultaneous electrophysiology – animal models?
- Synchronization improvements.

Technology

Methodology

Interpretation

Applications


Technology
MRI
EPI
1.5T,3T, 4T
Local Human Head Gradient Coils
BOLD
ASL
EPI on Clin. Syst.
Spiral EPI
Multi-shot fMRI
Nav. pulses
Diff. tensor
Real time fMRI
Quant. ASL
Dynamic IV volume
Simultaneous ASL and BOLD
Mg+
Venography
Z-shim
7T
SENSE
Baseline Susceptibility
>8 channels
"vaso"
Current Imaging?
Methodology
Baseline Volume
IVIM
Correlation Analysis
Parametric Design
Surface Mapping
Phase Mapping
Linear Regression
Event-related
Motion Correction
Multi-Modal Mapping
ICA
Mental Chronometry
Deconvolution
Fuzzy Clustering
$CO_2$ Calibration
Latency and Width Mod
Free-behavior Designs
Multi-variate Mapping
Interpretation
Blood T2
Hemoglobin
BOLD models
$B_o$ dep.
TE dep
SE vs. GE
Post-undershoot
NIRS Correlation
Veins
IV vs EV
Pre-undershoot
Resolution Dep.
$CO_2$ effect
Inflow
PET correlation
ASL vs. BOLD
PSF of BOLD
Extended Stim.
Linearity
Fluctuations
Balloon Model
Metab. Correlation
Optical Im. Correlation
Electrophys. correlation
Layer spec. latency
Excite and Inhibit
Applications
Volume - Stroke
∆ Volume-V1
BOLD -V1, M1, A1
V1, V2..mapping
Complex motor
Language
Motor learning
Presurgical
Plasticity
Imagery
Children
Attention
Priming/Learning
Face recognition
Memory
Tumor vasc.
Ocular Dominance
Clinical Populations
Performance prediction
Emotion
Drug effects
Mirror neurons
36
82
88
89
90
91
92
93
94
95
96
97
98
99
00
01
02
03

# FIM Unit & FMRI Core Facility

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