

fMRI: Where are we? Where are we going?

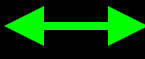
Peter A. Bandettini, Ph.D

Unit on Functional Imaging Methods
&
3T Neuroimaging Core Facility

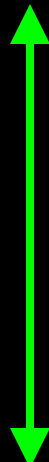
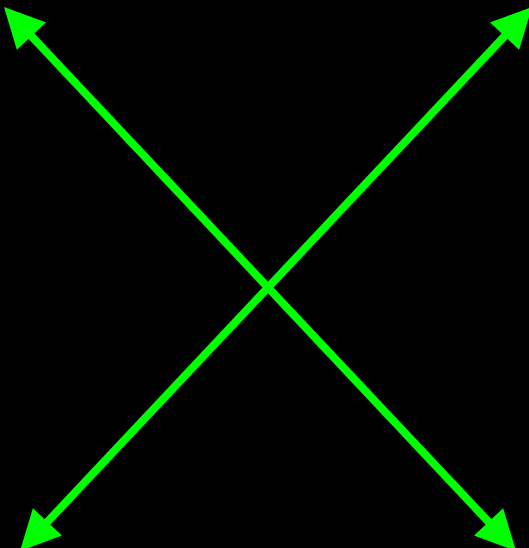
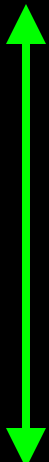
Laboratory of Brain and Cognition
National Institute of Mental Health



Technology



Methodology



Interpretation



Applications

Technology

Methodology

Engineers

Statisticians

Physicists

Mathematicians

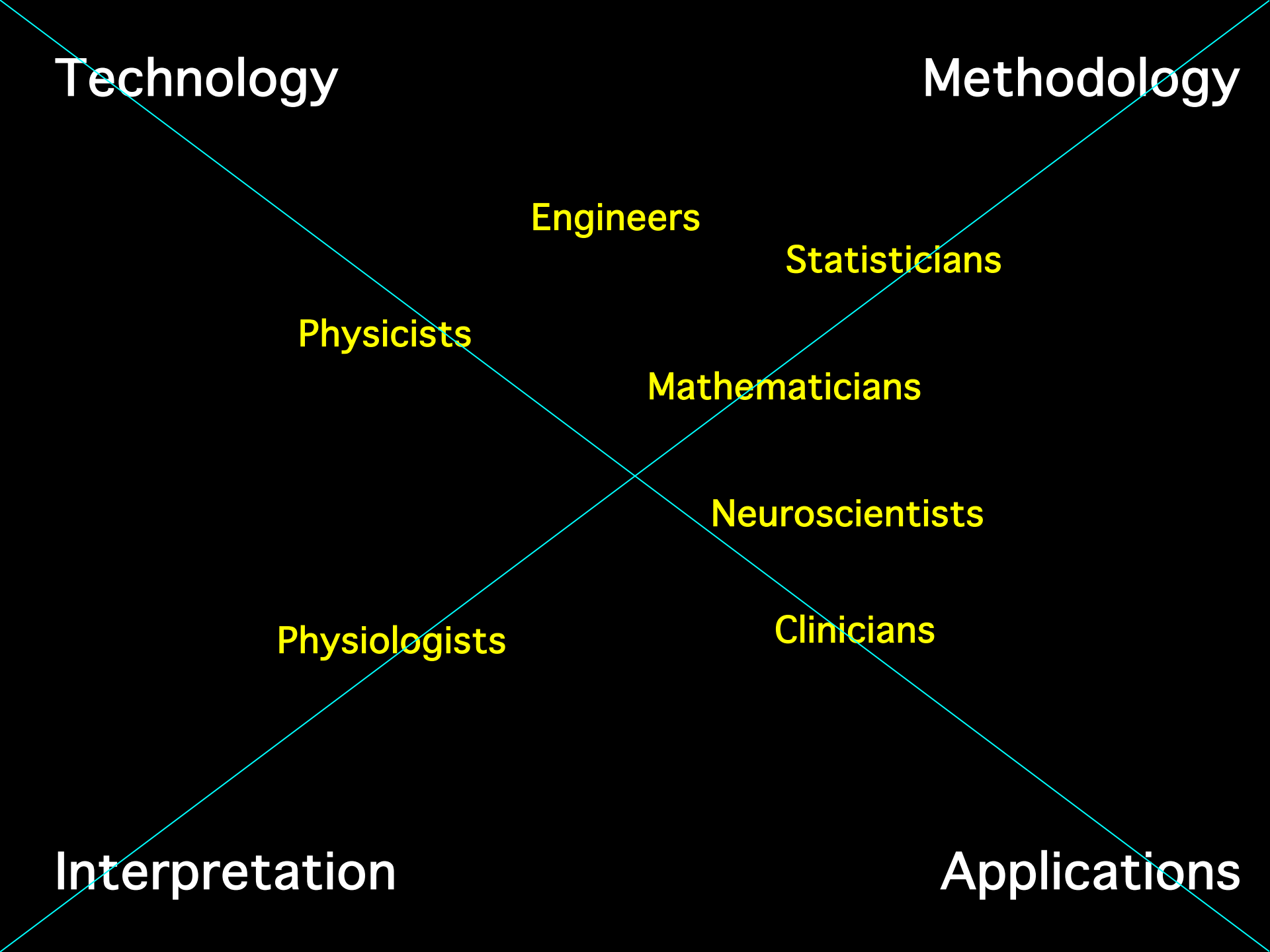
Neuroscientists

Physiologists

Clinicians

Interpretation

Applications



Where Are We?

Technology

MRI
 EPI
 Local Human Head Gradient Coils
 BOLD
 ASL
 Spiral EPI
 Multi-shot fMRI
 1.5T,3T, 4T
 EPI on Clin. Syst.
 Nav. pulses
 Diff. tensor
 Real time fMRI
 Quant. ASL
 Dynamic IV volume
 Simultaneous ASL and BOLD
 Mg⁺
 Venography
 Z-shim
 Baseline Susceptibility
 7T
 >8 channels
 SENSE
 Current Imaging?

Methodology

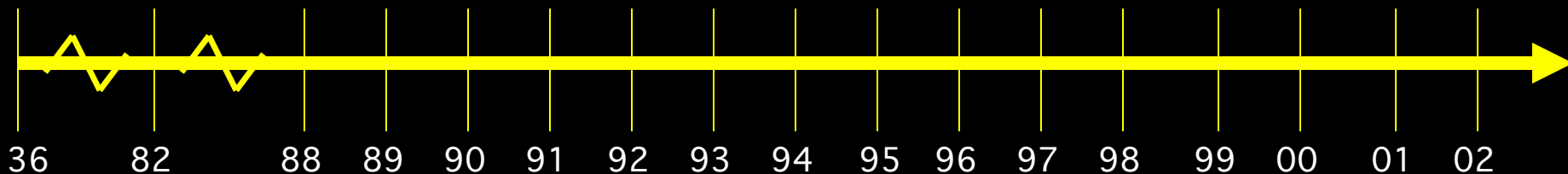
Baseline Volume
 IVIM
 Correlation Analysis
 Parametric Design
 Surface Mapping
 Phase Mapping
 Linear Regression
 Event-related
 Motion Correction
 Multi-Modal Mapping
 ICA
 Free-behavior Designs
 Mental Chronometry
 Multi-variate Mapping
 Deconvolution
 Fuzzy Clustering
 CO₂ Calibration

Interpretation

Blood T2
 Hemoglobin
 BOLD models
 B₀ dep.
 TE dep
 SE vs. GE
 NIRS Correlation
 Veins
 PET correlation
 IV vs EV
 Pre-undershoot
 Resolution Dep.
 Post-undershoot
 CO₂ effect
 Inflow
 ASL vs. BOLD
 PSF of BOLD
 Extended Stim.
 Linearity
 Fluctuations
 Balloon Model
 Metab. Correlation
 Optical Im. Correlation
 Electrophys. correlation

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
 Plasticity
 Face recognition
 Performance prediction





L. Pauling, C. D. Coryell, (1936) “The magnetic properties and structure of hemoglobin, oxyhemoglobin, and carbonmonoxyhemoglobin.” Proc.Natl. Acad. Sci. USA 22, 210-216.

Thulborn, K. R., J. C. Waterton, et al. (1982).“Oxygenation dependence of the transverse relaxation time of water protons in whole blood at high field.” Biochim. Biophys. Acta. 714: 265-270.

S. Ogawa, T. M. Lee, A. R. Kay, D. W. Tank, (1990) “Brain magnetic resonance imaging with contrast dependent on blood oxygenation.” Proc. Natl. Acad. Sci. USA 87, 9868-9872.

R. Turner, D. LeBihan, C. T. W. Moonen, D. Despres, J. Frank, (1991). Echo-planar time course MRI of cat brain oxygenation changes. Magn. Reson. Med. 27, 159-166.

Functional MRI Methods

Blood Volume Imaging

BOLD Contrast

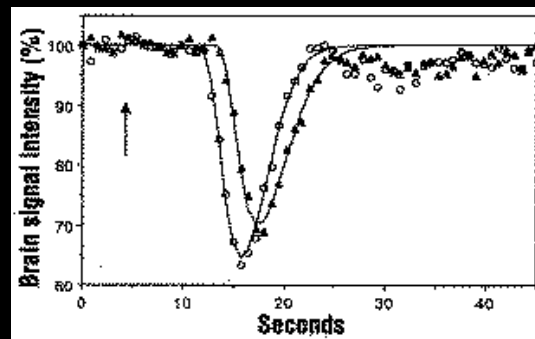
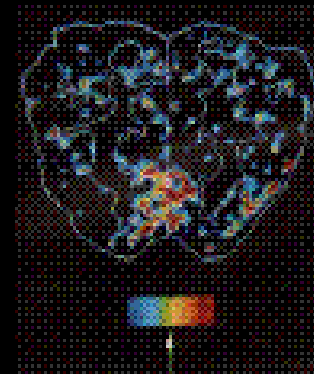
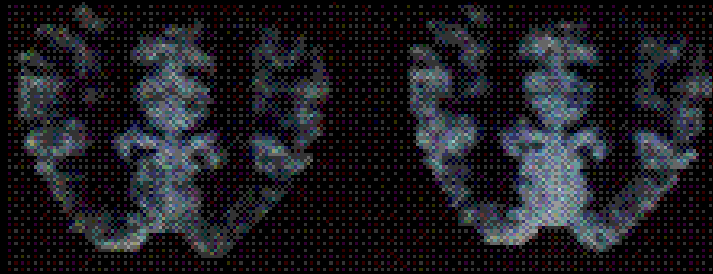
Arterial Spin Labeling

Blood Volume Imaging

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

Resting

Active

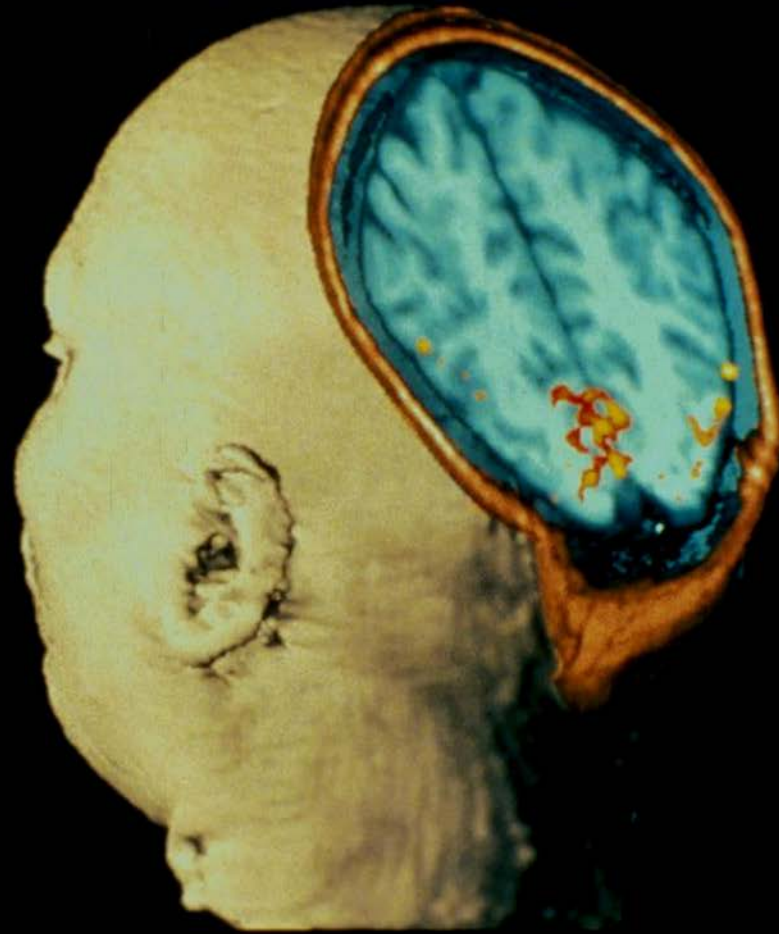


Blood Volume

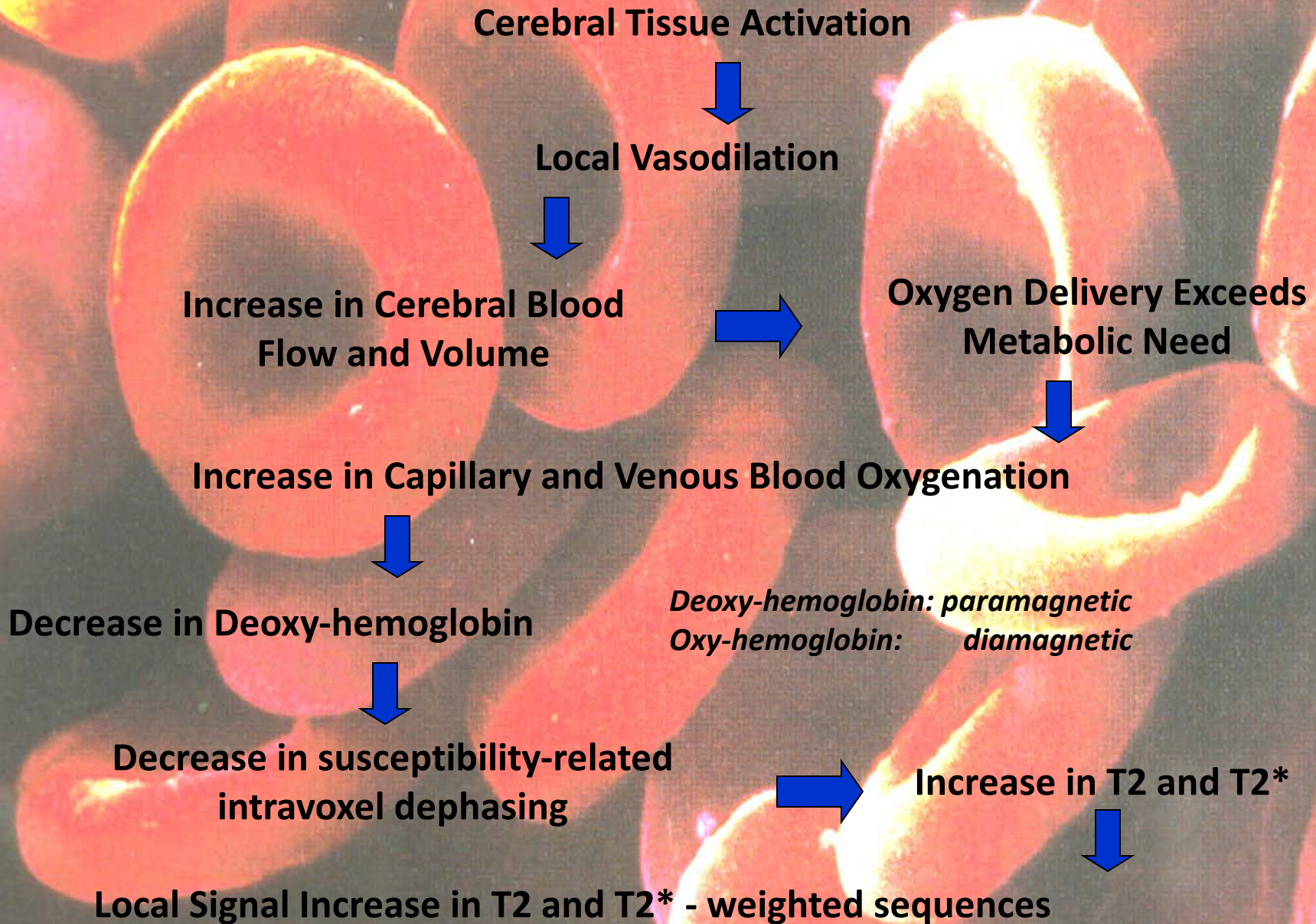
**Photic
Stimulation**

**MRI Image showing
activation of the
Visual Cortex**

**From Belliveau, et al.
Science Nov 1991**



BOLD Contrast in the Detection of Neuronal Activity



Alternating Left and Right Finger Tapping



~ 1992

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.

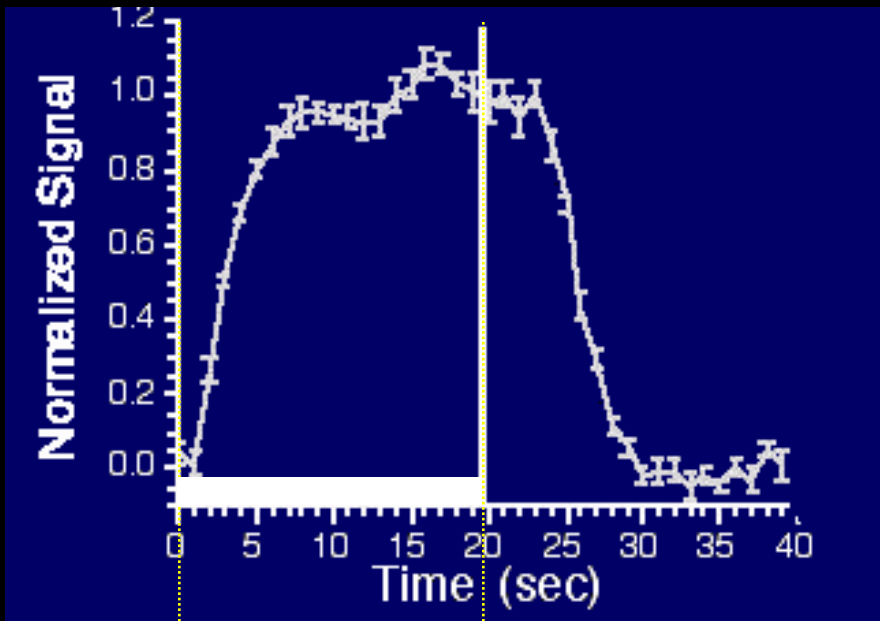
Correlation analysis, Fourier analysis, t-test, f-test...
SPM, AFNI, brain voyager, FIASCO, FSL, free surfer...



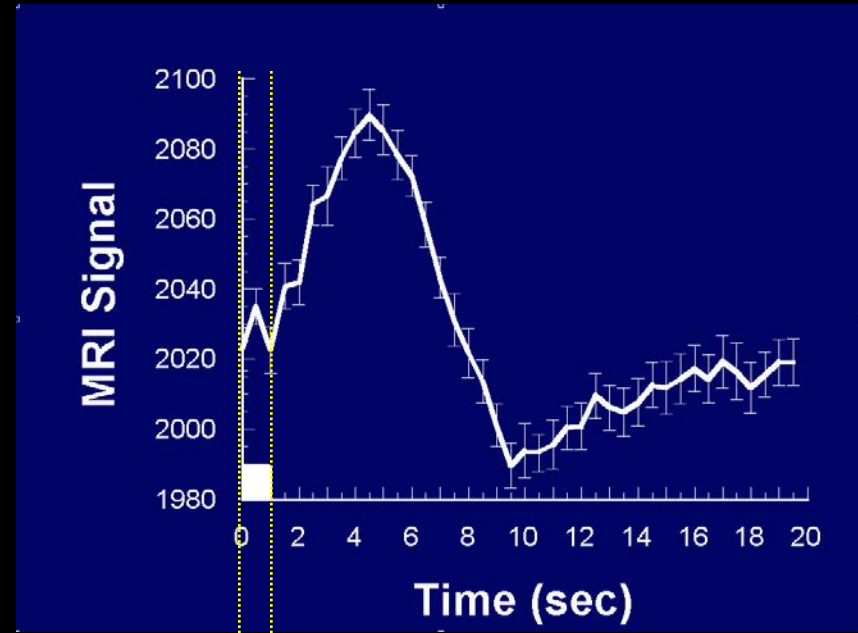
*Quality of results and importance of the findings depends on
type of question asked, experimental method, and analysis method...*

The BOLD Signal

Blood Oxygenation Level Dependent (BOLD) signal changes

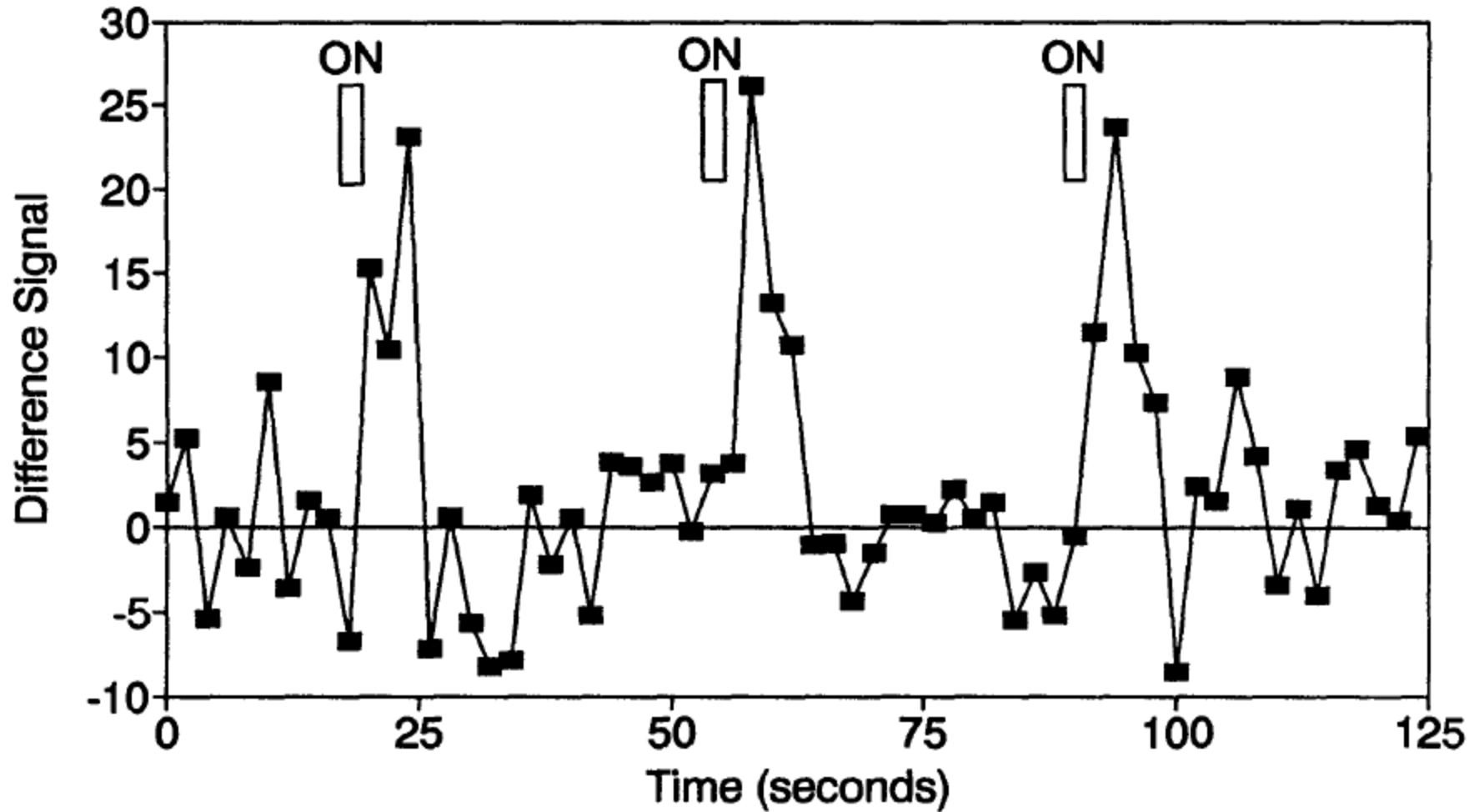


task

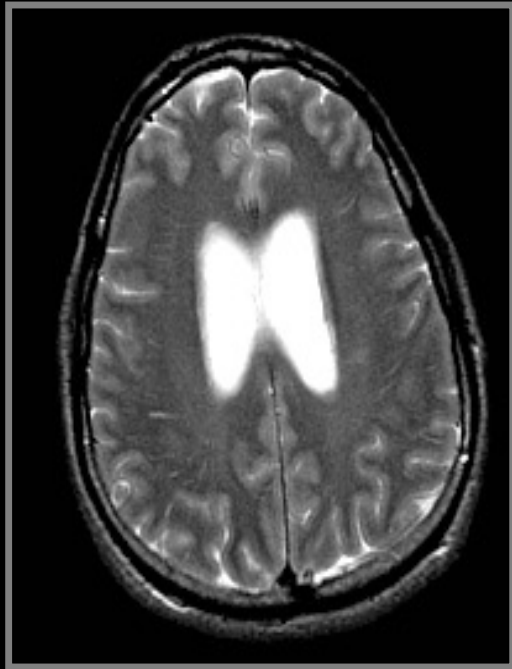


task

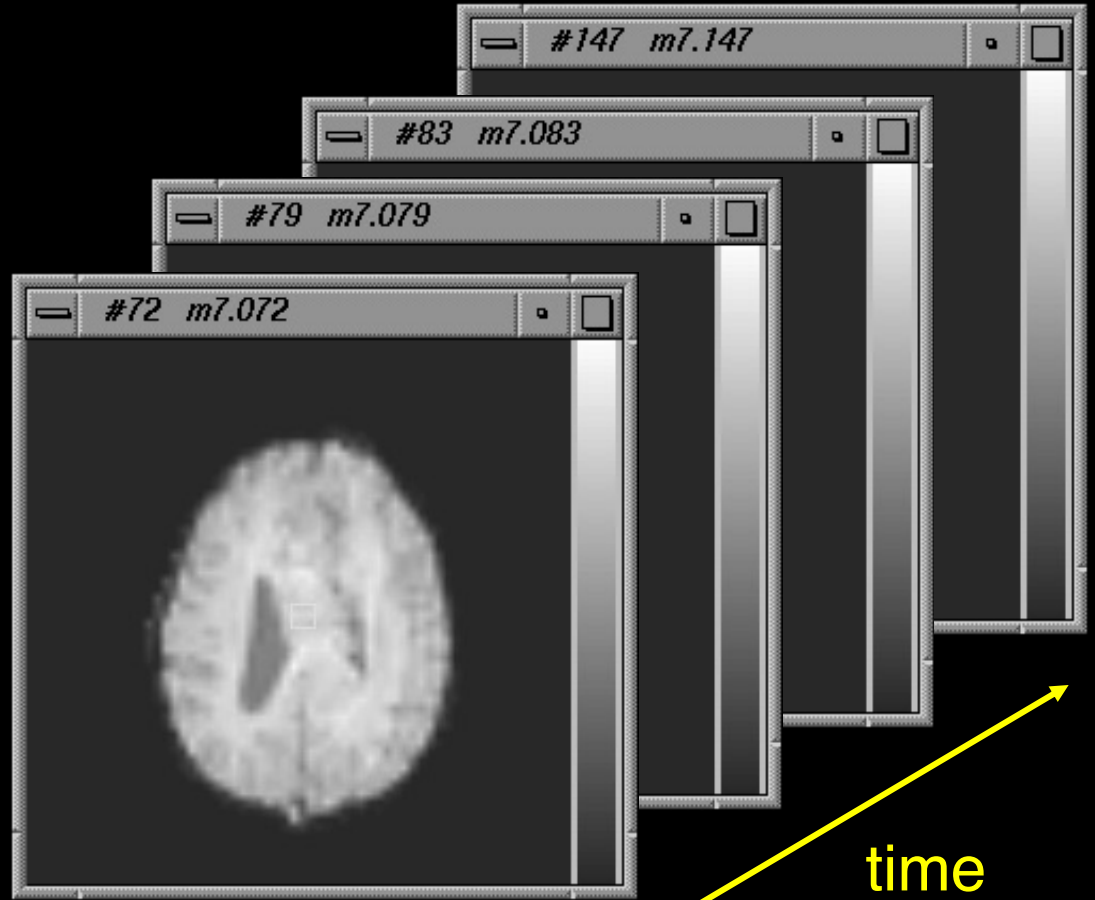
First Event-related fMRI Results



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.

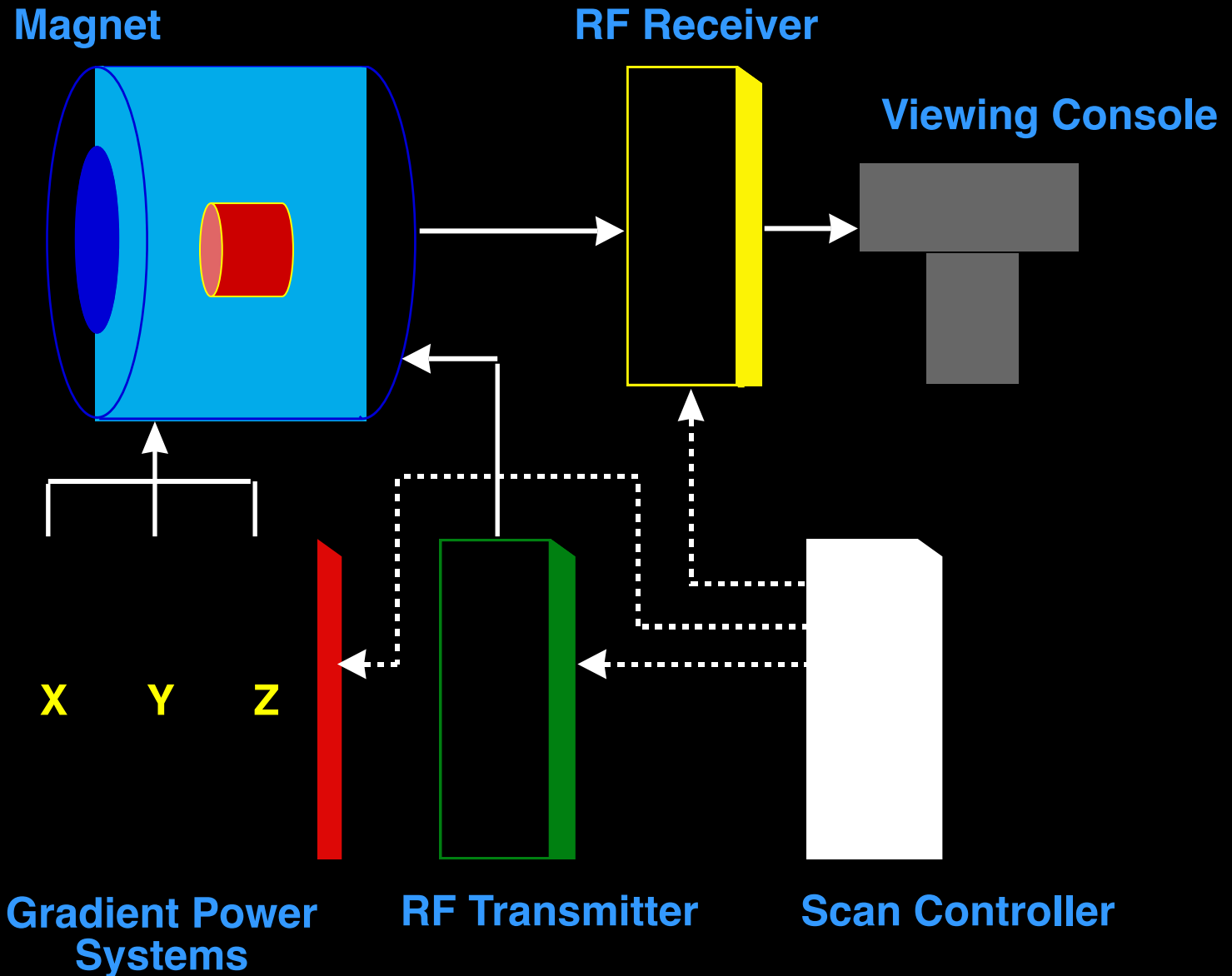


Anatomic

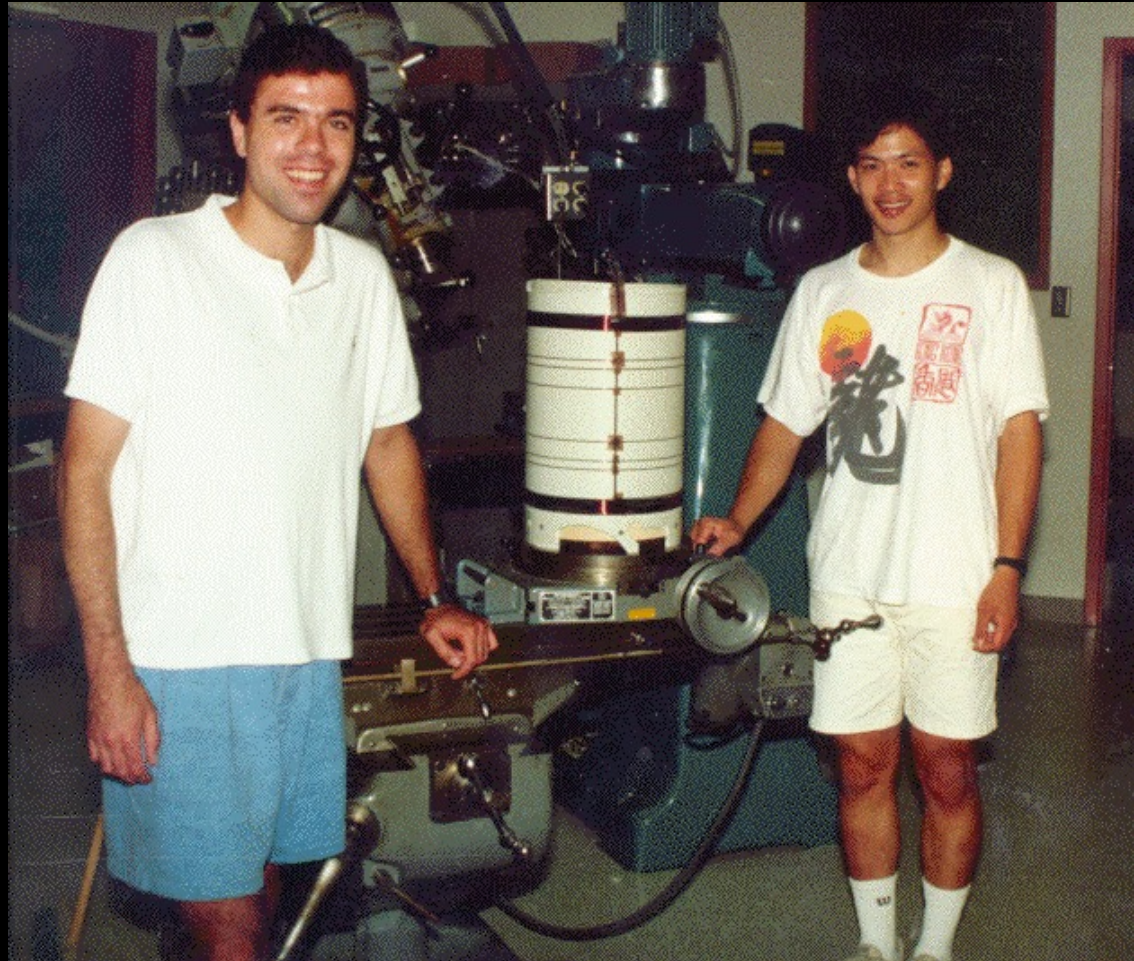


Functional

Imaging System Components



Local gradients solved the problem



August, 1991

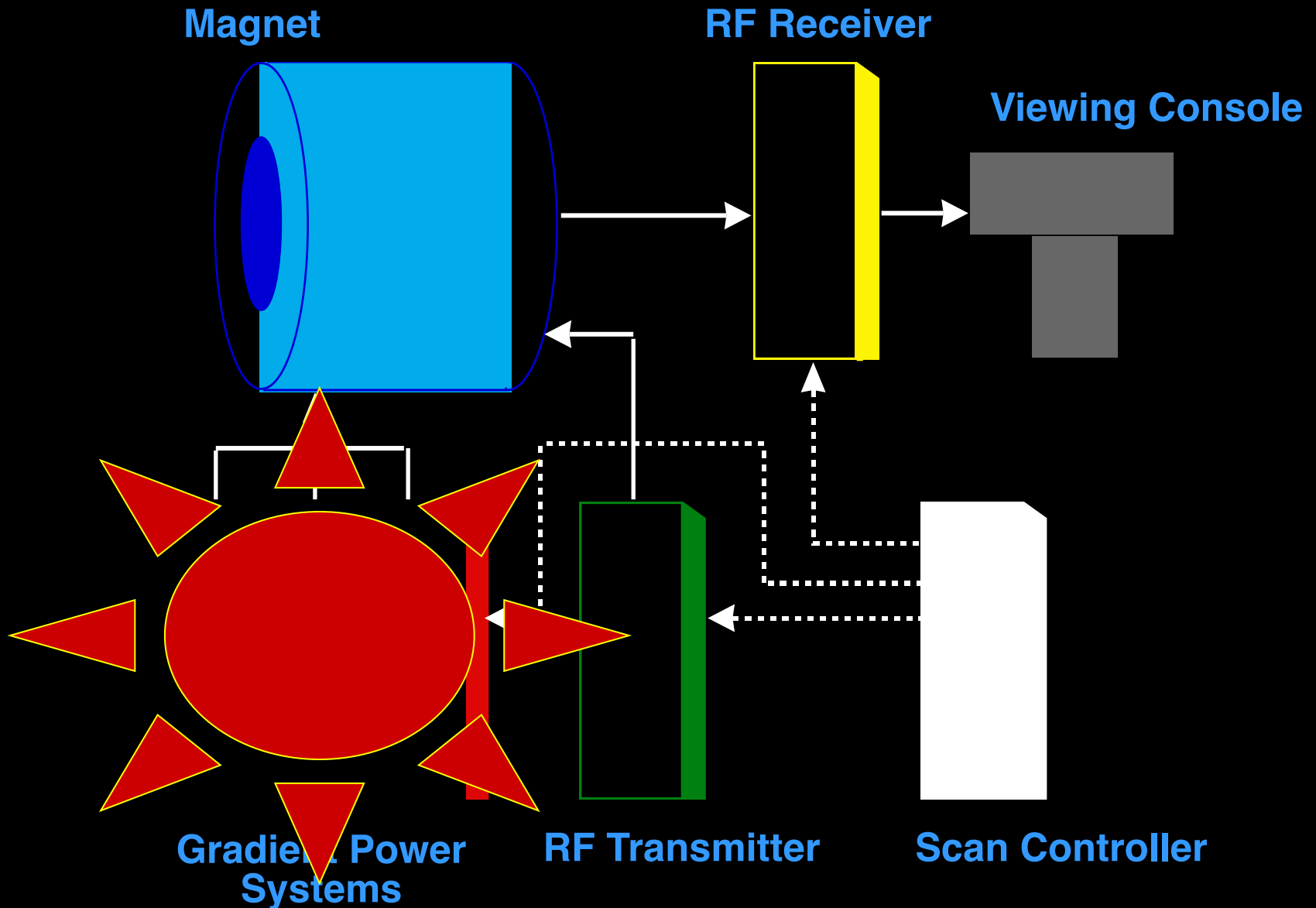
1991-1992



1992-1999



Imaging System Components

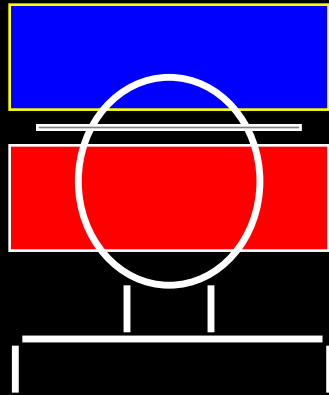


General Electric 3 Tesla Scanner

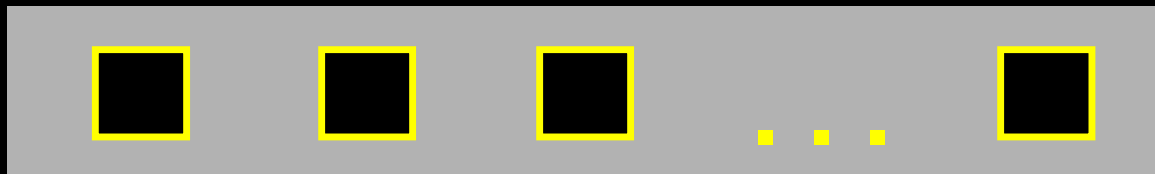
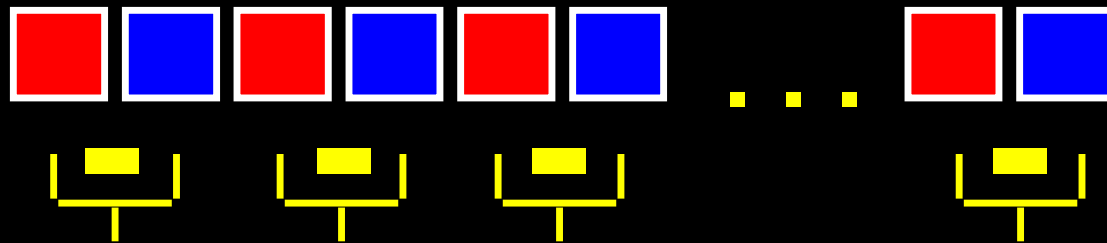
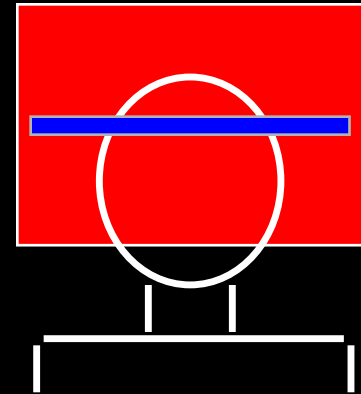


Blood Perfusion

EPISTAR



FAIR



**Perfusion
Time Series**

TI (ms)

FAIR

EPISTAR

200

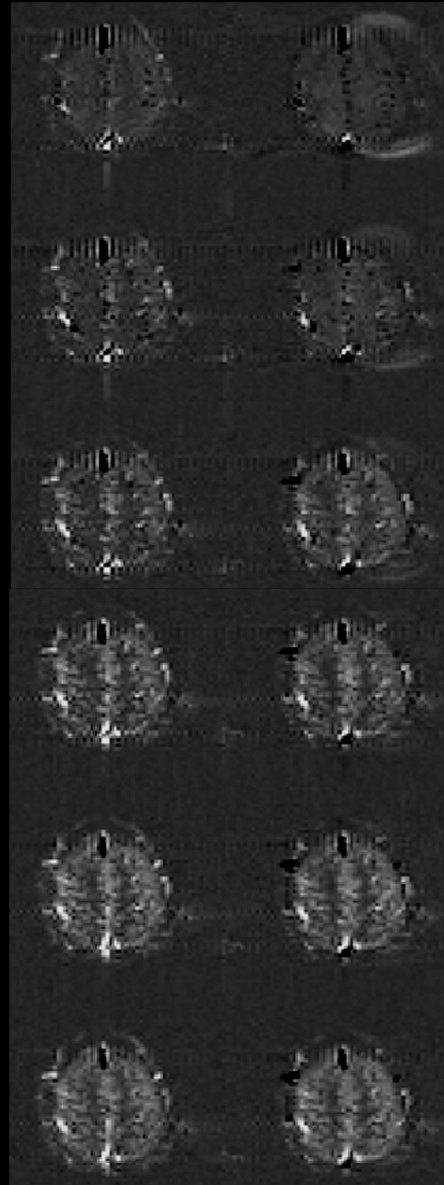
400

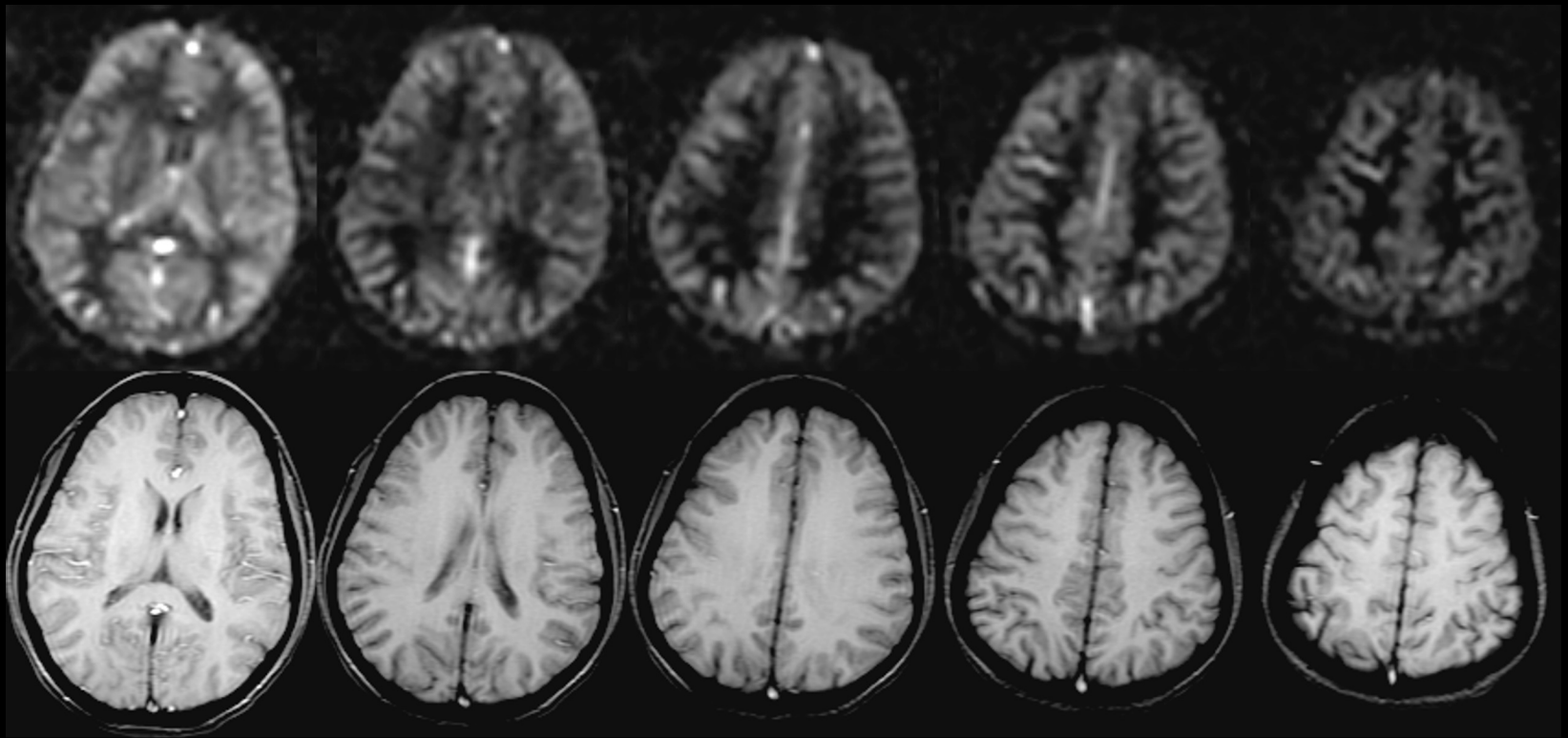
600

800

1000

1200





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 and 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.

Refinements

BOLD Contrast Interpretation

Paradigm Design and Processing

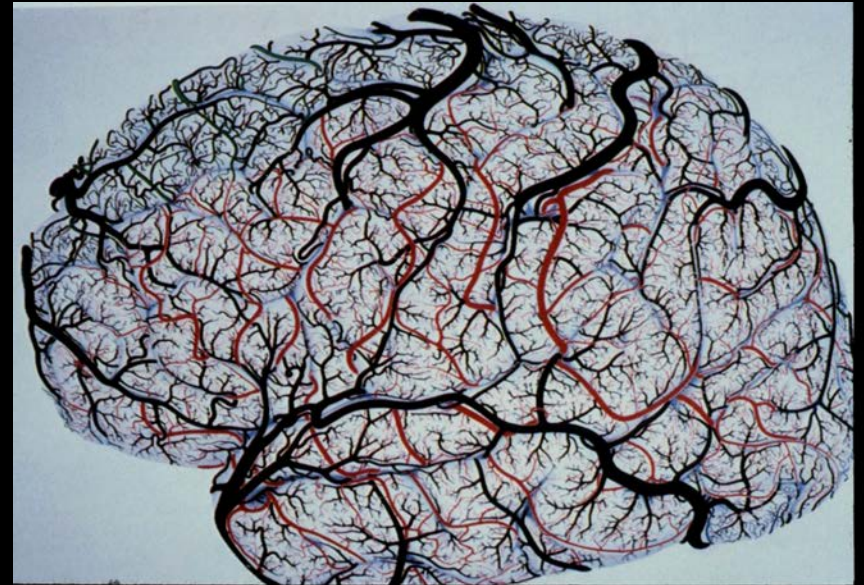
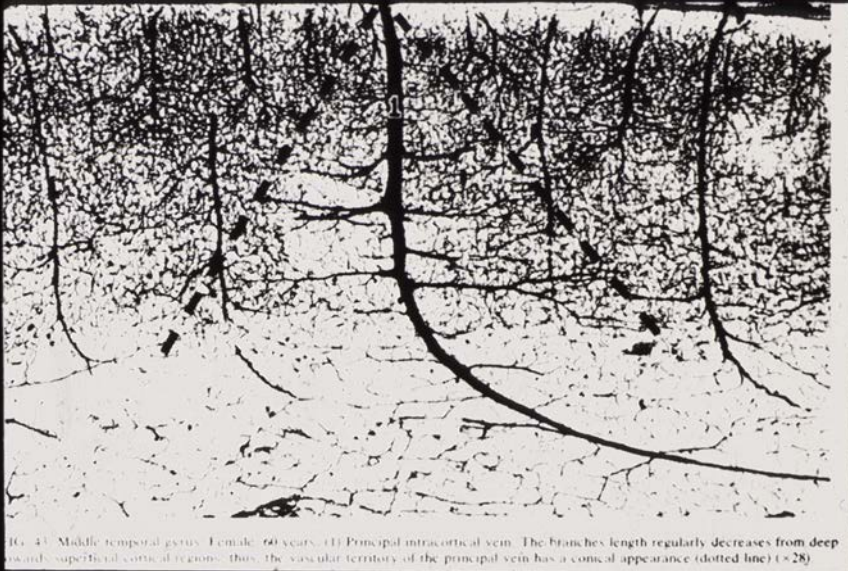
Refinements

BOLD Contrast Interpretation

Paradigm Design and Processing

The Neuroscientists' Challenge:

...to make progressively more precise inferences using fMRI without making too many assumptions about non-neuronal physiologic factors.



Neuronal
Activation



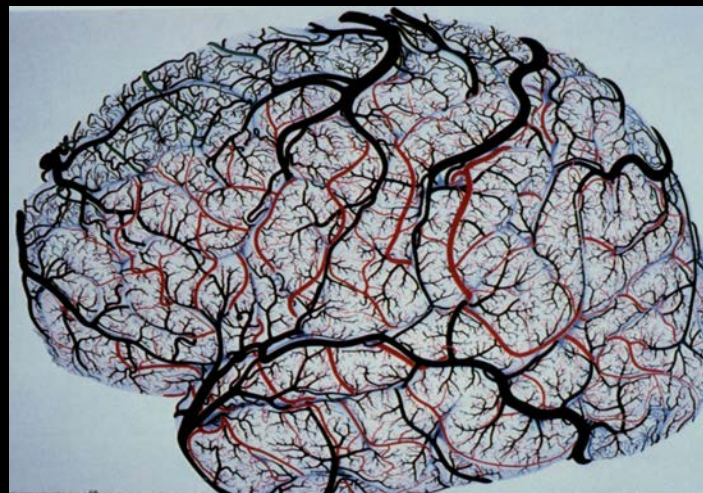
Measured
Signal

Hemodynamics

?

?

?



Noise

BOLD Contrast: Strategies for Better Interpretation

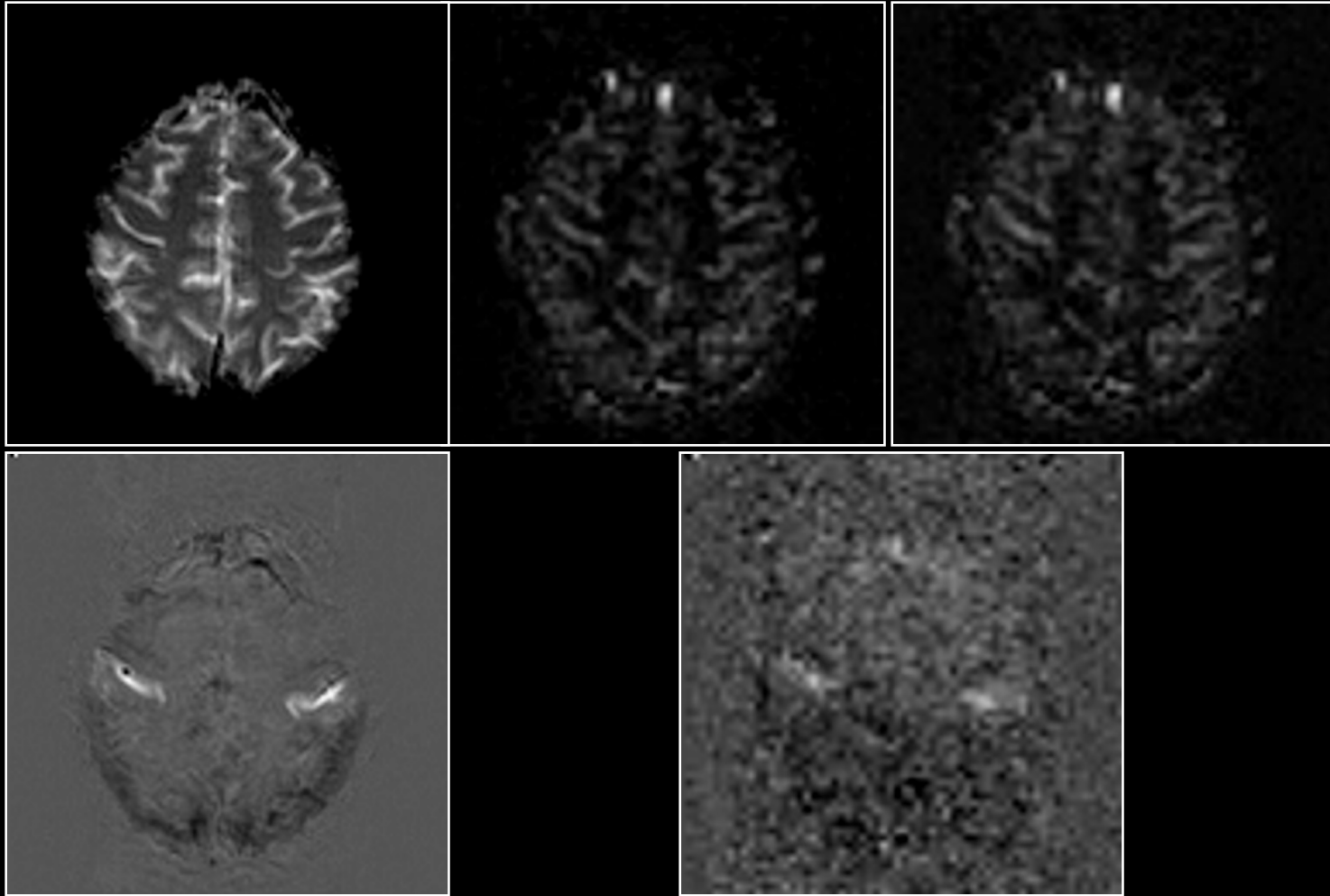
- Pulse sequence modulation
- Neuronal activation modulation
- Alternative measurement comparison

Perfusion

BOLD

Rest

Activation

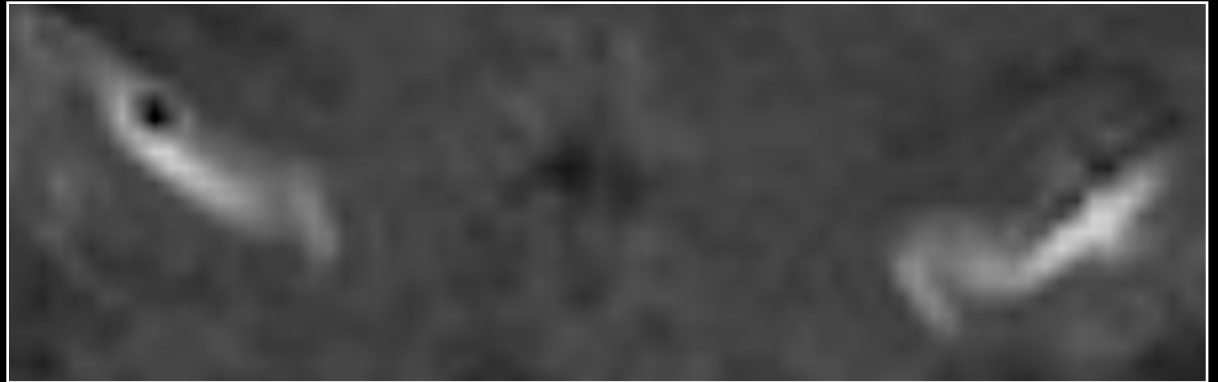


P. A. Bandettini, E. C. Wong, Magnetic resonance imaging of human brain function: principles, practicalities, and possibilities, *in* "Neurosurgery Clinics of North America: Functional Imaging" (M. Haglund, Ed.), p.345-371, W. B. Saunders Co., 1997.

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.

Arterial inflow
(BOLD TR < 500 ms)

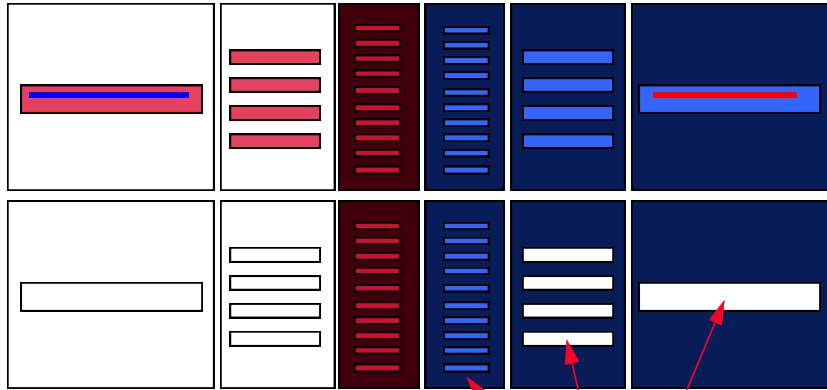
Perfusion

BOLD

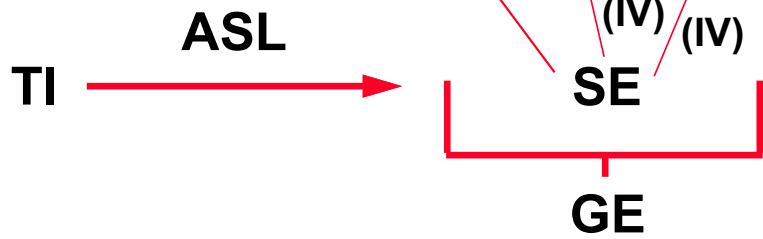
Venous inflow
(for ASL, w/ no VN)

No
Velocity
Nulling

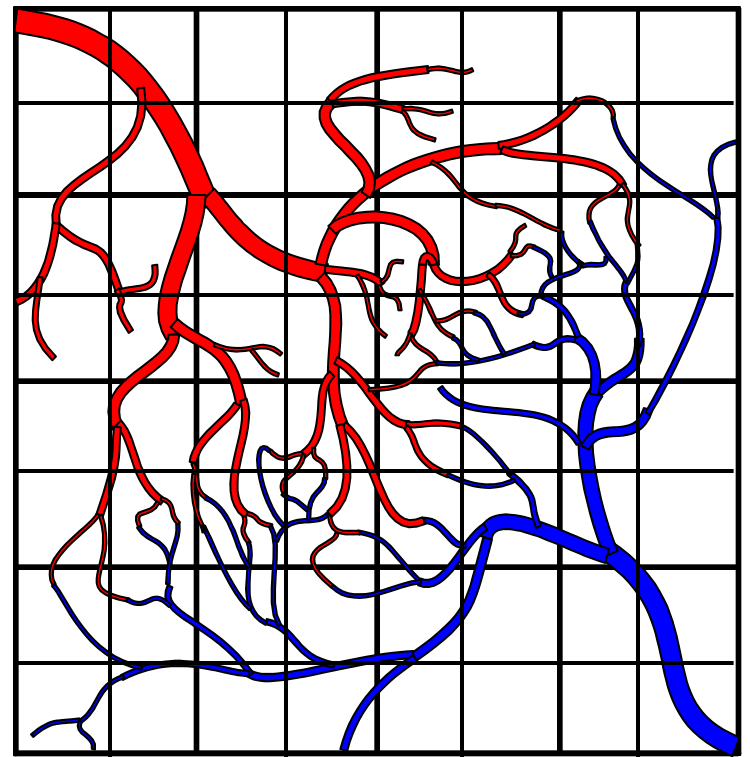
Velocity
Nulling



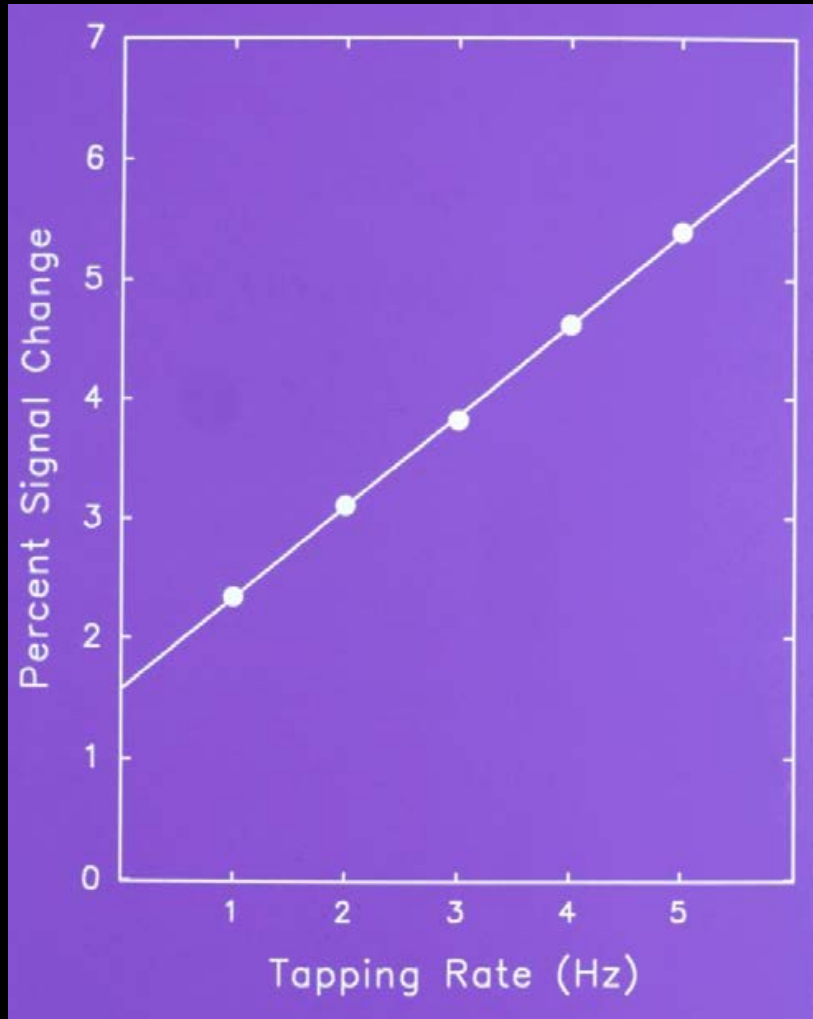
Pulse Sequence Sensitivity



Spatial Heterogeneity

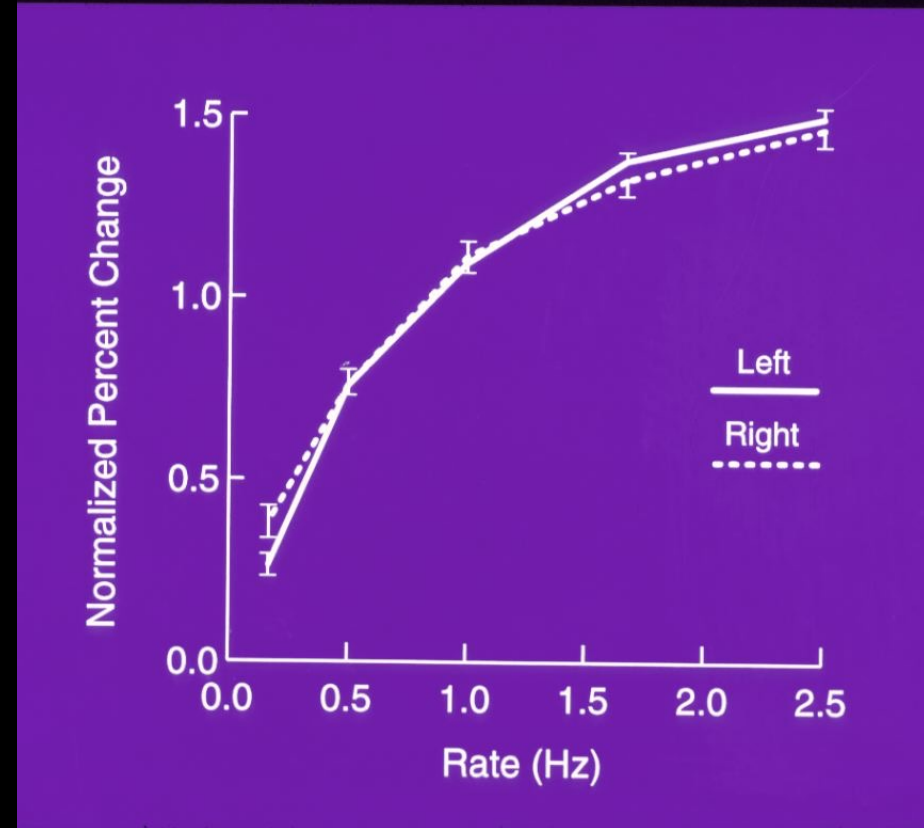


Motor Cortex



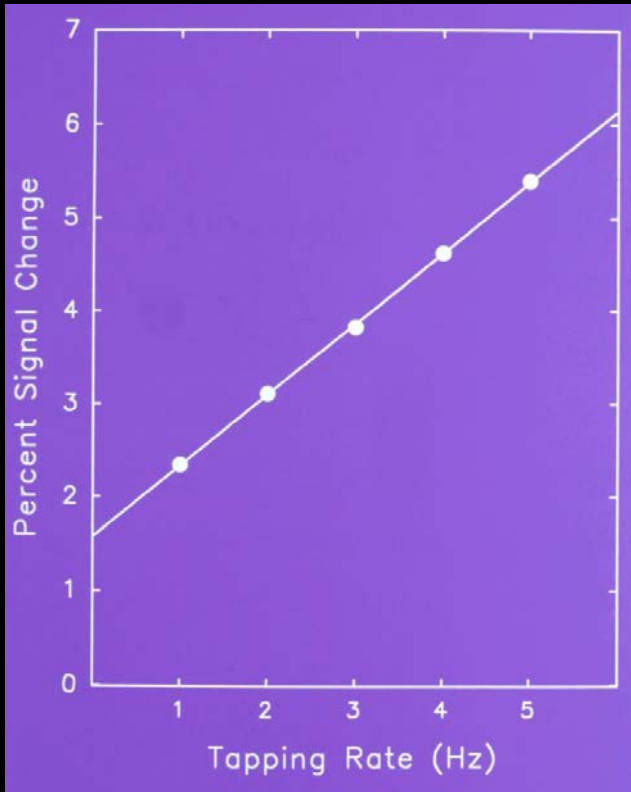
S. M. Rao et al, (1996) "Relationship between finger movement rate and functional magnetic resonance signal change in human primary motor cortex." *J. Cereb. Blood Flow and Met.* 16, 1250-1254.

Auditory Cortex

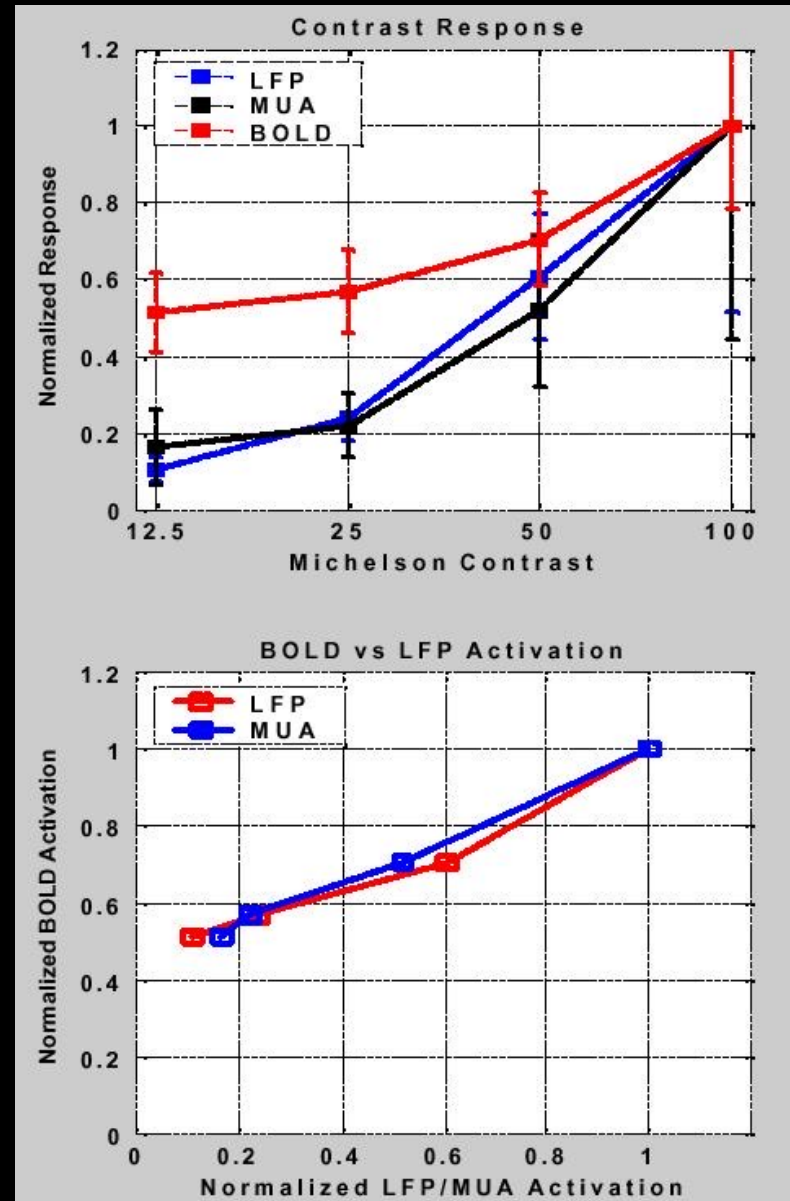


J. R. Binder, et al, (1994). "Effects of stimulus rate on signal response during functional magnetic resonance imaging of auditory cortex." *Cogn. Brain Res.* 2, 31-38

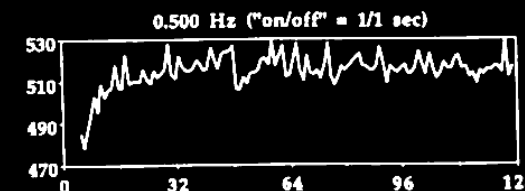
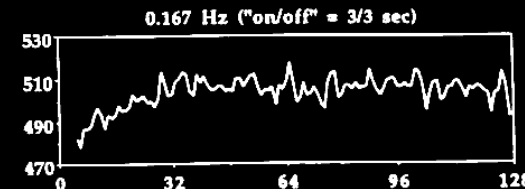
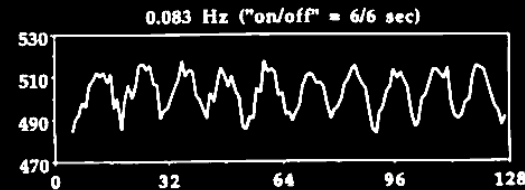
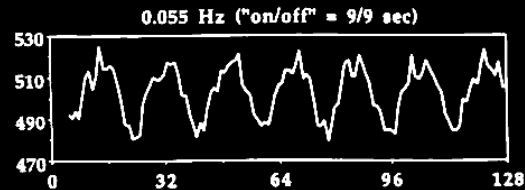
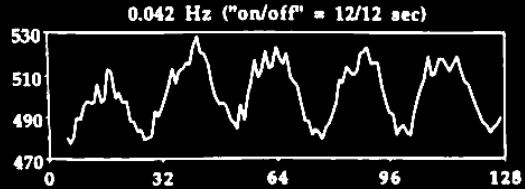
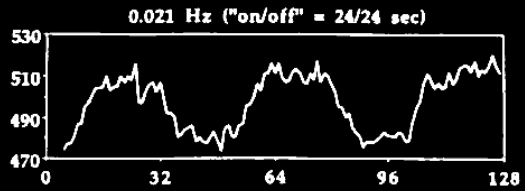
Logothetis et al. (2001) "Neurophysiological investigation of the basis of the fMRI signal" *Nature*, 412, 150-157



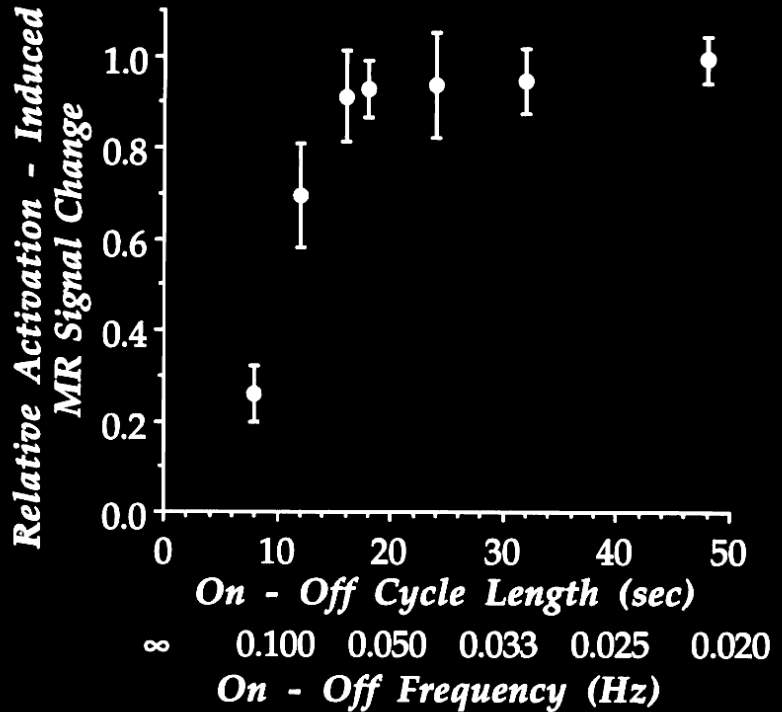
S. M. Rao et al, (1996) "Relationship between finger movement rate and functional magnetic resonance signal change in human primary motor cortex." *J. Cereb. Blood Flow and Met.* 16, 1250-1254.



MRI Signal

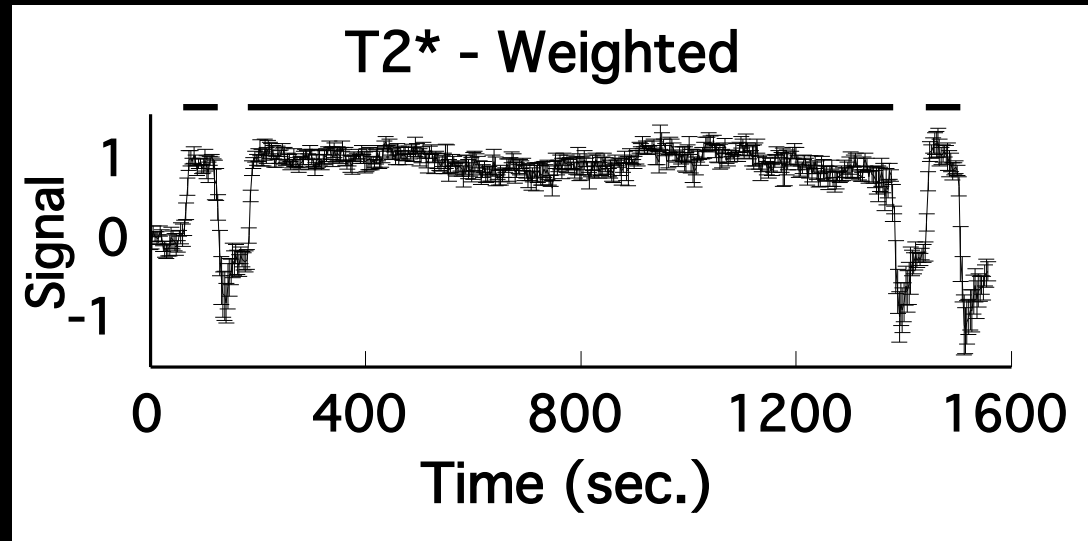


Time (seconds)

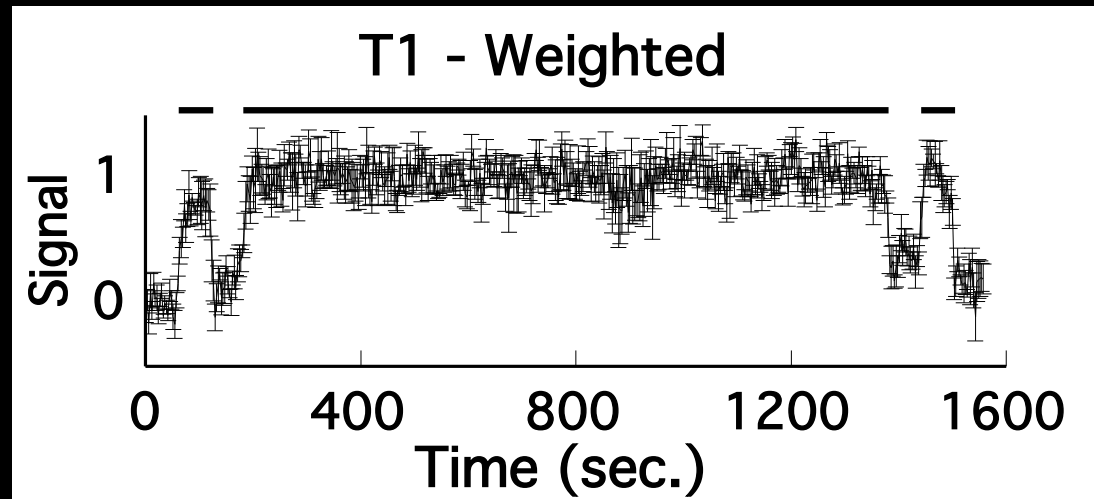


P. A. Bandettini, Functional MRI temporal resolution in "Functional MRI" (C. Moonen, and P. Bandettini., Eds.), p. 205-220, Springer - Verlag, 1999.

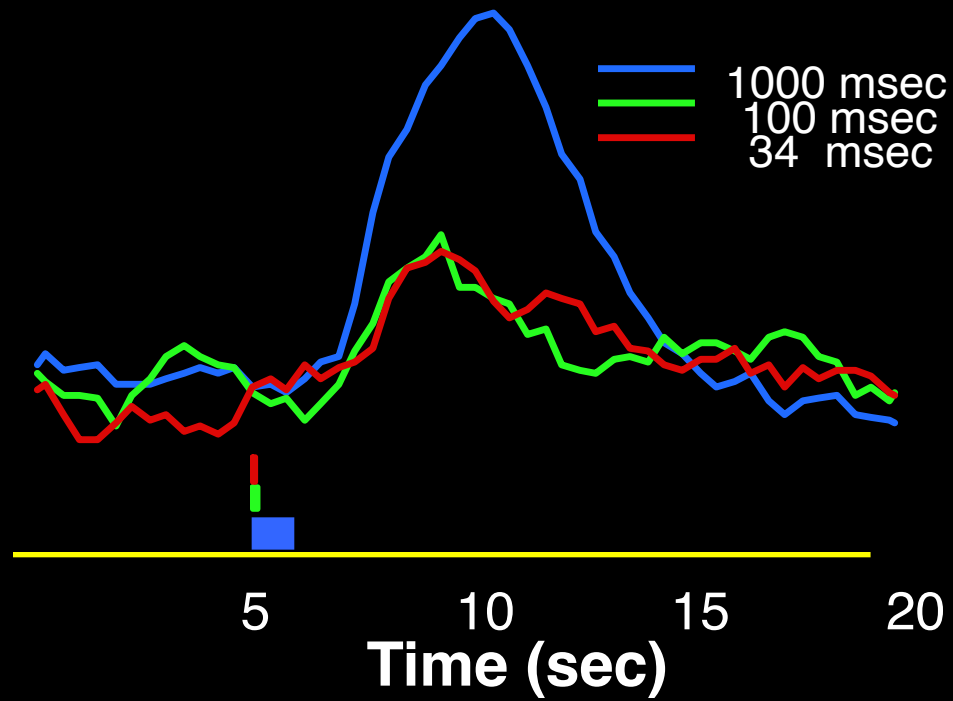
BOLD



Flow

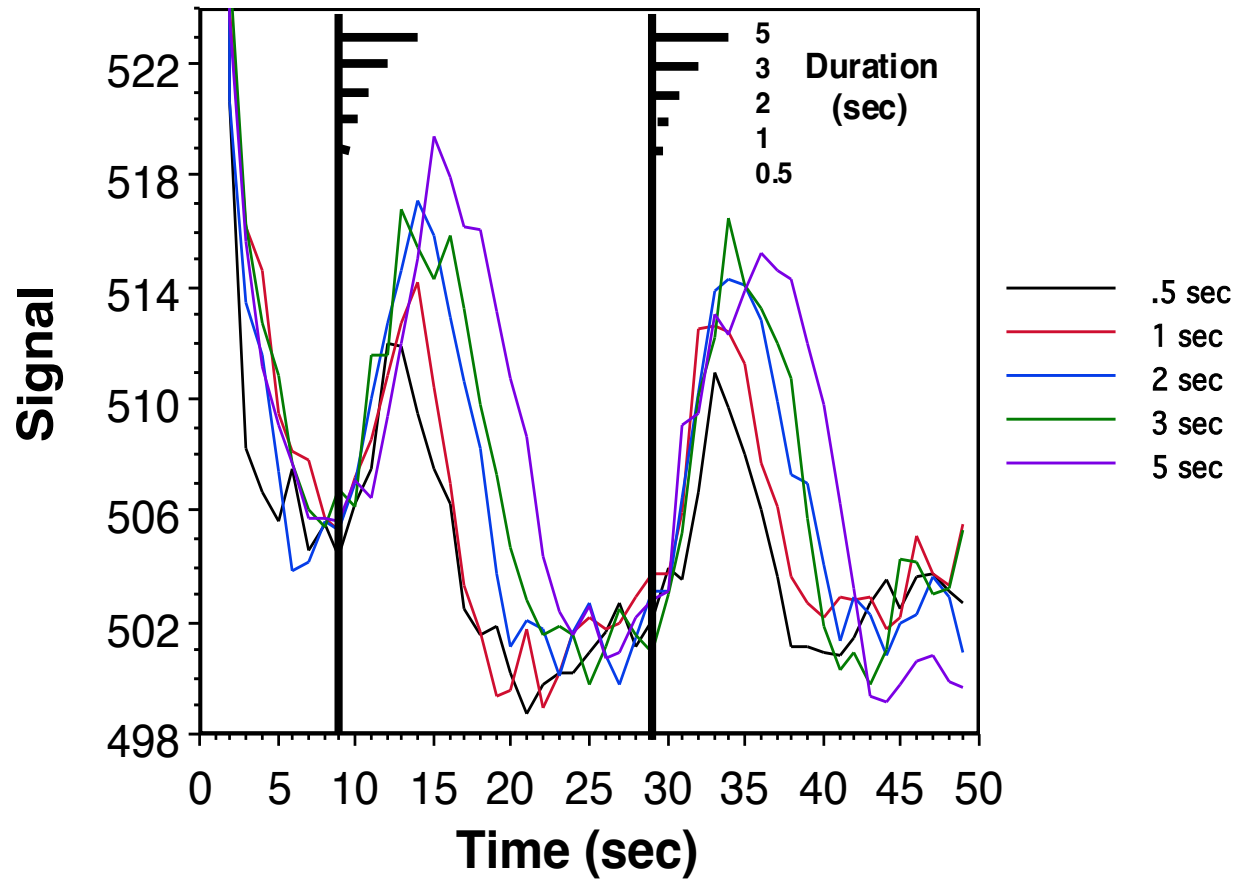


P. A. Bandettini, K. K. Kwong, T. L. Davis, R. B. H. Tootell, E. C. Wong, P. T. Fox, J. W. Belliveau, R. M. Weisskoff, B. R. Rosen, (1997). "Characterization of cerebral blood oxygenation and flow changes during prolonged brain activation." *Human Brain Mapping* 5, 93-109.



R. L. Savoy, et al., Pushing the temporal resolution of fMRI: studies of very brief visual stimuli, onset variability and asynchrony, and stimulus-correlated changes in noise [oral], 3rd Proc. Soc. Magn. Reson., Nice, p. 450. (1995).

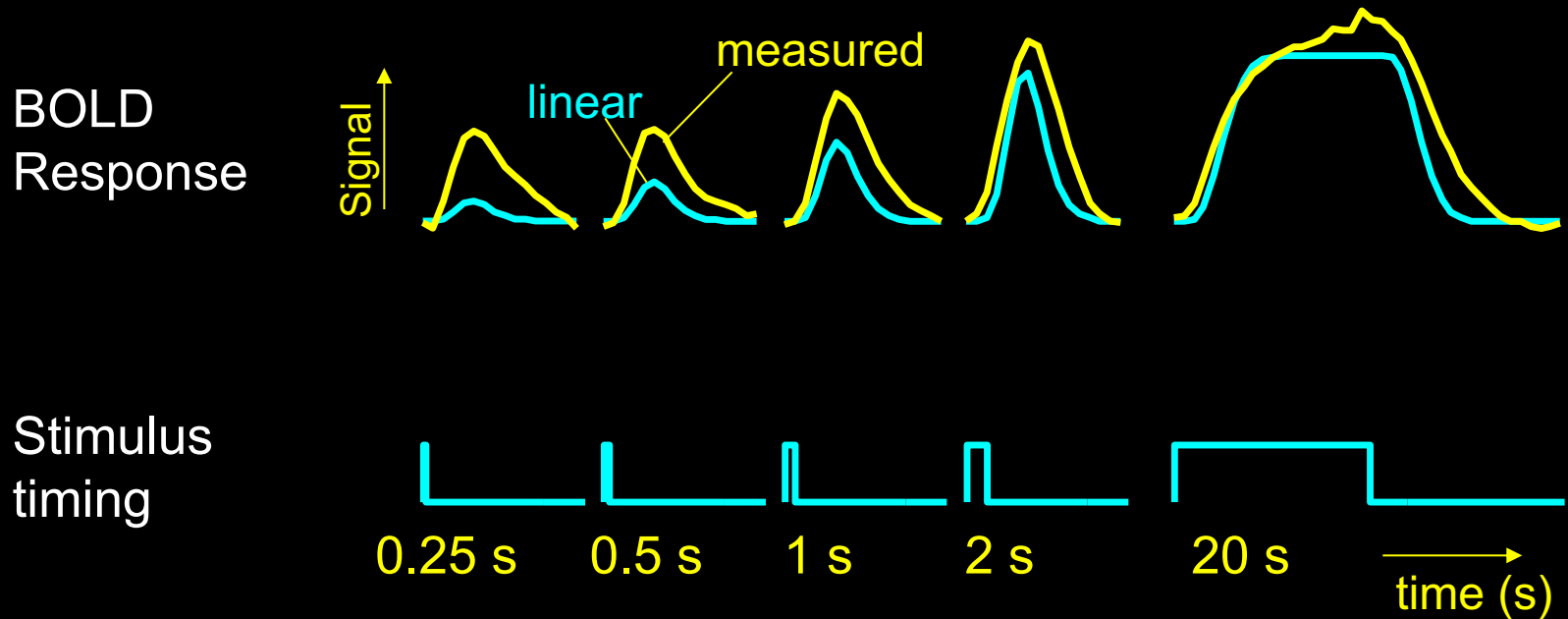
Motor Cortex



Bandettini, et al., The functional dynamics of blood oxygenation level contrast in the motor cortex, 12'th Proc. Soc. Magn. Reson. Med., New York, p. 1382. (1993).

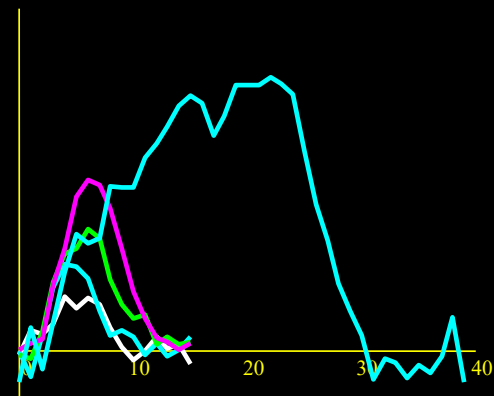
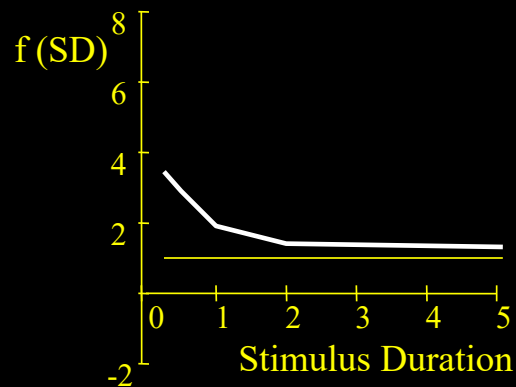
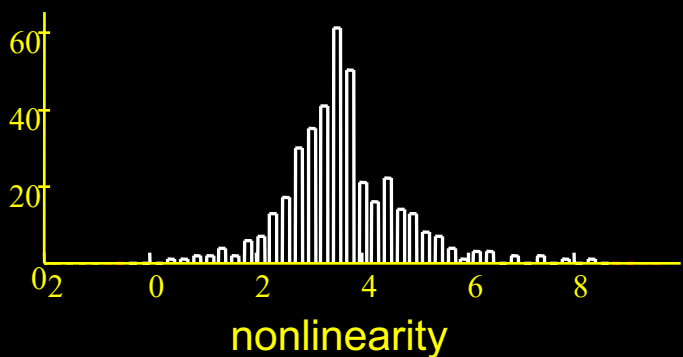
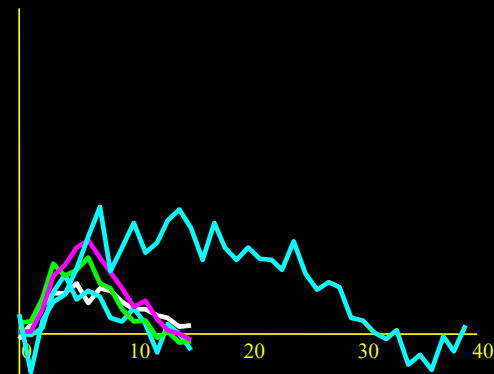
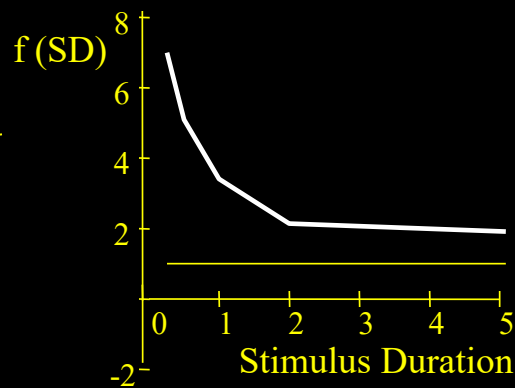
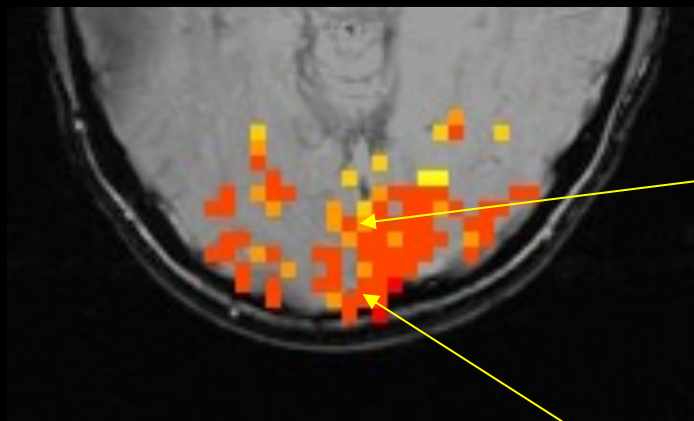
Dynamic Nonlinearity Assessment

Different stimulus “ON” periods



Brief stimuli produce larger responses than expected

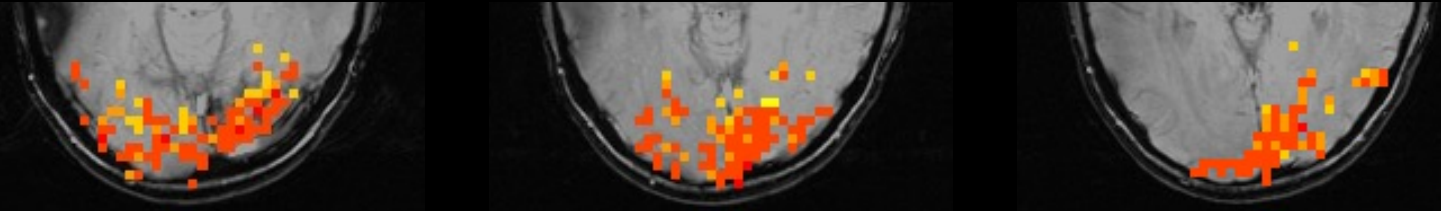
Spatial Heterogeneity of BOLD Nonlinearity



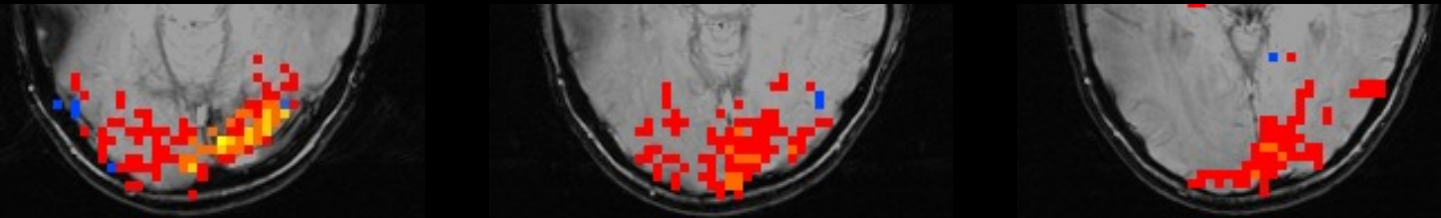
R. M. Birn, Z. Saad, P. A. Bandettini, (2001) "Spatial heterogeneity of the nonlinear dynamics in the fMRI BOLD response." *NeuroImage*, 14: 817-826.

Results – visual task

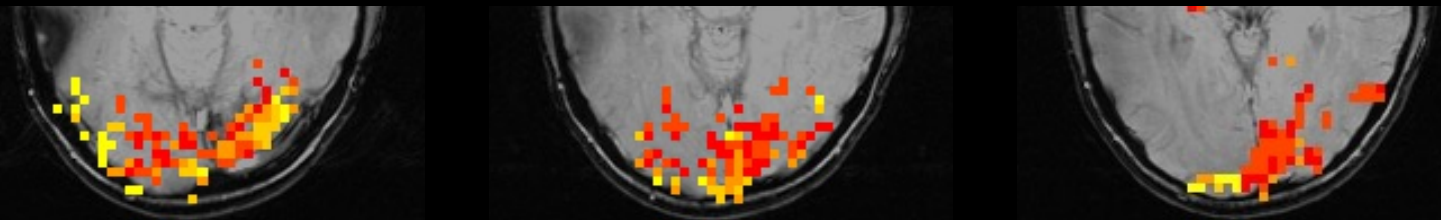
Nonlinearity



Magnitude

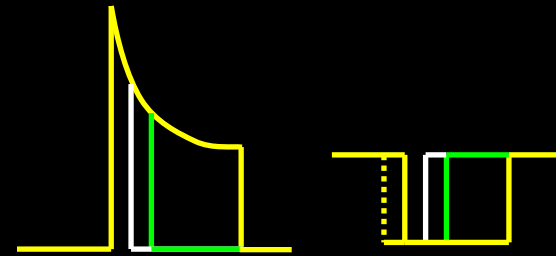
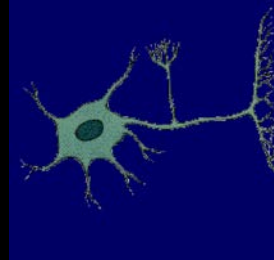


Latency



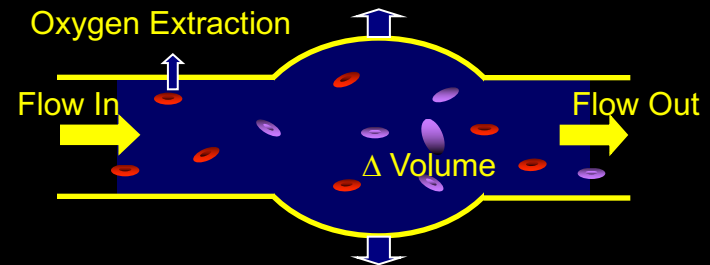
Sources of this Nonlinearity

- Neuronal



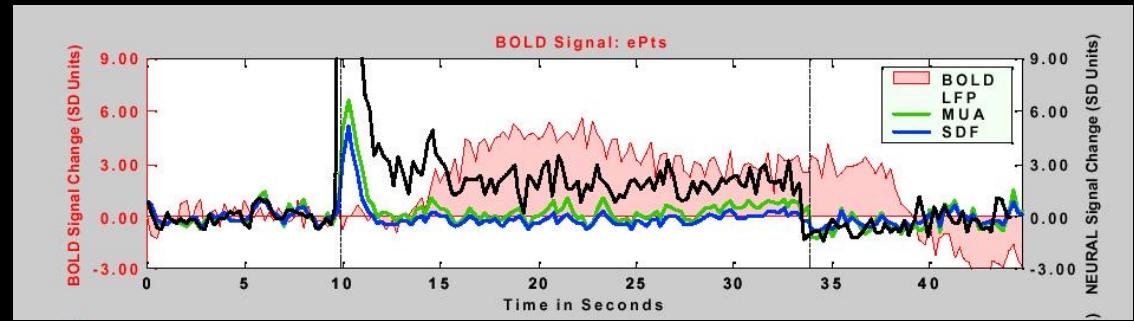
- Hemodynamic

- Oxygen extraction
- Blood volume dynamics

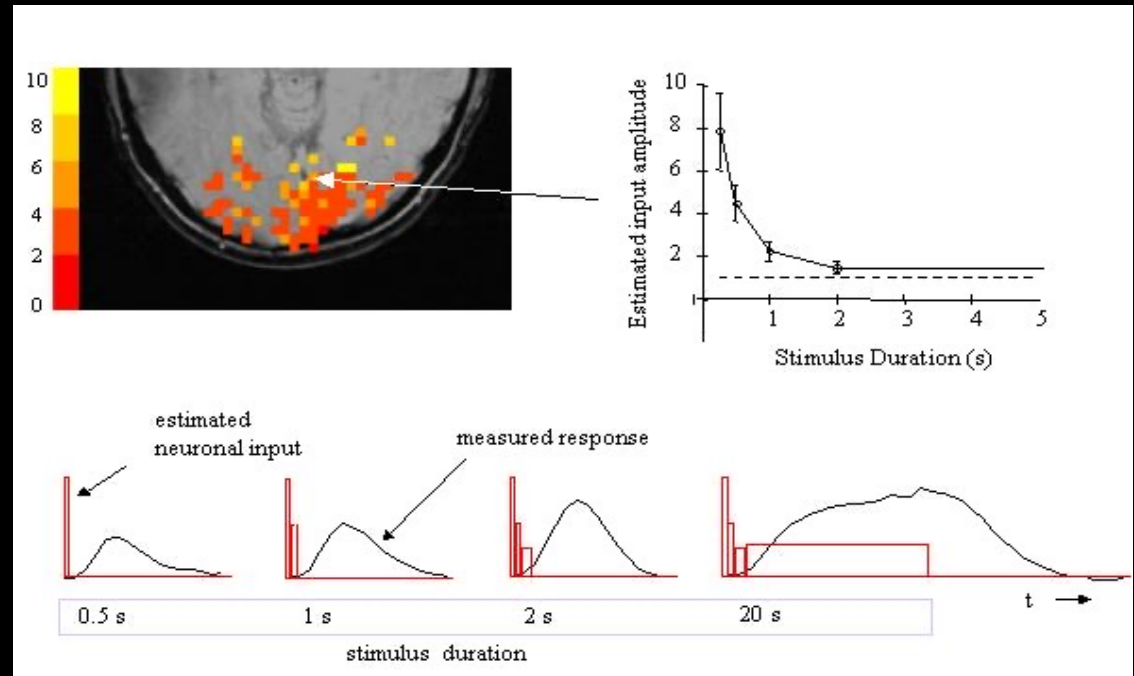


BOLD Correlation with Neuronal Activity

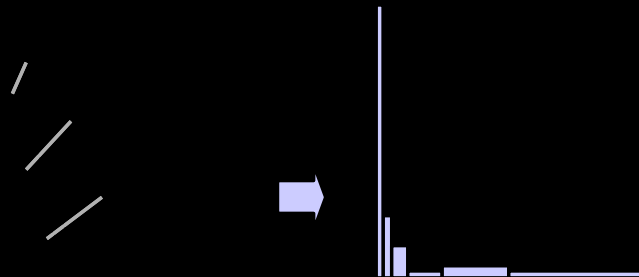
Logothetis et al. (2001)
“Neurophysiological investigation
of the basis of the fMRI signal”
Nature, 412, 150-157.



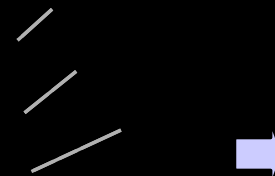
P. A. Bandettini and L. G. Ungerleider, (2001) “From neuron
to BOLD: new connections.”
Nature Neuroscience, 4: 864-866.



Stationary grating



Contrast-reversing checkerboard



Refinements

BOLD Contrast Interpretation

Paradigm Design and Processing

Neuronal
Activation



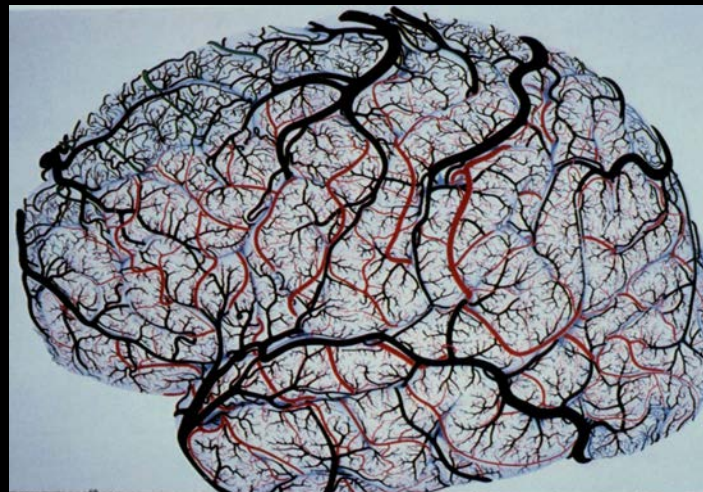
Measured
Signal

Hemodynamics

?

?

?



Noise

Neuronal Activation Input Strategies

1. Block Design

2. Parametric Design

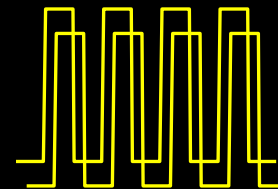
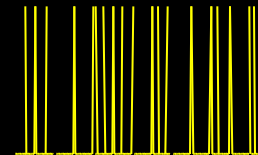
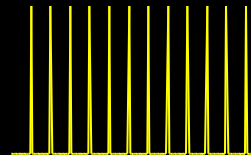
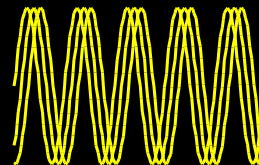
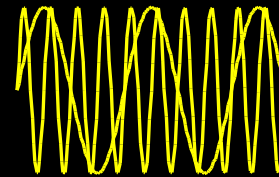
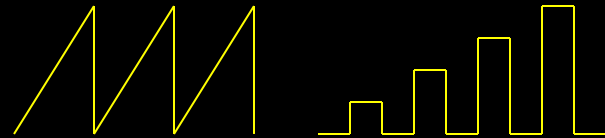
3. Frequency Encoding

4. Phase Encoding

5. Event Related

6. Orthogonal Design

7. Free Behavior Design



Neuronal Activation Input Strategies

1. Block Design

2. Parametric Design

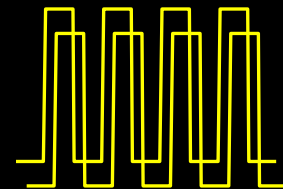
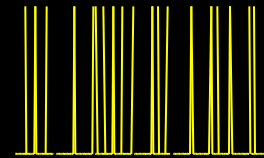
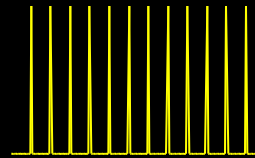
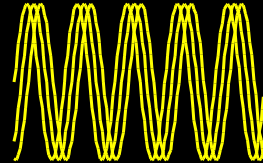
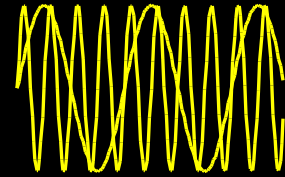
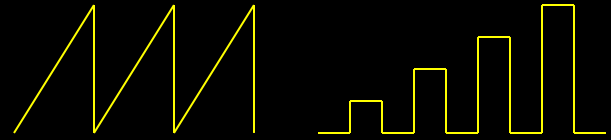
3. Frequency Encoding

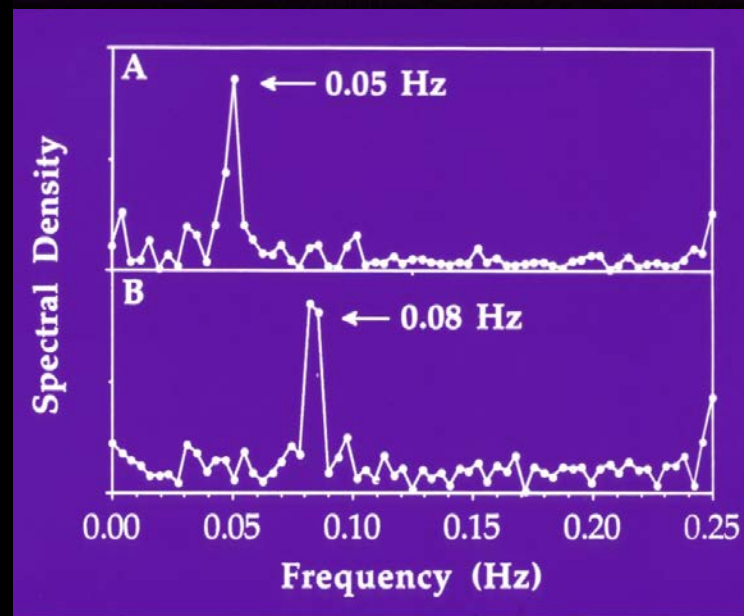
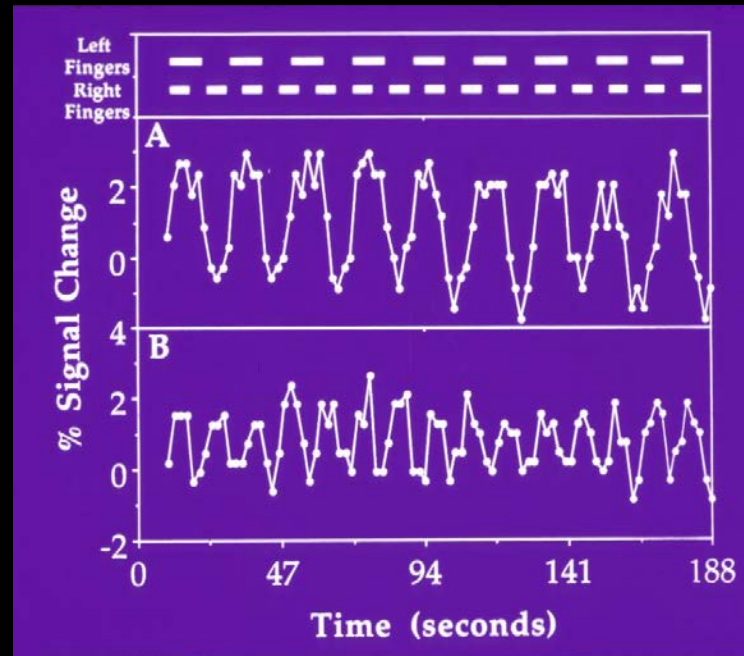
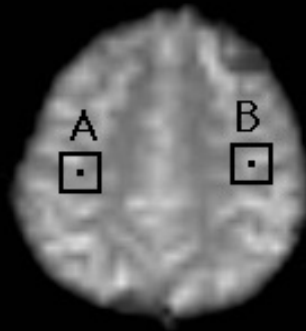
4. Phase Encoding

5. Event Related

6. Orthogonal Design

7. Free Behavior Design



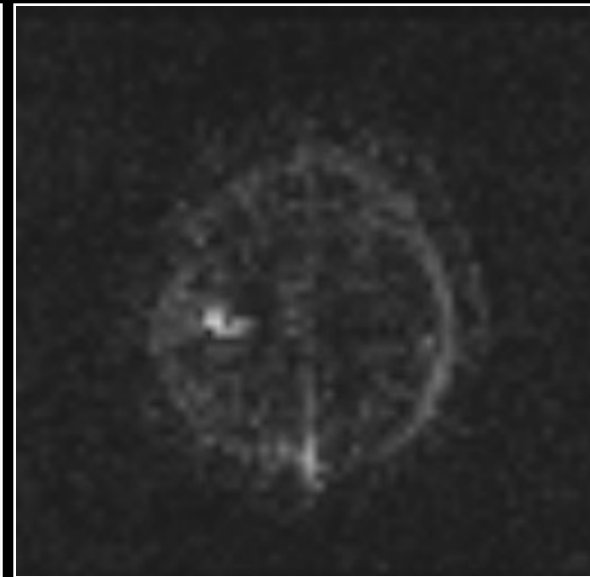
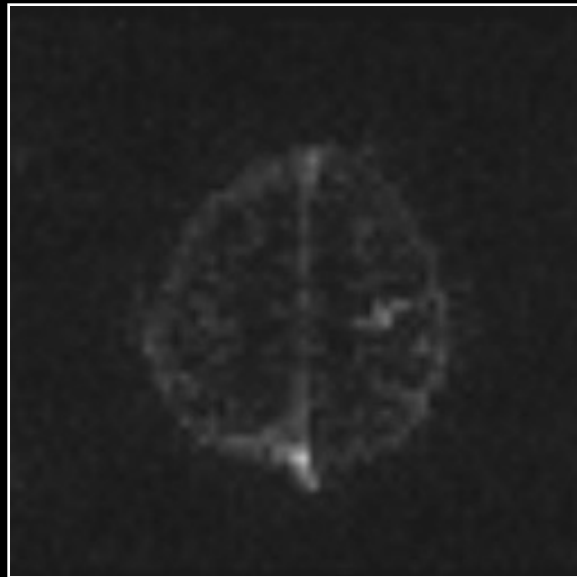


P. A. Bandettini, A. Jesmanowicz, E. C. Wong, J. S. Hyde, Processing strategies for time-course data sets in functional MRI of the human brain. *Magn. Reson. Med.* 30, 161-173 (1993).

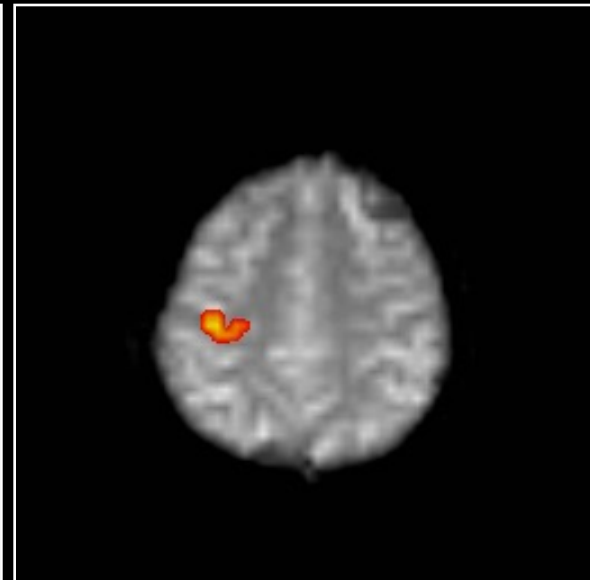
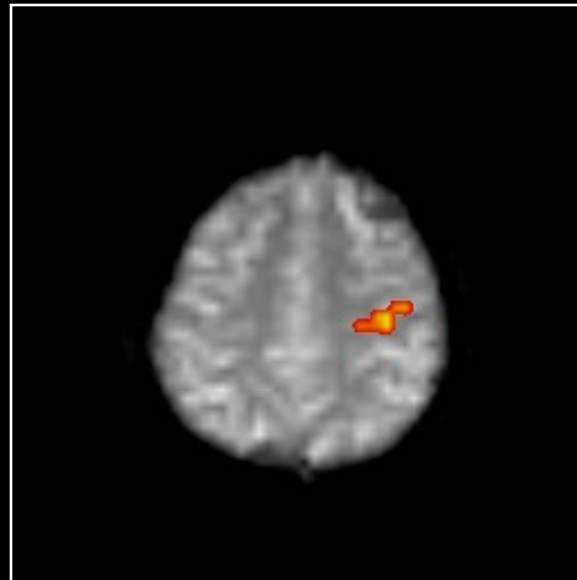
0.08 Hz

0.05 Hz

**spectral
density**



**c.c. > 0.5
with spectra**



P. A. Bandettini, A. Jesmanowicz, E. C. Wong, J. S. Hyde, Processing strategies for time-course data sets in functional MRI of the human brain. *Magn. Reson. Med.* 30, 161-173 (1993).

Neuronal Activation Input Strategies

1. Block Design

2. Parametric Design

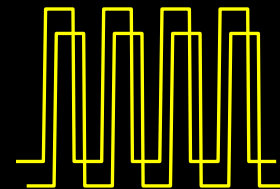
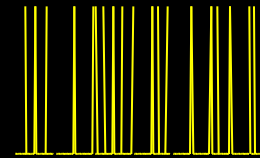
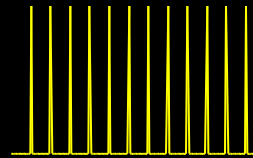
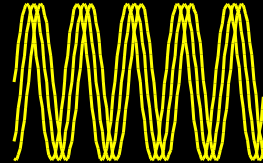
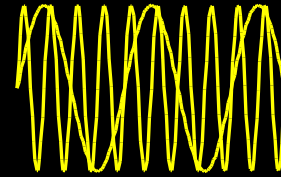
3. Frequency Encoding

4. Phase Encoding

5. Event Related

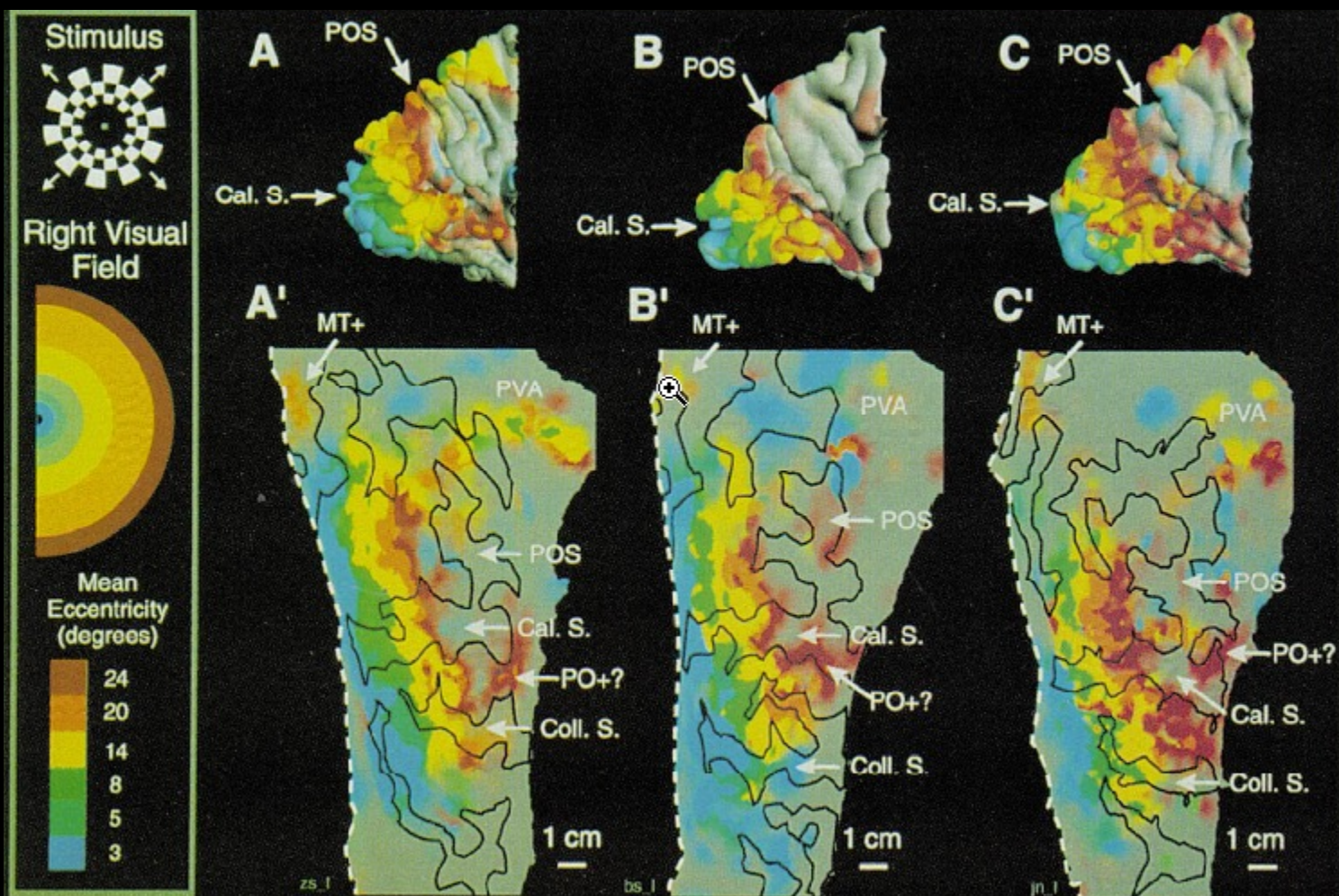
6. Orthogonal Design

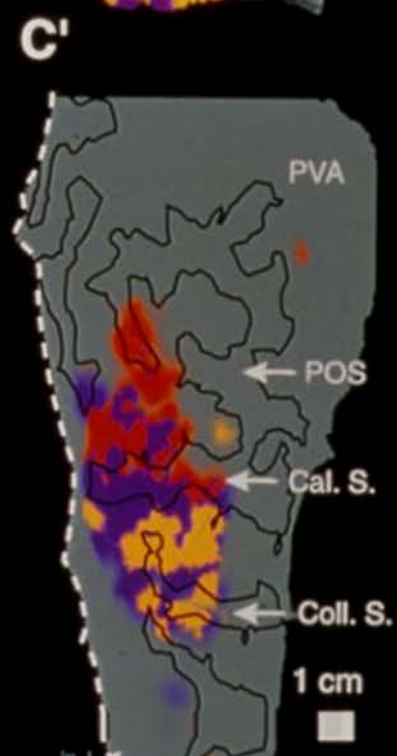
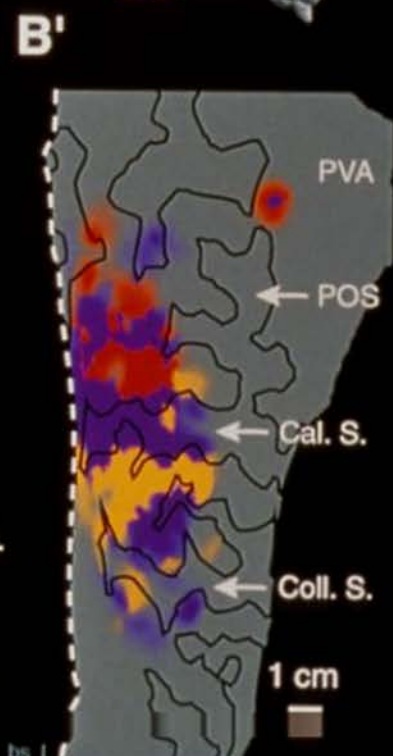
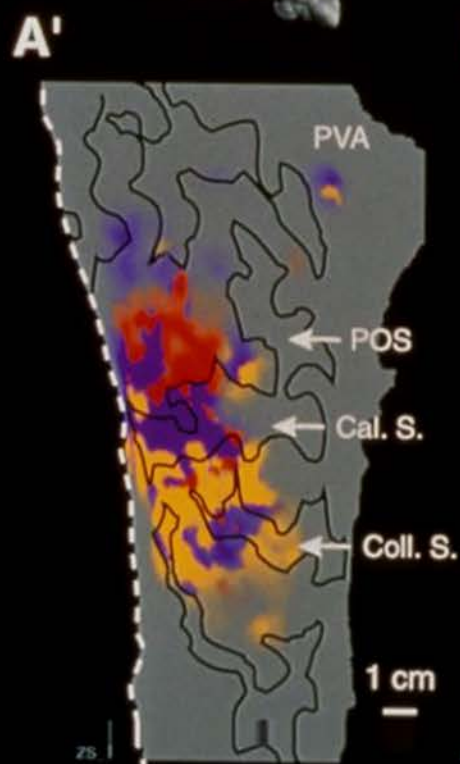
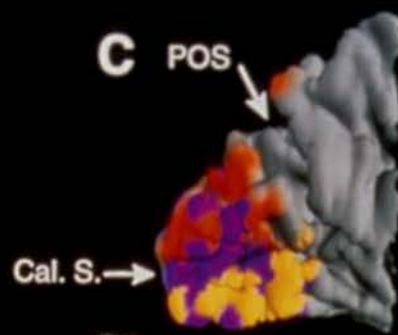
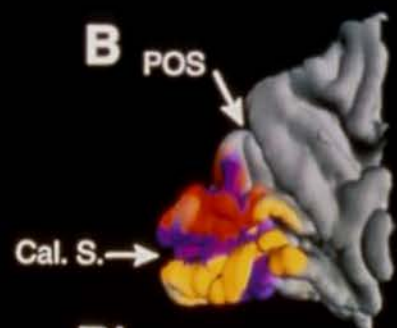
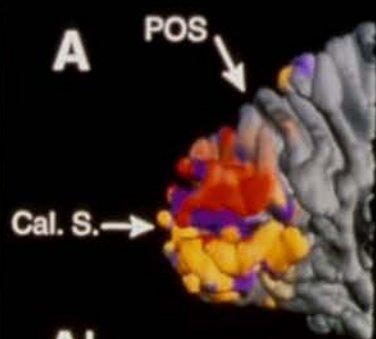
7. Free Behavior Design



Mapping striate and extrastriate visual areas in human cerebral cortex

EDGAR A. DEYOE*, GEORGE J. CARMAN†, PETER BANDETTINI‡, SETH GLICKMAN*, JON WIESER*, ROBERT COX§, DAVID MILLER¶, AND JAY NEITZ*





Neuronal Activation Input Strategies

1. Block Design

2. Parametric Design

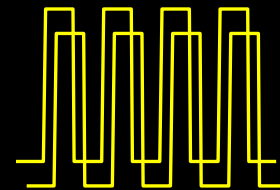
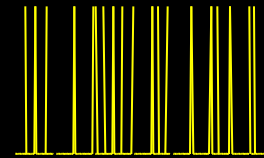
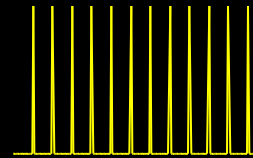
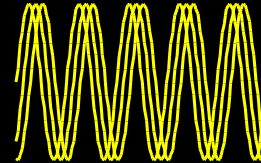
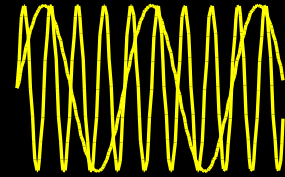
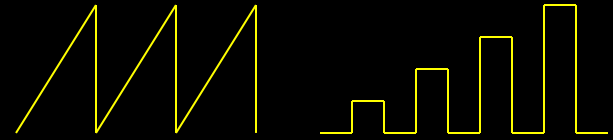
3. Frequency Encoding

4. Phase Encoding

5. Event Related

6. Orthogonal Design

7. Free Behavior Design

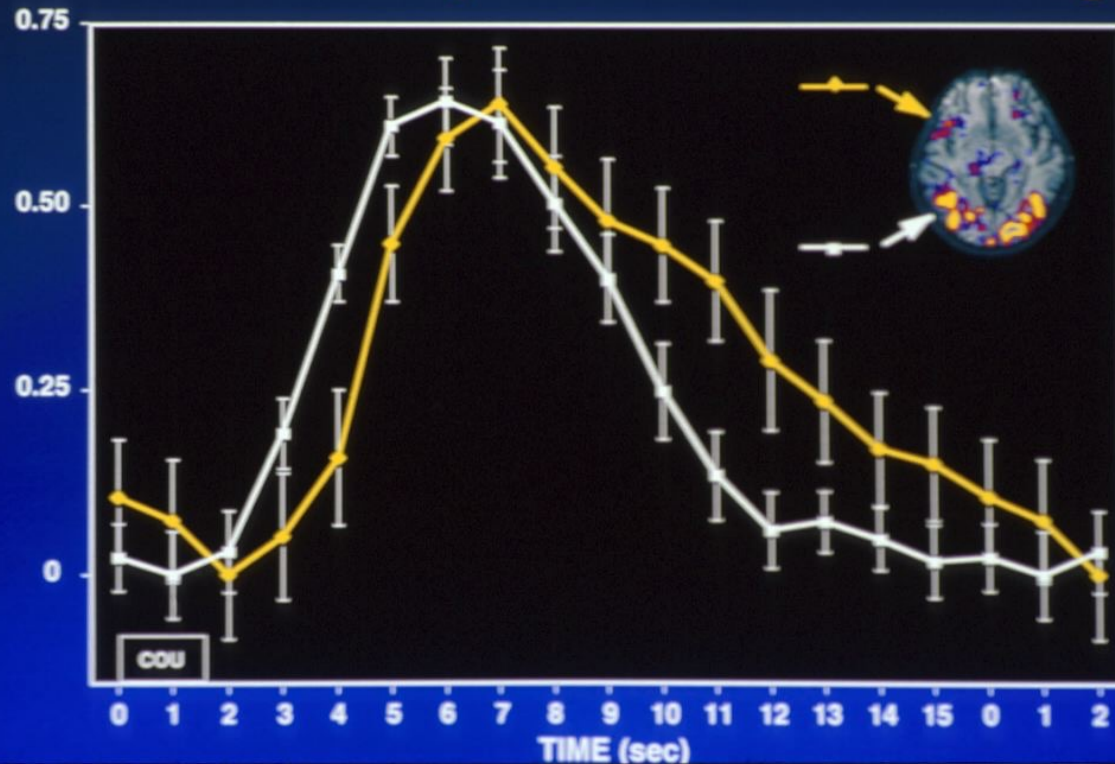


Detection of cortical activation during averaged single trials of a cognitive task using functional magnetic resonance imaging

(neuroimaging/single trial/language/prefrontal)

RANDY L. BUCKNER^{†‡§¶}, PETER A. BANDETTINI^{†‡}, KATHLEEN M. O'CRAVEN^{†||}, ROBERT L. SAVOY^{†||},
STEVEN E. PETERSEN^{**††}, MARCUS E. RAICHEL^{§**††}, AND BRUCE R. ROSEN^{†‡}

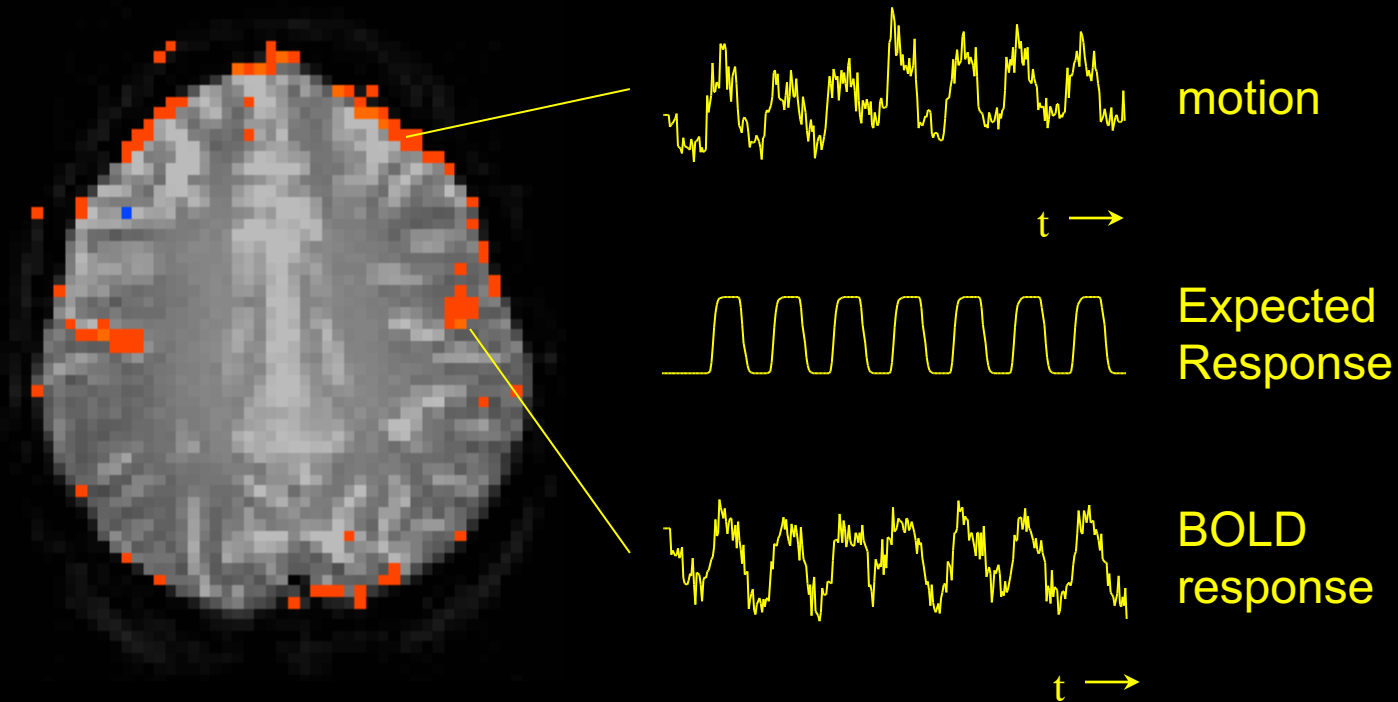
Time Course Comparison Across Brain Regions



Event Related Advantages

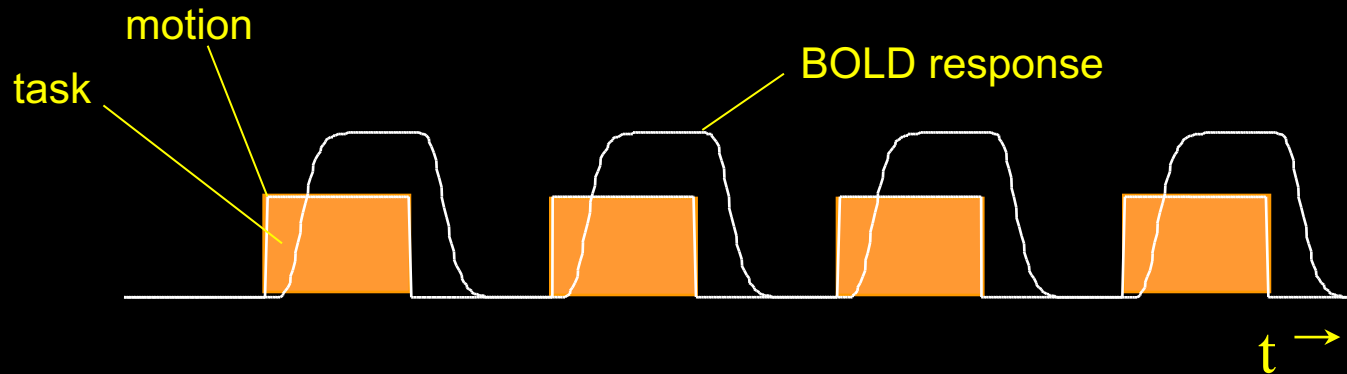
- Task Randomization
- Post acquisition, Performance-based, data binning
- Natural presentation
- Reduction of habituation effects
- Overt responses
- Reduction of scanner noise effects
- More precise estimation of hemodynamic responses

Speaking - Blocked Trial

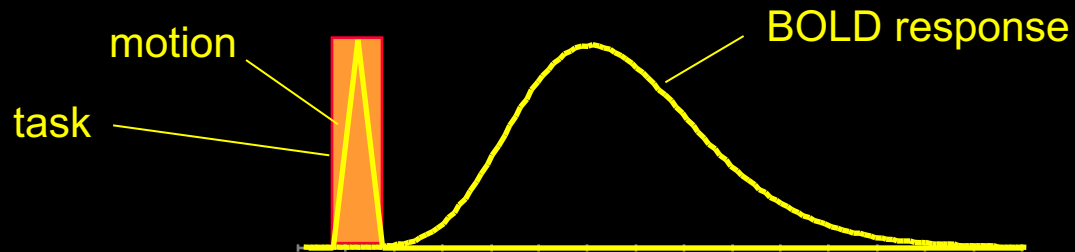


fMRI during tasks that involve brief motion

Blocked Design

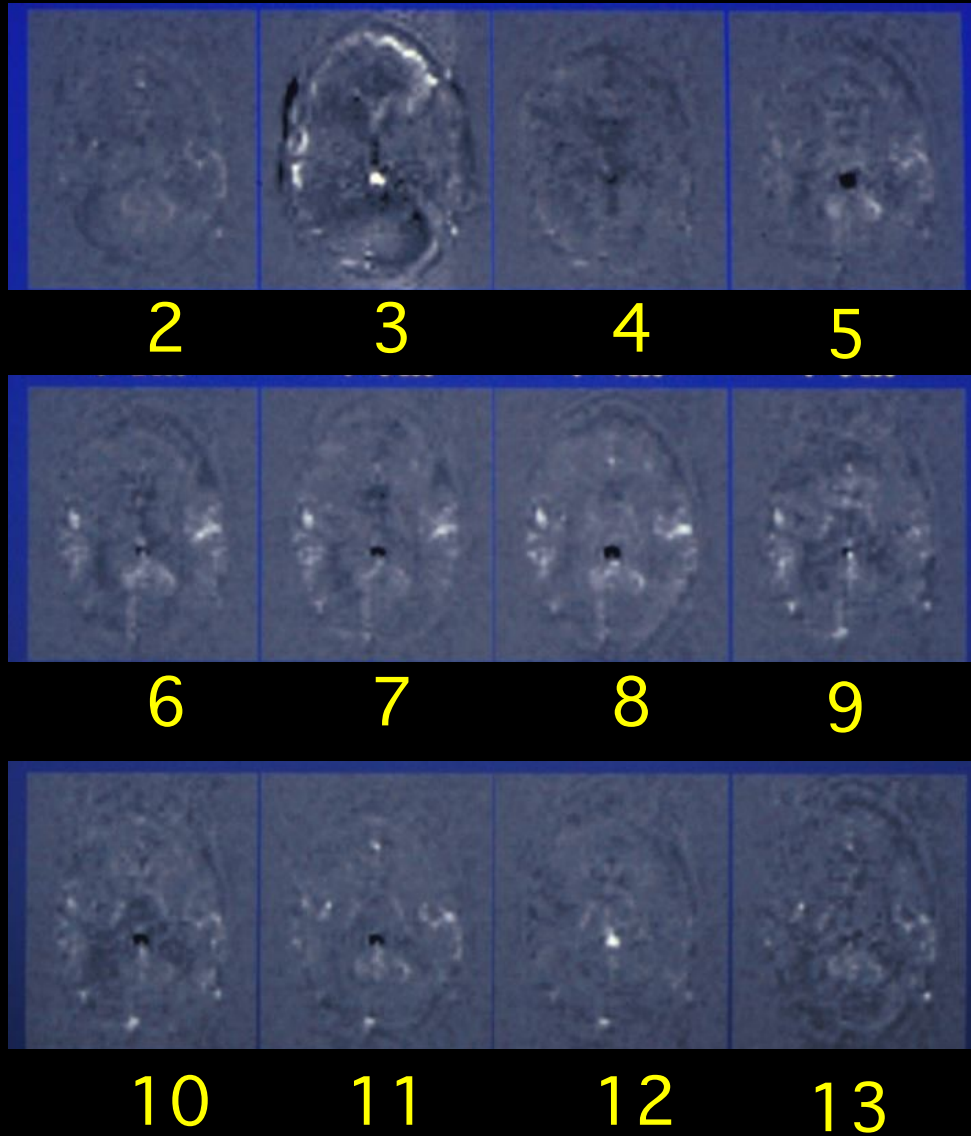


Event-Related Design



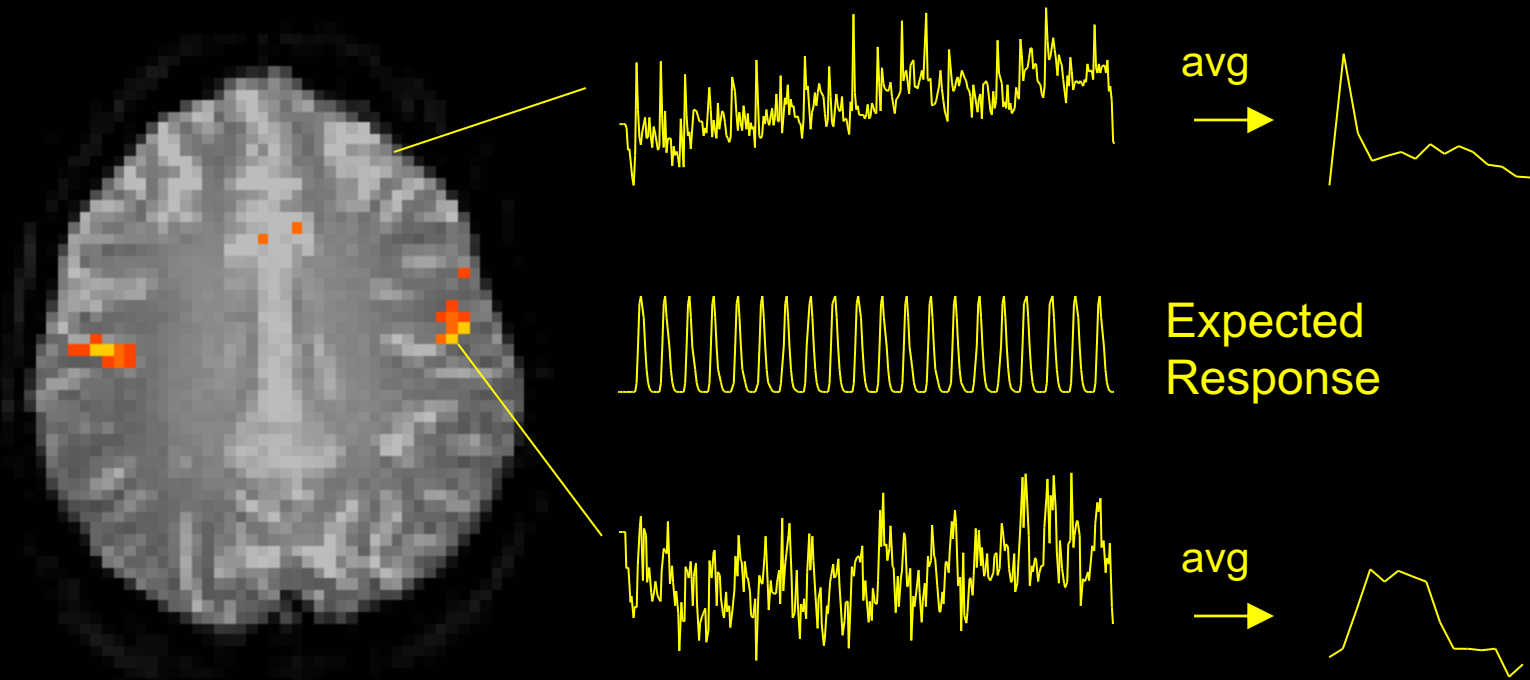
R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

Overt Word Production



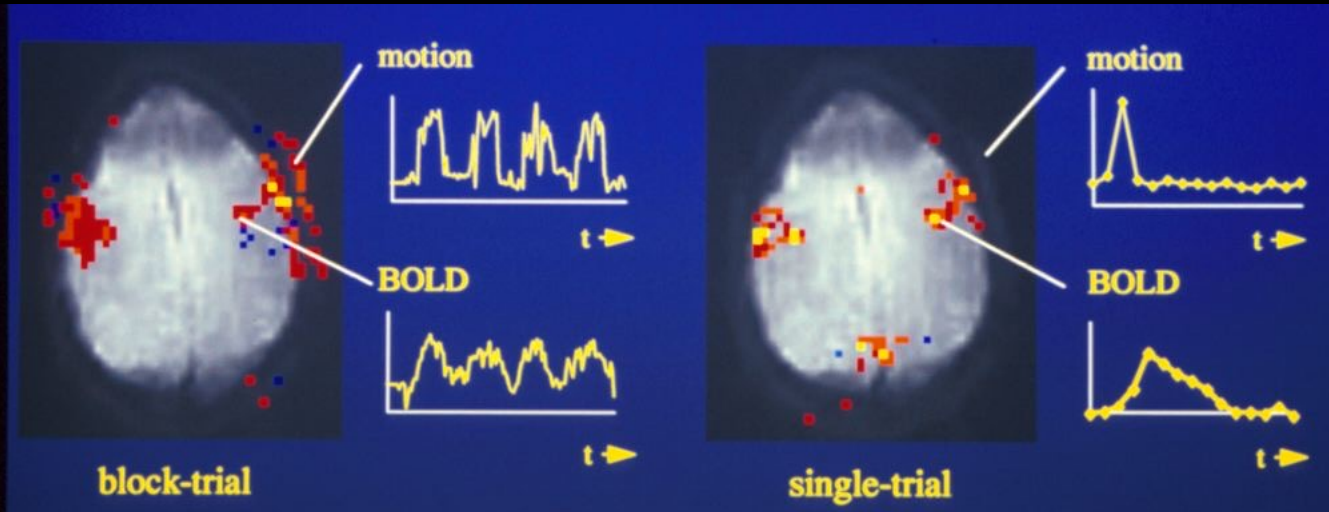
R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

Speaking - ER-fMRI

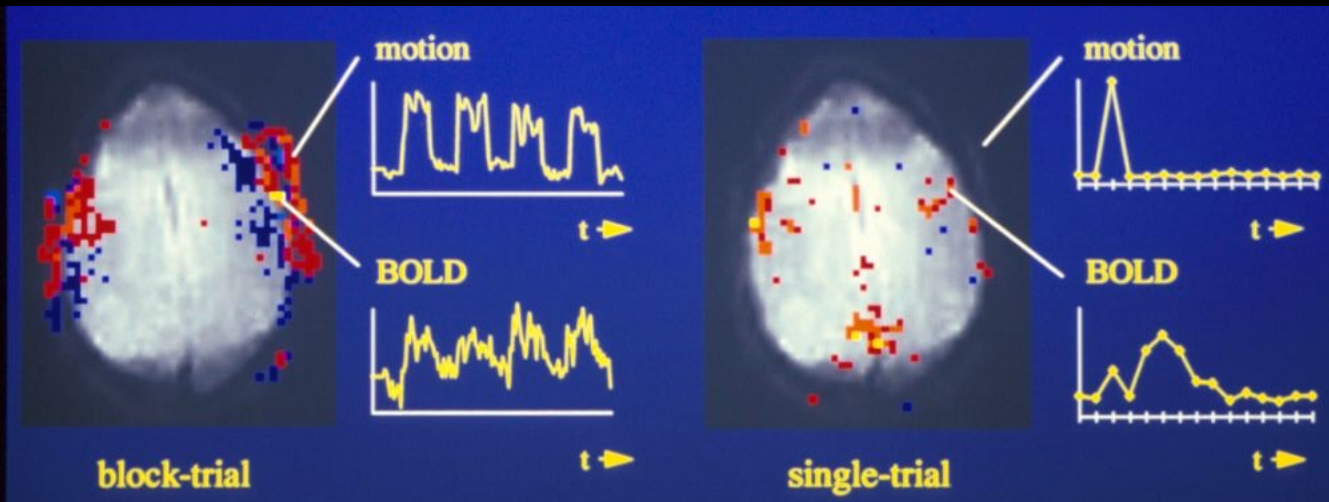


R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

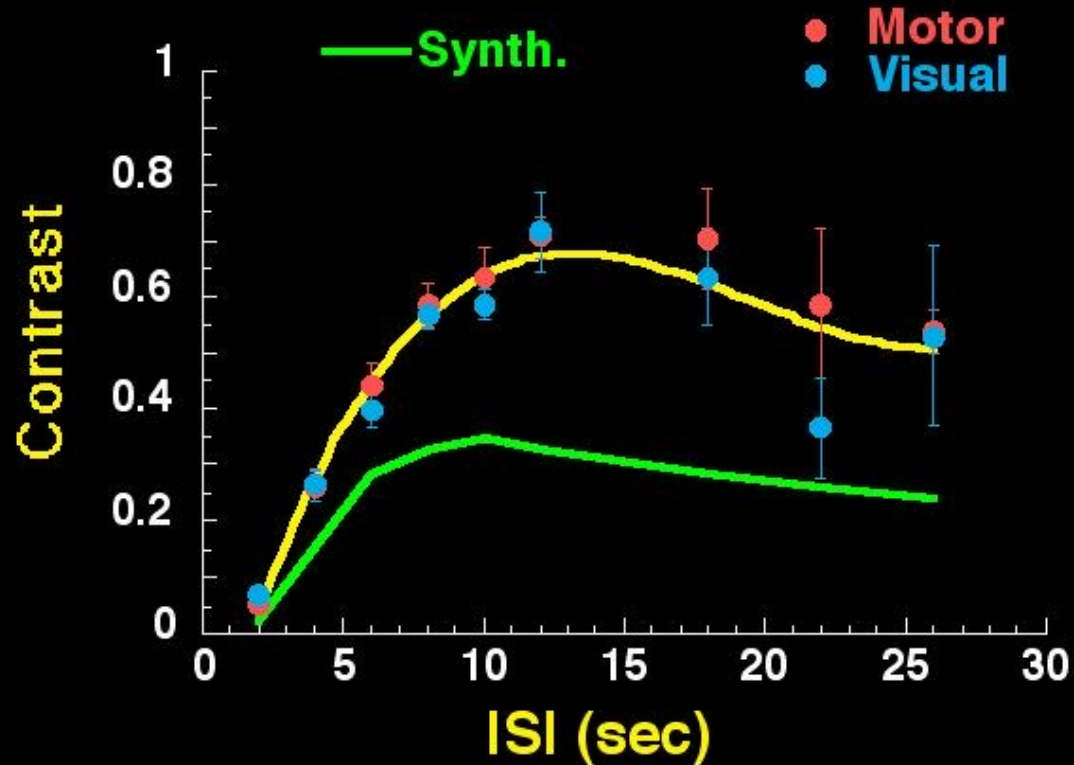
Tongue Movement



Jaw Clenching



Functional Contrast



(Block design = 1)

P. A. Bandettini, R. W. Cox. Functional contrast in constant interstimulus interval event - related fMRI: theory and experiment. *Magn. Reson. Med.* 43: 540-548 (2000).

Contrast to Noise Images

(ISI, SD)

20, 20

12, 2

10, 2

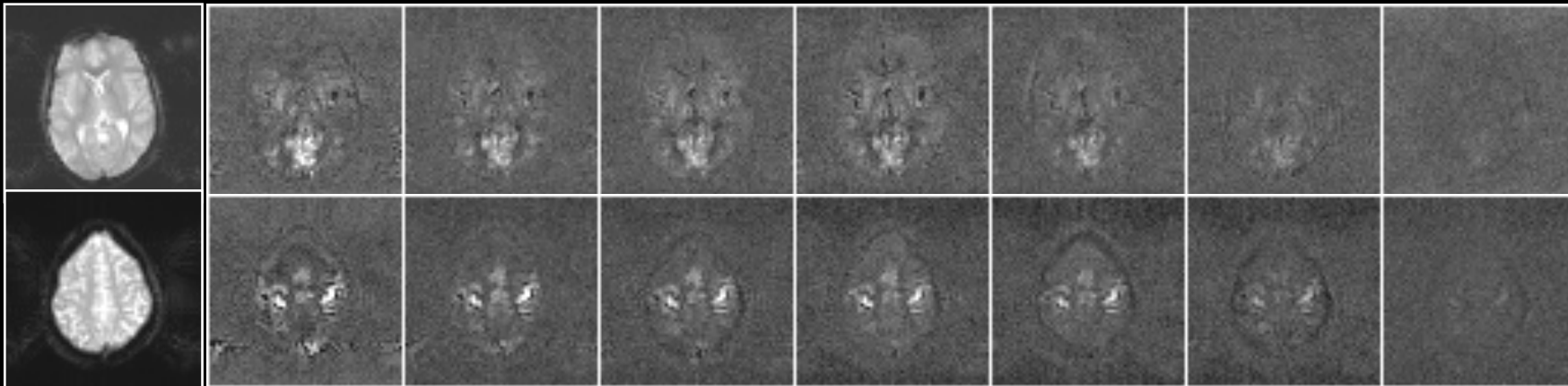
8, 2

6, 2

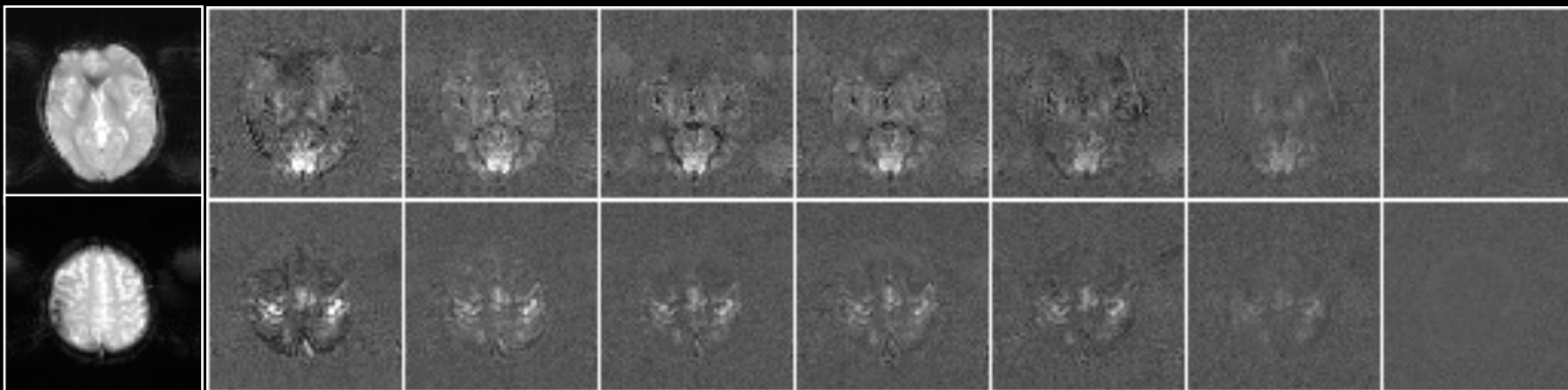
4, 2

2, 2

S1



S2

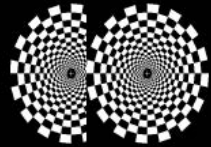


P. A. Bandettini, R. W. Cox. Functional contrast in constant interstimulus interval event - related fMRI: theory and experiment. *Magn. Reson. Med.* 43: 540-548 (2000).



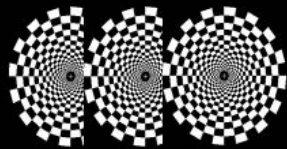
0 sec

20 sec



0 sec 2 sec

20 sec



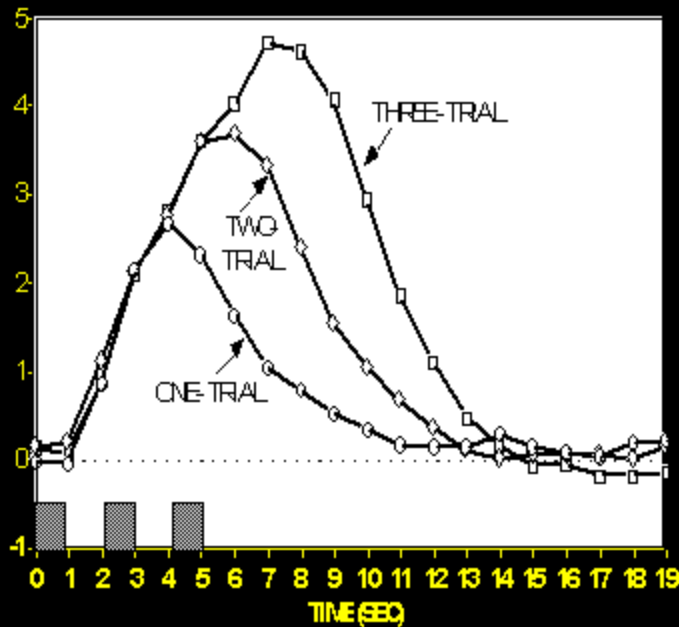
0 sec 2 sec 4 sec

20 sec

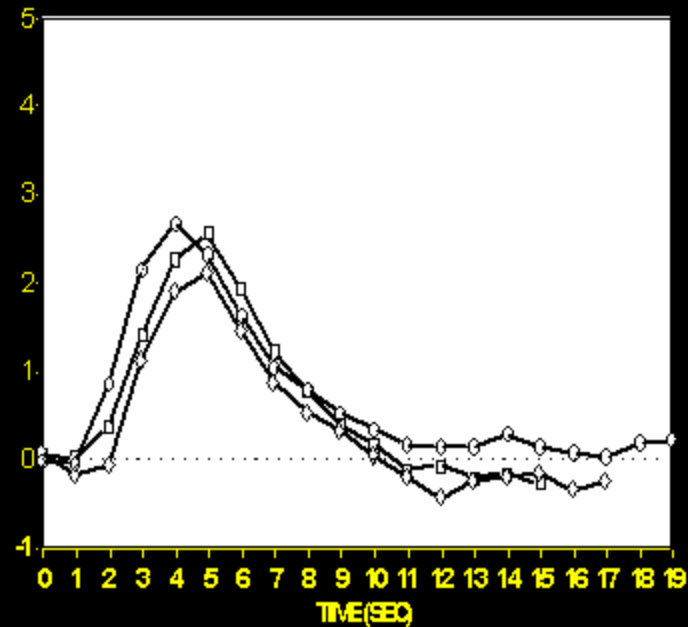
Selective Averaging of Rapidly Presented Individual Trials Using fMRI

Anders M. Dale* and Randy L. Buckner

RAW DATA



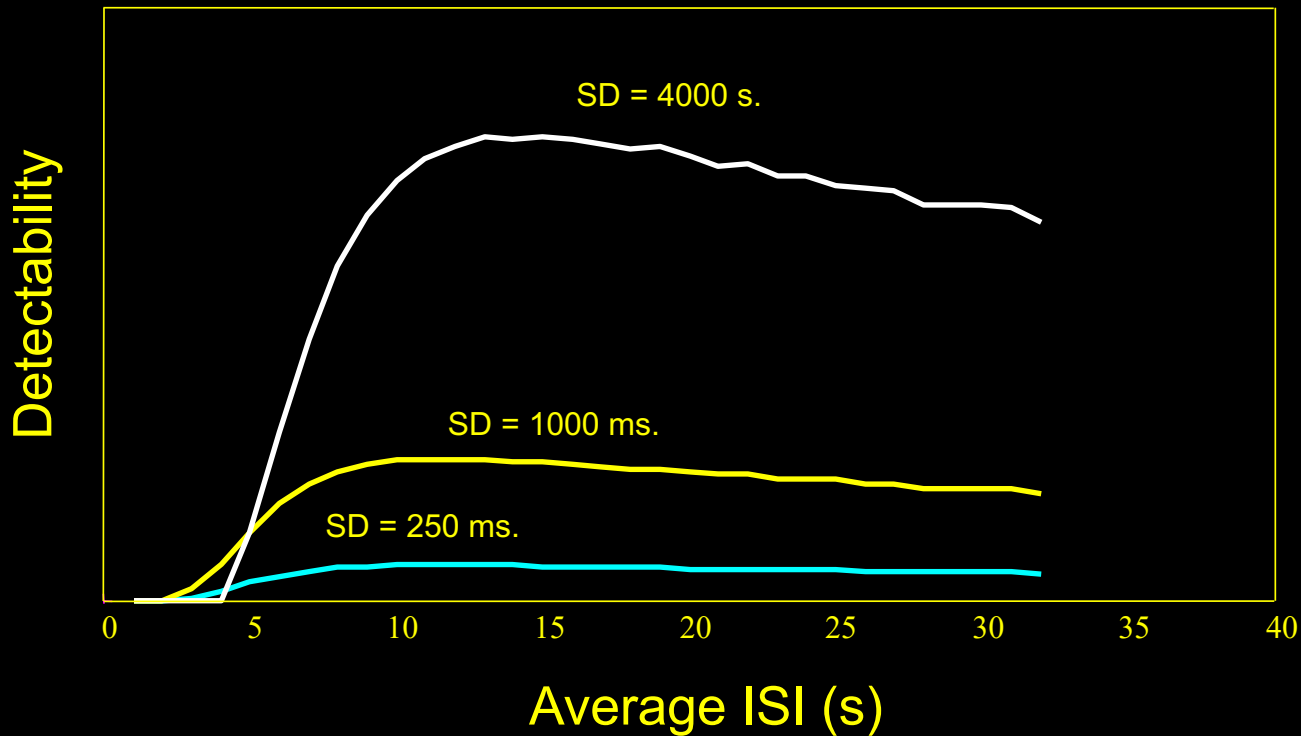
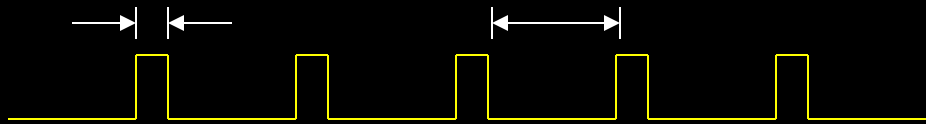
ESTIMATED RESPONSES



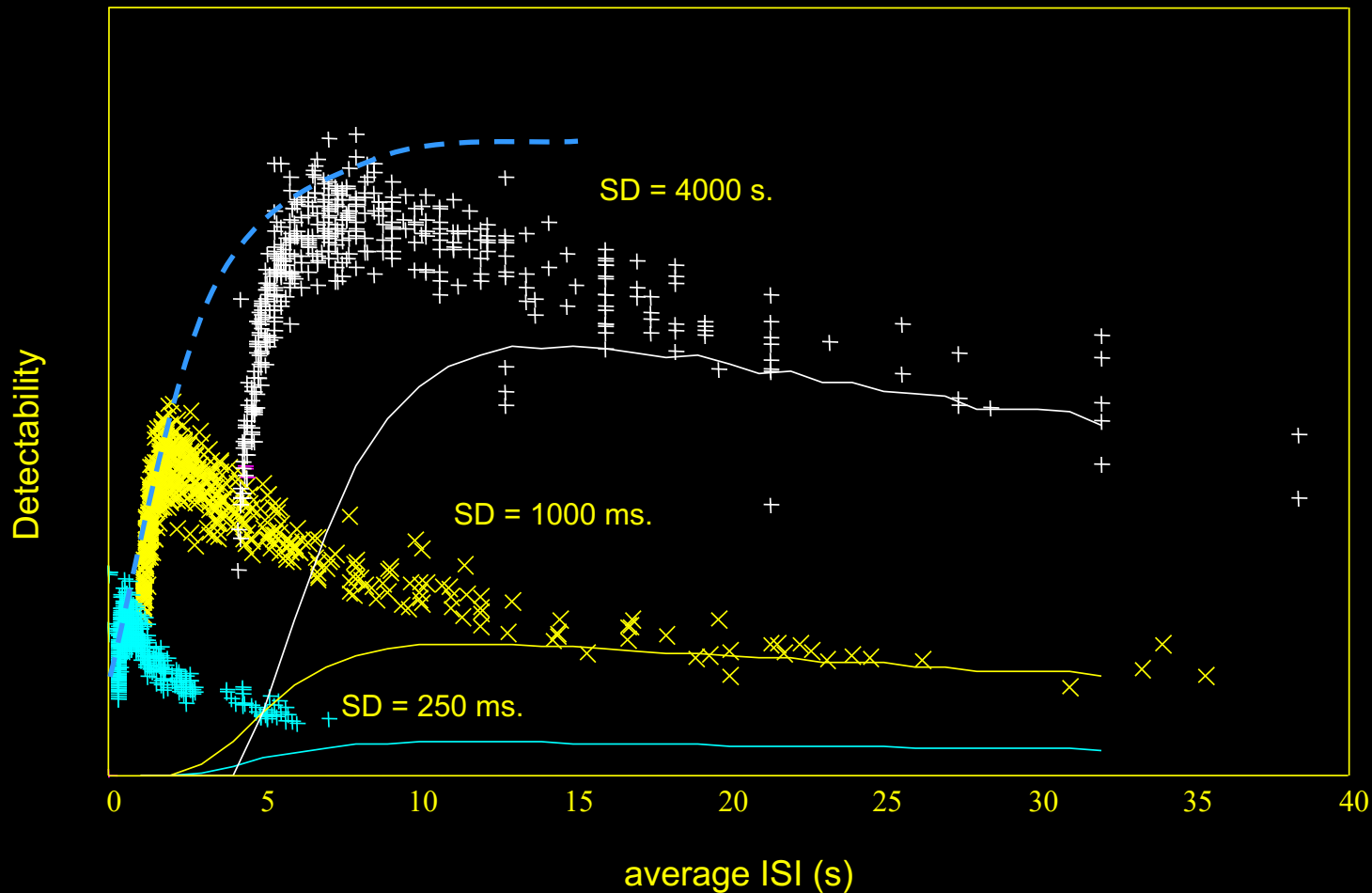
Detectability – constant ISI

SD – stimulus duration

ISI – inter-stimulus interval

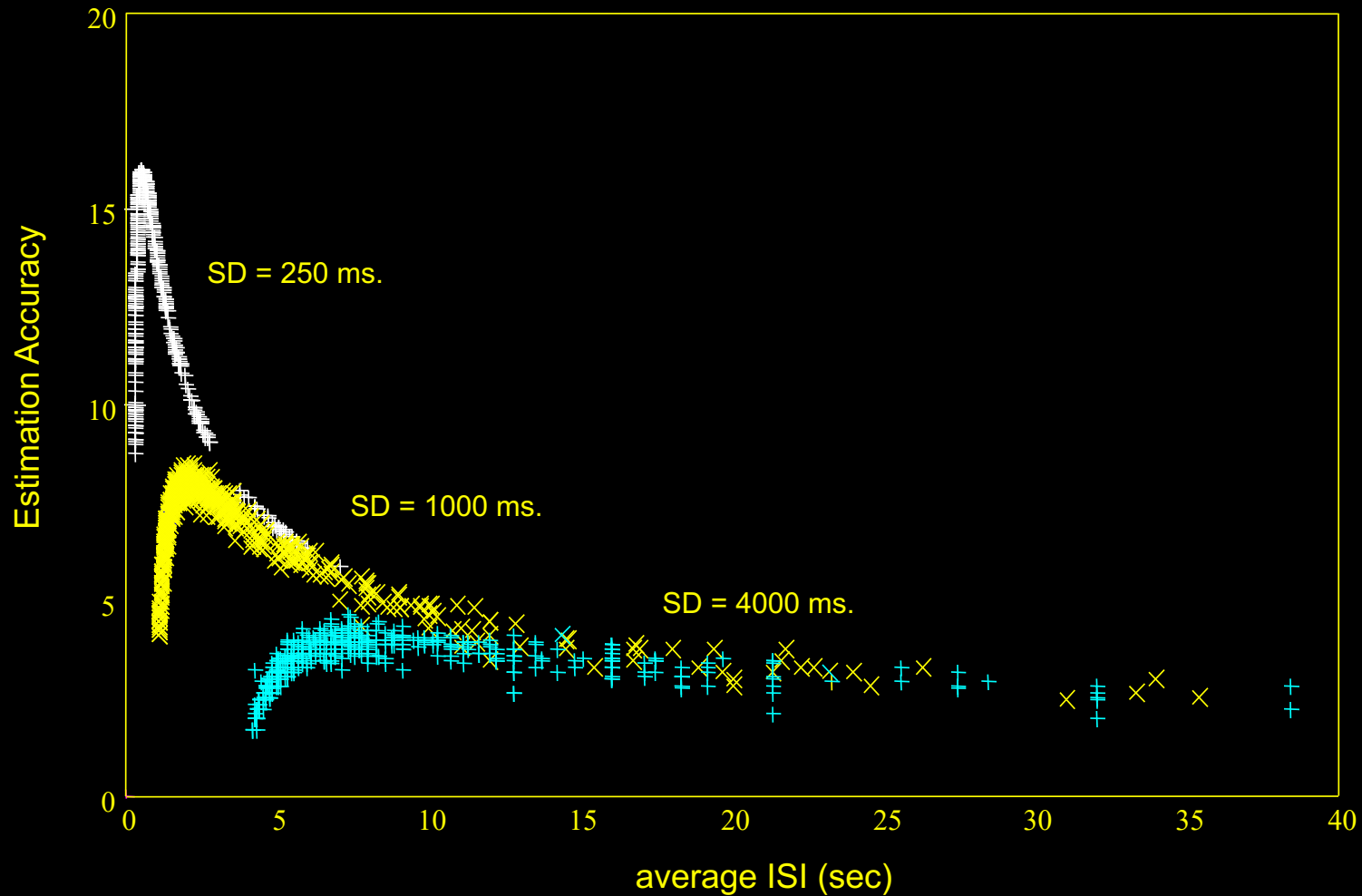


Detectability vs. Average ISI



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).

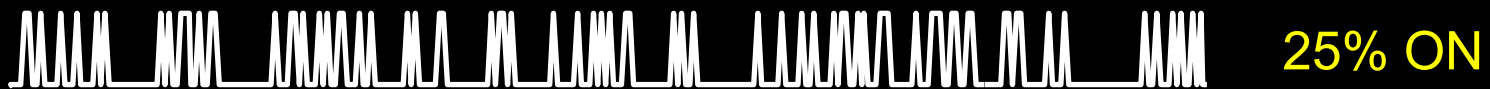
Estimation accuracy vs. average ISI



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).

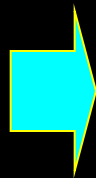
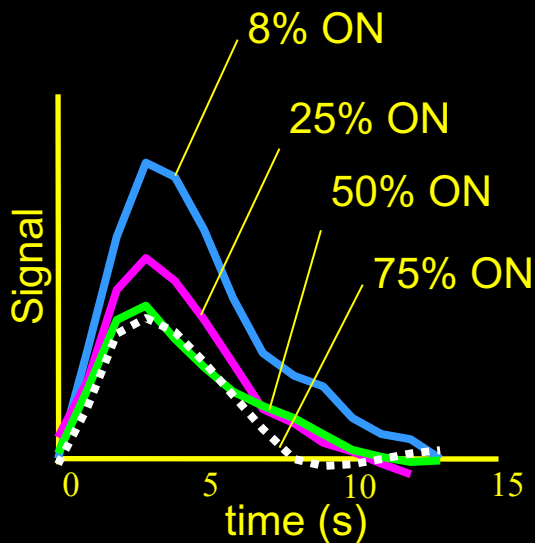
Varying “ON” and “OFF” periods

- *Rapid event-related design with varying ISI*

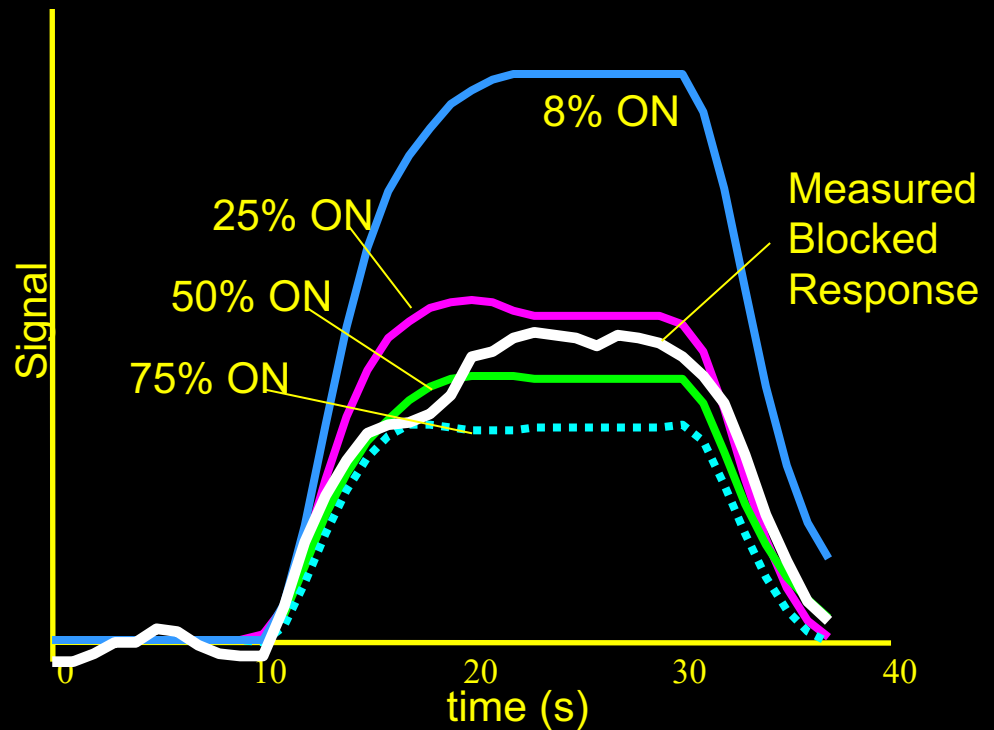


Varying “ON” and “OFF” periods

*Estimated
Impulse Response*



*Predicted Responses
to 20 s stimulation*



Neuronal Activation Input Strategies

1. Block Design

2. Parametric Design

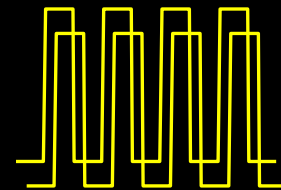
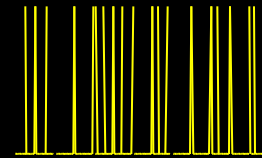
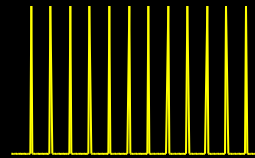
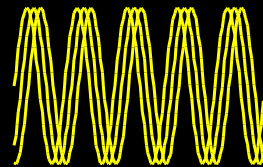
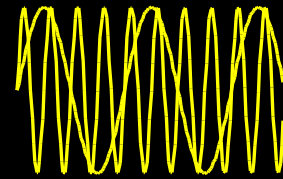
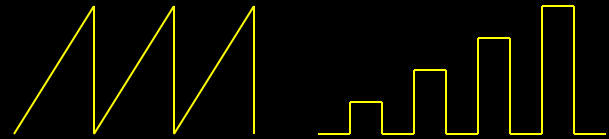
3. Frequency Encoding

4. Phase Encoding

5. Event Related

6. Orthogonal Design

7. Free Behavior Design

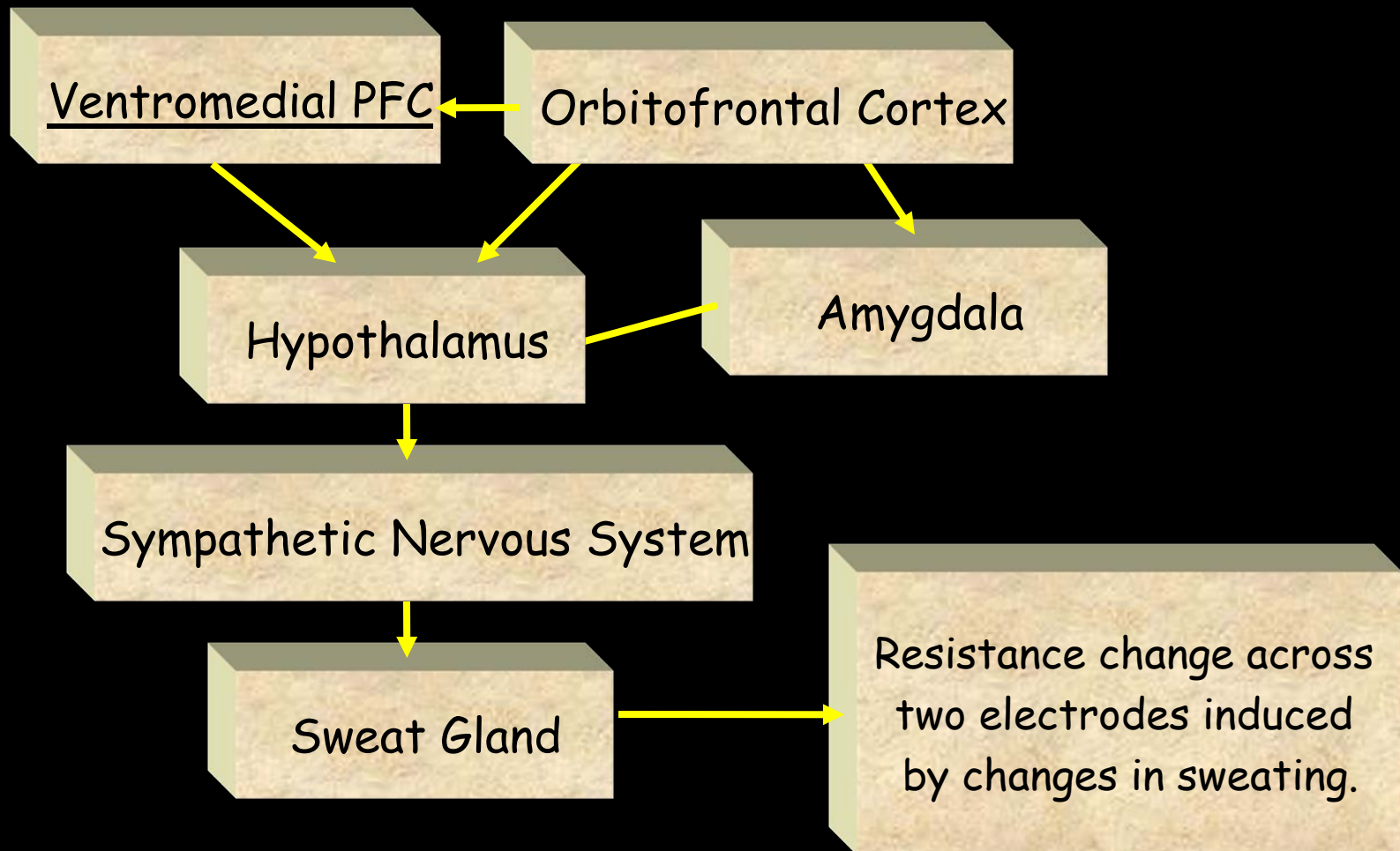


Free Behavior Design

Use a continuous measure as a reference function:

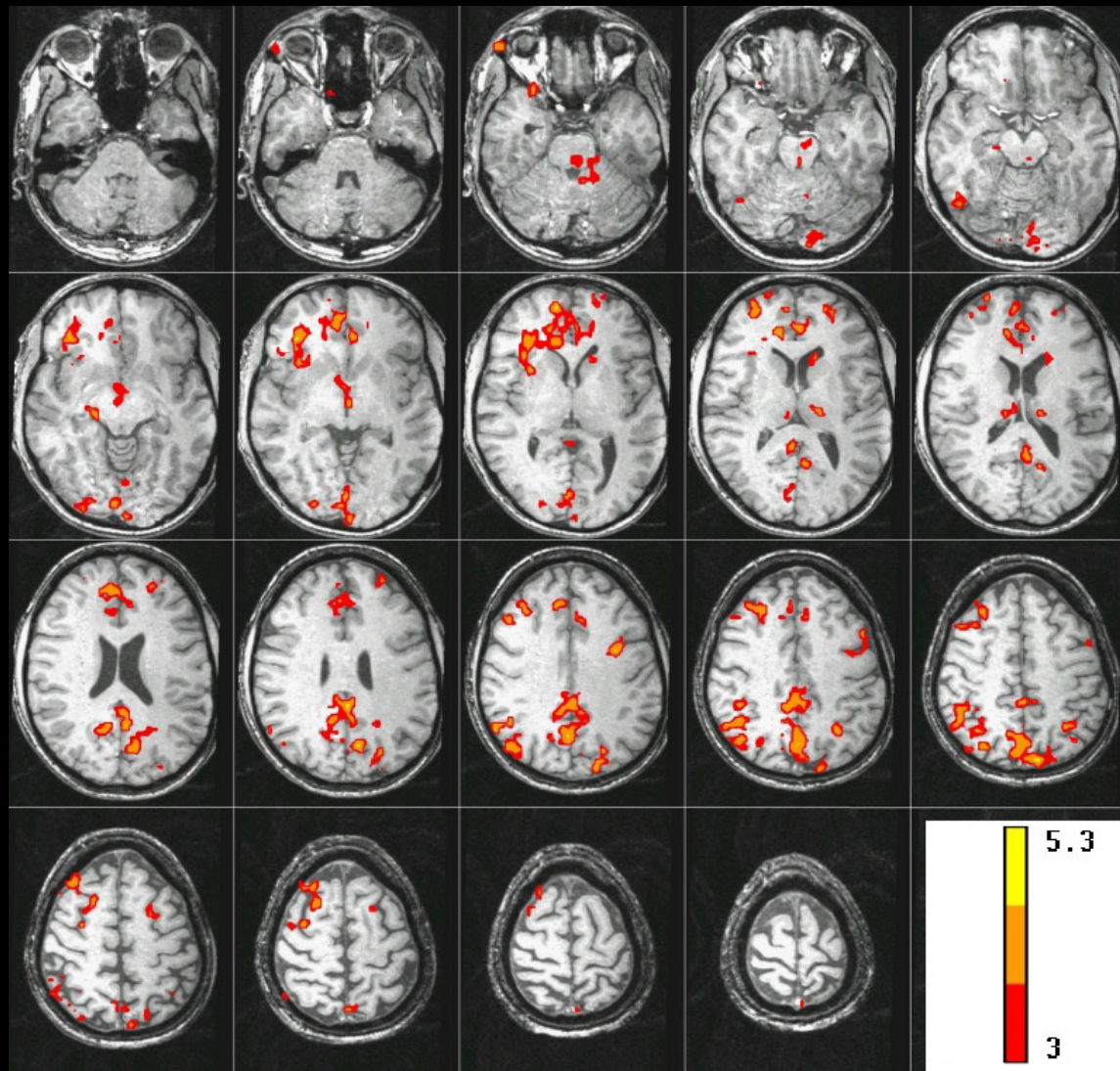
- Task performance
- Skin Conductance
- Heart, respiration rate..
- Eye position
- EEG

The Skin Conductance Response (SCR)



Patterson et al. (in press)

Brain activity correlated with SCR during “Rest”

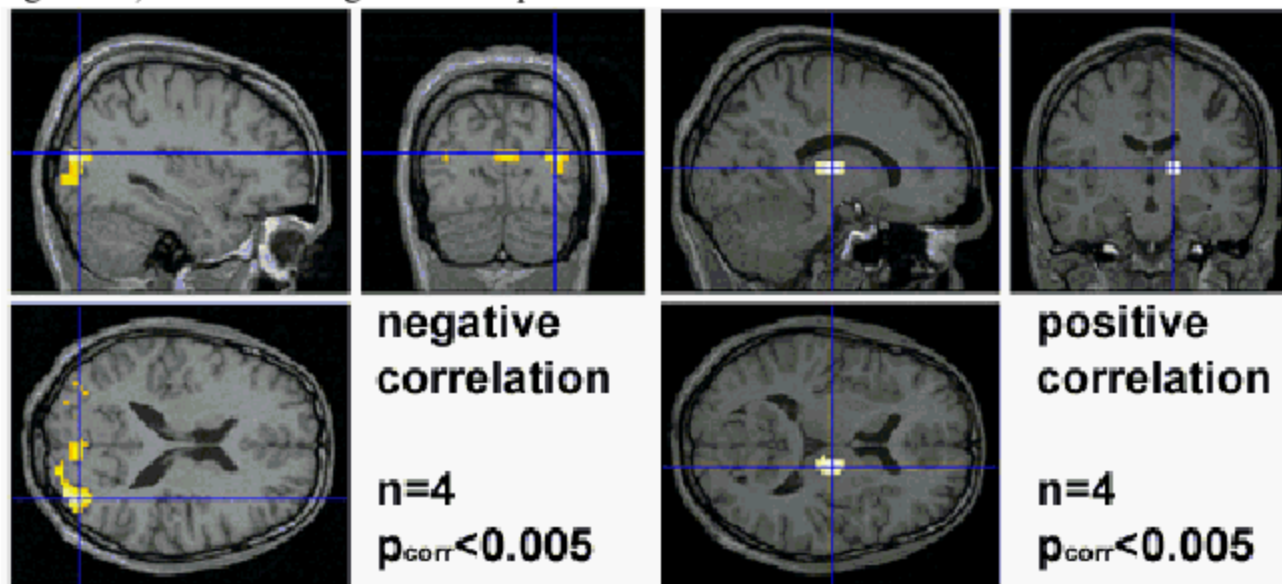


J. C. Patterson II, L. G. Ungerleider, and P. A. Bandettini, Task - independent functional brain activity correlation with skin conductance changes: an fMRI study. *NeuroImage* (in press)

Correlates of Alpha Rhythm in BOLD-fMRI

Matthias Moosmann, Petra Ritter, Andrea Brink, Ina Krastel, Sebastian Thees, Felix Blankenburg, Birol Taskin, Jan Ruben, Arno Villringer

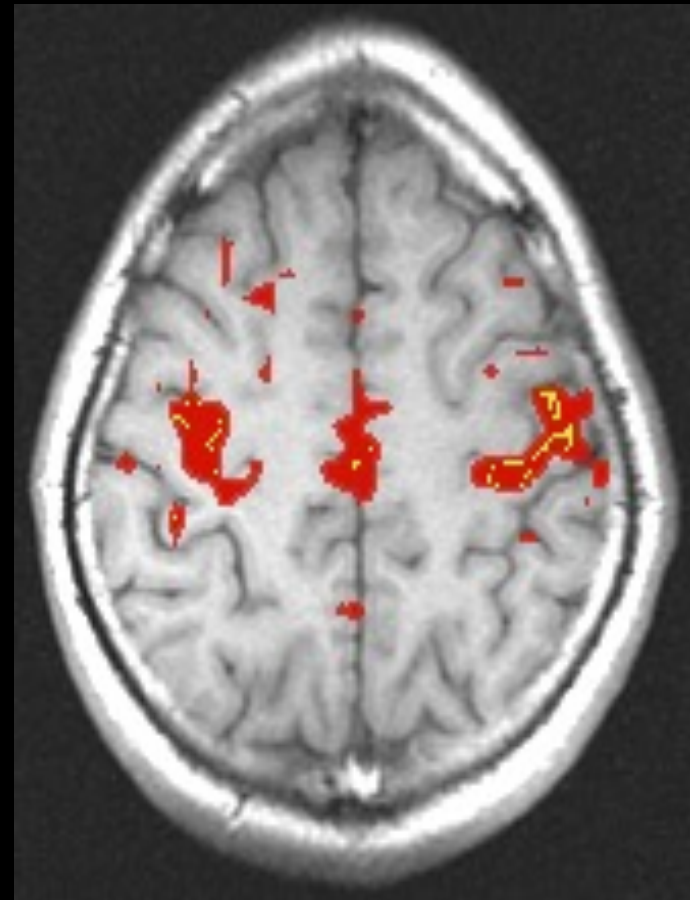
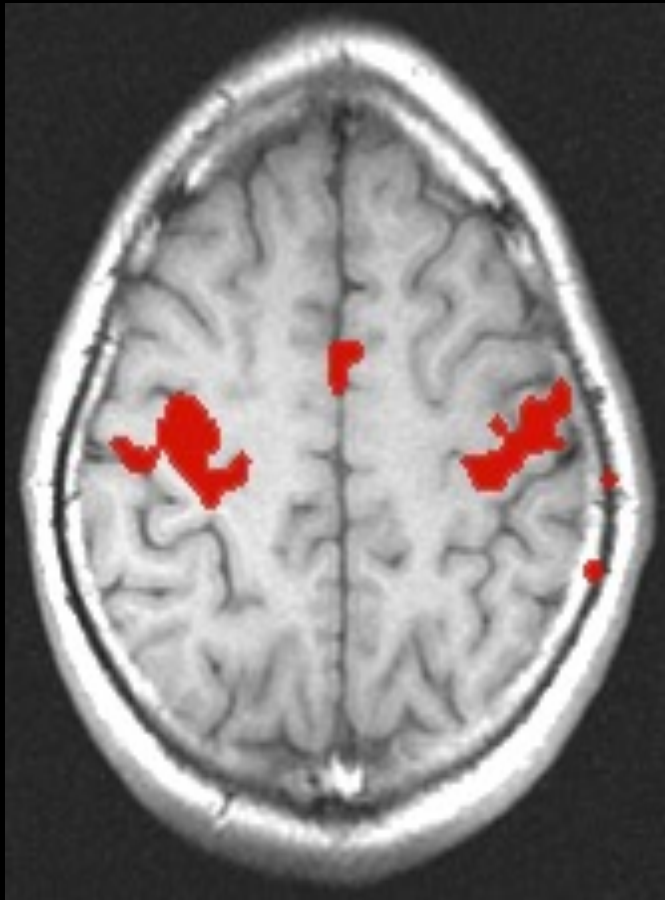
The group analysis based on four volunteers showed a negative correlation between alpha-power and fMRI signal in the occipital cortex (figure, left side) and a positive correlation in the thalamus (figure, right side). These findings were not present for the beta band.



Discussion:

Localization of alpha activity in the occipital lobe agrees with previous electrophysiological findings. The negative correlations of fMRI signal and alpha suggests less energy consumption with higher degrees of synchronization. Positive correlations in the thalamus suggest the thalamus to be an active energy consuming generator of alpha synchronization. Our results are in concordance with findings recently reported by other groups, showing deactivations in the occipital pole and activations in the thalamus or in the brain stem using PET (Sadato et al. 1998) and fMRI (Goldman et al. 2001).

Resting Hemodynamic Autocorrelations



Where Are We Going?

- Interpretation
- Temporal Resolution
- Spatial Resolution

- **Interpretation**
- Temporal Resolution
- Spatial Resolution

Δ Neuronal Activity

Number of Neurons

Local Field Potential

Spiking Coherence

Spiking Rate

Δ Metabolism

Aerobic Metabolism

Anaerobic Metabolism

Blood Volume

Deoxygenated Blood

Oxygenated Blood

Δ Hemodynamics

Flow Velocity

Perfusion

Δ BOLD Contrast

Δ Perfusion Contrast

Δ Inflow Contrast

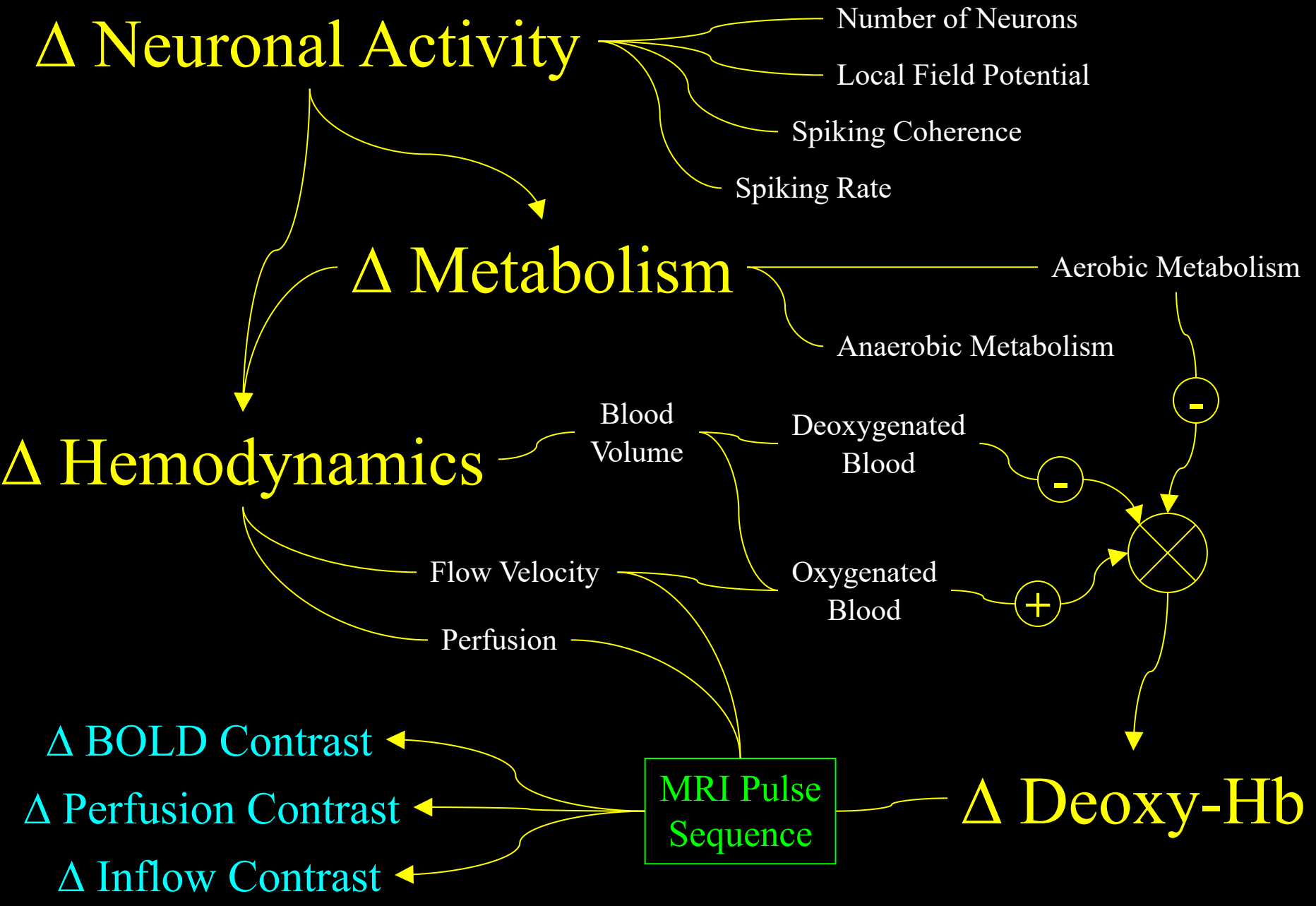
MRI Pulse Sequence

Δ Deoxy-Hb

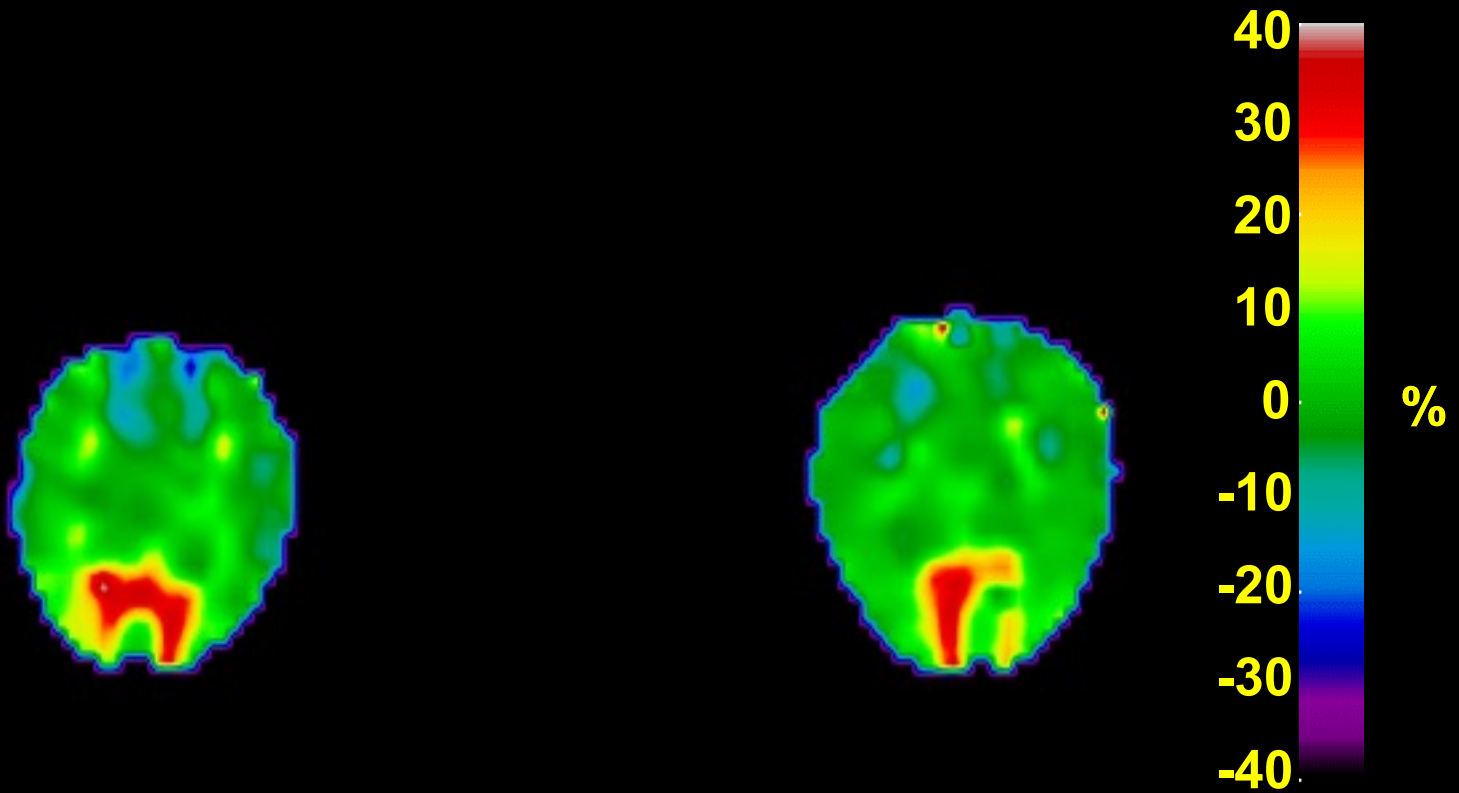
-

-

+



Computed CMRO₂ Changes

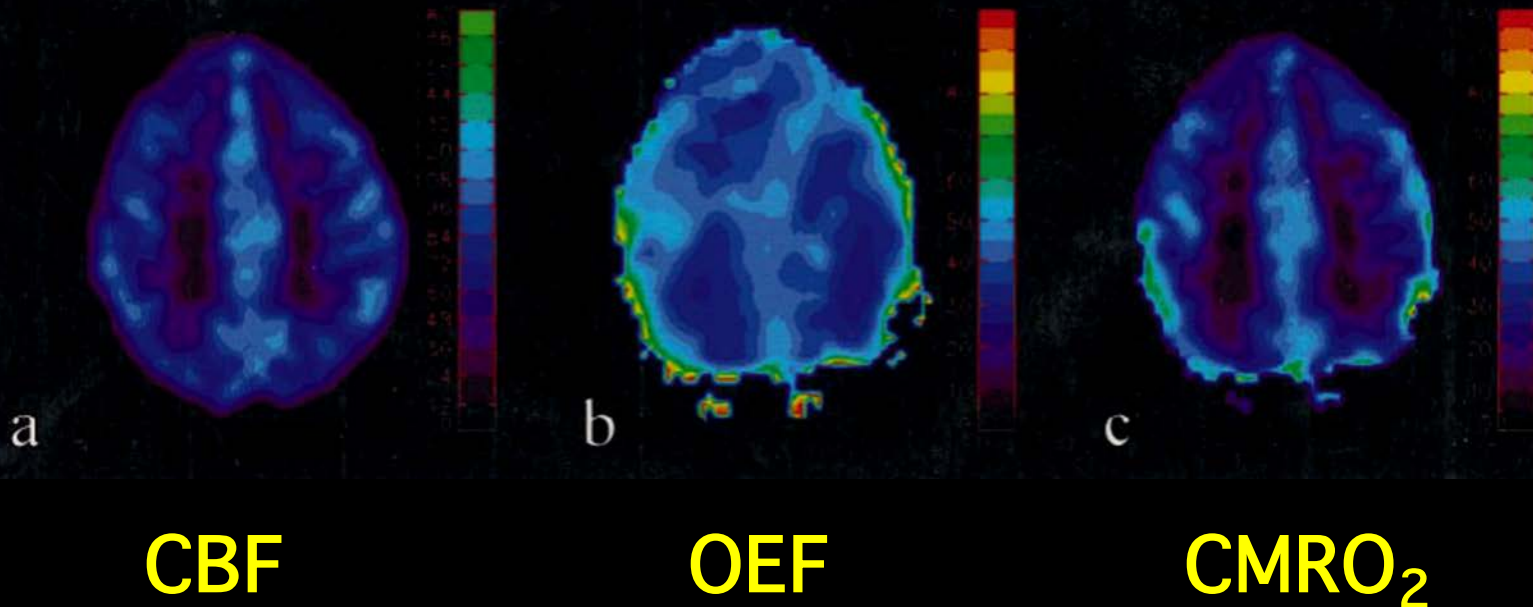


Subject 1

Subject 2

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

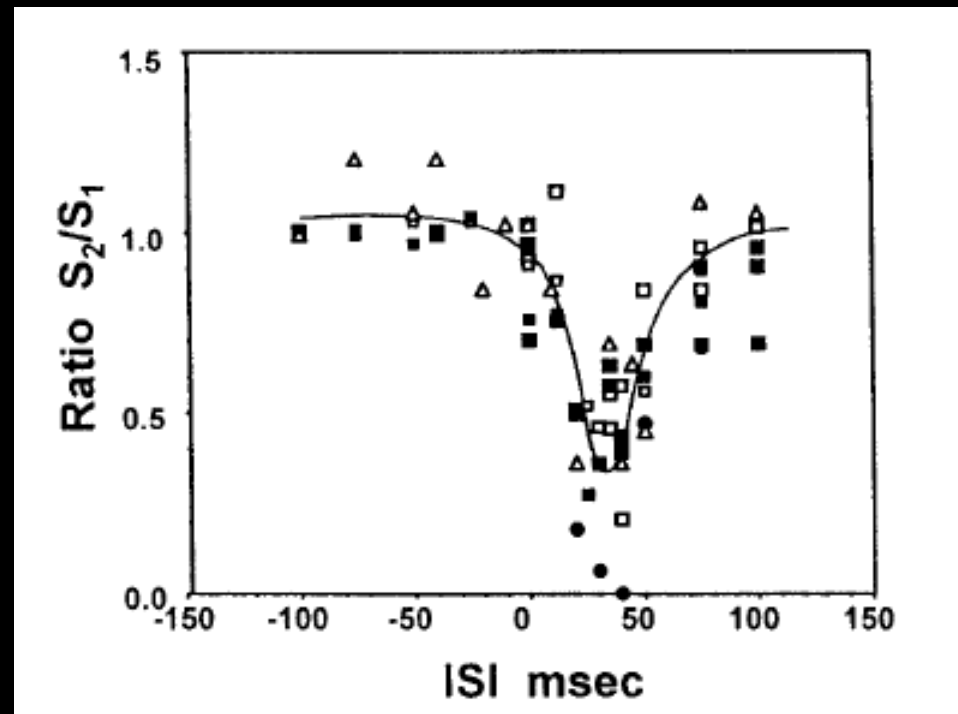
Hongyu An,¹ Weili Lin,^{2*} Azim Celik³ and Yueh Z. Lee²



- Interpretation
- **Temporal Resolution**
- Spatial Resolution

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[§]

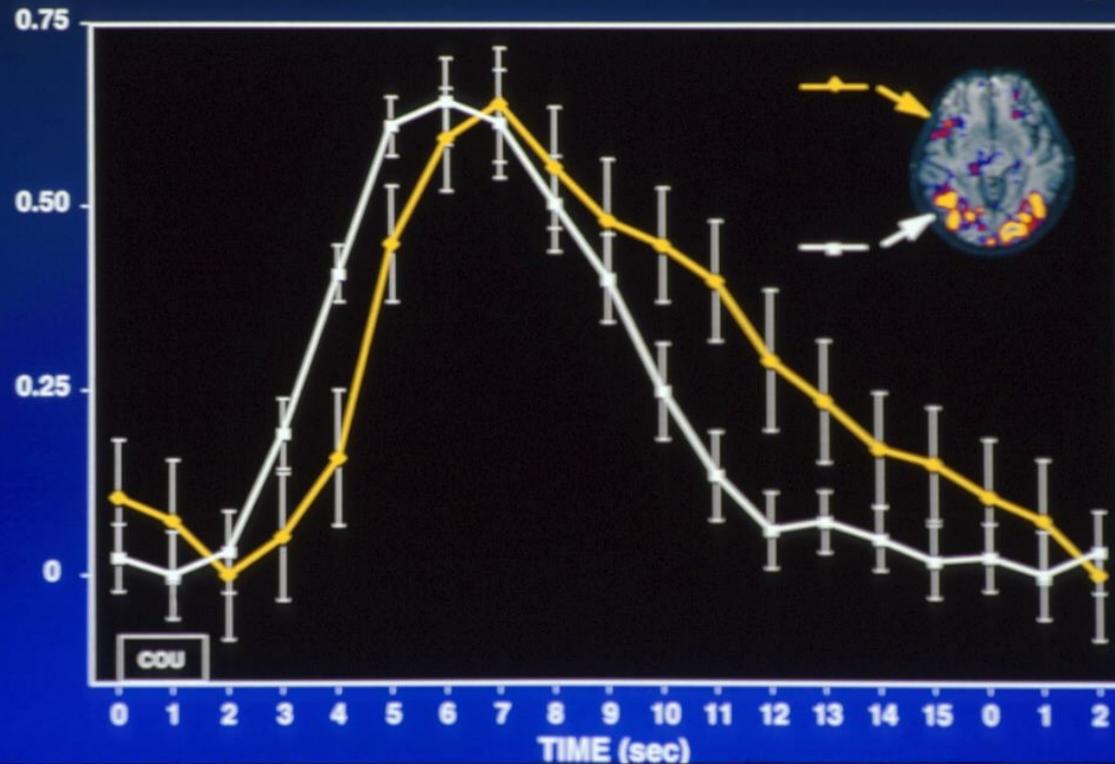


Detection of cortical activation during averaged single trials of a cognitive task using functional magnetic resonance imaging

(neuroimaging/single trial/language/prefrontal)

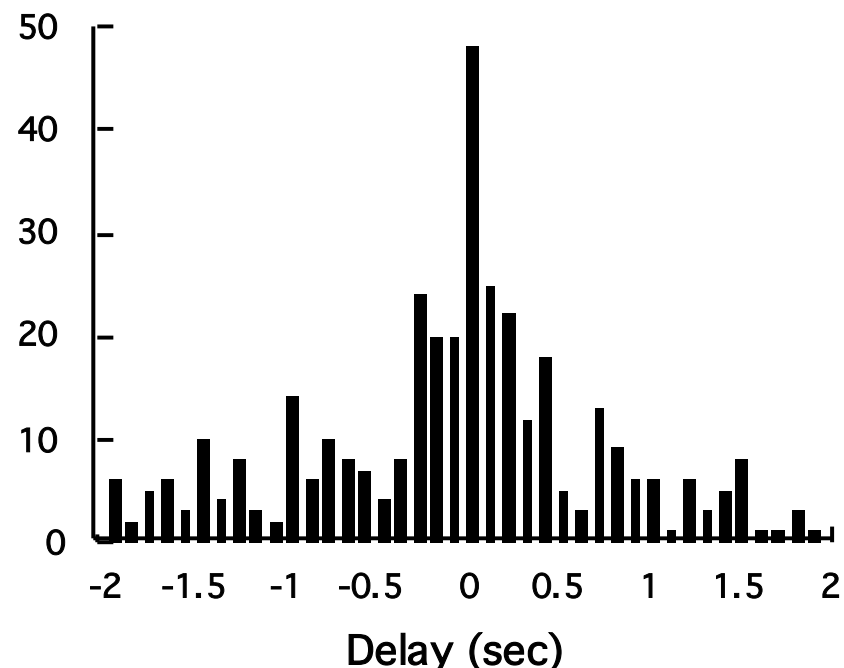
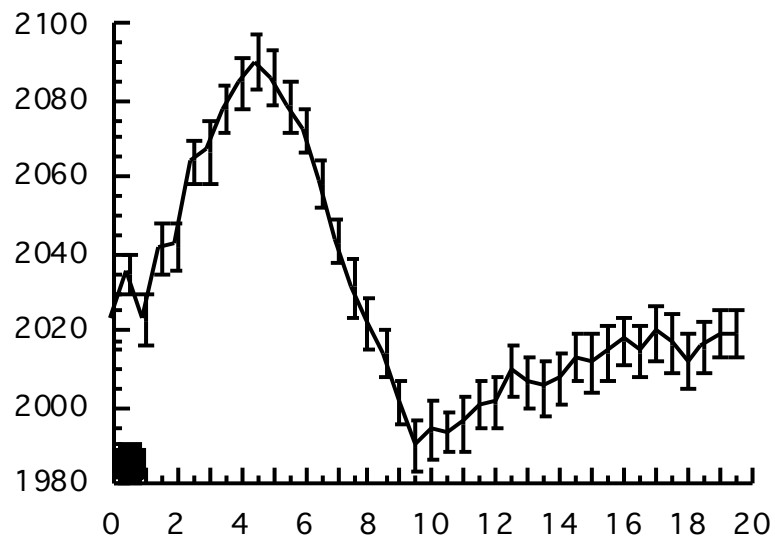
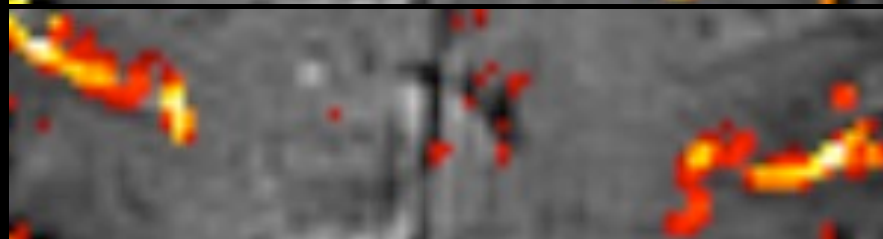
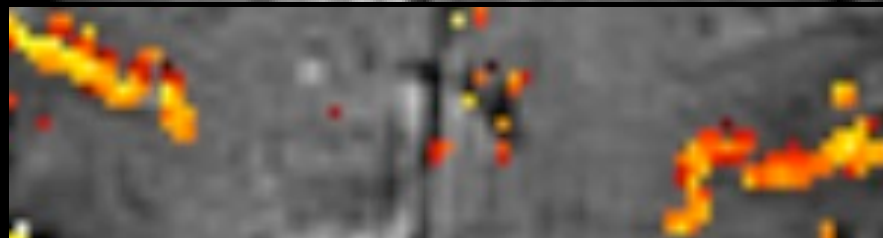
RANDY L. BUCKNER^{†‡§¶}, PETER A. BANDETTINI^{†‡}, KATHLEEN M. O' CRAVEN^{†||}, ROBERT L. SAVOY^{†||},
STEVEN E. PETERSEN^{**††}, MARCUS E. RAICHEL^{§**††}, AND BRUCE R. ROSEN^{†‡}

Time Course Comparison Across Brain Regions

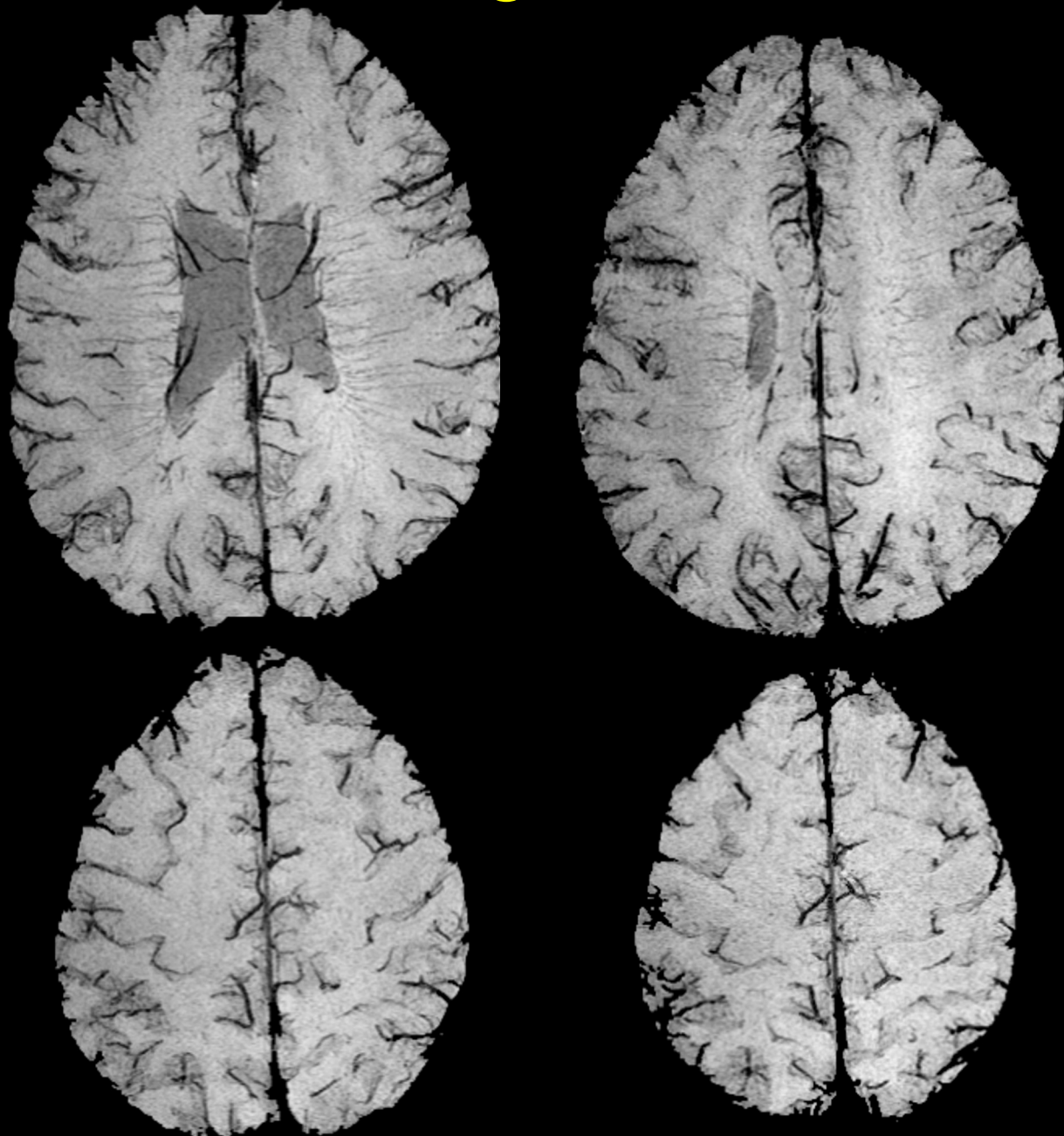


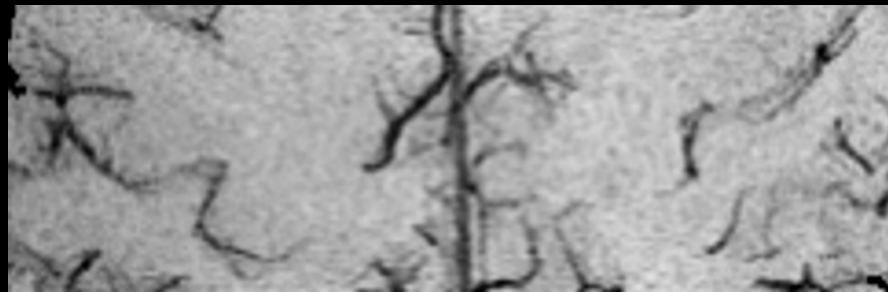
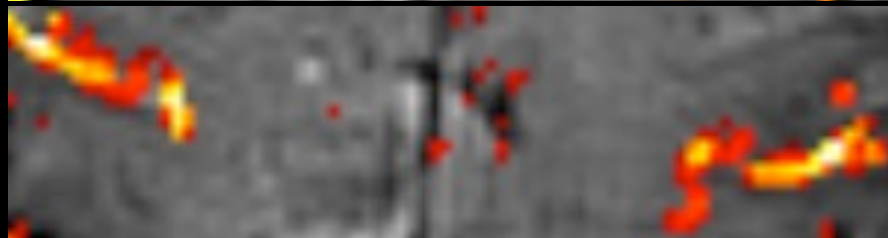
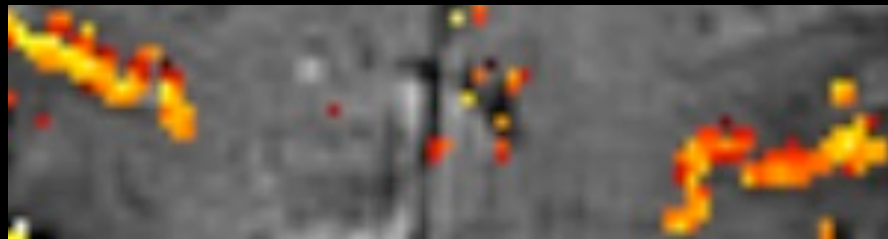
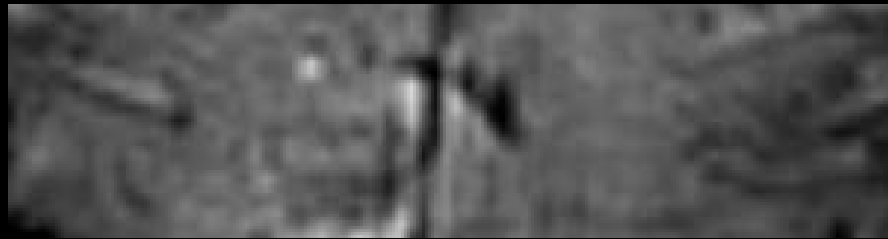
Latency

Magnitude



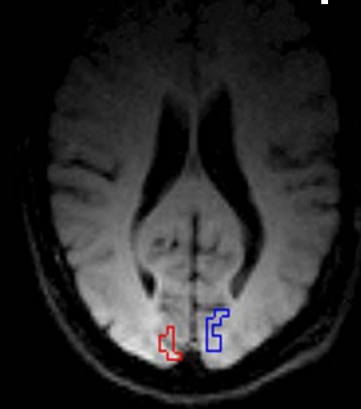
Venograms (3T)



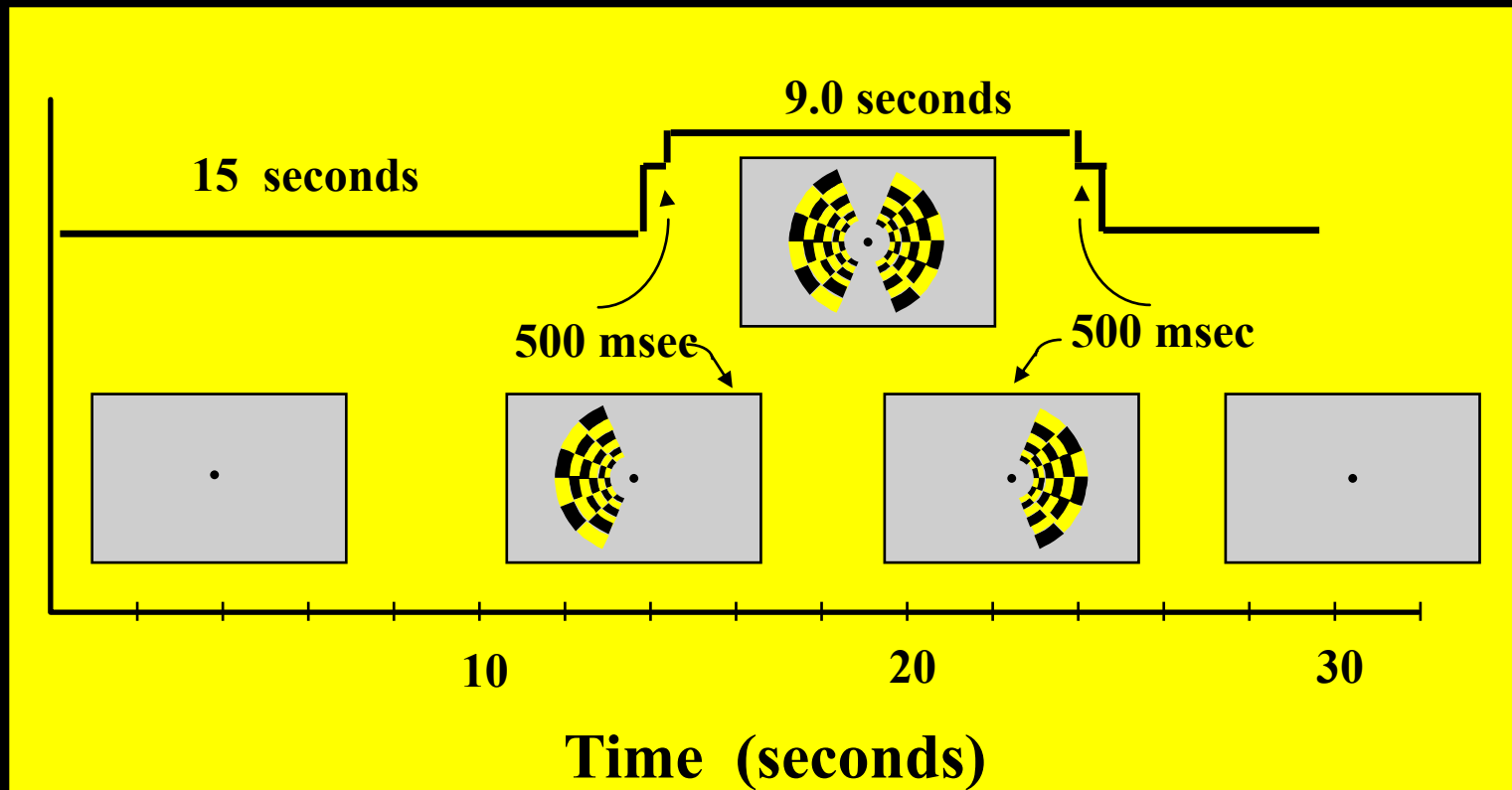


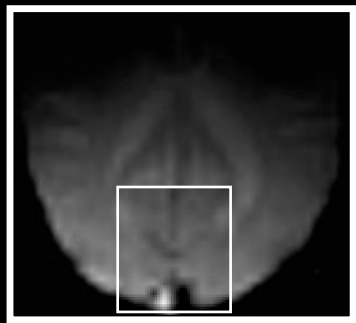
Hemi-Field Experiment

Left Hemisphere

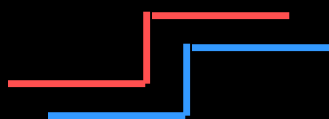


Right Hemisphere





500 ms



500 ms



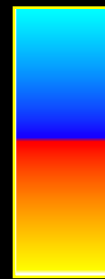
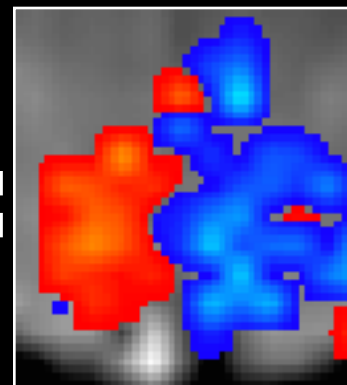
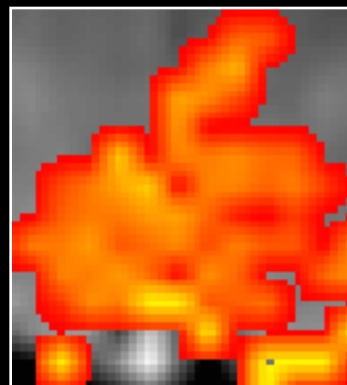
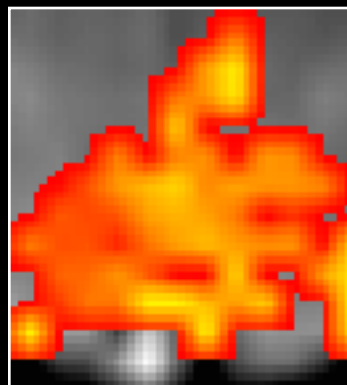
Right Hemifield

Left Hemifield

+ 2.5 s

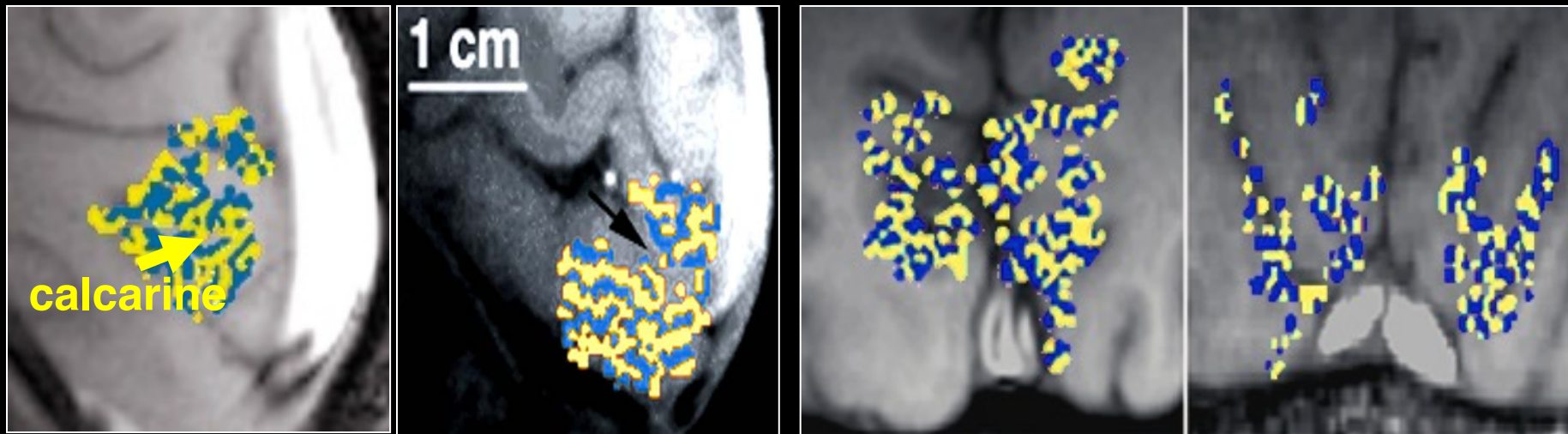
0 s

- 2.5 s

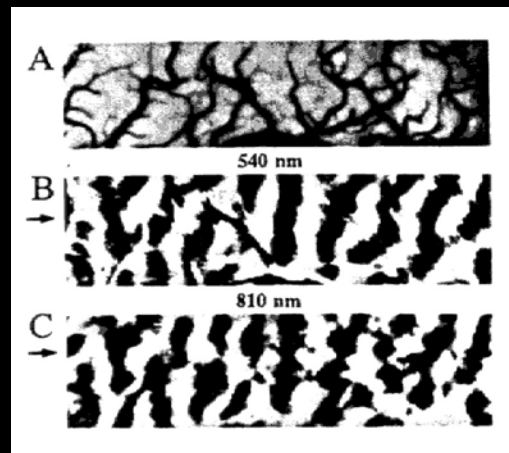


- Interpretation
- Temporal Resolution
- **Spatial Resolution**

Ocular Dominance Column Mapping using fMRI

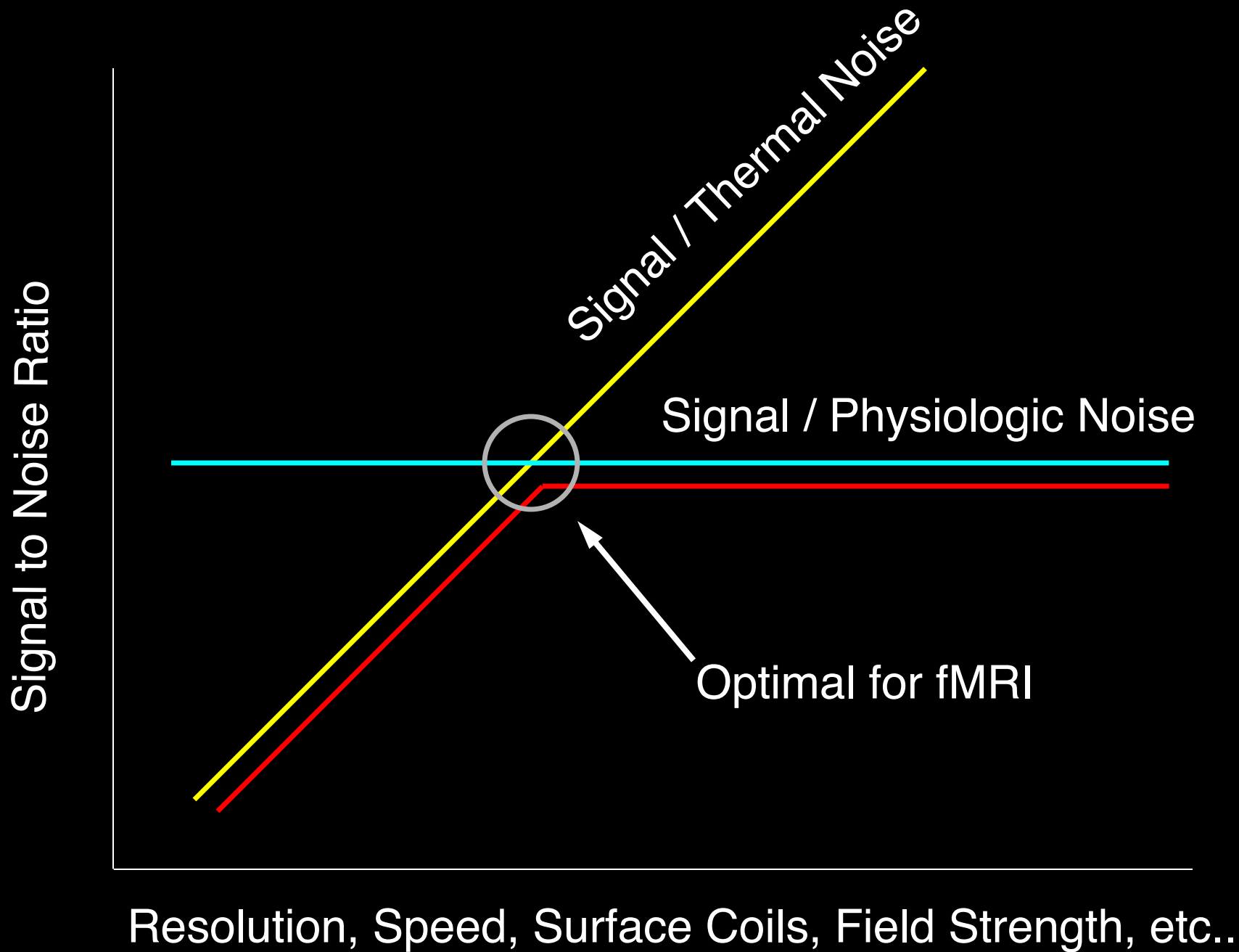


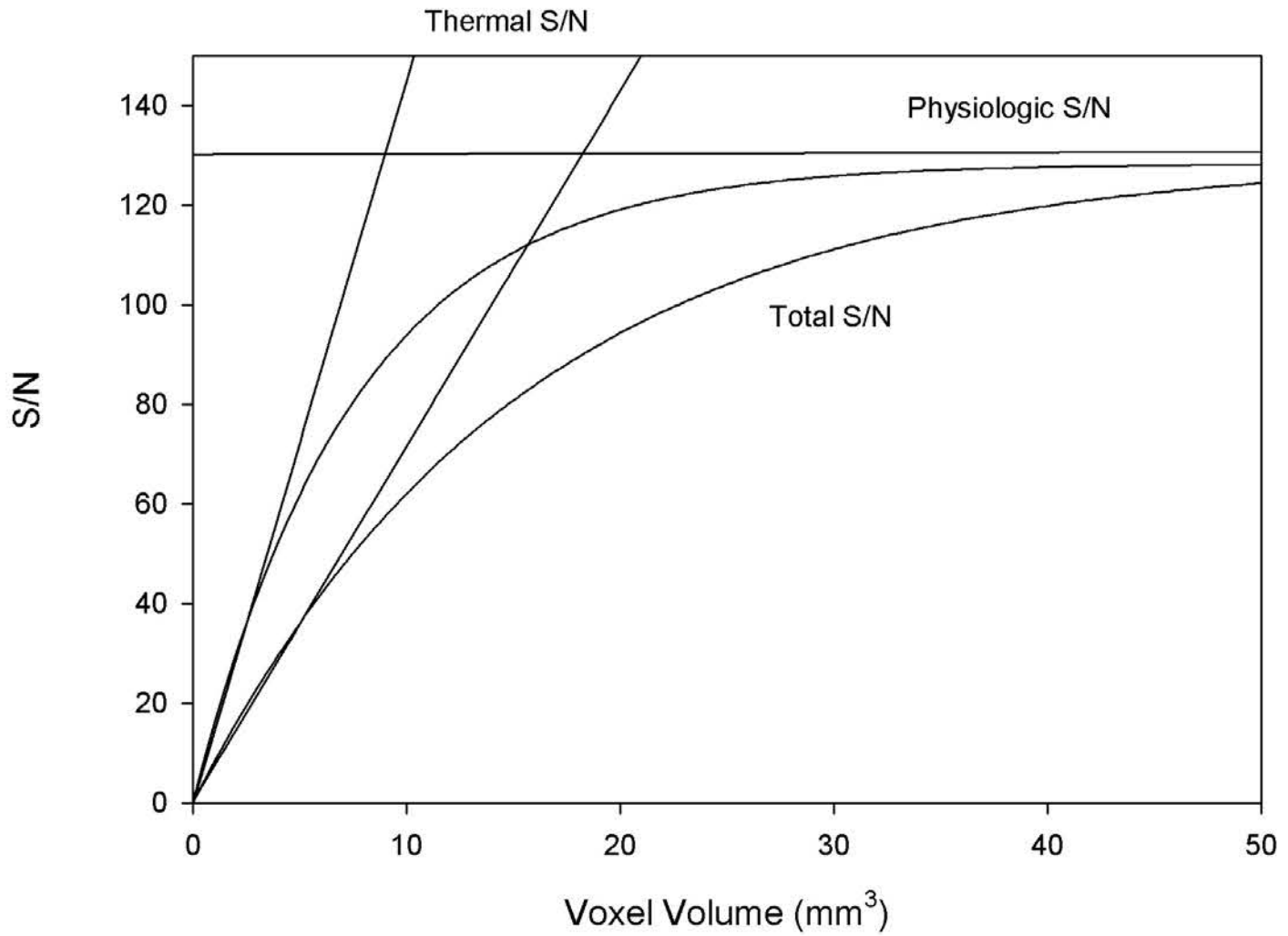
Menon, R. S., S. Ogawa, et al. (1997). "Ocular dominance in human V1 demonstrated by functional magnetic resonance imaging." *J Neurophysiol* 77(5): 2780-7.



Optical Imaging

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

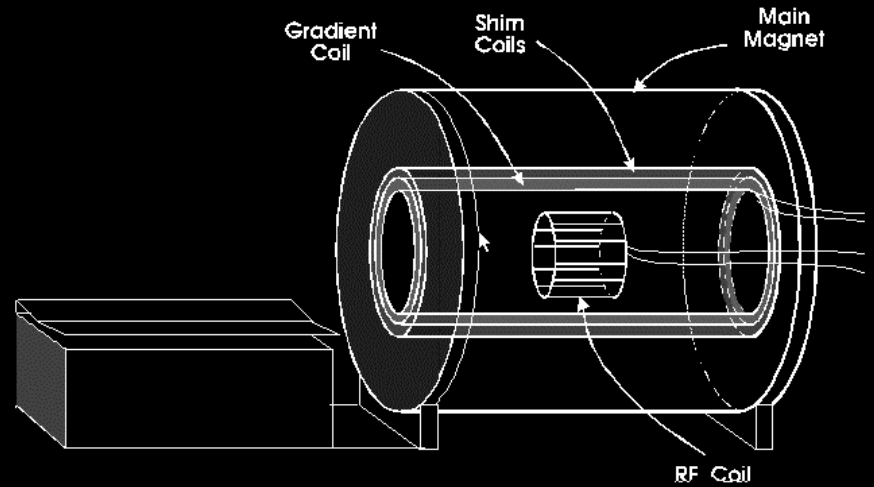




- Shimming
- Acoustic Noise
- Multishot Techniques
- Increased Gradient Performance
- Higher Field Strengths
- Surface Coil Arrays
- Calibration / Quantification
- Embedded Functional Contrast
- Noise / Fluctuations
- Direct Neuronal Current Imaging
- Clinical Populations
- Neuronal, Vascular, and Metabolic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

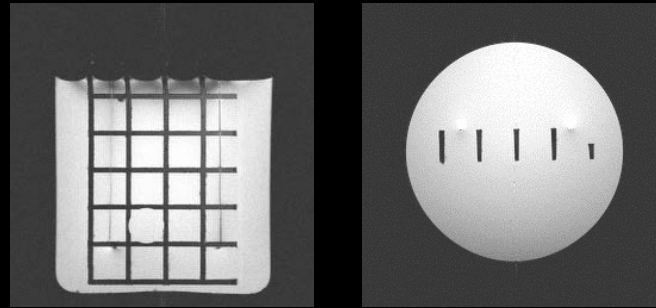
2 G/cm, 350 T/m/s

4 G/cm, 150 T/m/s



10 G/cm, 1000 T/m/s

Diffusion imaging
Faster imaging
Higher resolution



Neuronal Current Imaging

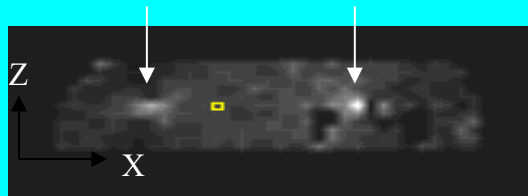
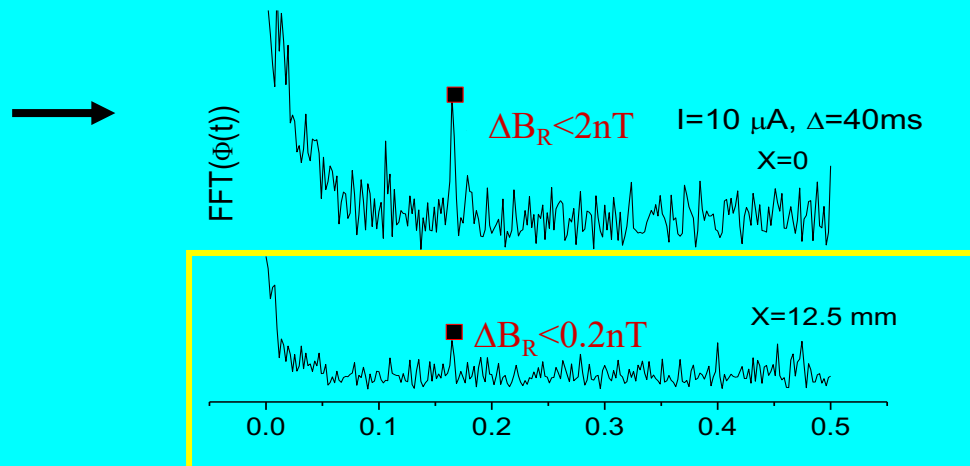


Figure 1



J. Bodurka, P. A. Bandettini. Toward direct mapping of neuronal activity: MRI detection of ultra weak transient magnetic field changes, Magn. Reson. Med. (in press).

Technology

MRI
 EPI
 Local Human Head Gradient Coils
 BOLD
 ASL
 Spiral EPI
 Multi-shot fMRI
 1.5T,3T, 4T
 EPI on Clin. Syst.
 Nav. pulses
 Diff. tensor
 Real time fMRI
 Quant. ASL
 Dynamic IV volume
 Simultaneous ASL and BOLD
 Mg⁺
 Venography
 Z-shim
 Baseline Susceptibility
 7T
 >8 channels
 SENSE
 Current Imaging?

Methodology

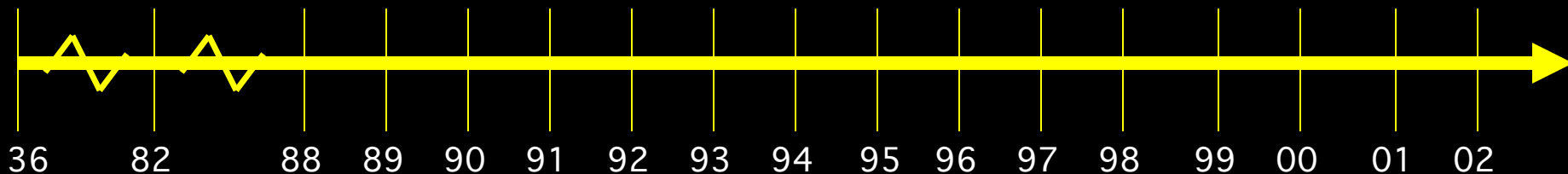
Baseline Volume
 IVIM
 Correlation Analysis
 Parametric Design
 Surface Mapping
 Phase Mapping
 Linear Regression
 Event-related
 Motion Correction
 Multi-Modal Mapping
 ICA
 Free-behavior Designs
 Mental Chronometry
 Multi-variate Mapping
 Deconvolution
 Fuzzy Clustering
 CO₂ Calibration

Interpretation

Blood T2
 Hemoglobin
 BOLD models
 B₀ dep.
 TE dep
 SE vs. GE
 NIRS Correlation
 Veins
 PET correlation
 IV vs EV
 Pre-undershoot
 Resolution Dep.
 Post-undershoot
 CO₂ effect
 Inflow
 ASL vs. BOLD
 PSF of BOLD
 Extended Stim.
 Linearity
 Fluctuations
 Balloon Model
 Metab. Correlation
 Optical Im. Correlation
 Electrophys. correlation

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
 Plasticity
 Face recognition
 Performance prediction



FIM Unit & FMRI Core Facility

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-Back. IRTA Students:

Elisa Kapler

August Tuan

Dan Kelley

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