Functional MRI: Past, Present, Future

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Unit on Functional Imaging Methods
&
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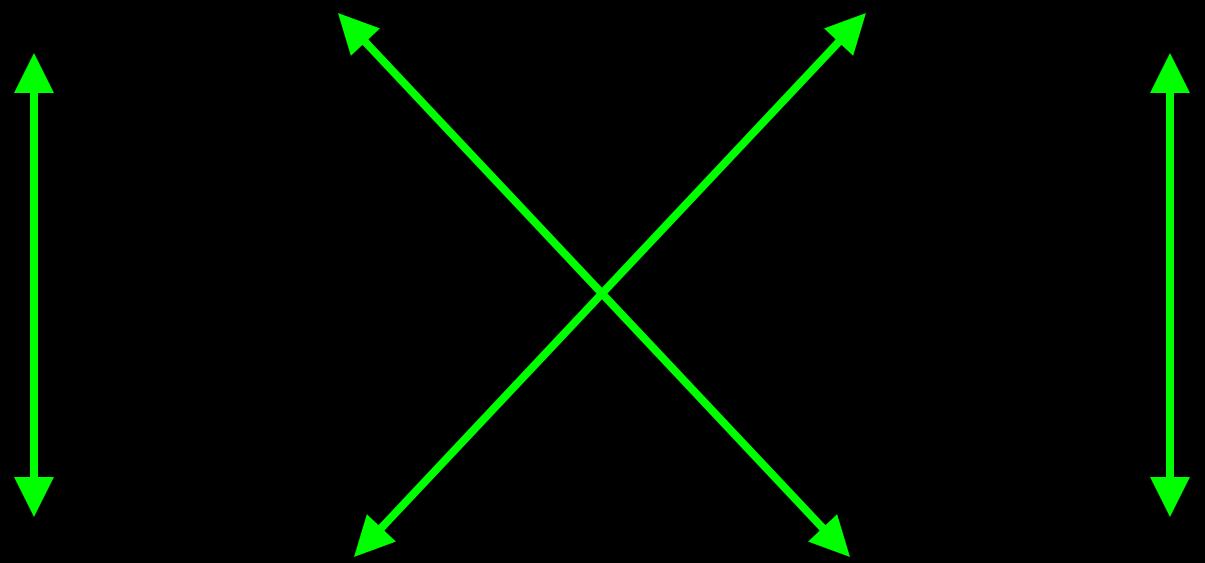
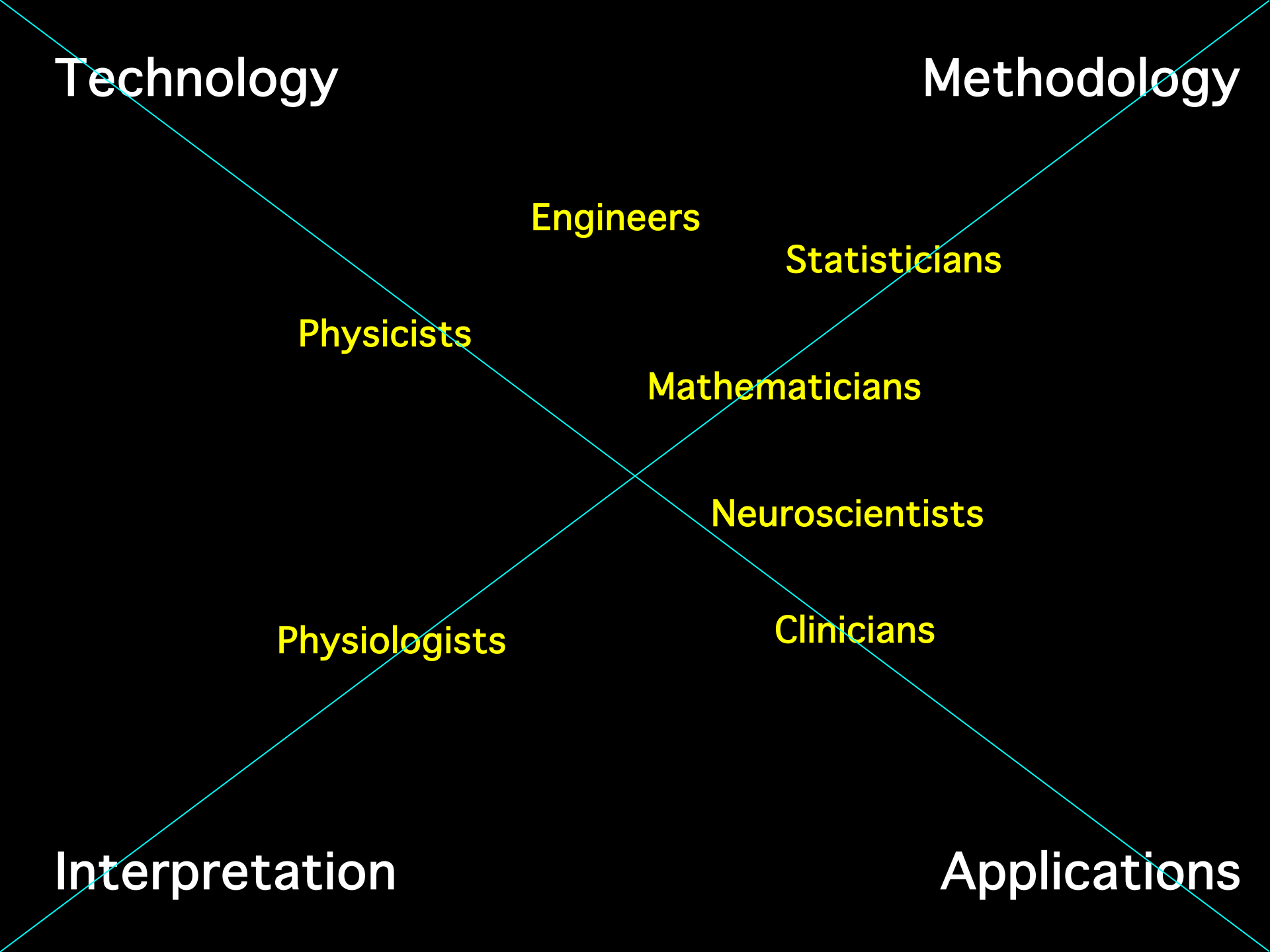
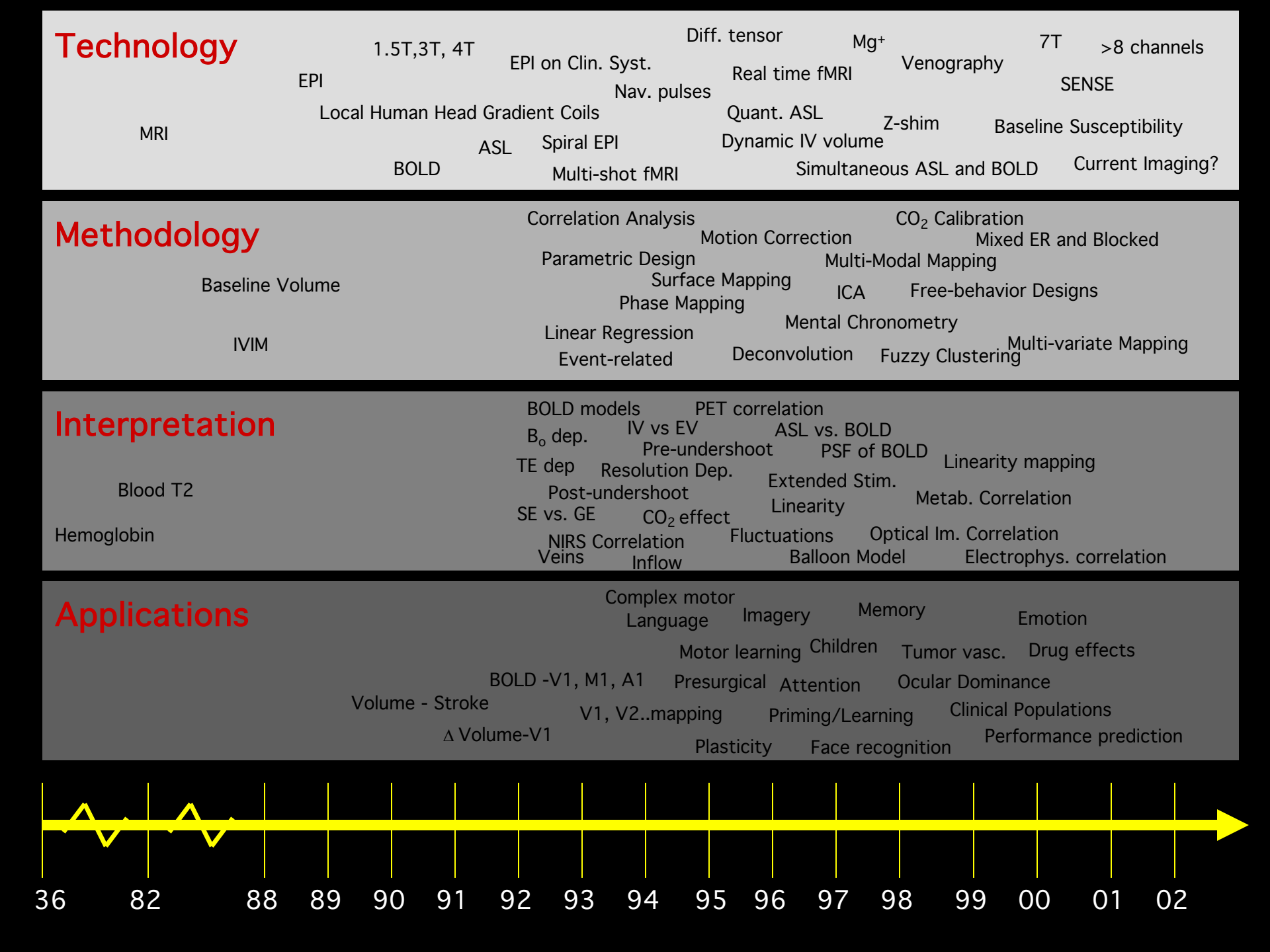
Laboratory of Brain and Cognition
National Institute of Mental Health

Technology ↔ Methodology



Interpretation ↔ Applications


Technology
Methodology
Engineers
Statisticians
Physicists
Mathematicians
Neuroscientists
Physiologists
Clinicians
Interpretation
Applications


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

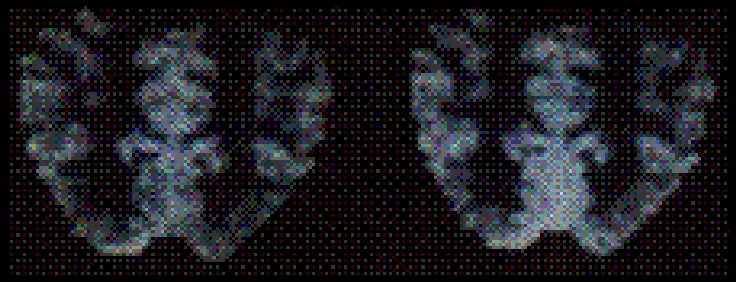
BOLD Contrast

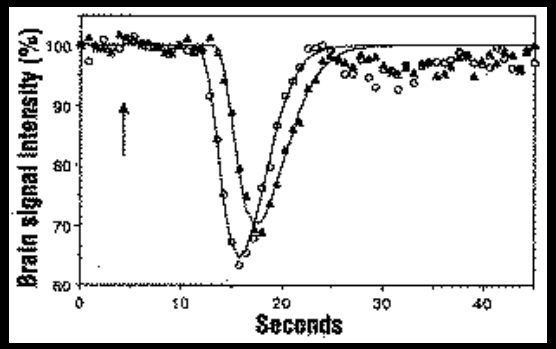
Arterial Spin Labeling

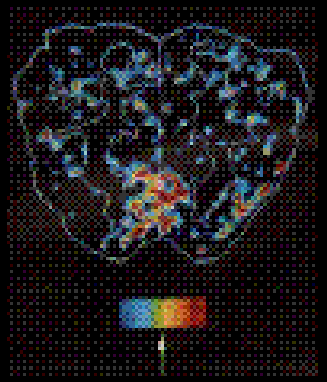
Blood Volume Imaging

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

Resting Active

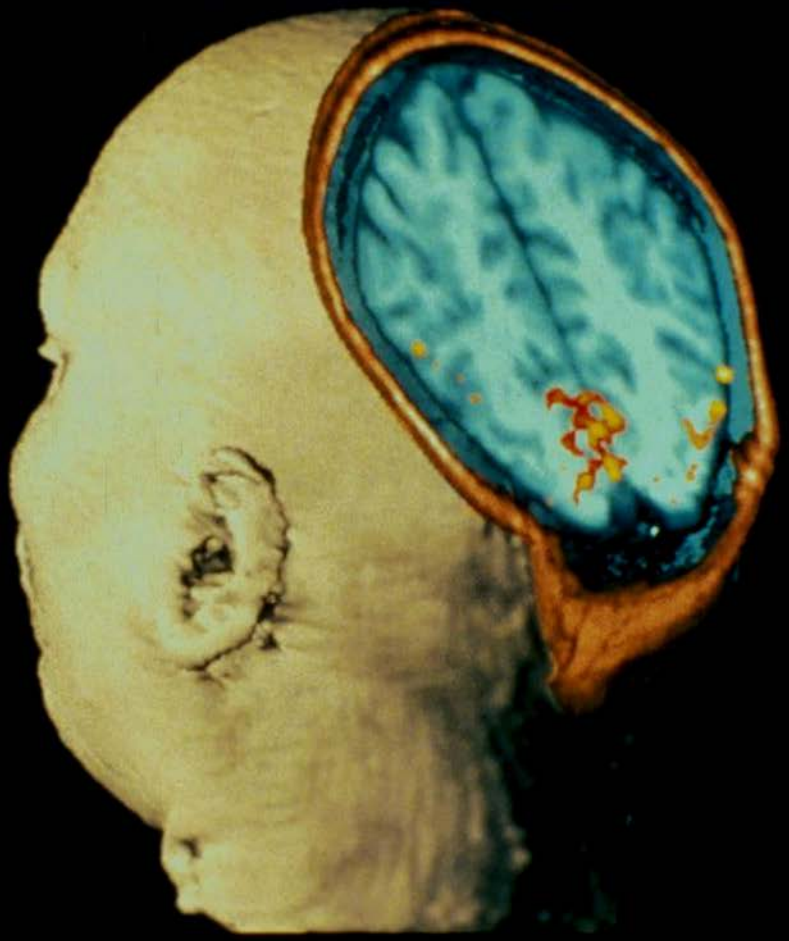






Blood Volume

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

Cerebral Tissue Activation

↓

Local Vasodilation

↓

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

↓

Increase in Capillary and Venous Blood Oxygenation

↓

Decrease in Deoxy-hemoglobin

Deoxy-hemoglobin: paramagnetic
Oxy-hemoglobin: diamagnetic

↓

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

↓

Local Signal Increase in T2 and T2* - weighted sequences

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.

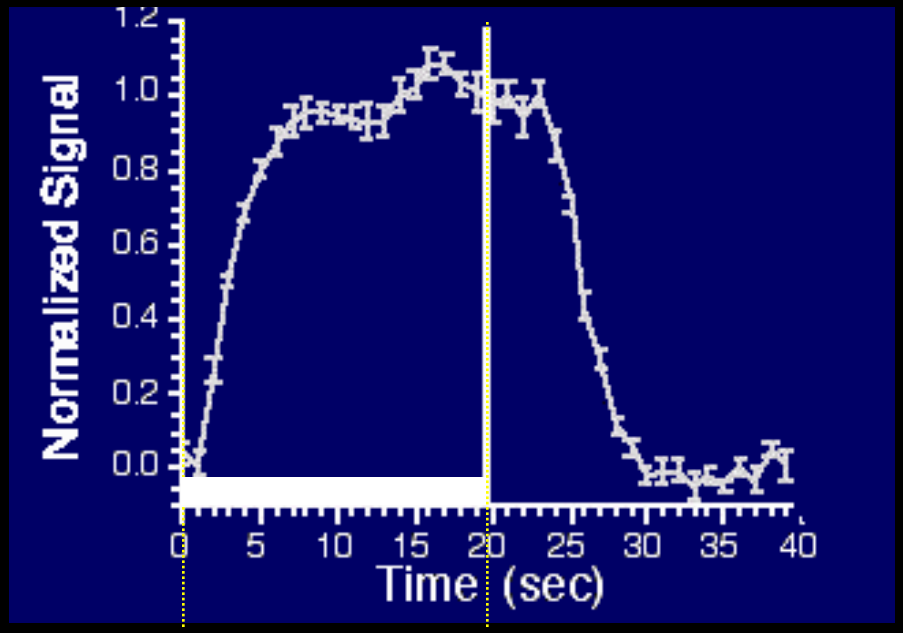
P. A. Bandettini, et al., (1992) "Time course EPI of human brain function during task activation." Magn. Reson. Med 25, 390-397.

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.

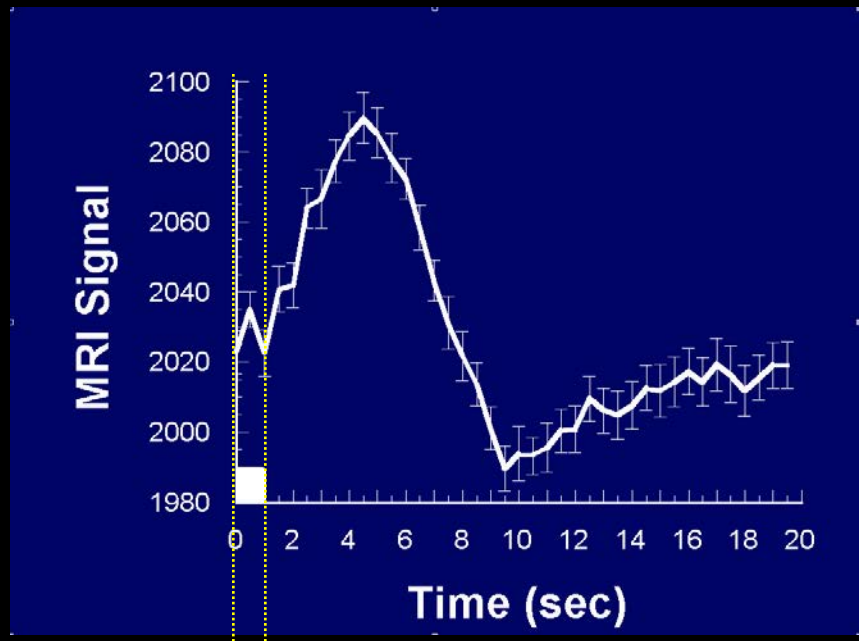
- Correlation analysis, Fourier analysis, t-test, f-test...
- SPM, AFNI, brain voyager, FIASCO, FSL, free surfer...

The BOLD Signal

Blood Oxygenation Level Dependent (BOLD) signal changes

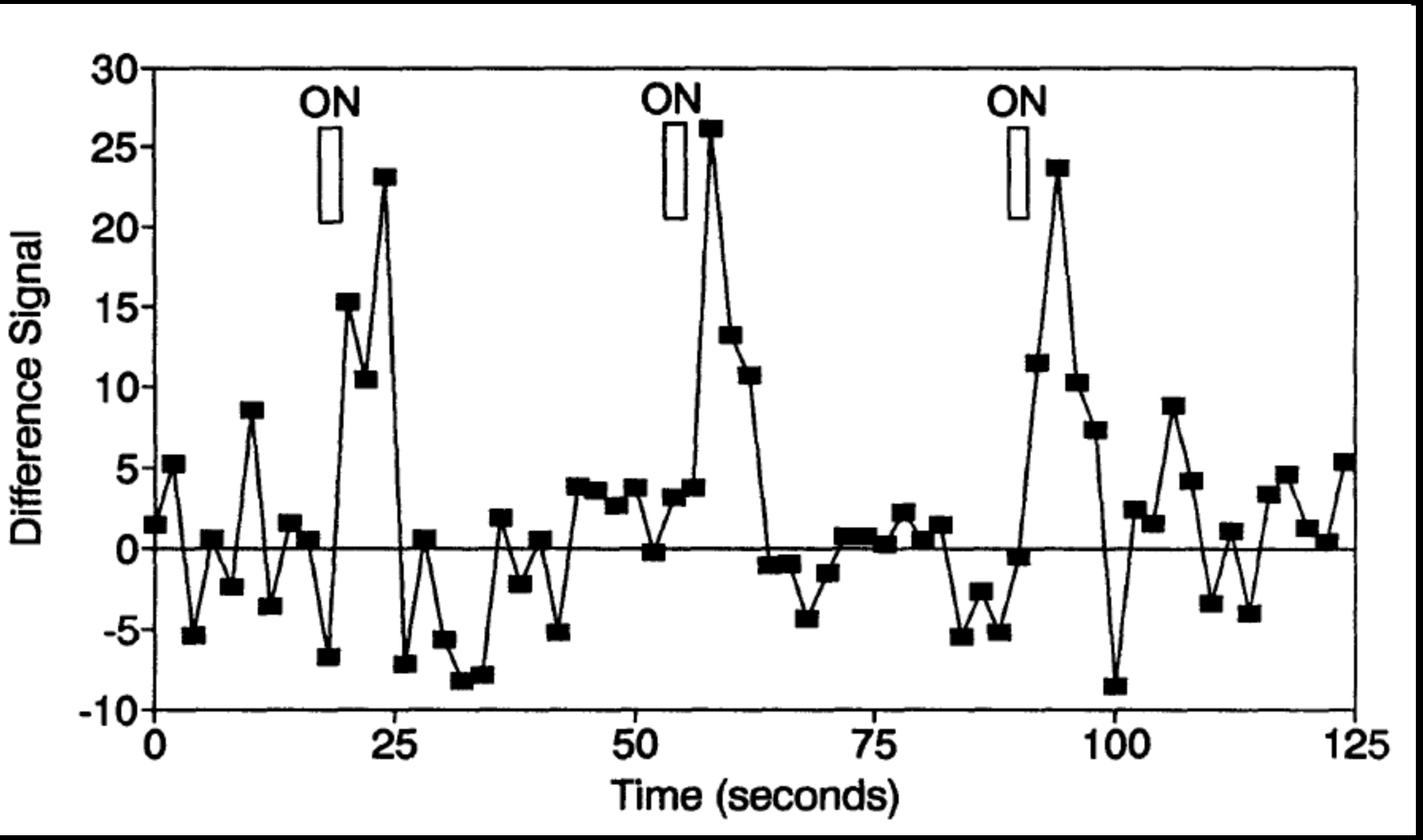


task



task

First Event-related fMRI Results



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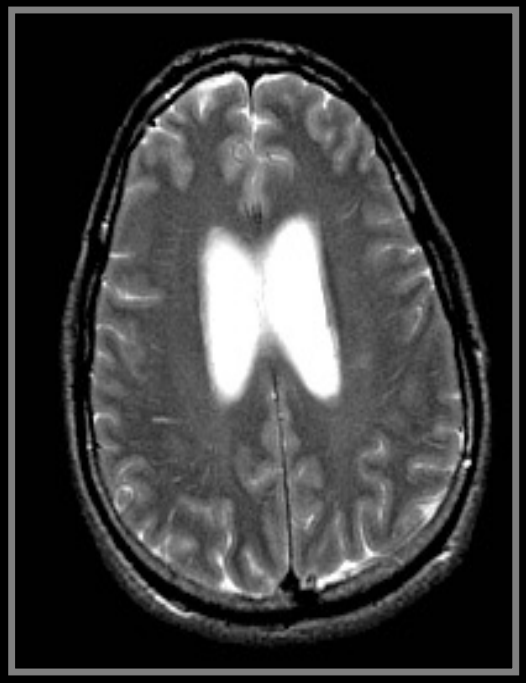
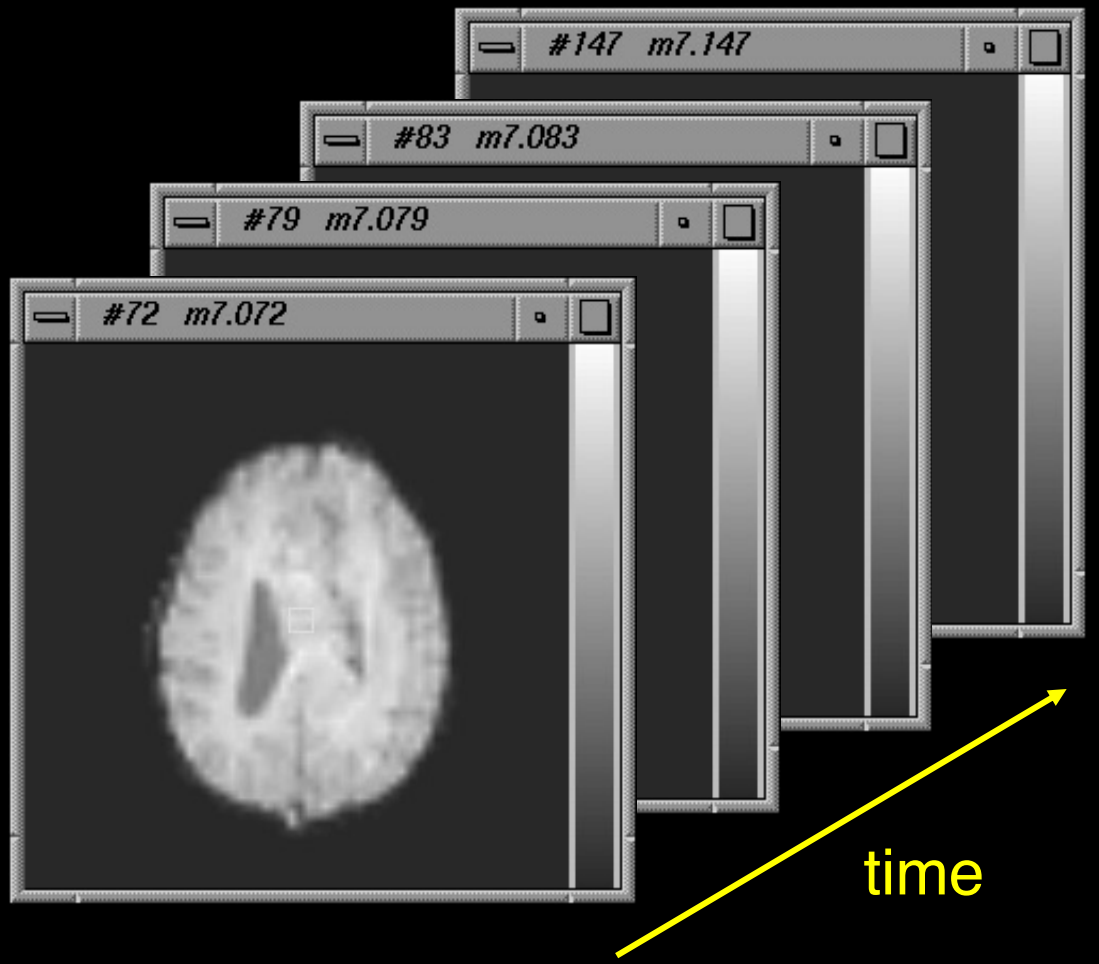
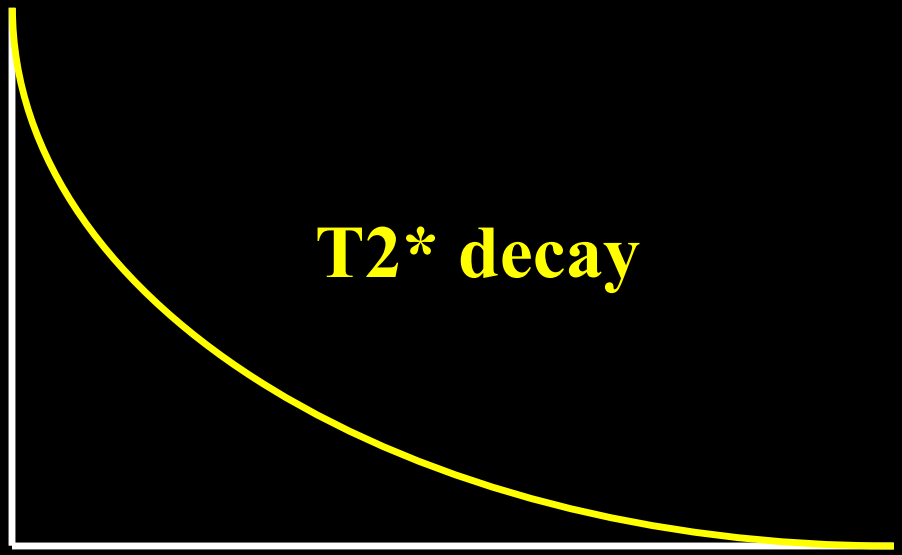


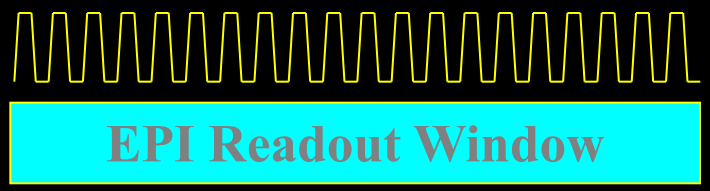


Anatomic

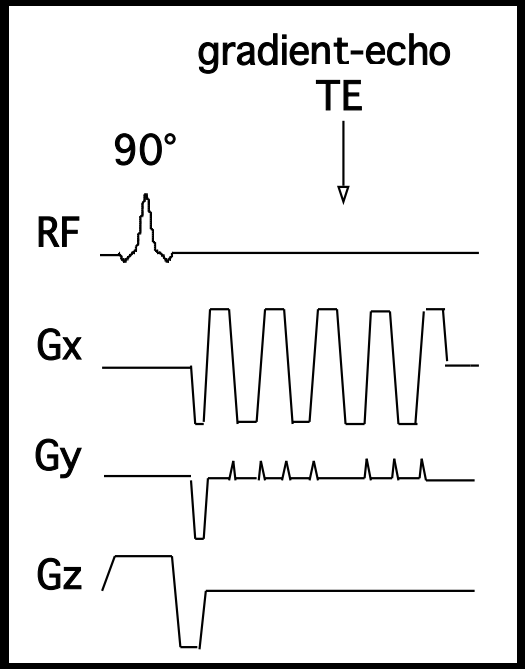
Functional

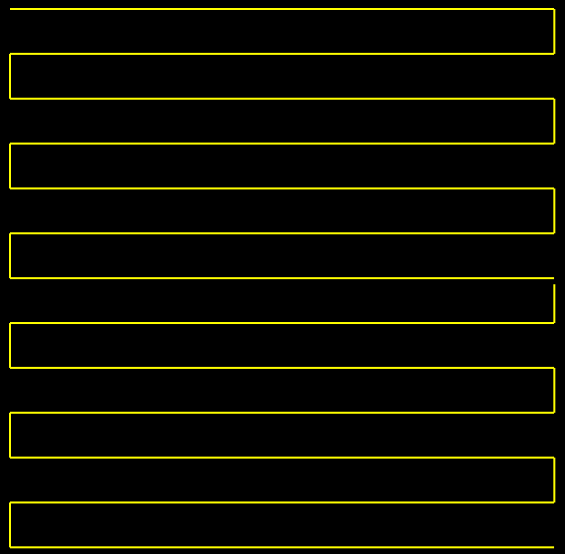
Single Shot EPI

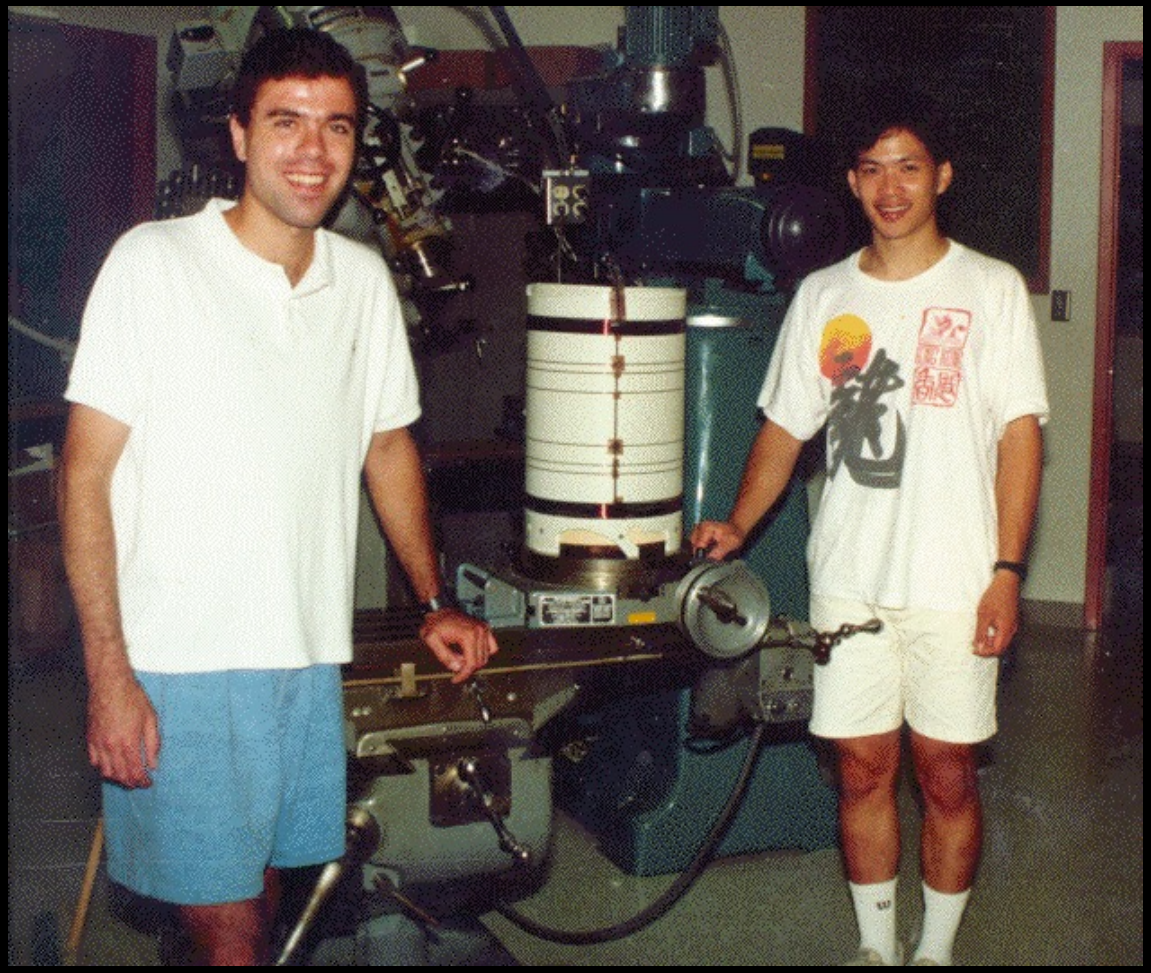




≈ 20 to 40 ms





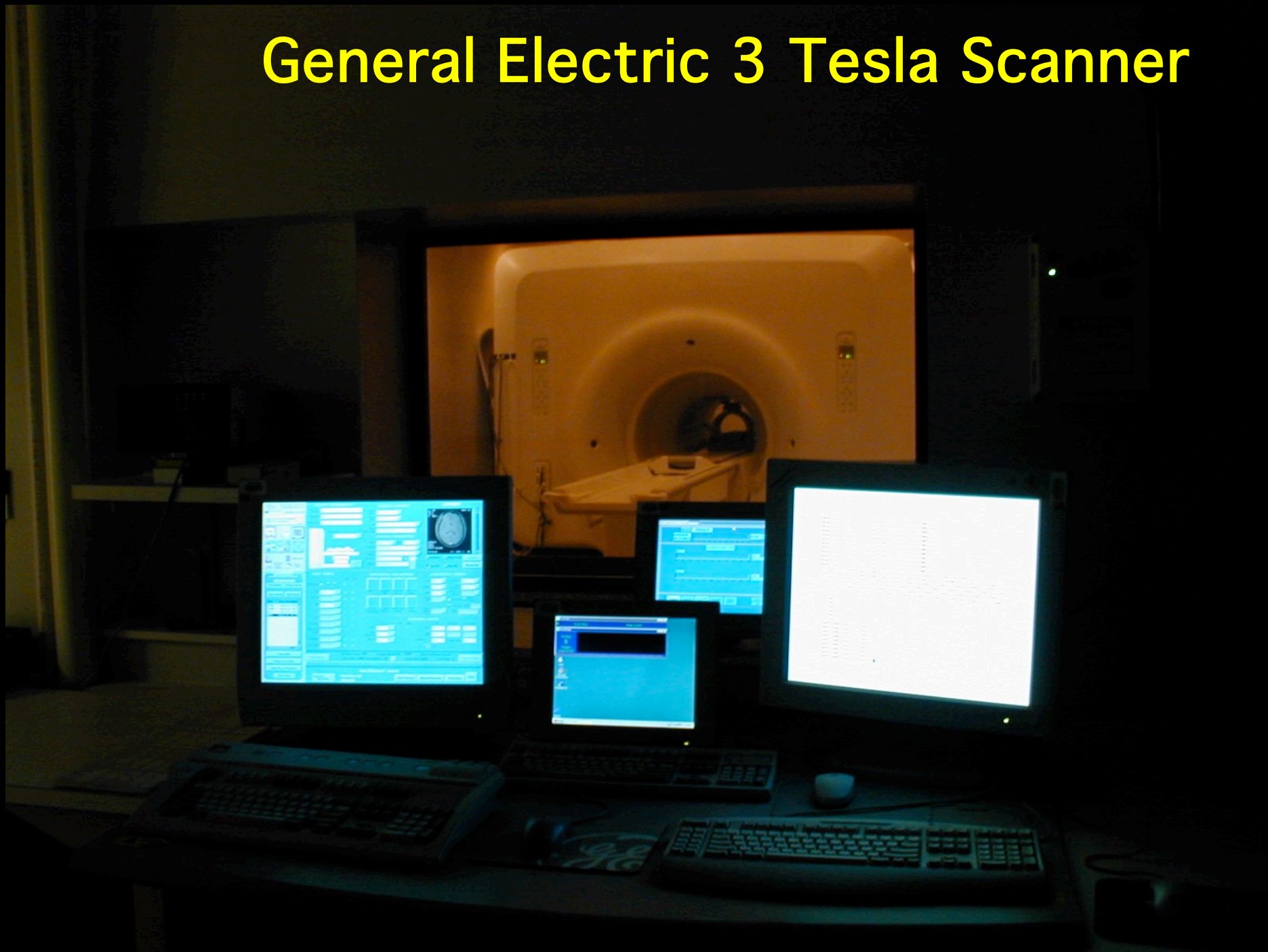


August, 1991

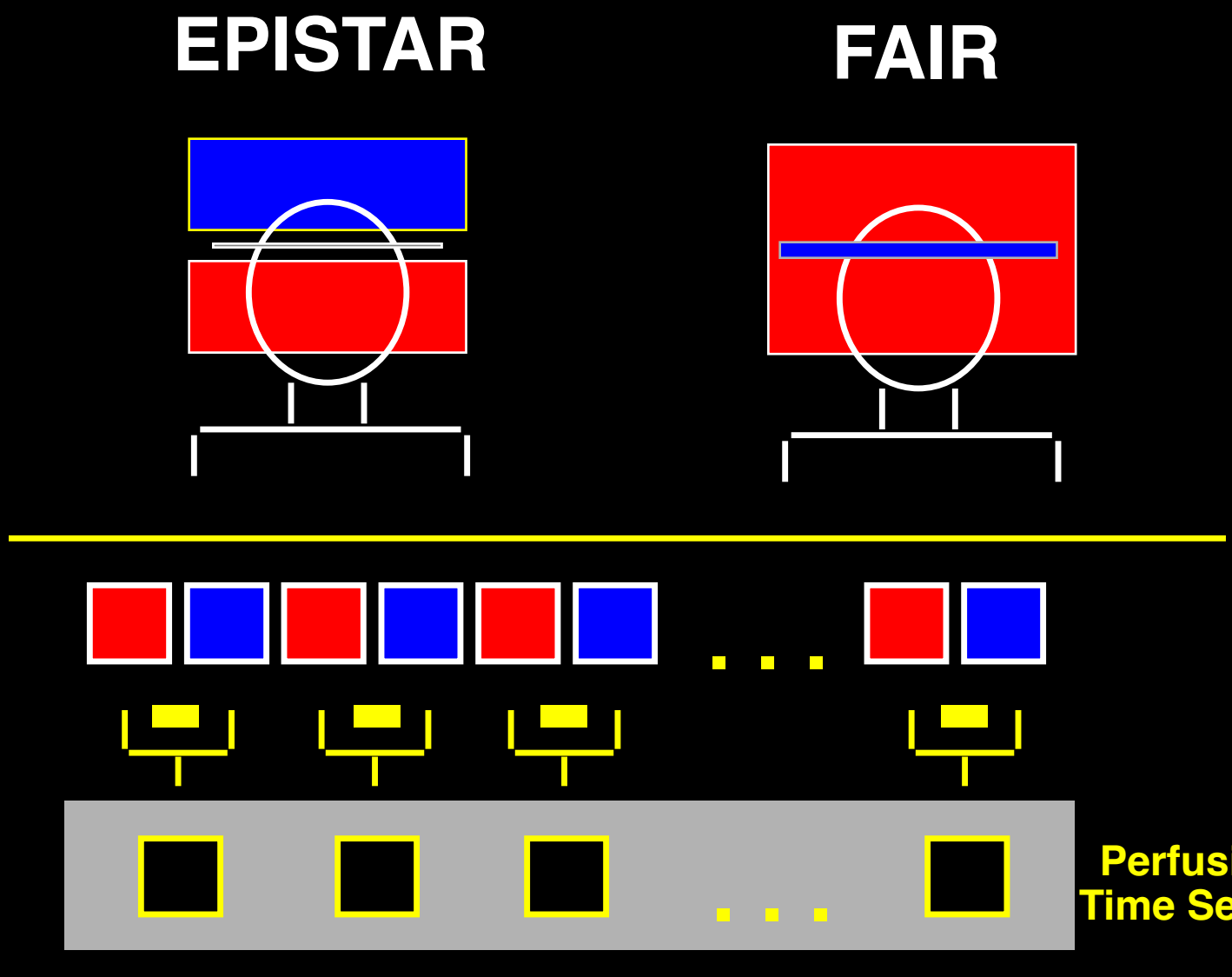
1991-1992

1992-1999

General Electric 3 Tesla Scanner



Blood Perfusion



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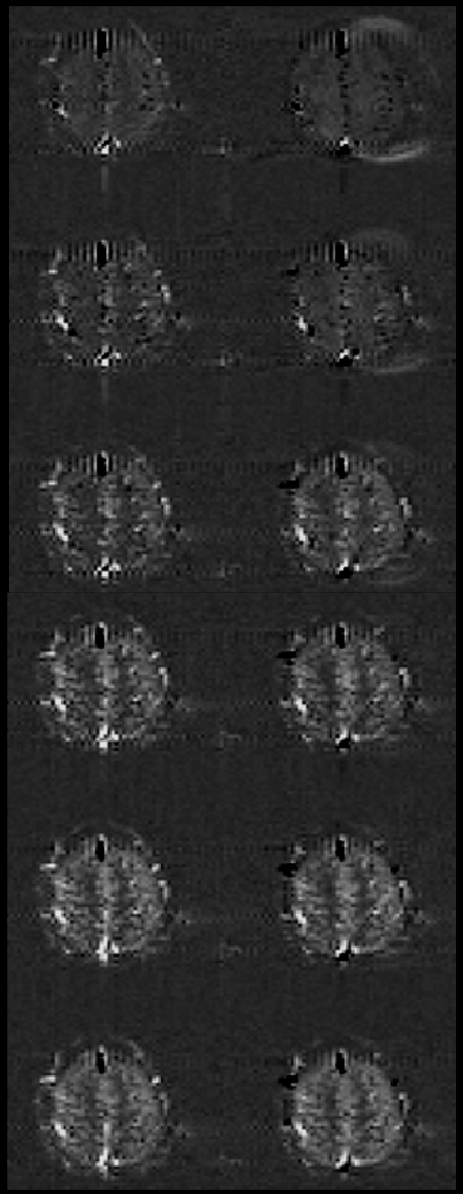
200		
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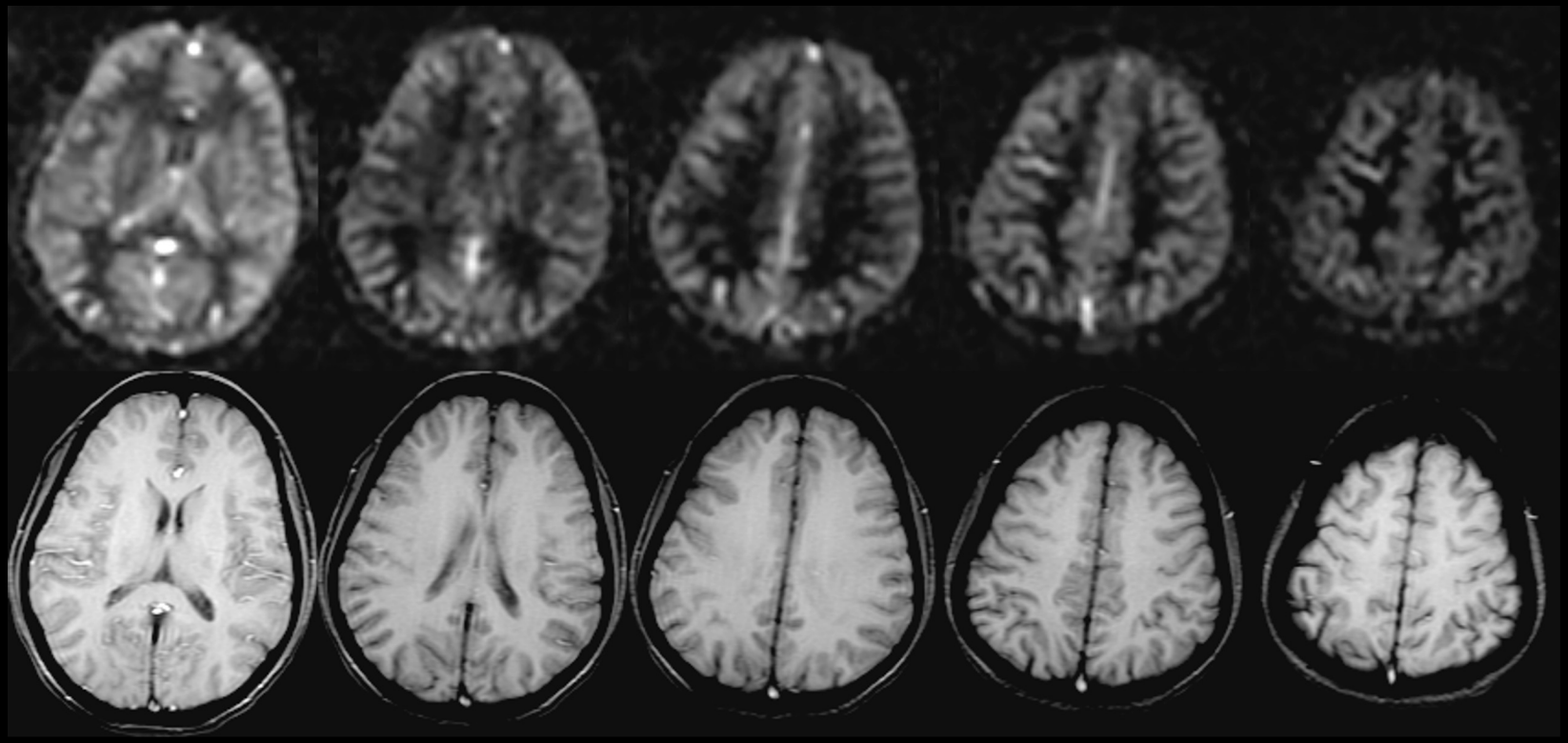

Williams, D. S., Detre, J. A., Leigh, J. S. & Koretsky, A. S. (1992) “Magnetic resonance imaging of perfusion using spin-inversion of arterial water.” Proc. Natl. Acad. Sci. USA 89, 212-216.

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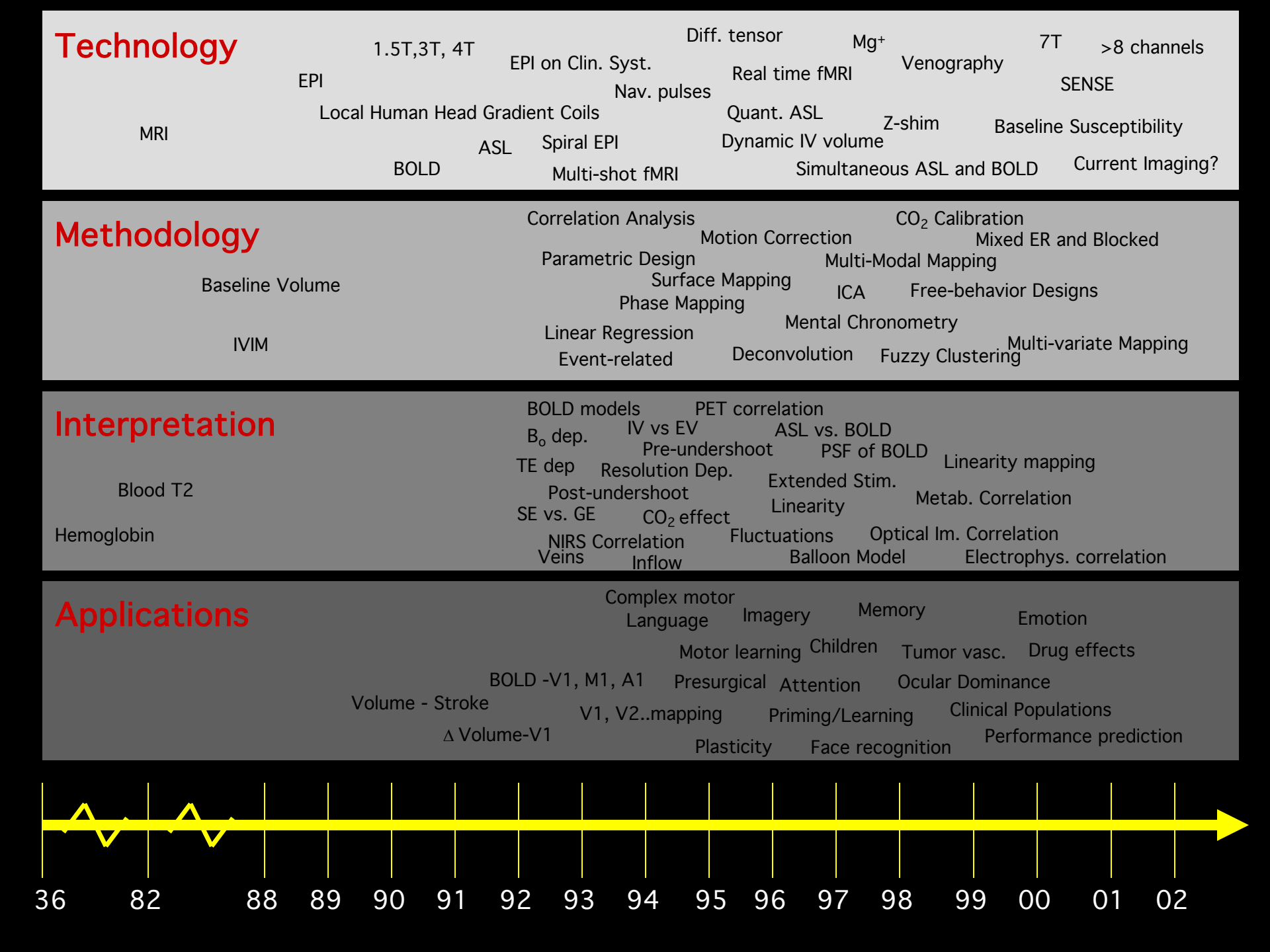
Kwong, K. K. et al. (1995) “MR perfusion studies with T1-weighted echo planar imaging.”Magn. Reson. Med. **34**, 878-887.

Refinements

BOLD Contrast Interpretation

Paradigm Design and Processing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Fluctuations
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NIRS Correlation
Veins
Balloon Model
Electrophys. correlation
Inflow
Applications
Complex motor
Language
Imagery
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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
36
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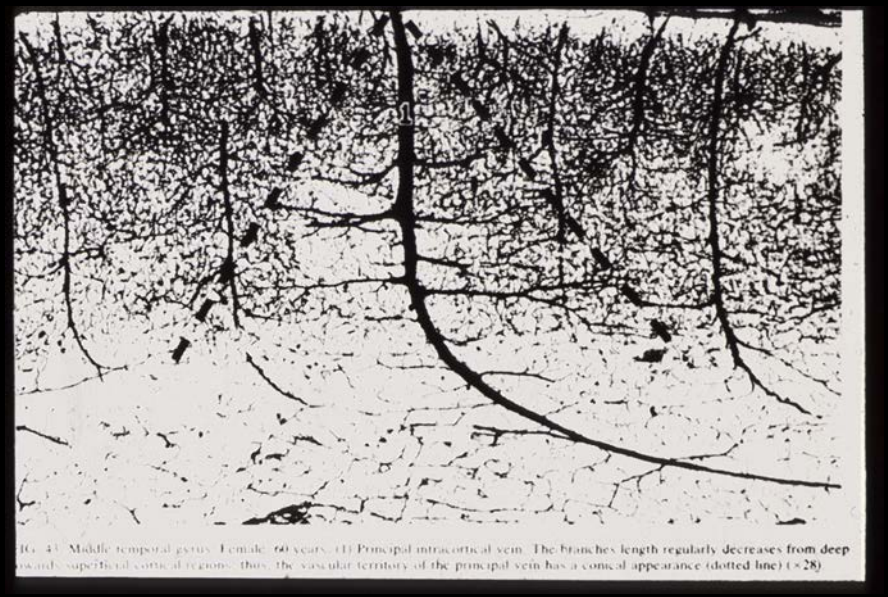
Refinements

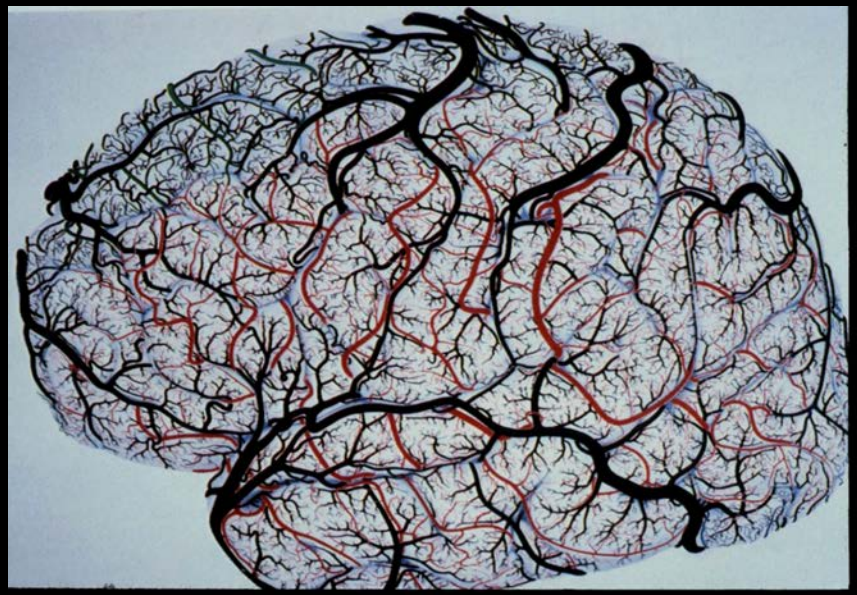
BOLD Contrast Interpretation

Paradigm Design and Processing

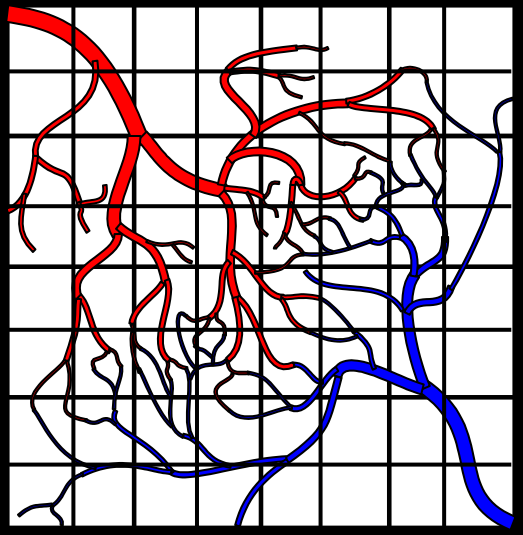
A challenge in using fMRI:

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





Neuronal Activation



Measured Signal

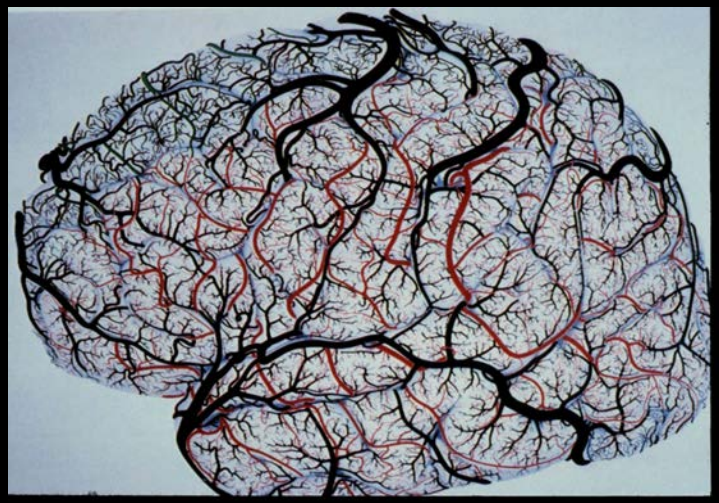
?

Hemodynamics

?

?

Noise

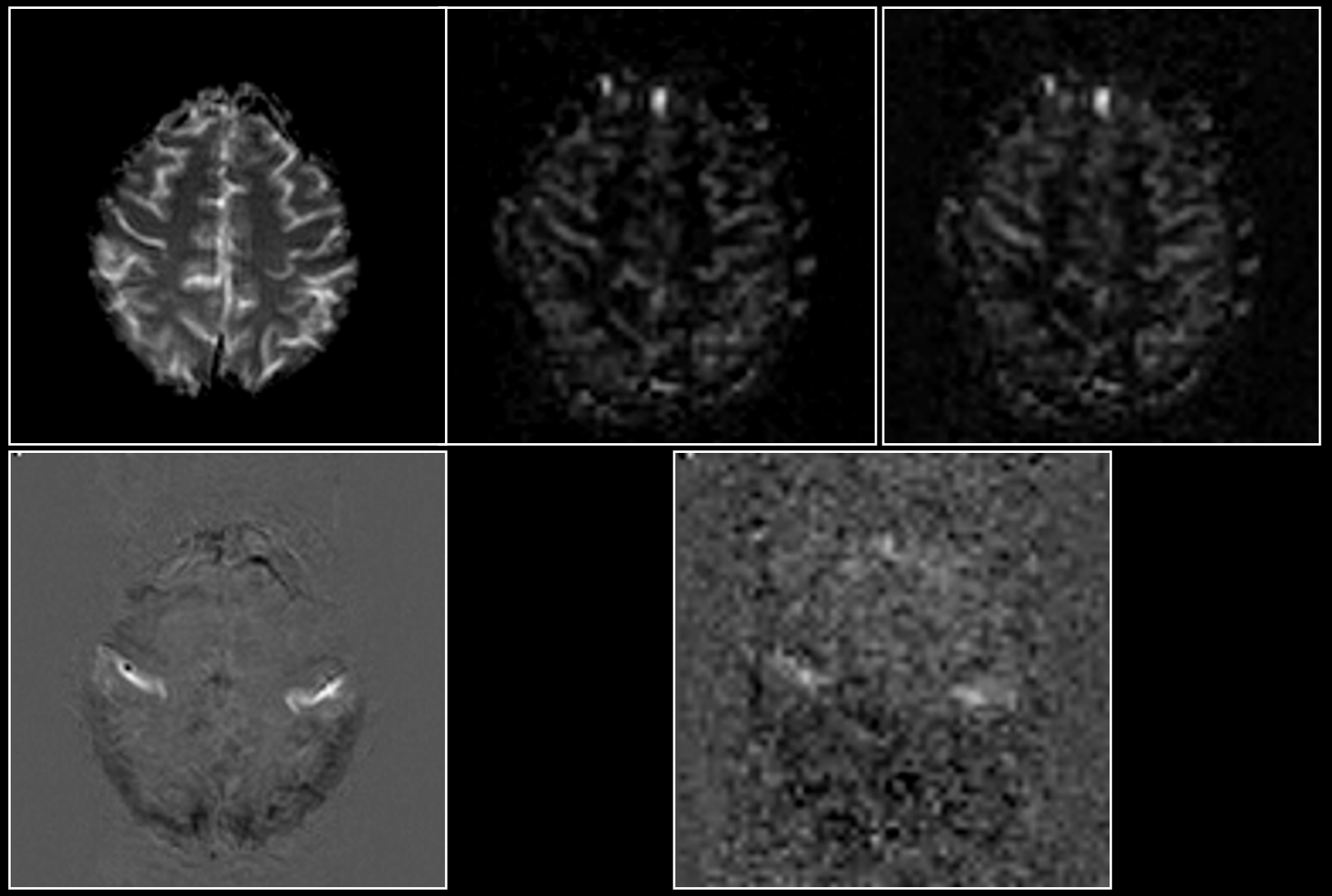


BOLD Contrast:
Strategies for Better Interpretation

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

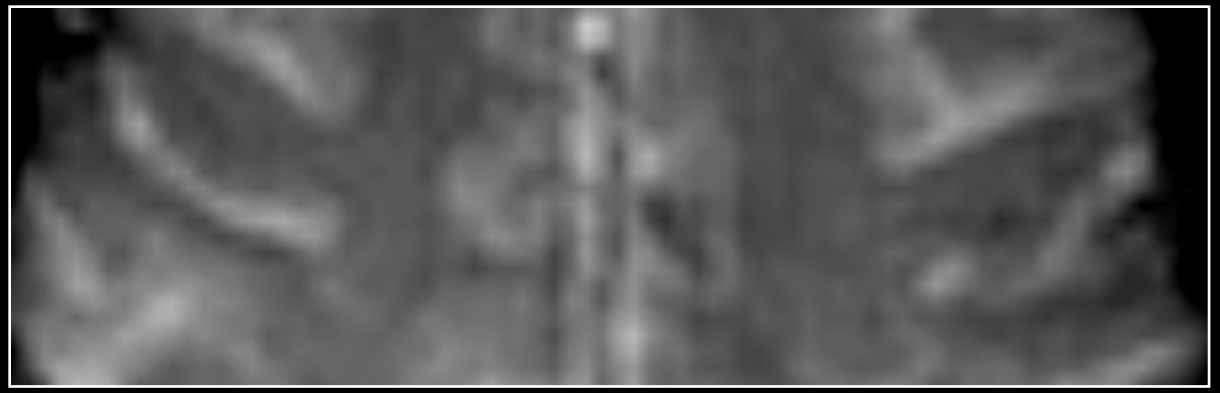
Perfusion

BOLD *Rest* *Activation*

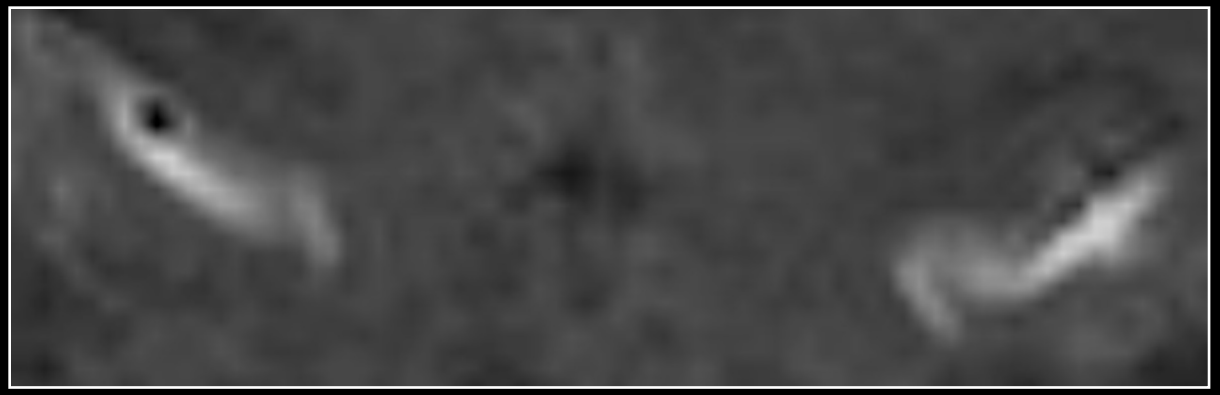


P. A. Bandettini, E. C. Wong, Magnetic resonance imaging of human brain function: principles, practicalities, and possibilities, *in* "Neurosurgery Clinics of North America: Functional Imaging" (M. Haglund, Ed.), p.345-371, W. B. Saunders Co., 1997.

Anatomy



BOLD



Perfusion

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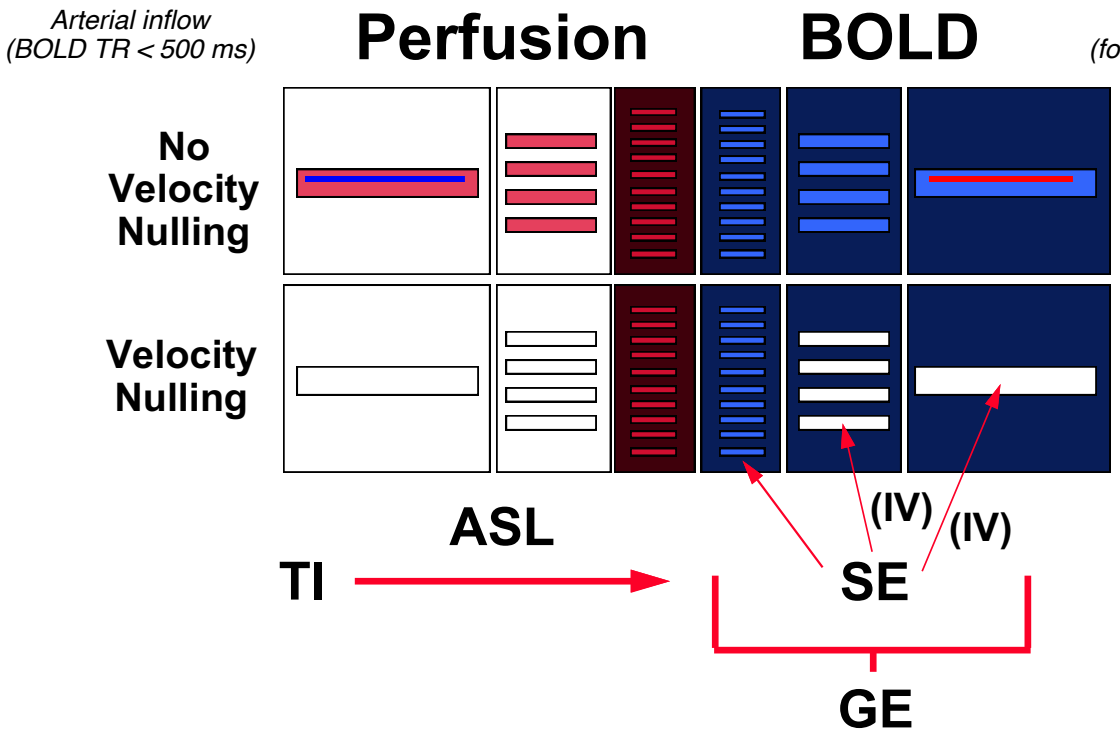
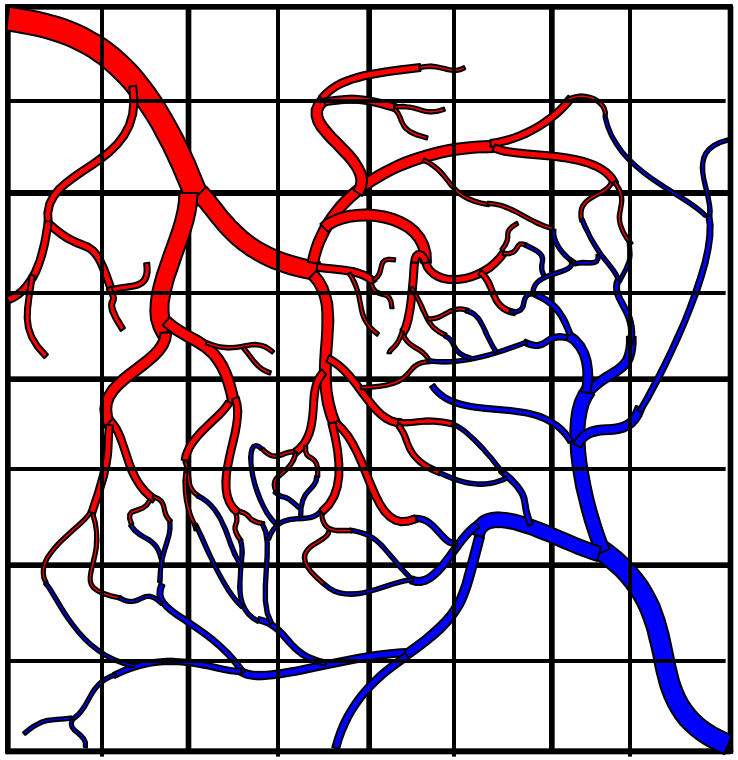
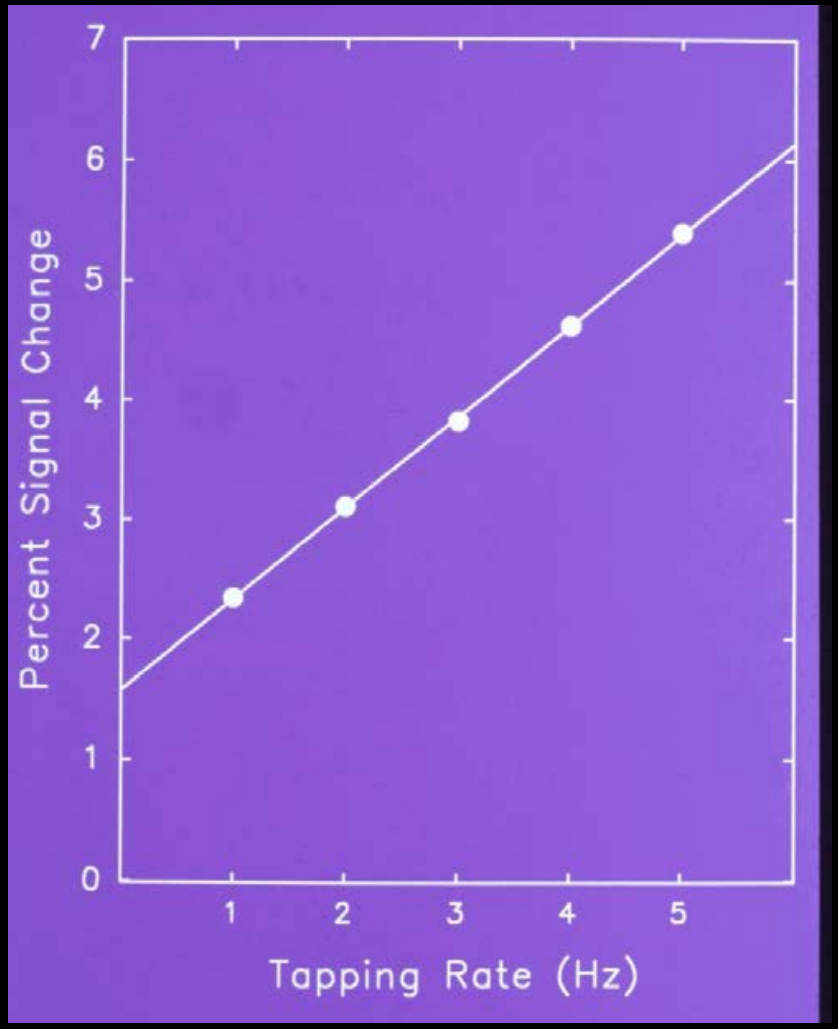


Pulse Sequence Sensitivity

Spatial Heterogeneity

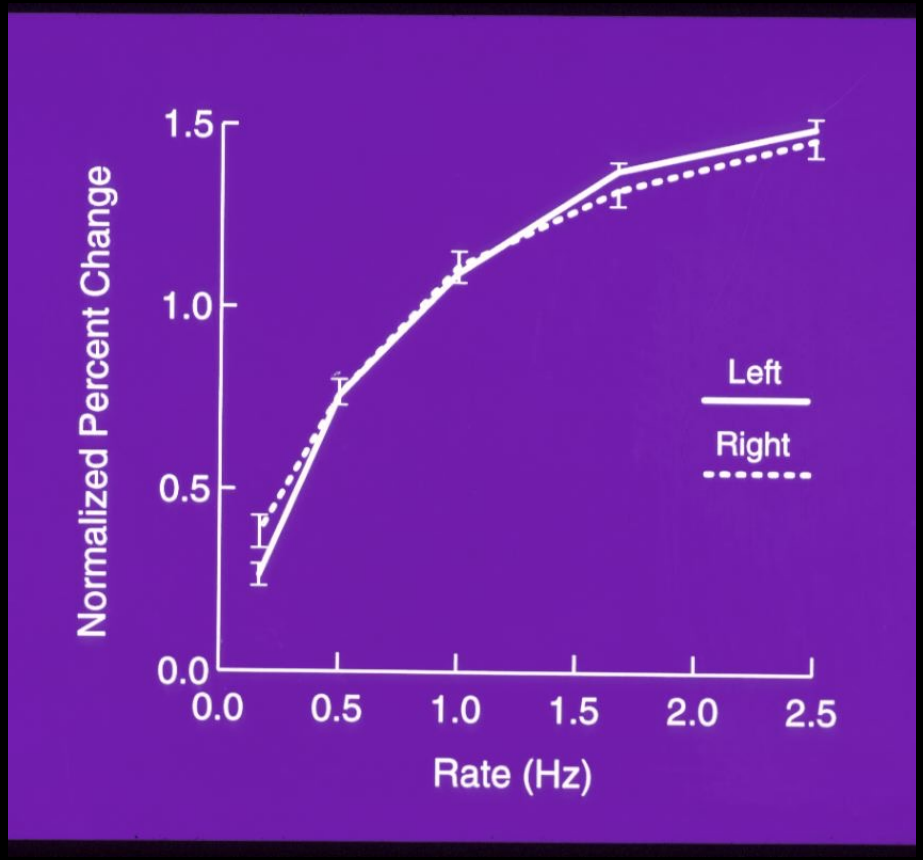


Motor Cortex

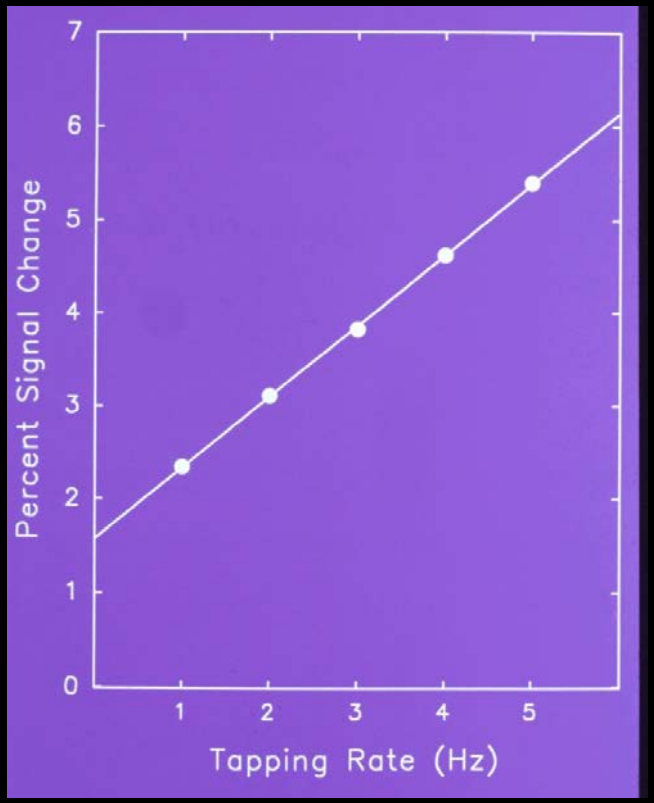


S. M. Rao et al, (1996) "Relationship between finger movement rate and functional magnetic resonance signal change in human primary motor cortex." *J. Cereb. Blood Flow and Met.* 16, 1250-1254.

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



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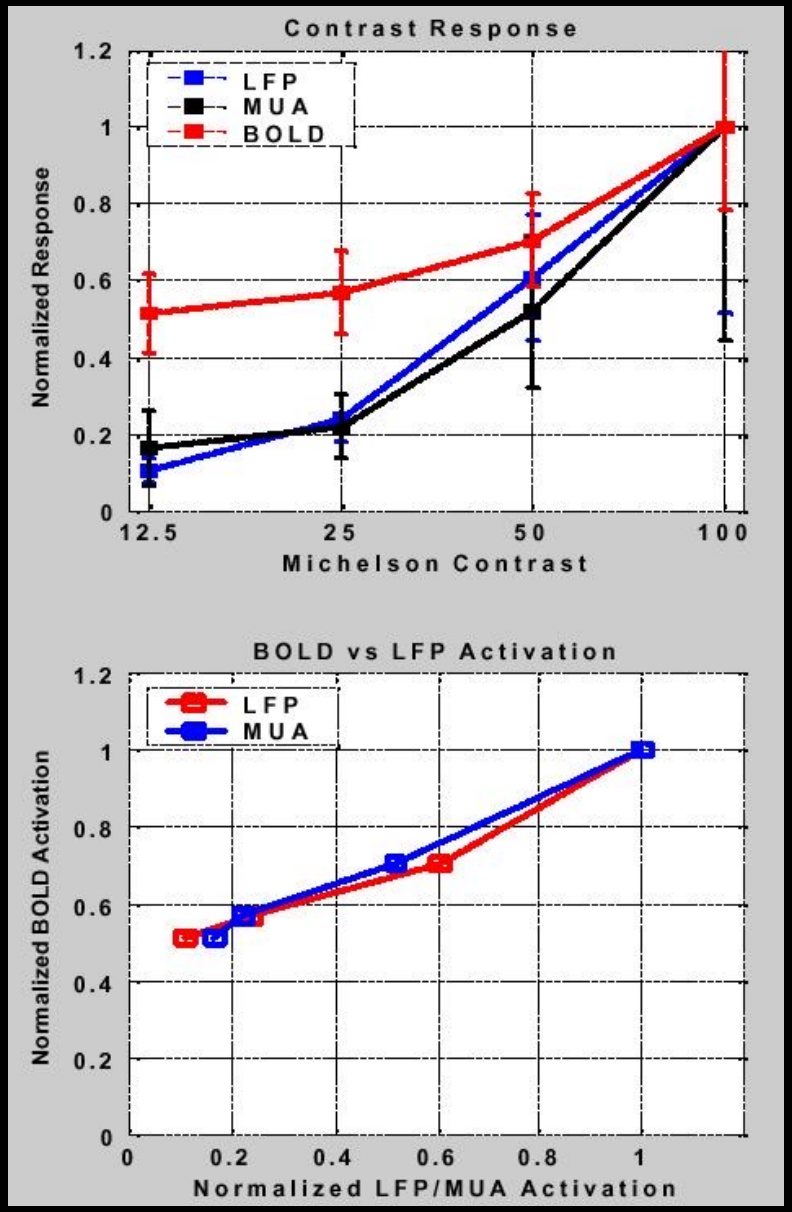
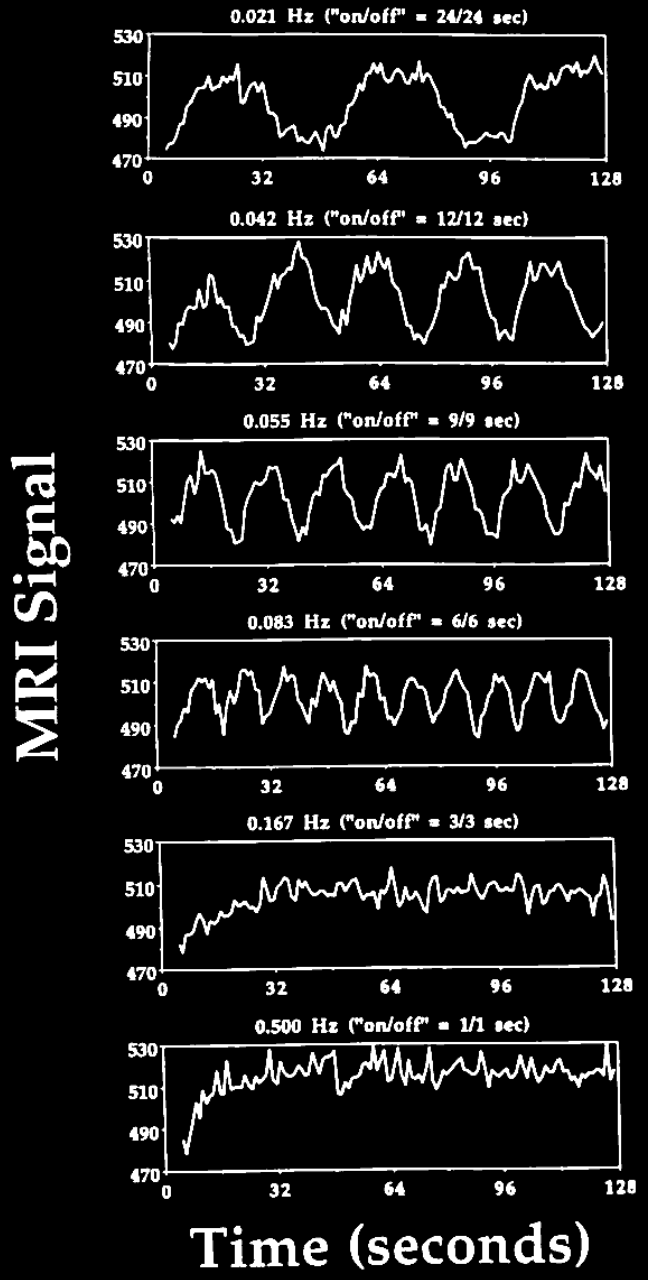
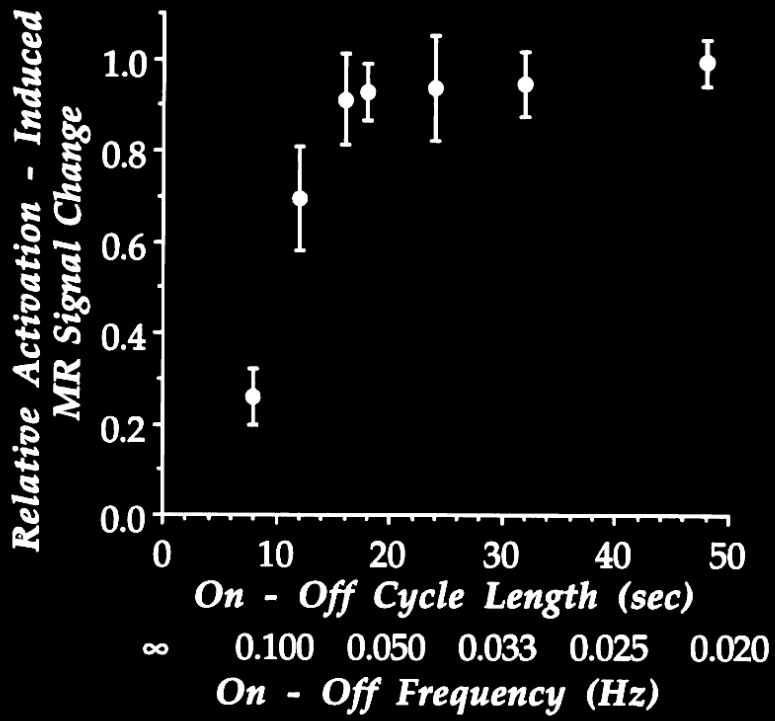
Logothetis et al. (2001) "Neurophysiological investigation of the basis of the fMRI signal" Nature, 412, 150-157

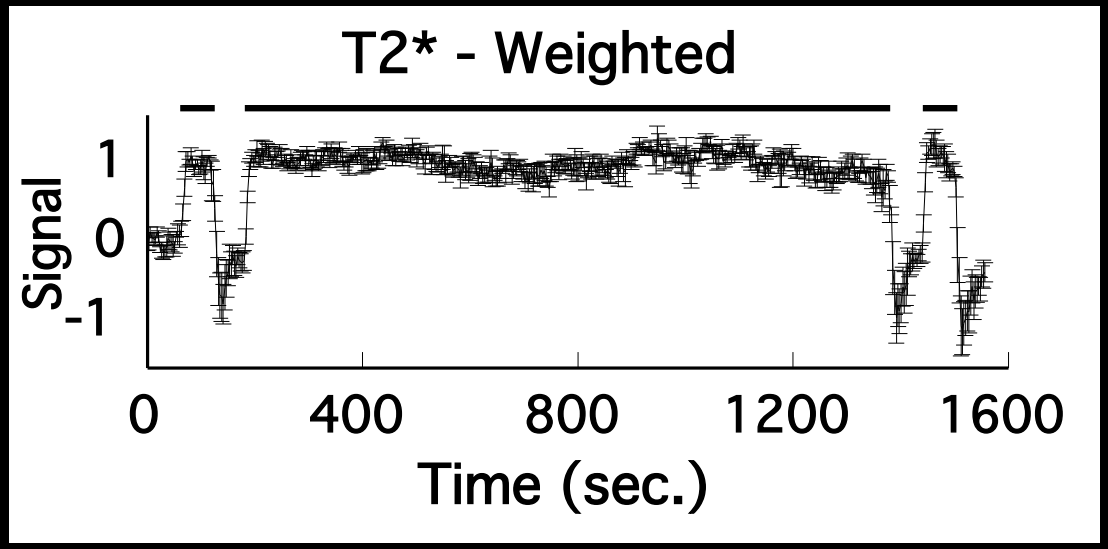




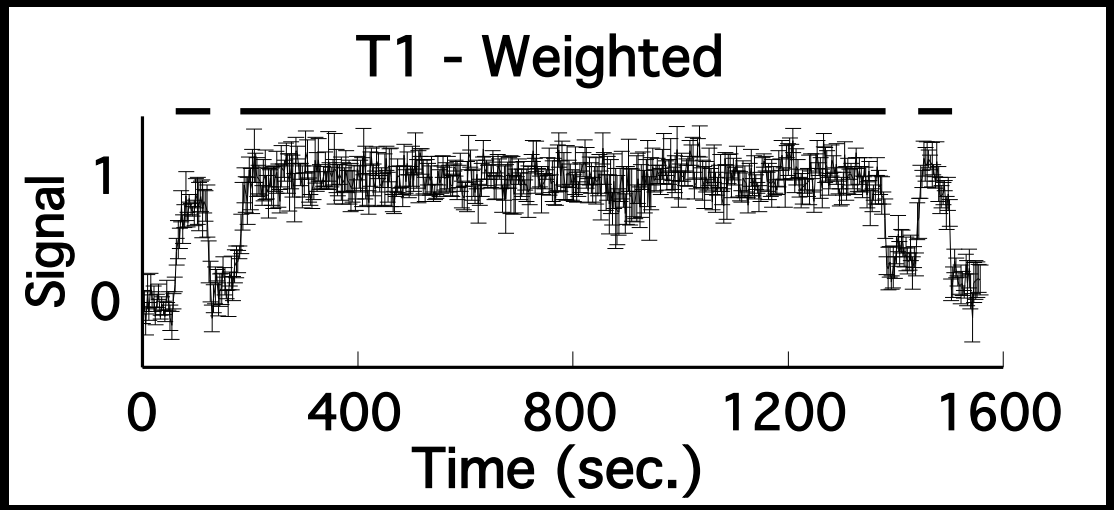


P. A. Bandettini, Functional MRI temporal resolution *in* "Functional MRI" (C. Moonen, and P. Bandettini., Eds.), p. 205-220, Springer - Verlag,. 1999.

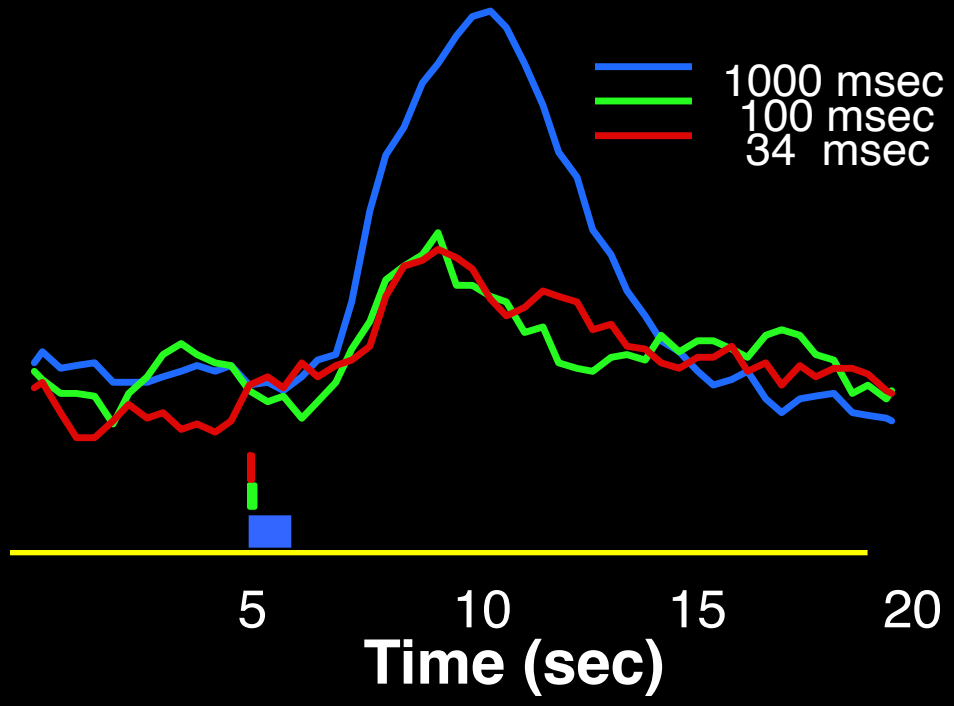
BOLD



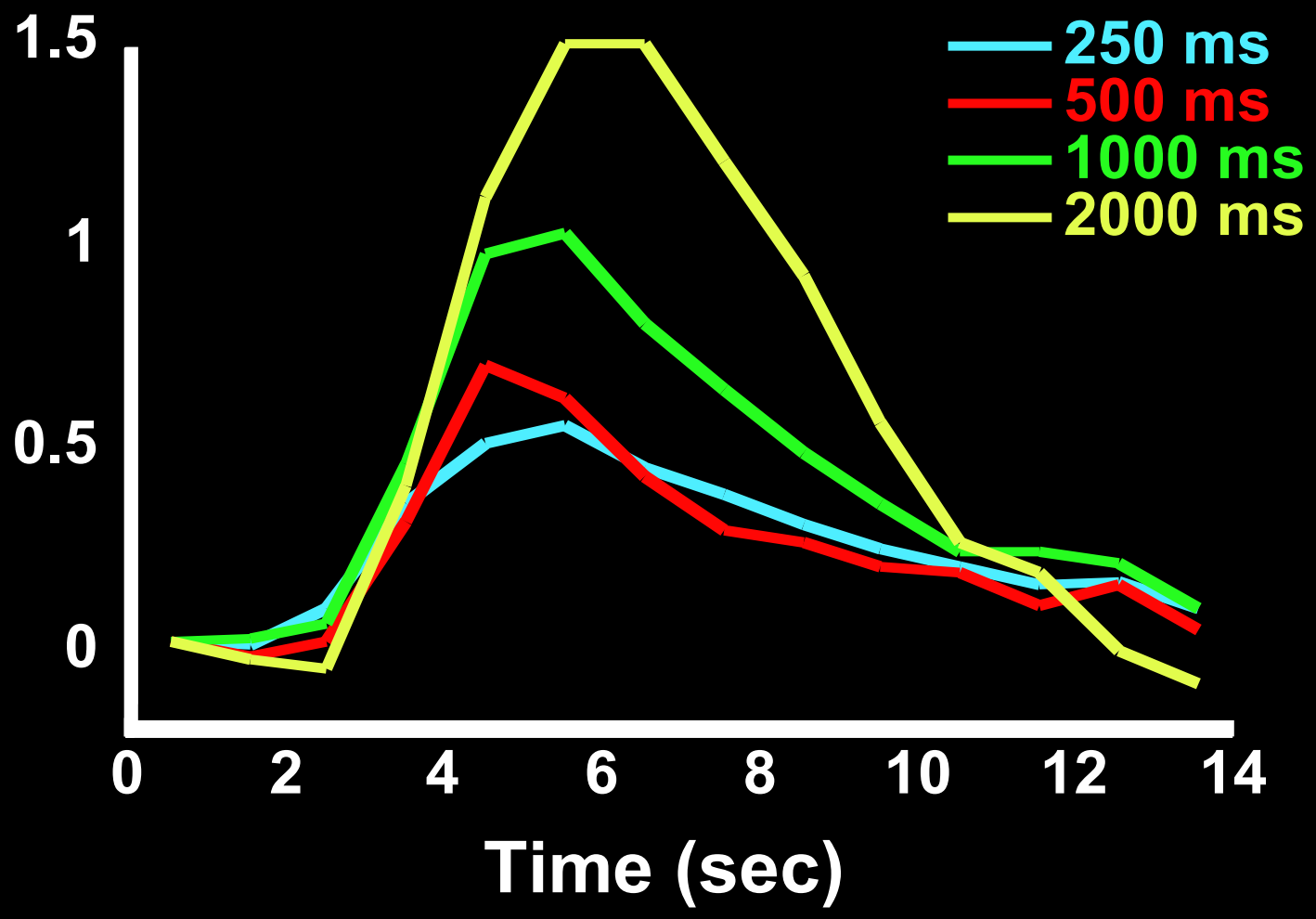
Flow

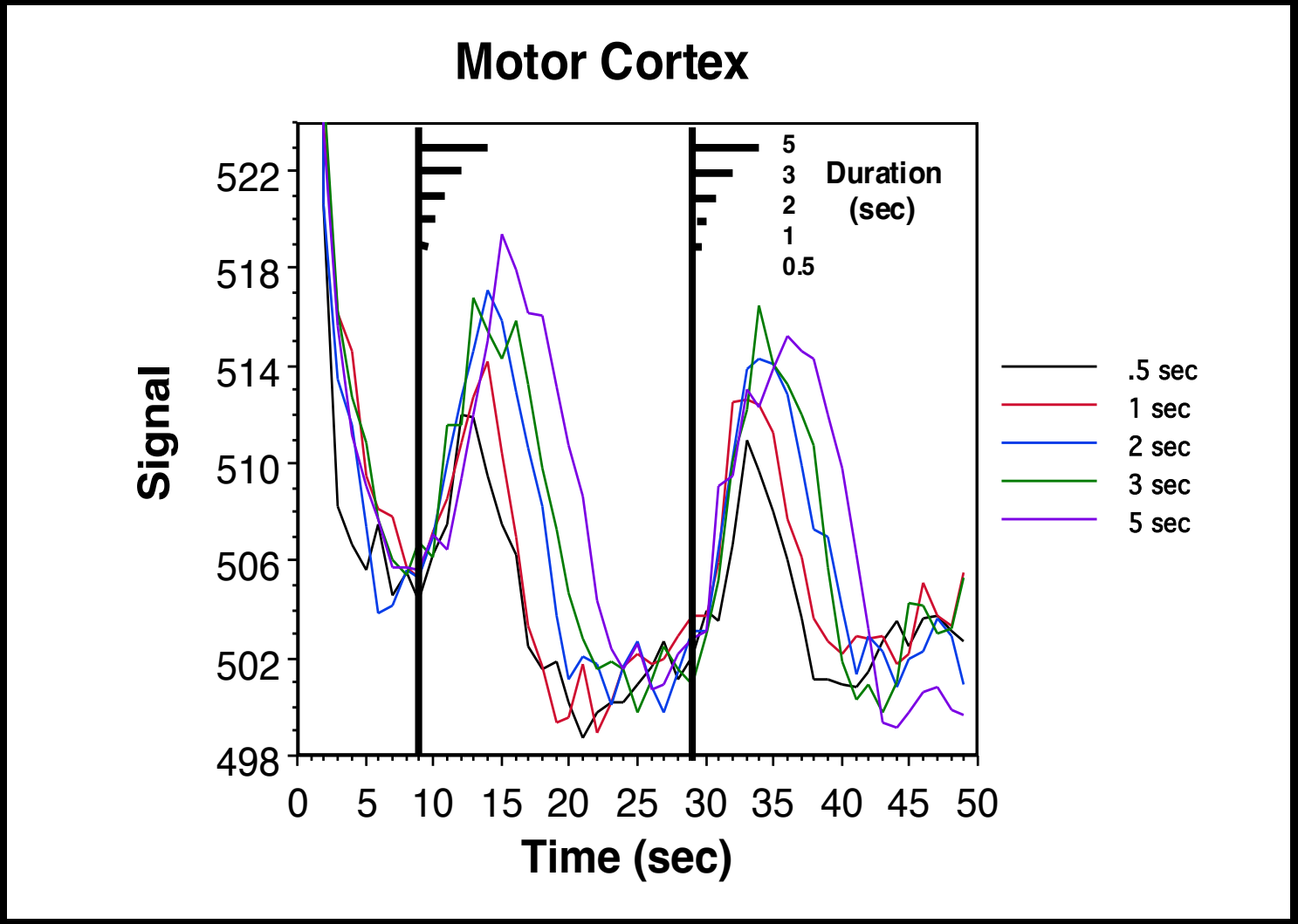


P. A. Bandettini, K. K. Kwong, T. L. Davis, R. B. H. Tootell, E. C. Wong, P. T. Fox, J. W. Belliveau, R. M. Weisskoff, B. R. Rosen, (1997). "Characterization of cerebral blood oxygenation and flow changes during prolonged brain activation." *Human Brain Mapping* 5, 93-109.

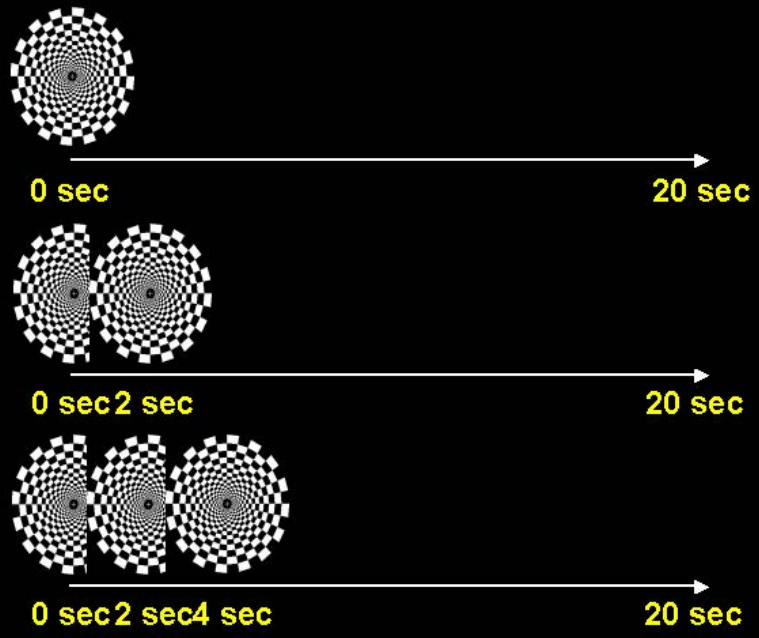


R. L. Savoy, et al., Pushing the temporal resolution of fMRI: studies of very brief visual stimuli, onset variability and asynchrony, and stimulus-correlated changes in noise [oral], 3'rd Proc. Soc. Magn. Reson., Nice, p. 450. (1995).


1.5
1
0.5
0
0
2
4
6
8
10
12
14
Time (sec)
250 ms
500 ms
1000 ms
2000 ms



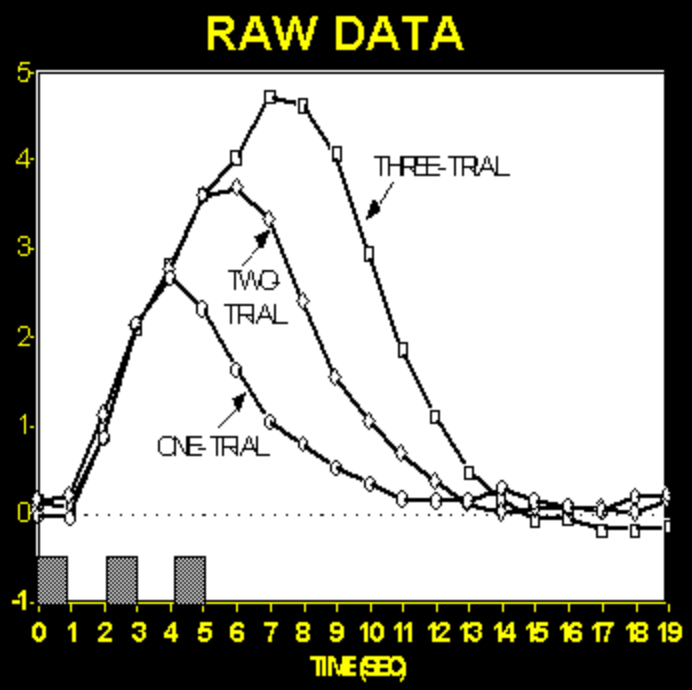
Bandettini, et al., The functional dynamics of blood oxygenation level contrast in the motor cortex, 12'th Proc. Soc. Magn. Reson. Med., New York, p. 1382. (1993).

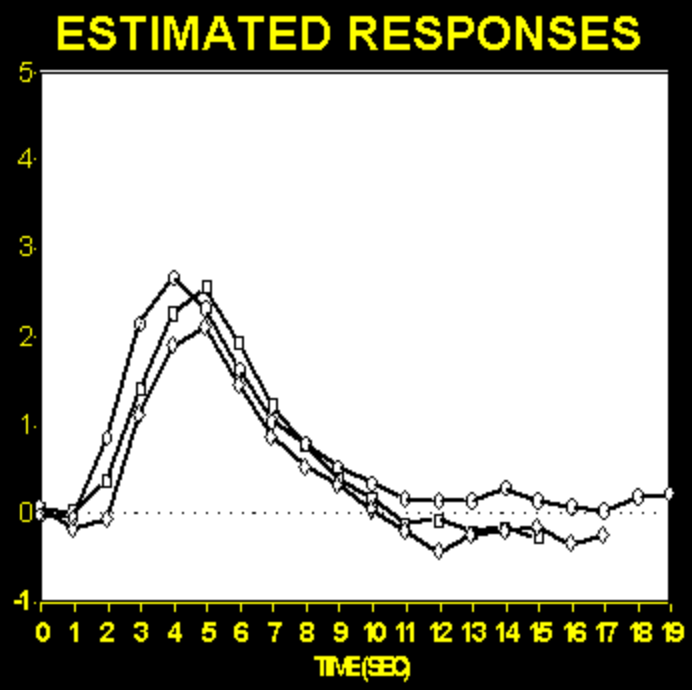


Human Brain Mapping 5:329–340(1997)

Selective Averaging of Rapidly Presented Individual Trials Using fMRI

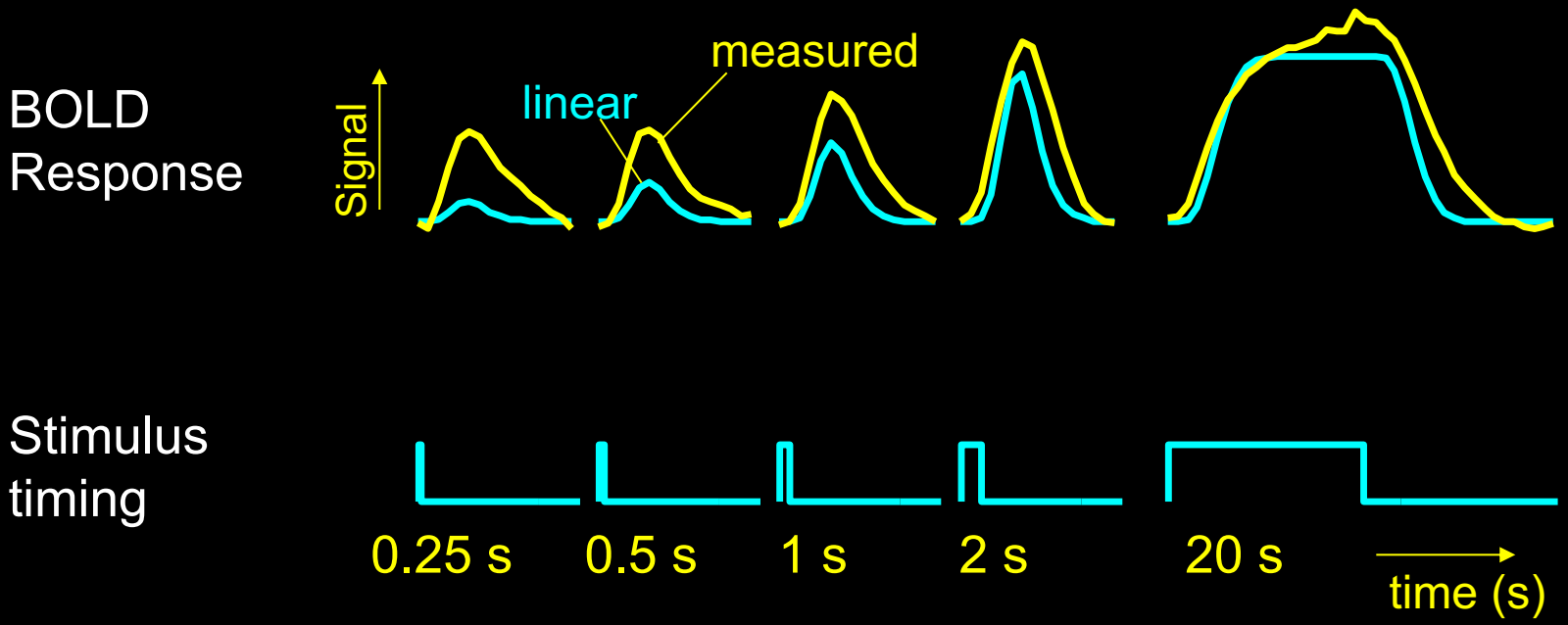
Anders M. Dale* and Randy L. Buckner





Dynamic Nonlinearity Assessment

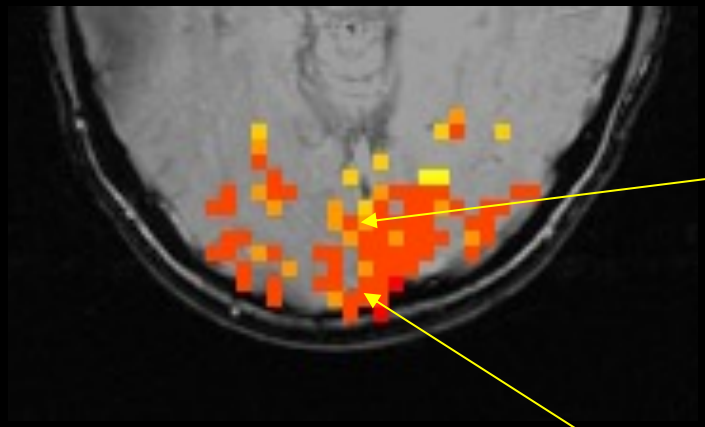
Different stimulus "ON" periods

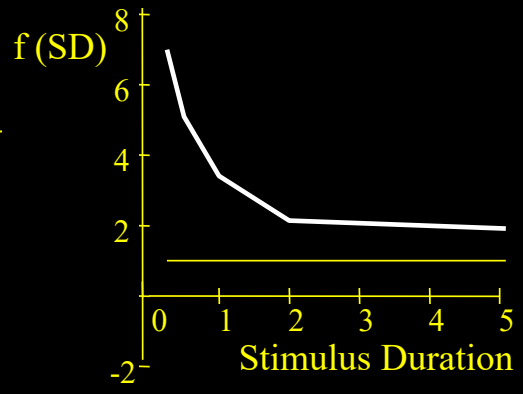


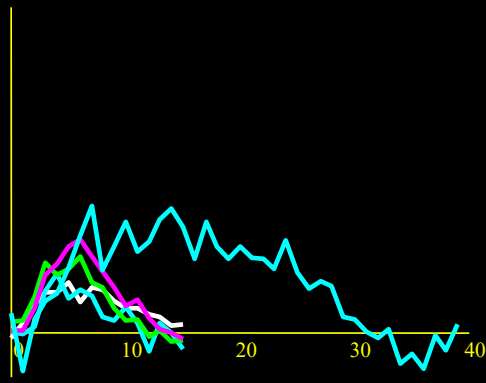
Brief stimuli produce larger responses than expected

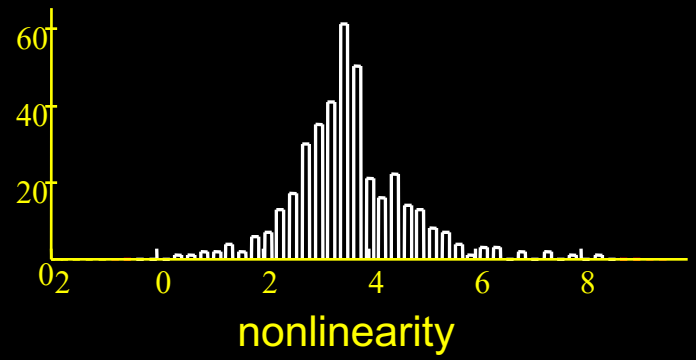
R. M. Birn, Z. Saad, P. A. Bandettini, (2001) "Spatial heterogeneity of the nonlinear dynamics in the fMRI BOLD response." *NeuroImage*, 14: 817-826.

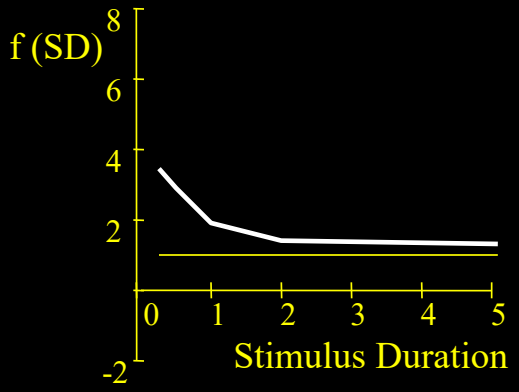
Spatial Heterogeneity of BOLD Nonlinearity

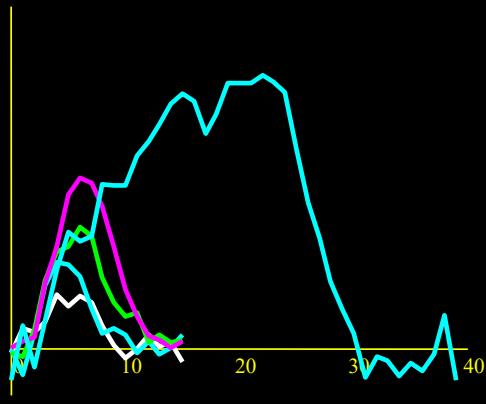












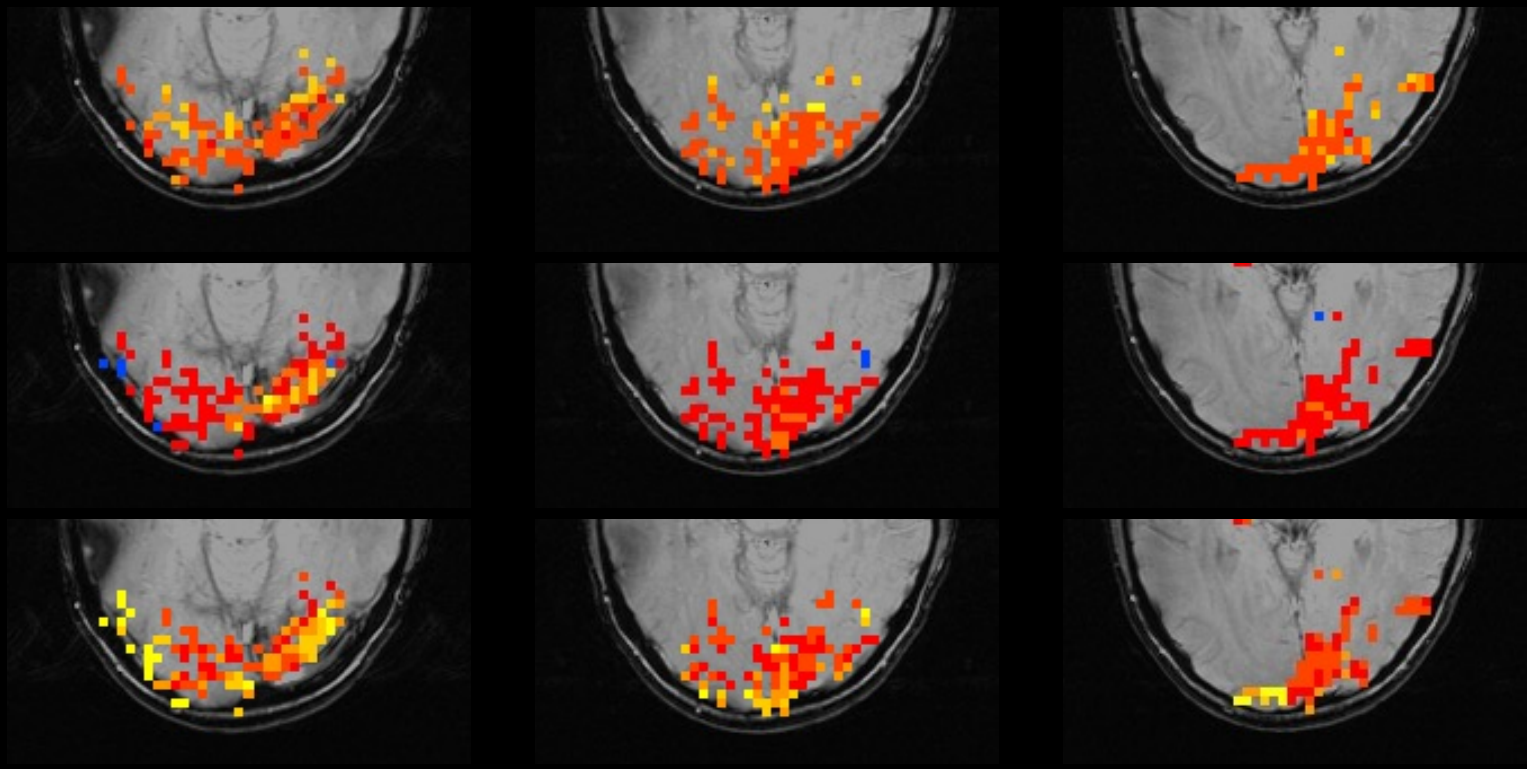
R. M. Birn, Z. Saad, P. A. Bandettini, (2001) "Spatial heterogeneity of the nonlinear dynamics in the fMRI BOLD response." *NeuroImage*, 14: 817-826.

Results – visual task

Nonlinearity

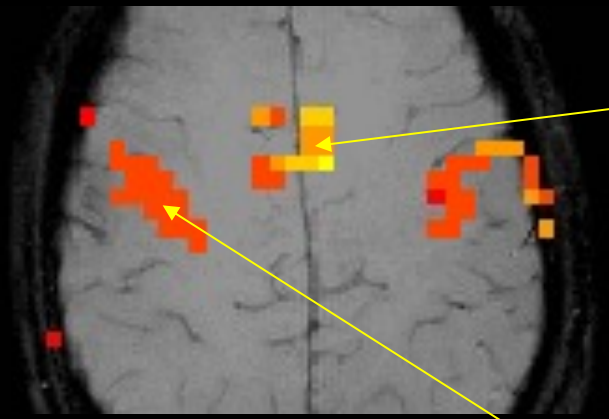
Magnitude

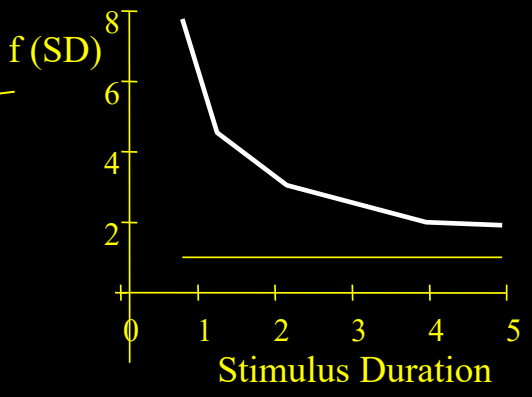
Latency

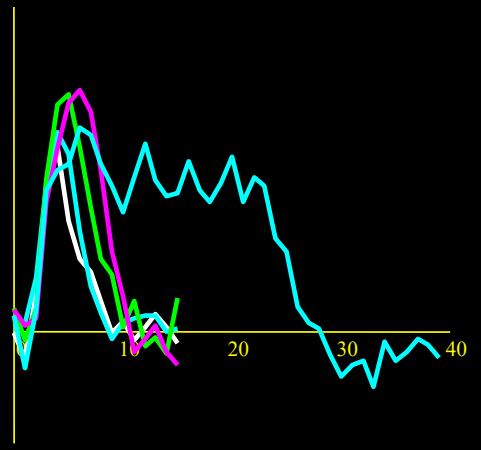


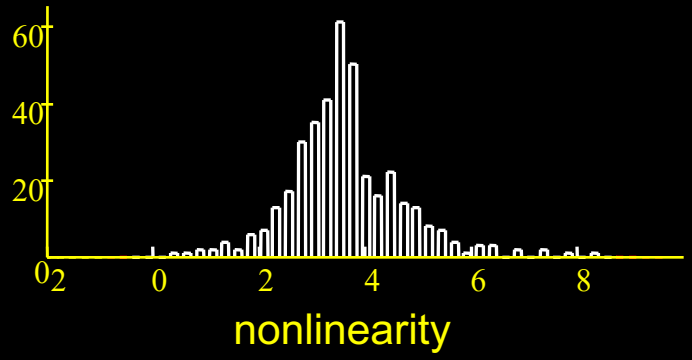
R. M. Birn, Z. Saad, P. A. Bandettini, (2001) "Spatial heterogeneity of the nonlinear dynamics in the fMRI BOLD response." *NeuroImage*, 14: 817-826.

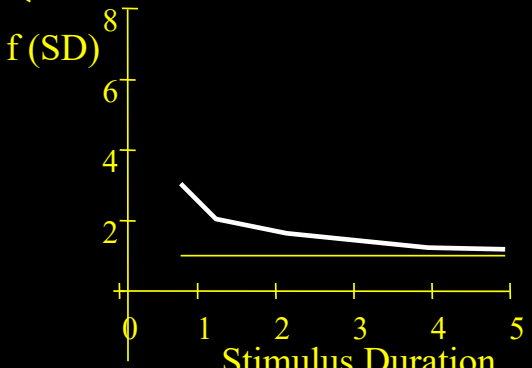
Results – motor task

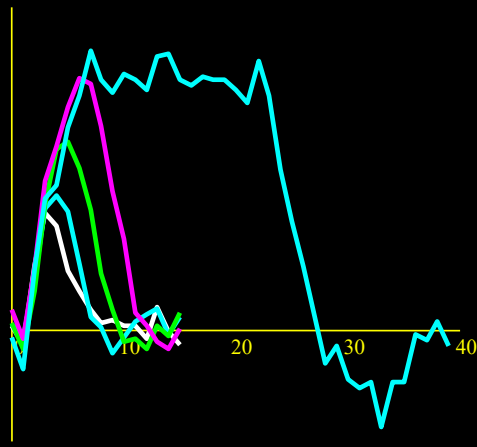










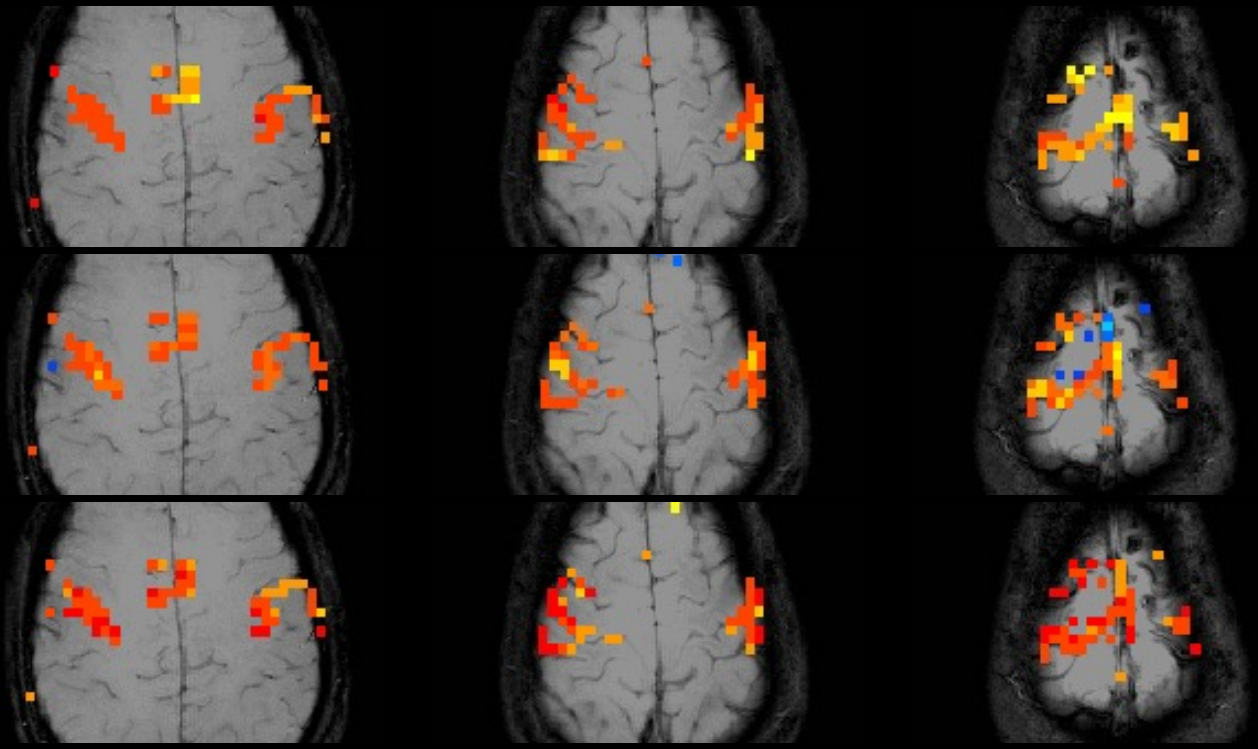


Results – motor task

Nonlinearity

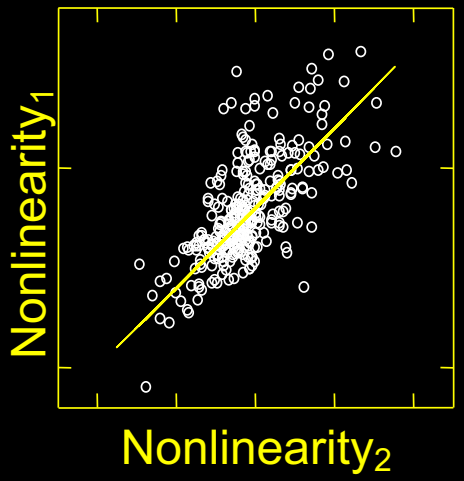
Magnitude

Latency

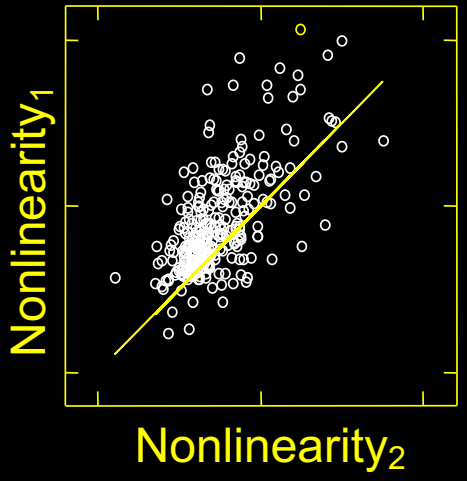


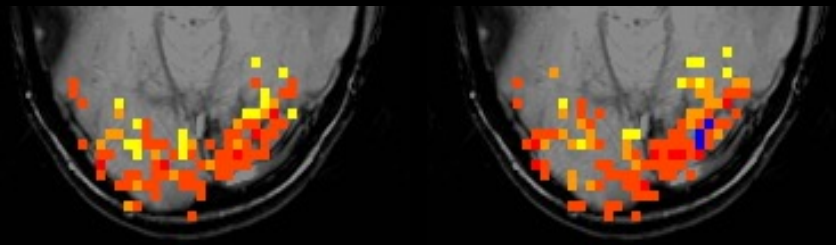
Reproducibility

Visual task

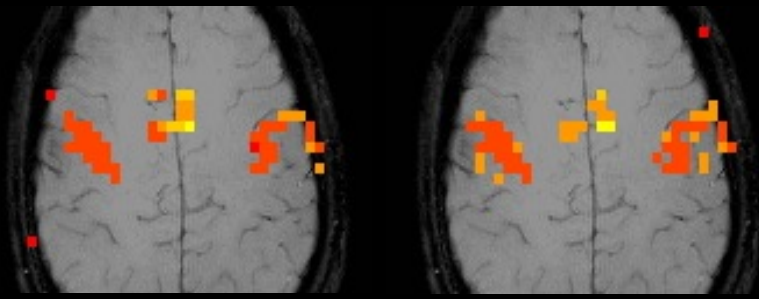


Motor task





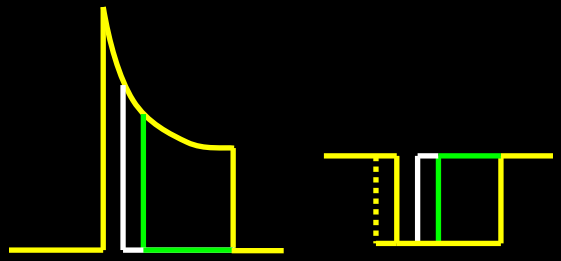
Experiment 1 Experiment 2



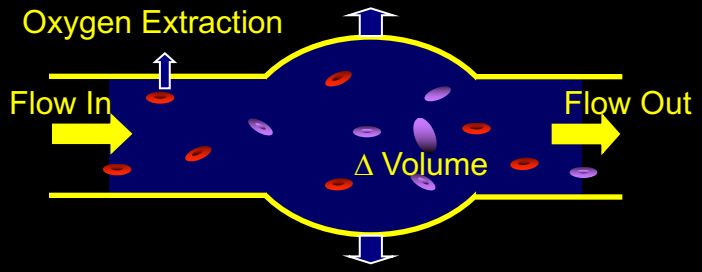
Experiment 1 Experiment 2

Sources of this Nonlinearity

- Neuronal

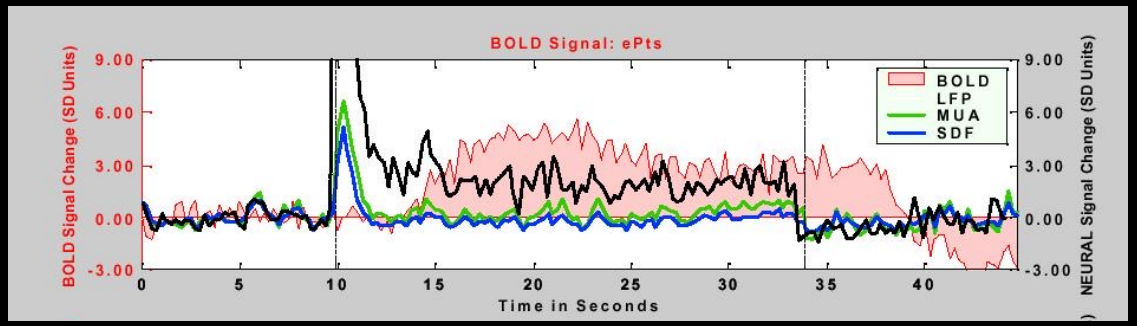


- Hemodynamic
  - Oxygen extraction
  - Blood volume dynamics

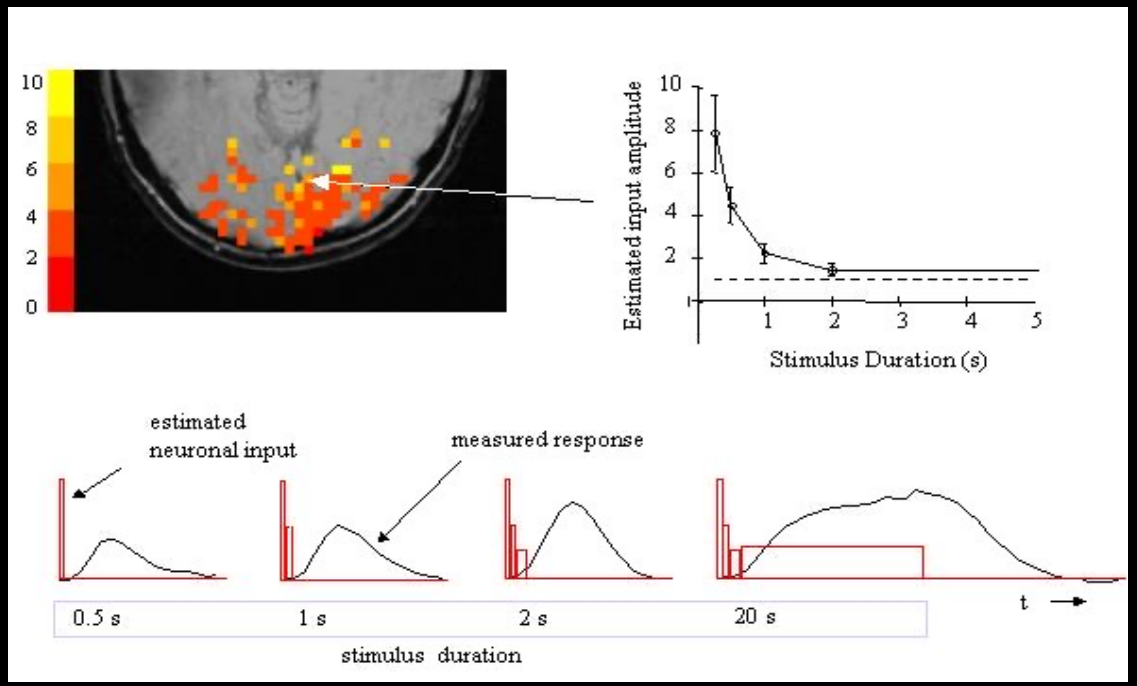


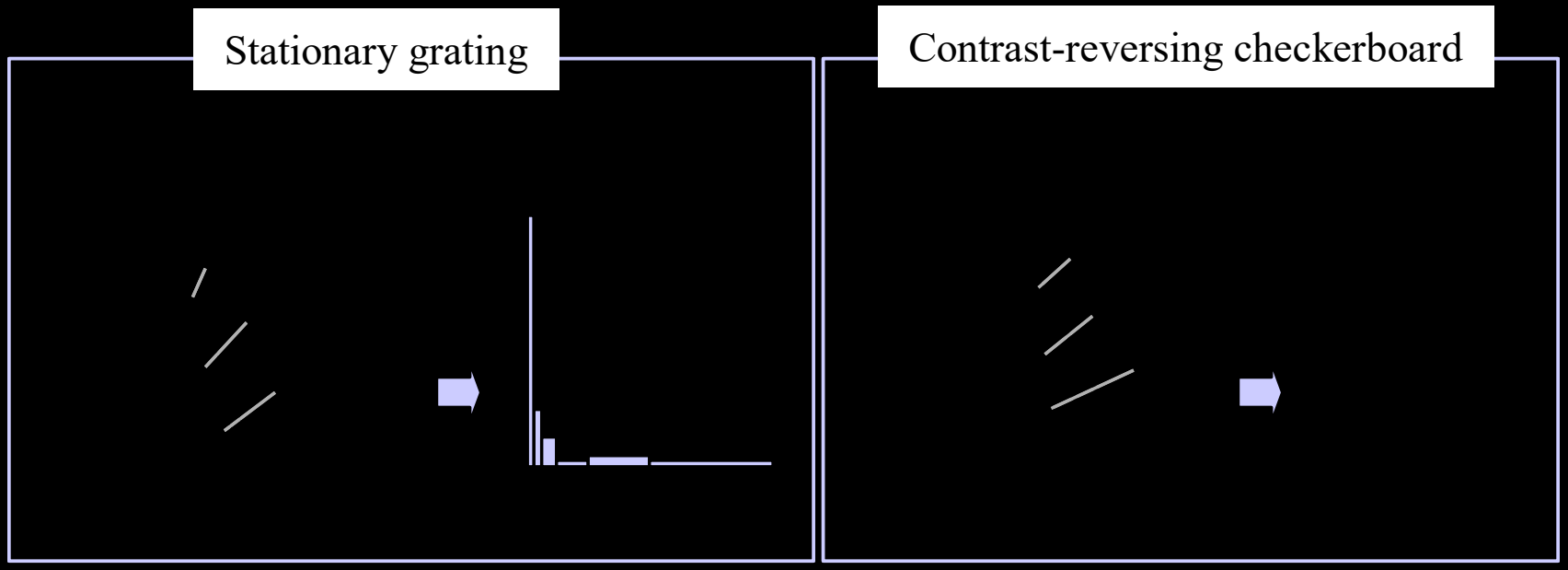
BOLD Correlation with Neuronal Activity

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

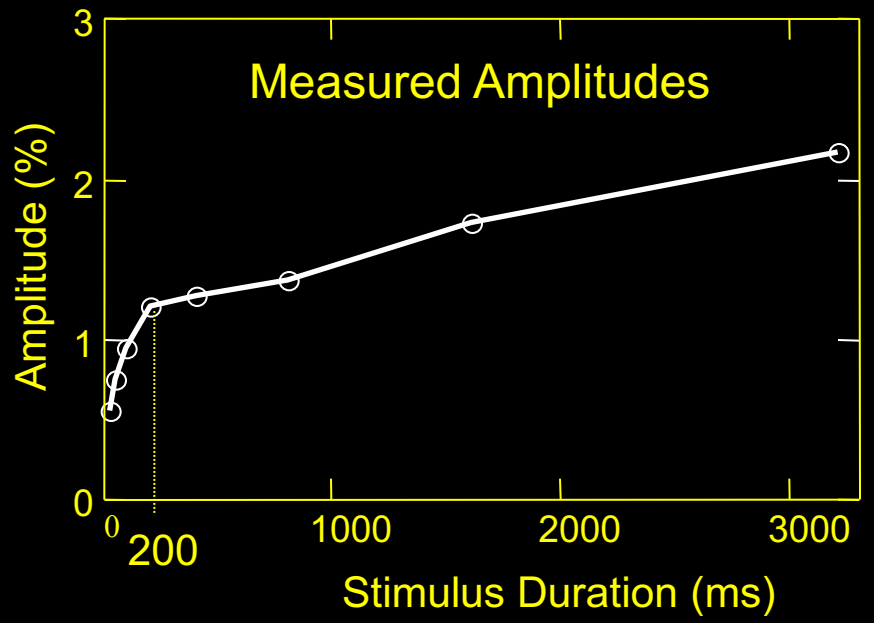


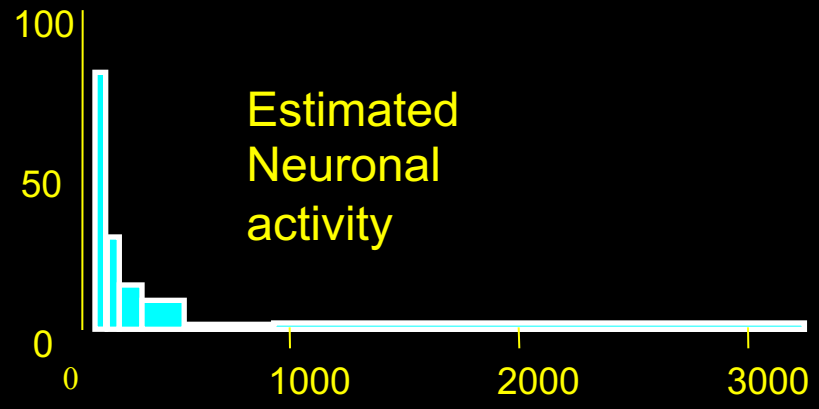
P. A. Bandettini and L. G. Ungerleider, (2001) "From neuron to BOLD: new connections." Nature Neuroscience, 4: 864-866.

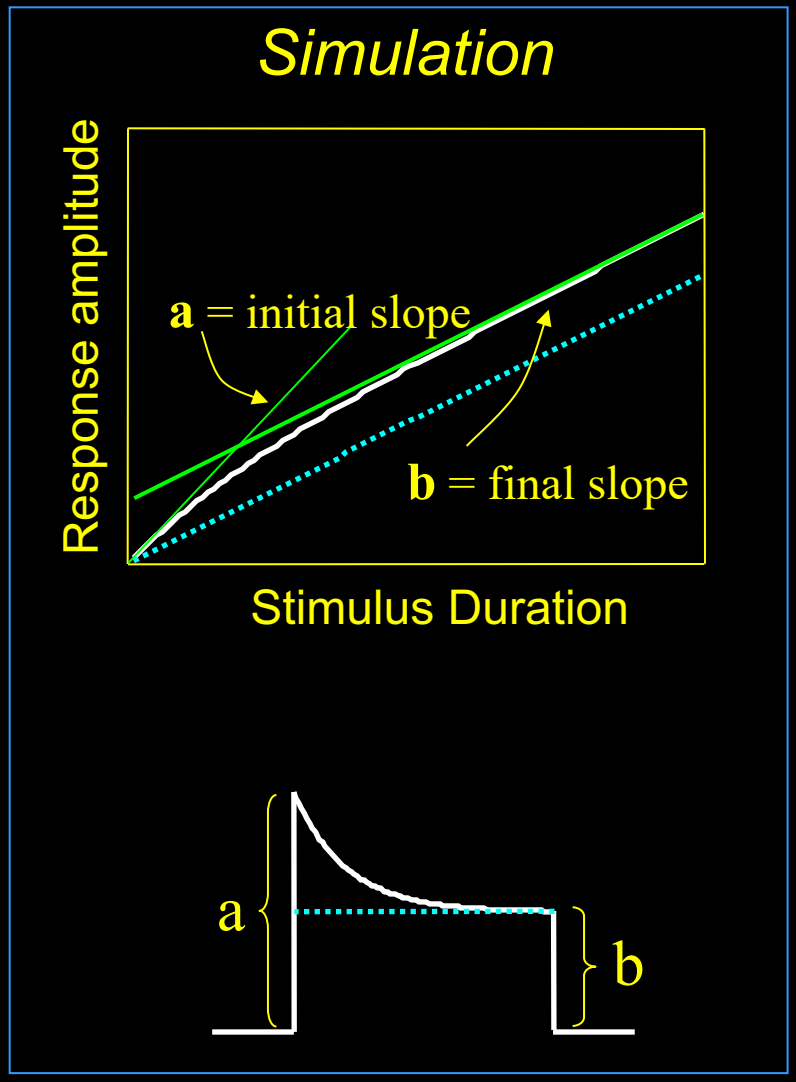



Stationary grating
Contrast-reversing checkerboard

Results – constant gratings





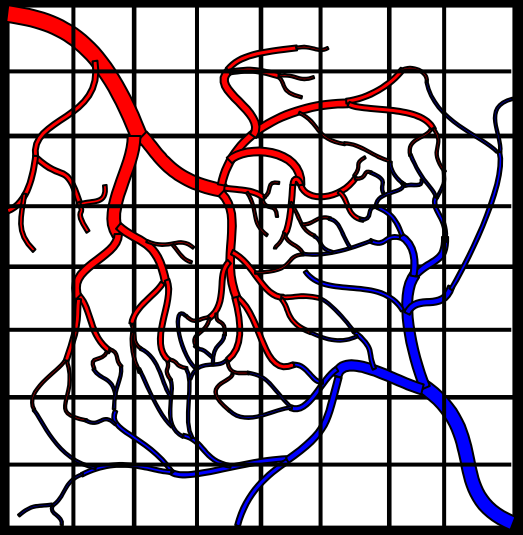


Refinements

BOLD Contrast Interpretation

Paradigm Design and Processing

Neuronal Activation



Measured Signal

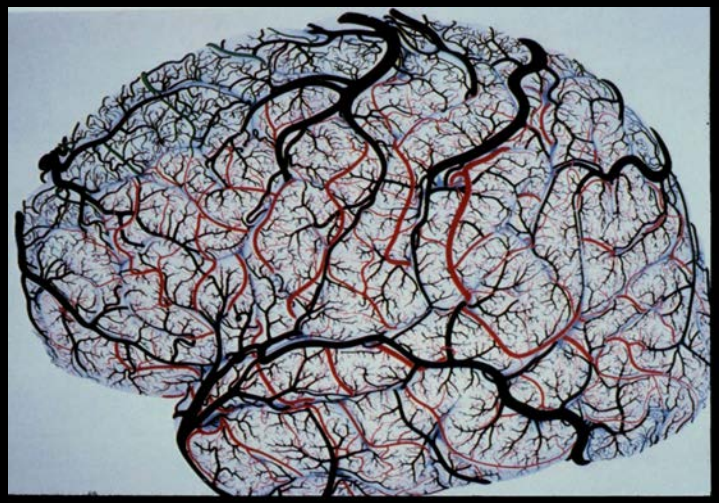
?

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
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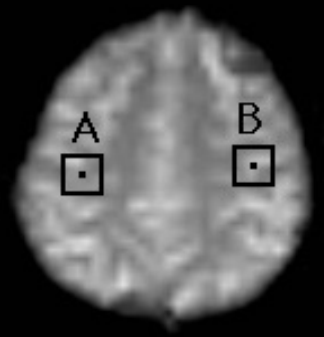
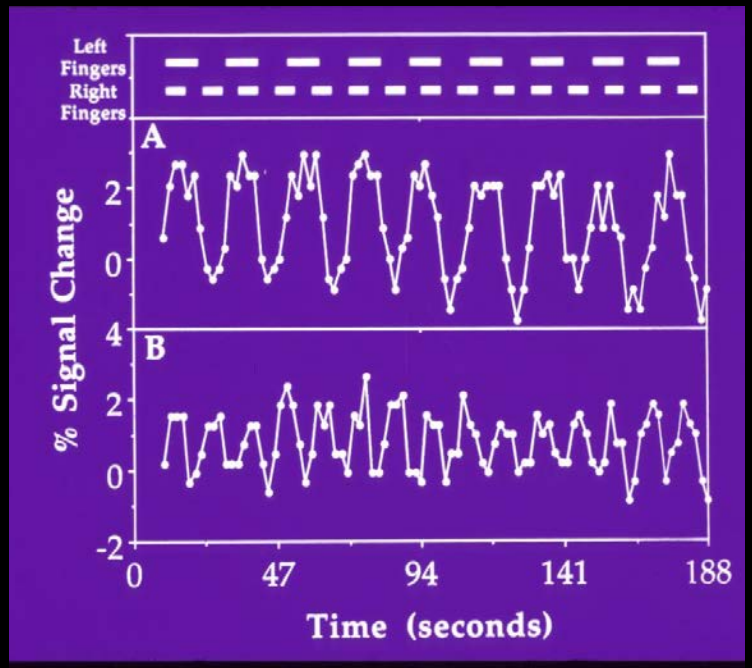
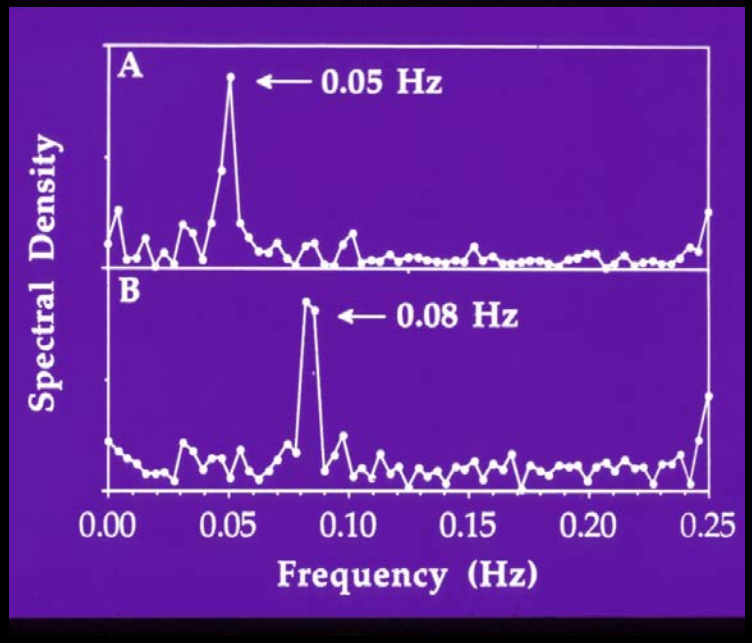
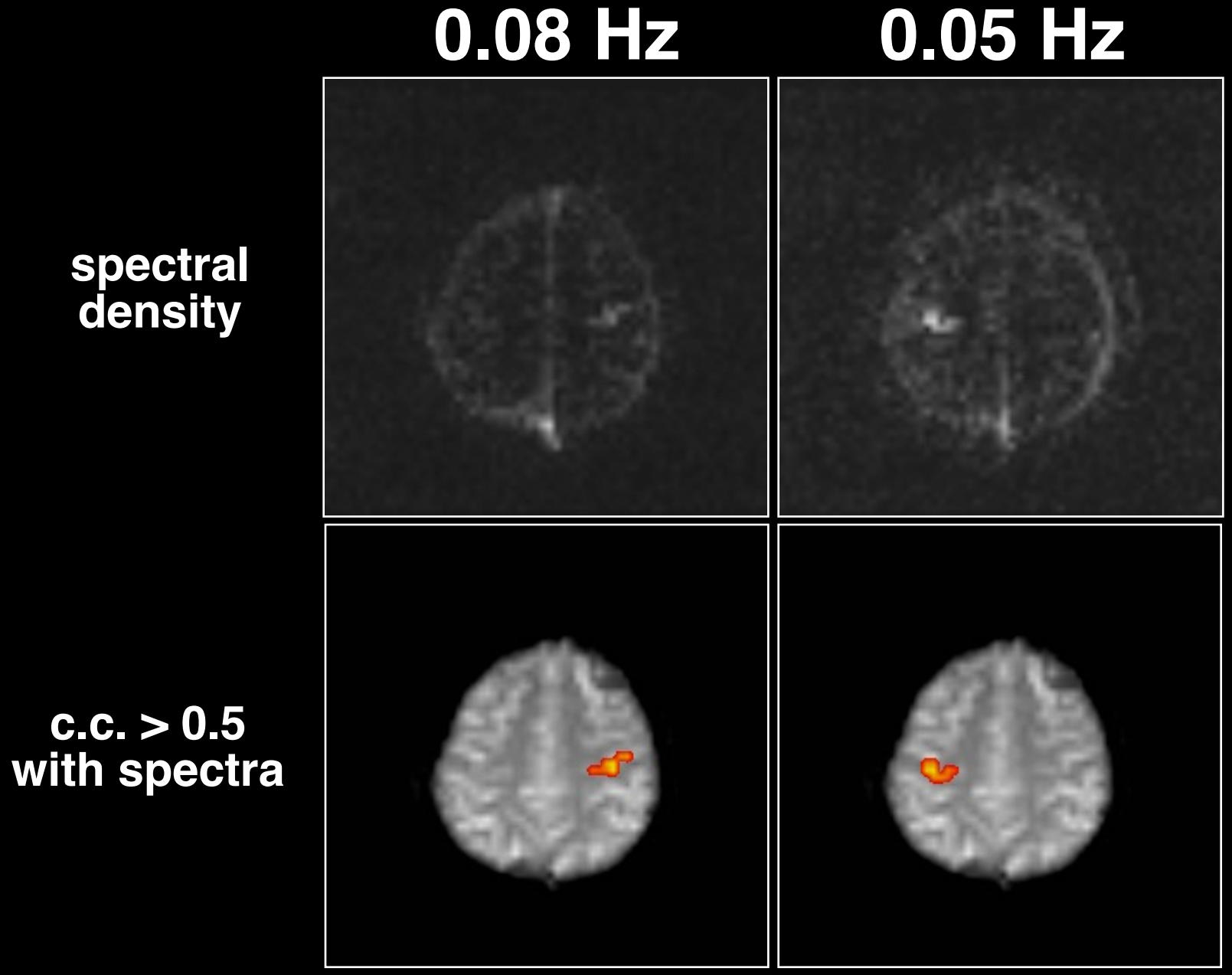
7. Free Behavior Design







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).



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).

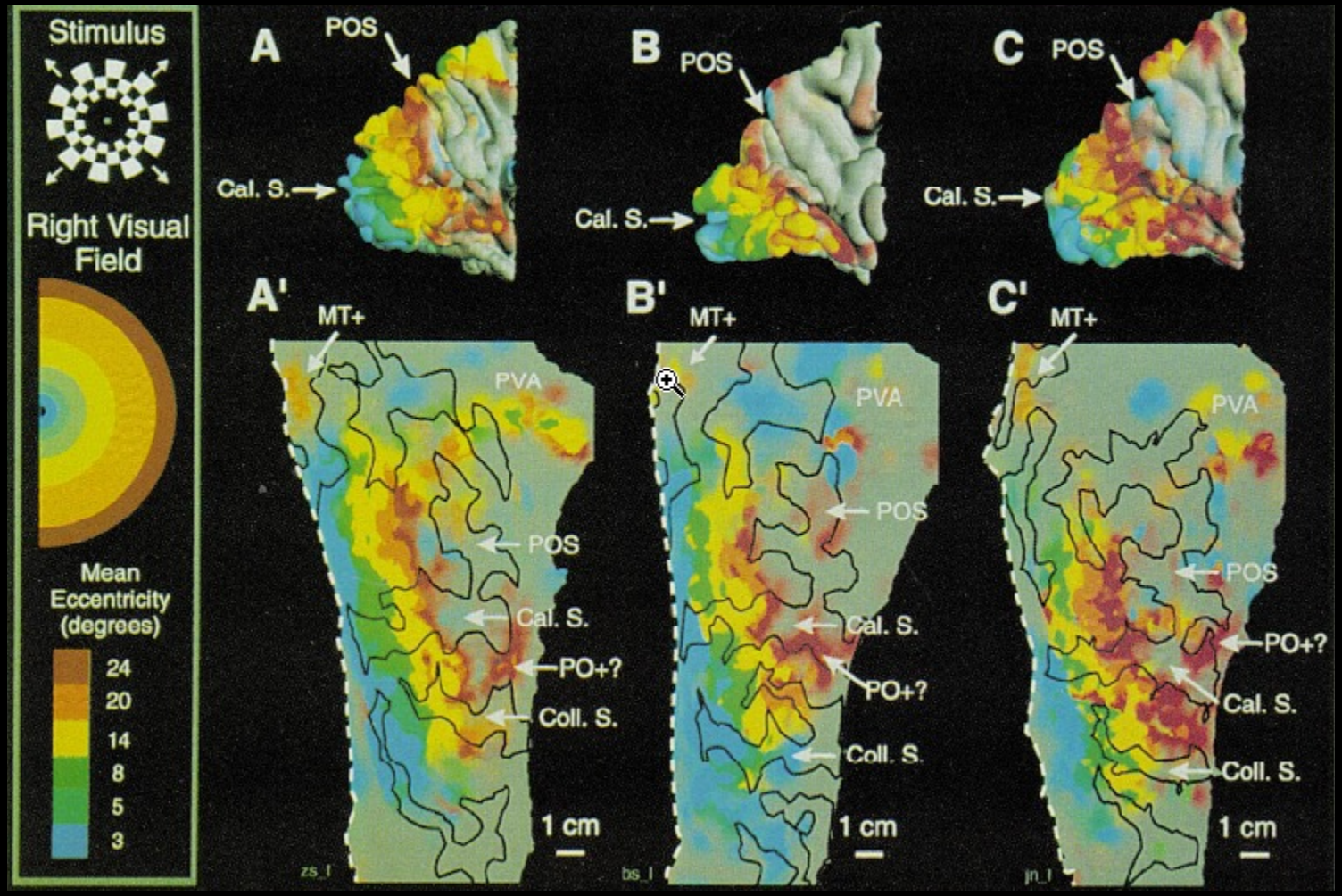
Neuronal Activation Input Strategies

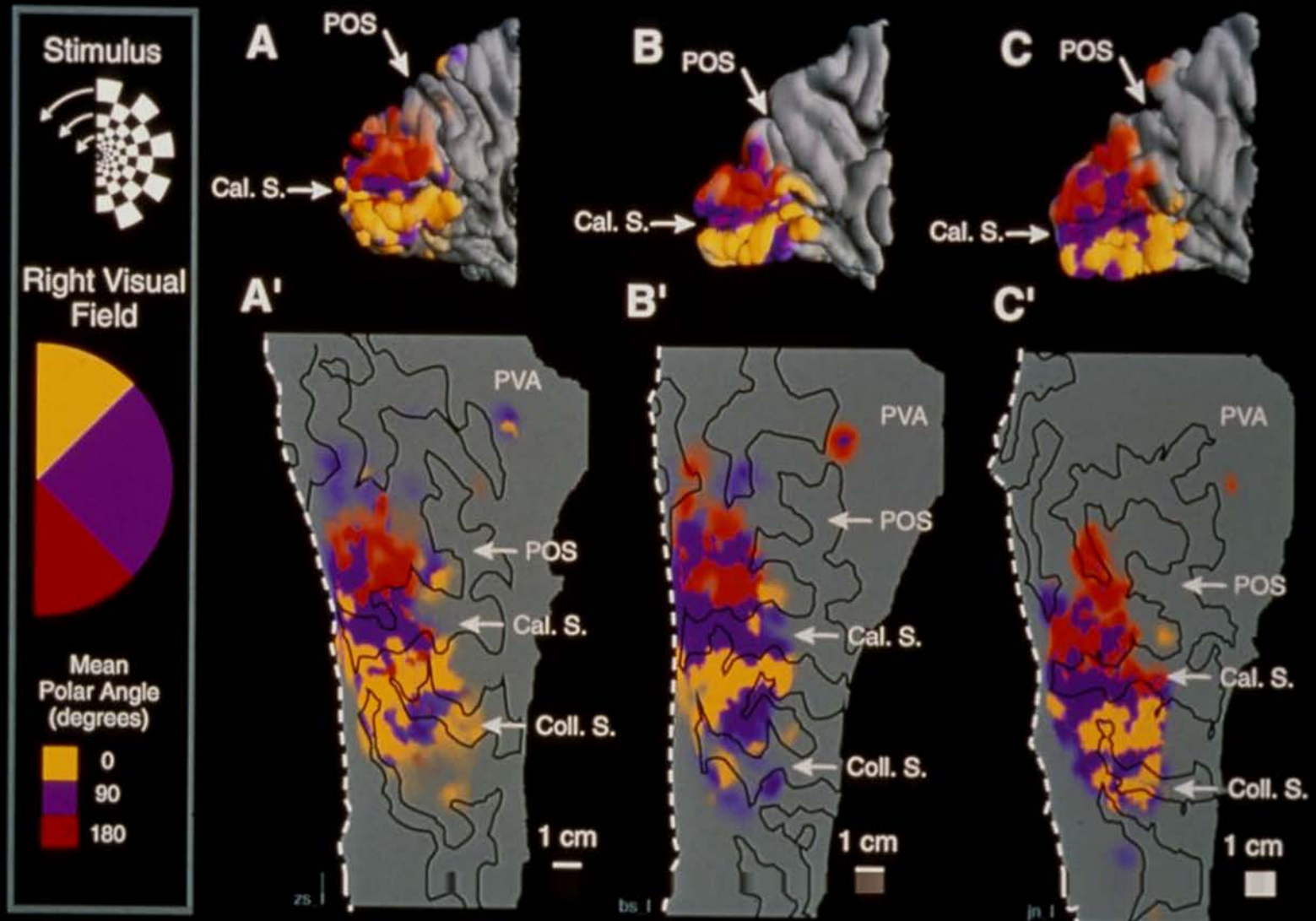
1. Block Design
2. Parametric Design
3. Frequency Encoding
4. **Phase Encoding**
5. Event Related
6. Orthogonal Design
7. Free Behavior Design

Proc. Natl. Acad. Sci. USA
Vol. 93, pp. 2382–2386, March 1996
Neurobiology

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*




Stimulus
Right Visual Field
Mean Polar Angle (degrees)
0
90
180
A
POS
Cal. S.
B
POS
Cal. S.
C
POS
Cal. S.
A'
PVA
POS
Cal. S.
Coll. S.
1 cm
zs
B'
PVA
POS
Cal. S.
Coll. S.
1 cm
bs
C'
PVA
POS
Cal. S.
Coll. S.
1 cm
jn

Neuronal Activation Input Strategies

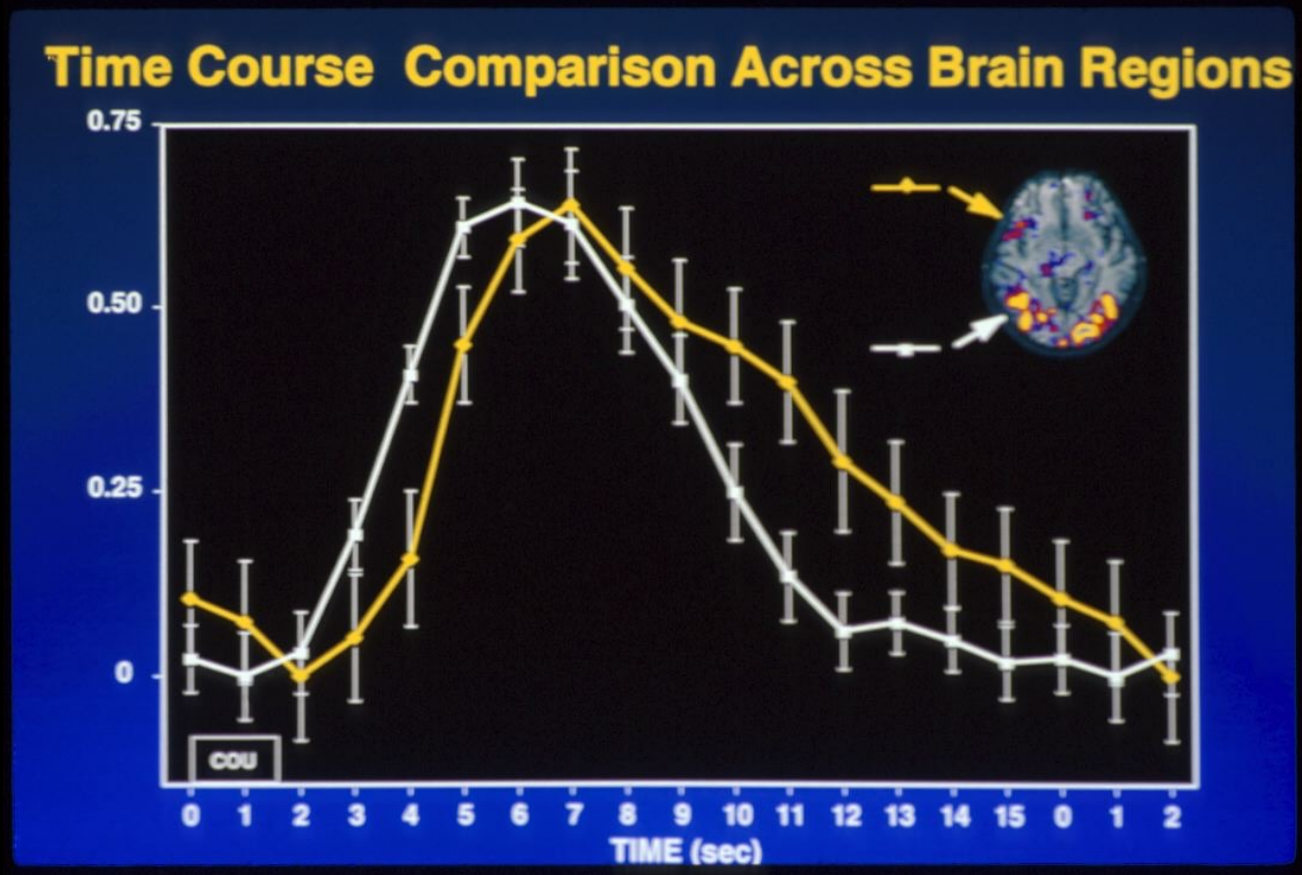
1. Block Design
2. Parametric Design
3. Frequency Encoding
4. Phase Encoding
5. **Event Related**
6. Orthogonal Design
7. Free Behavior Design

Proc. Natl. Acad. Sci. USA
Vol. 93, pp. 14878–14883, December 1996
Neurobiology

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. RAICHLE[§*†††], AND BRUCE R. ROSEN[†‡]

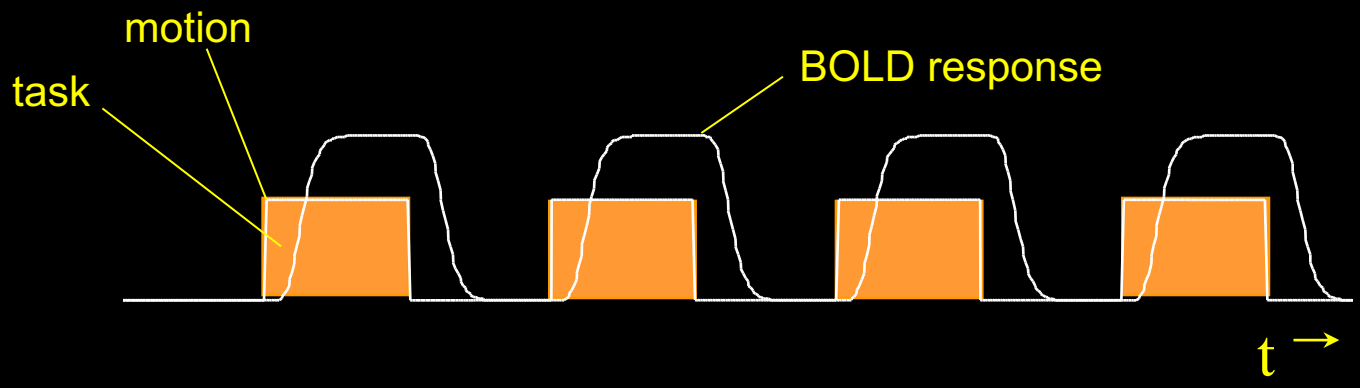


Event Related Advantages

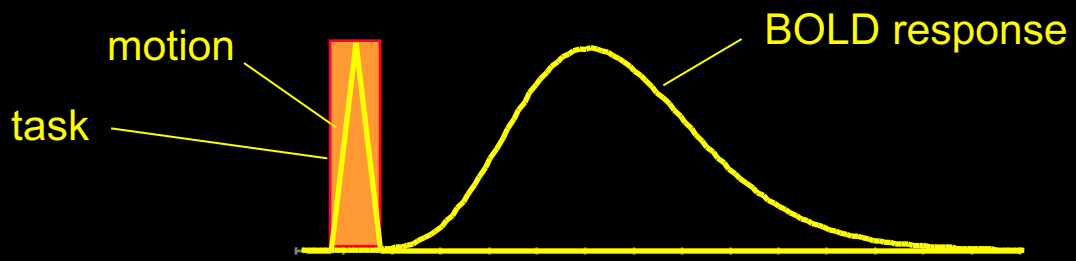
- Task Randomization
- Post acquisition, Performance-based, data binning
- Natural presentation
- Reduction of habituation effects
- Overt responses
- Reduction of scanner noise effects
- More precise estimation of hemodynamic respons

fMRI during tasks that involve brief motion

Blocked Design

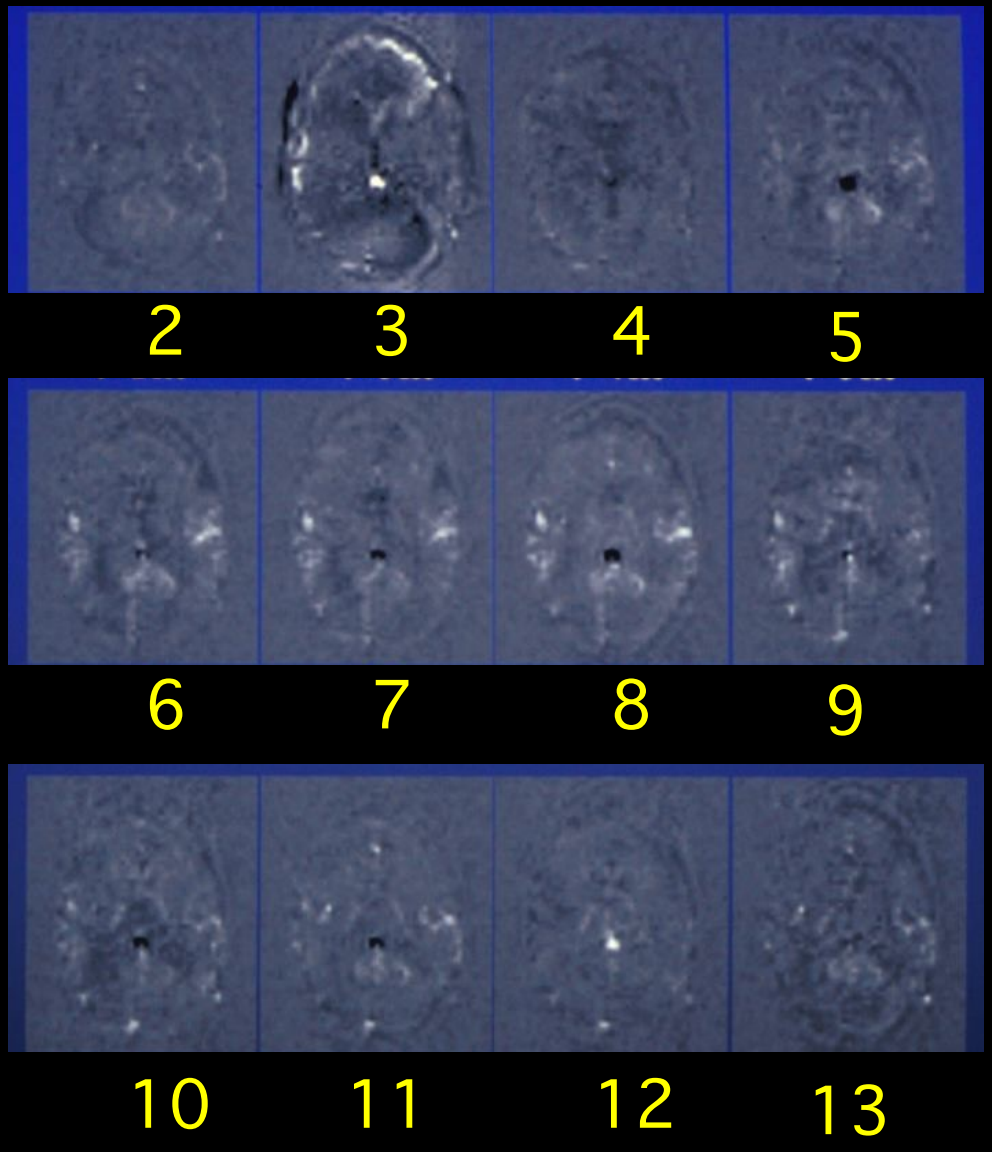


Event-Related Design



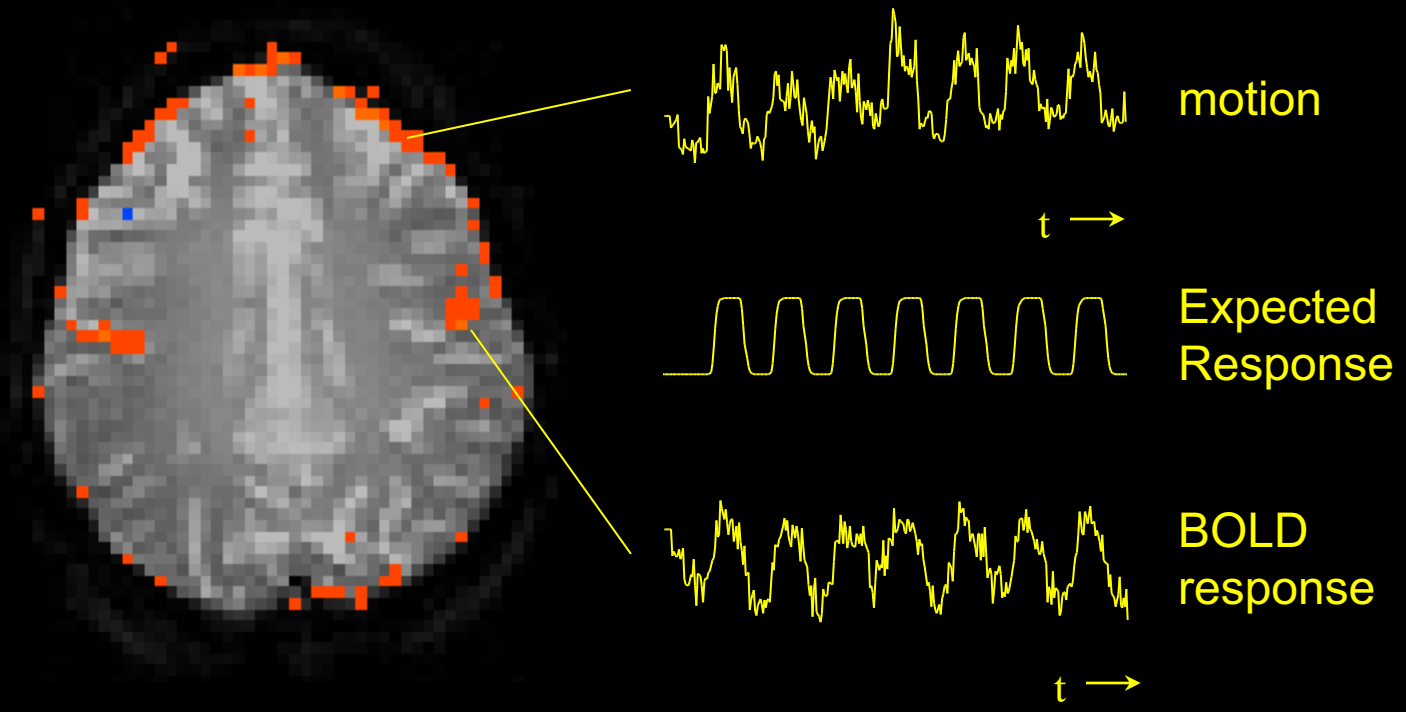
R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

Overt Word Production



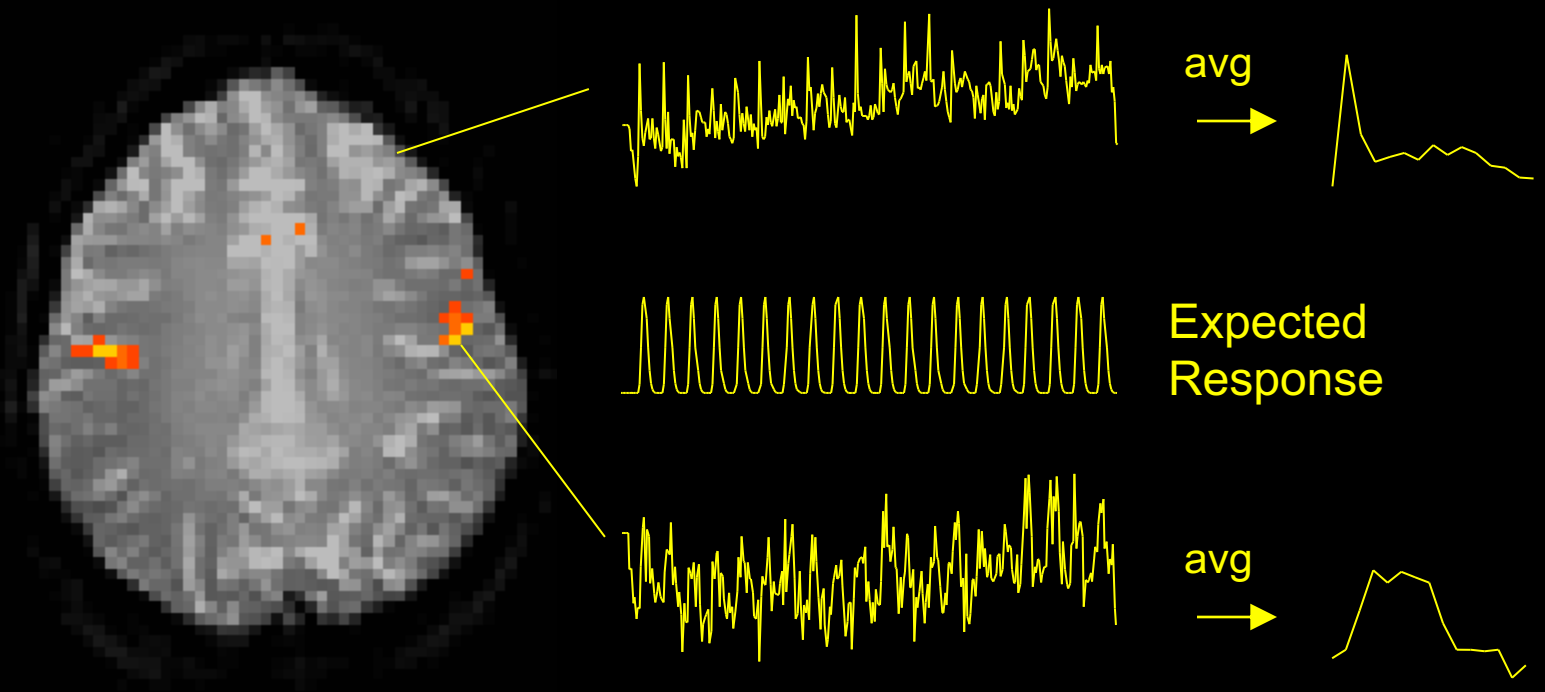
R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

Speaking - Blocked Trial



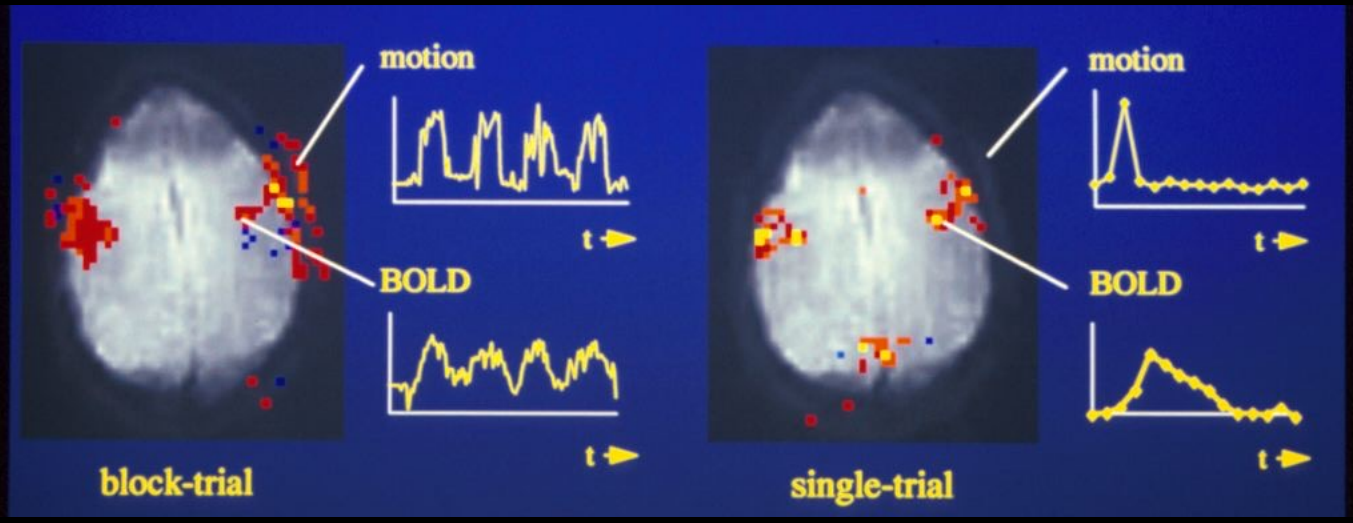
R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

Speaking - ER-fMRI

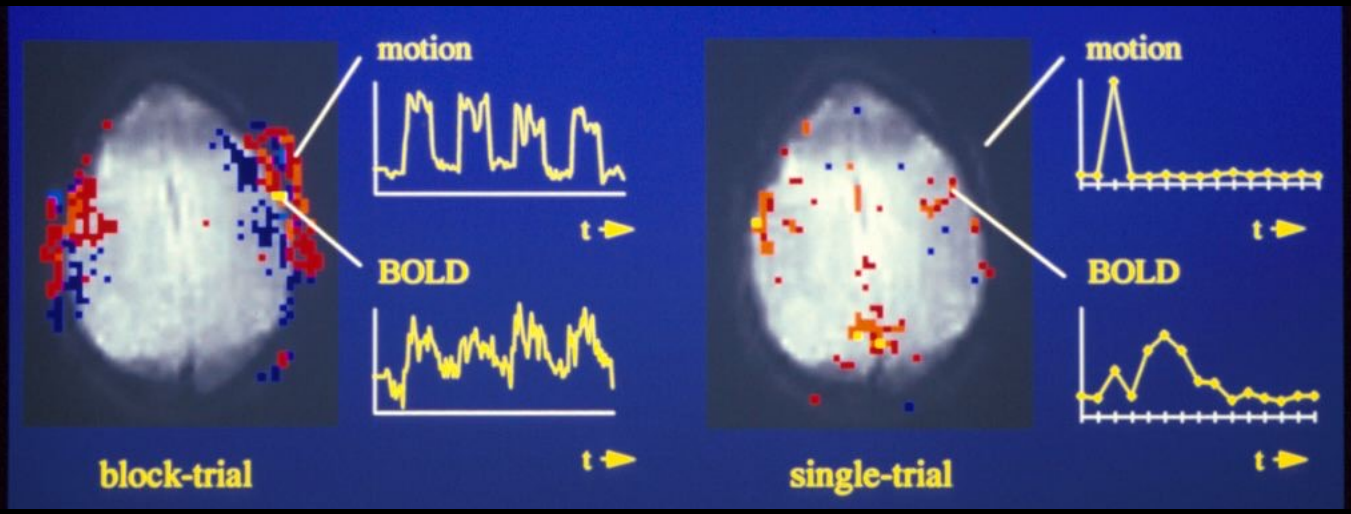


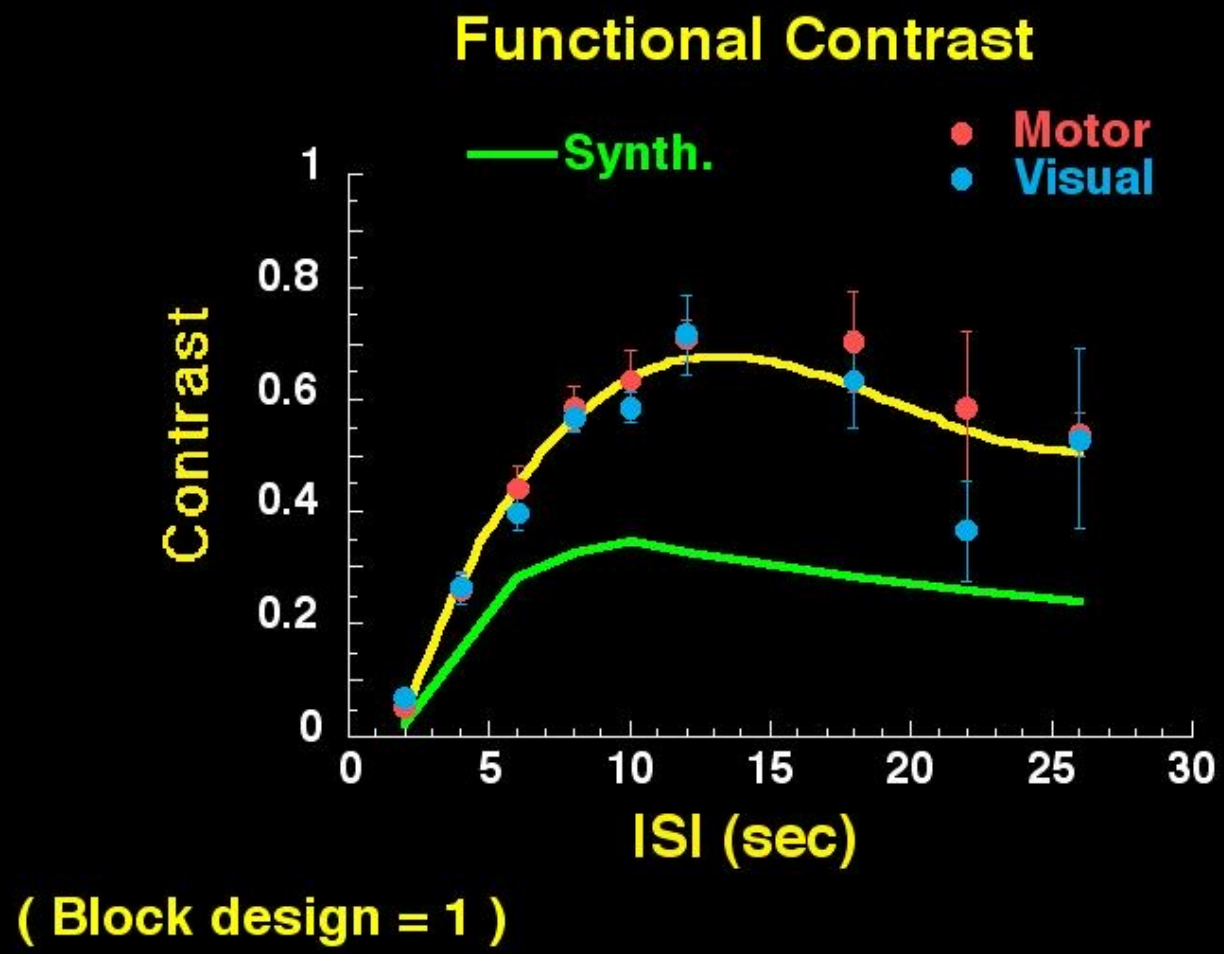
R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

Tongue Movement



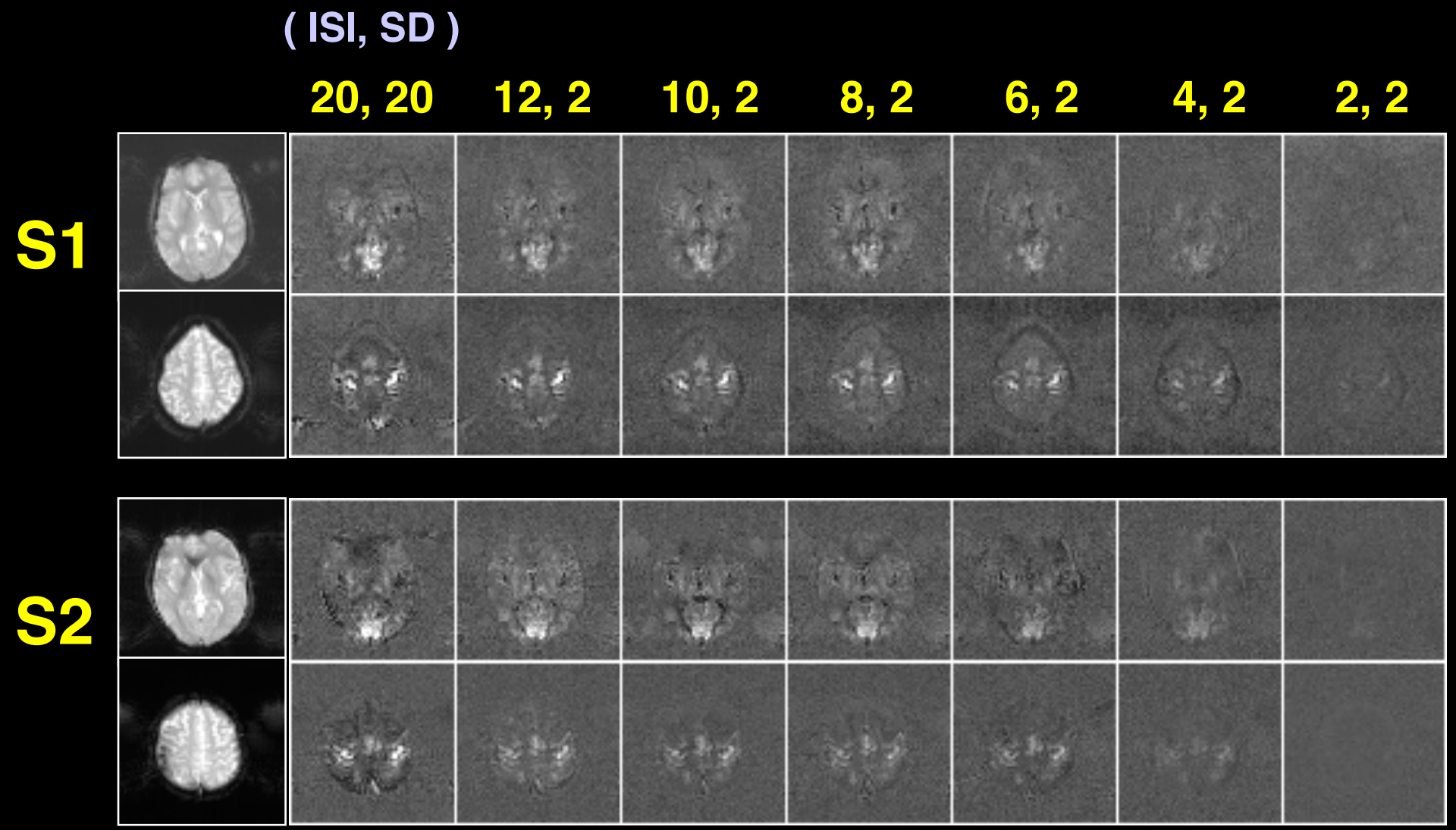
Jaw Clenching





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

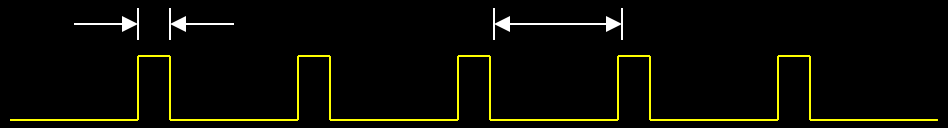


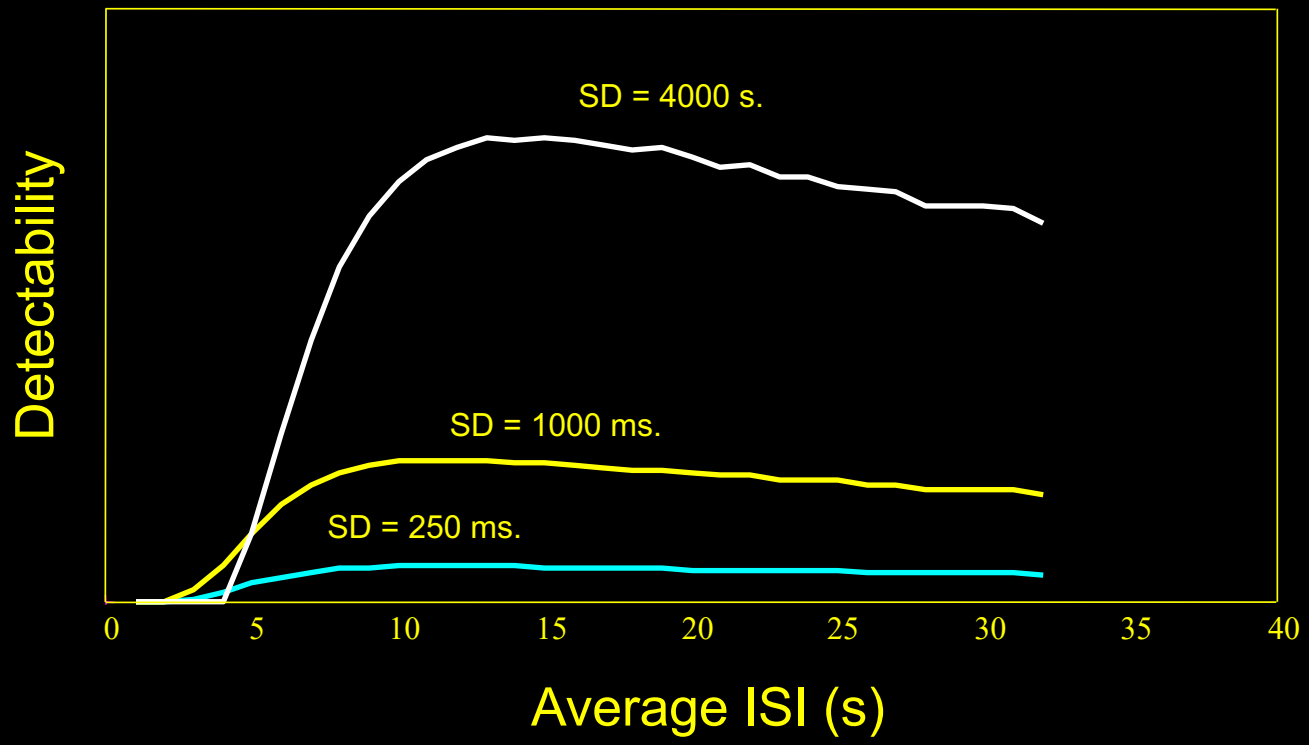
P. A. Bandettini, R. W. Cox. Functional contrast in constant interstimulus interval event - related fMRI: theory and experiment. *Magn. Reson. Med.* 43: 540-548 (2000).

Detectability – constant ISI

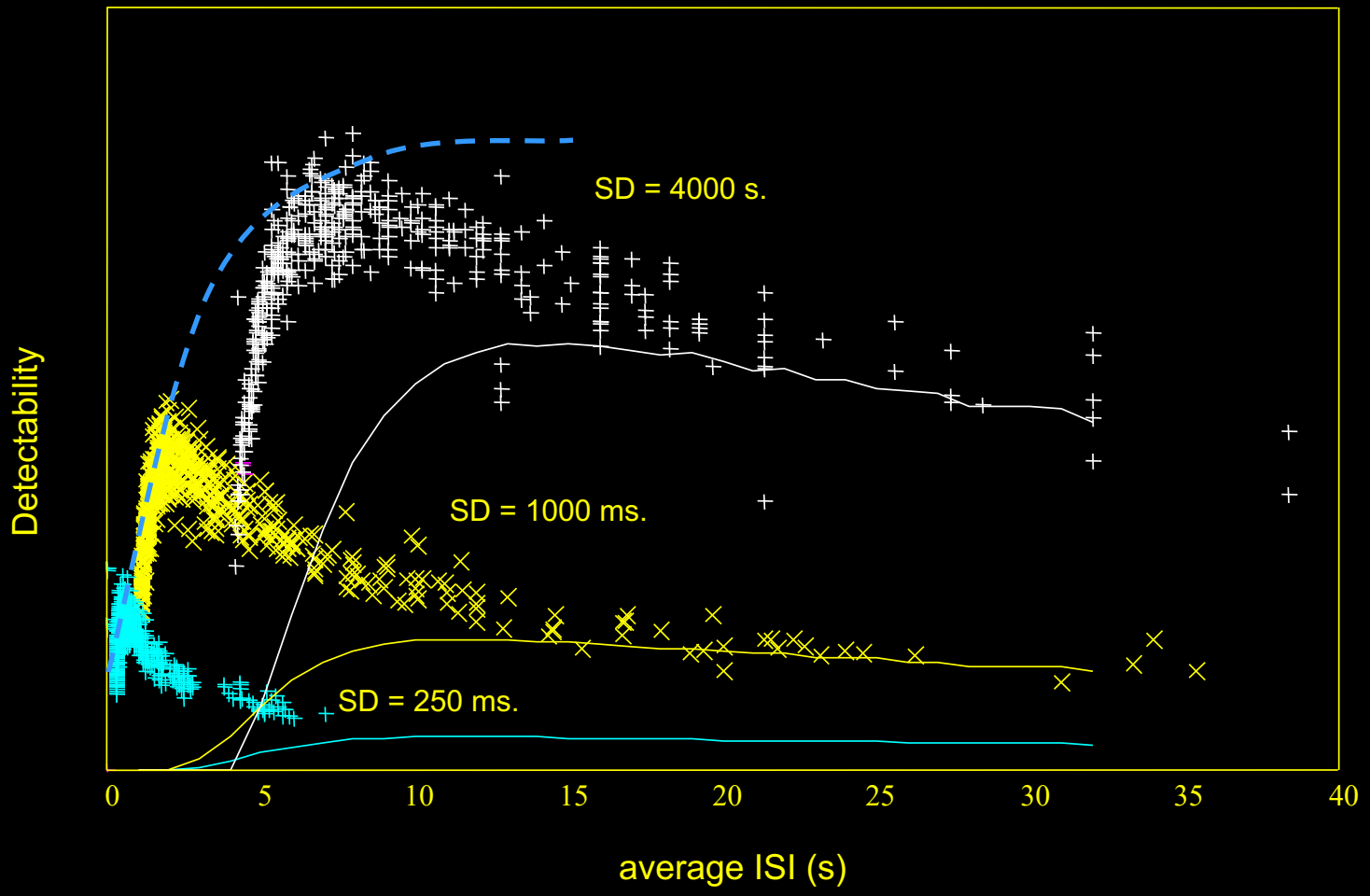
SD – stimulus duration

ISI – inter-stimulus interval



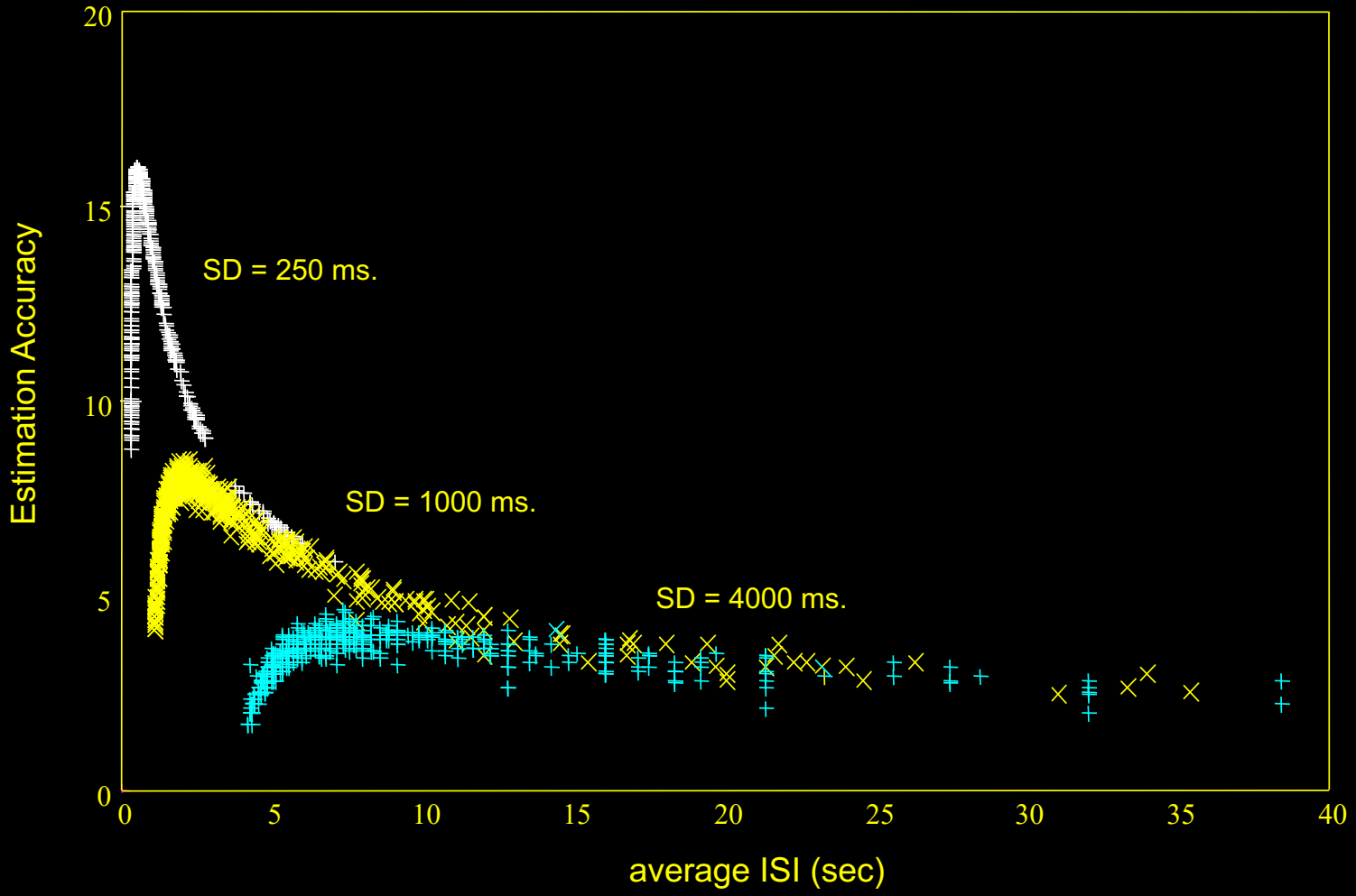


Detectability vs. Average ISI



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).

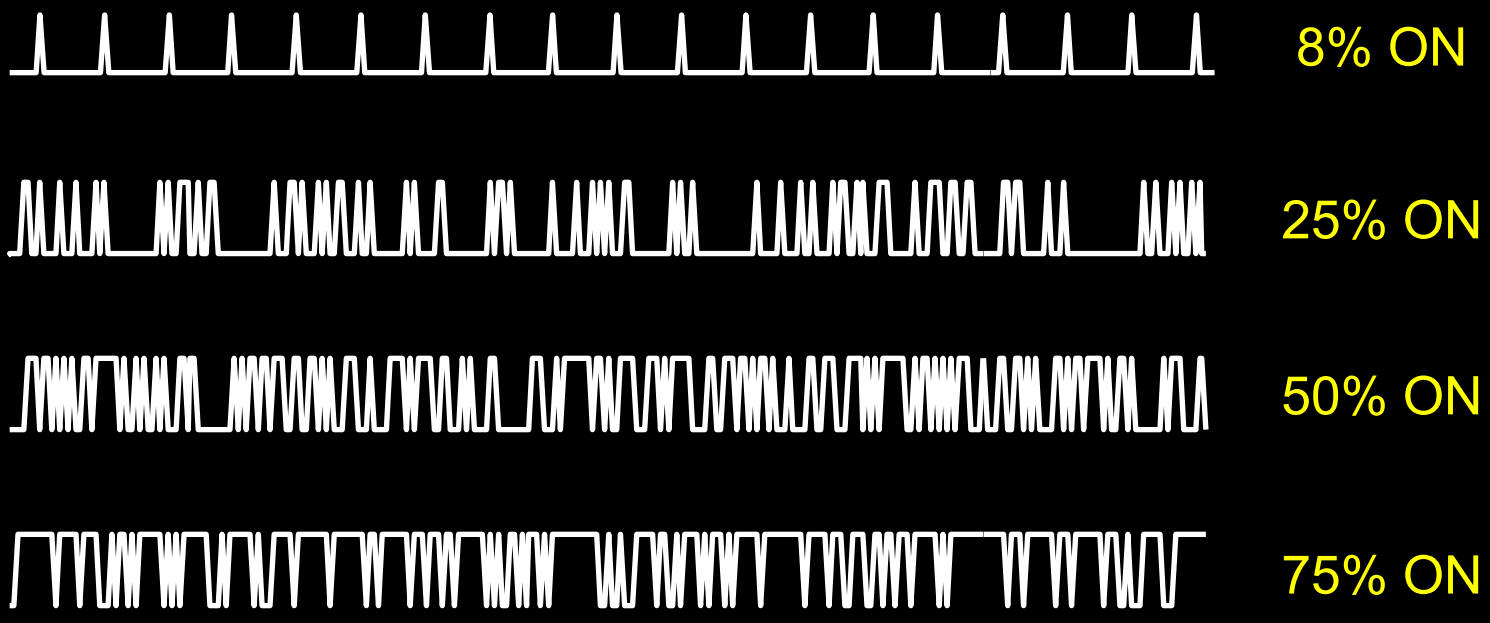
Estimation accuracy vs. average ISI



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).

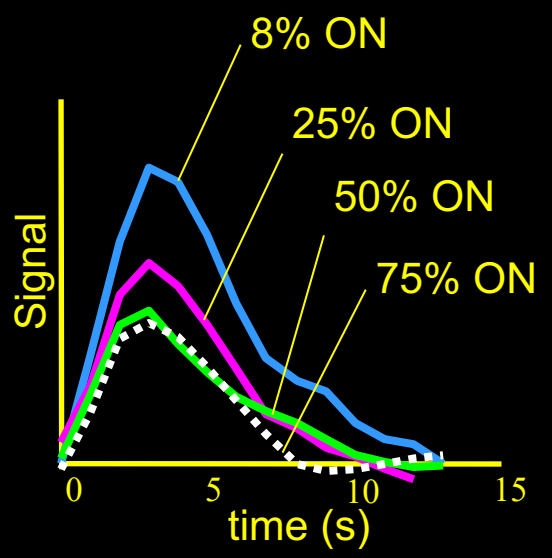
Varying “ON” and “OFF” periods

- *Rapid event-related design with varying ISI*

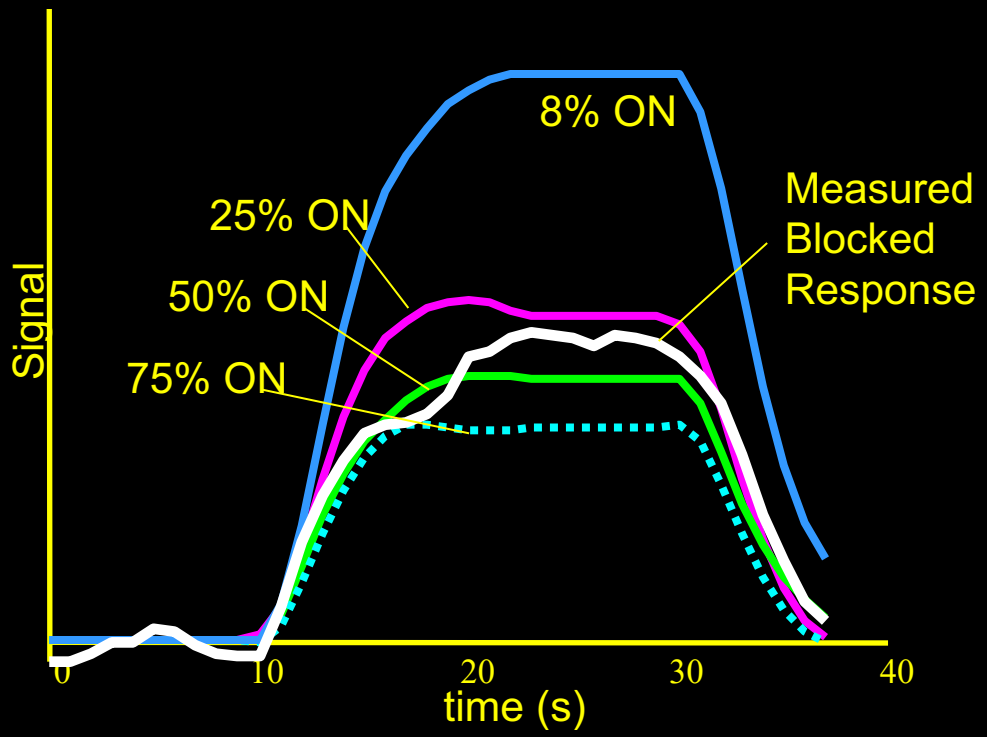


Varying “ON” and “OFF” periods

Estimated Impulse Response



Predicted Responses to 20 s stimulation



Neuronal Activation Input Strategies

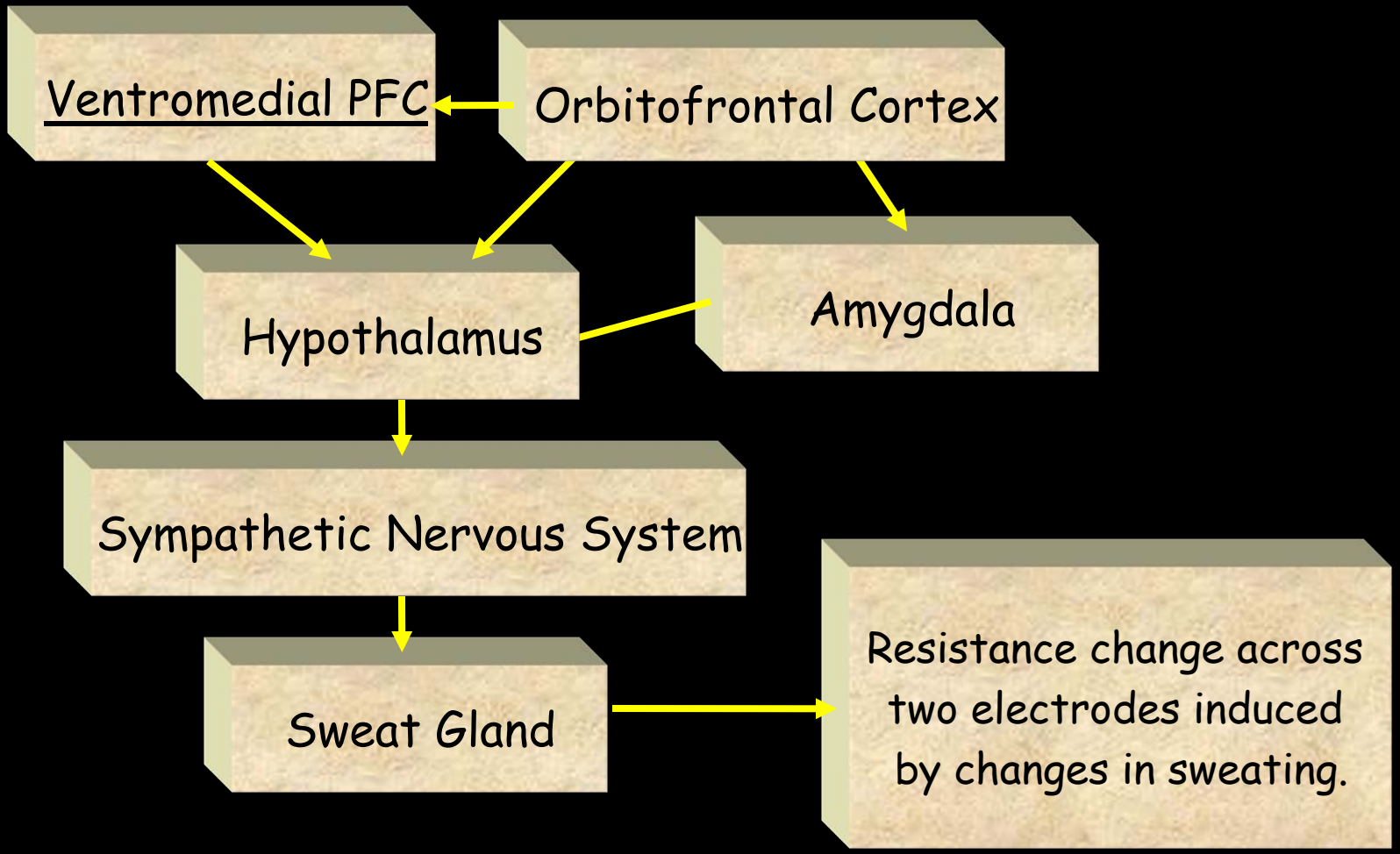
1. Block Design
2. Parametric Design
3. Frequency Encoding
4. Phase Encoding
5. Event Related
6. Orthogonal Design
7. **Free Behavior Design**

Free Behavior Design

Use a continuous measure as a reference function:

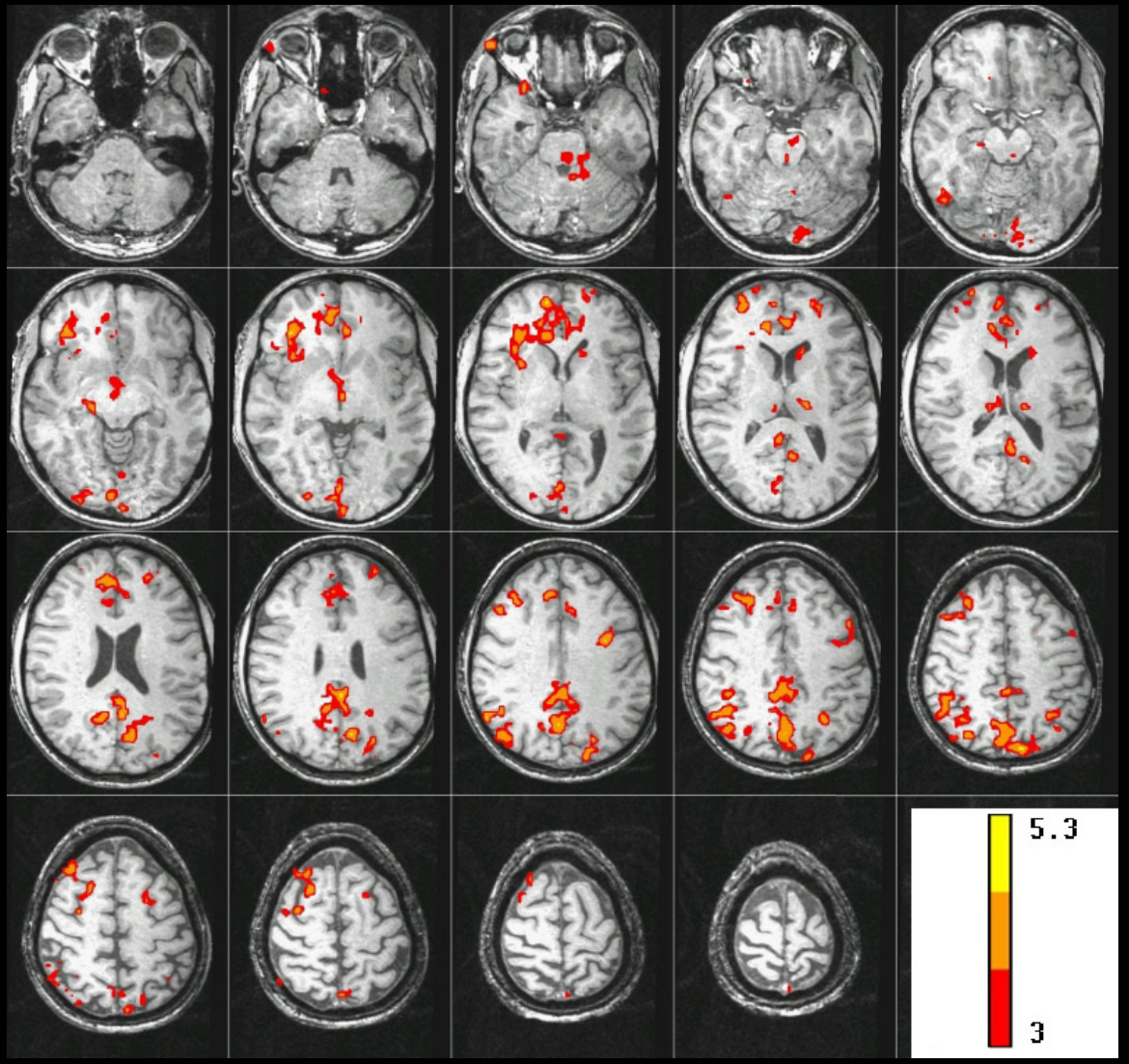
- Task performance
- Skin Conductance
- Heart, respiration rate..
- Eye position
- EEG

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)

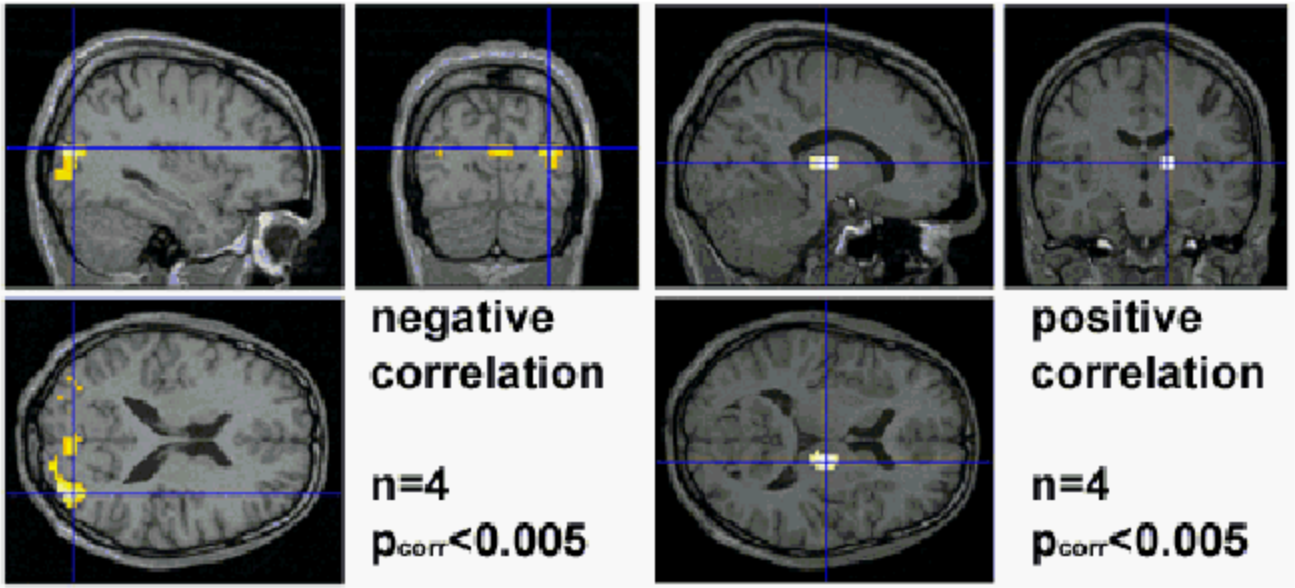
Order to appear: 20

OHBM 2002

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

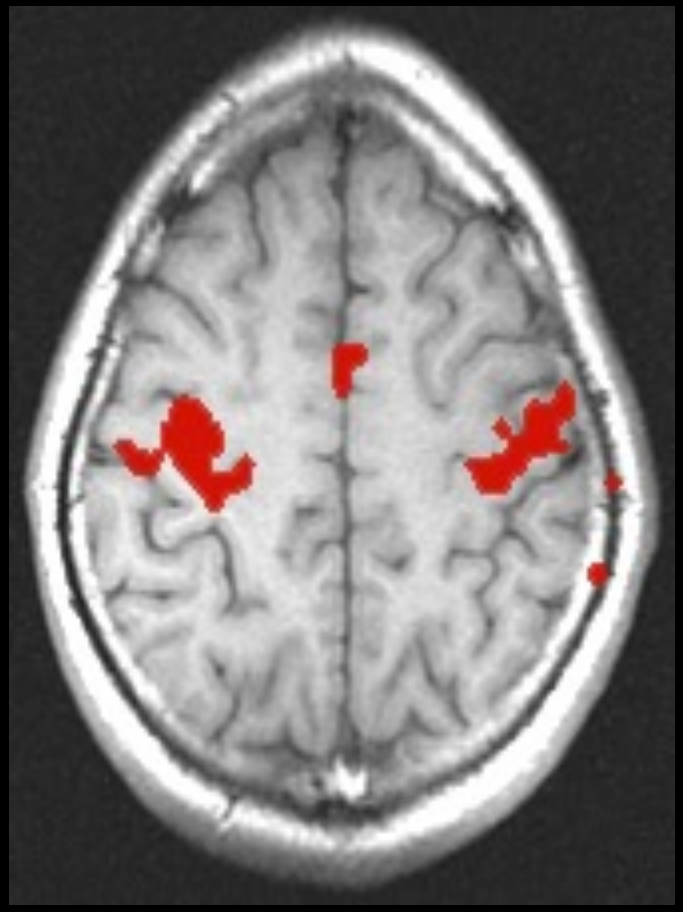
The group analysis based on four volunteers showed a negative correlation between alpha-power and fMRI signal in the occipital cortex (figure, left side) and a positive correlation in the thalamus (figure, right side). These findings were not present for the beta band.

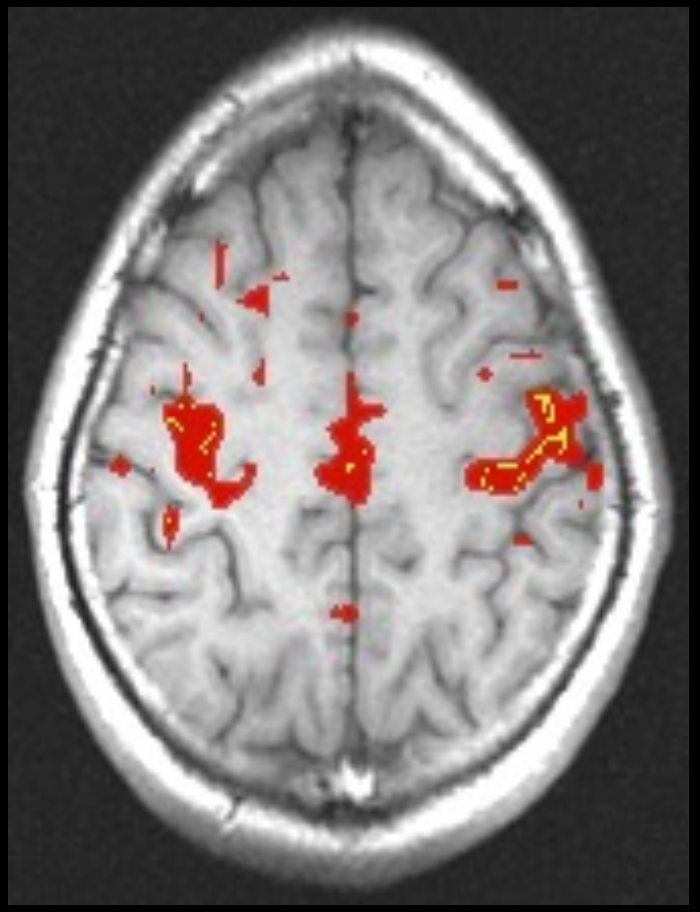


Discussion:

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



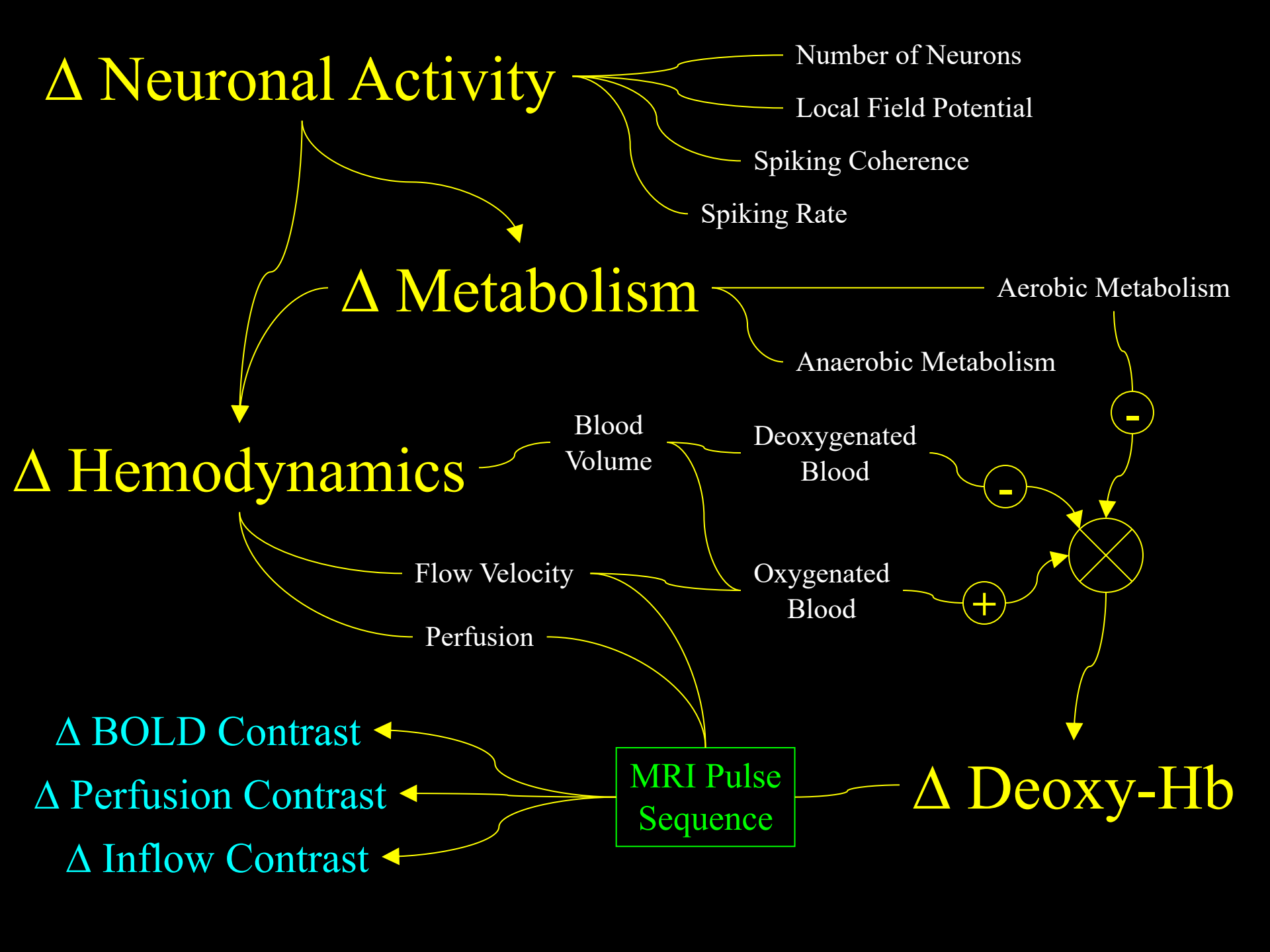


B. Biswal *et al*., MRM, 34:537 (1995)

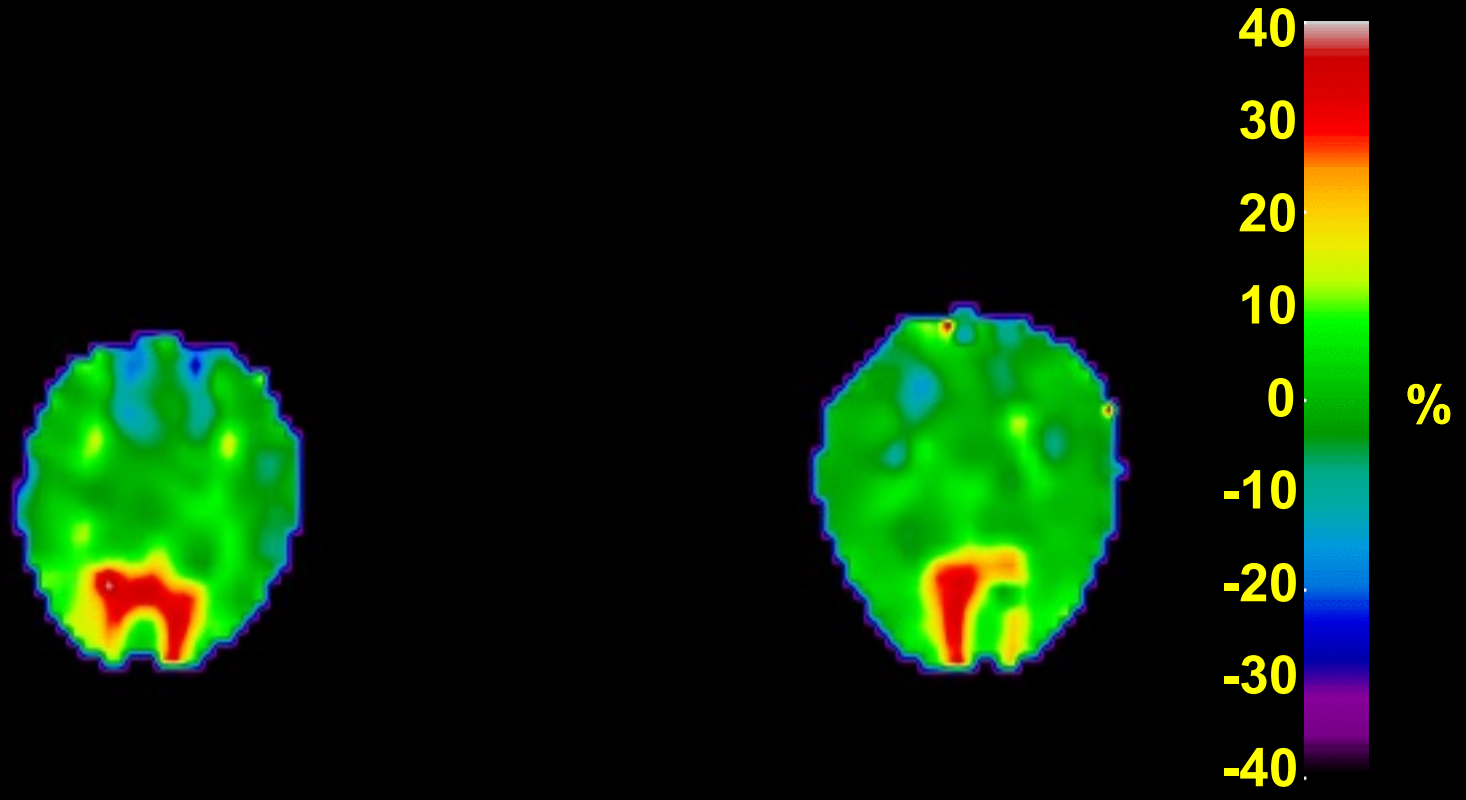
Where Are We Going?

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

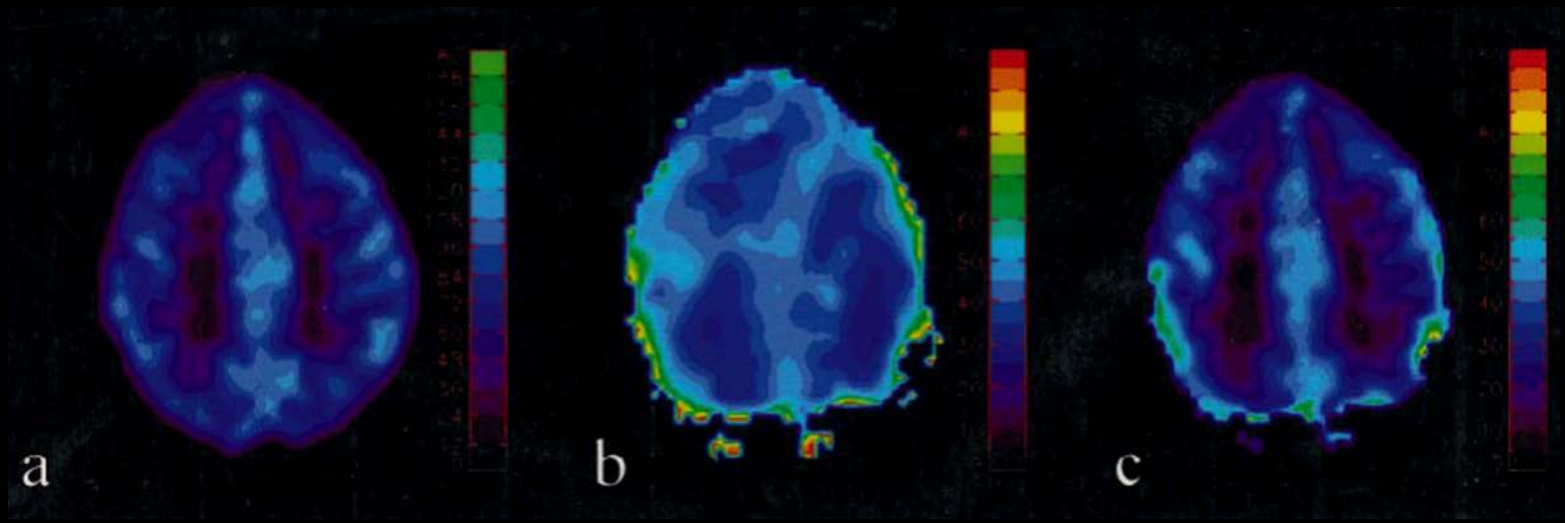
Computed $CMRO_2$ Changes



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

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

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



CBF OEF $CMRO_2$

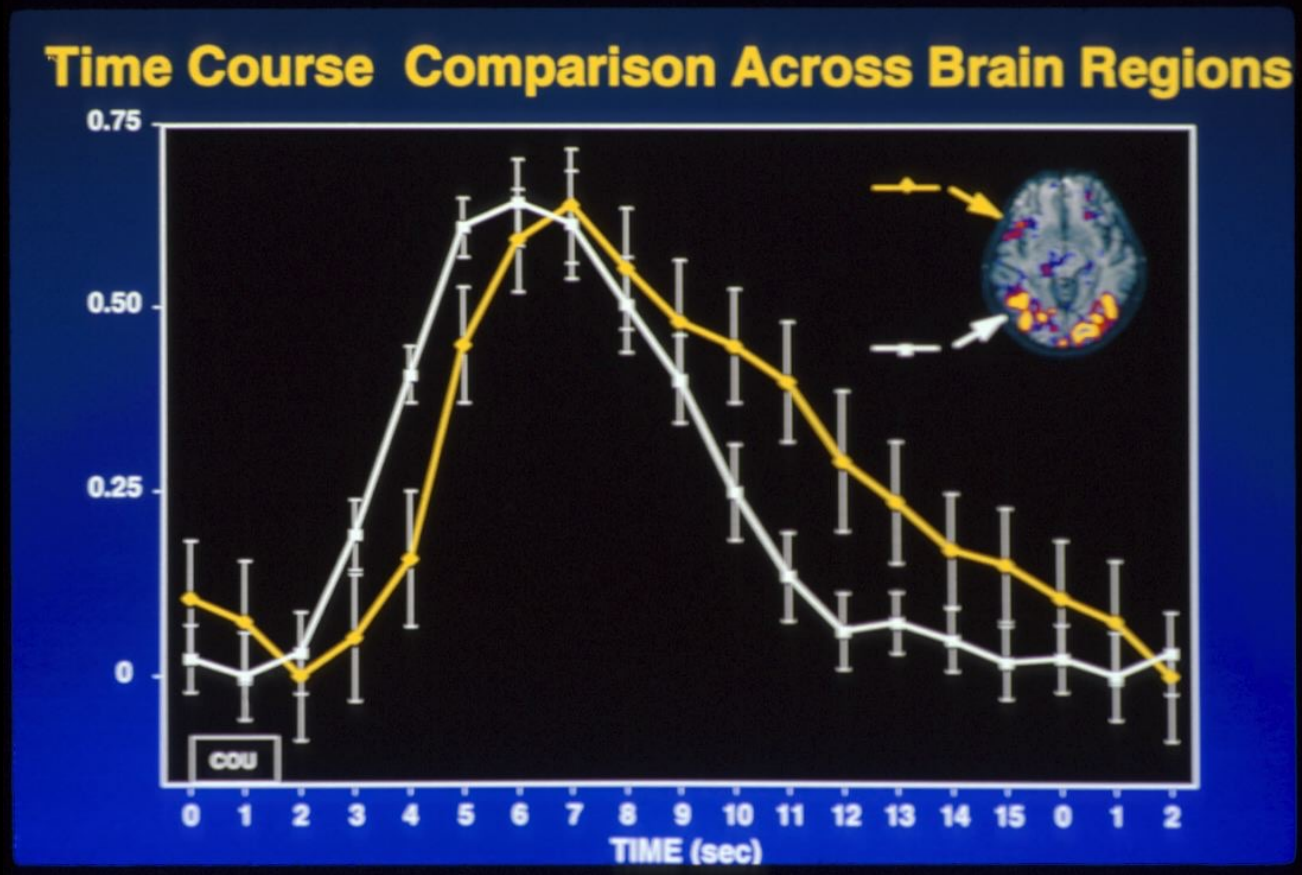
- Interpretation
- **Temporal Resolution**
- Spatial Resolution

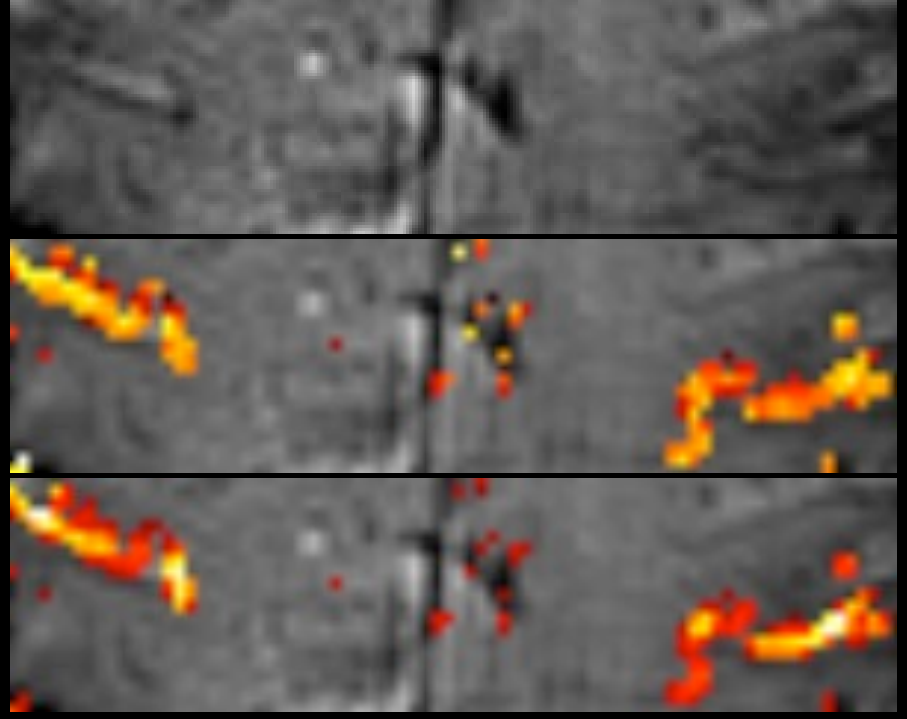
Proc. Natl. Acad. Sci. USA
Vol. 93, pp. 14878–14883, December 1996
Neurobiology

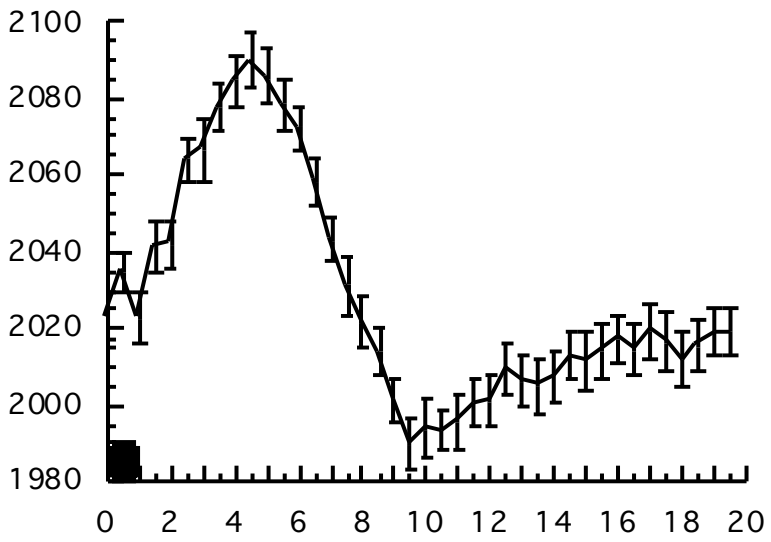
Detection of cortical activation during averaged single trials of a cognitive task using functional magnetic resonance imaging

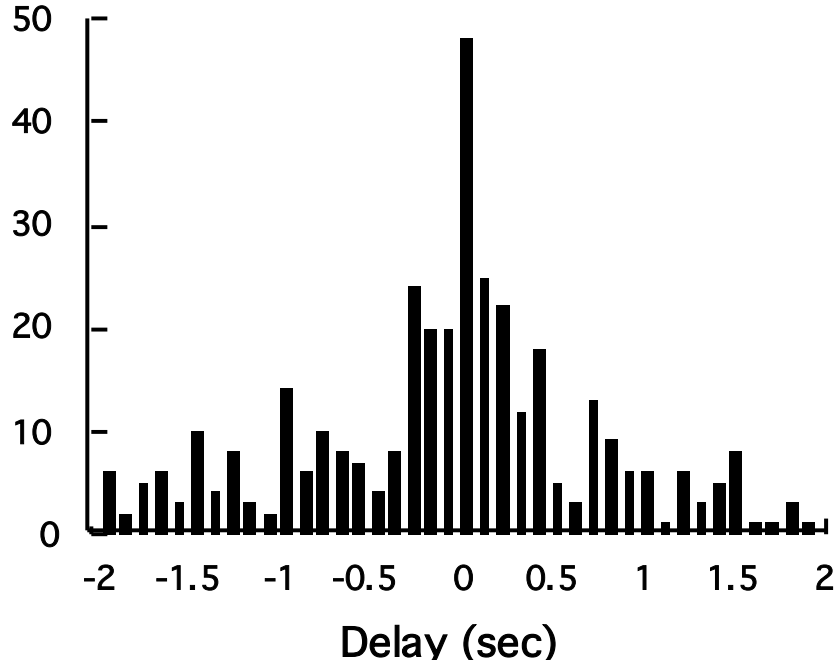
(neuroimaging/single trial/language/prefrontal)

RANDY L. BUCKNER[†‡§¶], PETER A. BANDETTINI[†‡], KATHLEEN M. O'CRAVEN[†‖], ROBERT L. SAVOY[†‖], STEVEN E. PETERSEN[*††], MARCUS E. RAICHLE[§*†††], AND BRUCE R. ROSEN[†‡]

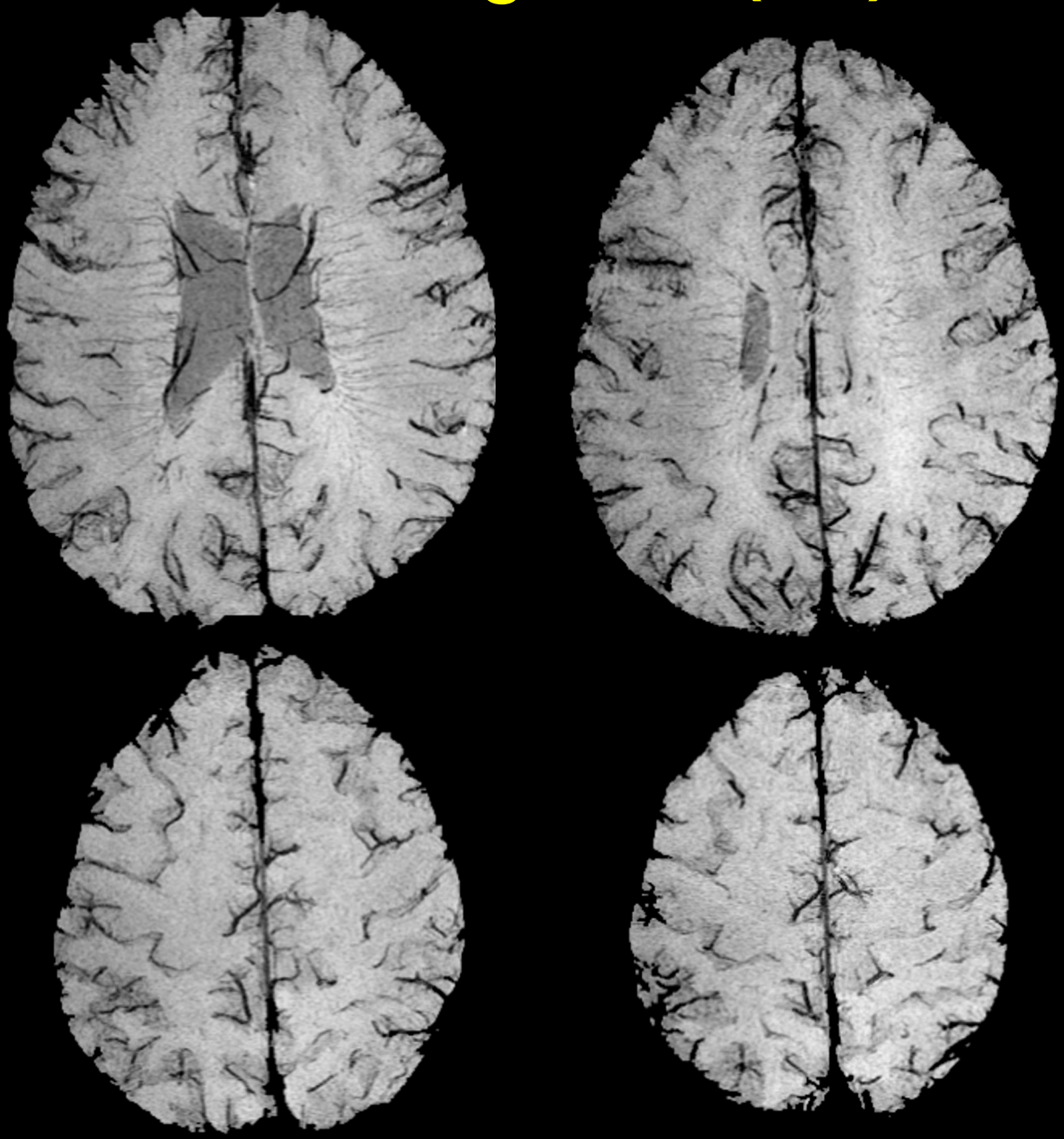


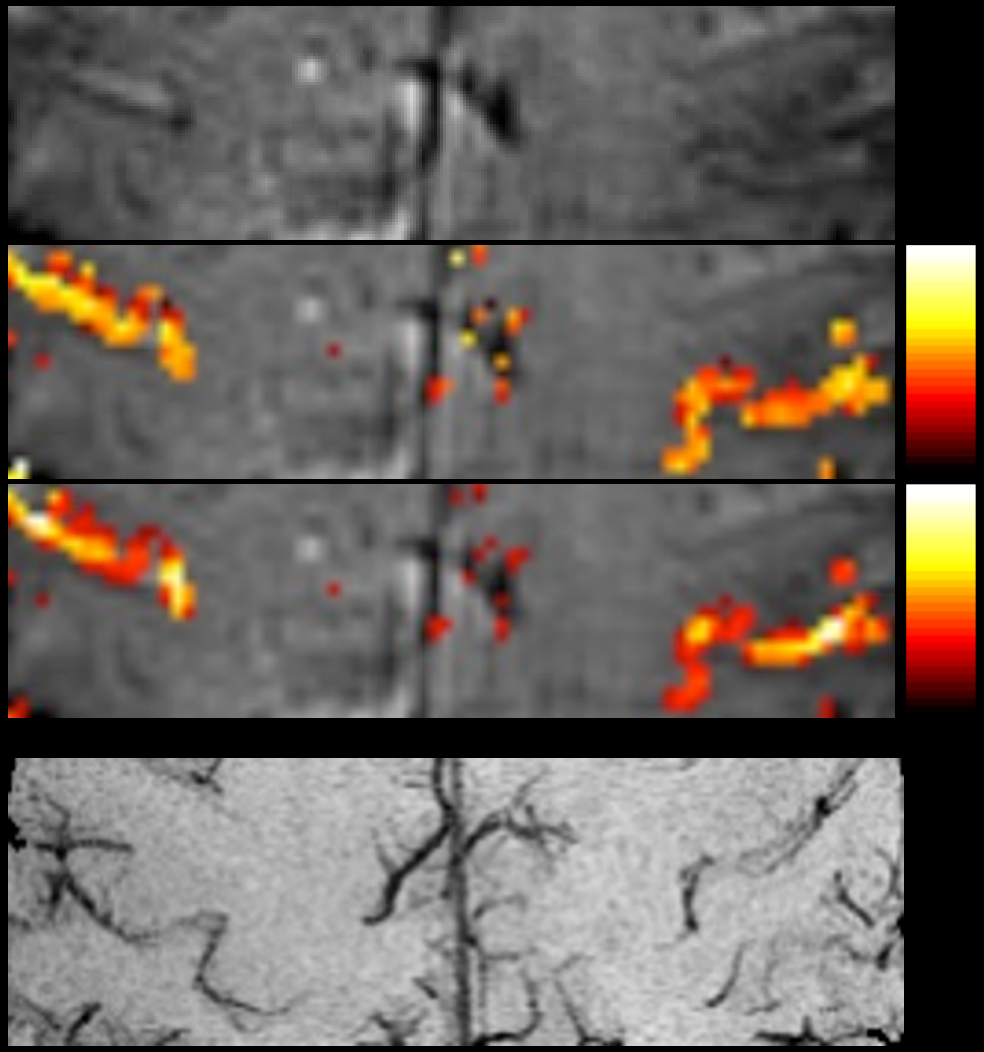

Latency
Magnitude
+ 2 sec
- 2 sec


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)

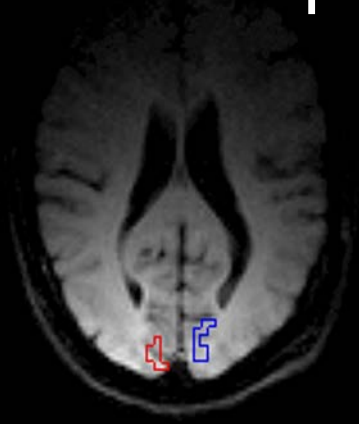
Venograms (3T)



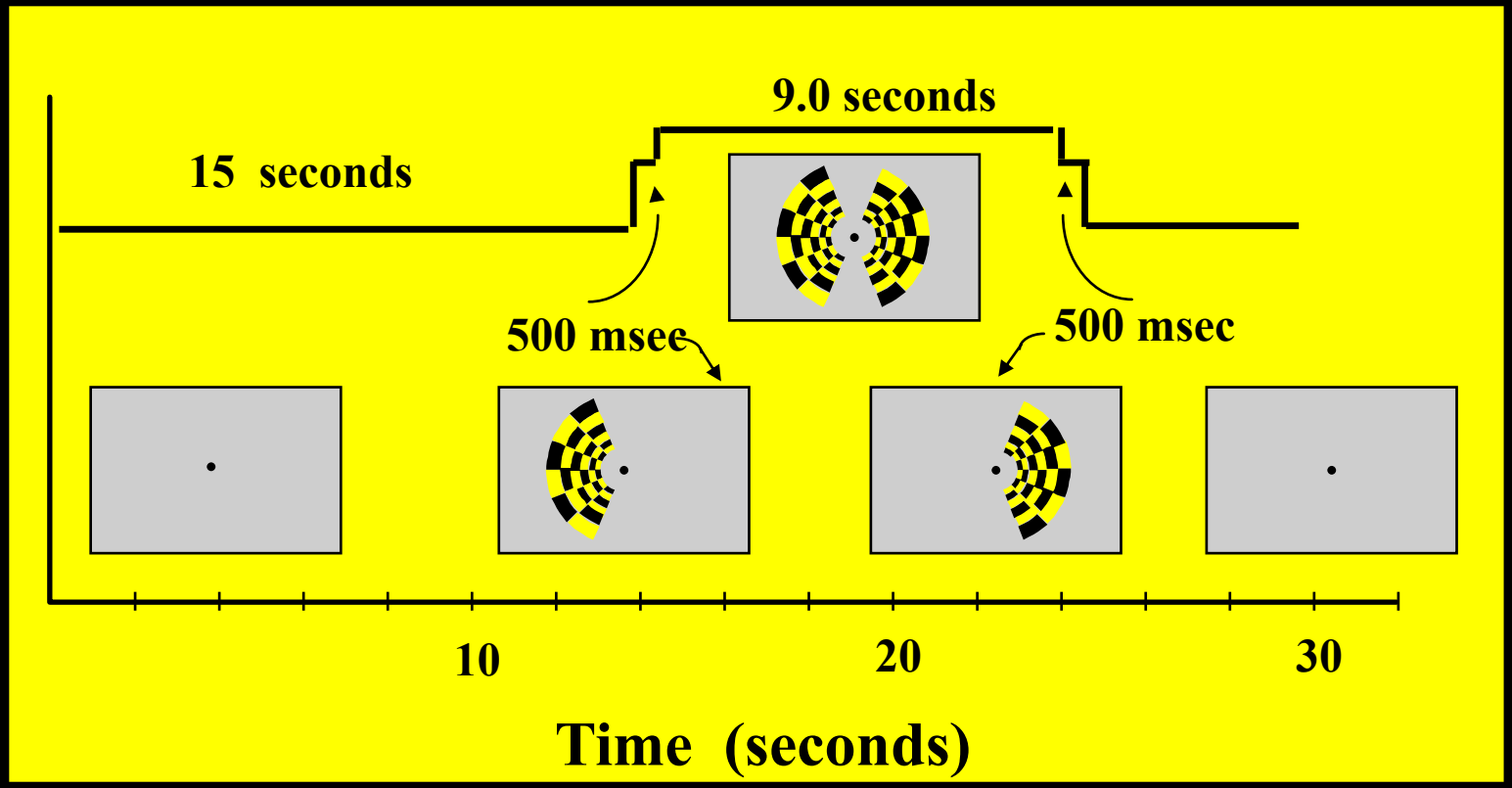


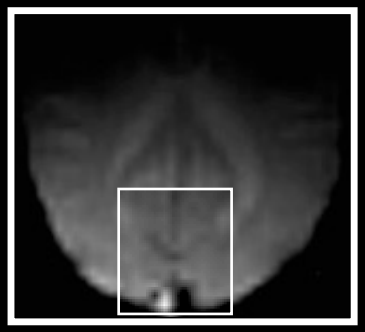
Hemi-Field Experiment

Left Hemisphere



Right Hemisphere

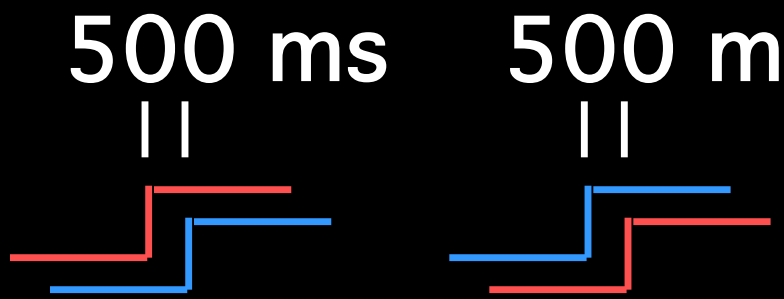




500 ms 500 ms

Right Hemifield

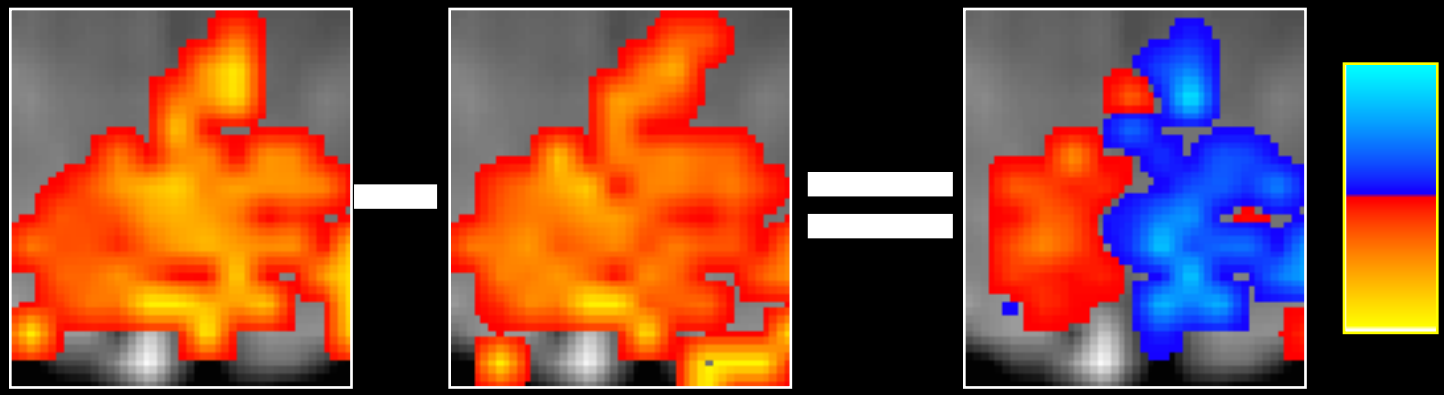
Left Hemifield



+ 2.5 s

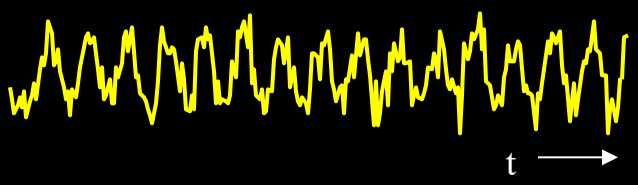
0 s

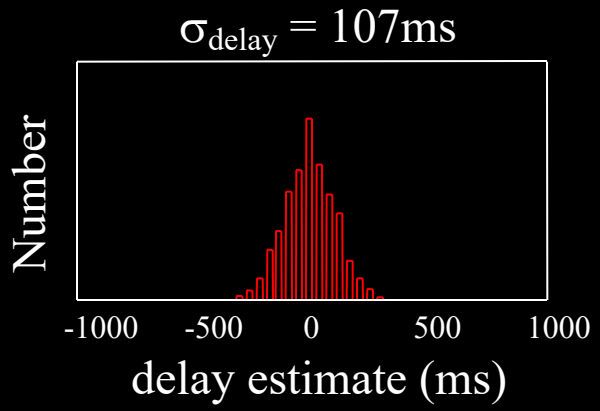
- 2.5 s



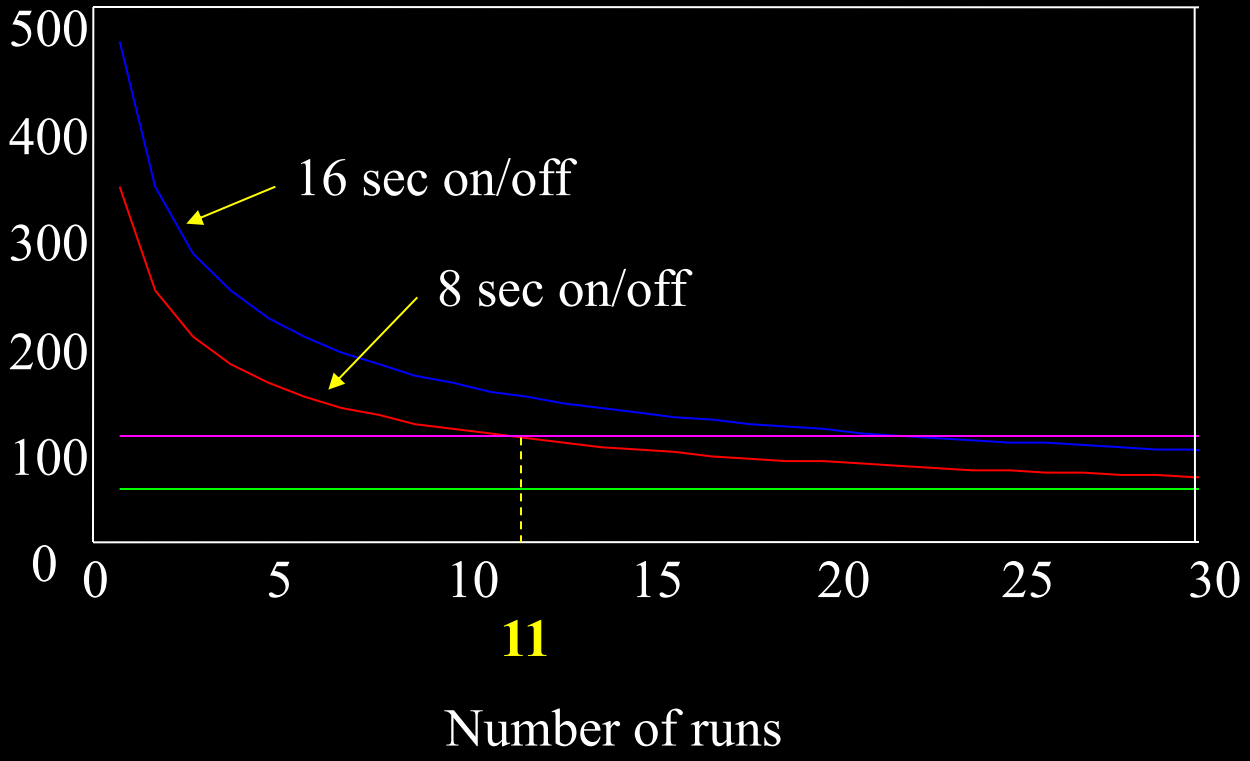
1 run:

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

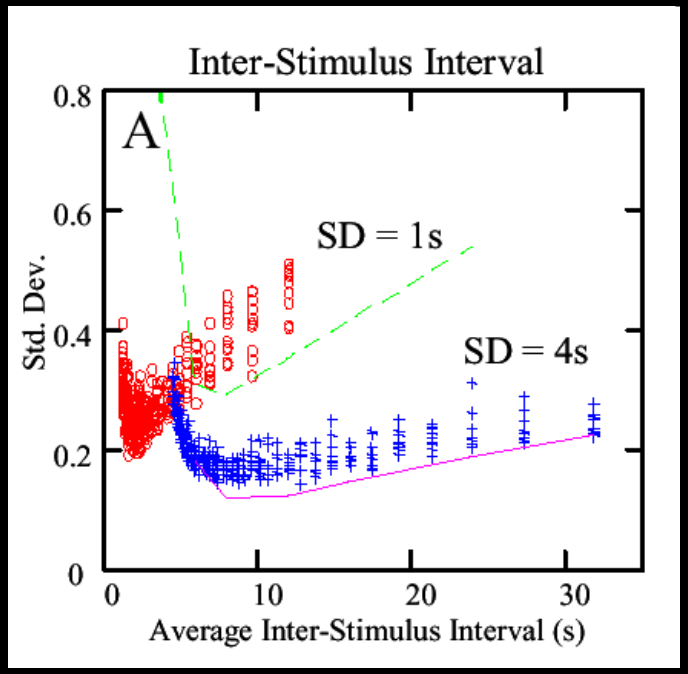


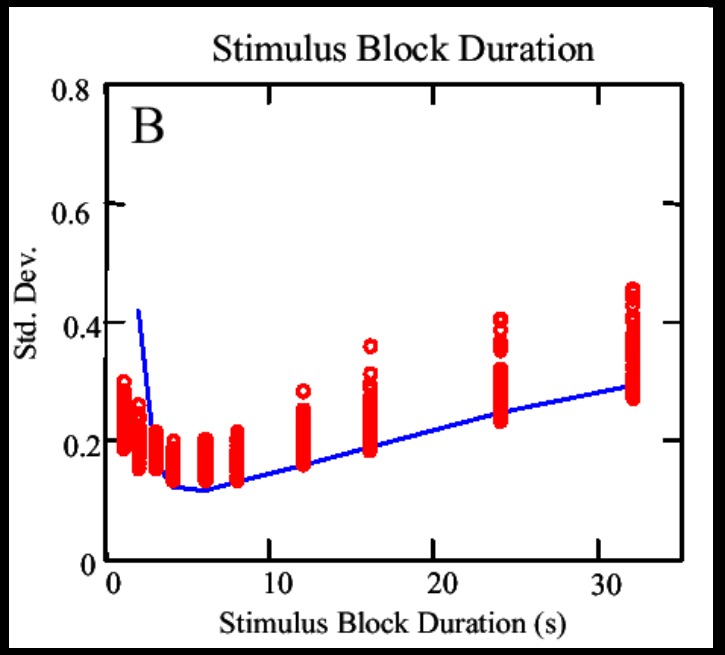


Smallest latency Variation Detectable (ms) (p < 0.001)

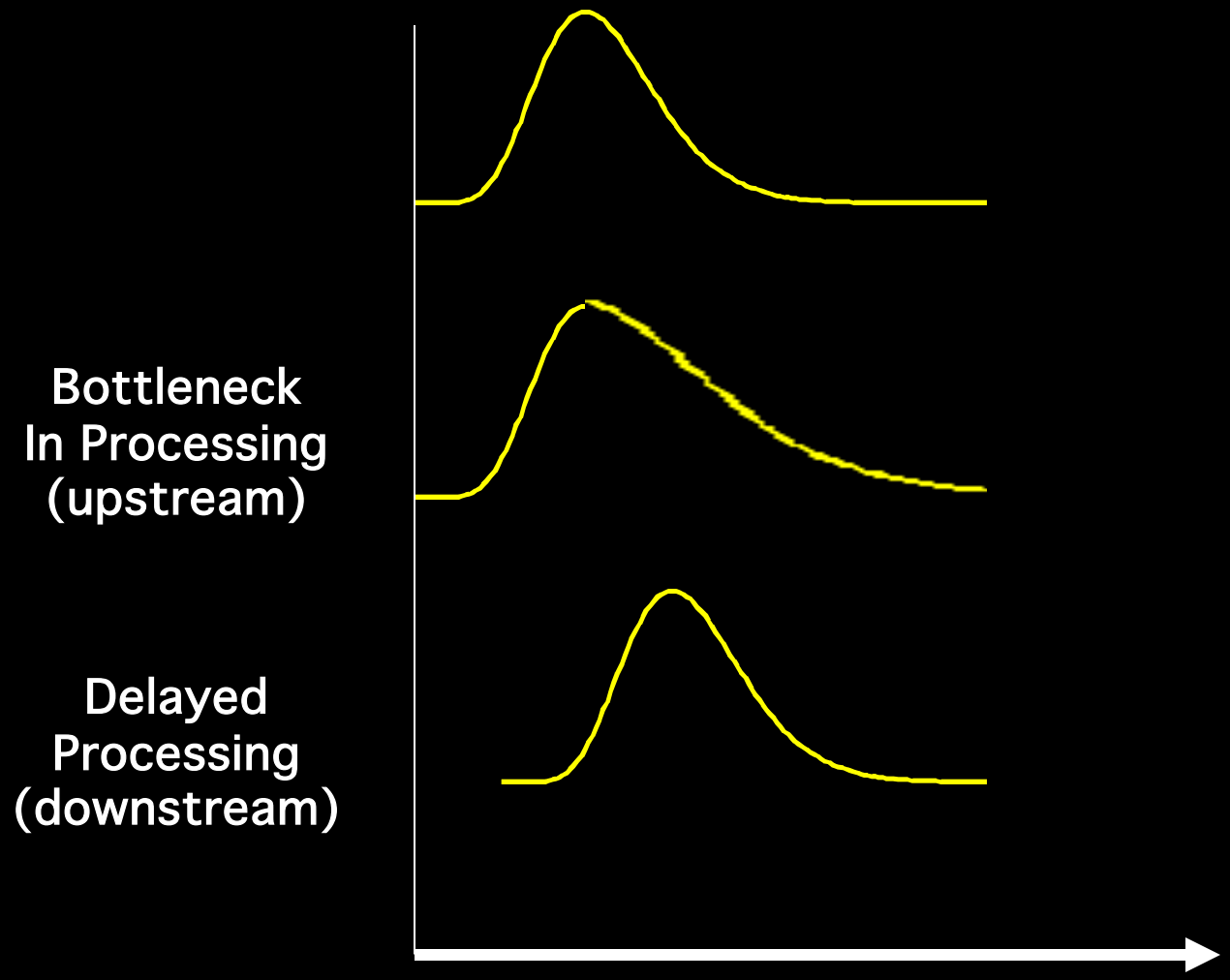


Optimal Detection of Hemodynamic Latency





Hemodynamic Response Modulation



Use of Task Timing Modulation to Extract Processing Streams

Stimuli – Six-letter English words and pronounceable non-words.
Each word or non-word was rotated either 0, 60,or 120 degrees

Task – Lexical Decision (word / non-word).

Dependent Measures – Percent Correct and Reaction Time.

Hypotheses :

1) Stimulus rotation of 120 degrees will result in:

a) Longer Reaction Times

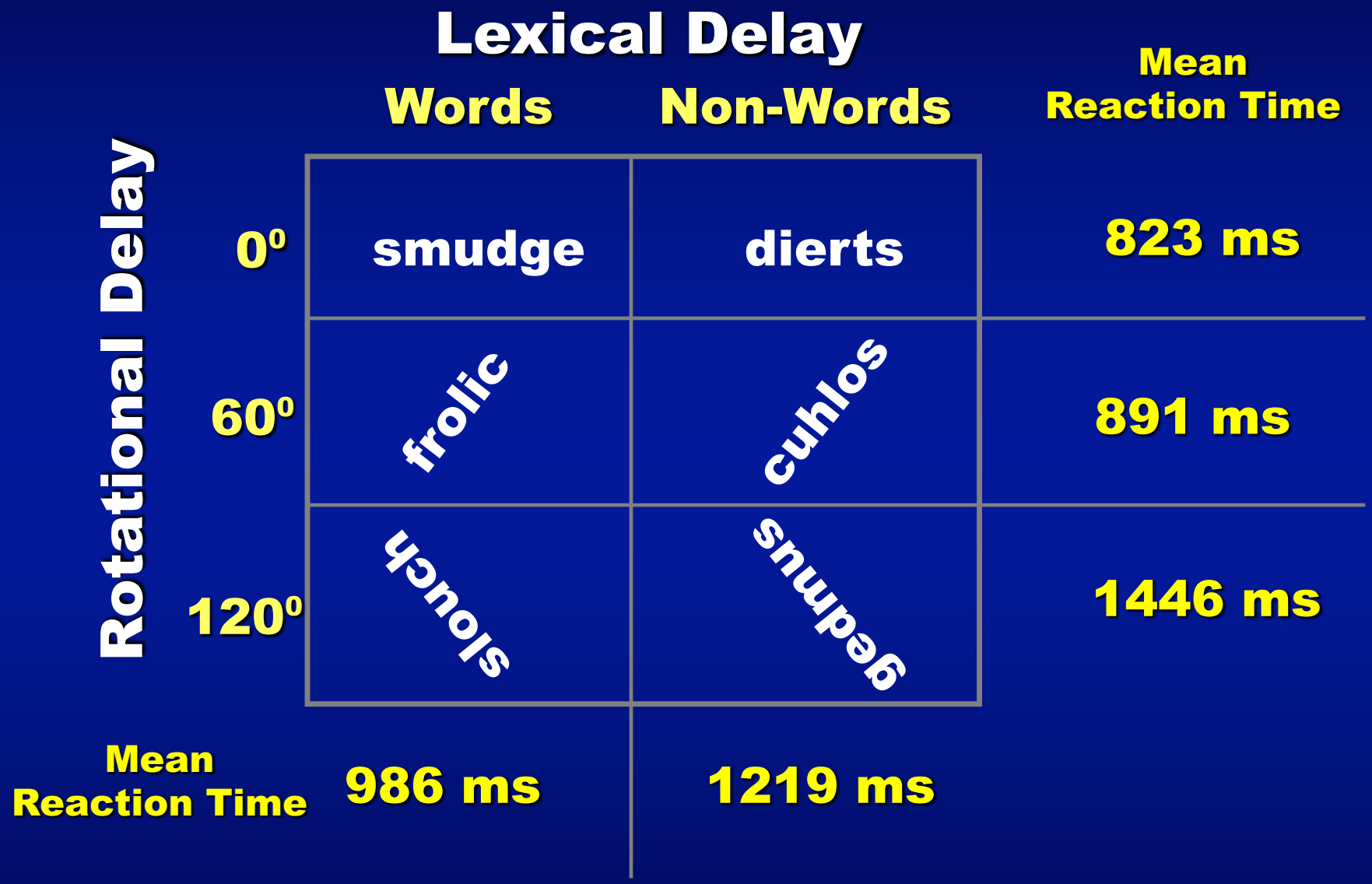
b) Stimulus rotation demands a change in perceptual perspective prior to linguistic processing. This will result in a delayed IRF onset in areas involved in Lexical and Pre-Lexical processing.

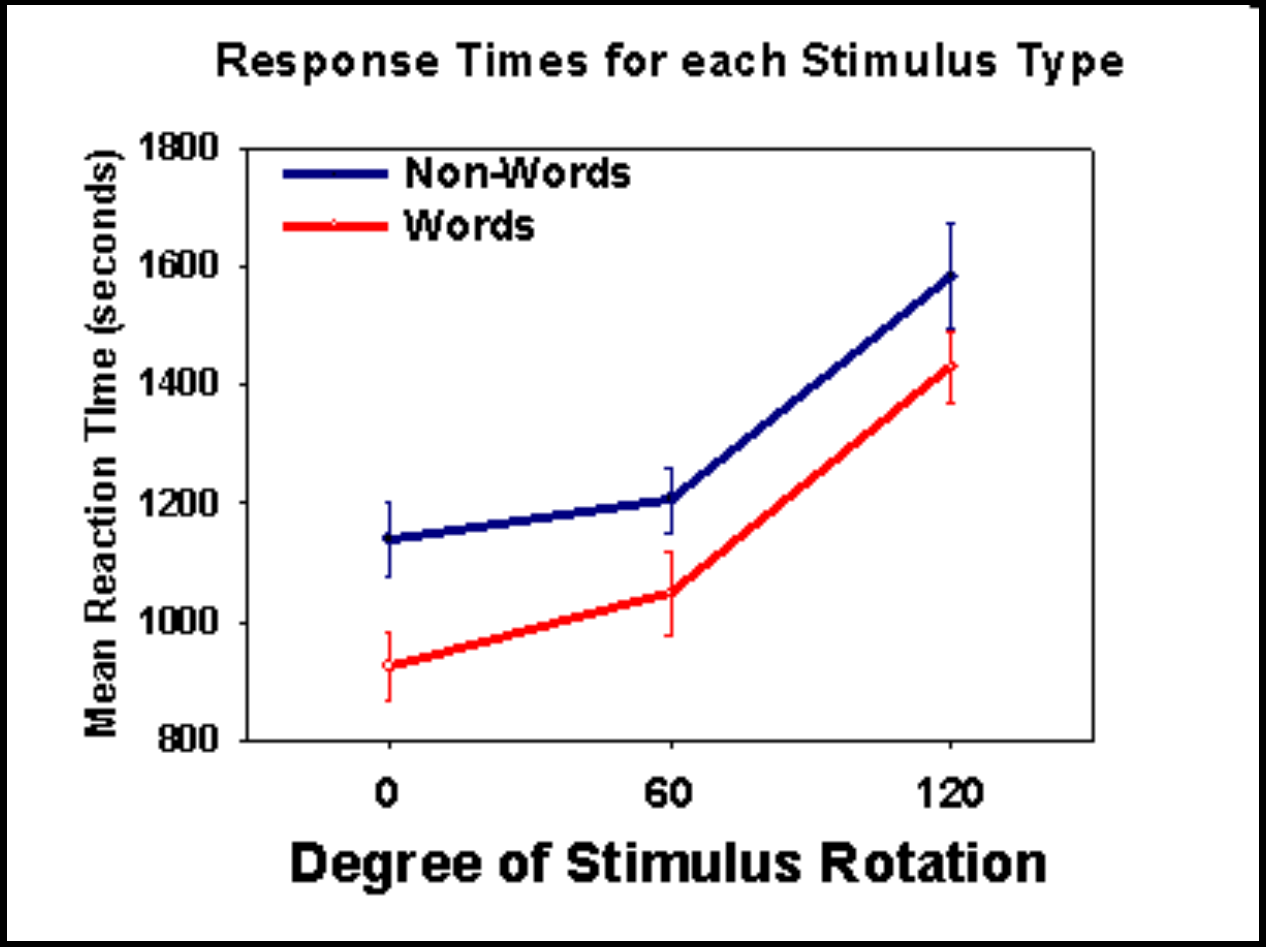
2) Lexical discrimination will result in :

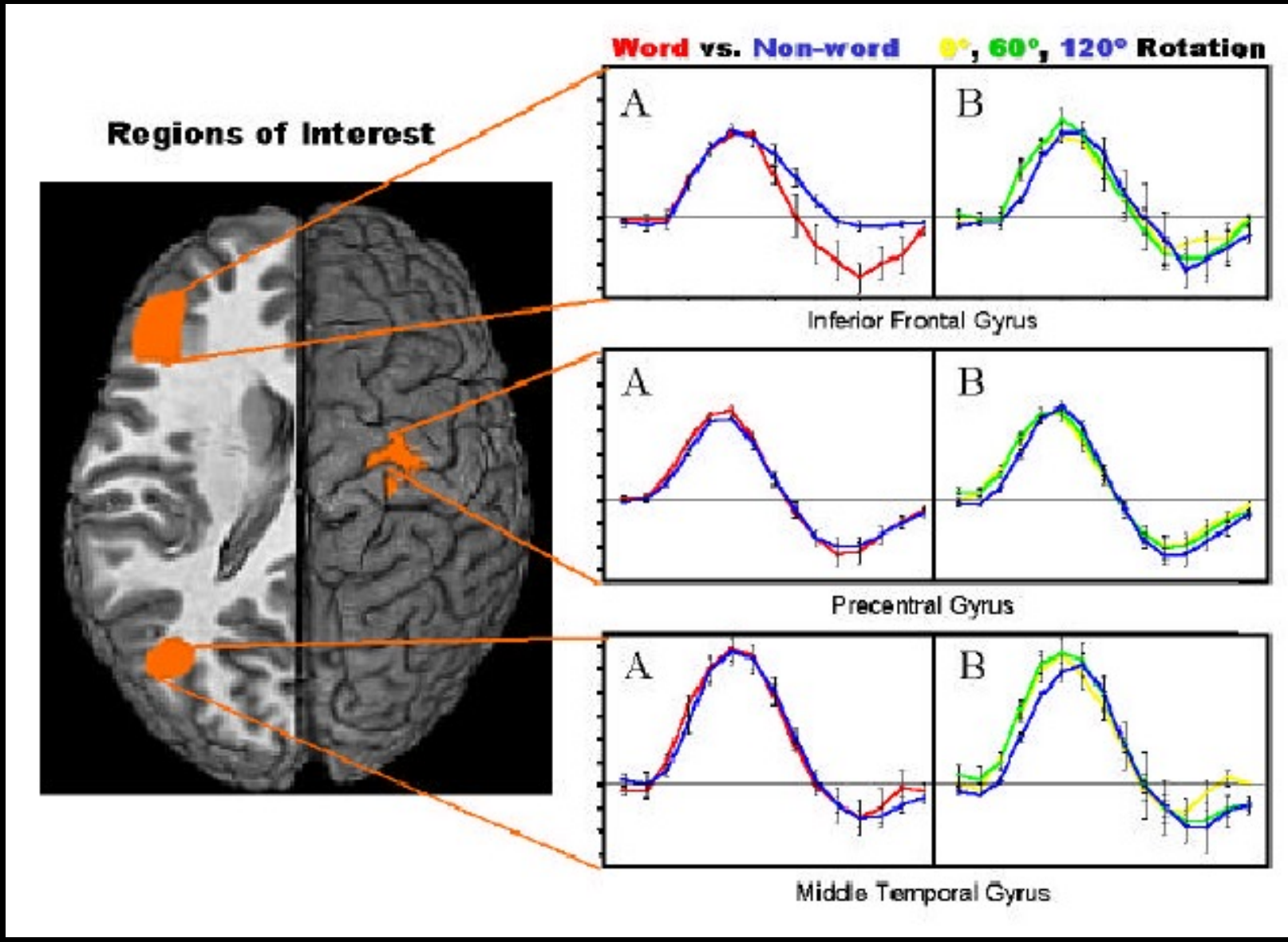
a) Longer Reaction Times for non-words due to increased Pre-Lexical processing demands.

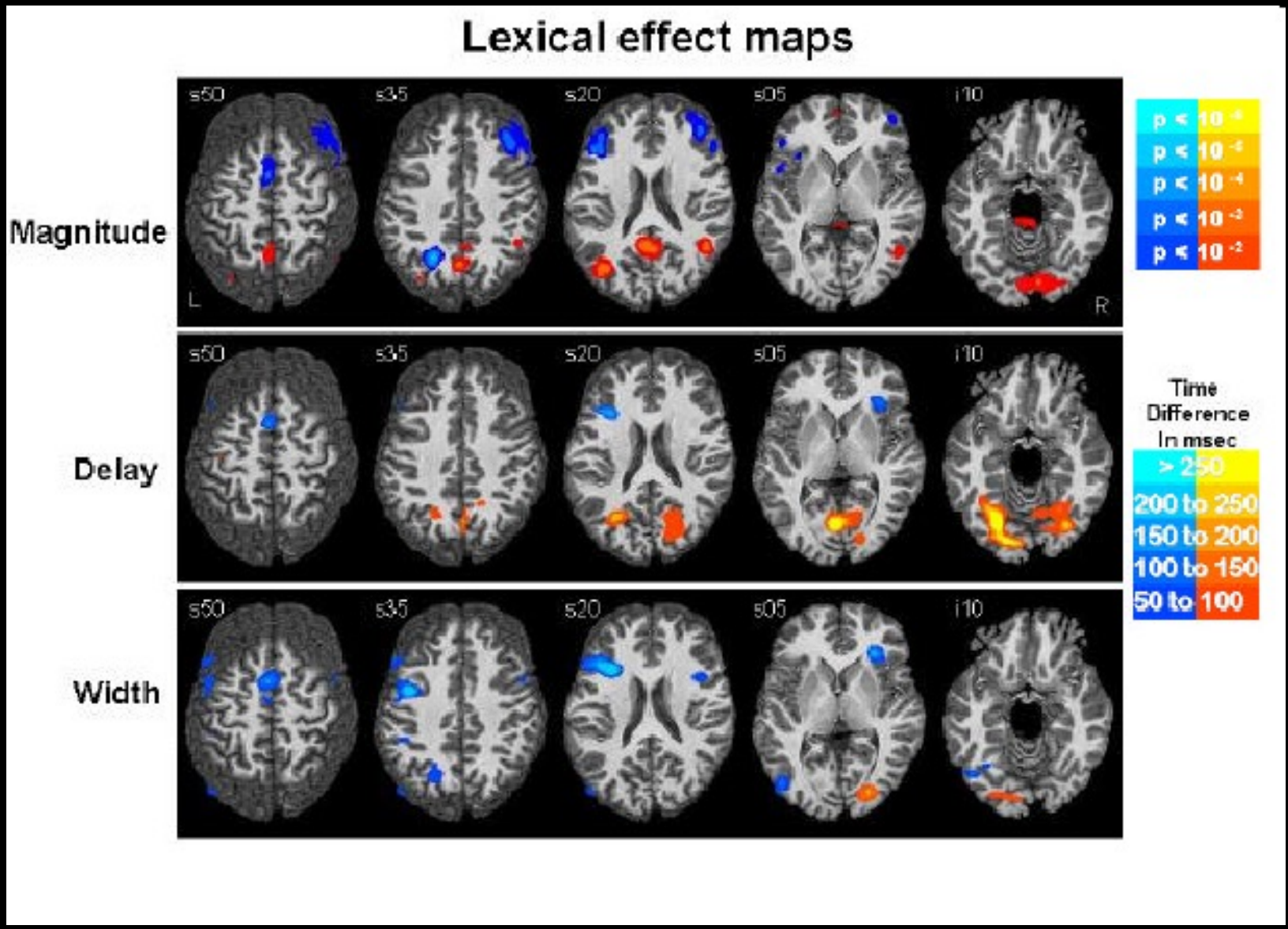
b) Wider IRF in Inferior Frontal cortex for non-words

c) Delayed IRF onset in Left Middle Frontal Cortex


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


Response Times for each Stimulus Type
Mean Reaction Time (seconds)
1800
1600
1400
1200
1000
800
Non-Words
Words
0
60
120
Degree of Stimulus Rotation

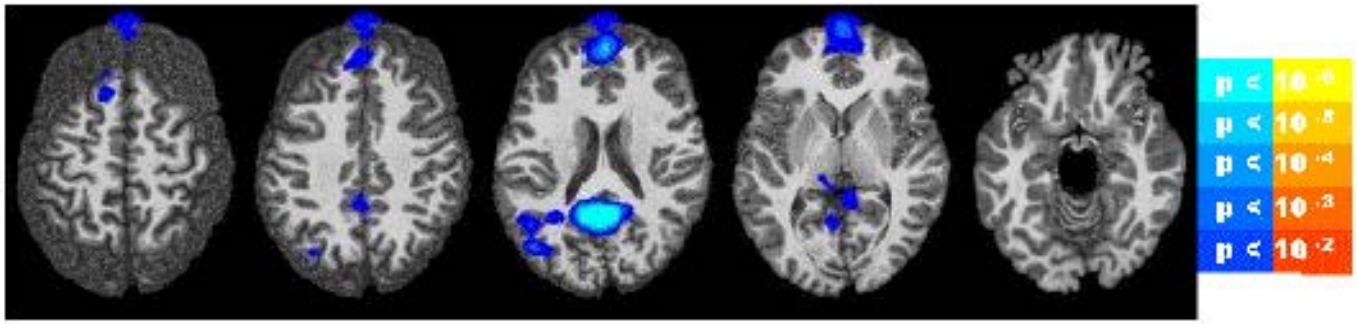

Word vs. Non-word
0°, 60°, 120° Rotation
Regions of Interest
A
B
Inferior Frontal Gyrus
A
B
Precentral Gyrus
A
B
Middle Temporal Gyrus



Warm colors are areas where Words > Non-words. Cool colors (blues) are areas where Non-words > words.

Rotational effect maps

Magnitude

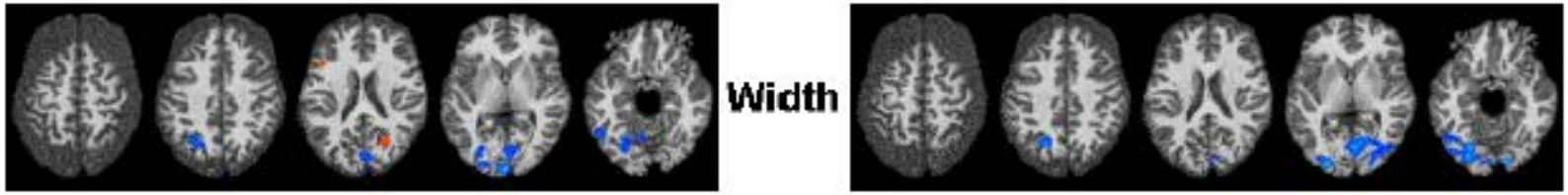


Non-rotated vs. 120° rotated

Non-rotated vs. 60° rotated

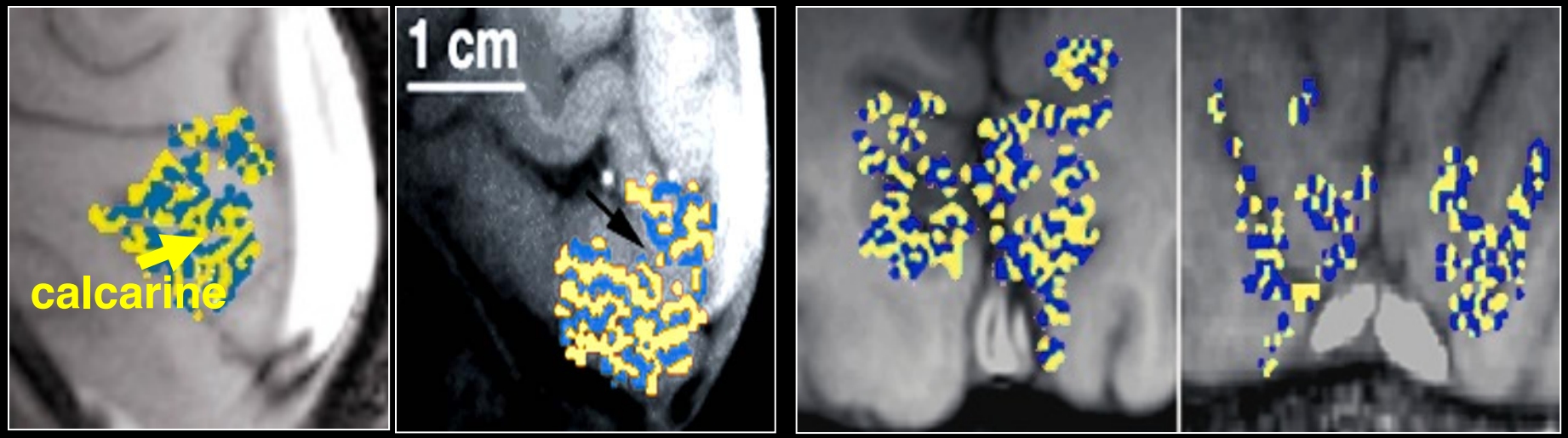
Delay

Width

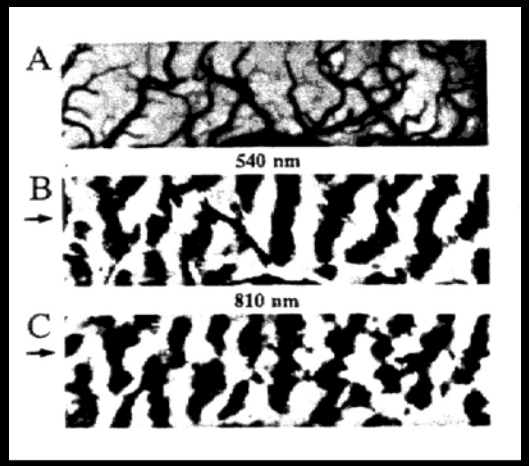


- Interpretation
- Temporal Resolution
- Spatial Resolution

Ocular Dominance Column Mapping using fMRI

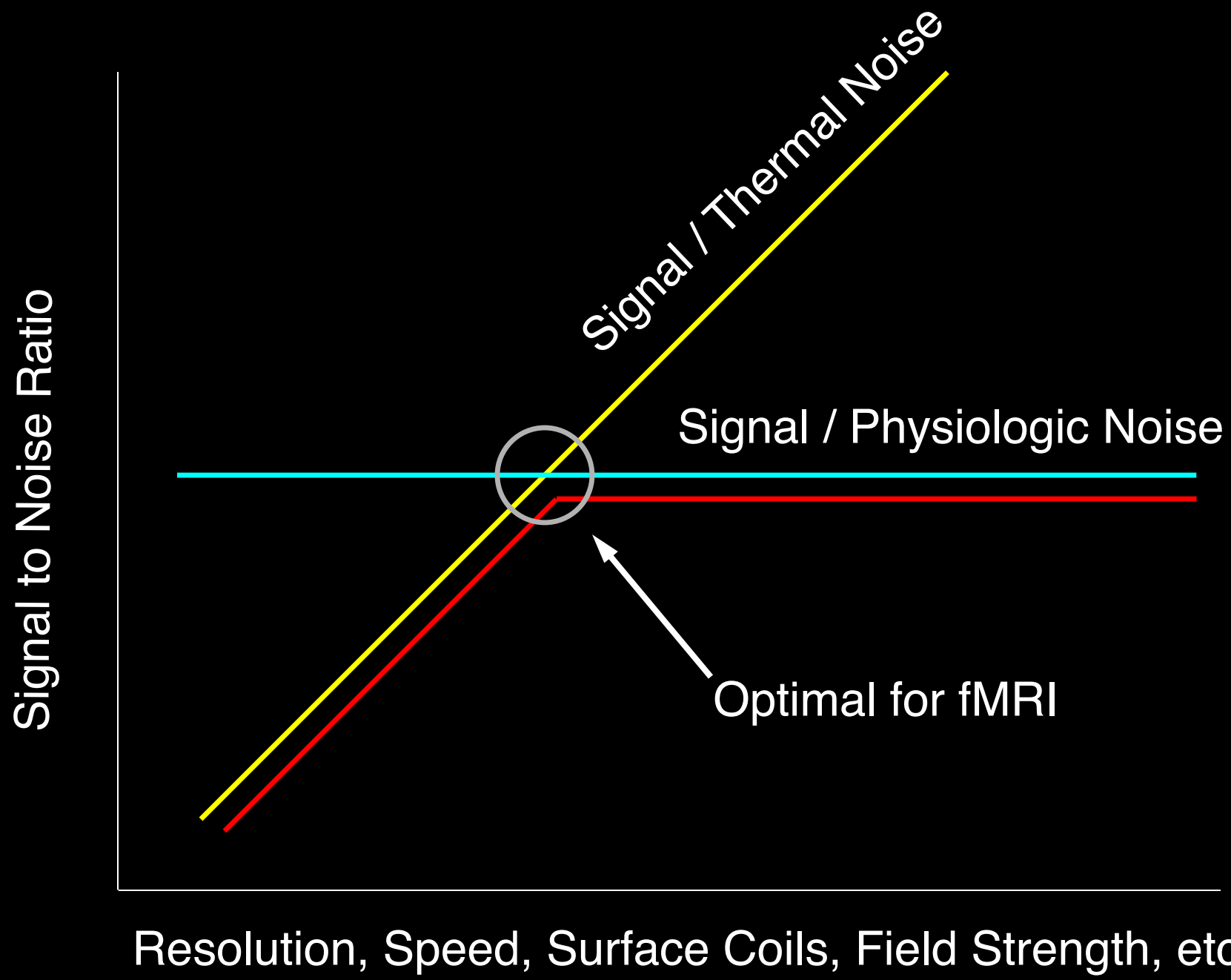


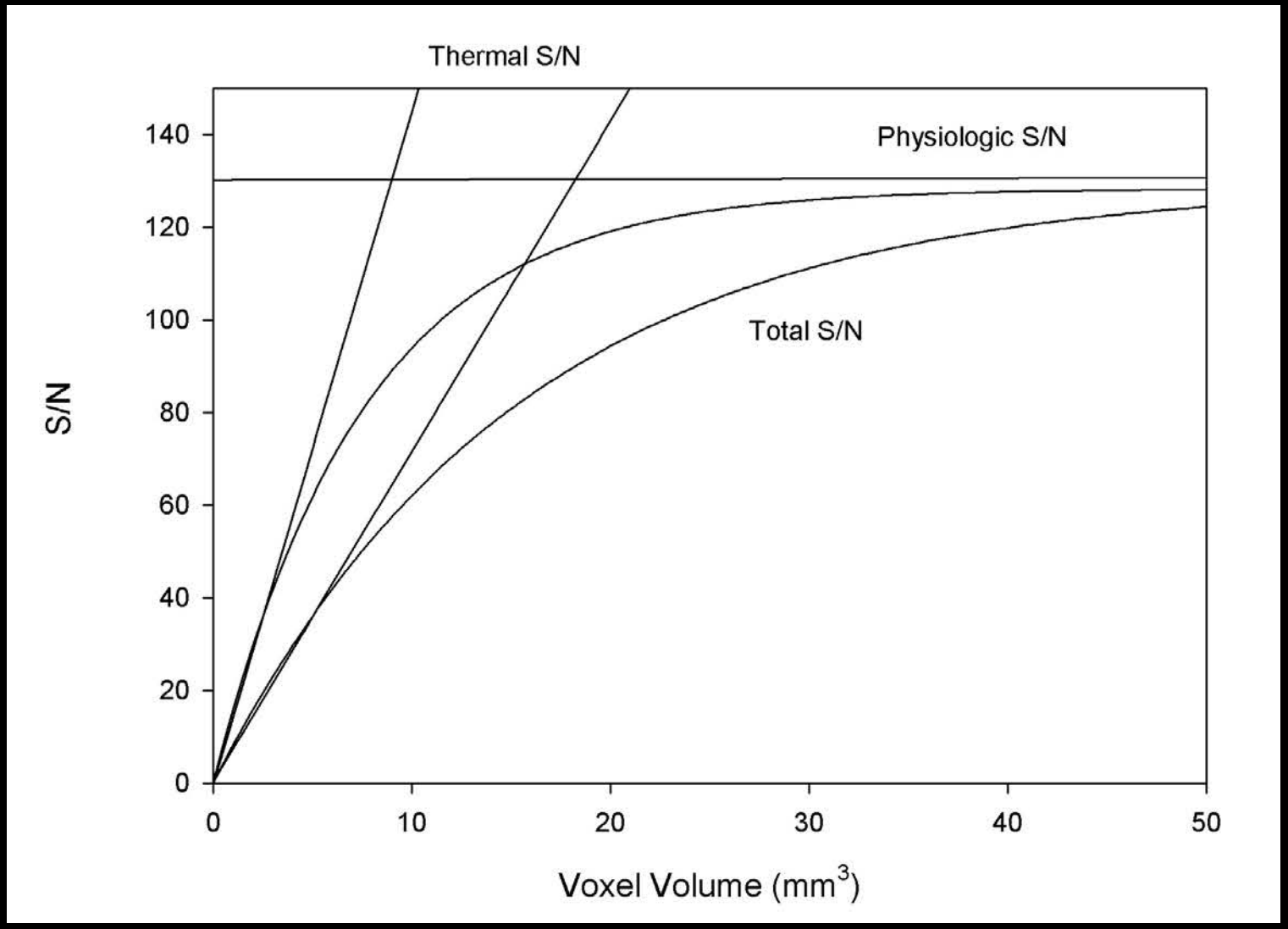
Menon, R. S., S. Ogawa, et al. (1997). "Ocular dominance in human V1 demonstrated by functional magnetic resonance imaging." J Neurophysiol 77(5): 2780-7.



Optical Imaging

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


Signal / Thermal Noise
Signal / Physiologic Noise
Optimal for fMRI
Signal to Noise Ratio
Resolution, Speed, Surface Coils, Field Strength, etc..


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)

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

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Quadrature Head Coil

8 Channel Array

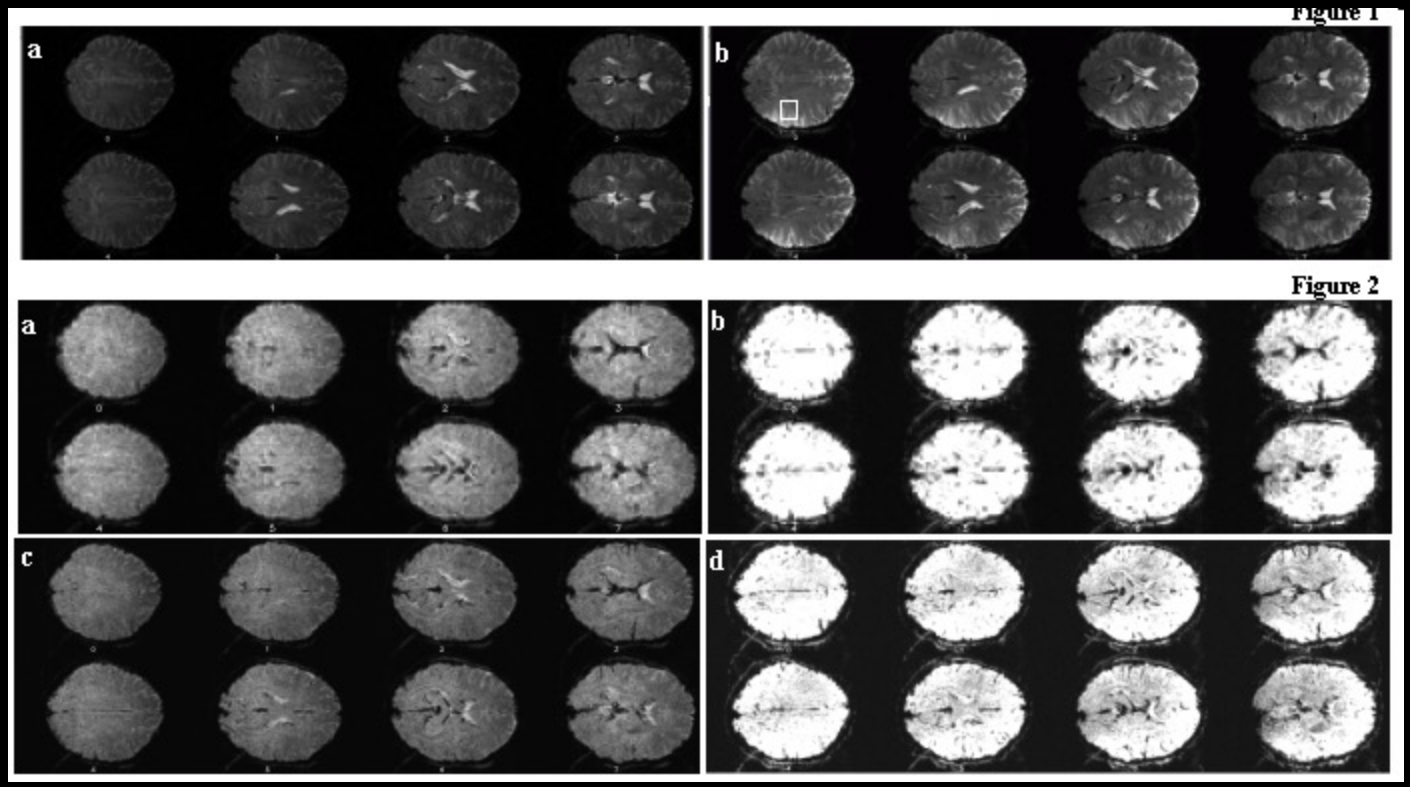
128 x 96

64 x 48

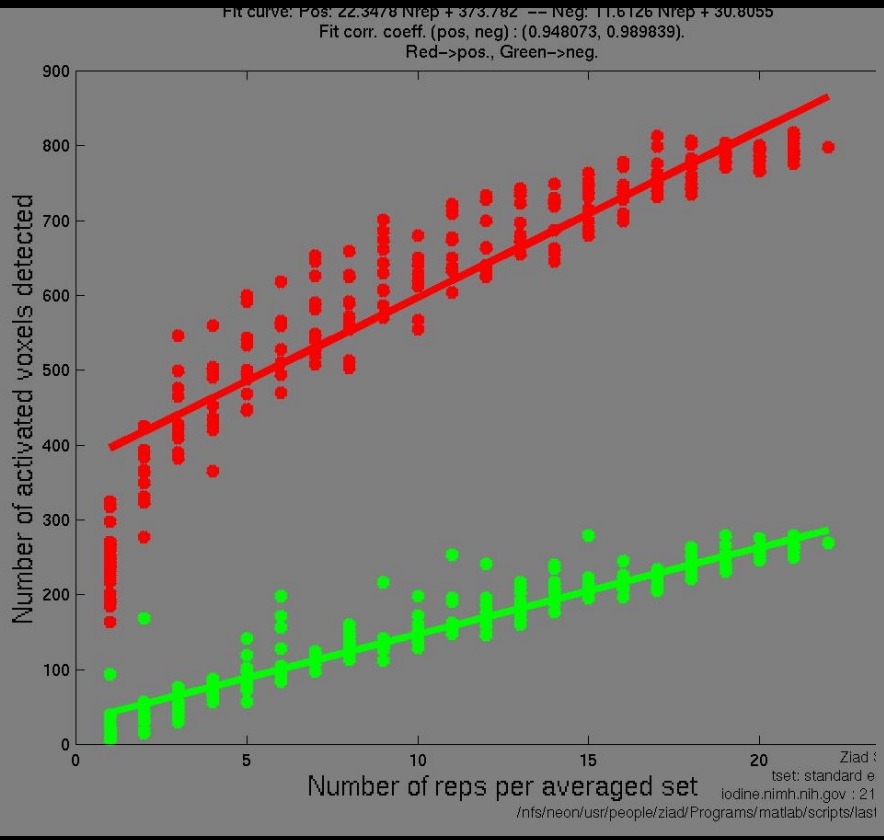
128 x 96

SNR

TSNR

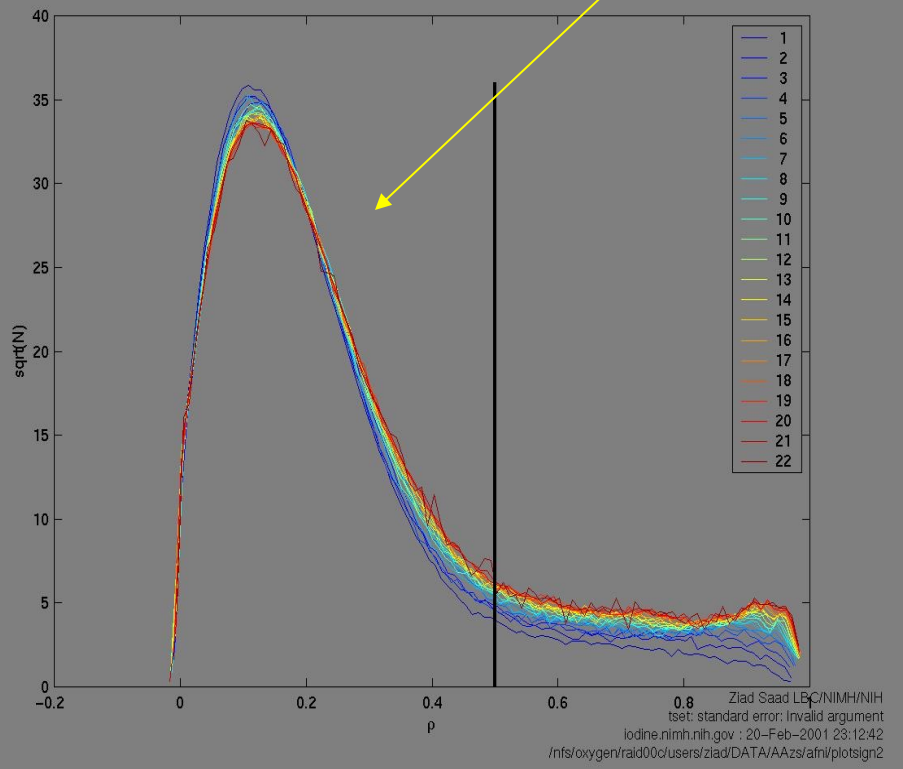


Continuously Growing Activation Area



CC Histogram

Inflection Point

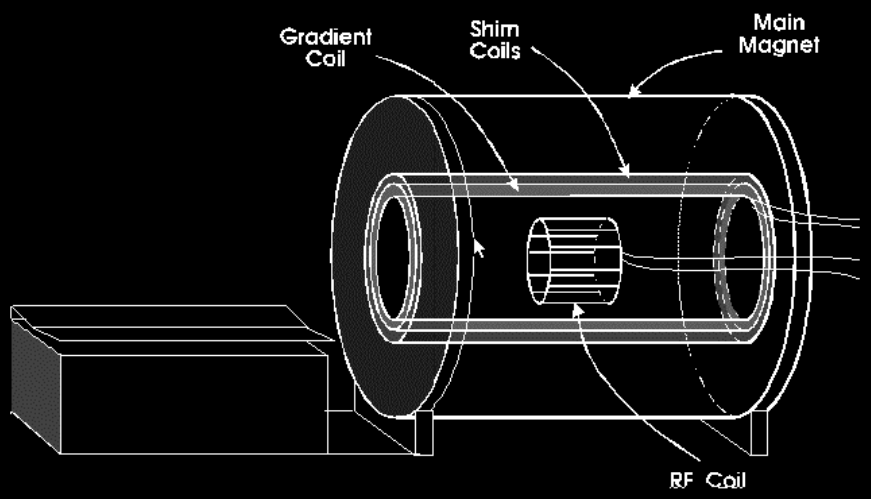


Ziad Saad, et al (Submitted)

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

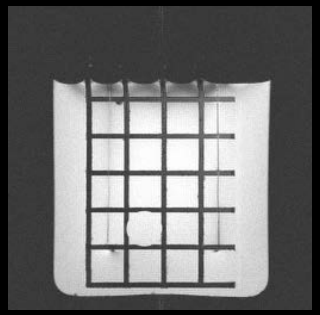
2 G/cm, 350 T/m/s

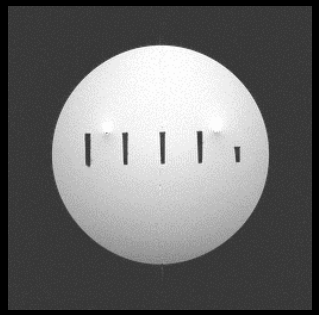
4 G/cm, 150 T/m/s



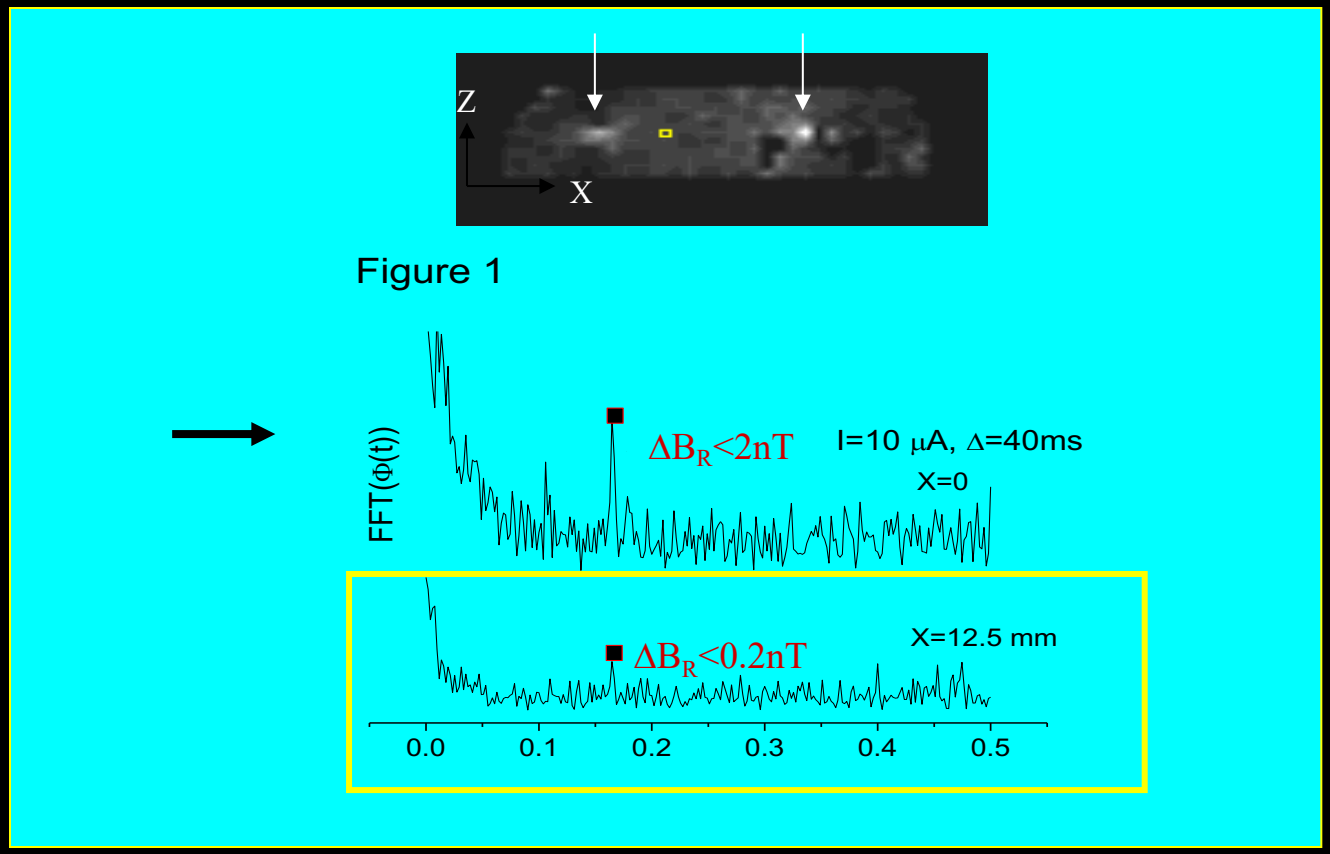
10 G/cm, 1000 T/m/s

Diffusion imaging
Faster imaging
Higher resolution

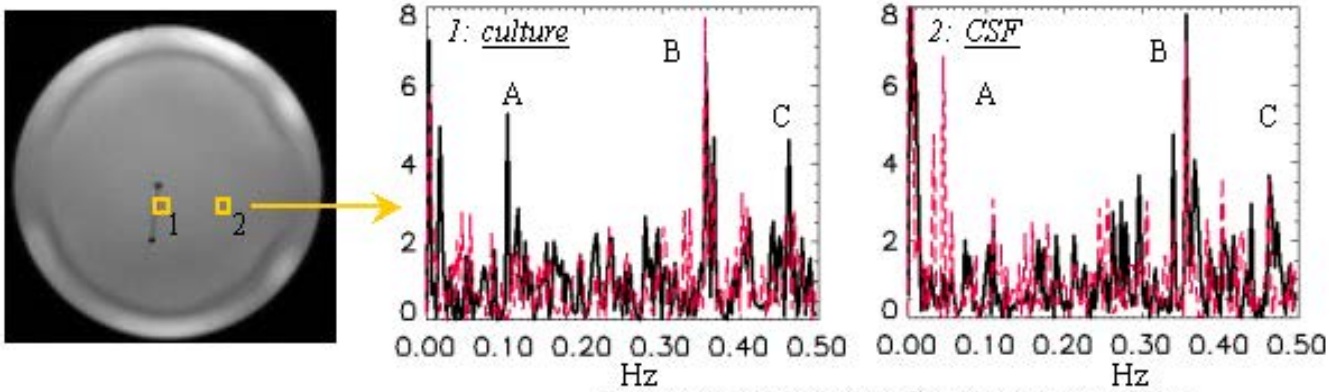




Neuronal Current Imaging

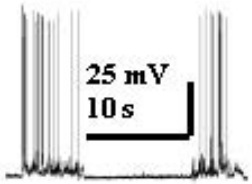


J. Bodurka, P. A. Bandettini. Toward direct mapping of neuronal activity: MRI detection of ultra weak transient magnetic field changes, Magn. Reson. Med. (in press).

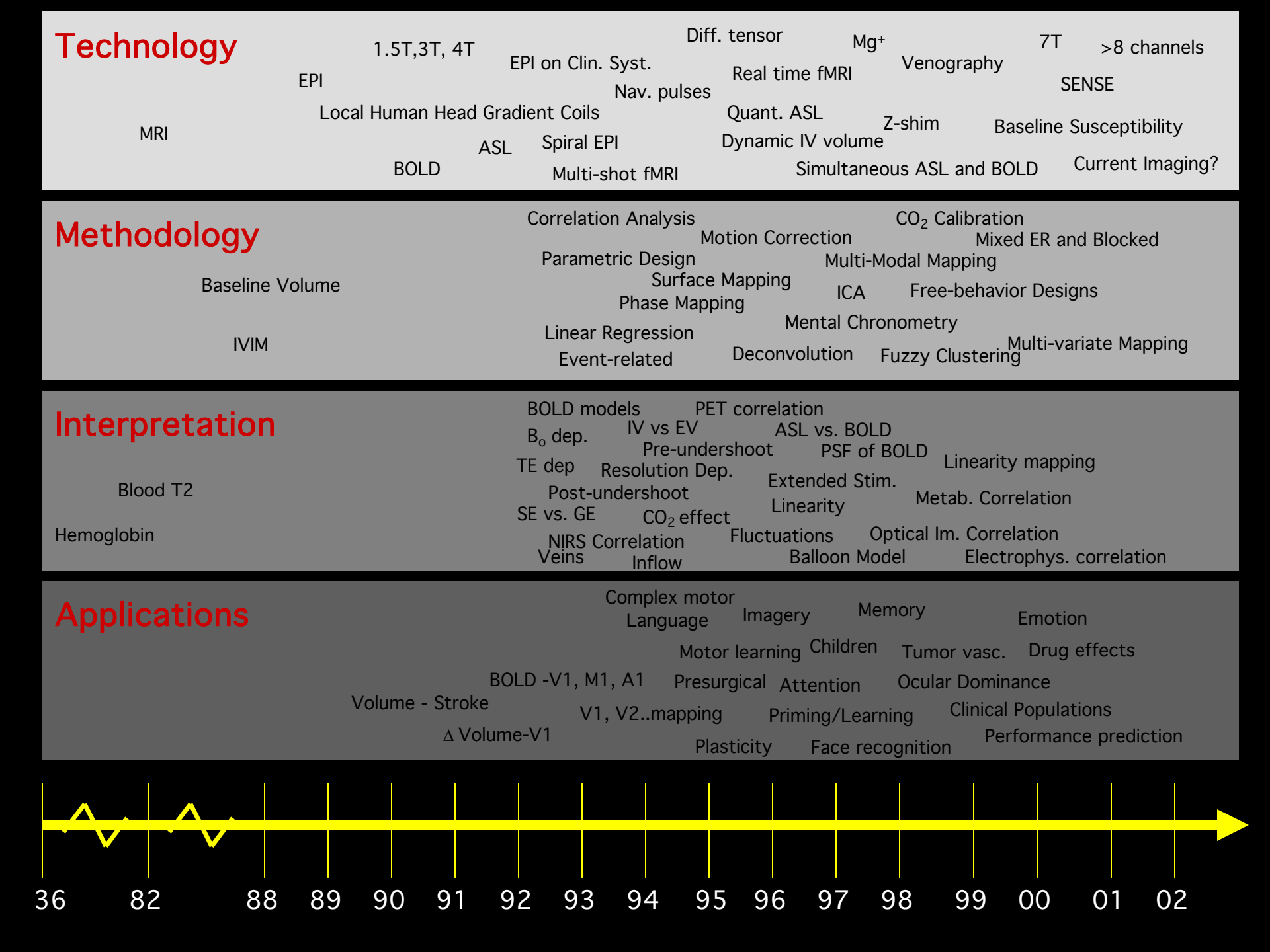


Active state: black line, Inactive state: red line

A: activity, on-off frequency (see trace)
B: scanner noise (cooling-pump)
C: activity



Typical Electrophysiology trace


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

FIM Unit & FMRI Core Facility

Director:

Peter Bandettini

Staff Scientists:

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Jerzy Bodurka

Frank Ye

Wen-Ming Luh

Computer Specialist:

Adam Thomas

Post Docs:

Rasmus Birn

Hauke Heekeren

David Knight

Patrick Bellgowan

Ziad Saad

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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

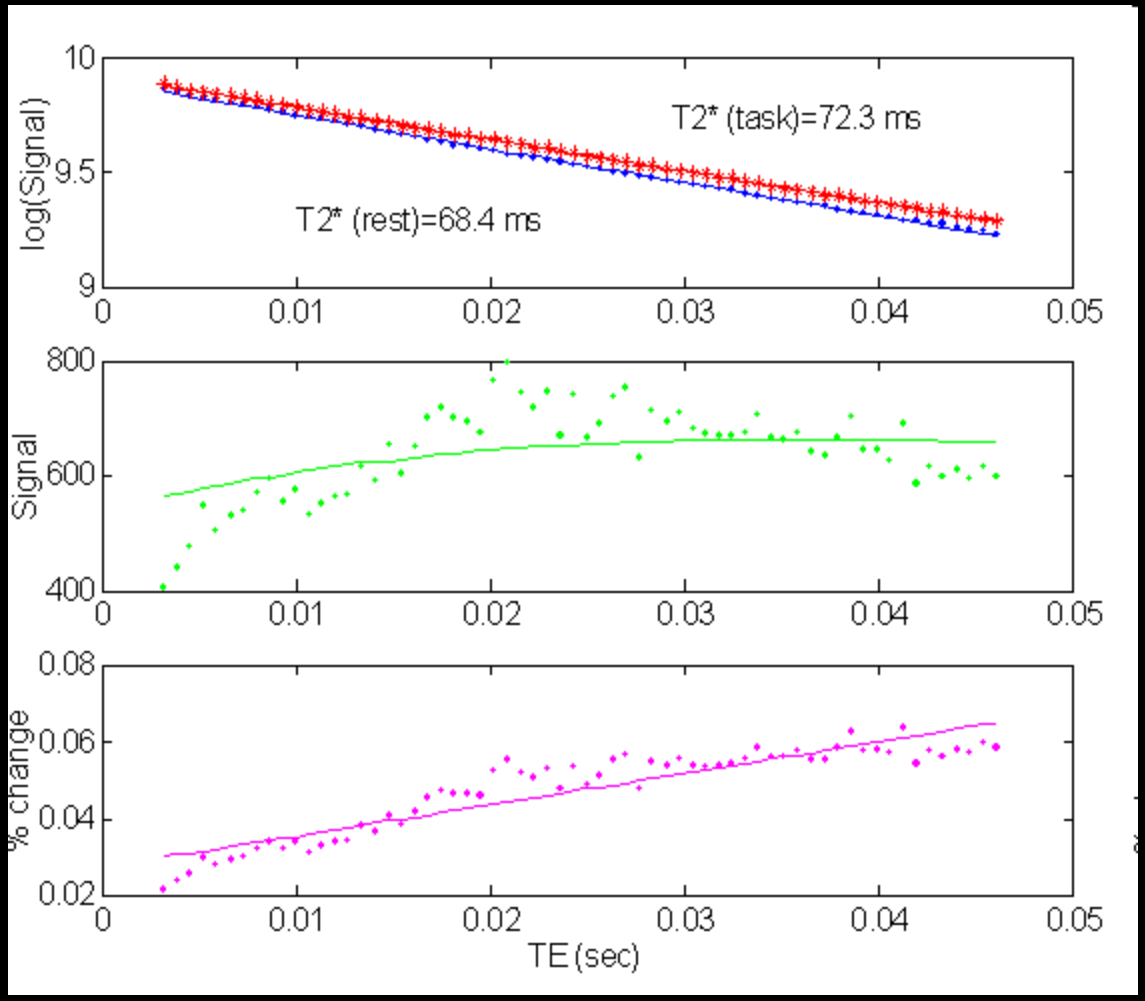
Program Assistant:

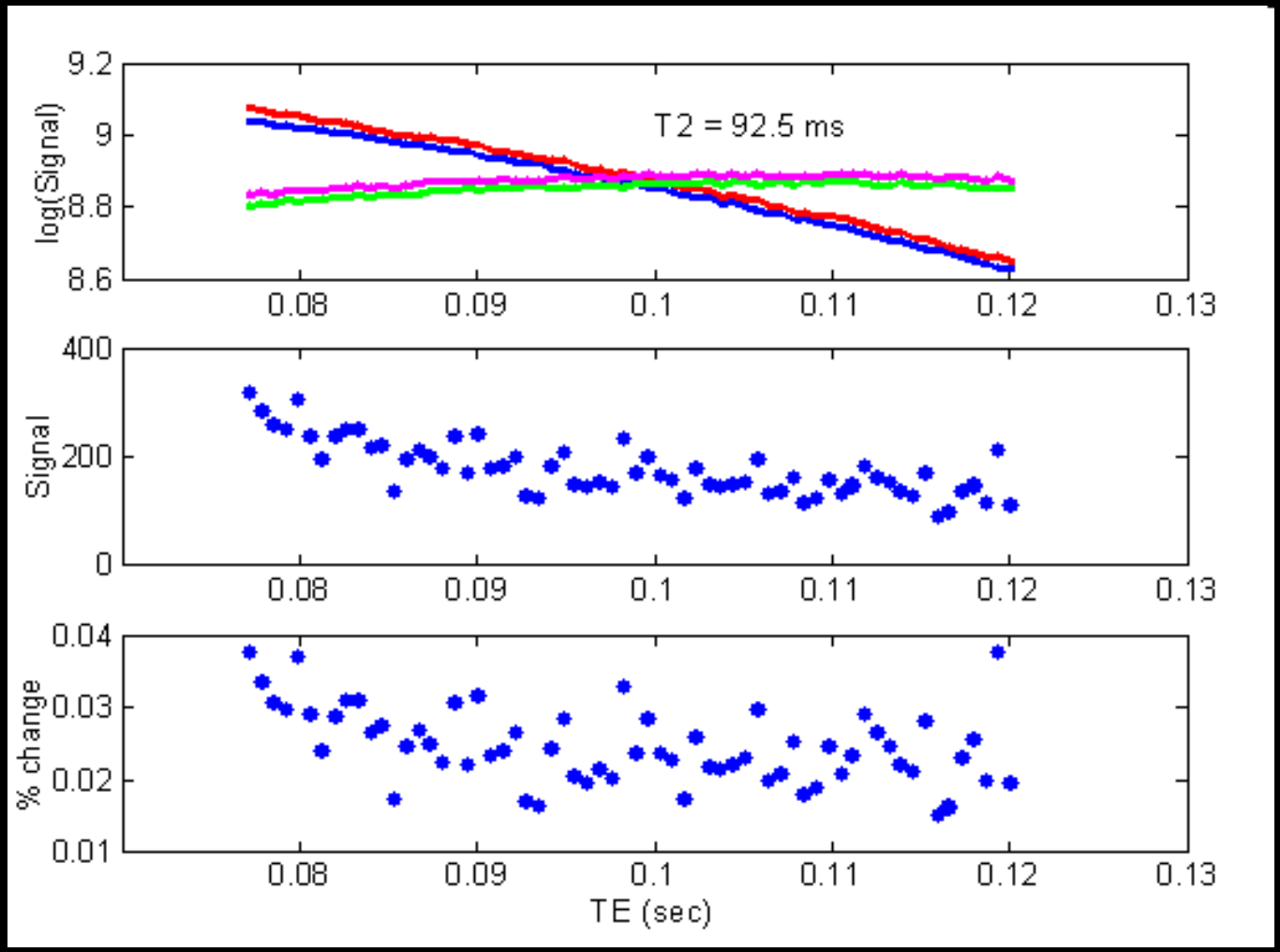
Kay Kuhns

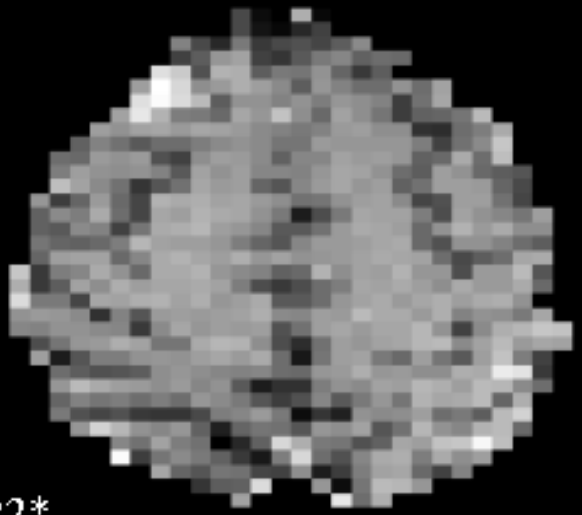
Scanning Technologists:

Karen Bove-Bettis

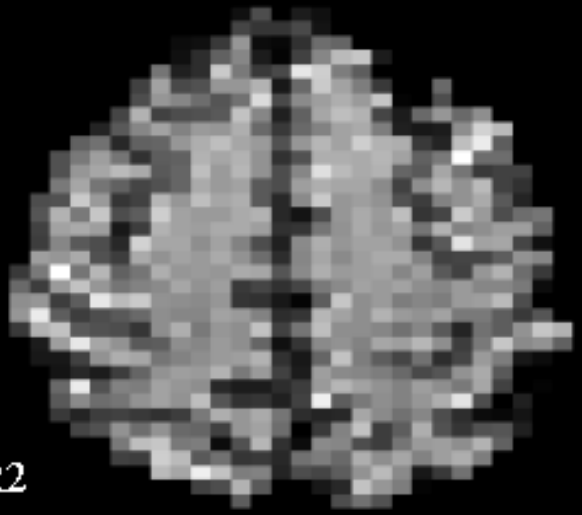
Paula Rowser


log(Signal)
10
9.5
9
T2* (task)=72.3 ms
T2* (rest)=68.4 ms
0
0.01
0.02
0.03
0.04
0.05
Signal
800
600
400
% change
0.08
0.06
0.04
0.02
TE (sec)


T2 = 92.5 ms
log(Signal)
Signal
% change
TE (sec)
9.2
9
8.8
8.6
400
200
0
0.04
0.03
0.02
0.01
0.08
0.09
0.1
0.11
0.12
0.13



R2*



R2

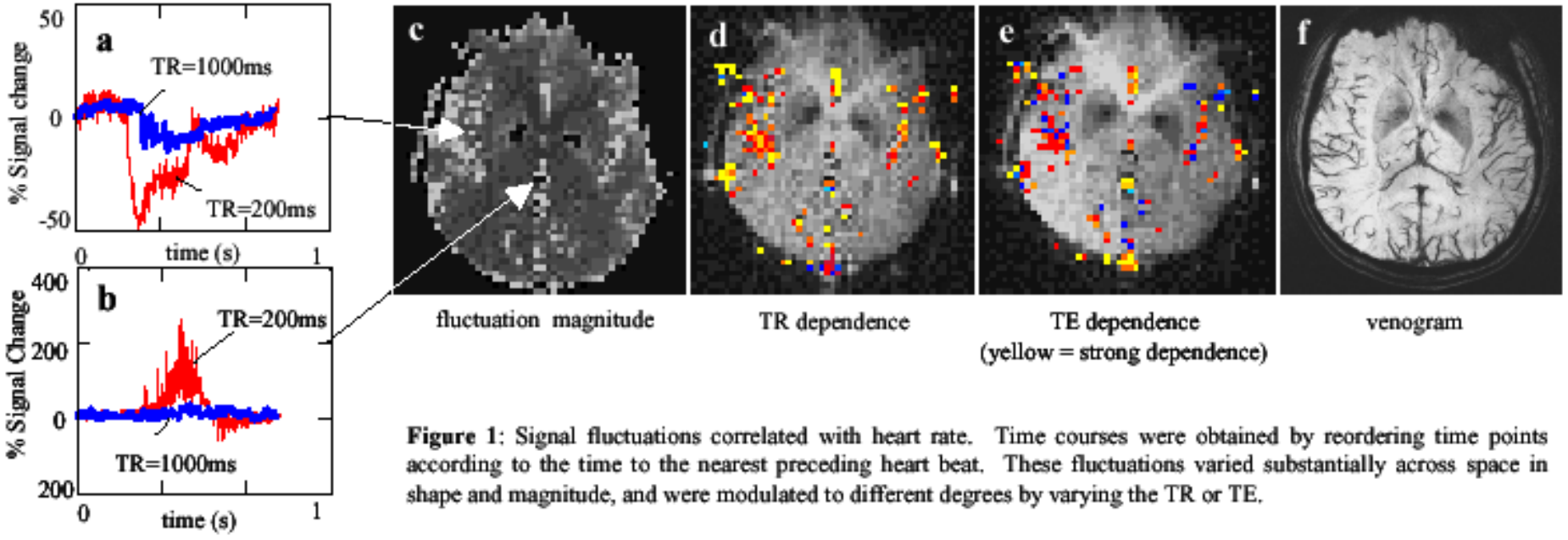


Figure 1: Signal fluctuations correlated with heart rate. Time courses were obtained by reordering time points according to the time to the nearest preceding heart beat. These fluctuations varied substantially across space in shape and magnitude, and were modulated to different degrees by varying the TR or TE.