Tradeoffs and Limits in: Spatial Resolution,Temporal Resolution, Sensitivity, and Interpretability

Peter A. Bandettini, Ph.D

Unit on Functional Imaging Methods
&
3T Neuroimaging Core Facility

Laboratory of Brain and Cognition
National Institute of Mental Health

Variables to Optimize

- Information Content
- Sensitivity
- Speed
- Resolution
- Image quality

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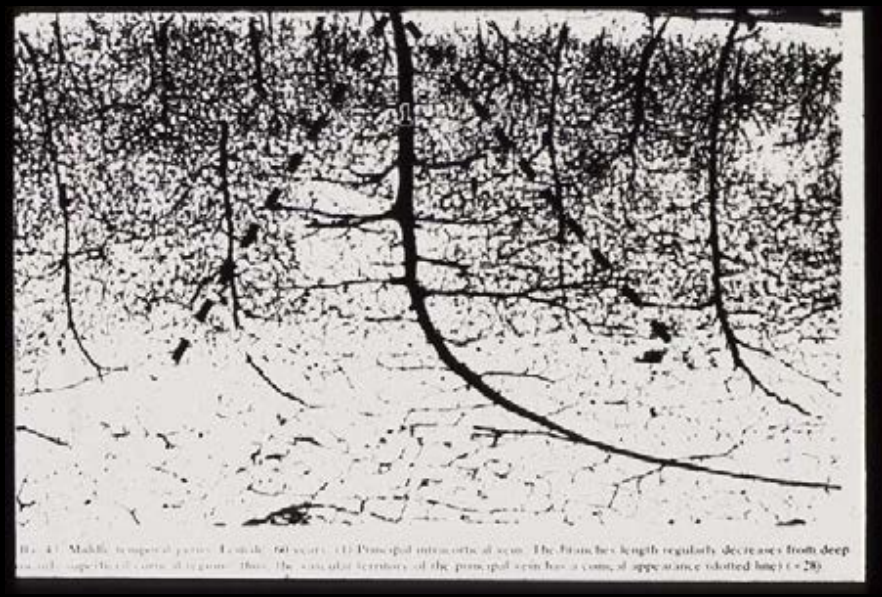
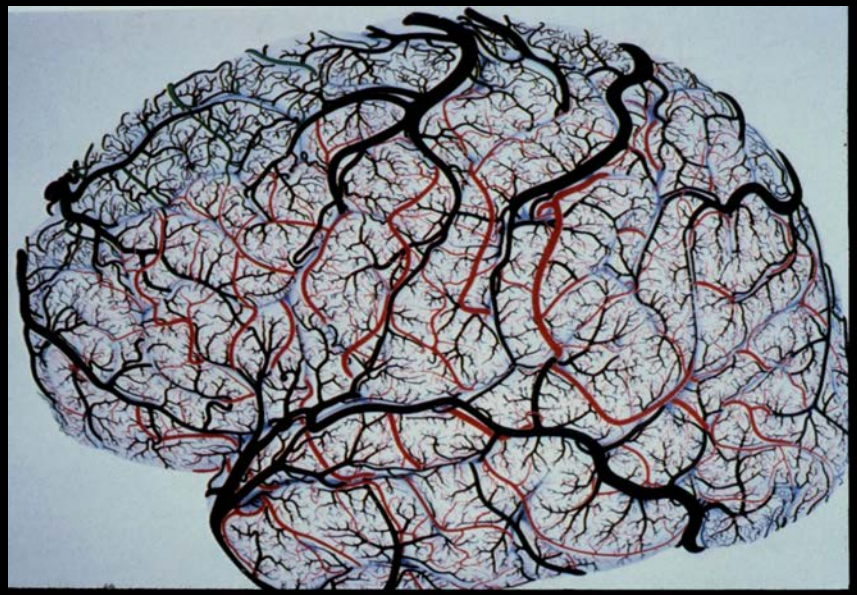
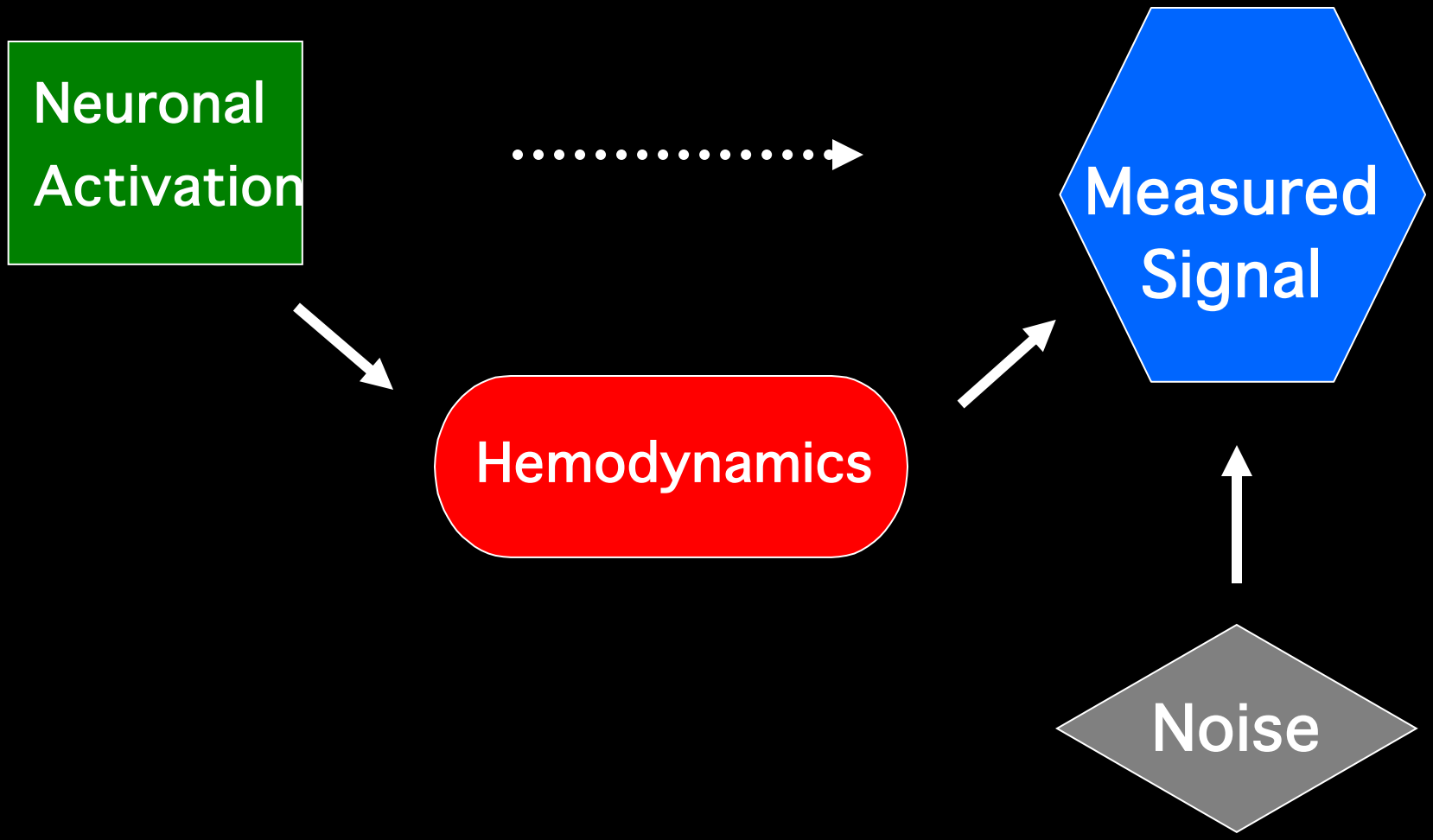
A Primary Challenge:

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






Neuronal Activation
Measured Signal
Hemodynamics
Noise

Contrast in Functional MRI

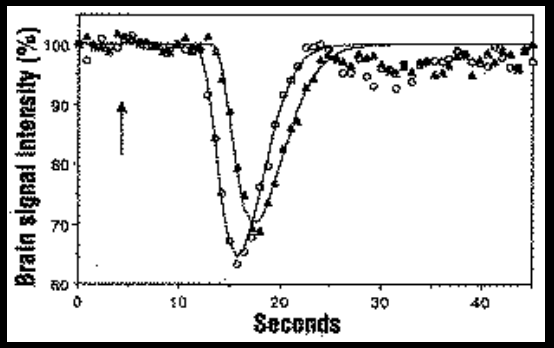
- **Blood Volume**
  - Contrast agent injection and time series collection of T2* or T2 - weighted images
- **BOLD**
  - Time series collection of T2* or T2 - weighted images
- **Perfusion**
  - T1 weighting
  - Arterial spin labeling
- **$CMRO_2$**
  - BOLD and Perfusion w/

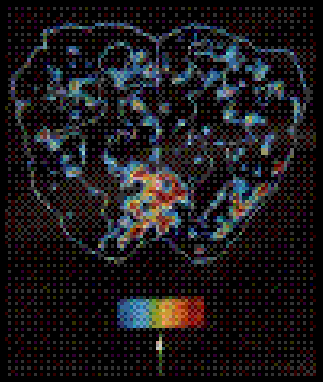
  Normalization to Global Perfusion Change

Blood Volume

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

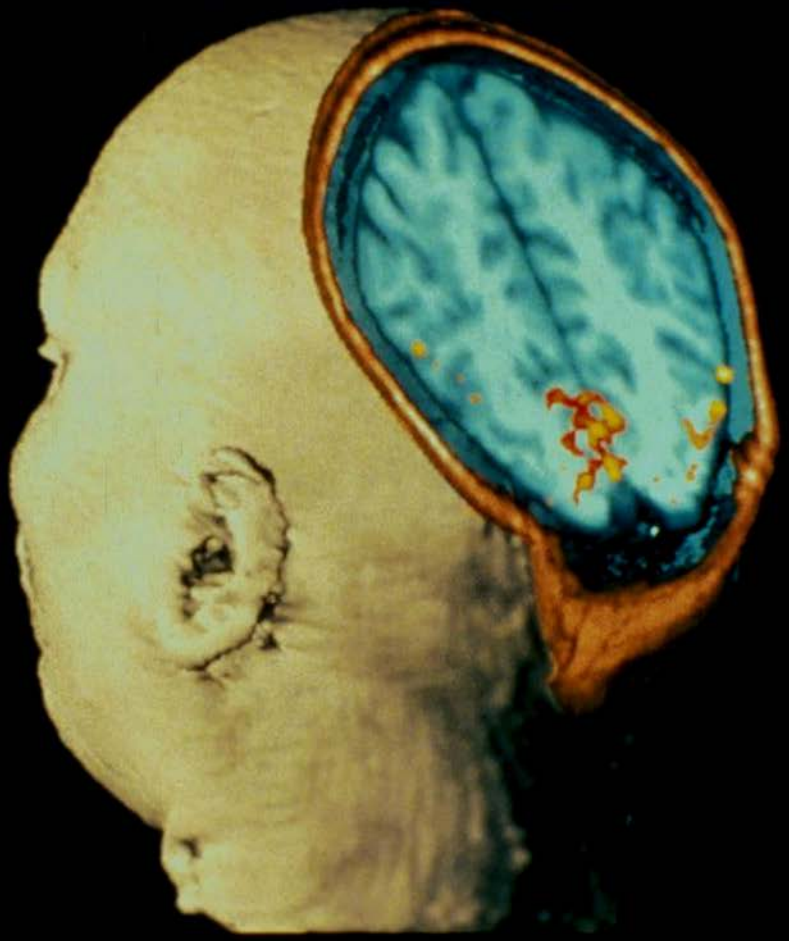
Resting Active





Blood Volume

Photic Stimulation

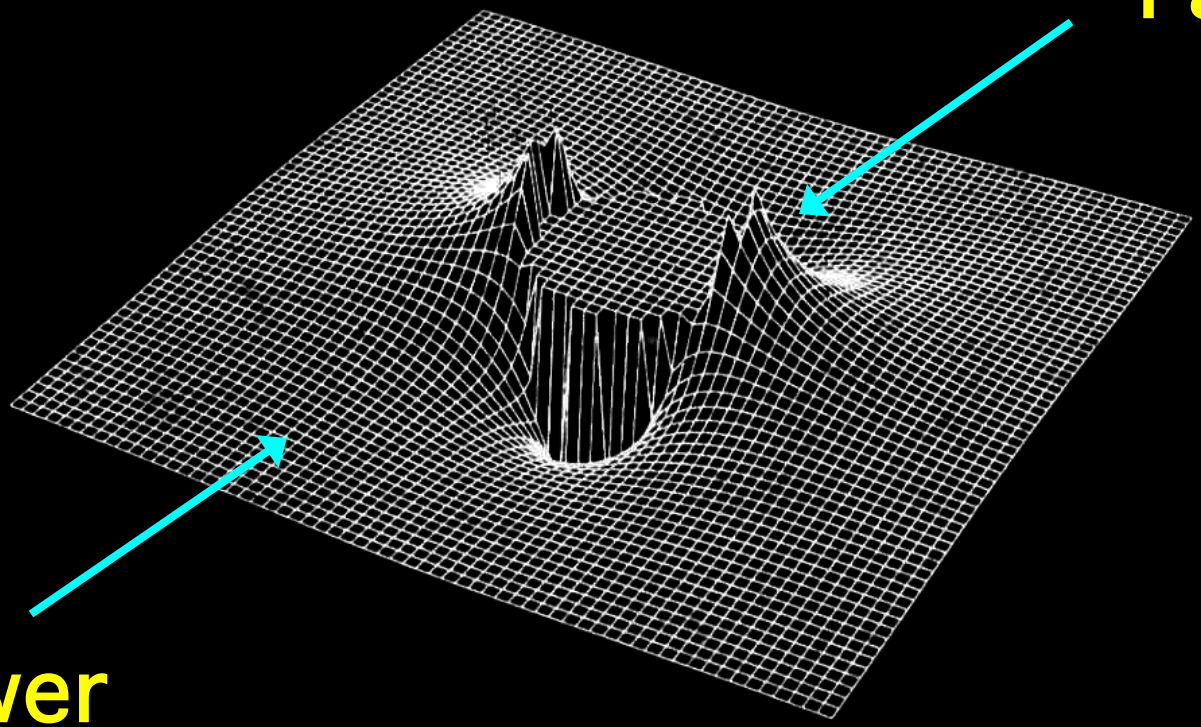


MRI Image showing activation of the Visual Cortex

From Belliveau, et al. Science Nov 1991

Susceptibility Contrast

Susceptibility-Induced Field Distortion in the Vicinity of a Microvessel $\perp$ to B_o.



Blood Oxygenation

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

↓

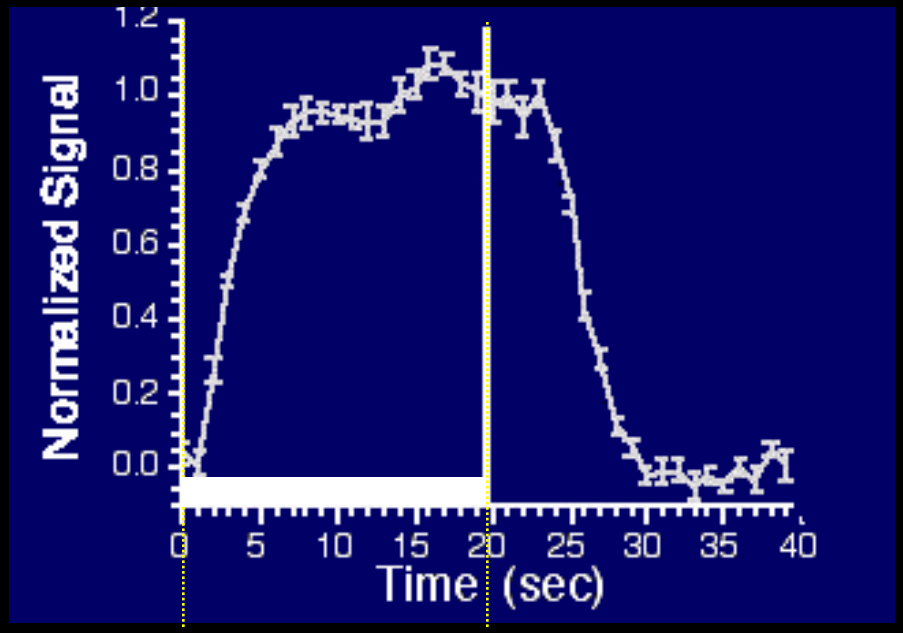
Decrease in susceptibility-related intravoxel dephasing → Increase in T2 and T2*

↓

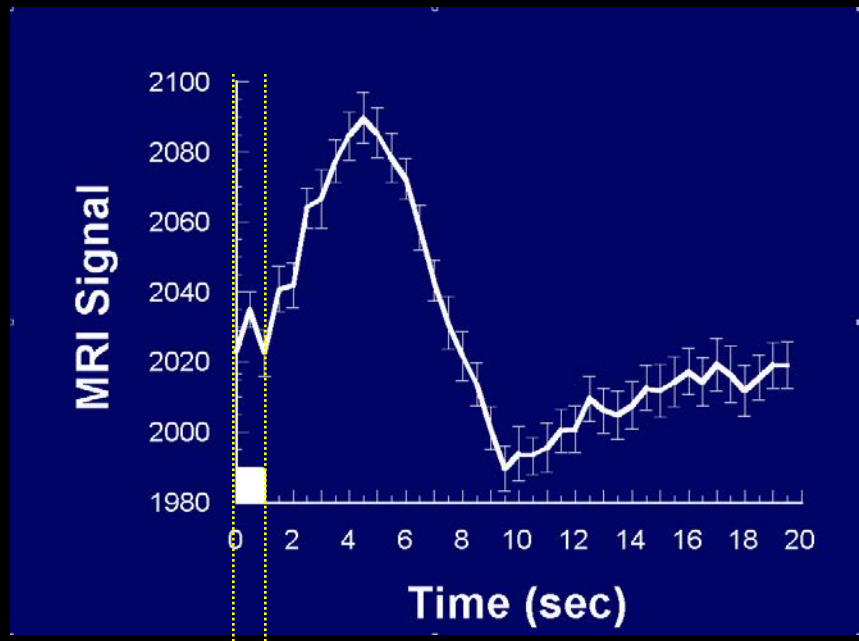
Local Signal Increase in T2 and T2* - weighted sequences

The BOLD Signal

Blood Oxygenation Level Dependent (BOLD) signal changes



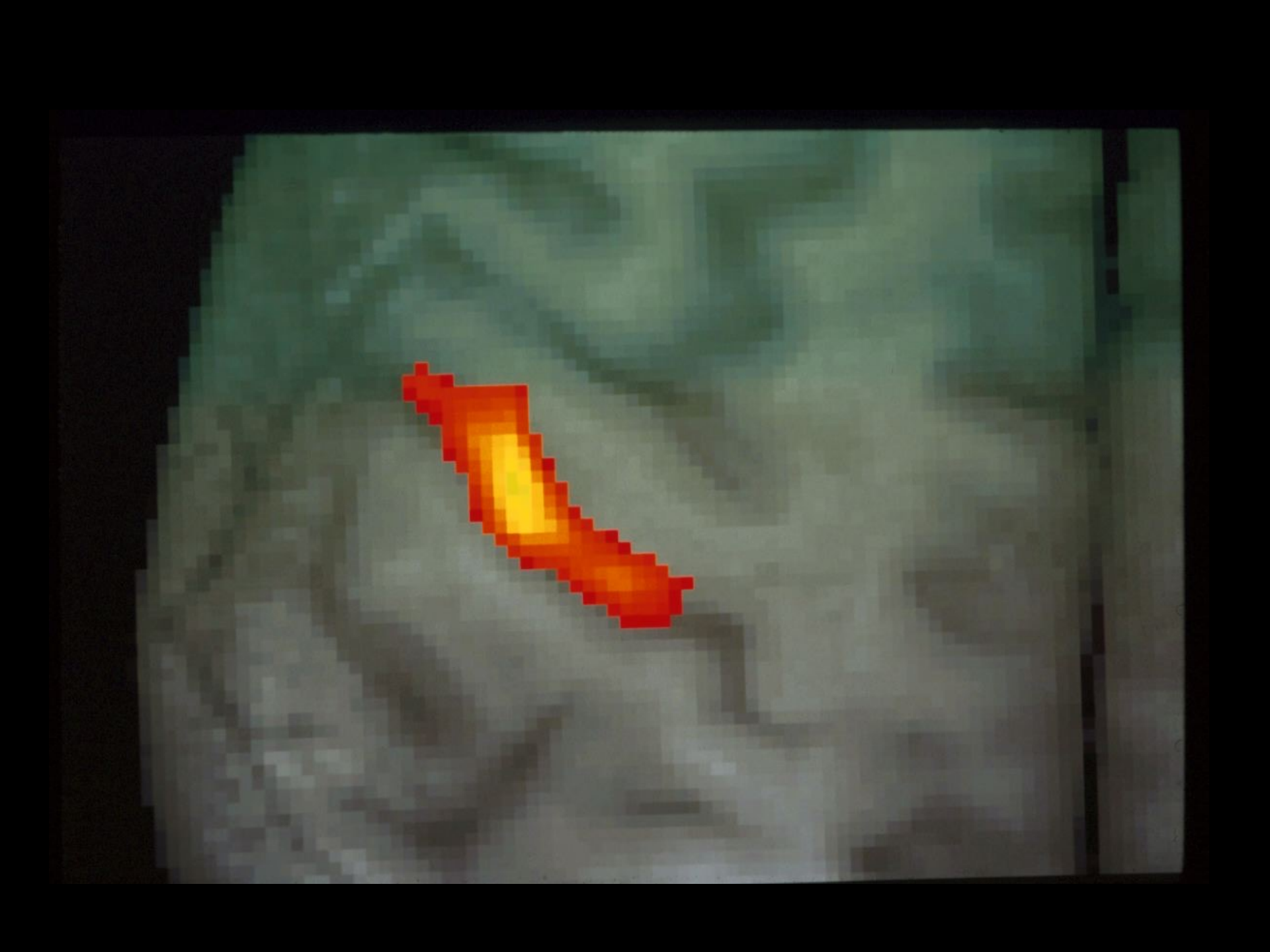
task



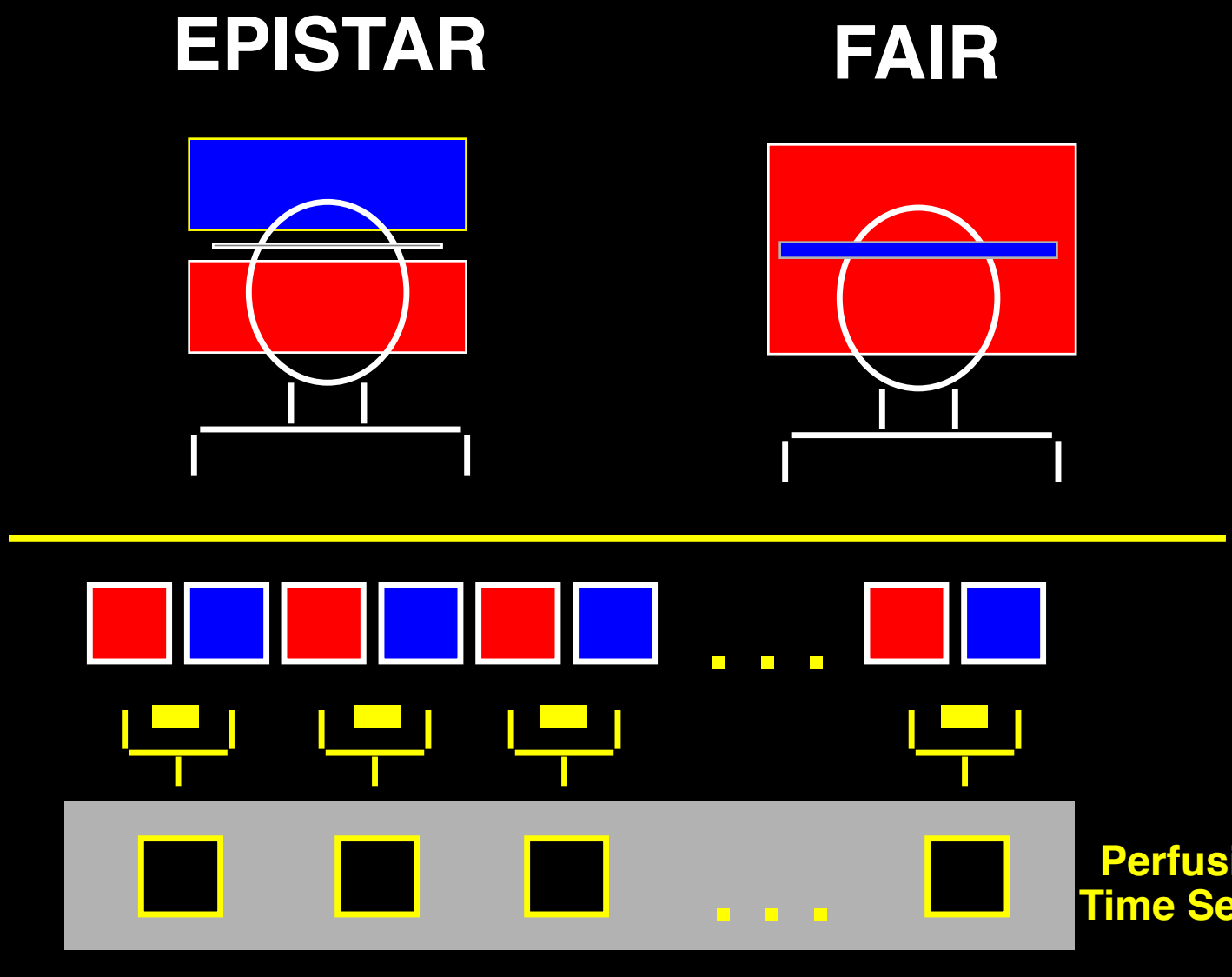
task

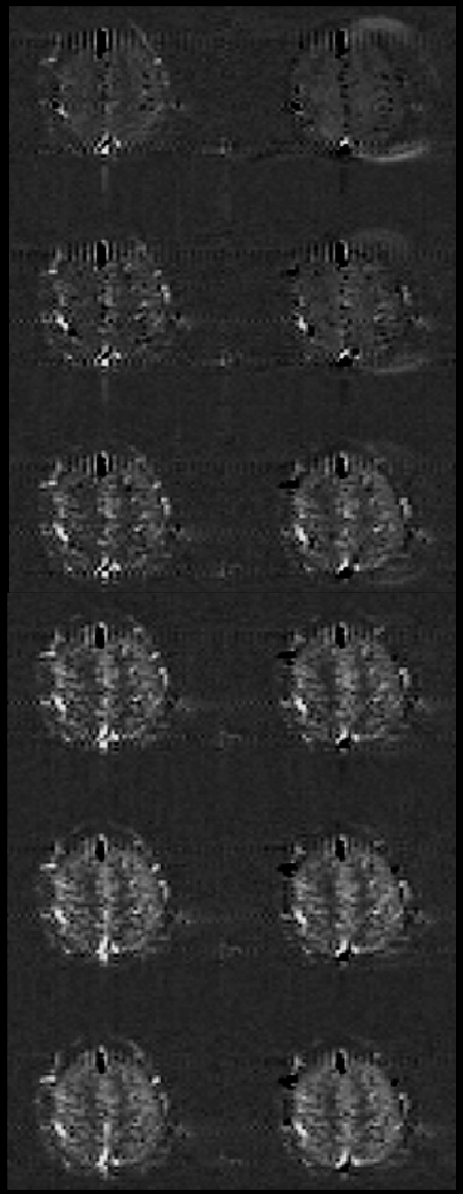
Alternating Left and Right Finger Tapping

~ 1992

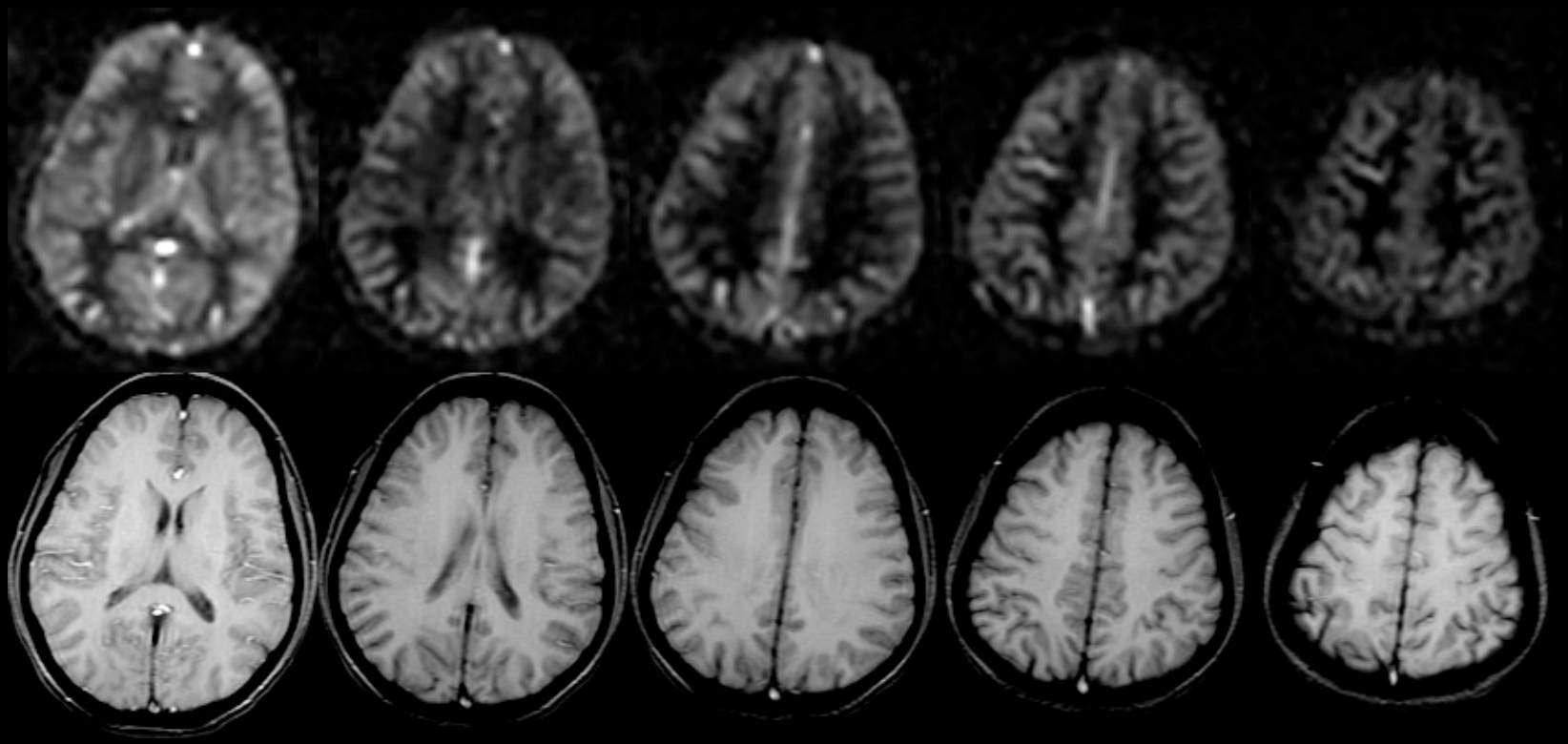


Blood Perfusion

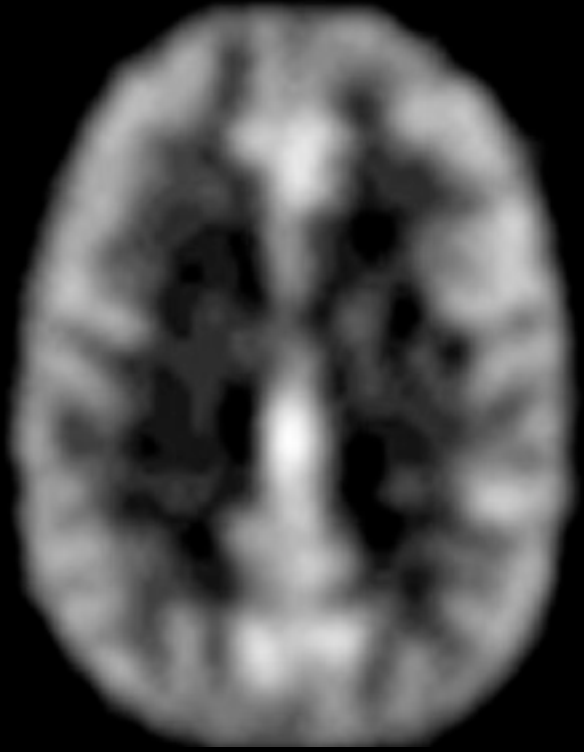


TI (ms)	FAIR	EPISTAR
200		
400		
600		
800		
1000		
1200		

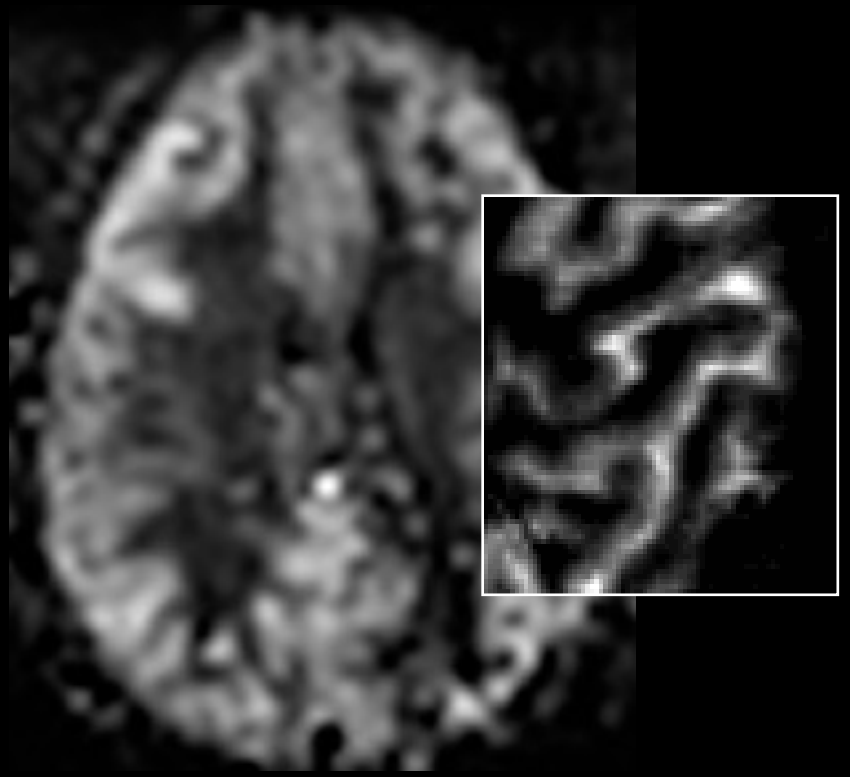
Resting ASL Signal



Comparison with Positron Emission Tomography



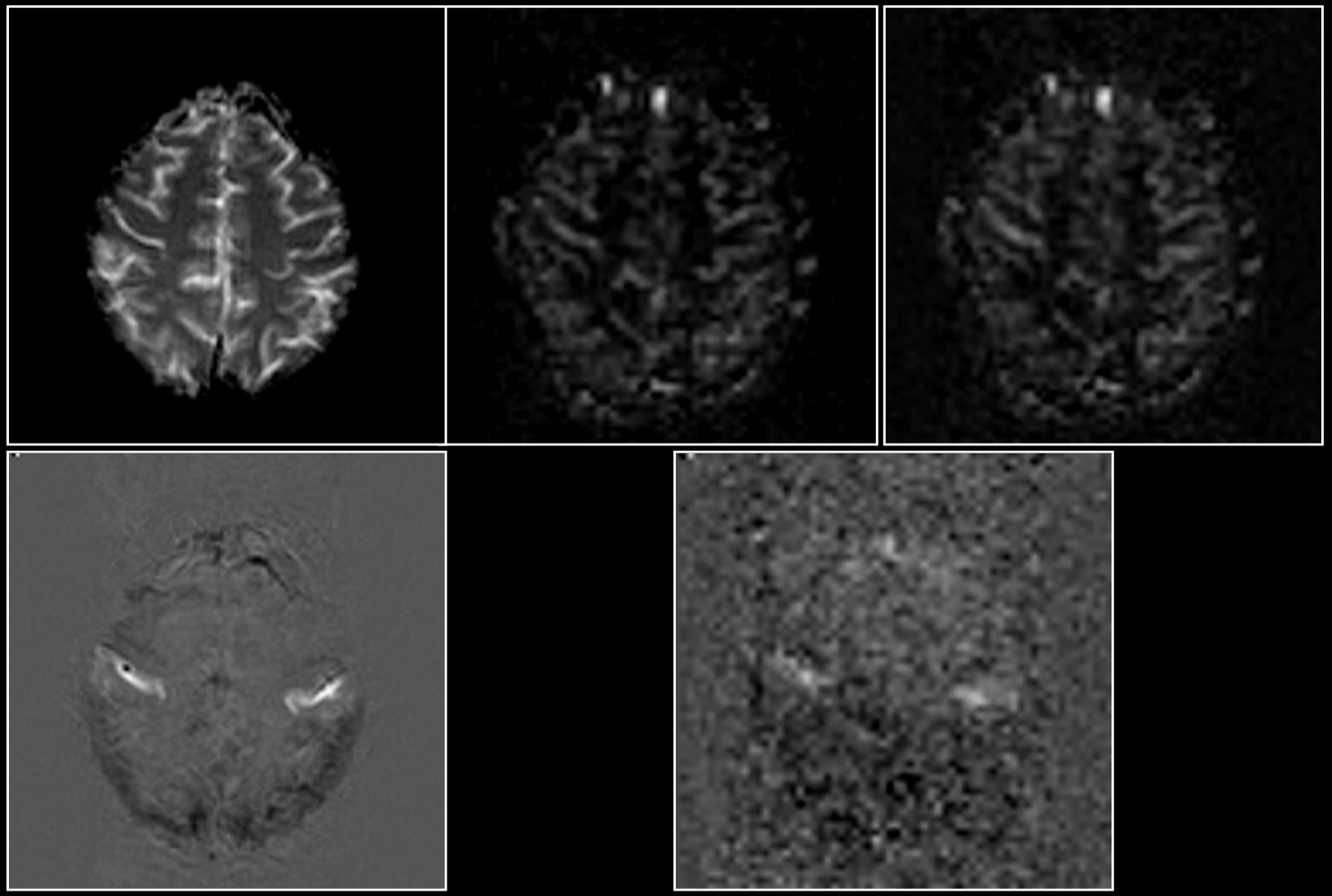
PET: $H_2{}^{15}O$



MRI: ASL

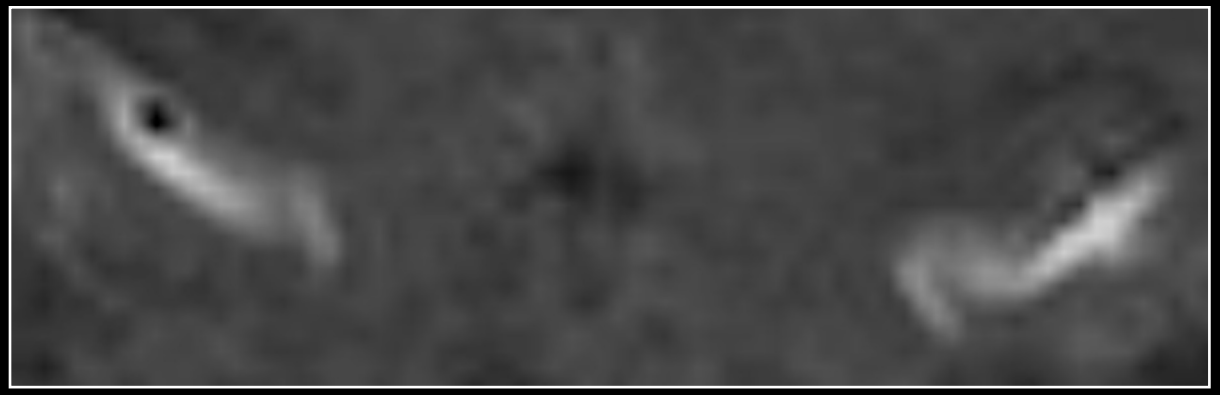
Perfusion

BOLD *Rest* *Activation*



Anatomy

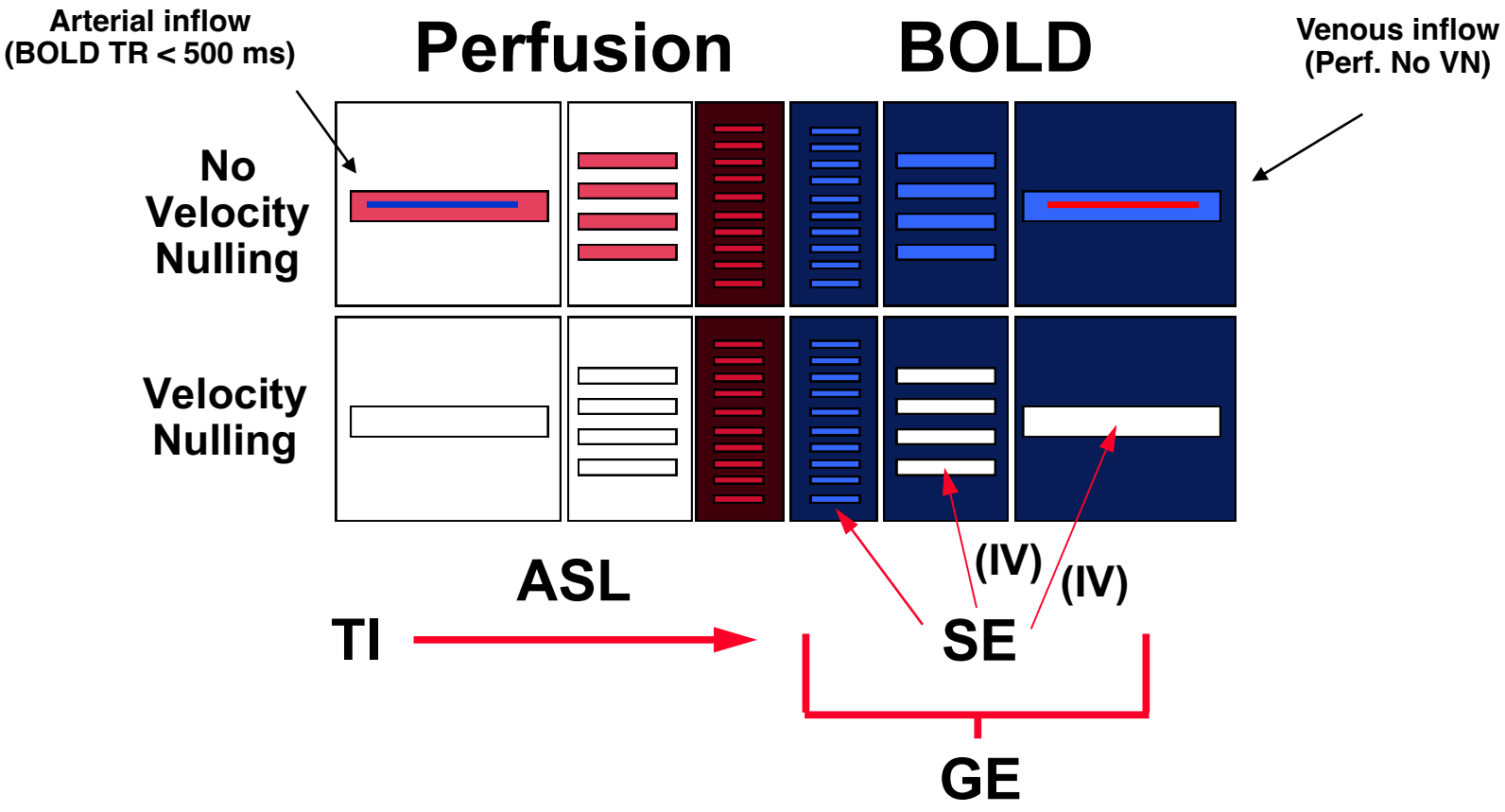
BOLD



Perfusion

	+	-
Volume	• unique information • baseline information • multislice trivial	• invasive • low C / N for func.
BOLD	• highest C / N • easy to implement • multislice trivial • non invasive • highest temp. res.	• complicated signal • no baseline info.
Perfusion	• unique information • control over ves. size • baseline information • non invasive	• multislice non trivial • lower temp. res. • low C / N

Hemodynamic Specificity

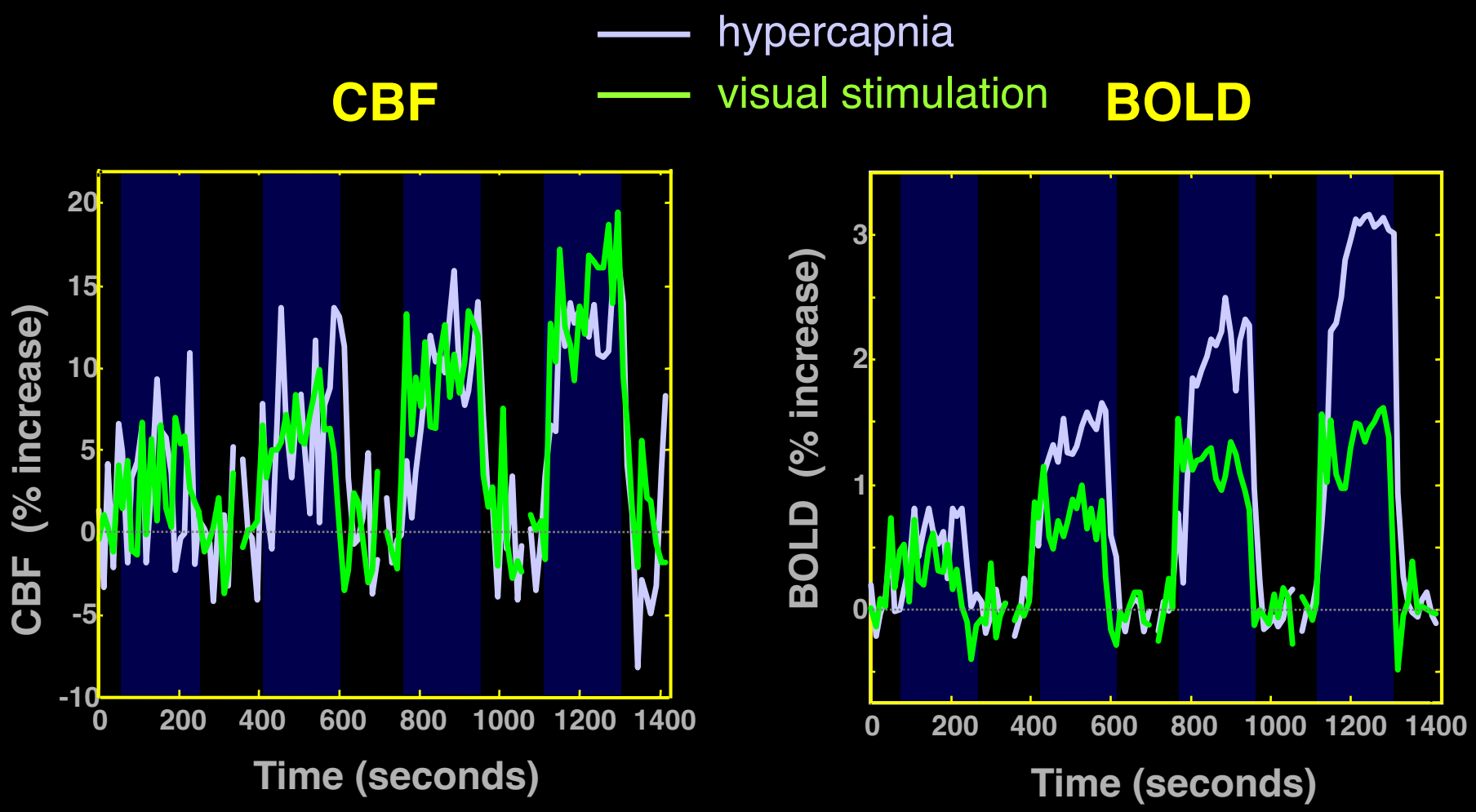


Mapping of $CMRO_2$

Activation:	Flow	⇑⇑
	$CMRO_2$	⇑
	Blood Oxygenation	⇑
CO_2 stress:	Flow	⇑⇑
	$CMRO_2$	⇒
	Blood Oxygenation	⇑⇑

$CMRO_2$-related BOLD signal deficit:

Hoge, et al.

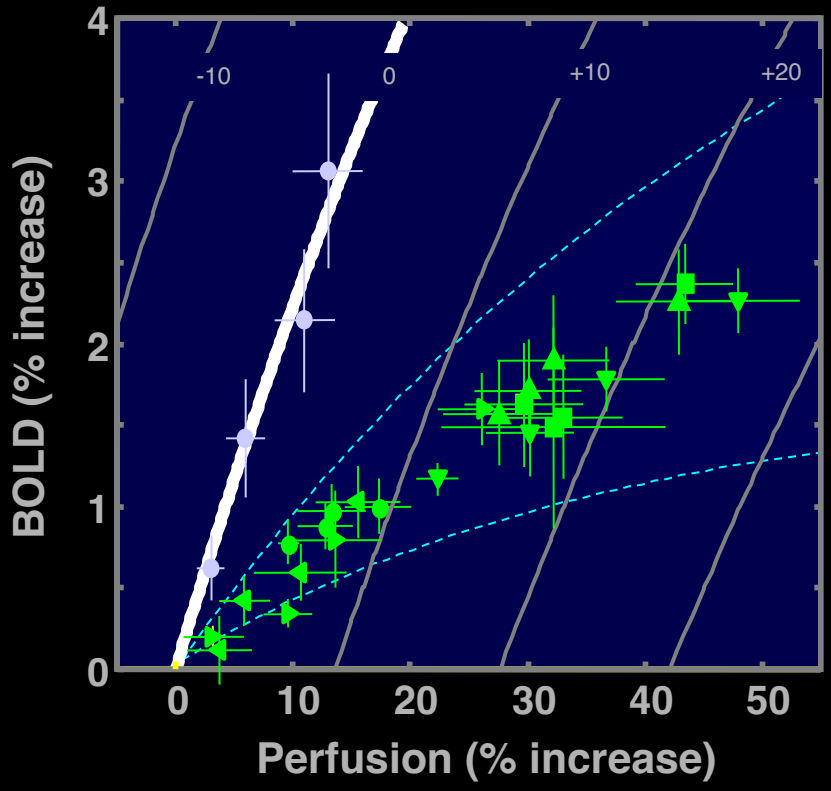


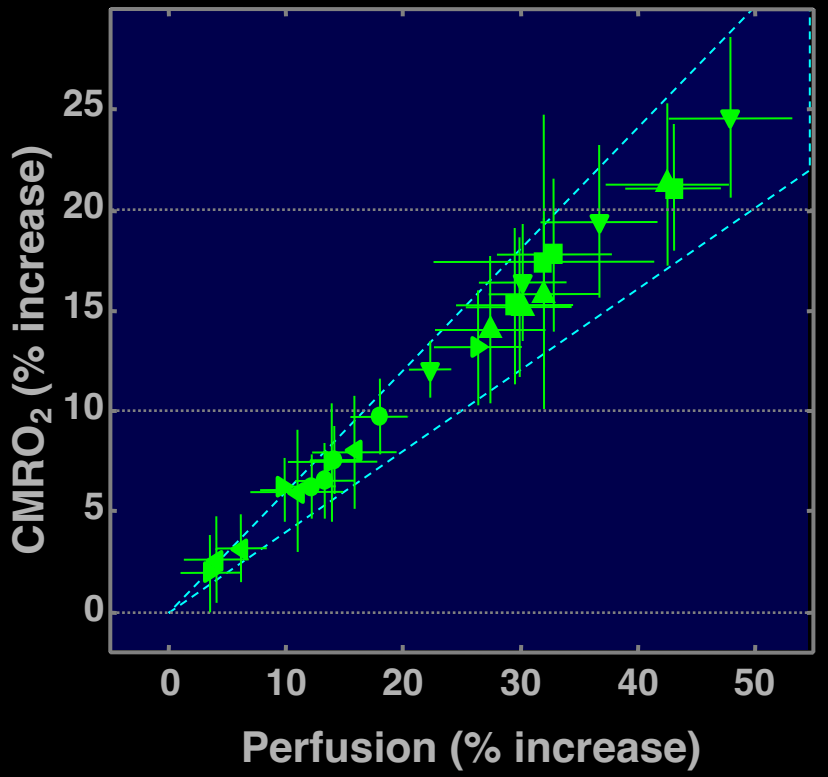
Simultaneous Perfusion and BOLD imaging during graded visual activation and hypercapnia

N=12

CBF-$CMRO_2$ coupling

Hoge, et al.

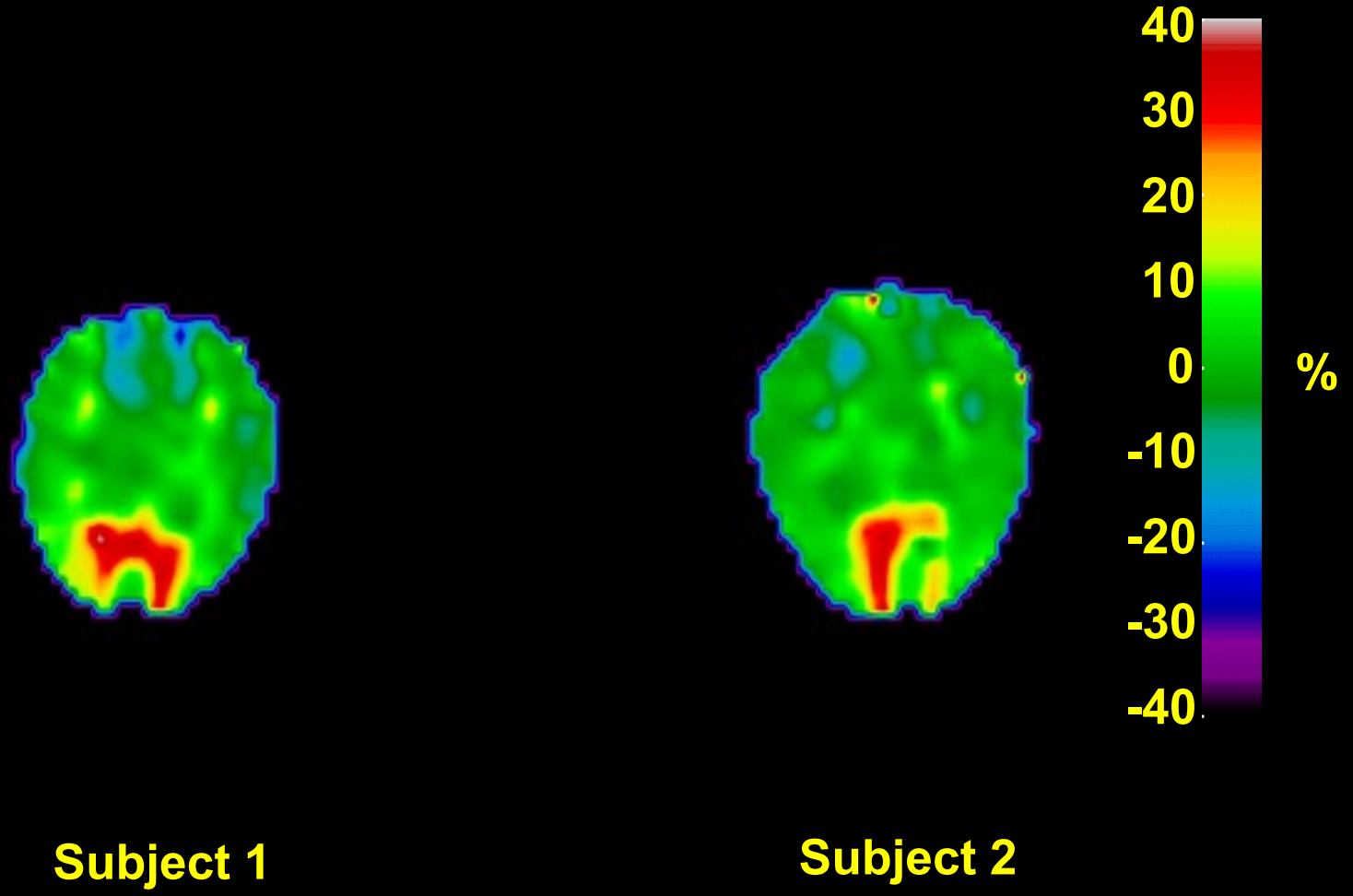




Characterizing Activation-induced $CMRO_2$ changes using calibration with hypercapnia

Hoge, et al.

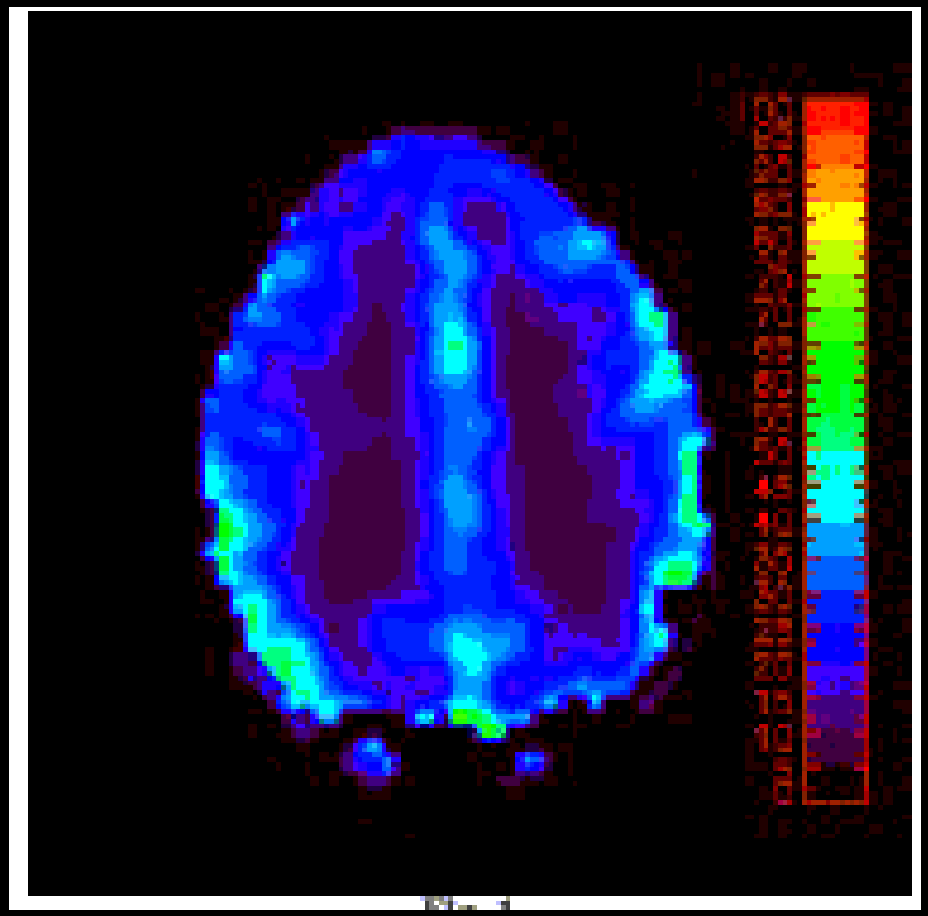
Computed $CMRO_2$ Changes



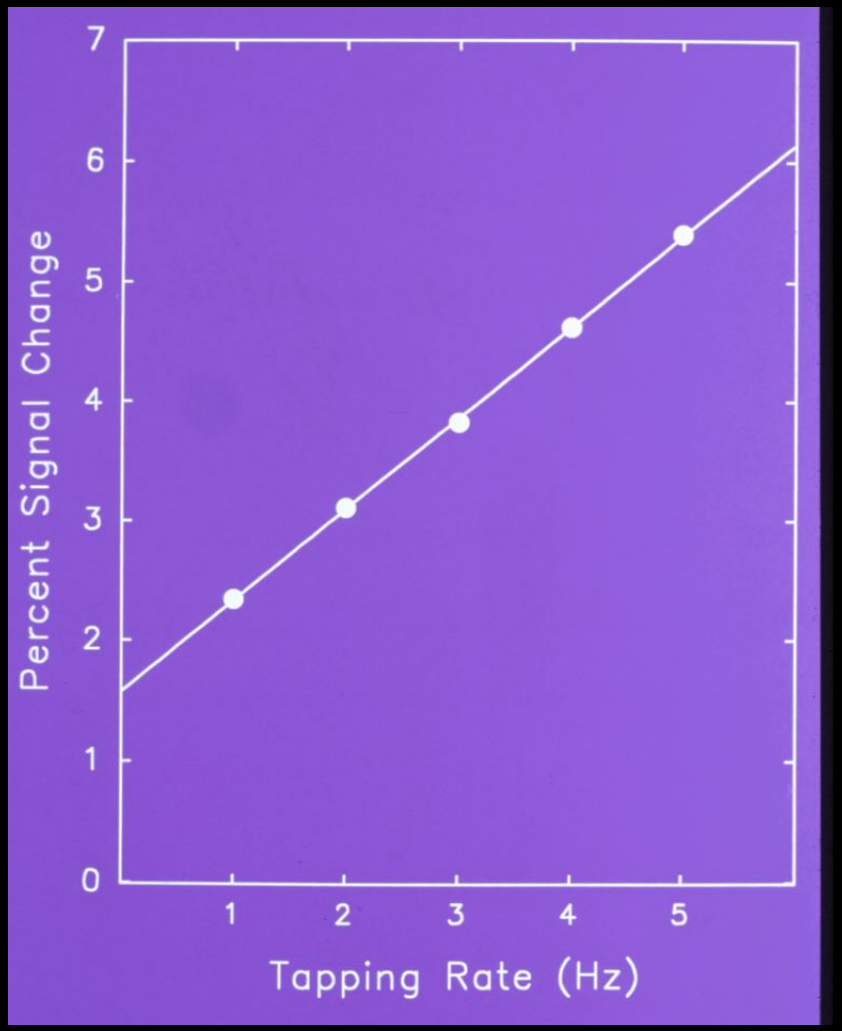
Quantitative Measurements of Cerebral Metabolic Rate of Oxygen (CMRO2) Using MRI: A Volunteer Study

Hongyu AN[1], Weili LIN[2], Azim CELIK[3], Yueh Z. LEE[4]

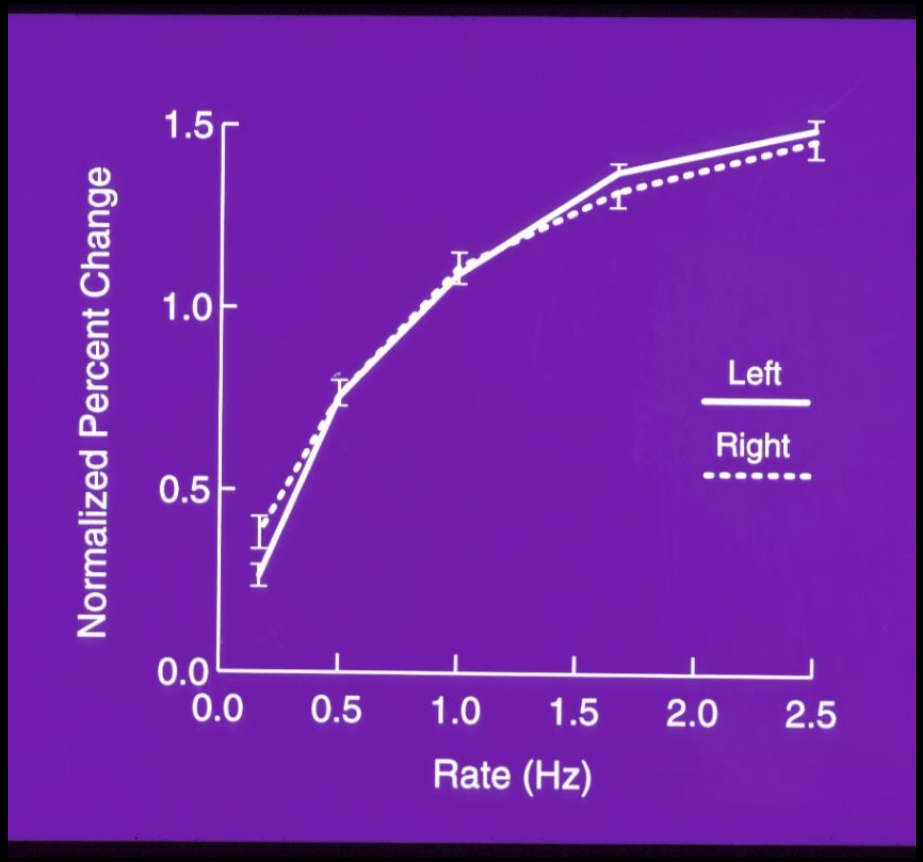
[1]Washington University, 600 Airport Road, Chapel Hill, NC USA; [2]UNC-Chapel Hill, Department of Radiology, CB#7515, Chapel Hill, NC USA; [3]GE Medical Systems, ; [4]UNC-Chapel Hill, ;

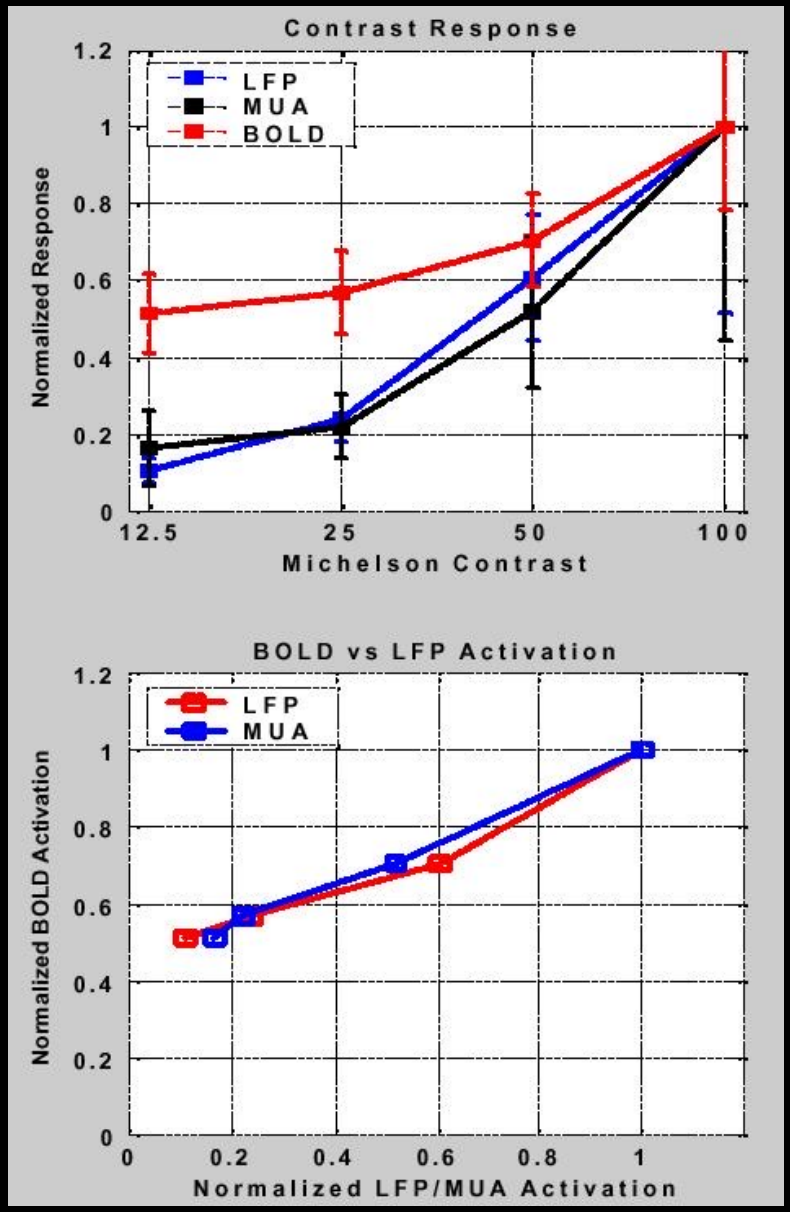


Motor Cortex



Auditory Cortex





Logothetis et al. Nature, 412, 150-157

Variables to Optimize

- Information Content
- Sensitivity
- Speed
- Resolution
- Image quality

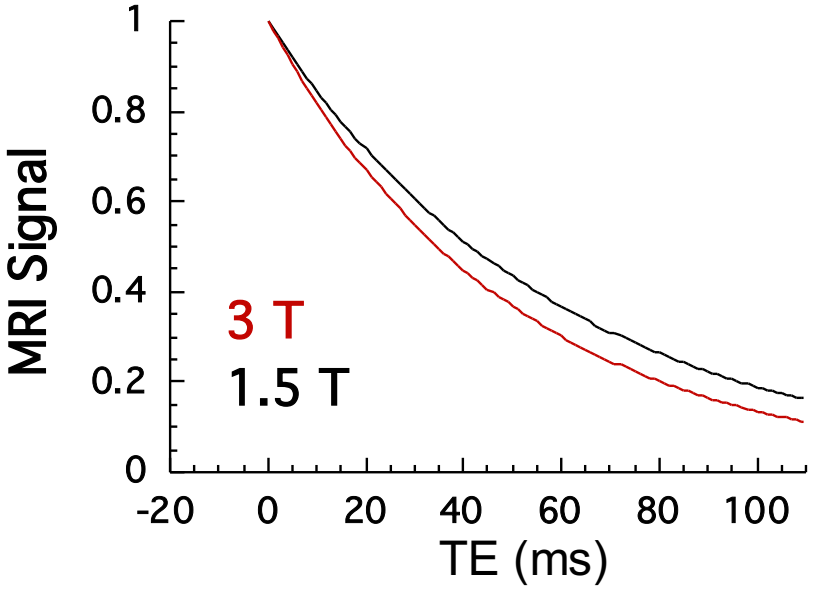
Sensitivity

- Optimizing fMRI Contrast
- Maximizing Signal
- Reducing Physiologic Fluctuations
- Minimizing Temporal Artifacts

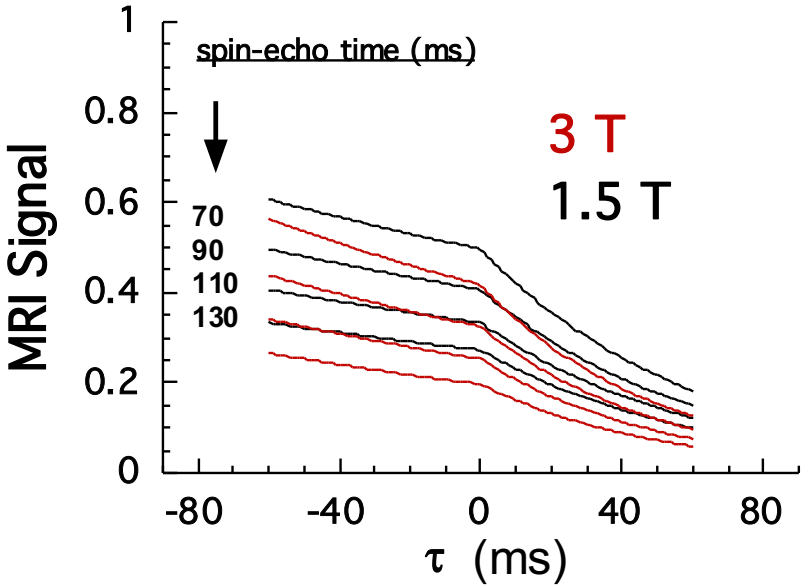
Optimizing fMRI Contrast

- Increase field strength
- Choose the right pulse sequence
- Adjust pulse sequence timing (TE ≈ T2*)
- Adjust voxel volume (≈ activation volume)

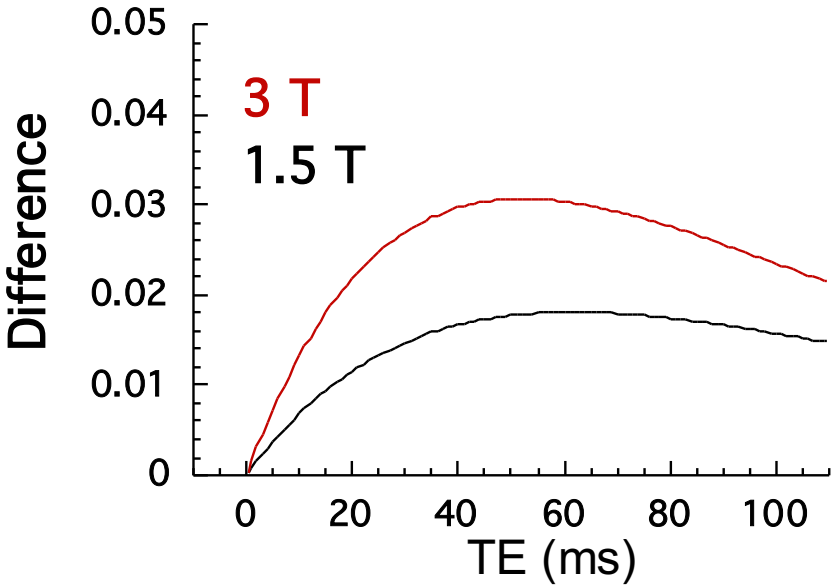
Gradient - Echo



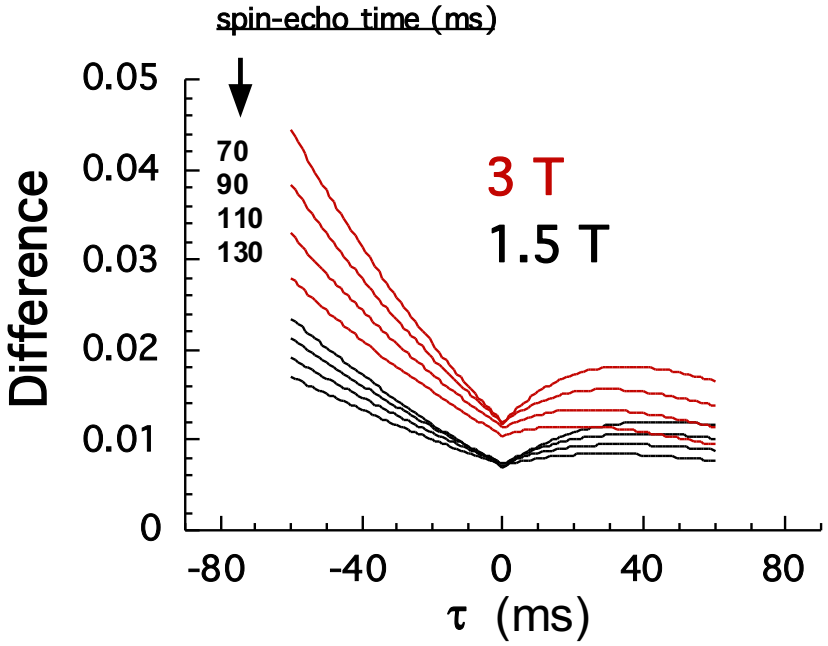
Asymmetric Spin - Echo



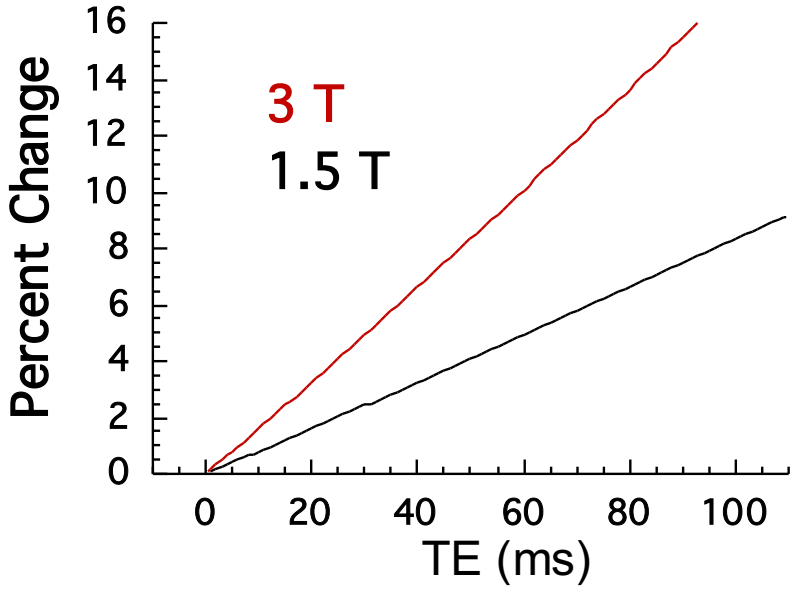
Gradient - Echo



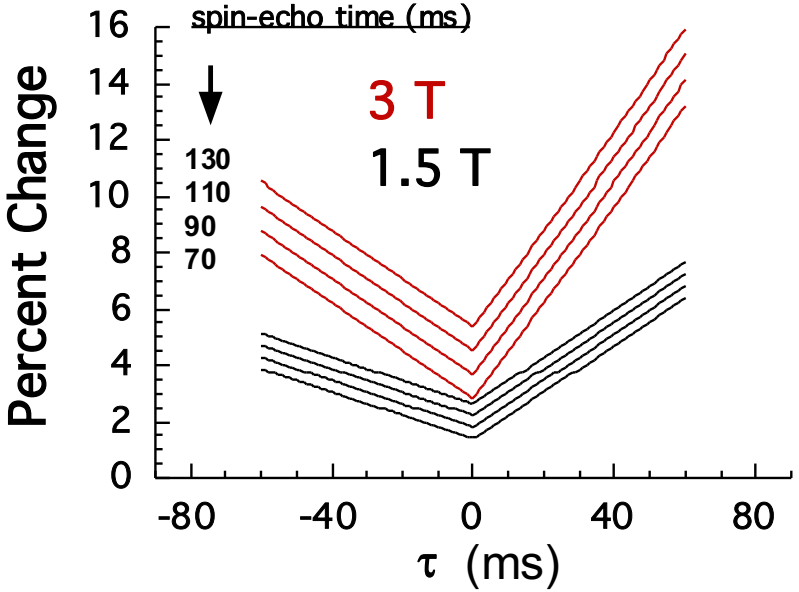
Asymmetric Spin - Echo



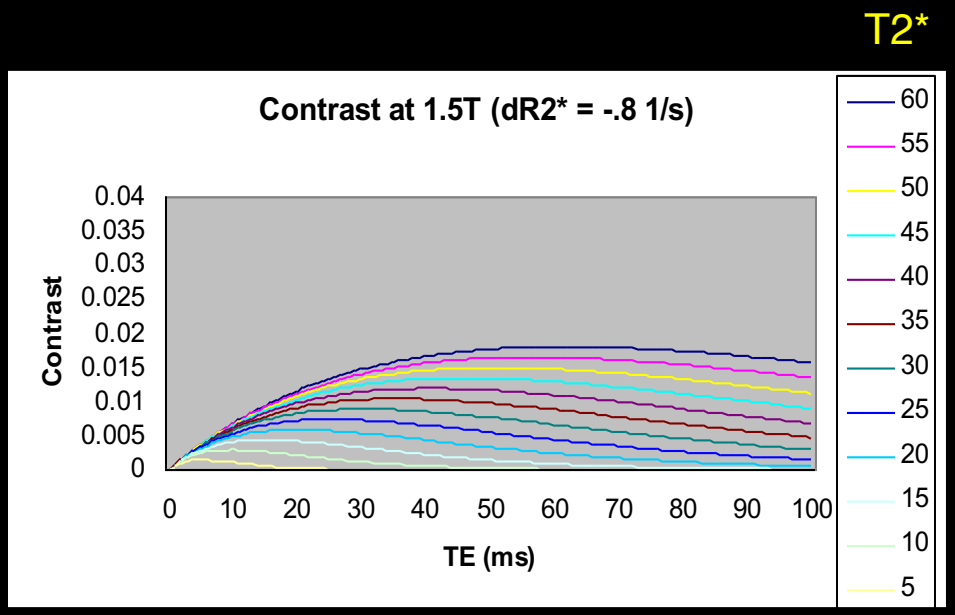
Gradient - Echo

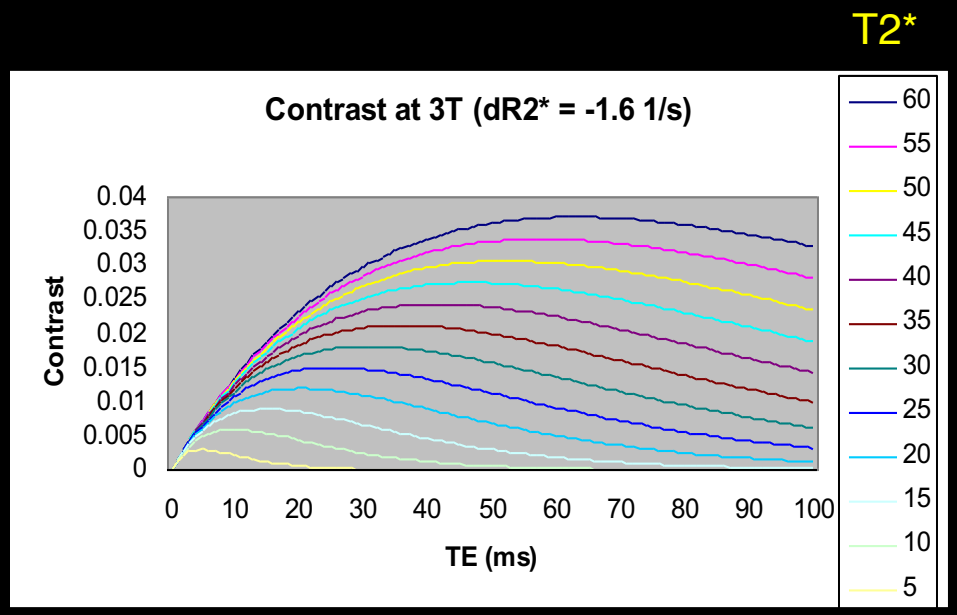


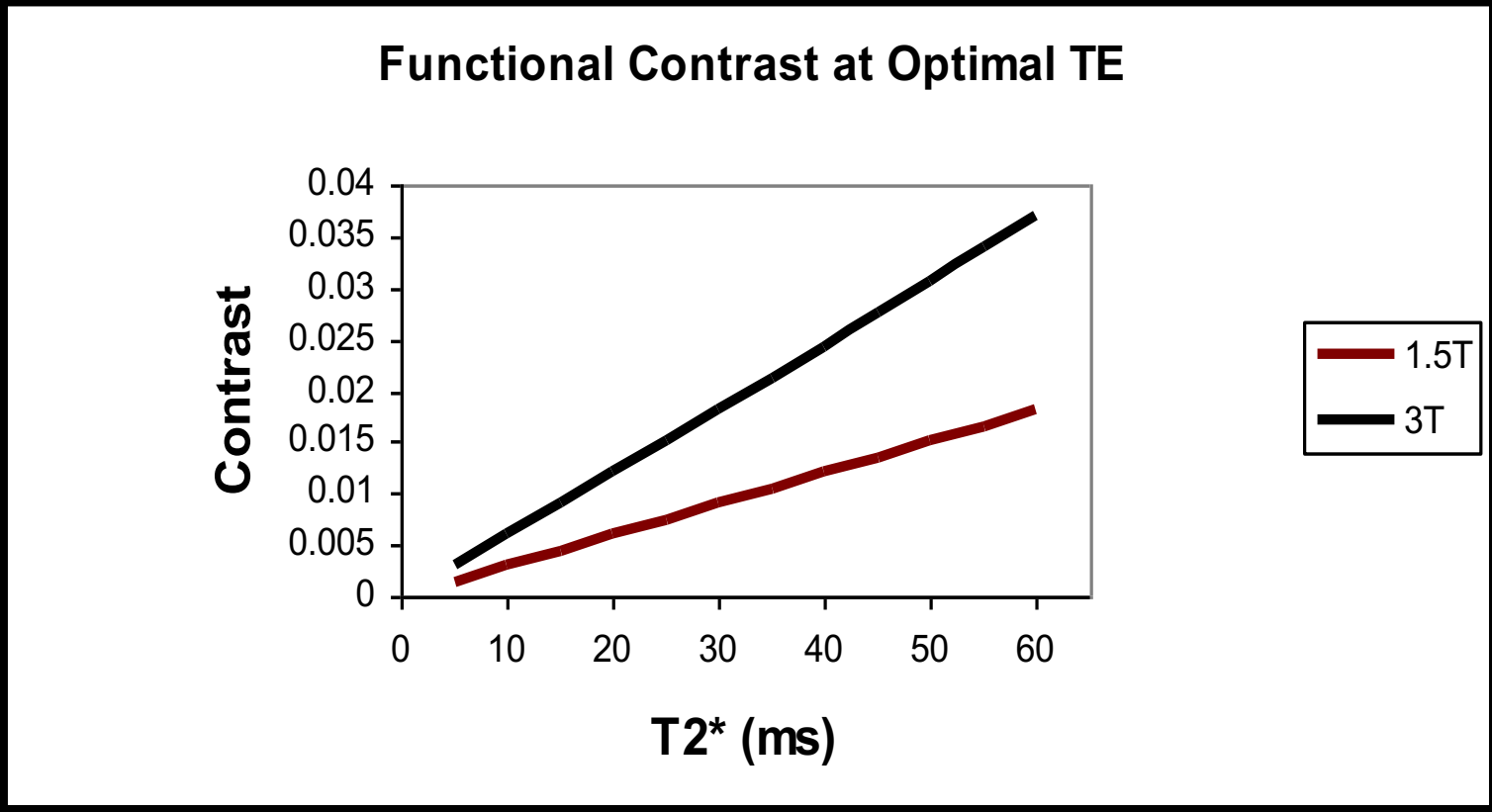
Asymmetric Spin - Echo

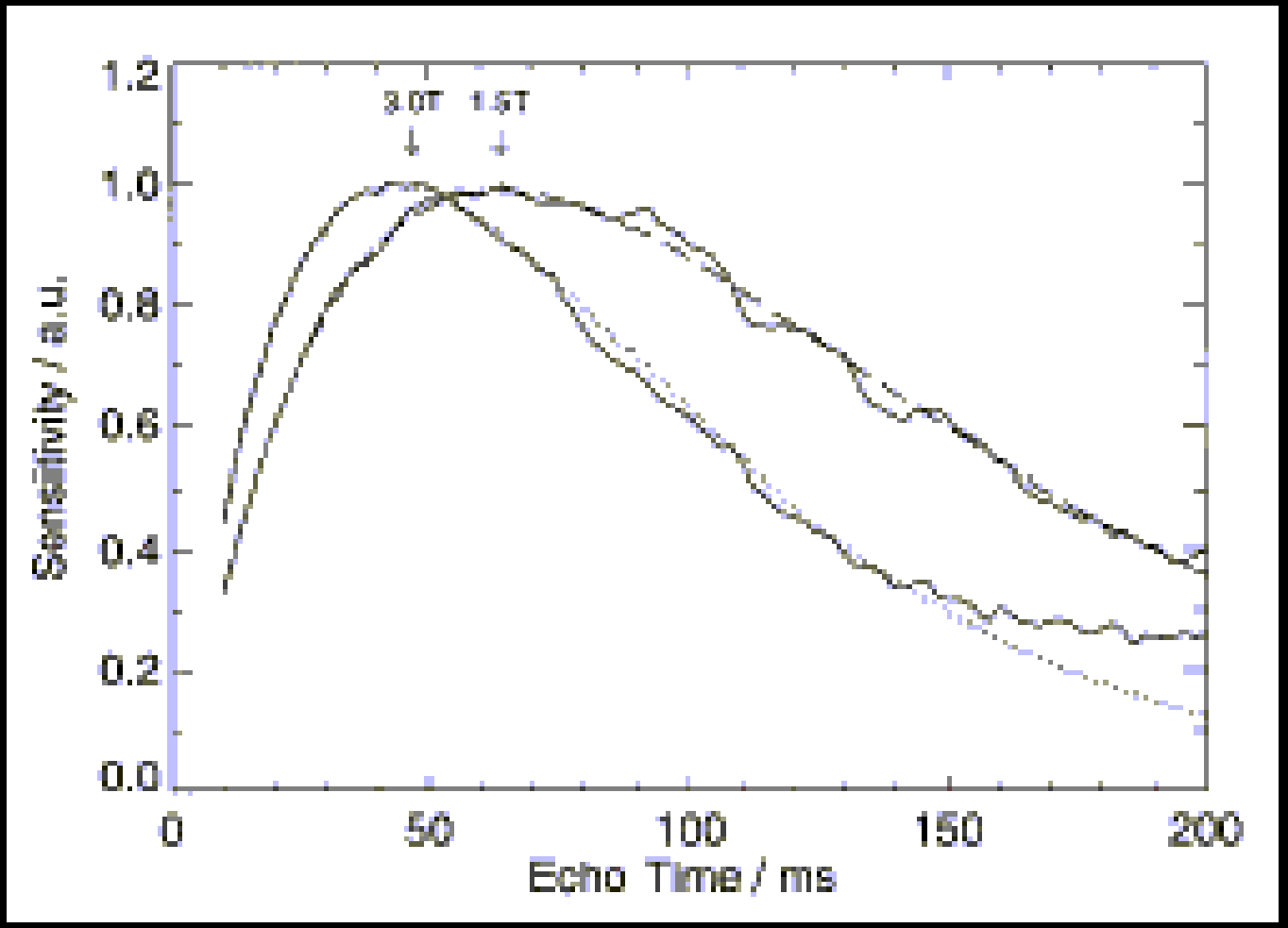


Contrast depends on:
activation-induced changes in T2* *and* resting T2*

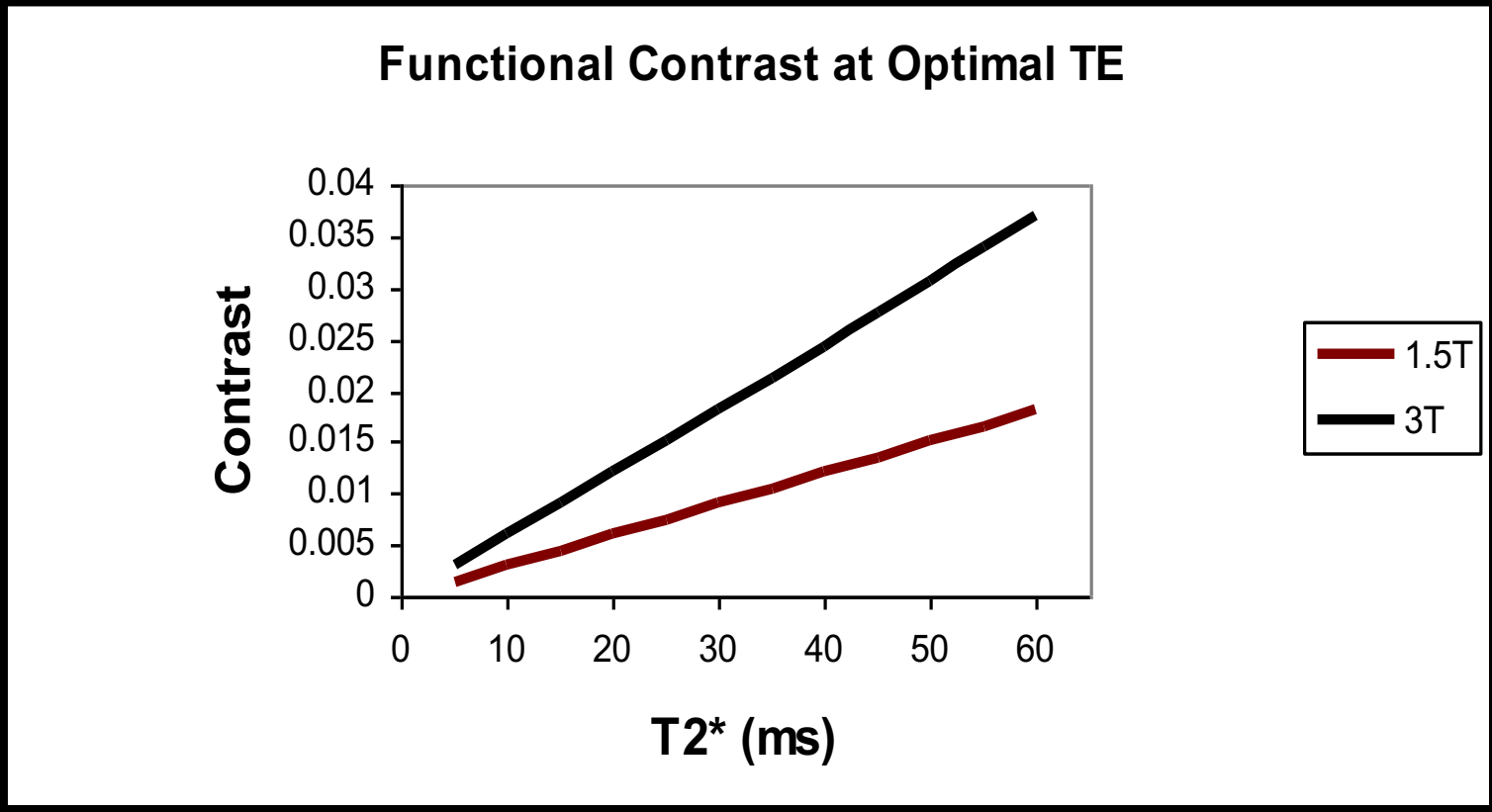


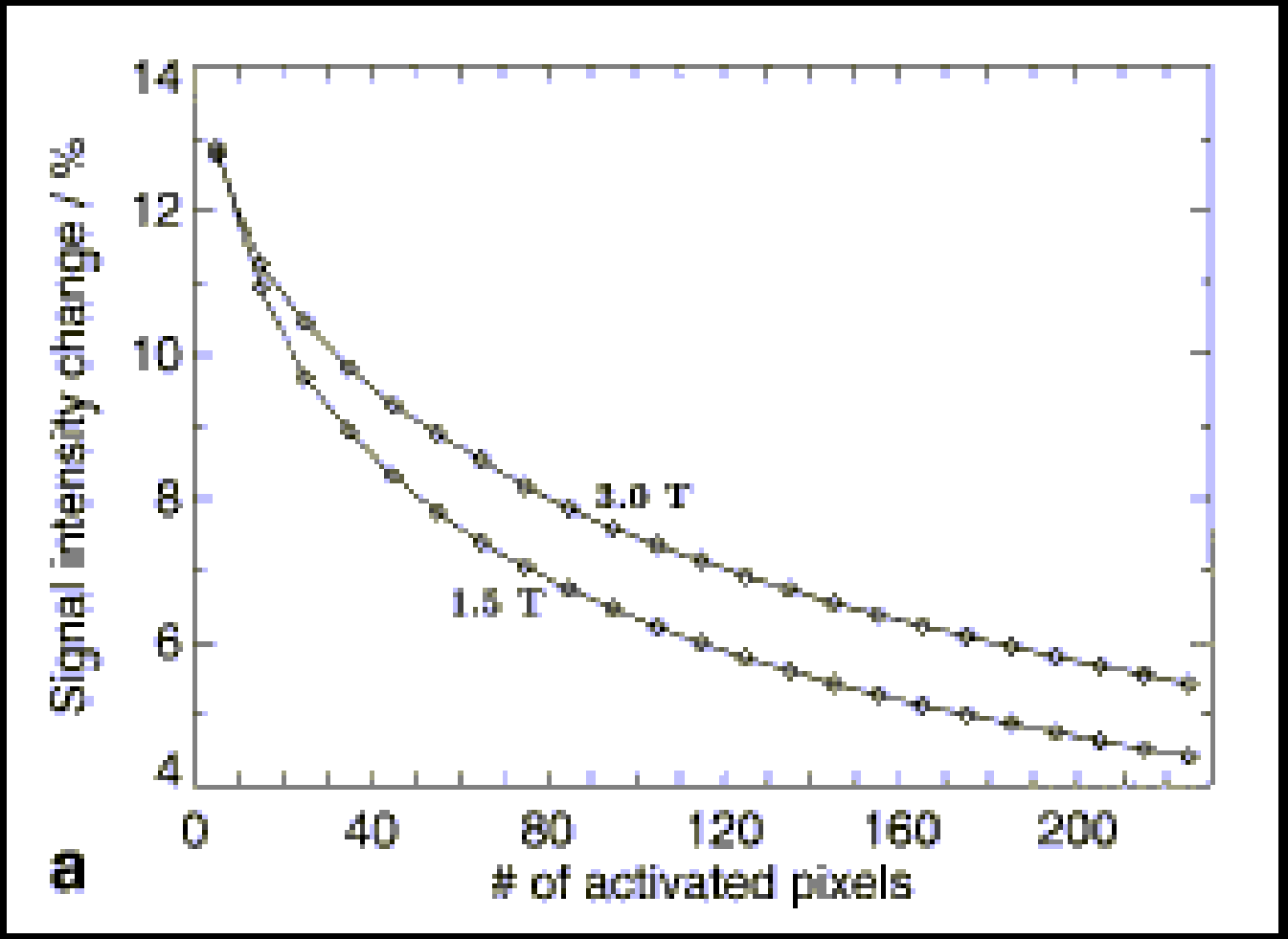



Functional Contrast at Optimal TE
Contrast
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
10
20
30
40
50
60
T2* (ms)
1.5T
3T

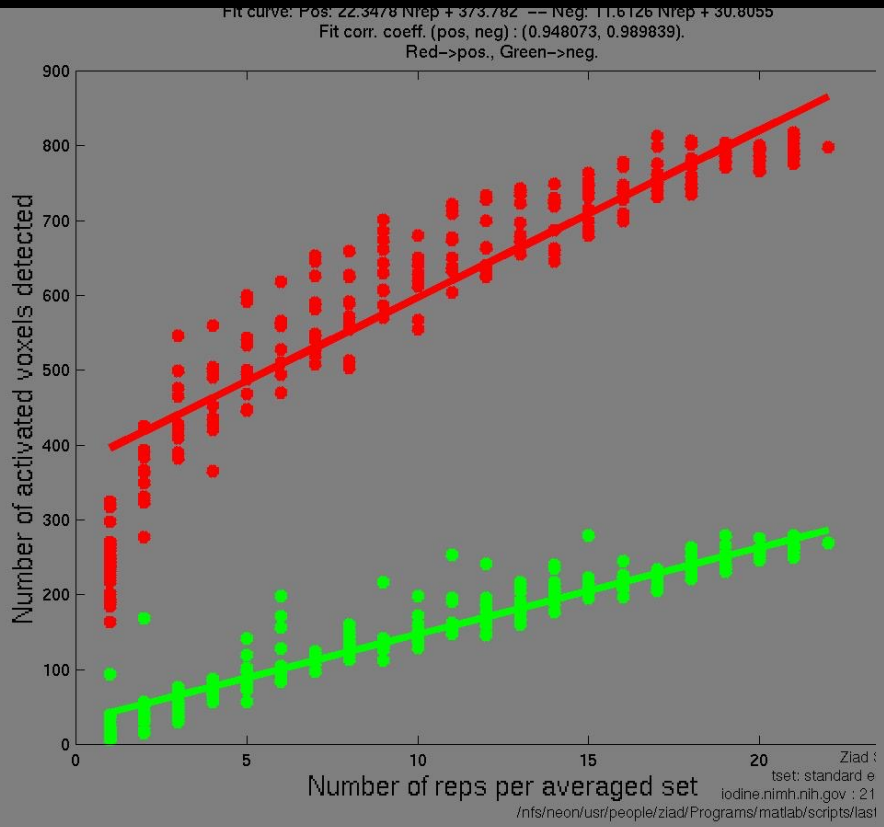

3.0T
1.5T
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Sensitivity / a.u.
0
50
100
150
200
Echo Time / ms

Kruger et al.


Functional Contrast at Optimal TE
Contrast
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
10
20
30
40
50
60
T2* (ms)
1.5T
3T

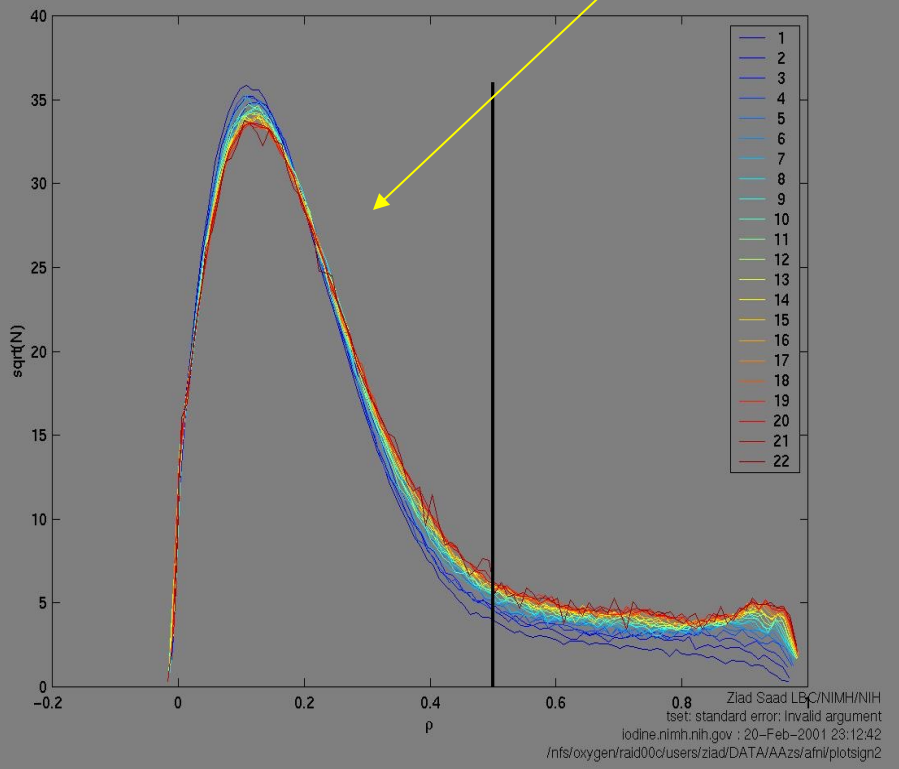

14
12
10
8
6
4
Signal intensity change / %
3.0 T
1.5 T
0
40
80
120
160
200
# of activated pixels
a

Continuously Growing Activation Area

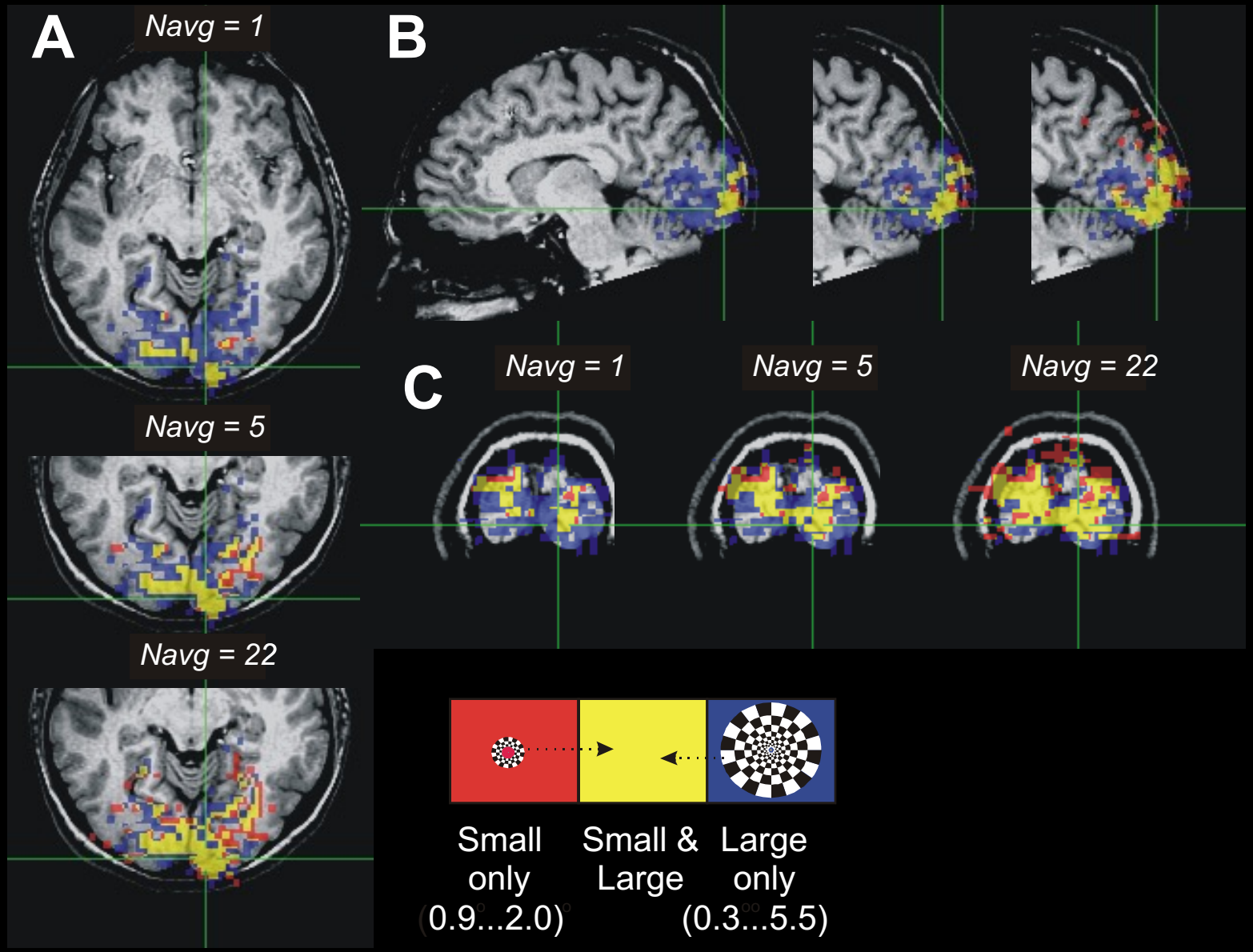


CC Histogram

Inflection Point



Ziad Saad, et al


A
Navg = 1
Navg = 5
Navg = 22
B
C
Navg = 1
Navg = 5
Navg = 22
Small only (0.9...2.0)
Small & Large
Large only (0.3...5.5)

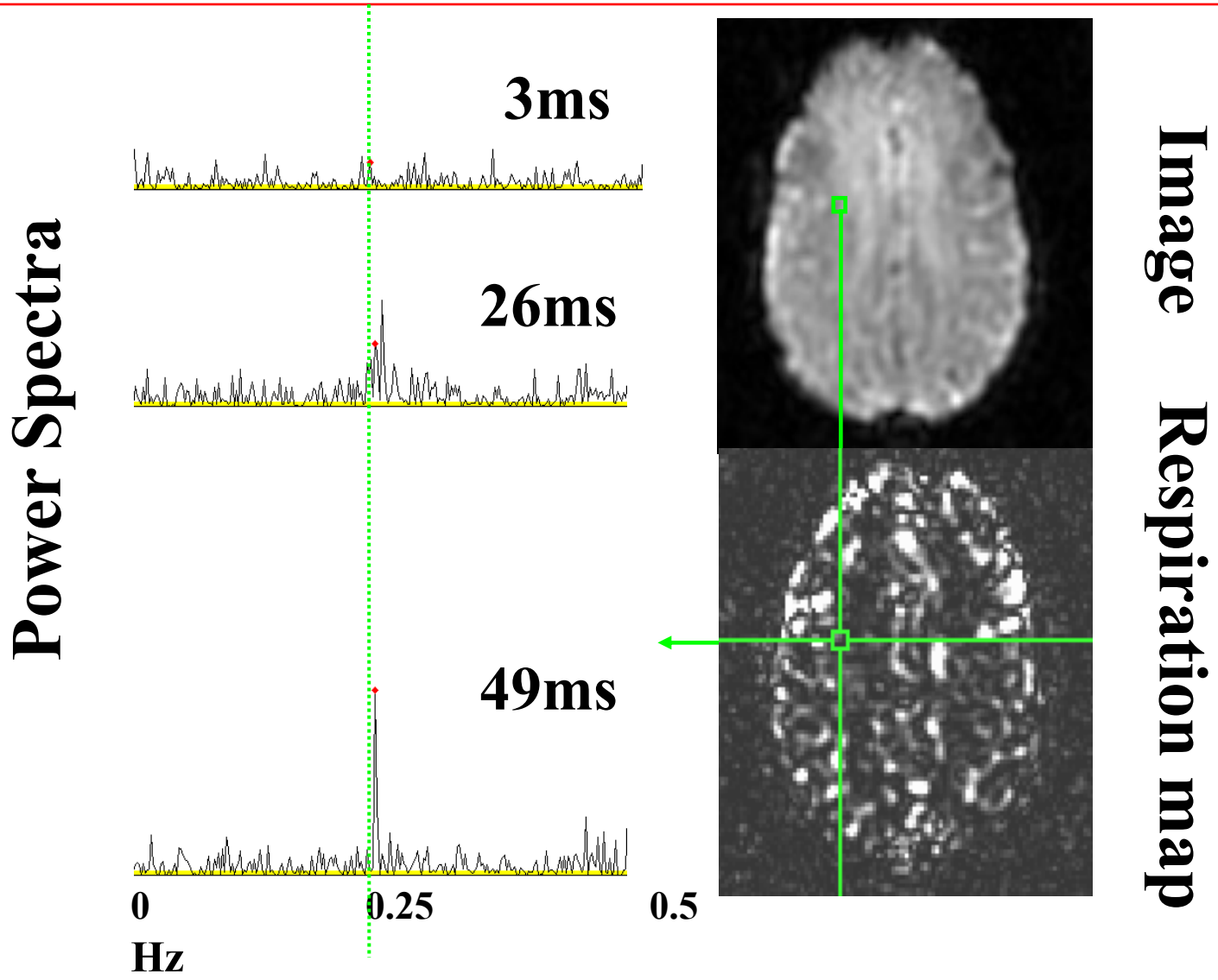
Maximizing Signal

- Higher Bo Field
  - Linear or greater increase in S/N
  - Tradeoff in susceptibility artifacts
- Radio frequency Coils
  - Smaller the coil the higher the S/N
  - Tradeoff in coverage
- Choice of repetition time (TR)
  - Faster is better (more data points to average)
  - Tradeoff in coverage (10 slices/sec)
    - *min TR = (time/slice) x number of slices in volume*
  - Diminishing returns because of noise correlation
- Voxel volume
  - Linear relationship between S/N and voxel volume
  - Larger voxels increase partial volume averaging -> reduction of functional signal
- Averaging
  - Increase in sensitivity by sqrt(N)
  - System and subject instabilities increase with longer

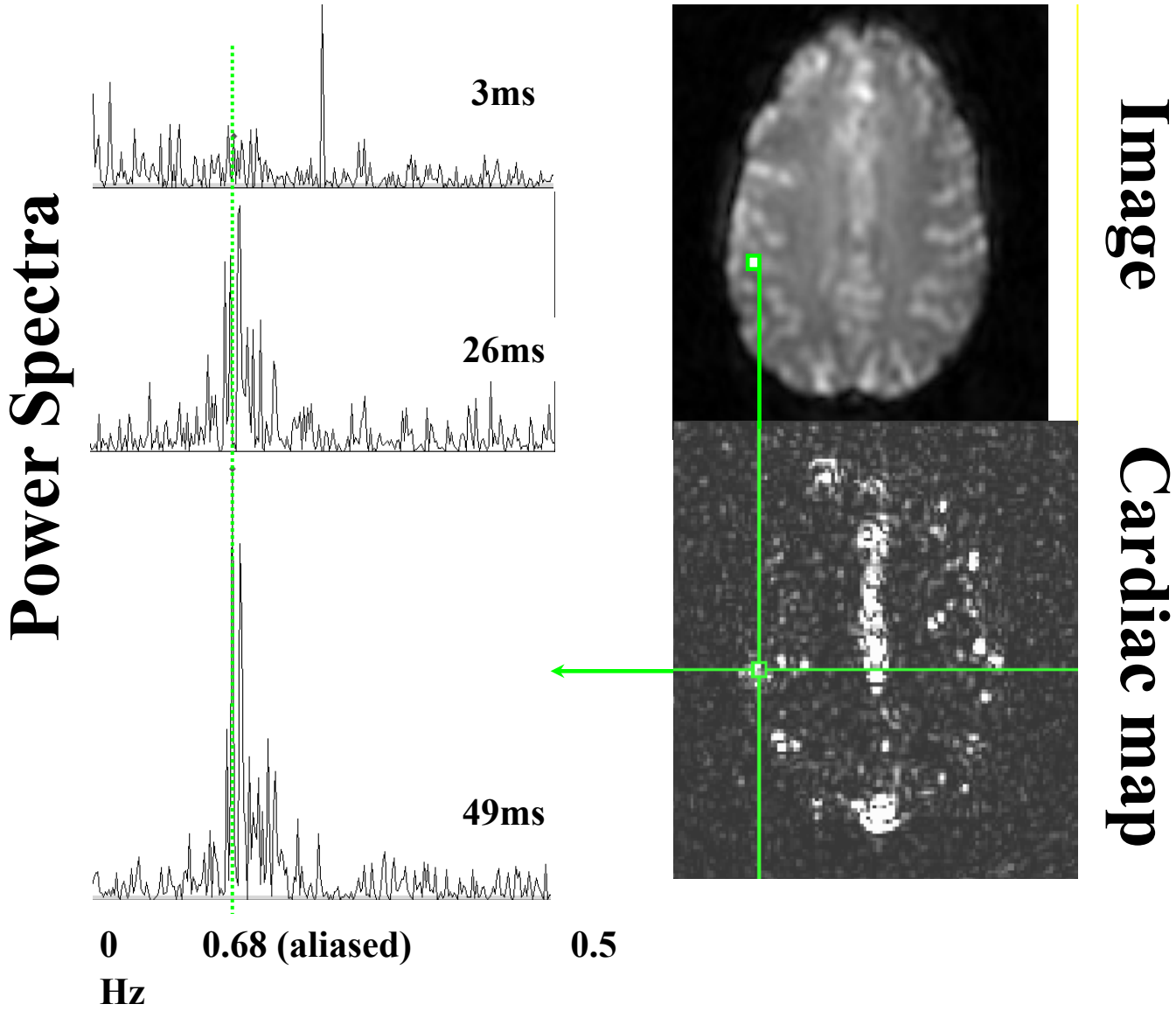
Physiologic Fluctuations

Cardiac	0.6 to 1.2 Hz
Respiratory	0.1 to 0.2 Hz
Low Frequency	0.0 to 0.1 Hz

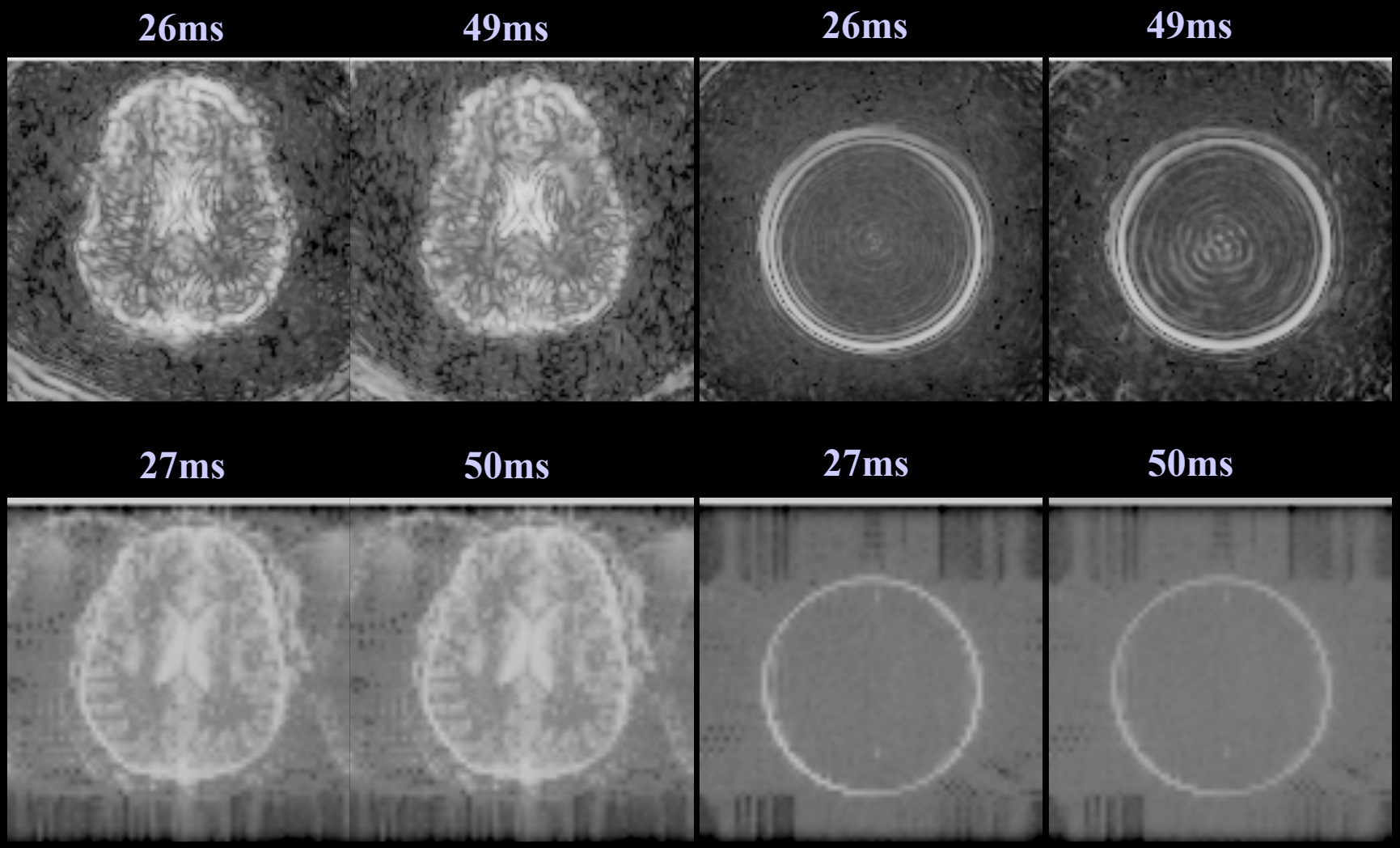
0.25 Hz Breathing at 1.5T



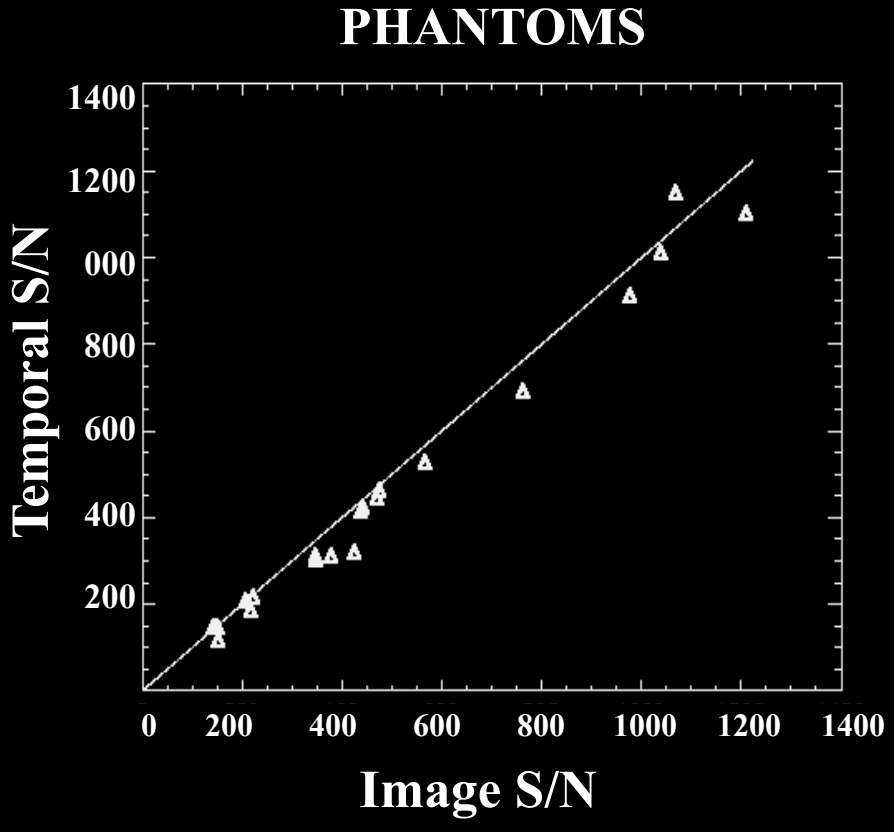
0.68 Hz Cardiac rate at 3T

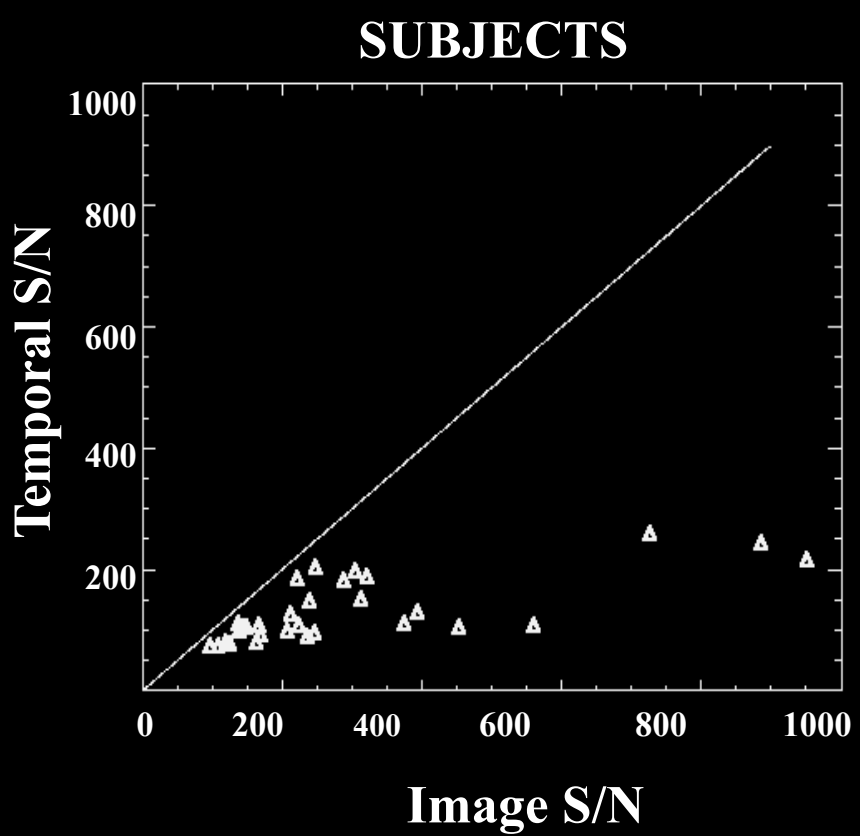


Temporal vs. Spatial SNR- 3T



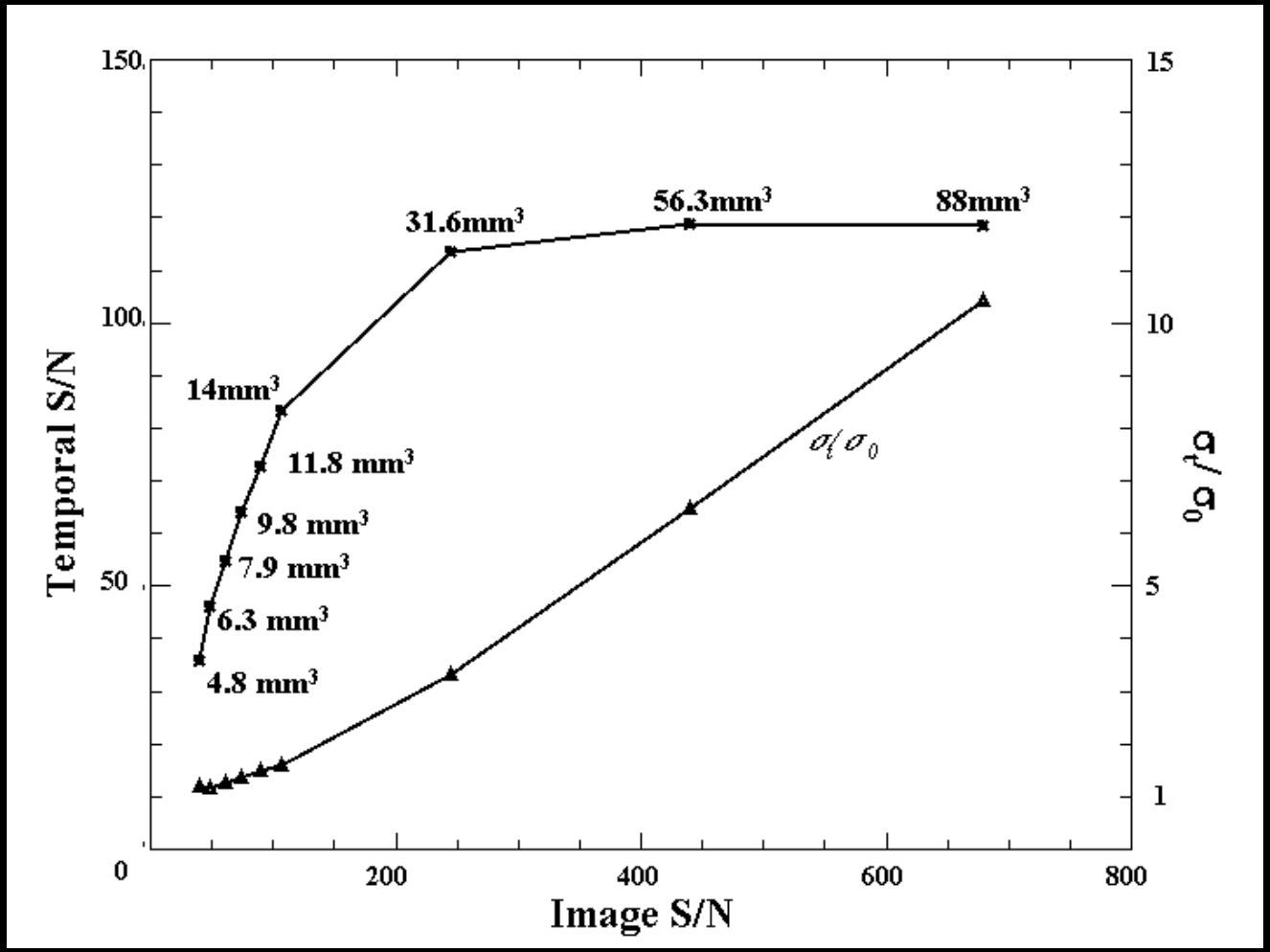
Temporal S/N vs. Image S/N





N. Petridou

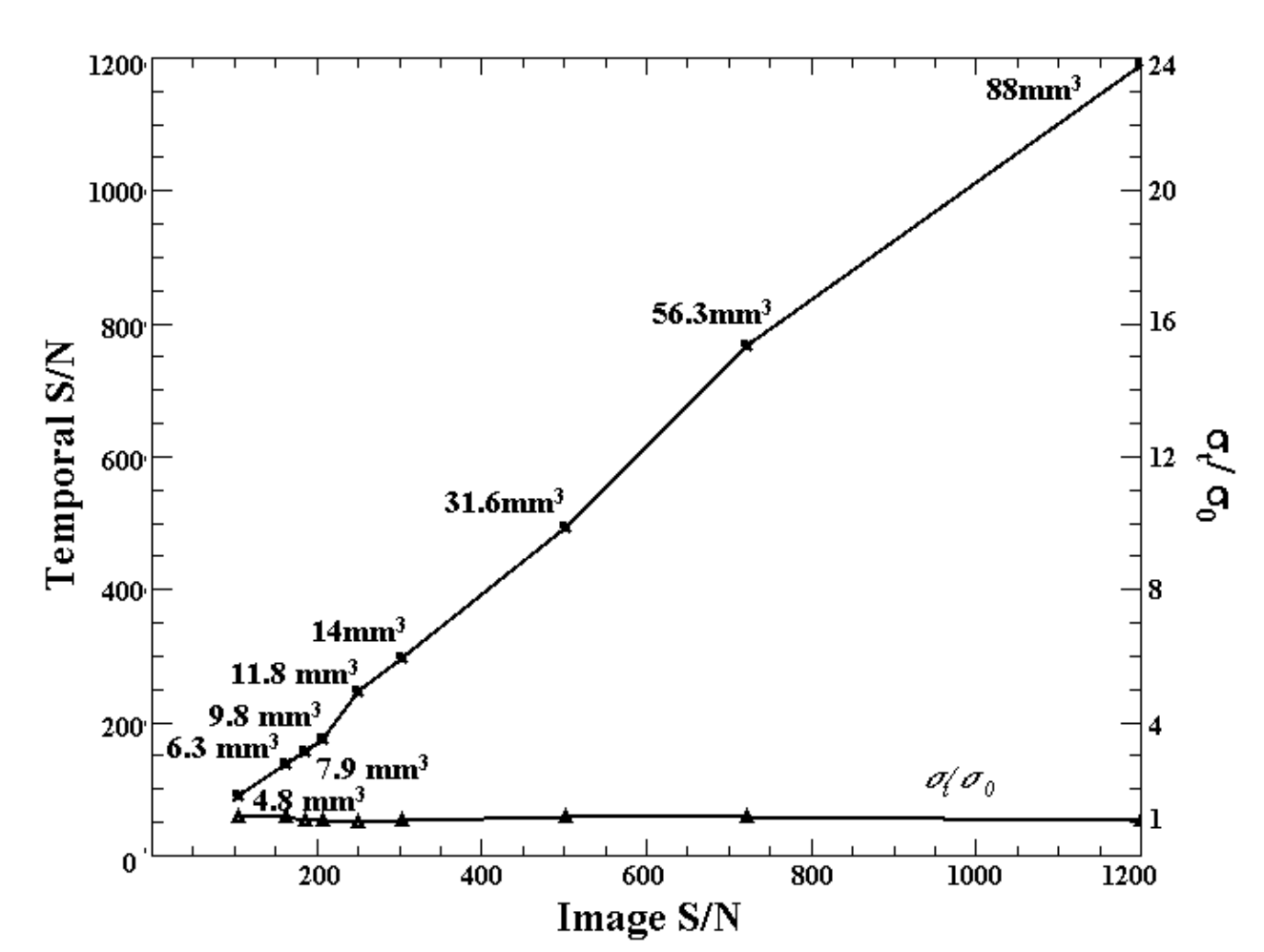
Temporal vs. Image S/N
Optimal Resolution Study



Human data

Petridou et al

Temporal vs. Image S/N
Optimal Resolution Study



Phantom data

Petridou et al

Reducing Physiologic Fluctuations

- Filtering
- Pulse sequence
  - single vs. multishot
  - strategies for multishot
- Gating with correction for variable TR

Temporal Artifacts

- System instabilities
- Motion
  - Drift
  - Stimulus correlated
  - Stimulus uncorrelated

Minimizing Temporal Artifacts

Recognize?
- Edge effects
- Shorter signal change latencies
- Unusually high signal changes
- External measuring devices

Correct?
- Image registration algorithms
- Orthogonalize to motion-related function *(cardiac, respiration, movement)*
- Navigator echo for k-space alignment *(for multishot techniques)*
- Re-do scan

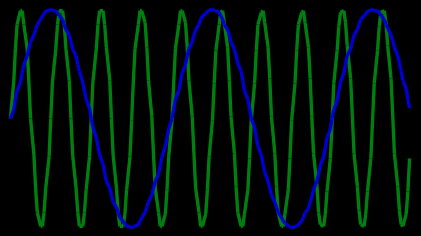
Bypass?
- Paradigm timing strategies..
- Gating (with T1-correction)

Suppress?
- Flatten image contrast
- Physical restraint
- Averaging, smoothing

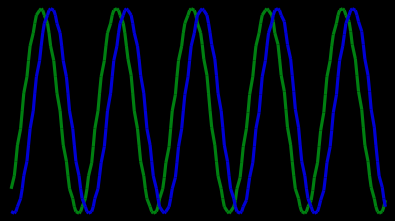
Neuronal Activation Input Strategies

1. Block Design

2. Frequency Encoding

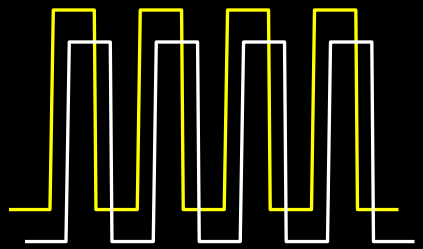


3. Phase Encoding



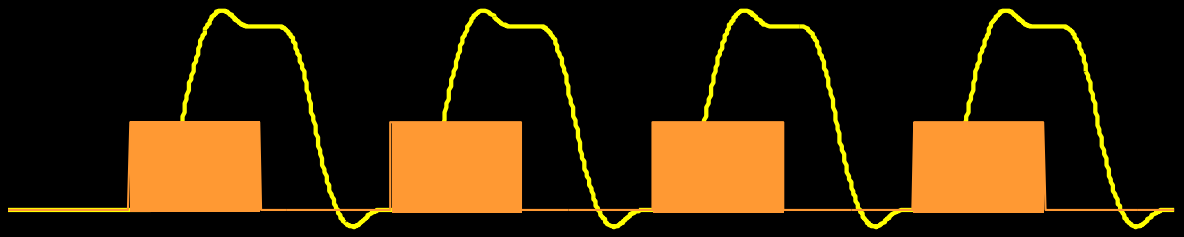
4. Event Related

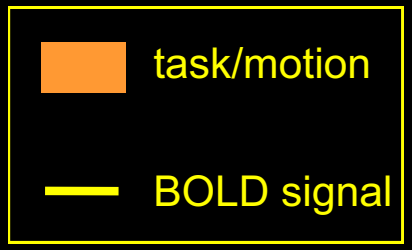
5. Orthogonal Block Design



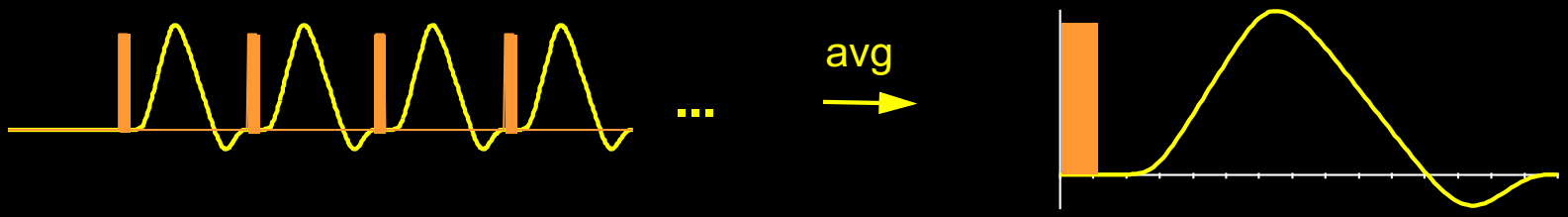
6. Free behavior Design.

Block-trial

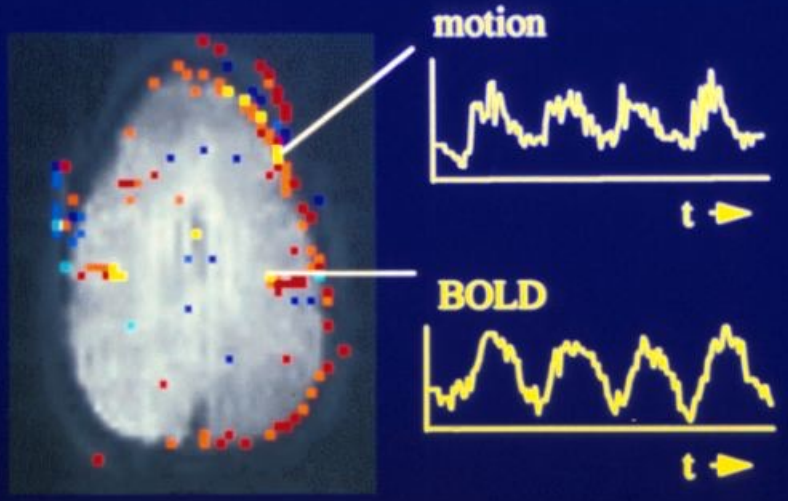


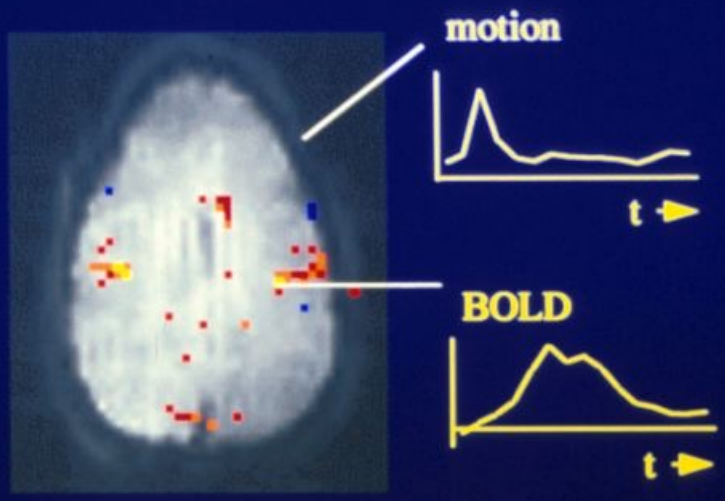


Single-trial (brief stimulus)



Motion-Decoupled fMRI:
Functional MRI during of overt word production





"block-trial" paradigm

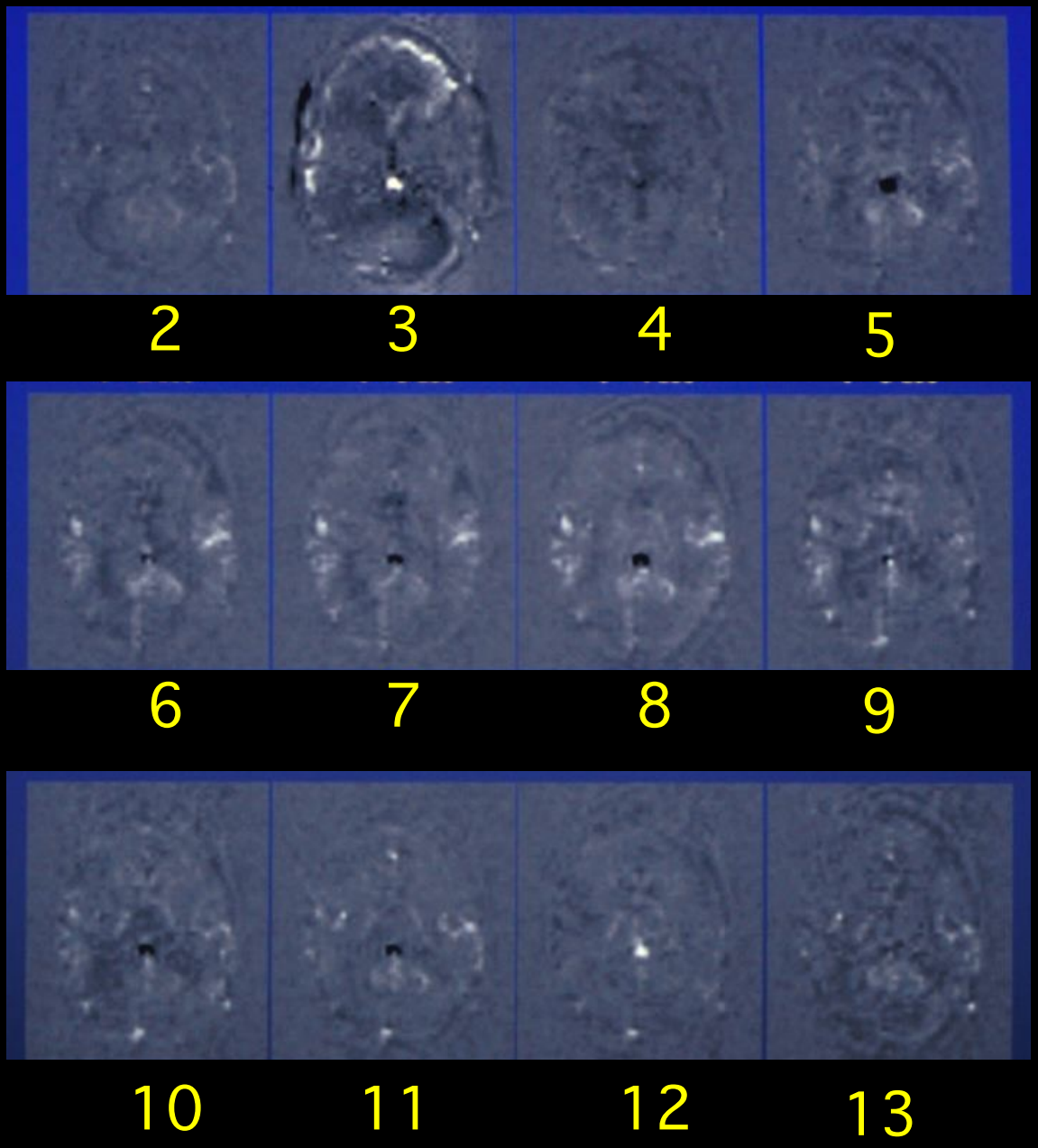
Motion induced signal changes resemble functional (BOLD) signal changes

"single-trial" paradigm

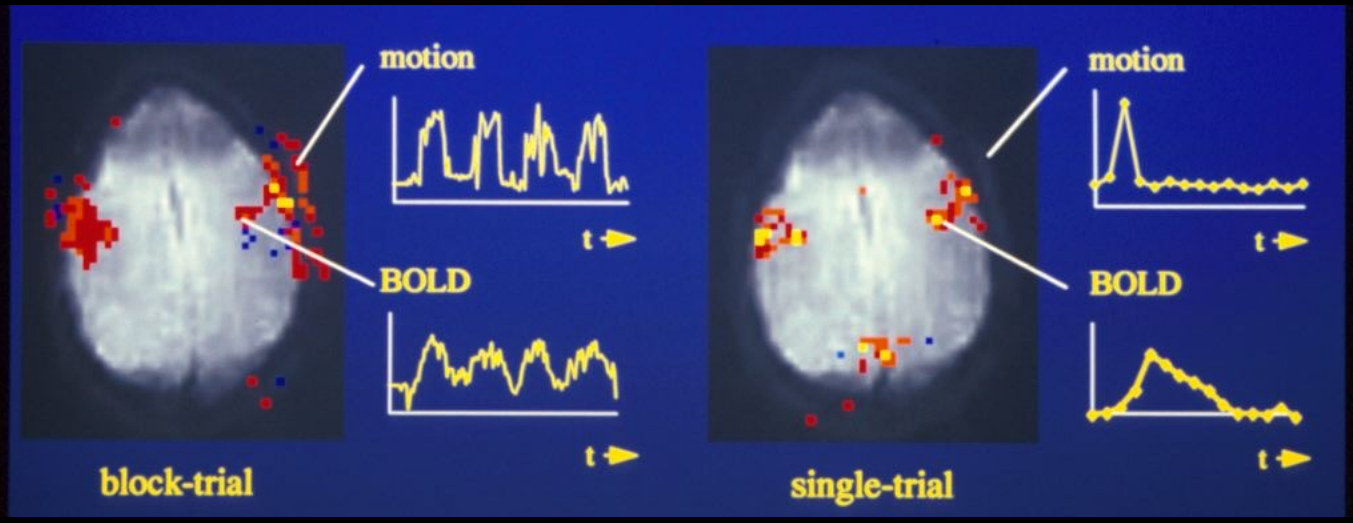
Motion induced and BOLD signal changes are separated in time

R.M. Birn, et al.

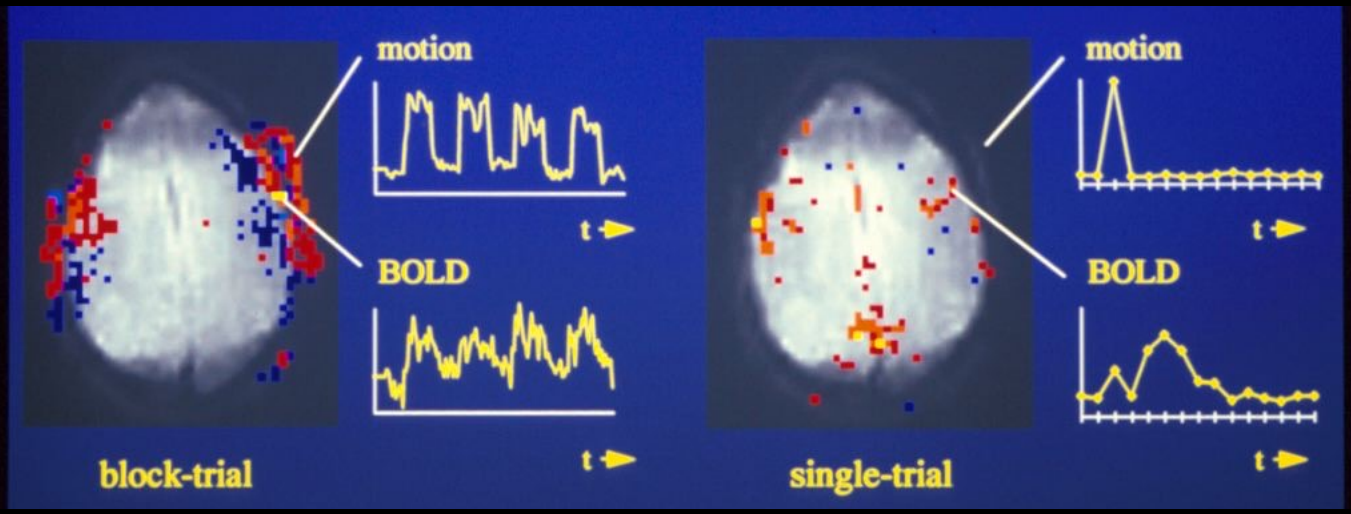
Overt Word Production



Tongue Movement



Jaw Clenching



Visual Cortex

ISI, SD

20, 20

12, 2

10, 2

ISI, SD

8, 2

6, 2

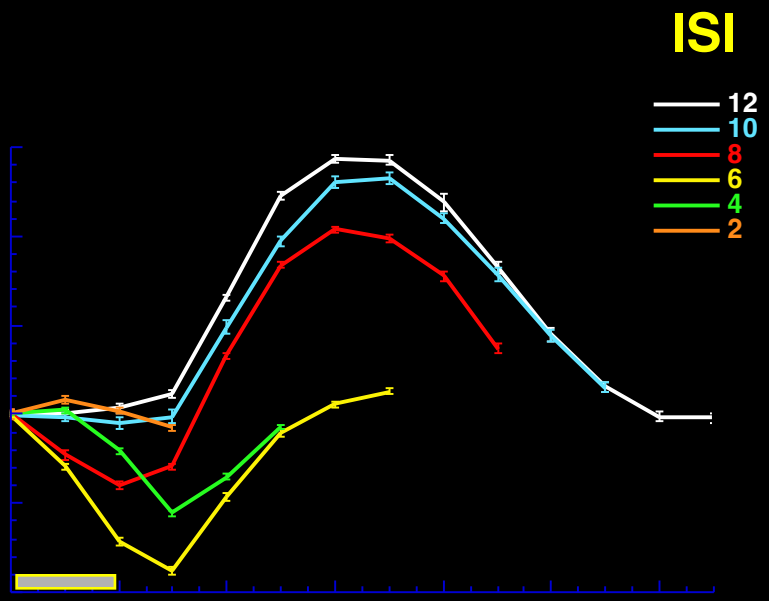
4, 2

2, 2

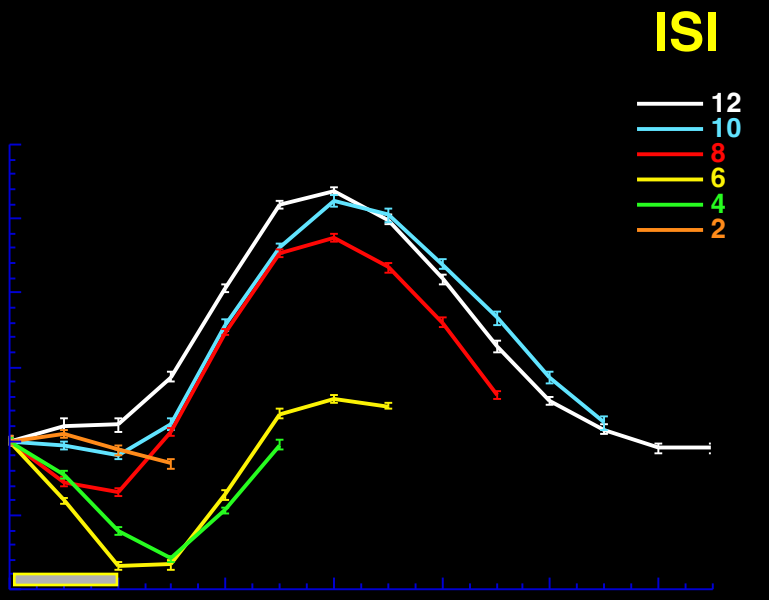
Motor Cortex

ISI, SD	ISI, SD
20, 20	8, 2
12, 2	6, 2
10, 2	4, 2
	2, 2

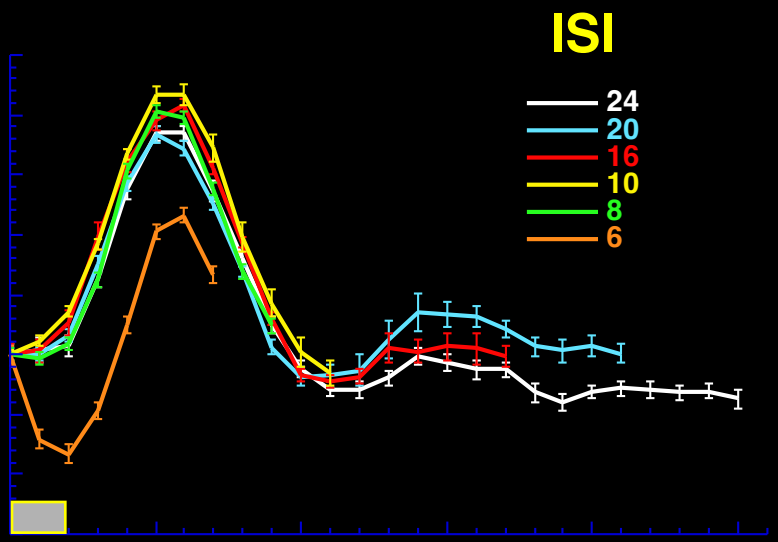
Motor Cortex



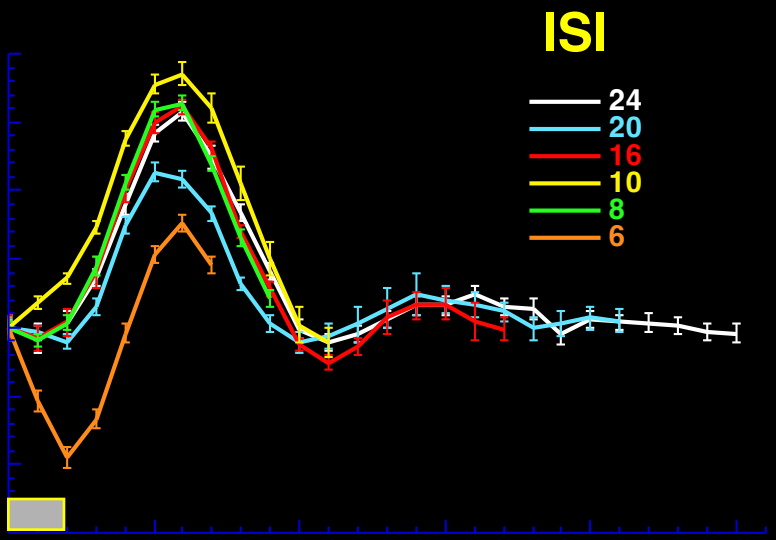
Visual Cortex



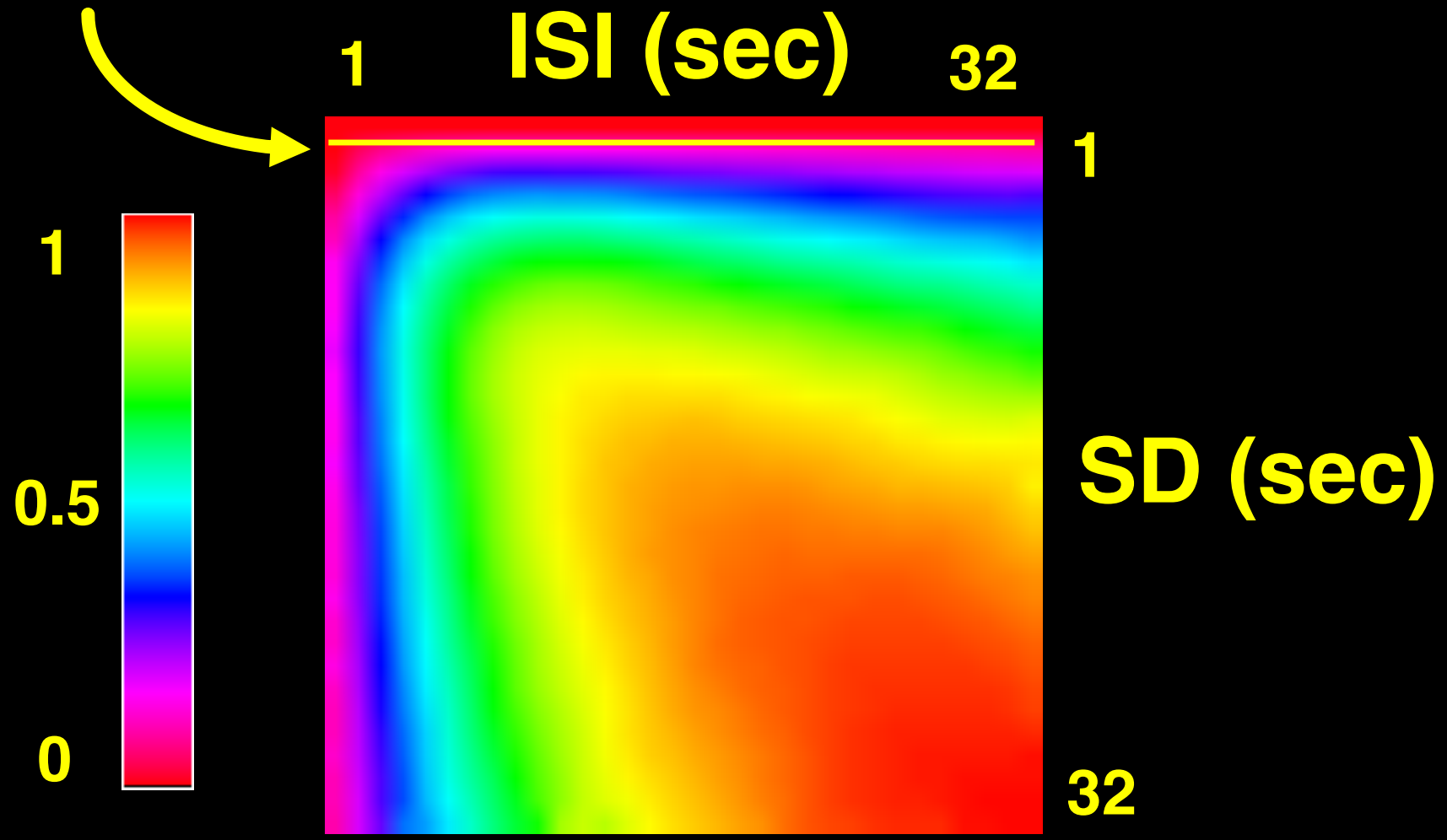
Motor Cortex

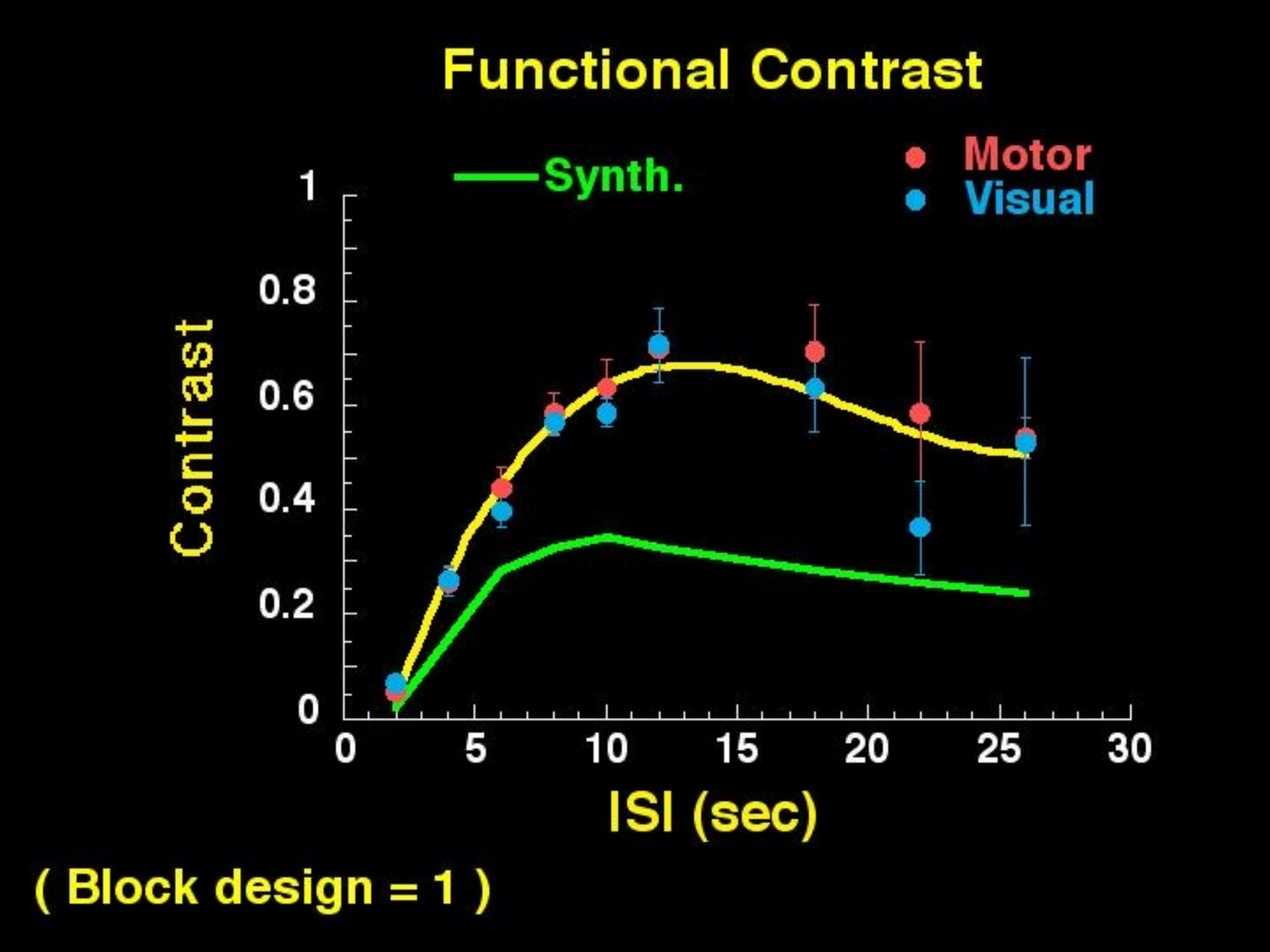


Visual Cortex

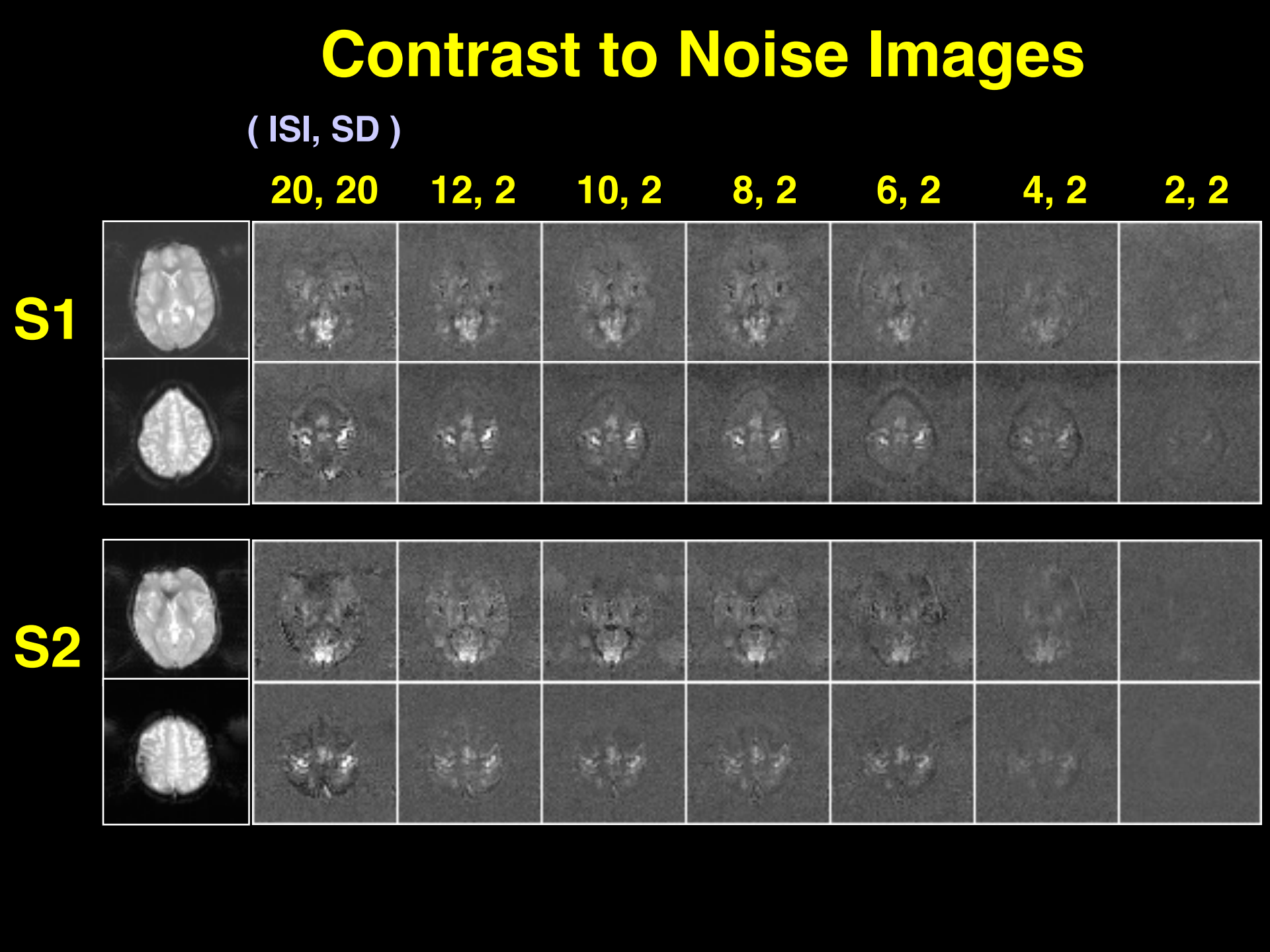


Functional Contrast




Functional Contrast
Synth.
Motor
Visual
Contrast
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
ISI (sec)
(Block design = 1)

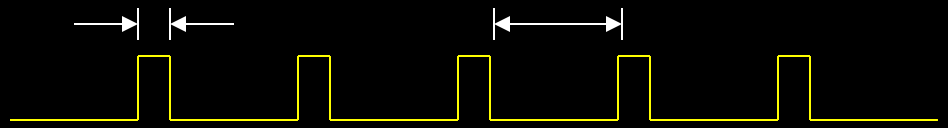
Contrast to Noise Images

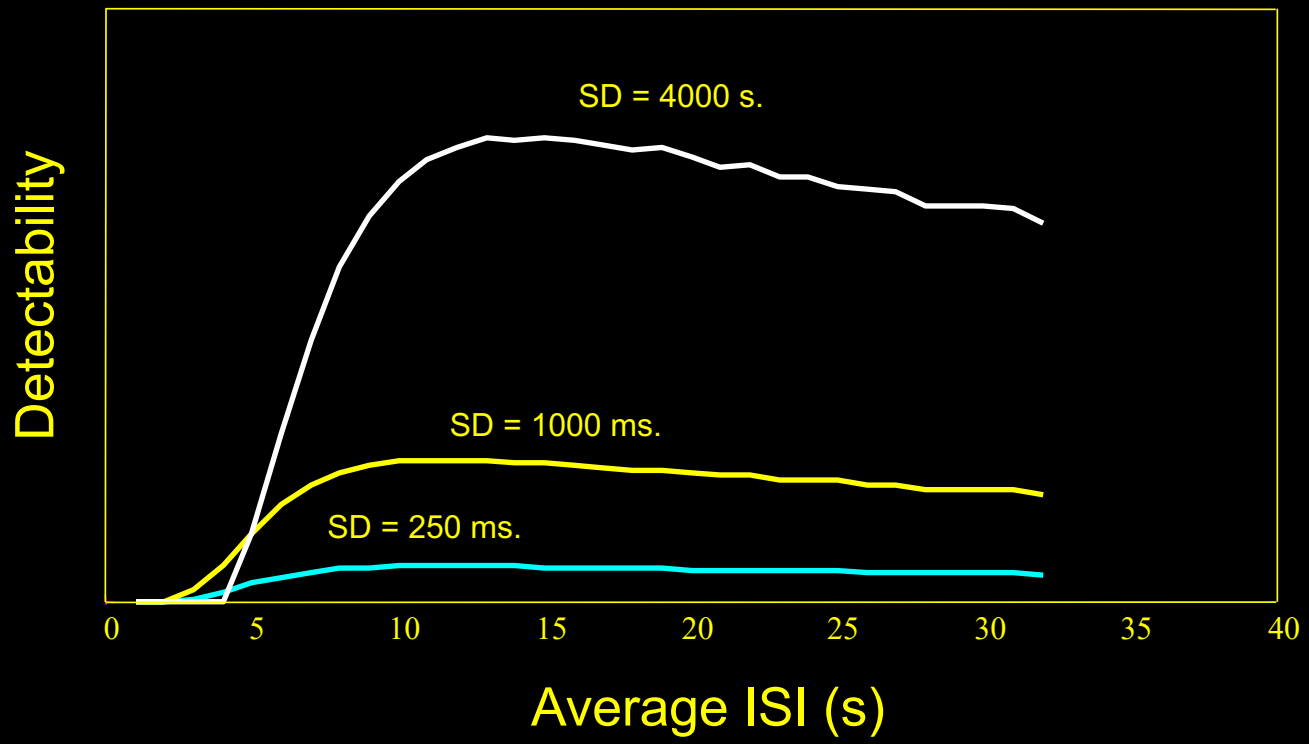


Detectability – constant ISI

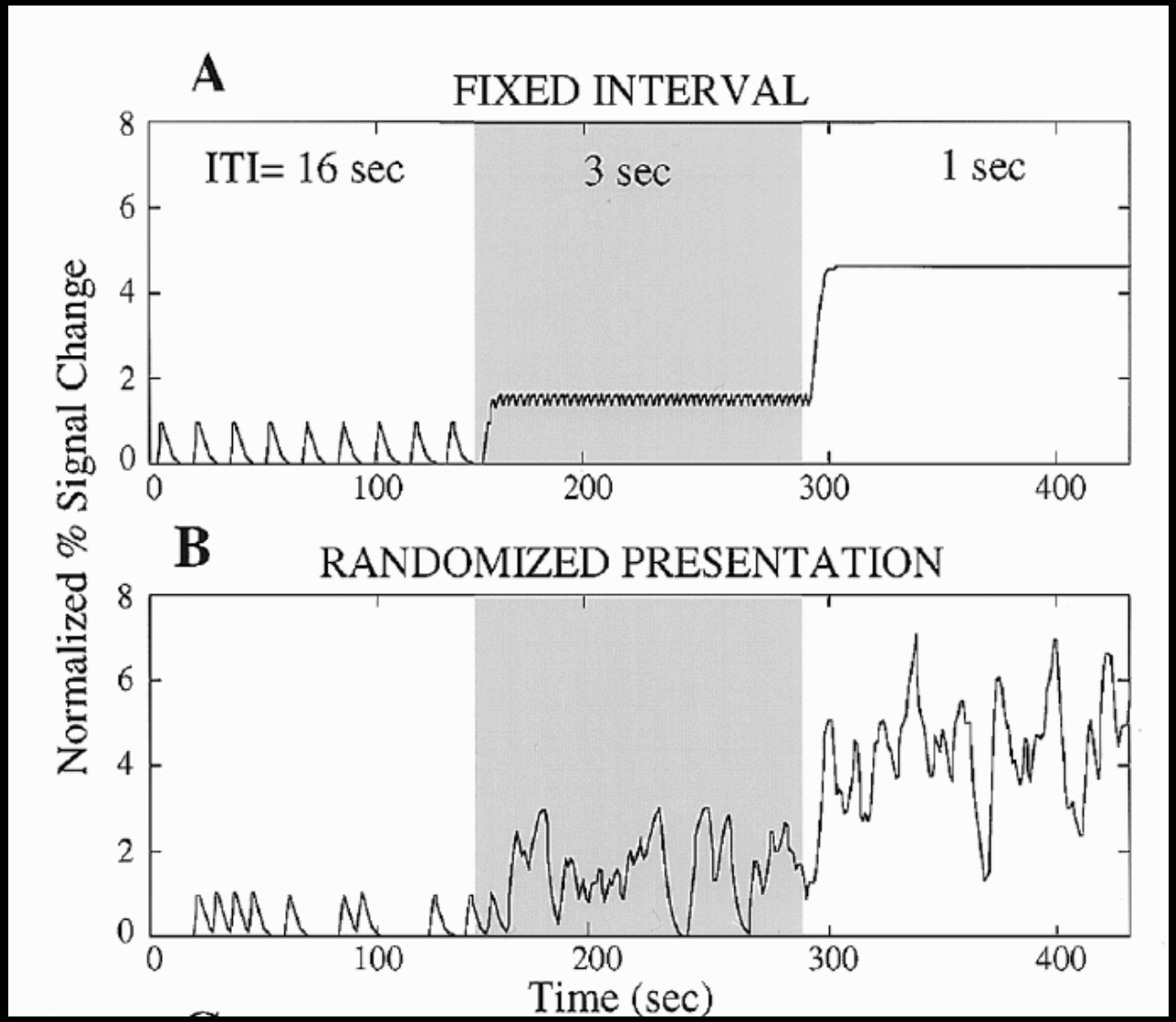
SD – stimulus duration

ISI – inter-stimulus interval

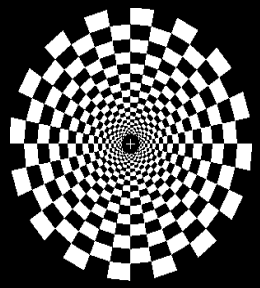




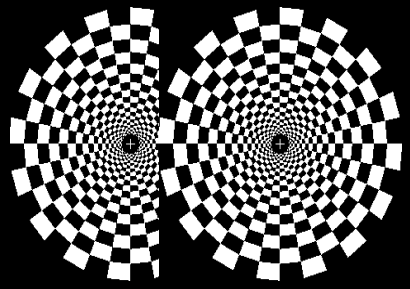
M.A. Burock et al. *NeuroReport*, 9, 3735-9 (1998)



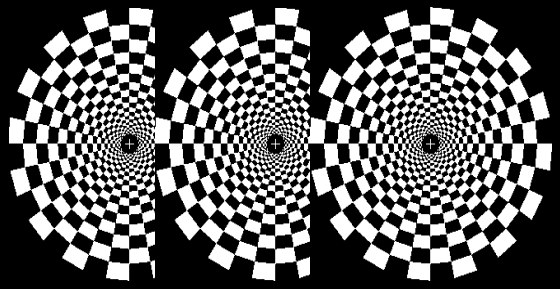
Visual Activation Paradigm: 1 , 2, & 3 Trials



0 sec 20 sec



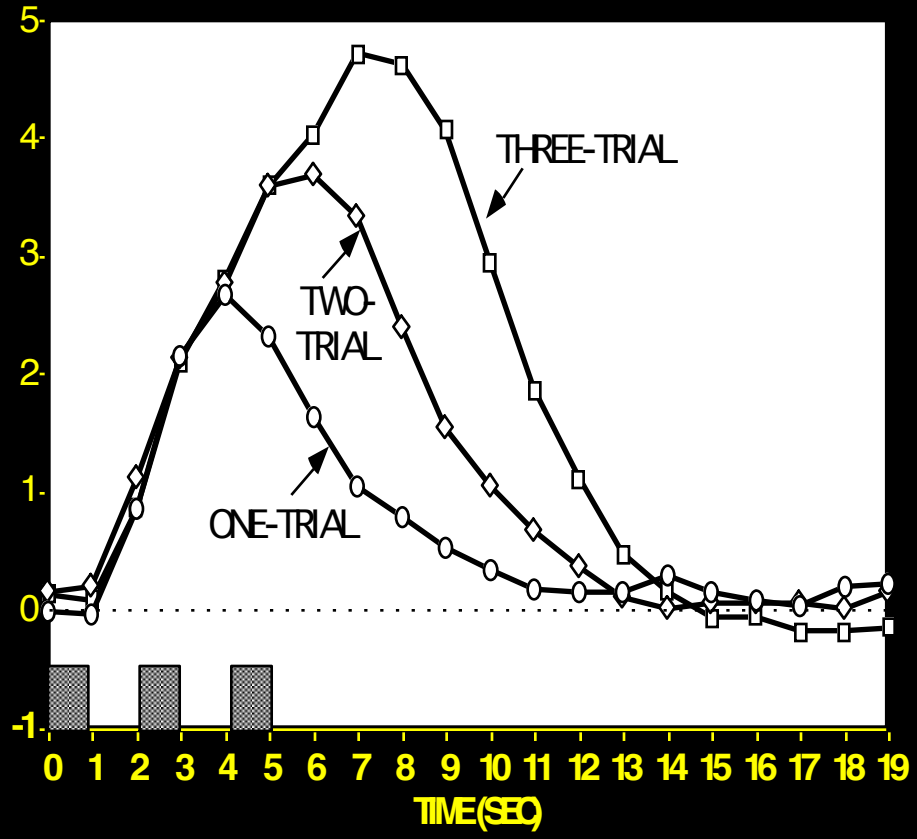
0 sec2 sec 20 sec



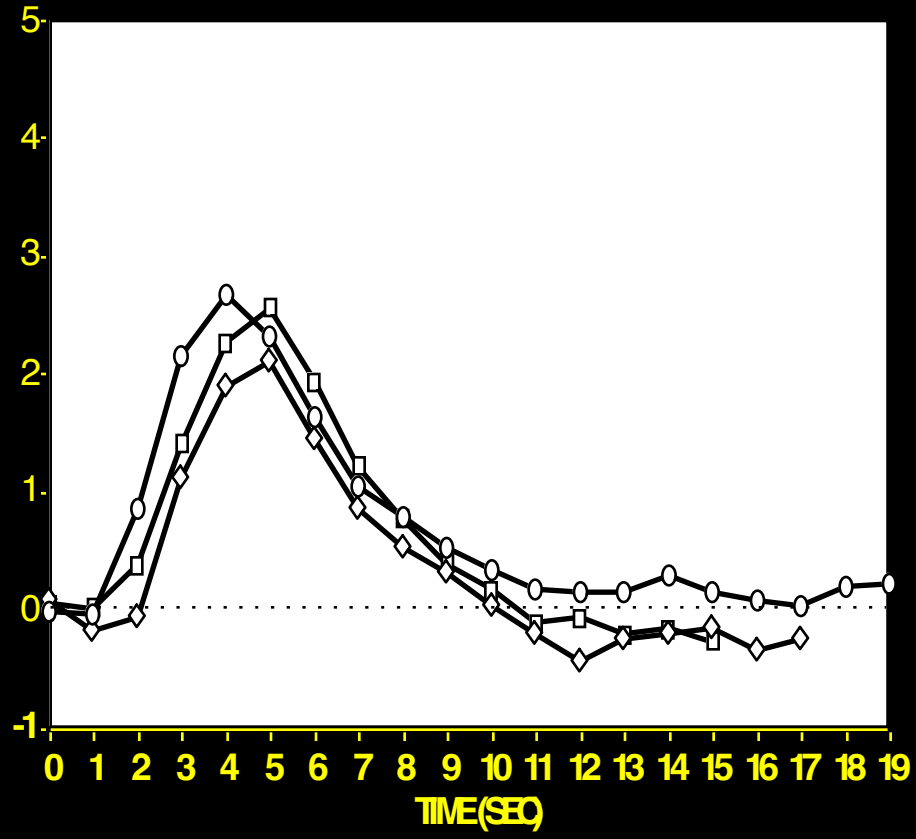
0 sec2 sec4 sec 20 sec

Response to Multiple Trials: Subject RW

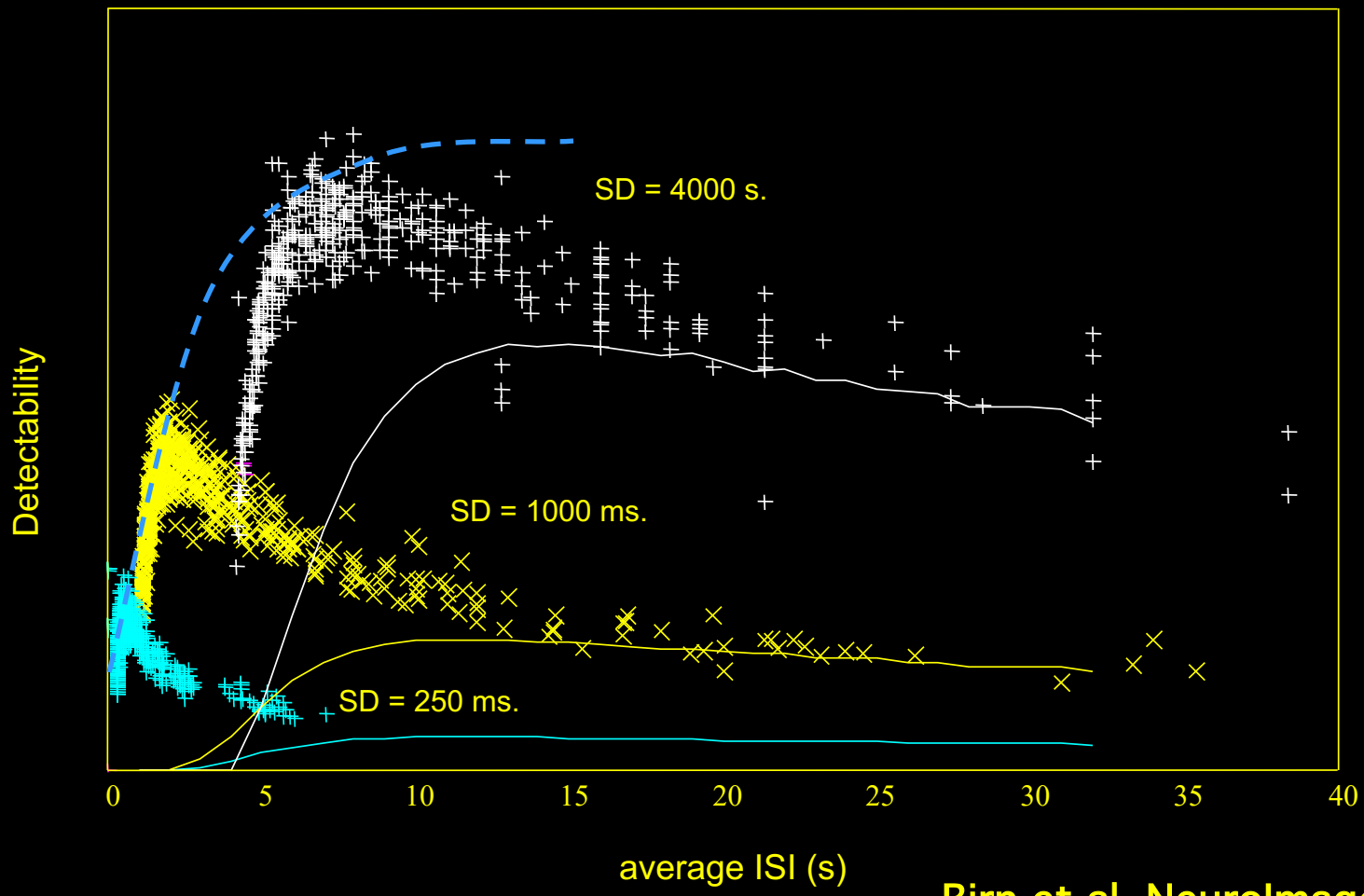
RAW DATA



ESTIMATED RESPONSES

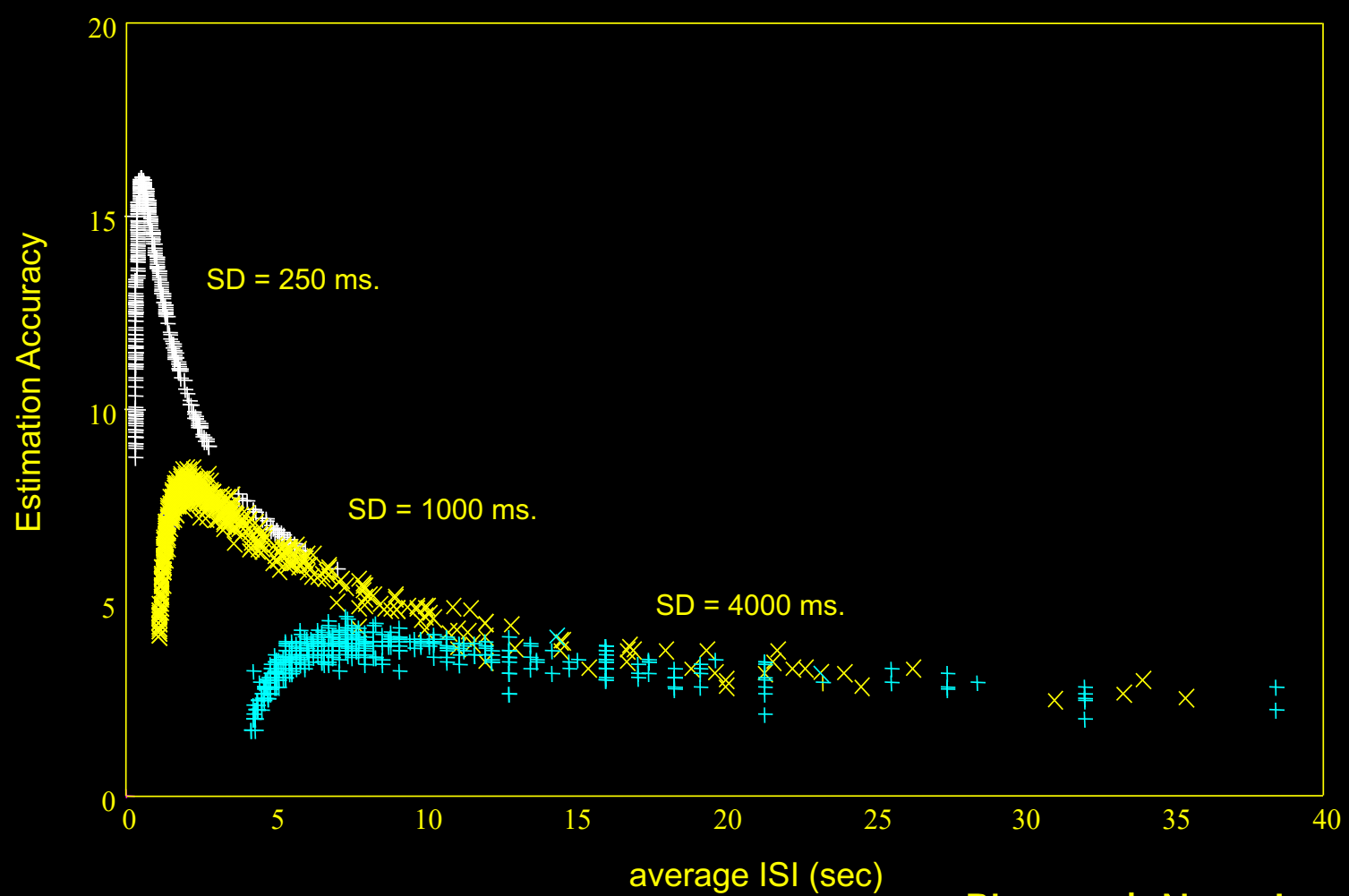


Detectability vs. Average ISI



Birn et al. NeuroImage (in press)

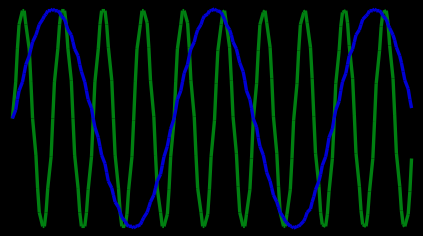
Estimation accuracy vs. average ISI

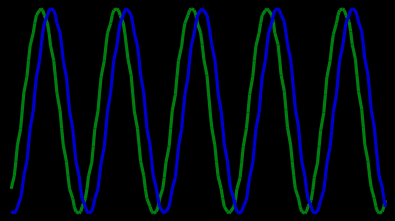


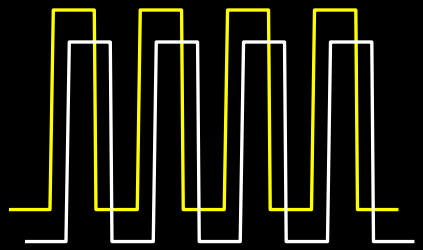
Birn et al. NeuroImage (in press)

Neuronal Activation Input Strategies

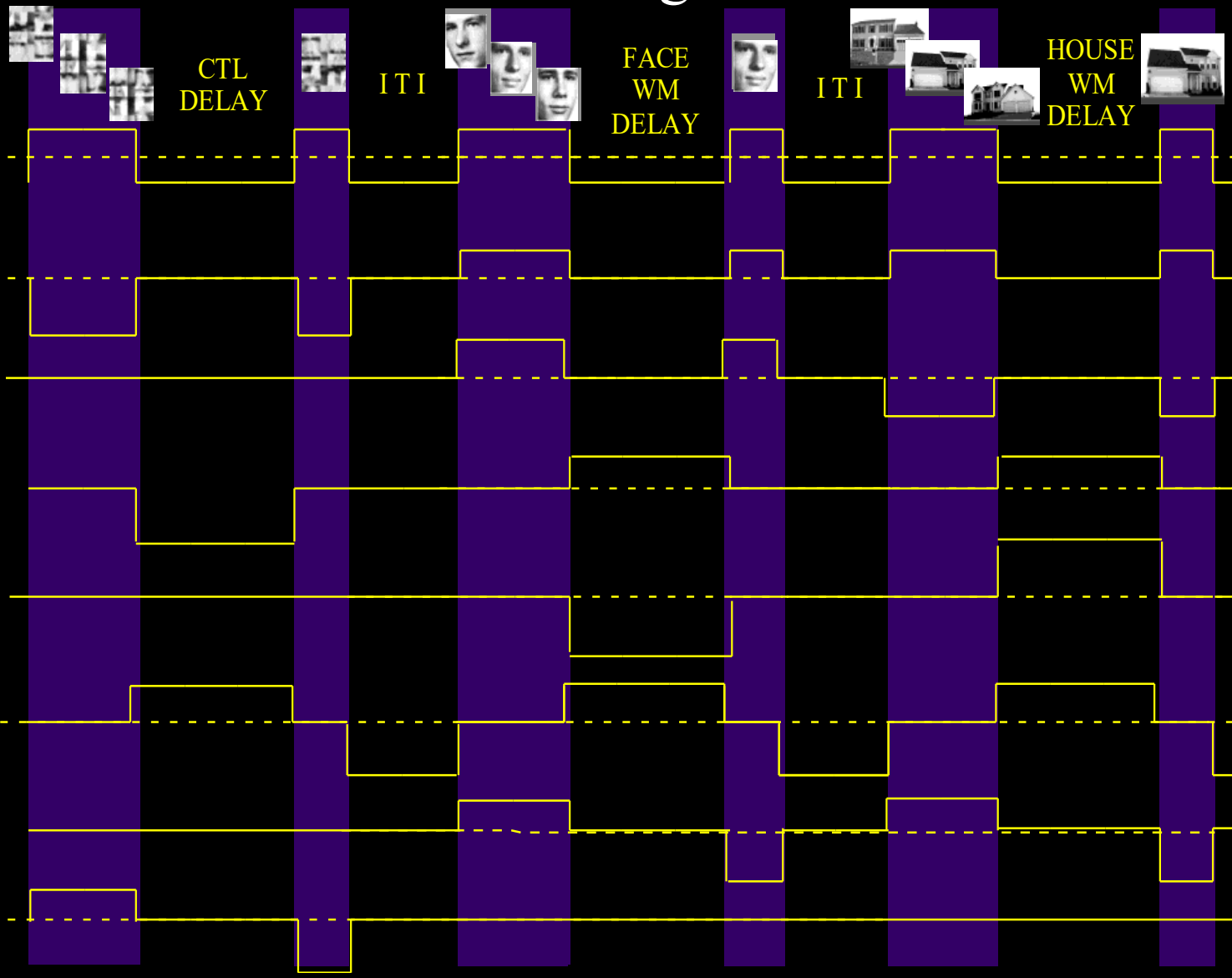
1. Block Design
2. Frequency Encoding
3. Phase Encoding
4. Event Related
5. Orthogonal Block Design
6. Free behavior Design







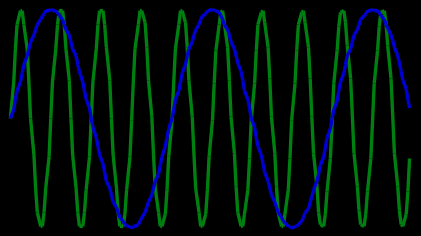
Example of a Set of Orthogonal Contrasts for Multiple Regression



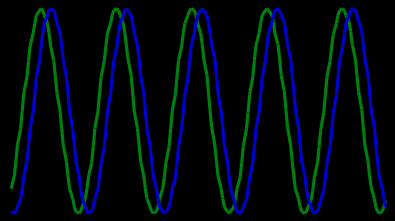
Neuronal Activation Input Strategies

1. Block Design

2. Frequency Encoding

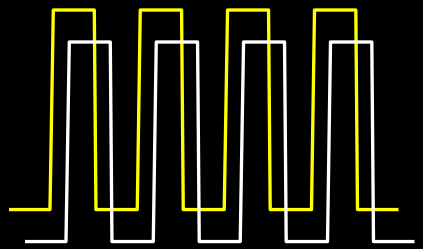


3. Phase Encoding



4. Single Event

5. Orthogonal Block Design



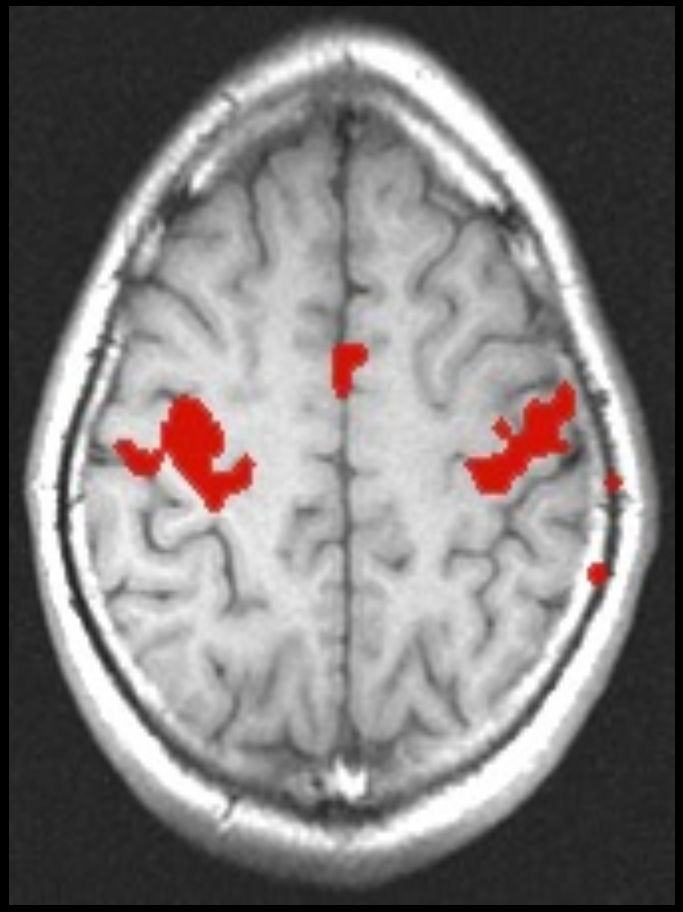
6. Free Behavior Design.

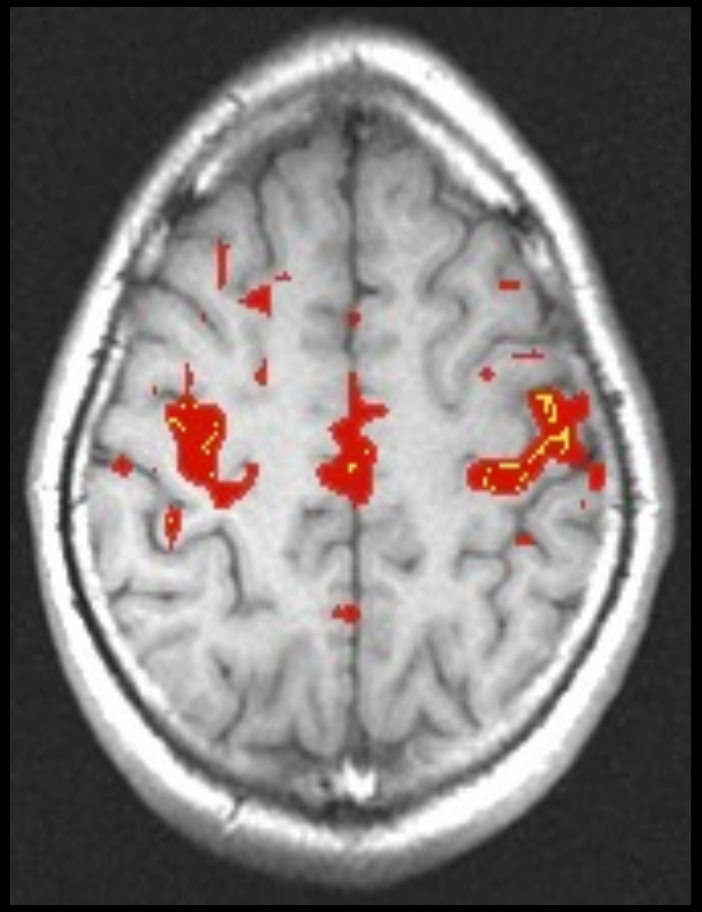
Free Behavior Design

Use a continuous measure as a reference function:

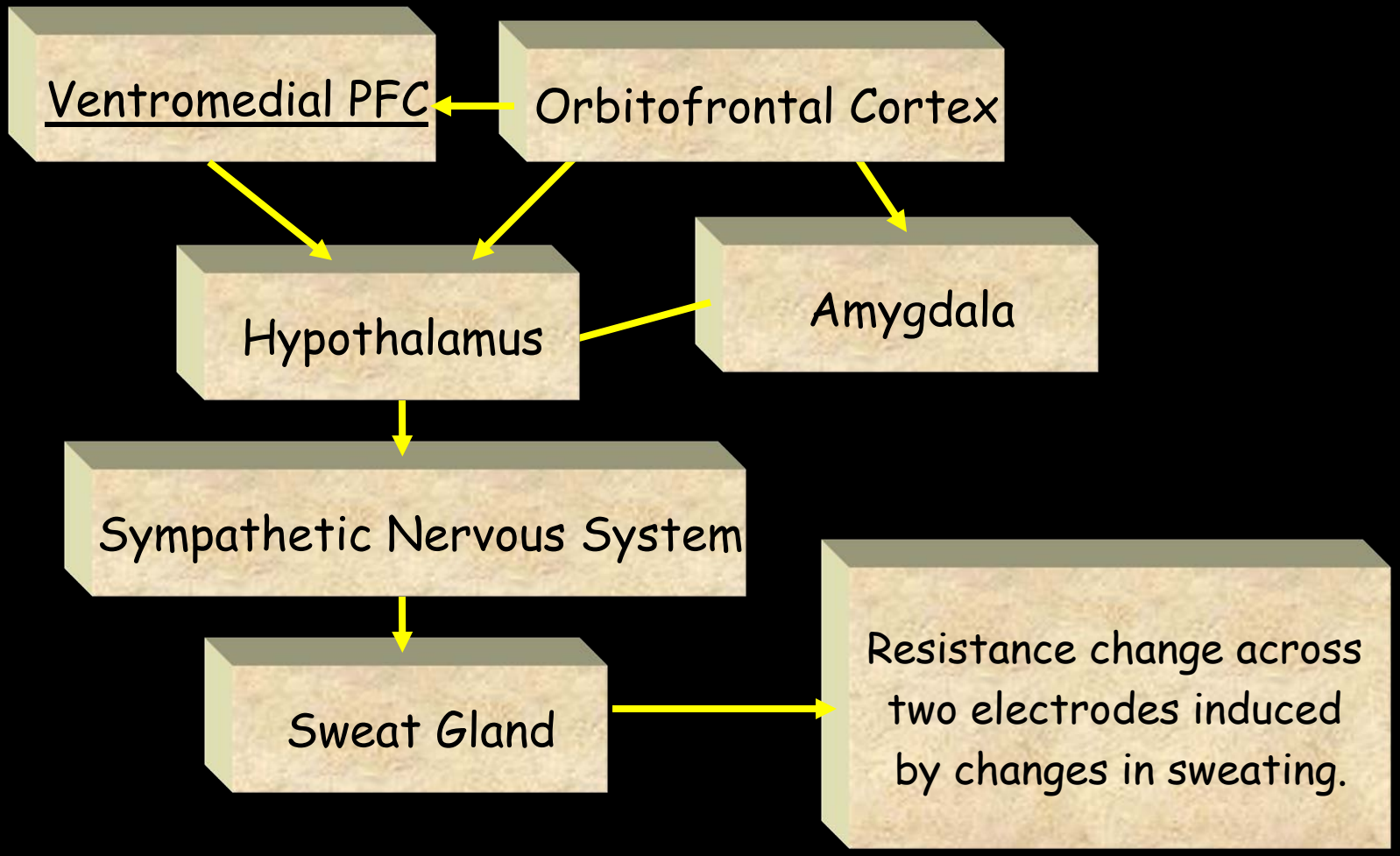
- Task performance
- Skin Conductance
- Heart, respiration rate..
- Eye position
- EEG

Resting Hemodynamic Autocorrelations





The Skin Conductance Response (SCR)



Skin Conductance Dynamics

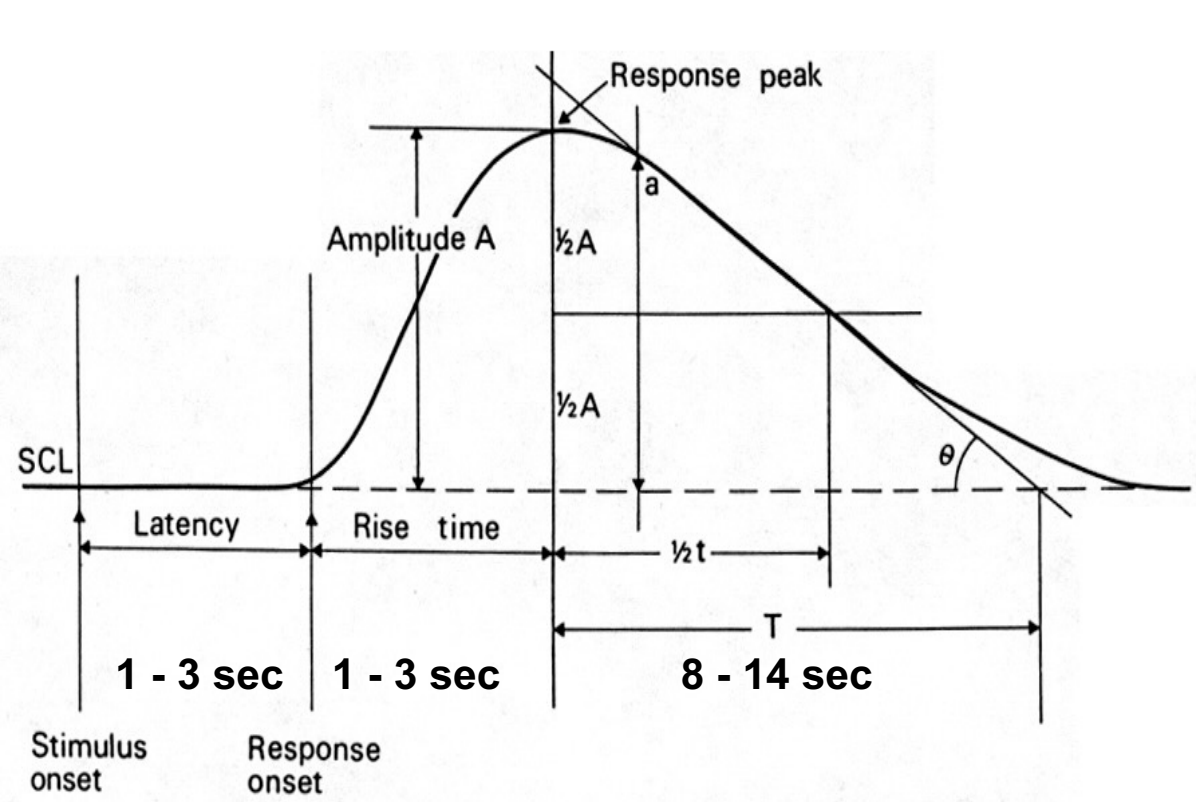
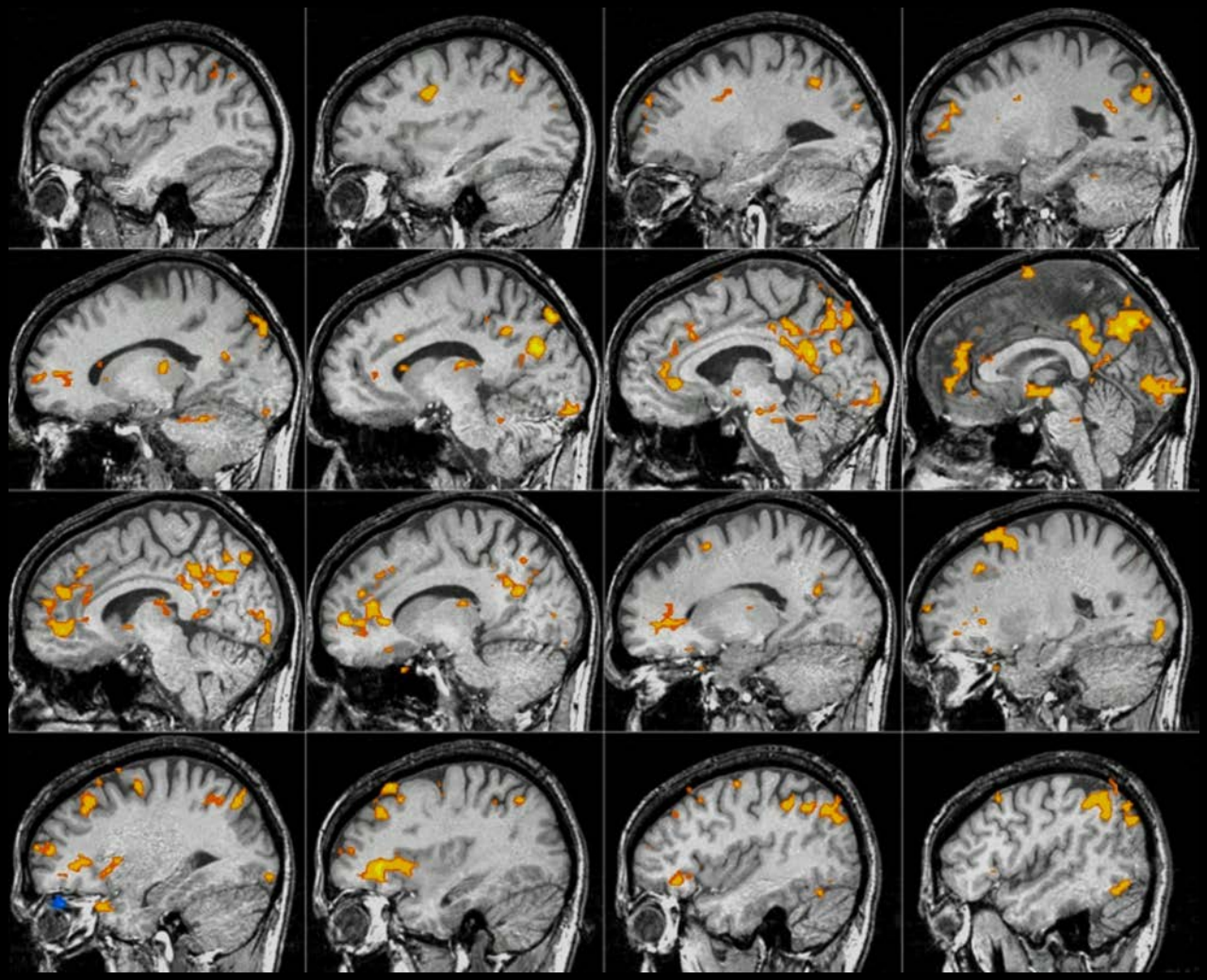


FIGURE 1. Diagrammatic skin conductance response.

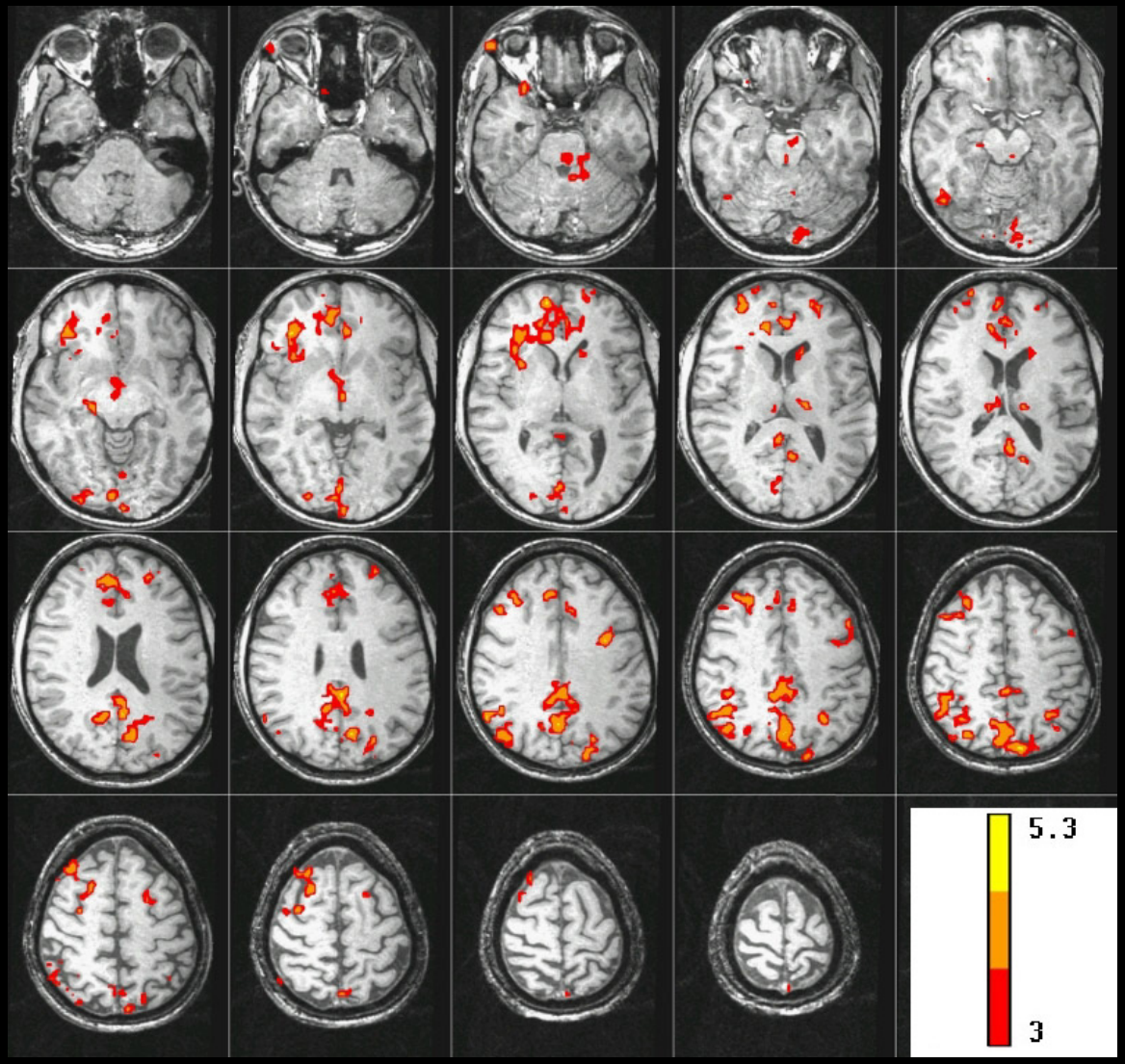
•Boucsein, Wolfram (1992). Electrodermal Activity. Plenum Press, NY

•Venables, Peter, (1991). Autonomic Activity ANYAS 620:191-207.

Brain activity correlated with SCR during “Rest”



Brain activity correlated with SCR during “Rest”



Variables to Optimize

- Information Content
- Sensitivity
- Speed
- Resolution
- Image quality

Speed

Temporal Resolution factors:

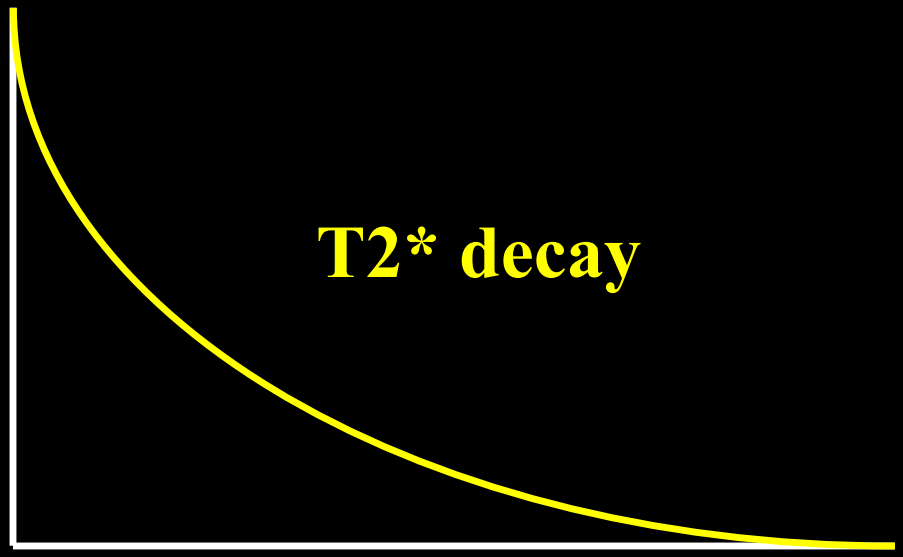
- Image acquisition rate
- Amount of signal averaging to make functional activation map

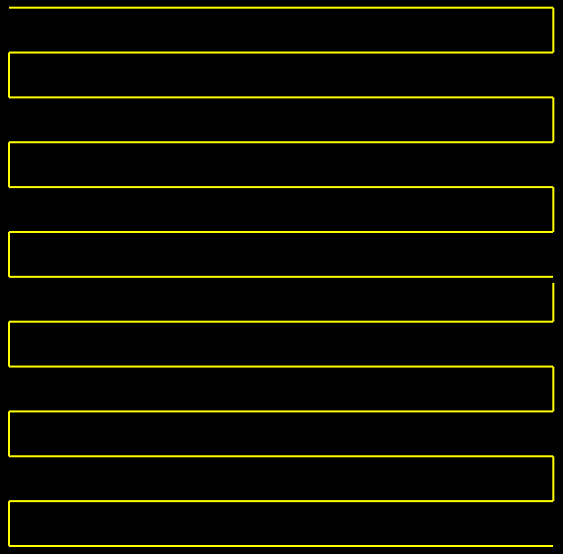
- Time for signal to deviate from baseline
- Fastest on-off rate in which amplitude is not compromised
- Fastest on-off rate in which hemodynamic response keeps up
- Minimum activation duration

- Standard deviation of hemodynamic response measures per voxel

- Range of latencies over space

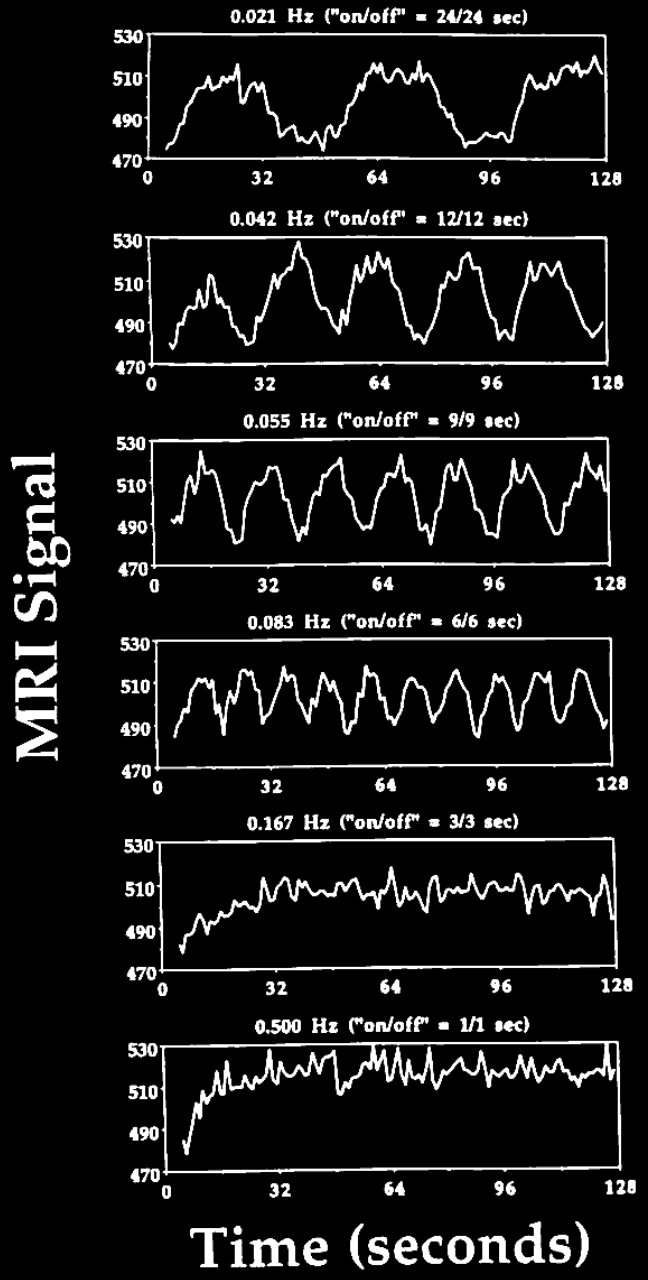
Single Shot Imaging

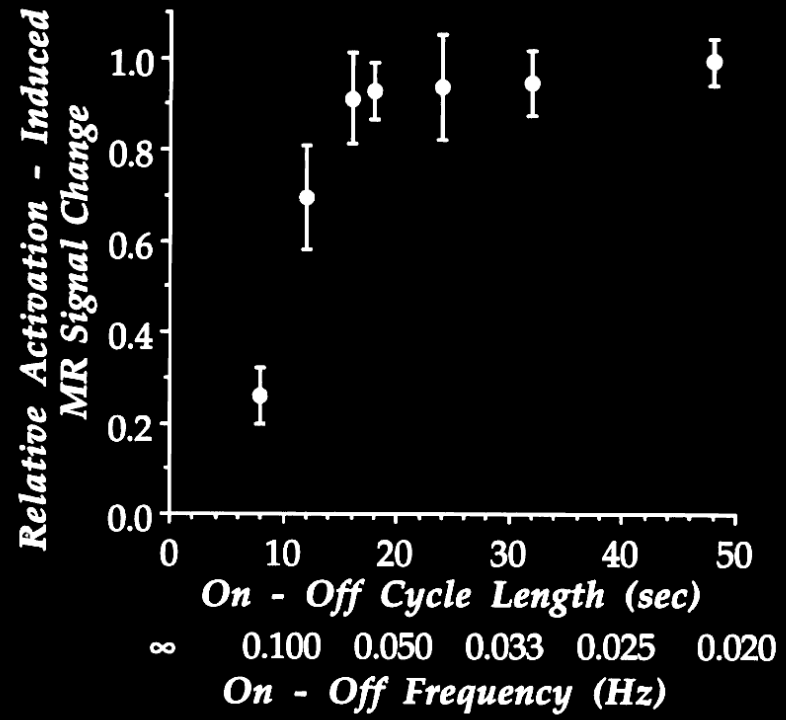


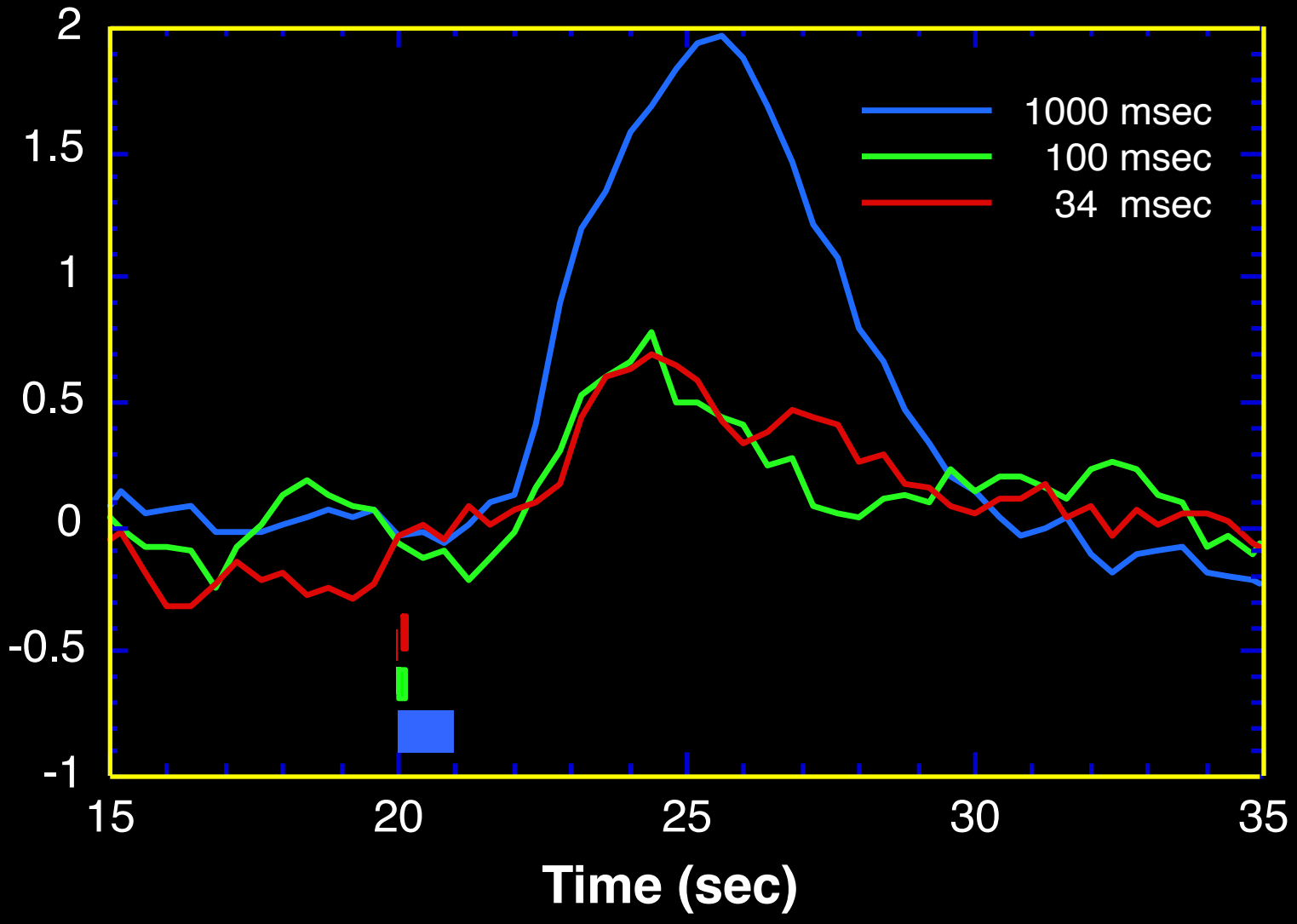


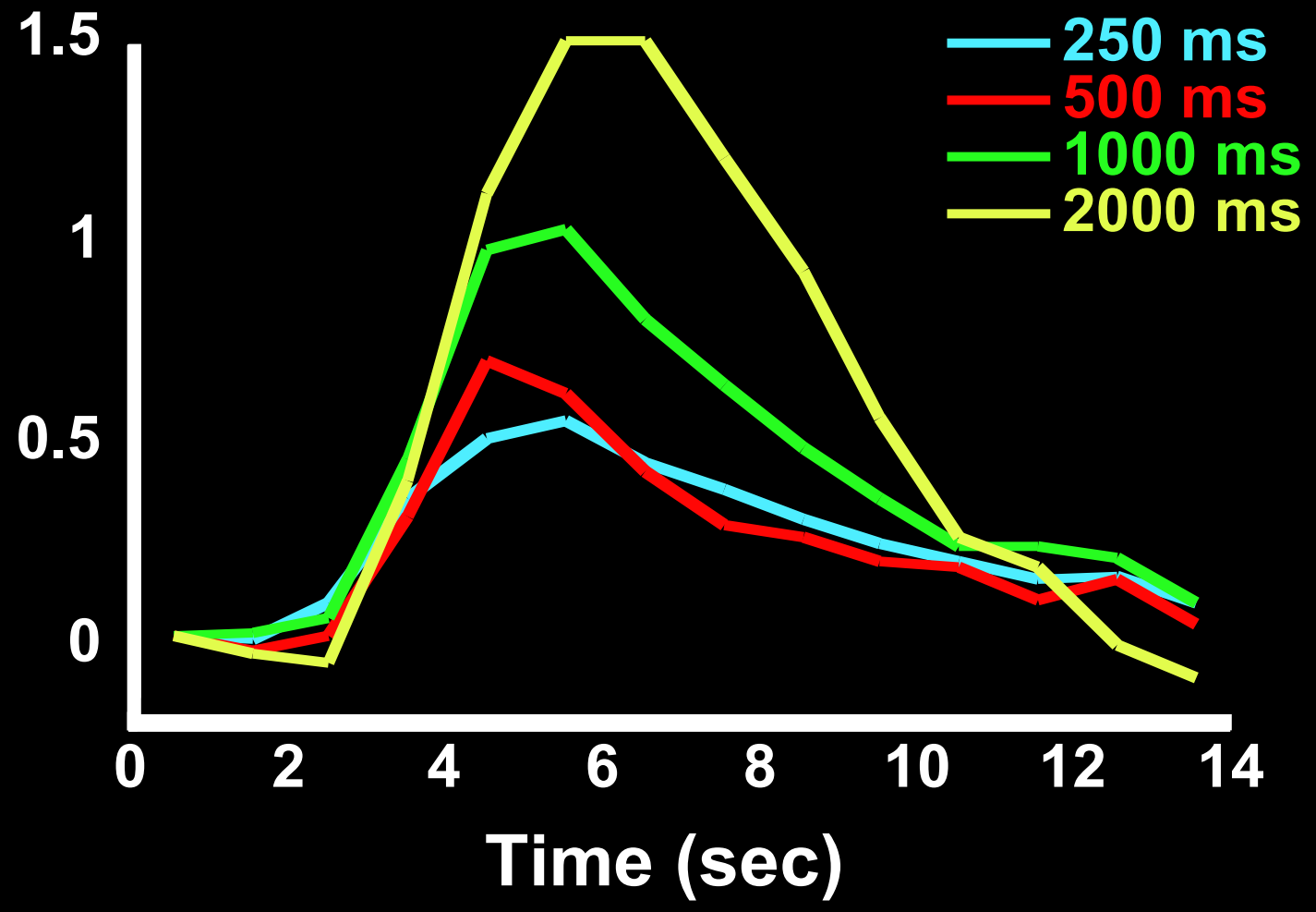
EPI Readout Window

≈ 20 to 40 ms

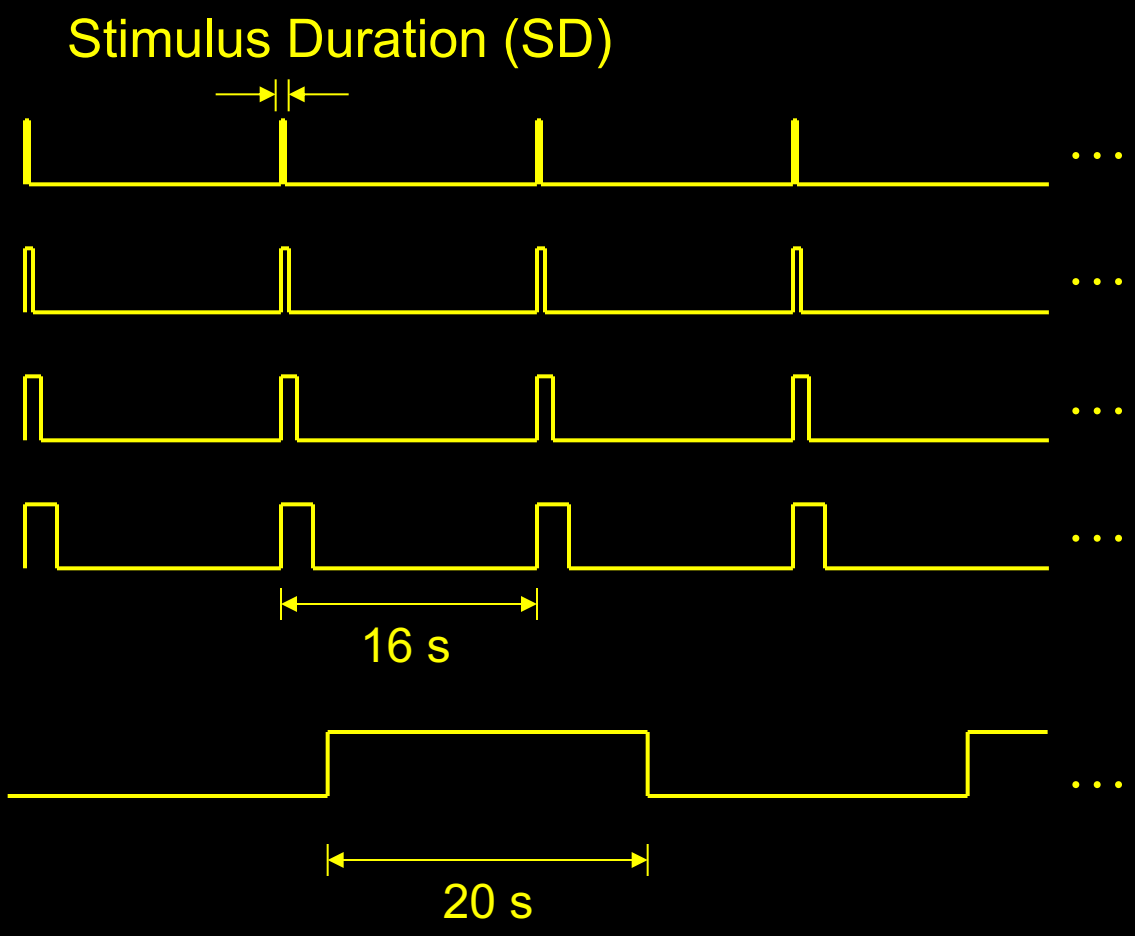

0.021 Hz ("on/off" = 24/24 sec)
0.042 Hz ("on/off" = 12/12 sec)
0.055 Hz ("on/off" = 9/9 sec)
0.083 Hz ("on/off" = 6/6 sec)
0.167 Hz ("on/off" = 3/3 sec)
0.500 Hz ("on/off" = 1/1 sec)
530
510
490
470
0
32
64
96
128
MRI Signal
Time (seconds)


Relative Activation - Induced MR Signal Change
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
On - Off Cycle Length (sec)
∞
0.100
0.050
0.033
0.025
0.020
On - Off Frequency (Hz)


2
1.5
1
0.5
0
-0.5
-1
15
20
25
30
35
Time (sec)
1000 msec
100 msec
34 msec

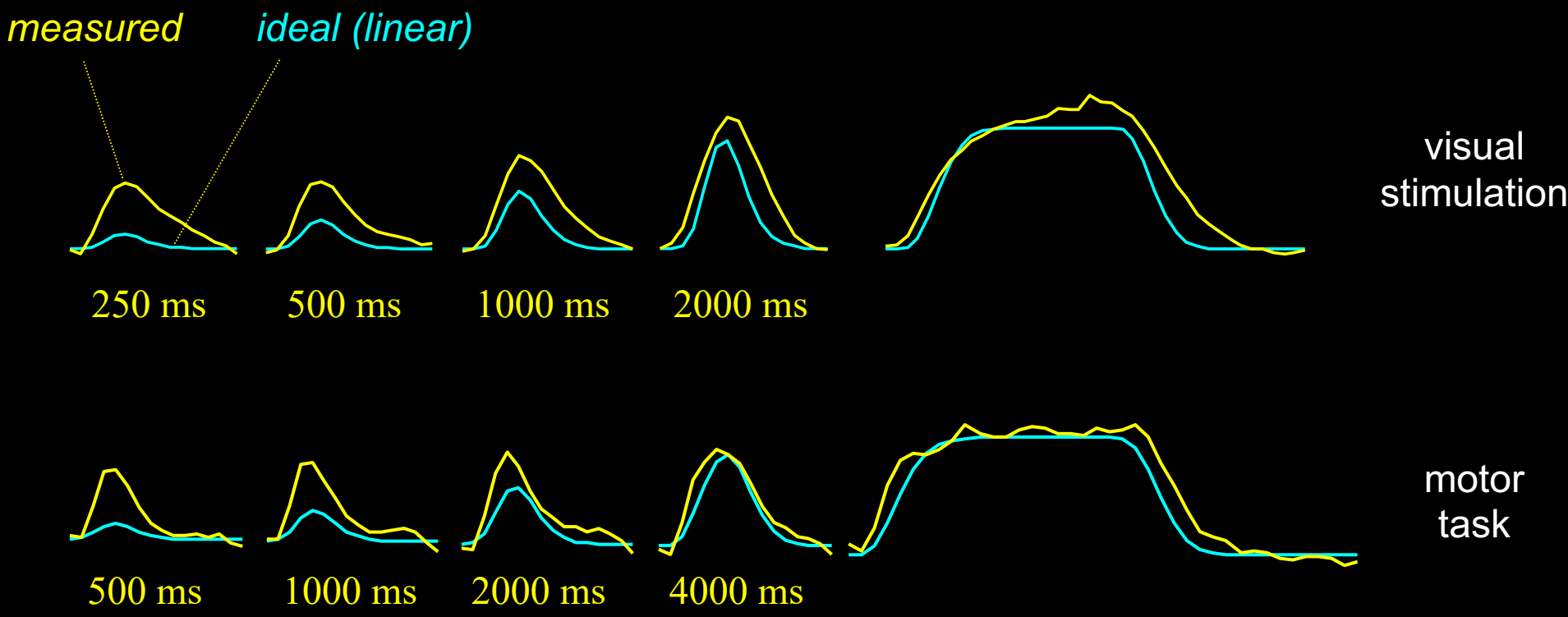

1.5
1
0.5
0
0
2
4
6
8
10
12
14
Time (sec)
250 ms
500 ms
1000 ms
2000 ms

Methods

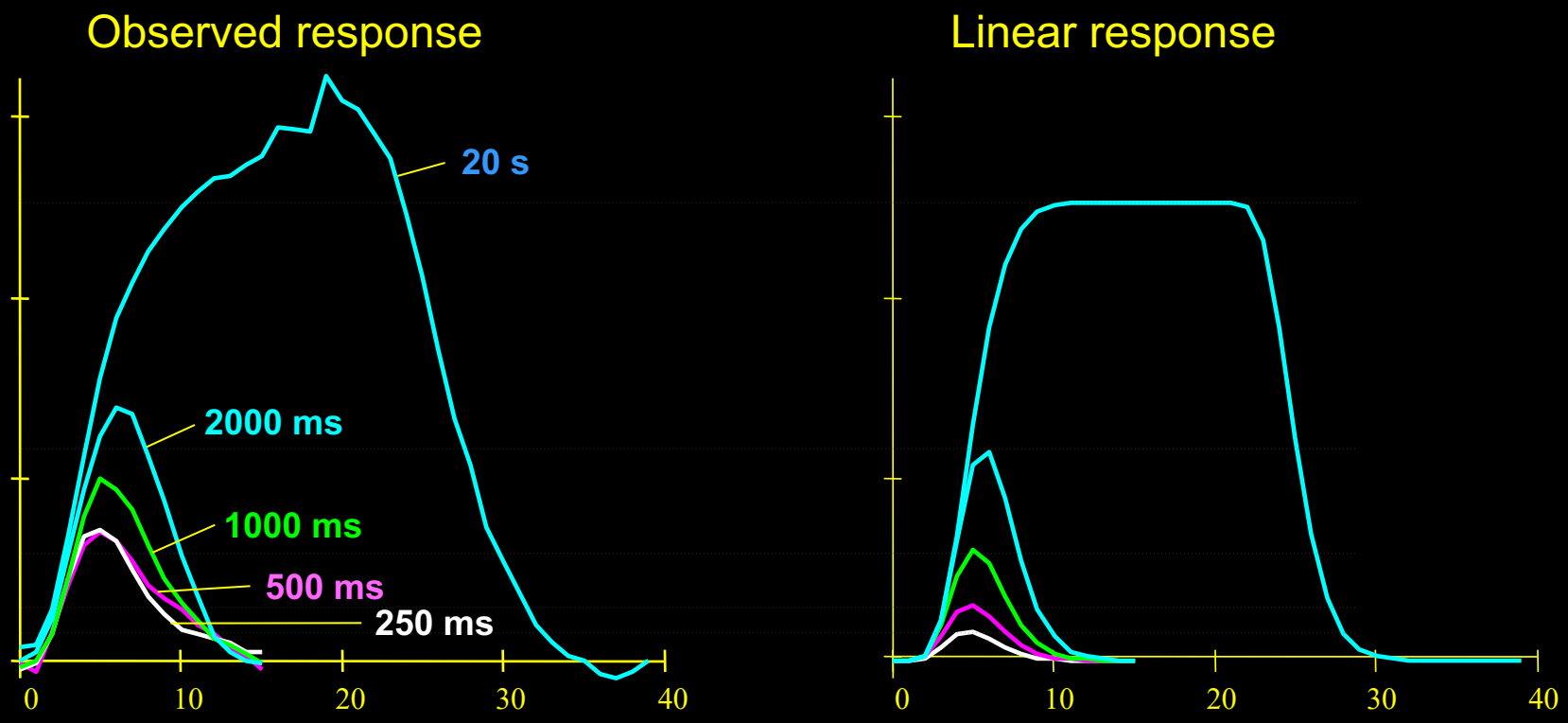


	Visual	*Motor*
···	SD = 250 ms	SD = 500 ms
···	SD = 500 ms	SD = 1000 ms
···	SD = 1000 ms	SD = 2000 ms
···	SD = 2000 ms	SD = 4000 ms
···	Blocked Trial	

Observed Responses



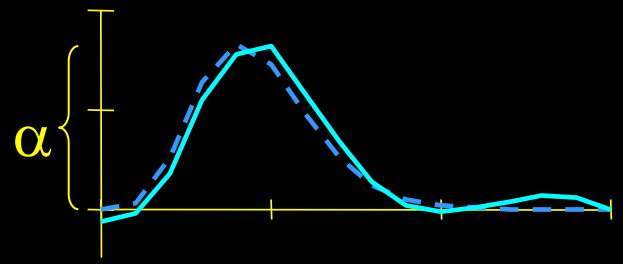
BOLD response is nonlinear



Short duration stimuli produce larger responses than expected

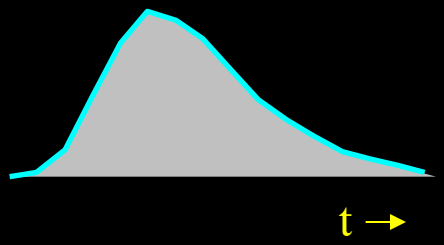
Compute nonlinearity *(for each voxel)*

- Amplitude of Response



Fit ideal (linear) to response

- Area under response / Stimulus Duration



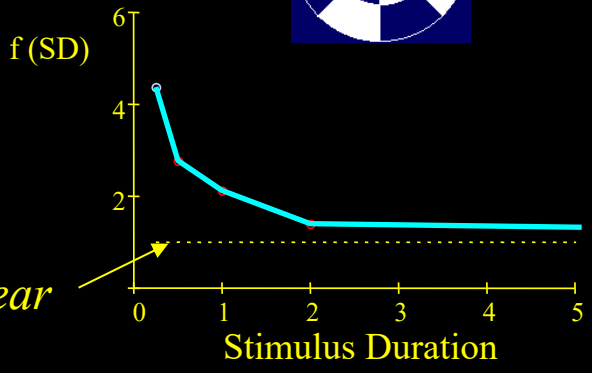
Output Area / Input Area

Nonlinearity

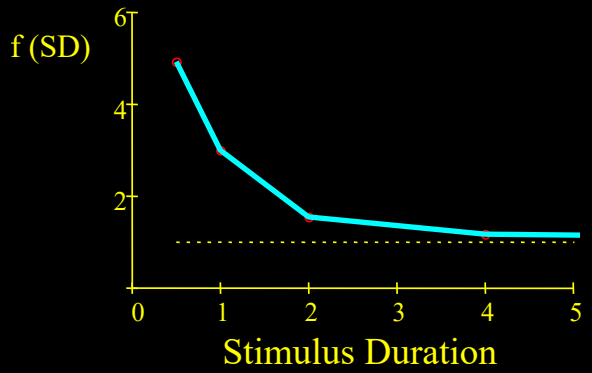
Visual

Motor

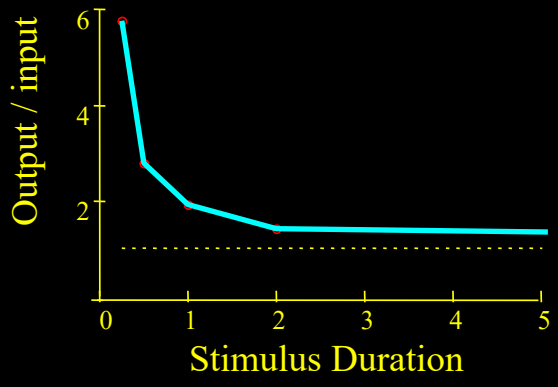
Magnitude

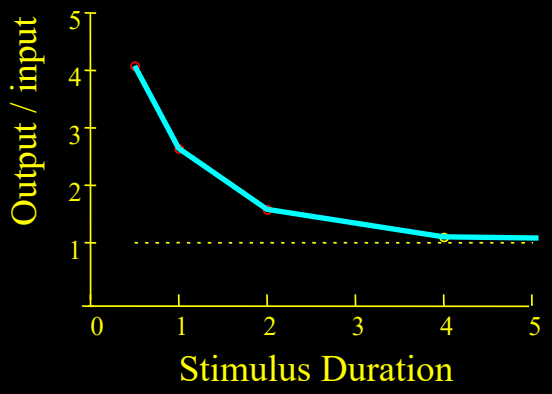


linear

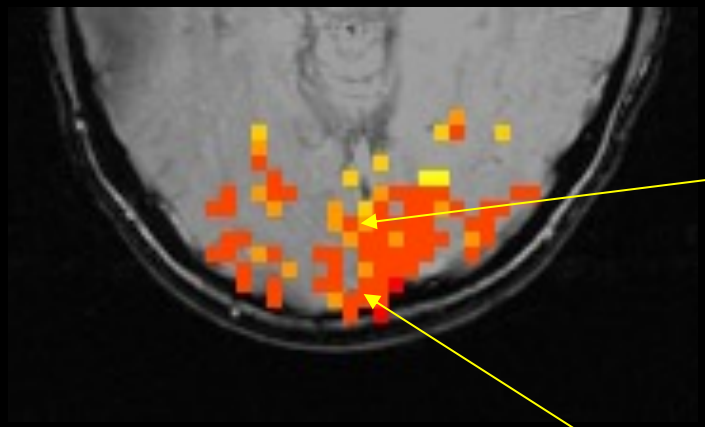


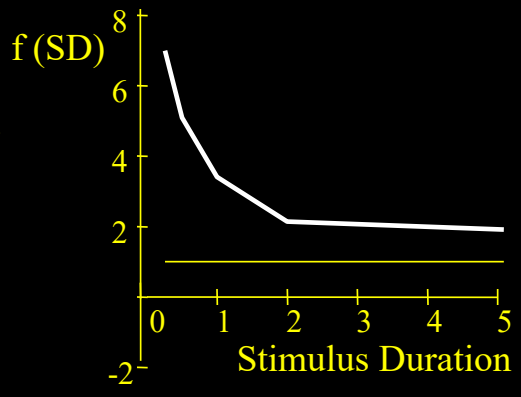
Area

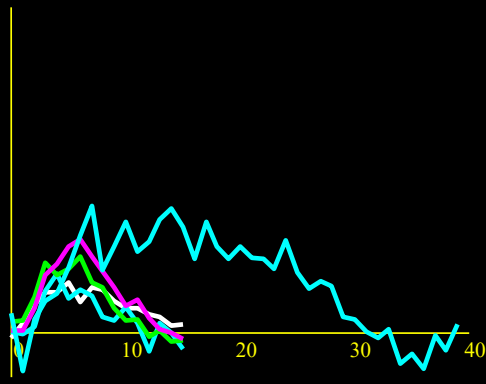


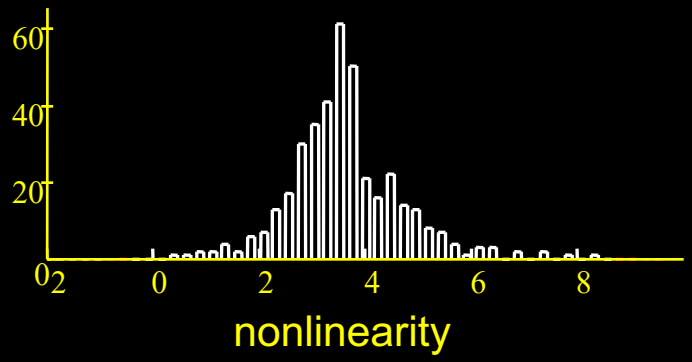


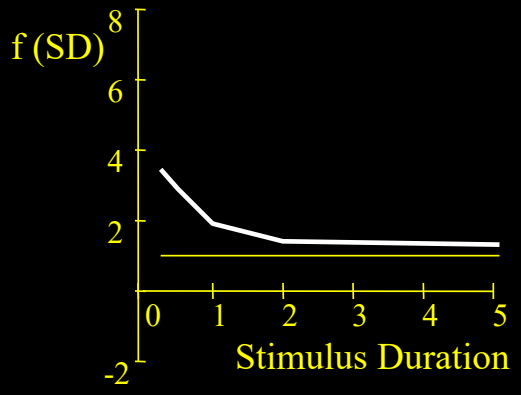
Results – visual task

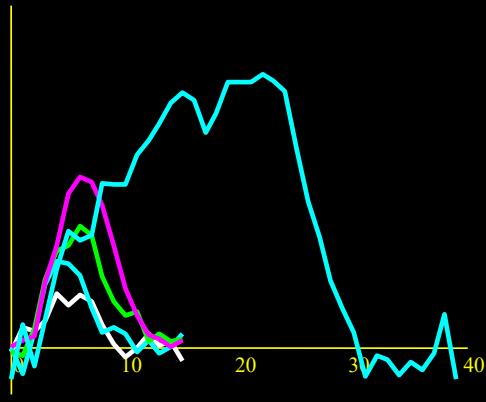










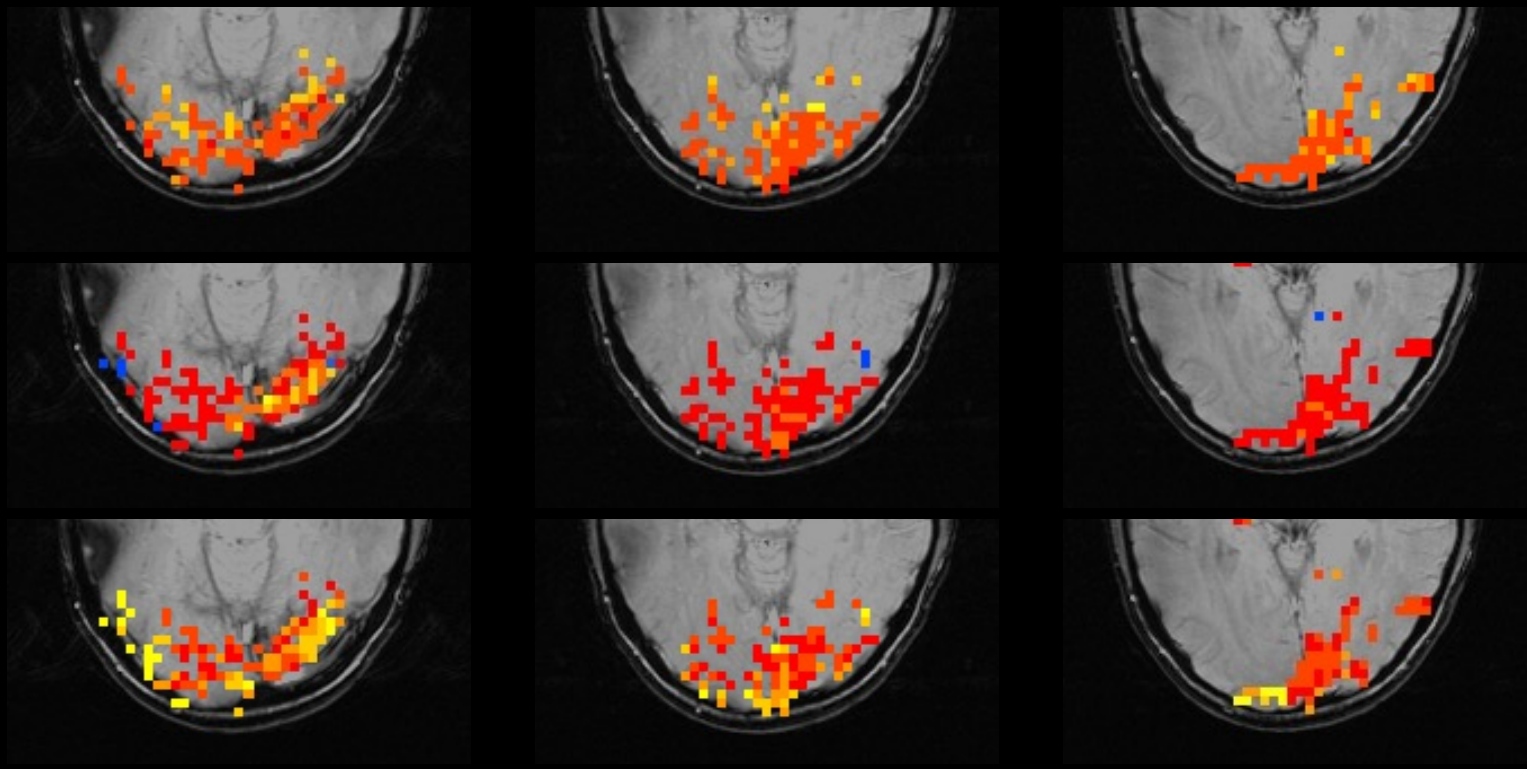


Results – visual task

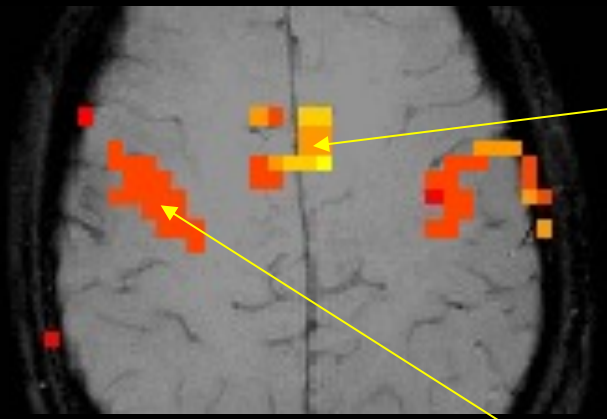
Nonlinearity

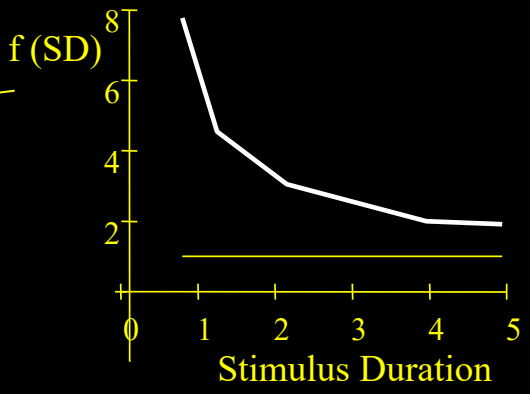
Magnitude

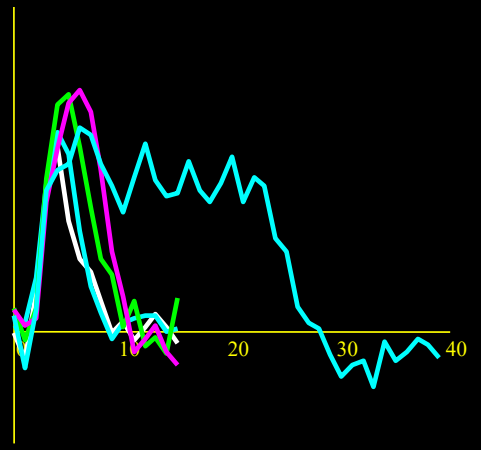
Latency

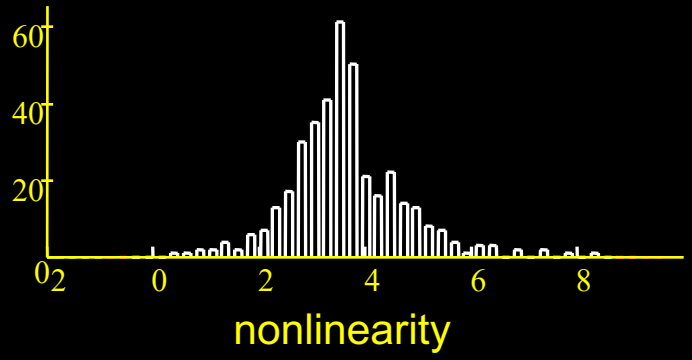


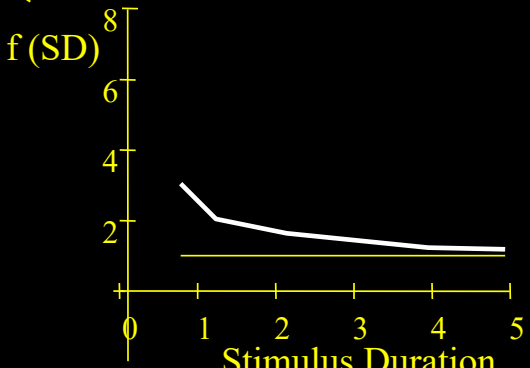
Results – motor task

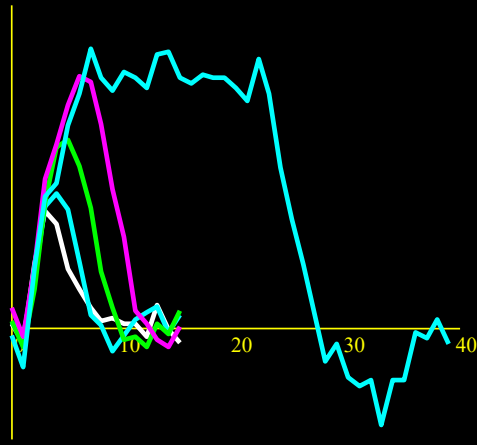










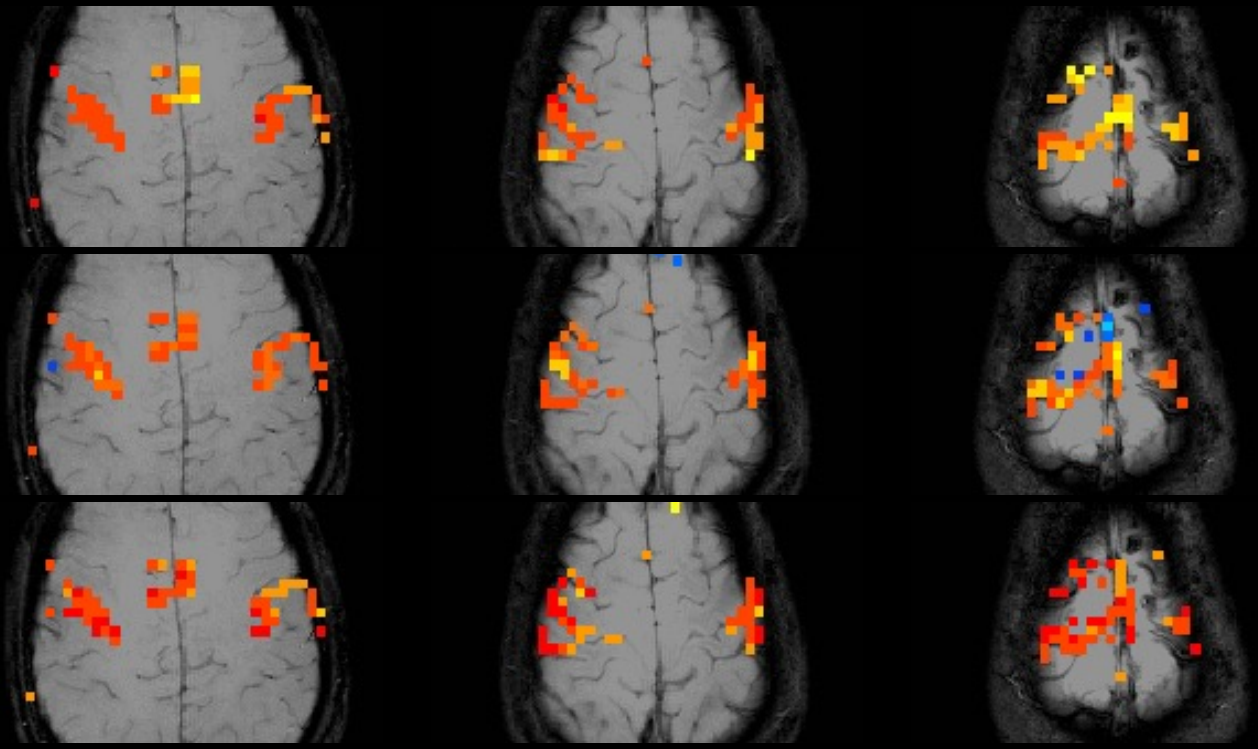


Results – motor task

Nonlinearity

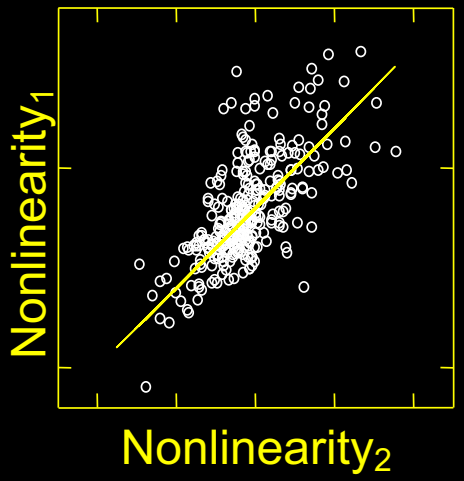
Magnitude

Latency

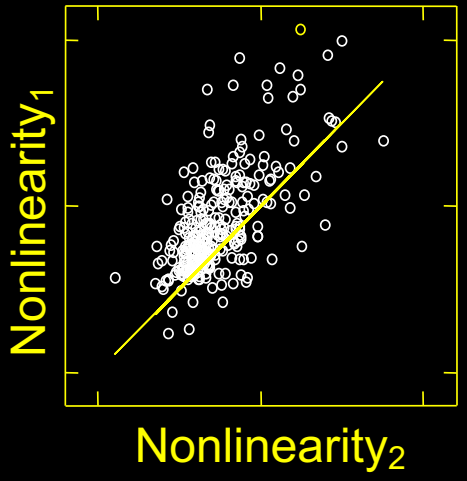


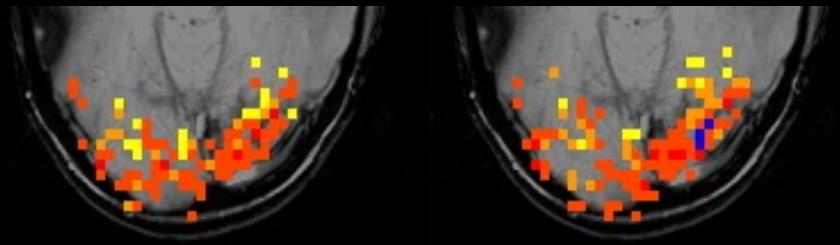
Reproducibility

Visual task

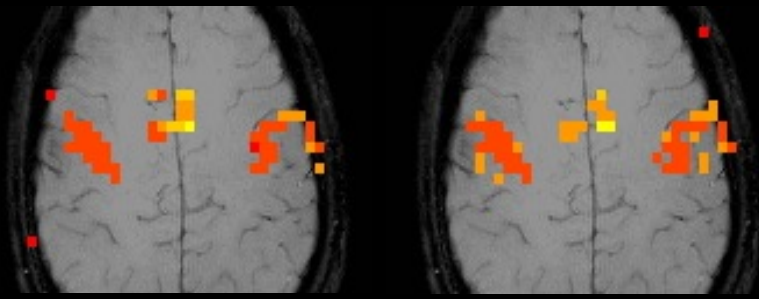


Motor task



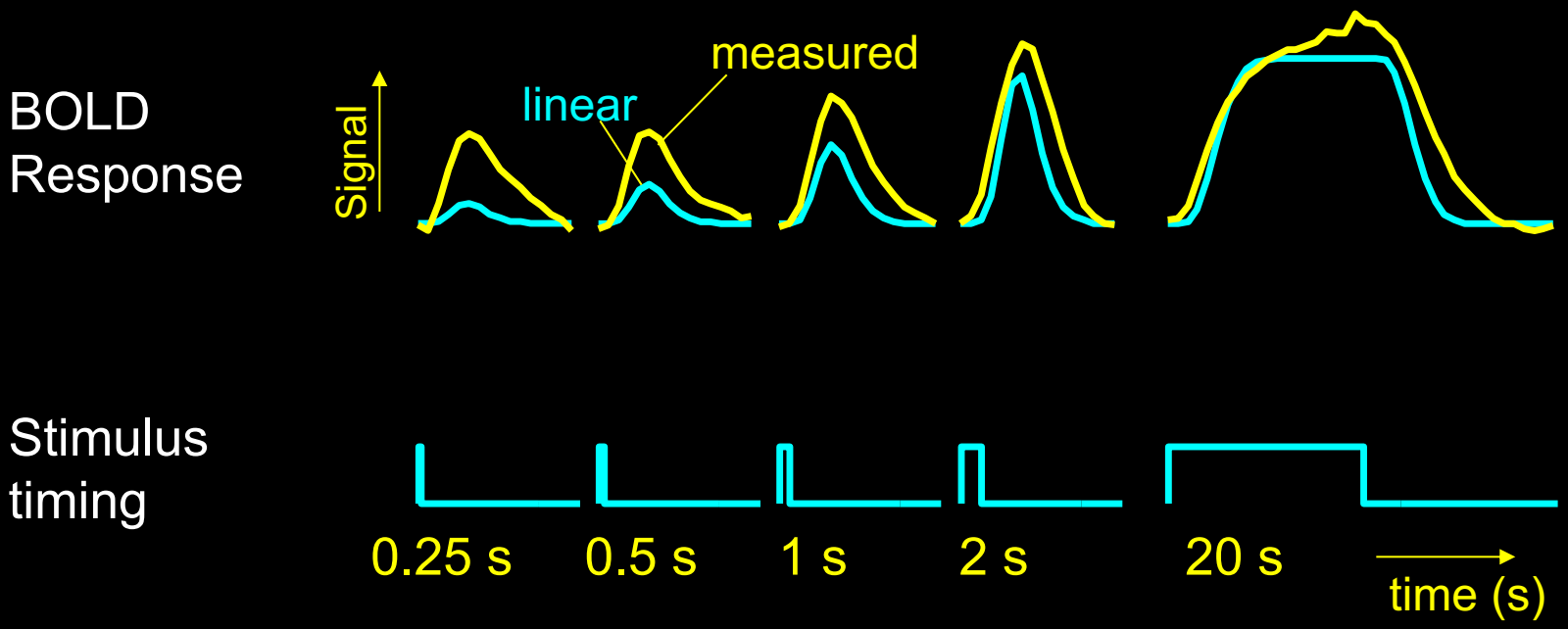


Experiment 1 Experiment 2



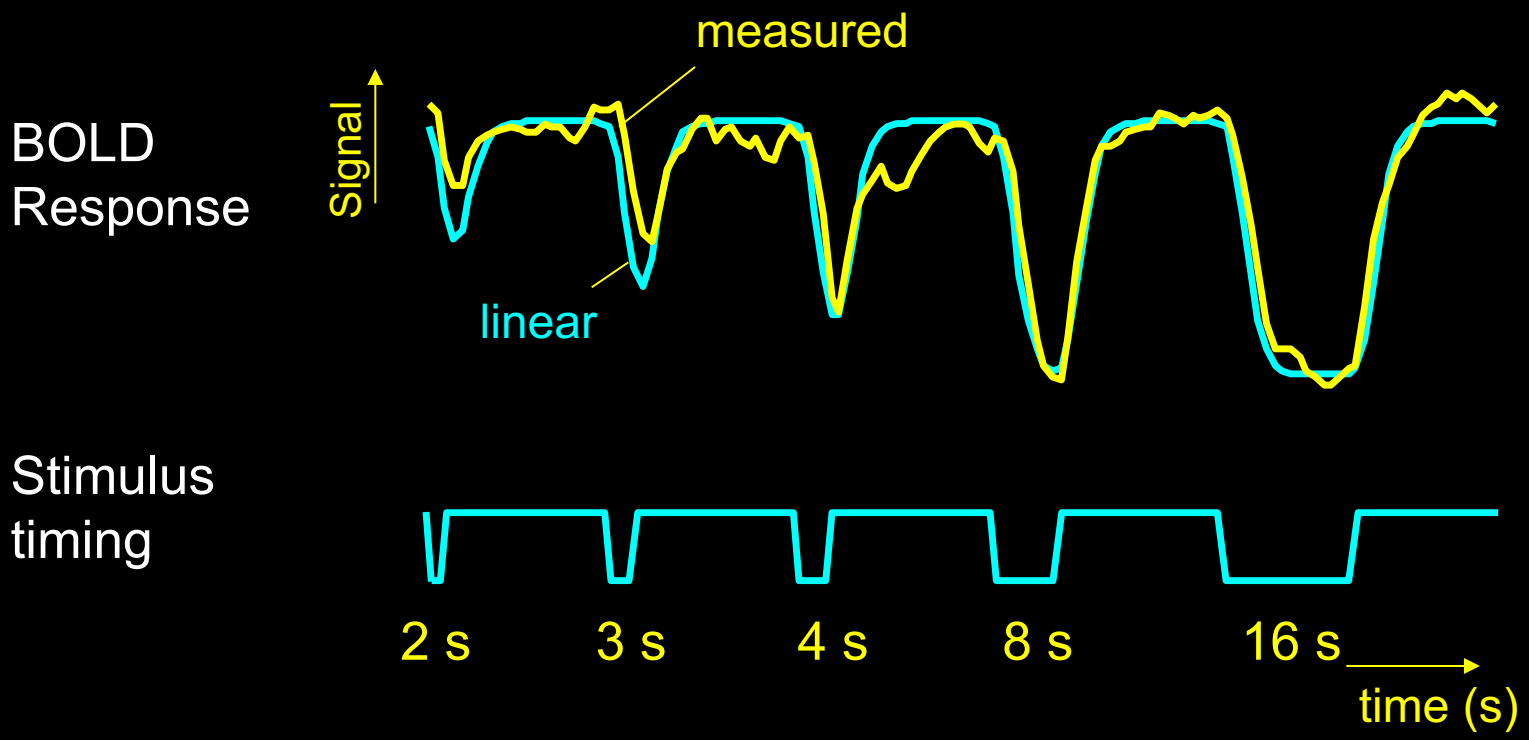
Experiment 1 Experiment 2

Different stimulus “ON” periods



Brief stimuli produce larger responses than expected

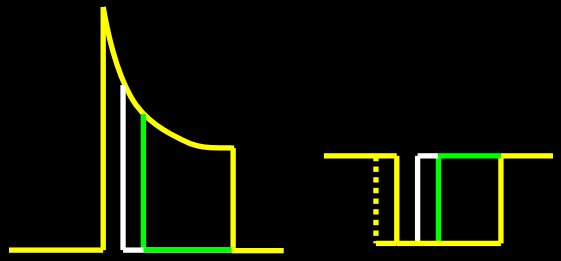
Different stimulus “ON” periods



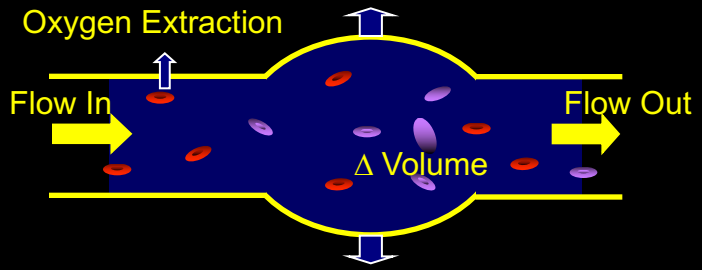
Brief stimulus OFF periods produce smaller decreases than expecte

Sources of this Nonlinearity

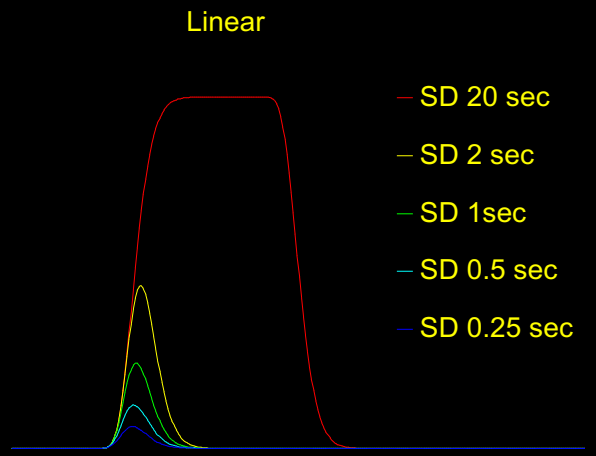
- Neuronal

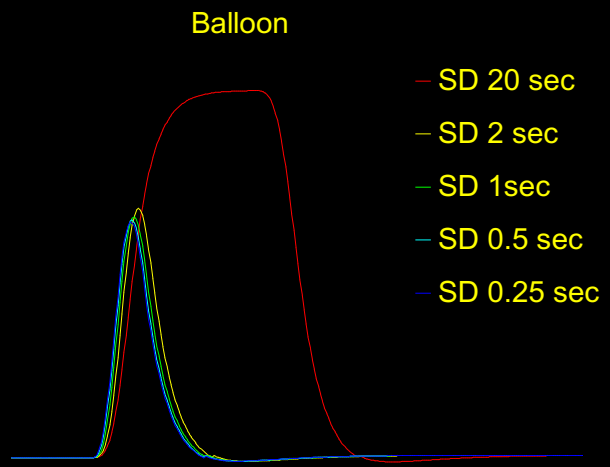


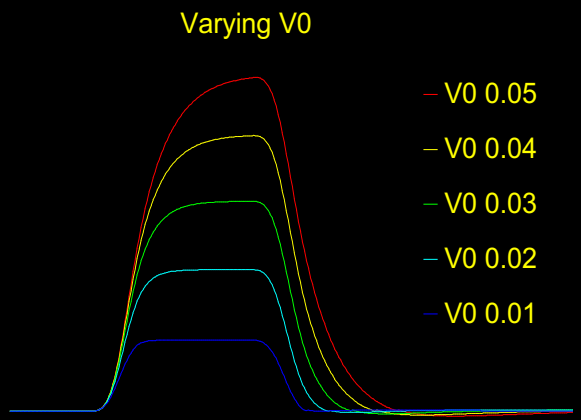
- Hemodynamic
  - Oxygen extraction
  - Blood volume dynamics

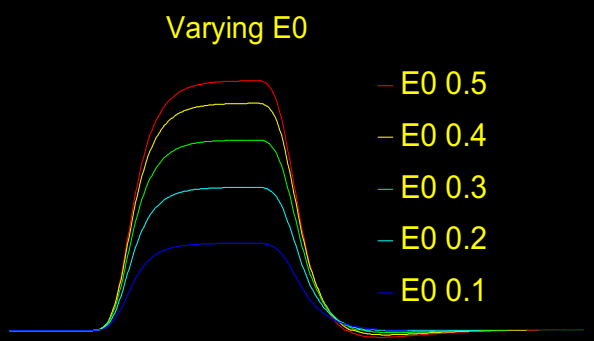


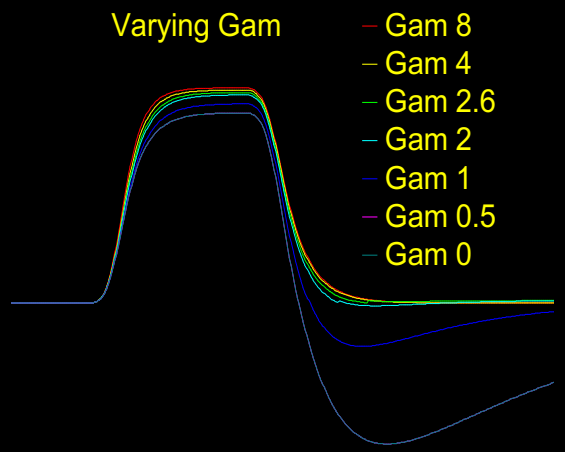
Balloon Model







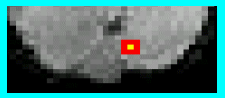




Overview

Balloon Input

ShiftedFlowIn(t)



Functional Dataset

Balloon Model Equations

$$\frac{\Delta S}{S} = V_0\left[(k1+k2)(1-q(t)) - (k2+k3)(1-v(t)\right]$$

$$Exfrac(t) = 1-(1-E_0)^{\frac{1}{ShiftedFlowIn(t)}}$$

$$CMRO_2(t) = ShiftedFlowIn(t) * \frac{Exfrac(t)}{E_0}$$

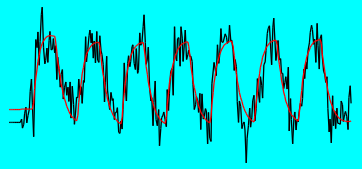
$$FlowOut(t) = v(t)^{\,Gam};\quad \frac{df}{dv} = Gam\left(v(t)\right)^{(Gam-1)}$$

$$\tau_0 = \frac{V_0}{FlowOut(0)}$$

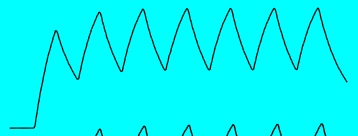
$$q(t) = \frac{Q(t)}{Q_0};\quad \frac{dq}{dt} = \frac{1}{\tau_0}\left[ShiftedFlowIn(t)\frac{Exfrac(t)}{E_0} - FlowOut(t)\frac{q(t)}{v(t)}\right]$$

$$v(t) = \frac{V(t)}{V_0};\quad \frac{dv}{dt} = \frac{1}{\tau_0}\left[\frac{ShiftedFlowIn(t) - FlowOut(t)}{1+0.5\left(\frac{dt}{\tau_0}\right)\left(\frac{df}{dv}\right)+\left(\frac{viscos}{\sqrt{v(t)}}\right)}\right]$$

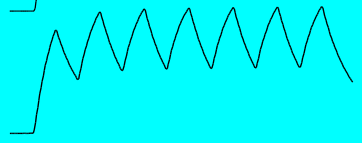
Optimized Balloon Output



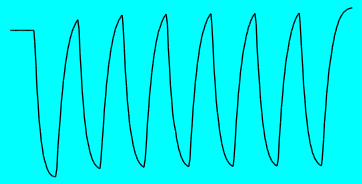
Balloon Fit to BOLD Signal



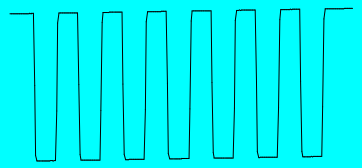
FlowOut(t)



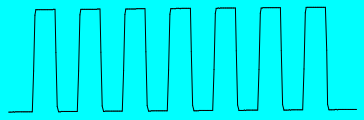
v(t)



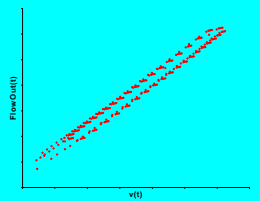
q(t)



Exfrac(t)



$CMRO_2$



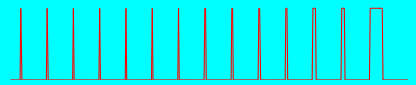
FlowOut(t) versus v(t)

Stimulus

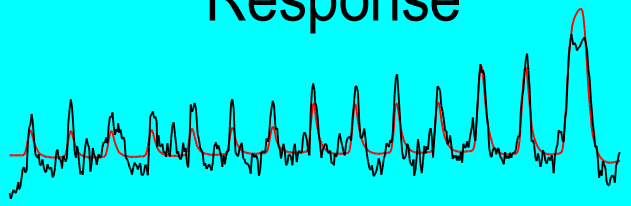
Voxelwise Analysis

Response

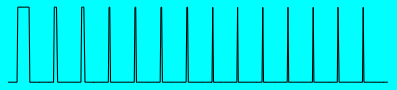
A



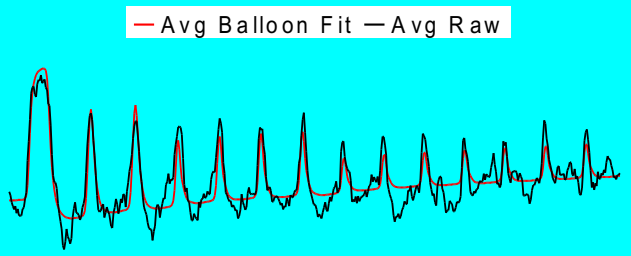
Balloon Model



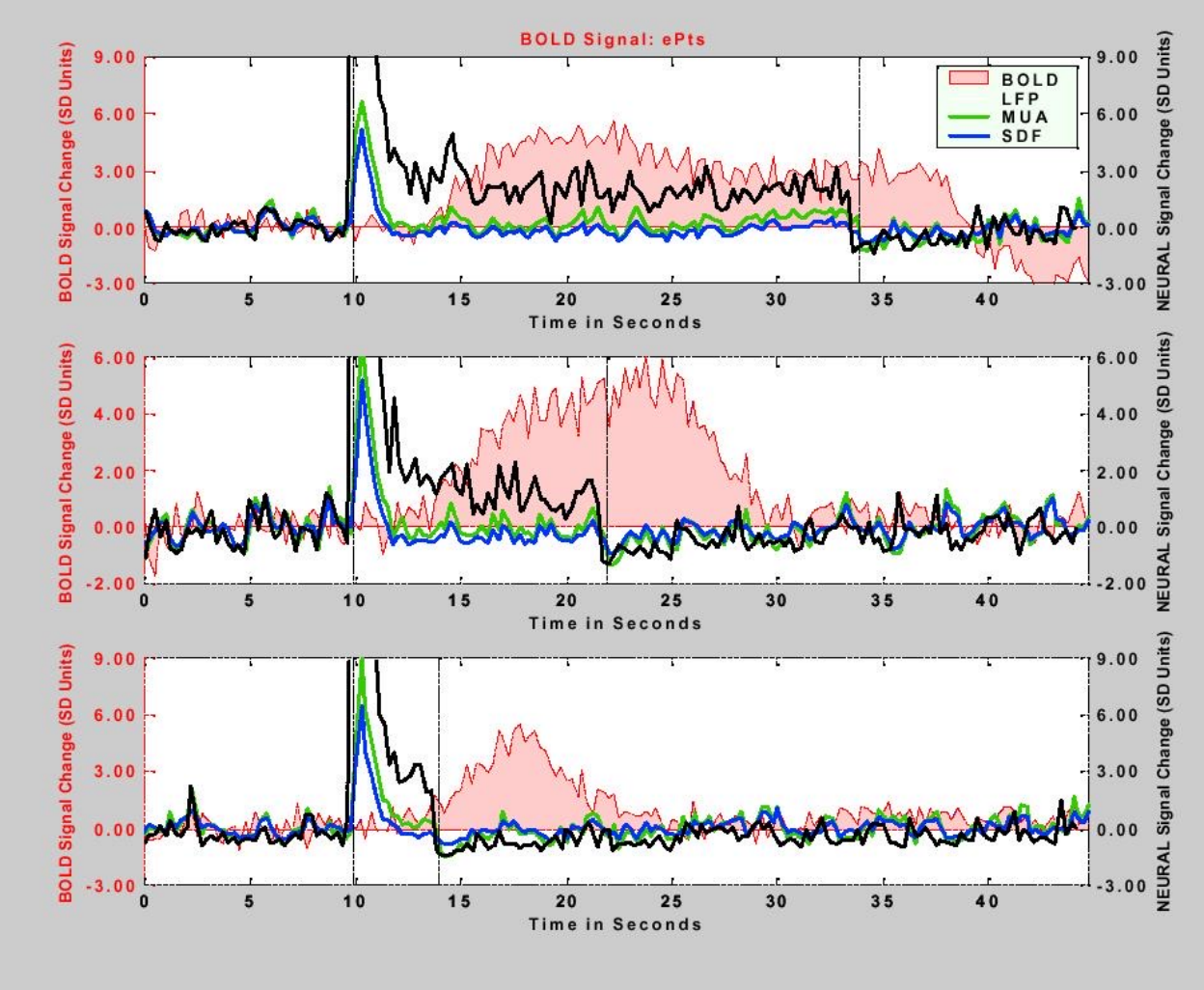
B



Functional Dataset

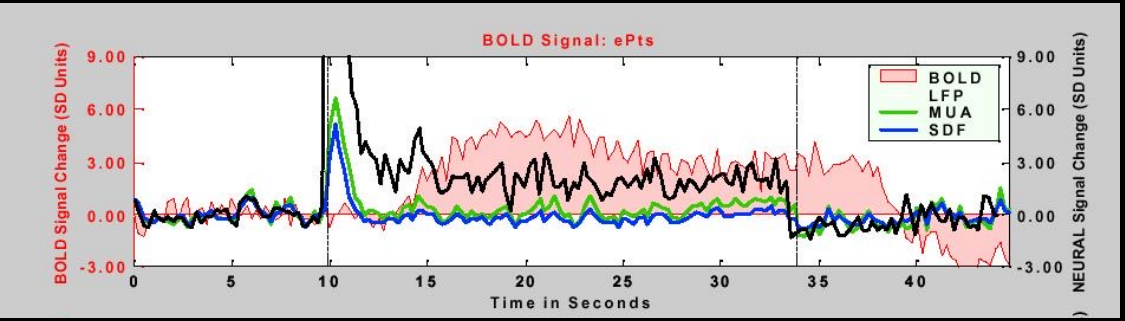


BOLD Correlation with Neuronal Activity

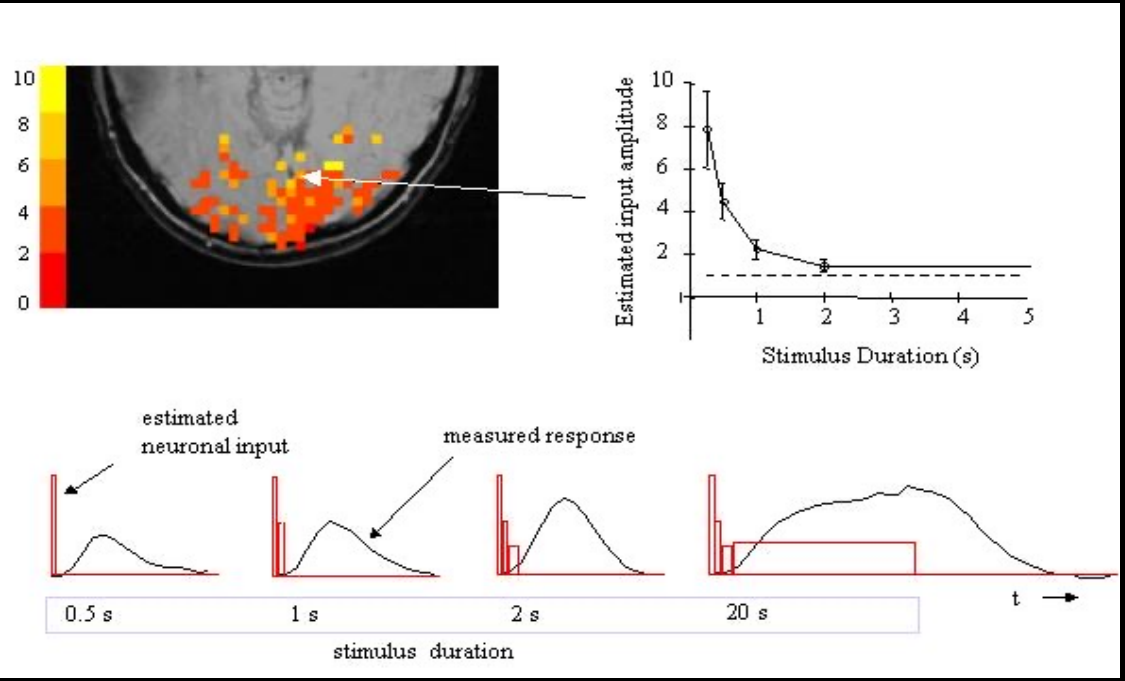


Logothetis et al. Nature, 412, 150-157

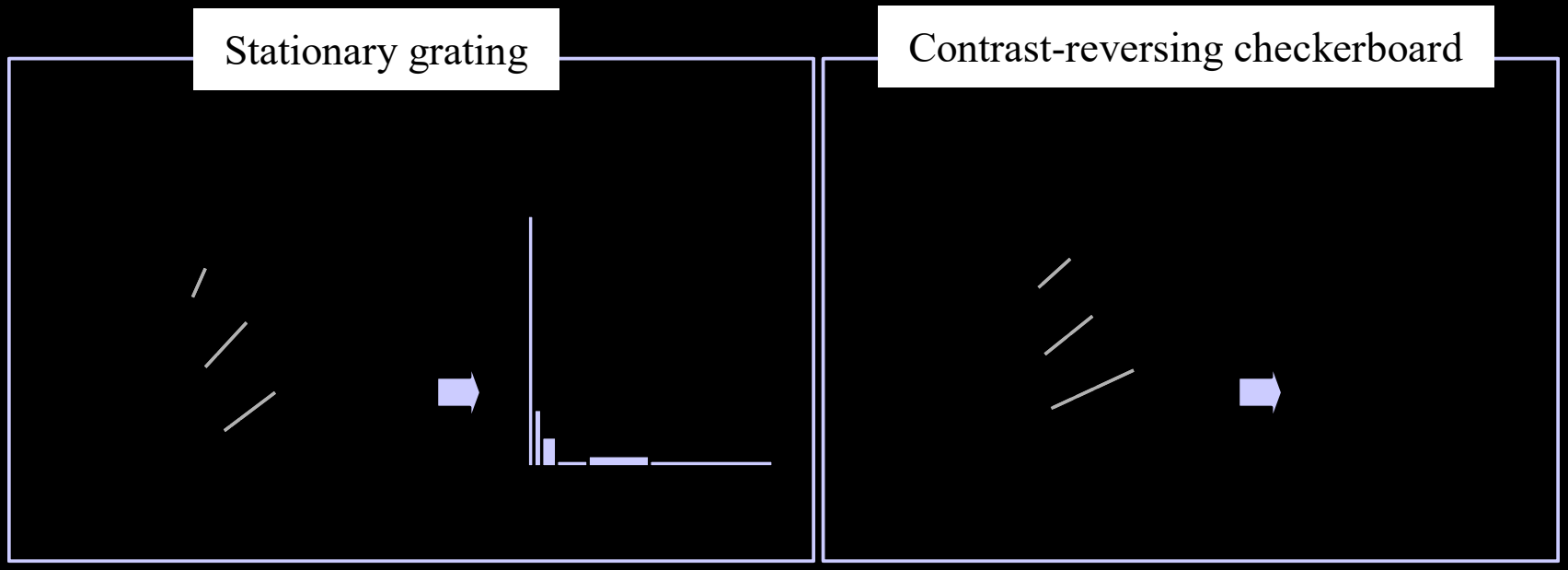
BOLD Correlation with Neuronal Activity



Logothetis et al. Nature, 412, 150-157

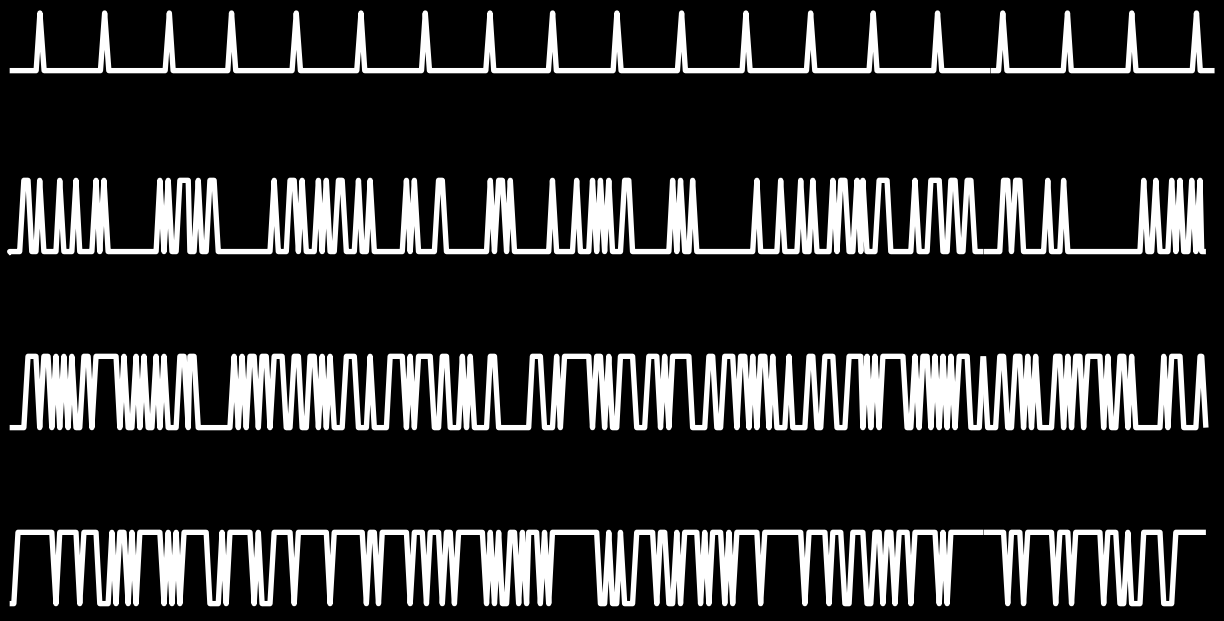


Bandettini and Ungerleider, Nature Neuroscience, 4, 864-866


Stationary grating
Contrast-reversing checkerboard

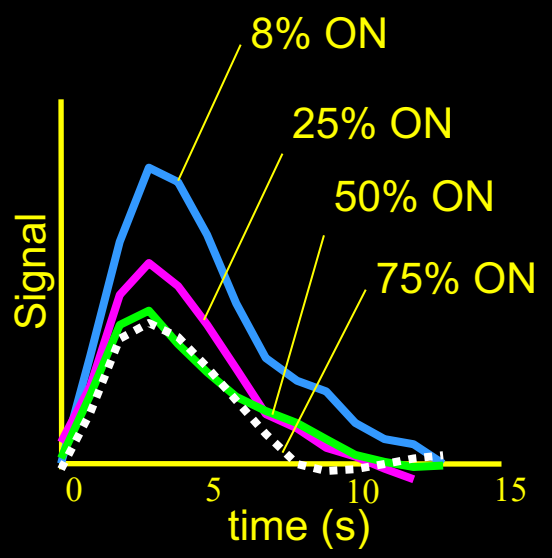
Varying “ON” and “OFF” periods

- *Rapid event-related design with varying ISI*

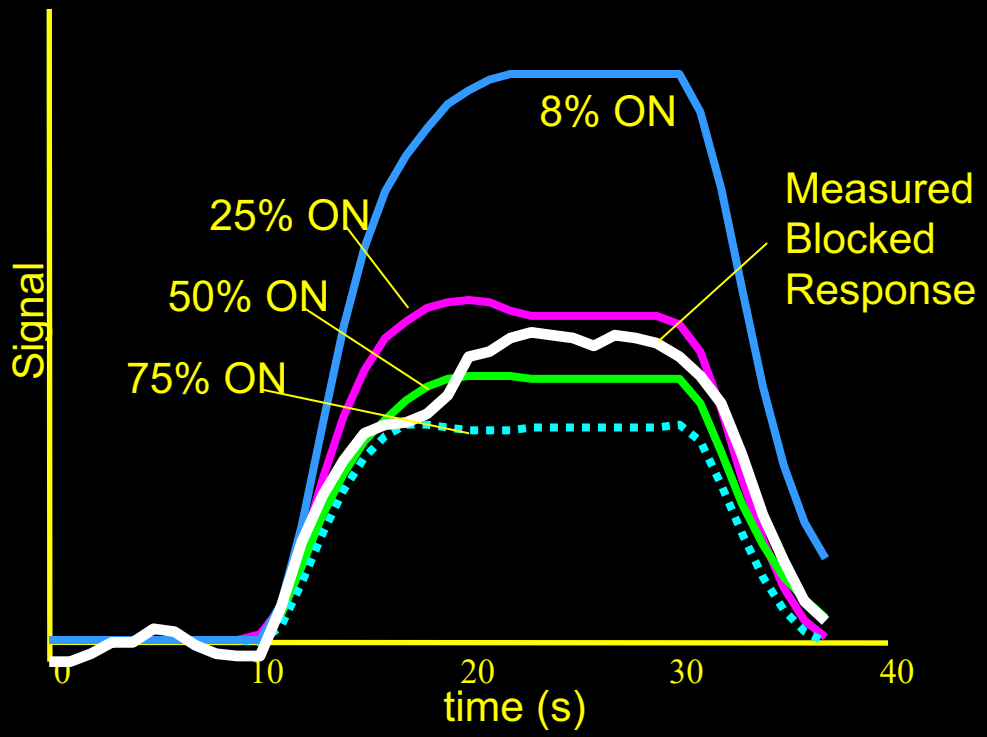


Varying “ON” and “OFF” periods

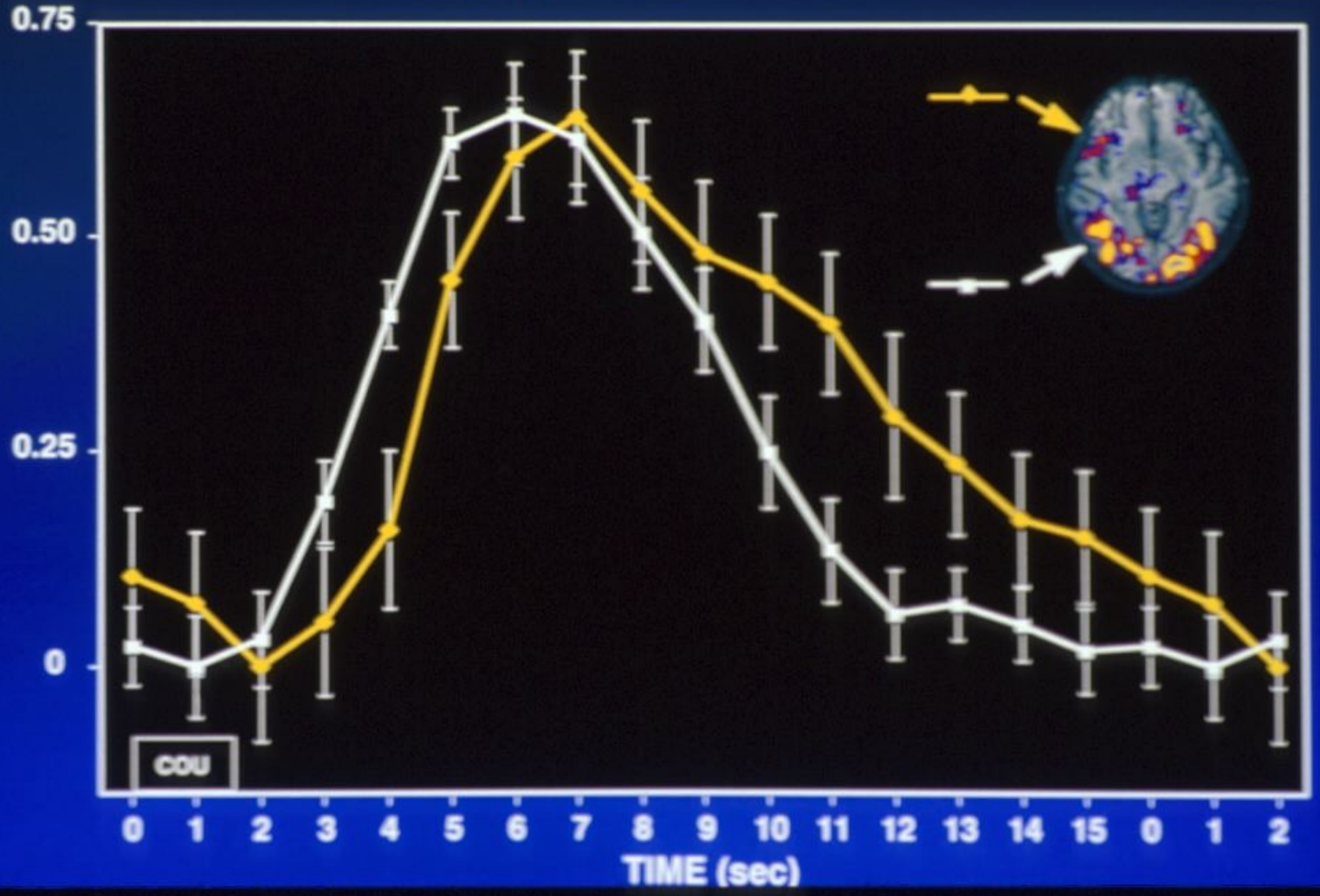
Estimated Impulse Response

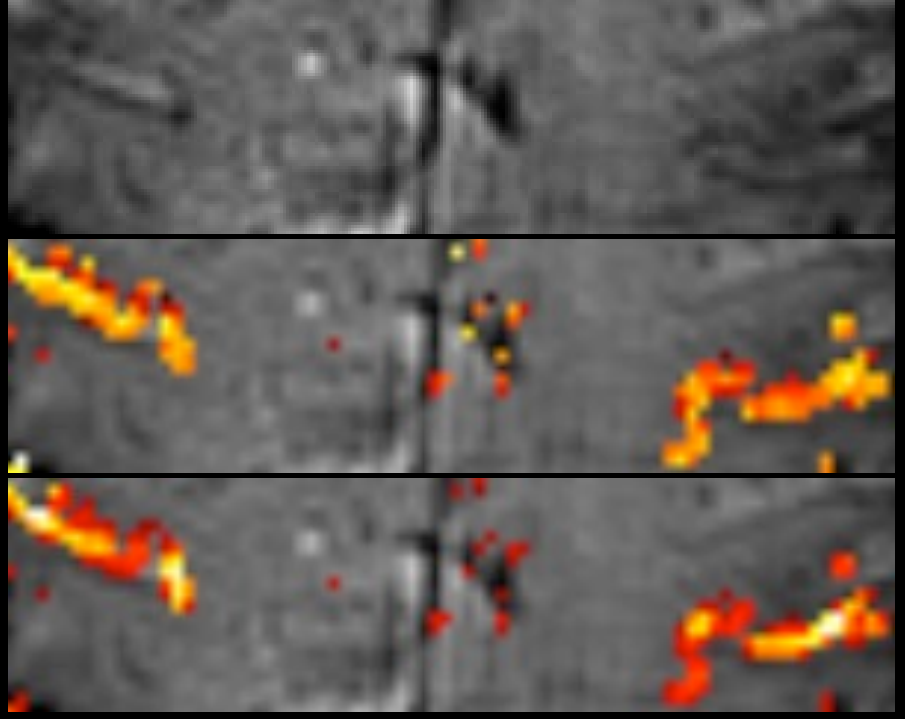


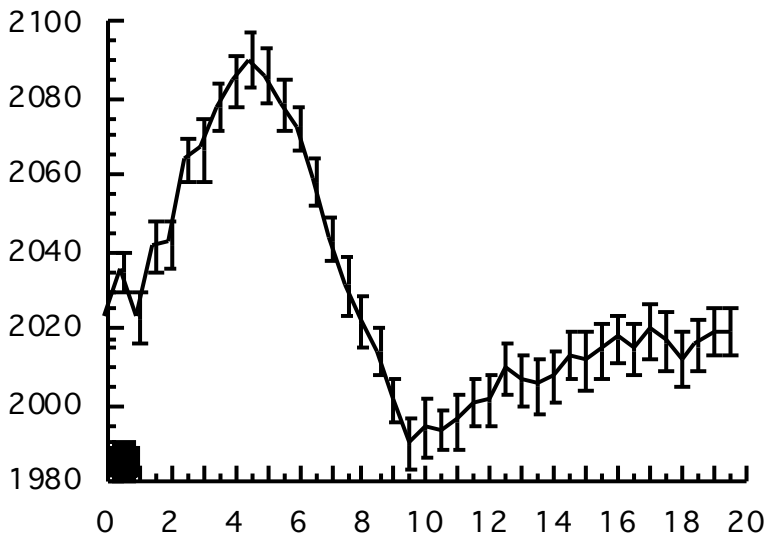
Predicted Responses to 20 s stimulation

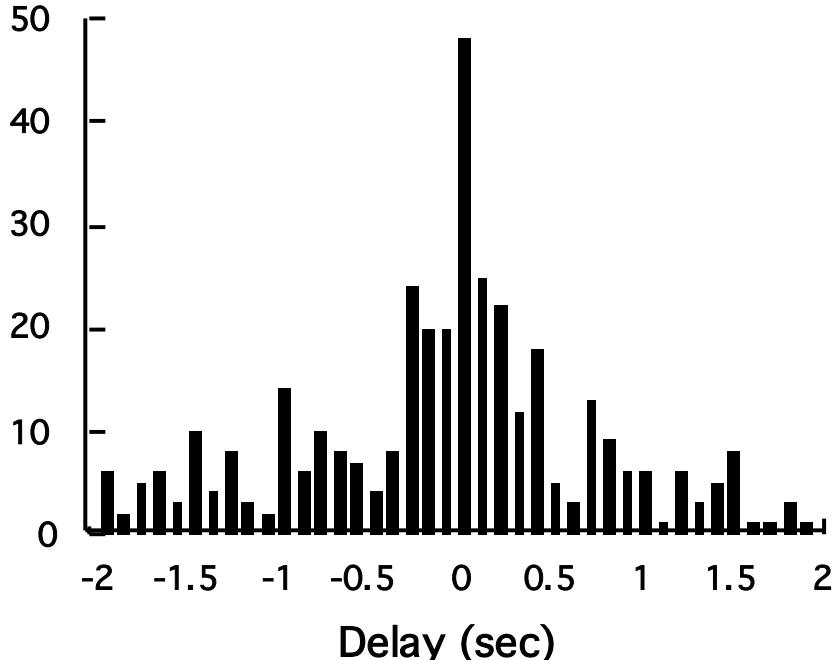


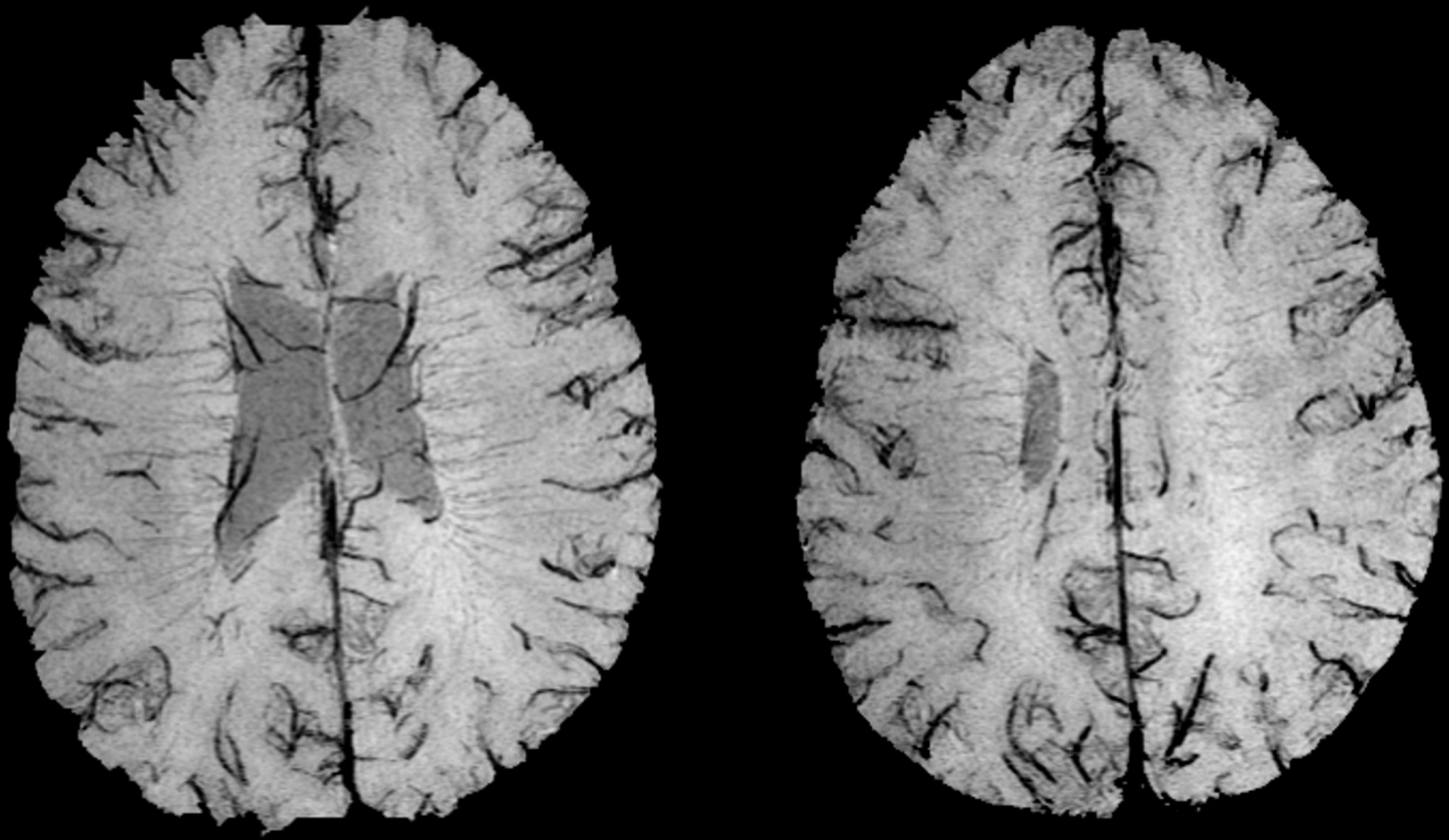
Time Course Comparison Across Brain Regions

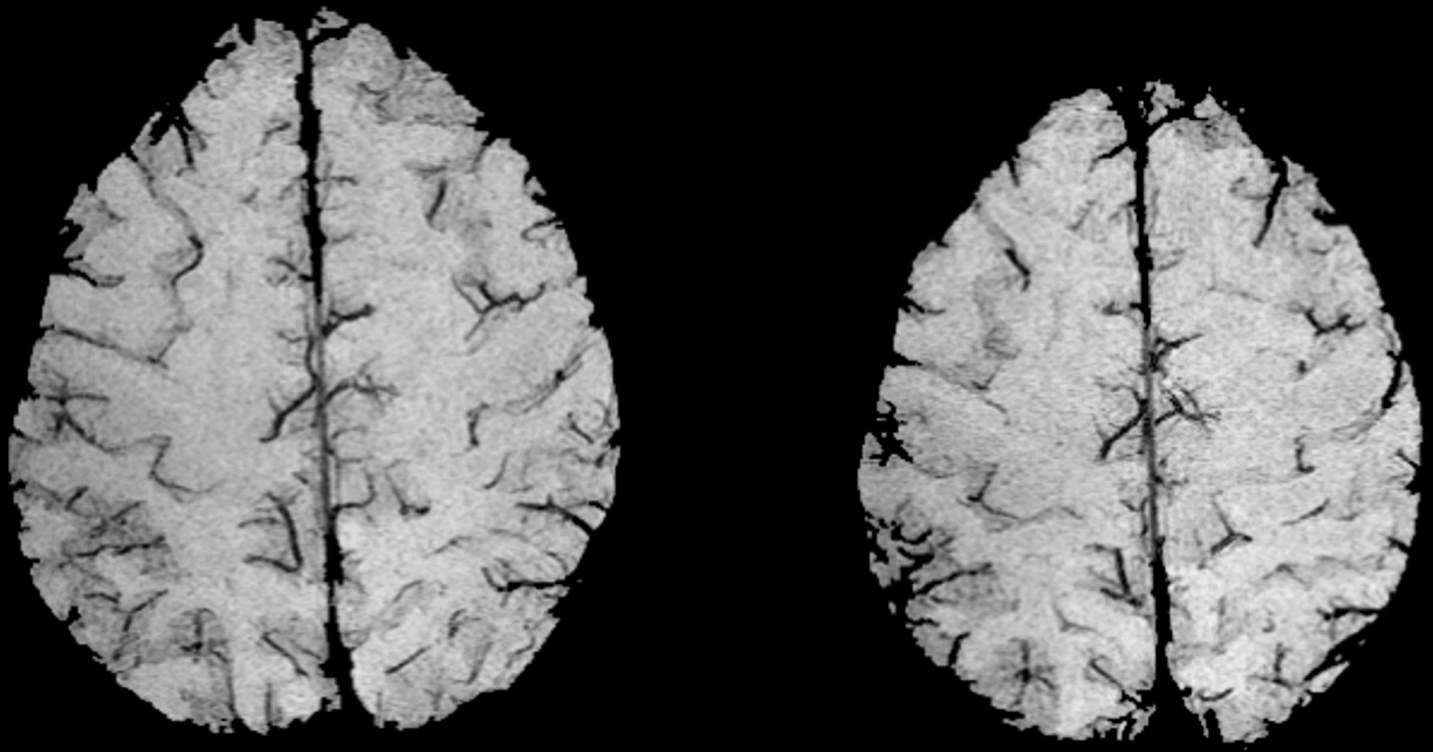


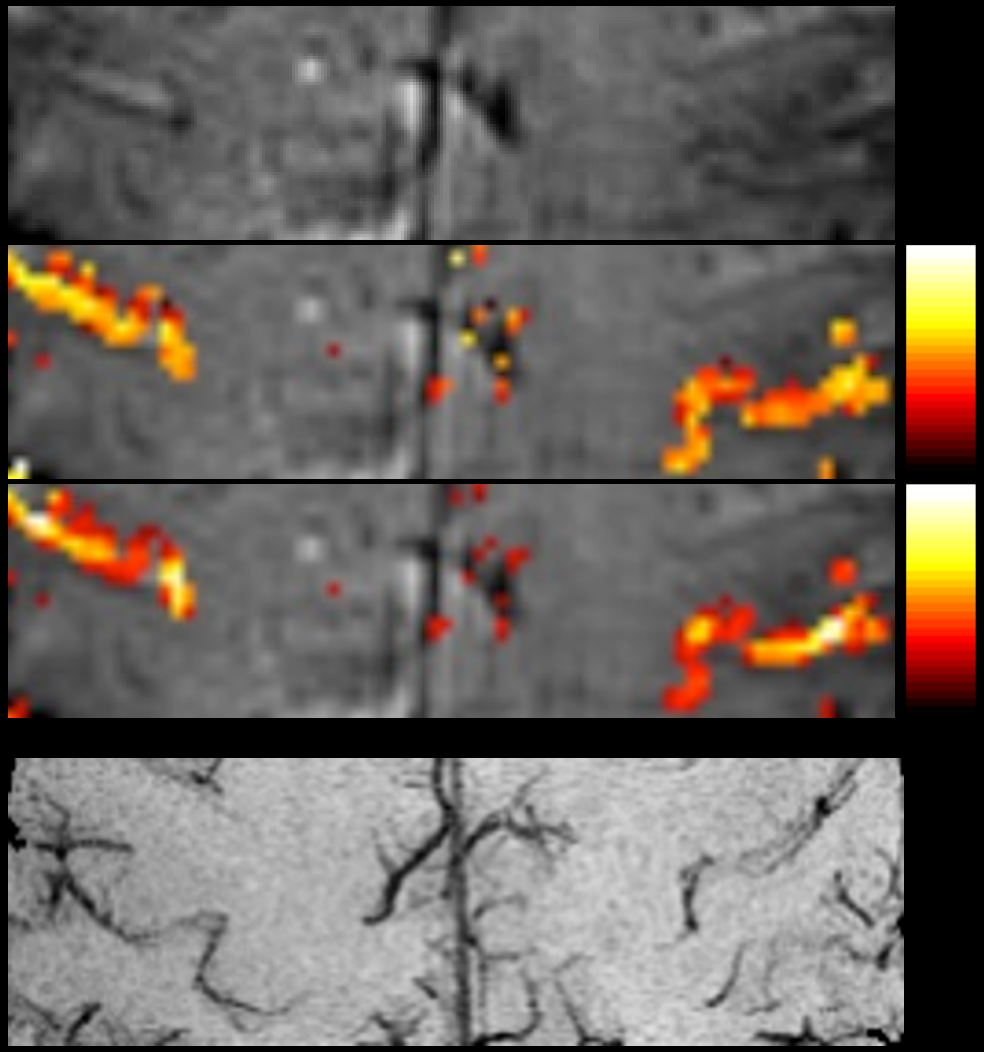

Latency
Magnitude
+ 2 sec
- 2 sec

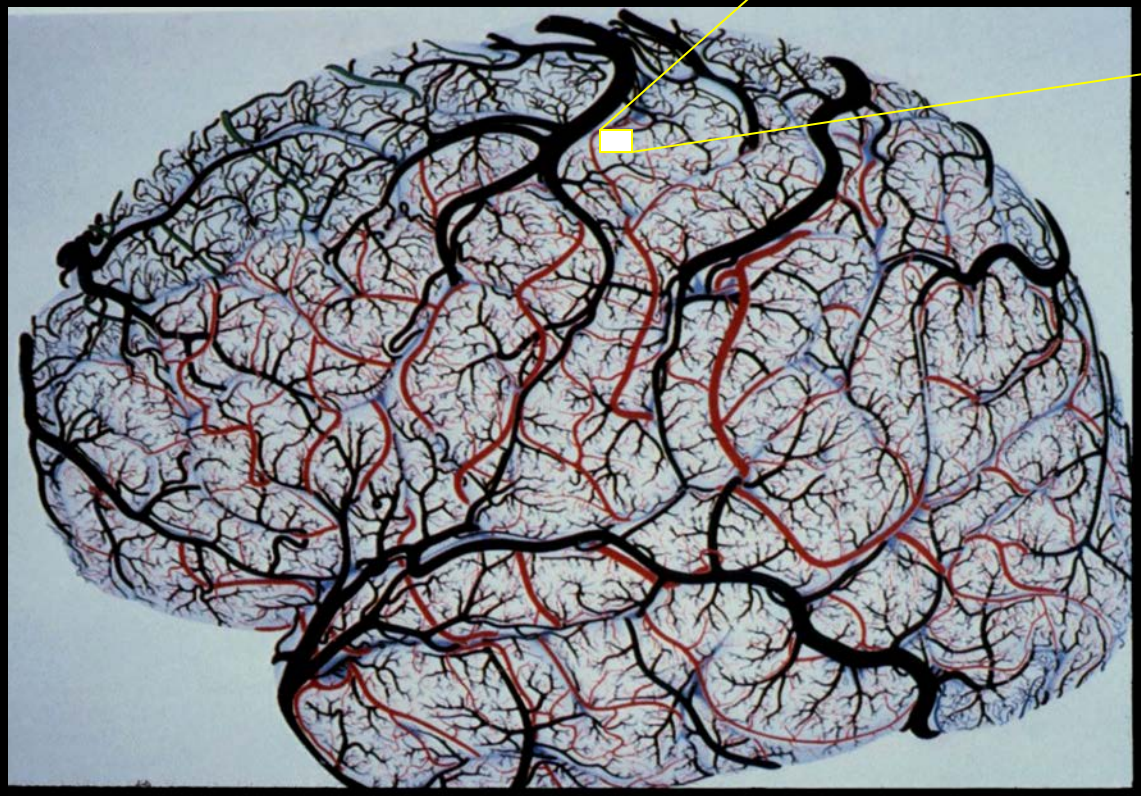

2100
2080
2060
2040
2020
2000
1980
0 2 4 6 8 10 12 14 16 18 20
Time (sec)


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

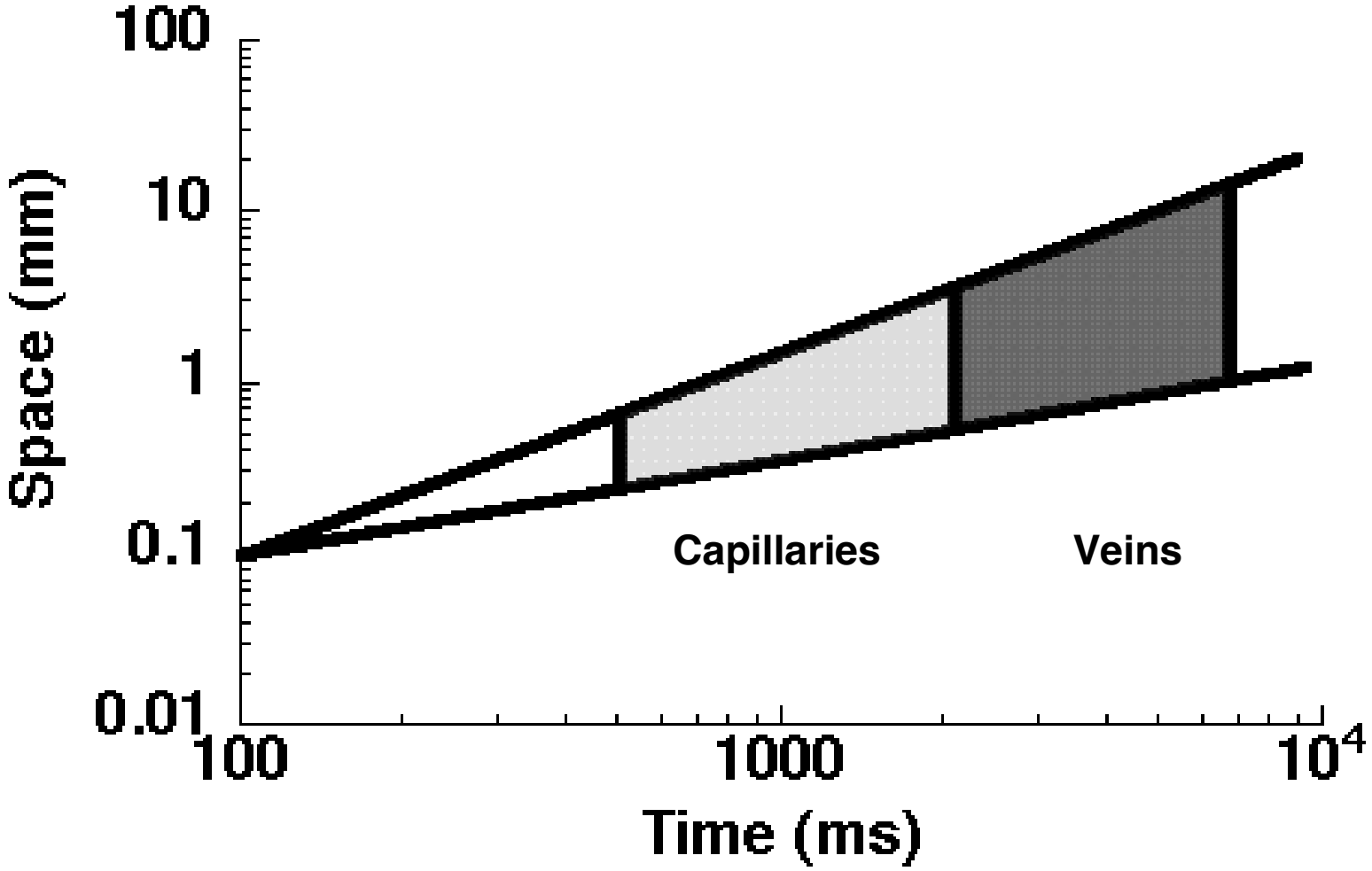




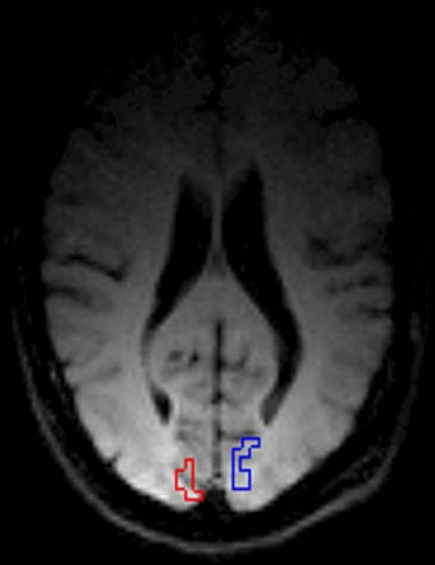




Hemodynamic Latency and Variability Following Neuronal Activation

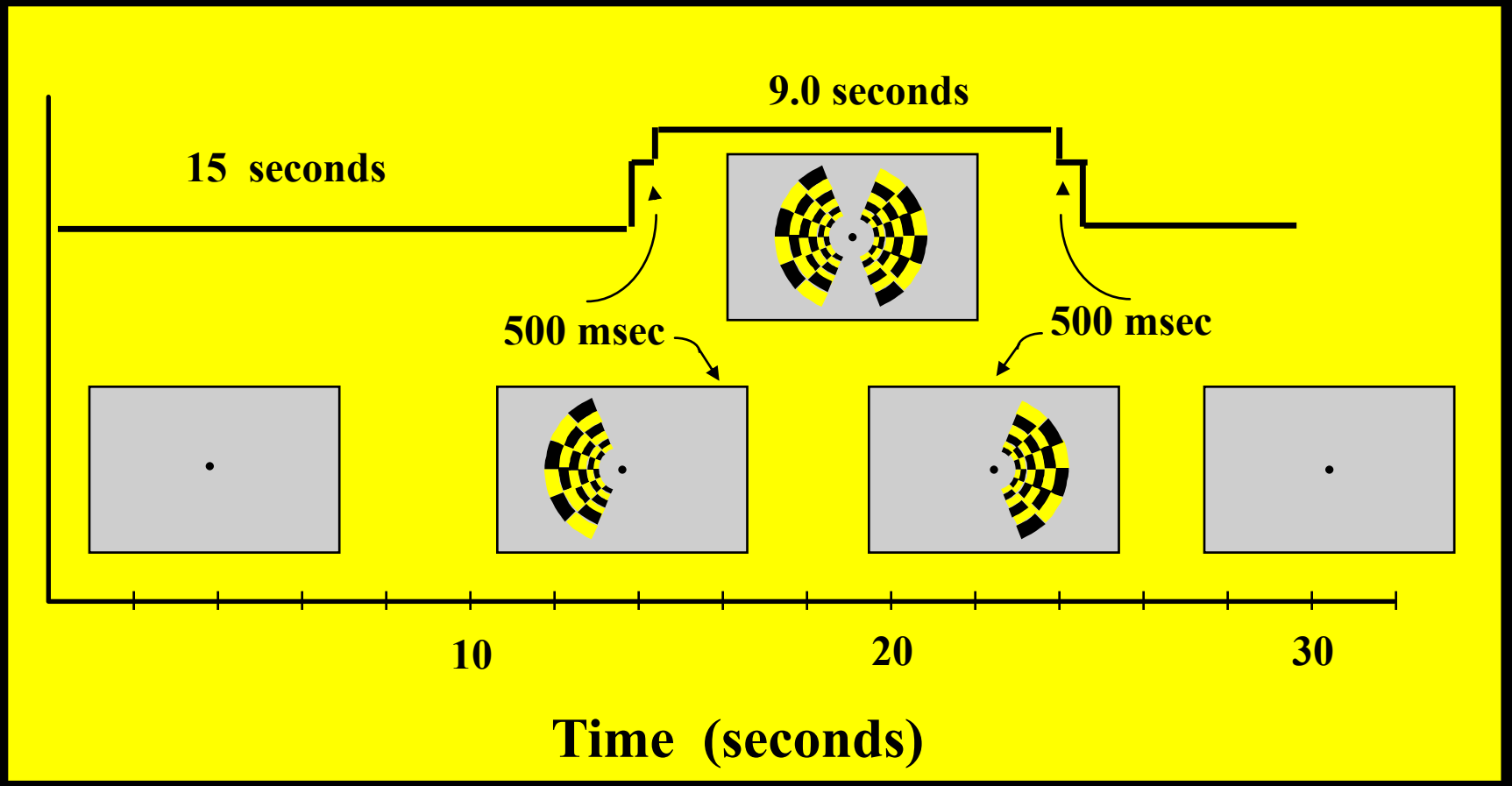


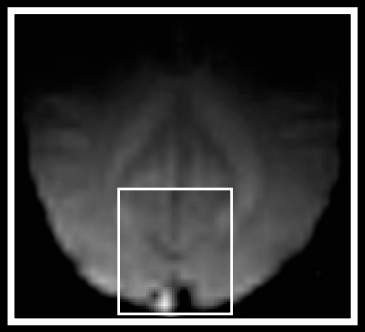
Regions of Interest Used for Hemi-Field Experiment



Right Hemisphere

Left Hemisphere

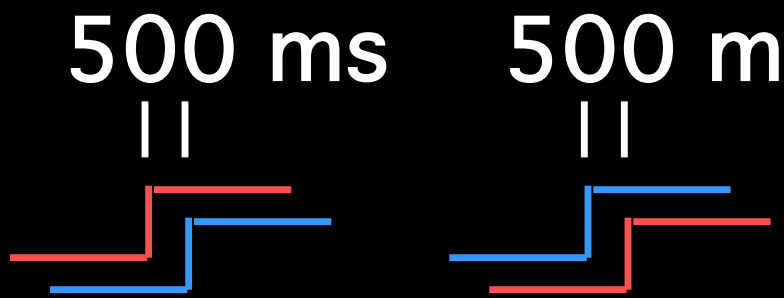

9.0 seconds
15 seconds
500 msec
500 msec
10
20
30
Time (seconds)



500 ms 500 ms

Right Hemifield

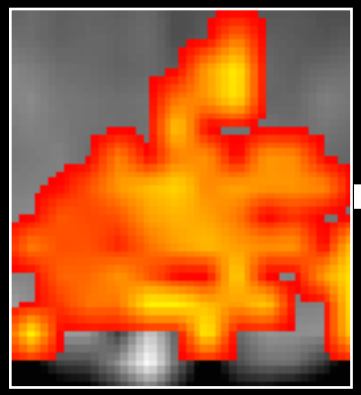
Left Hemifield

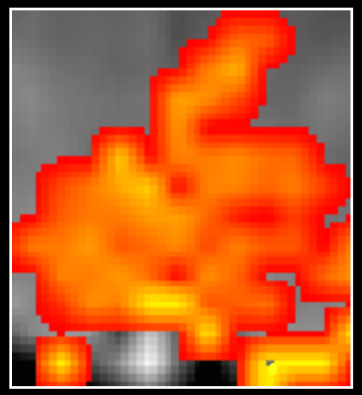


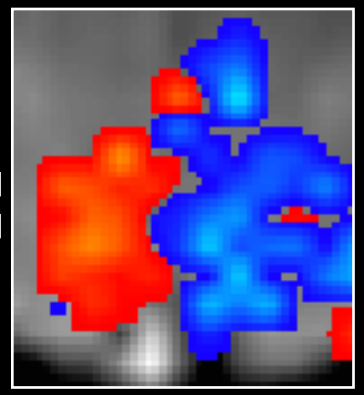
+ 2.5 s

0 s

- 2.5 s







PURPOSE / METHODS

Imaging Method: Scanner – 3T TR - 1000 ms TE - 30 ms

Behavioral Method:

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

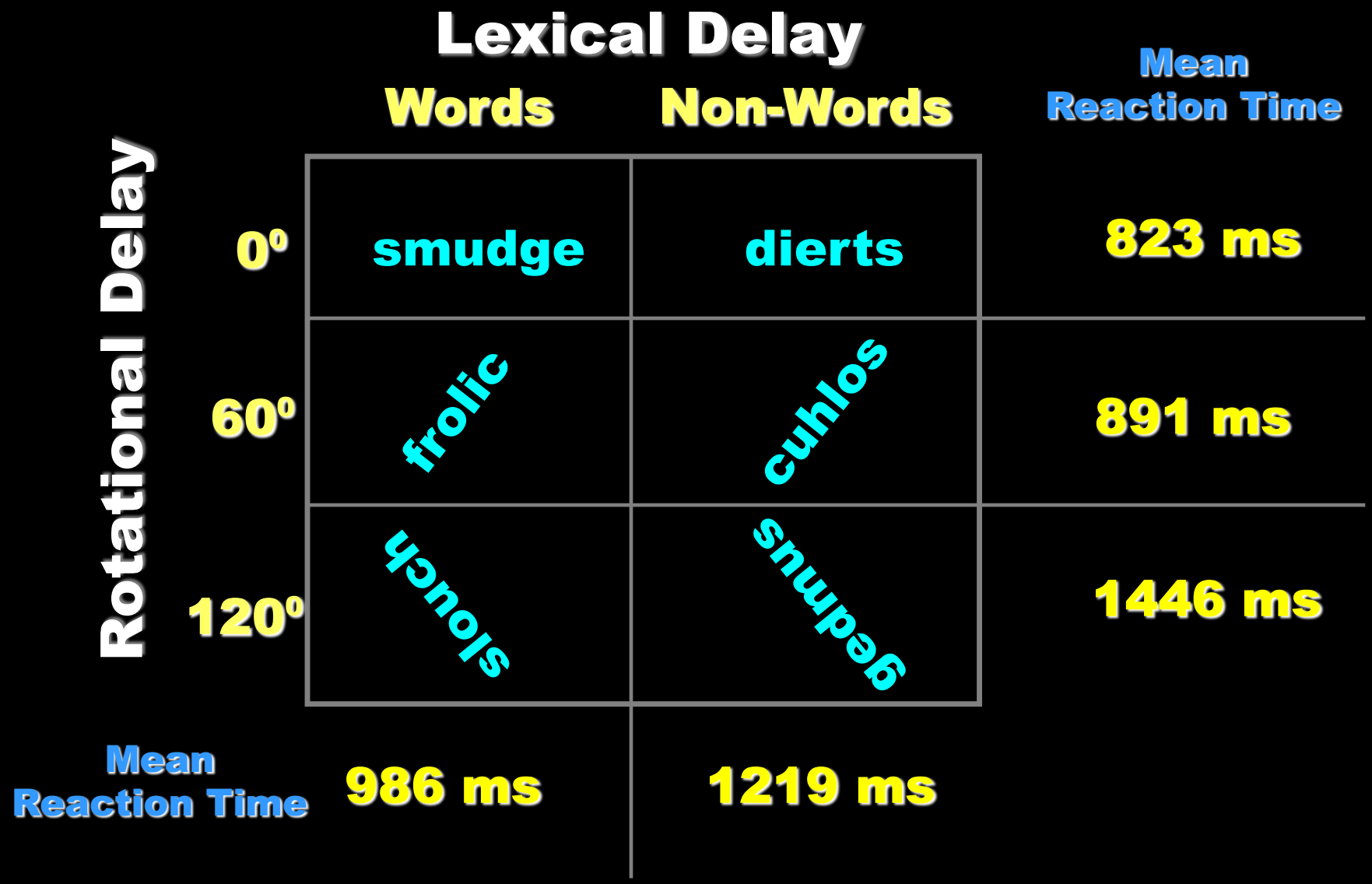
Task – Lexical Decision (word / non-word).

Dependent Measures – Percent Correct and Reaction Time.

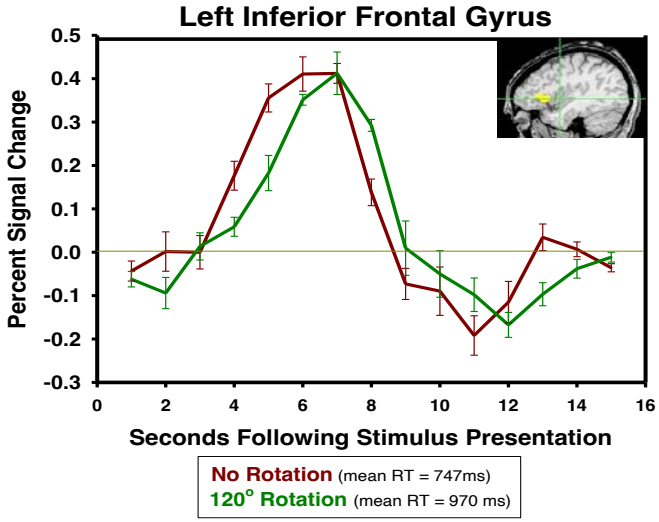
Hypotheses :

1) Stimulus rotation of 120 degrees will result in:
   a) Longer Reaction Times
   b) Wider IRF in Parietal Lobe
   c) Delayed IRF onset in Left Inferior Frontal cortex

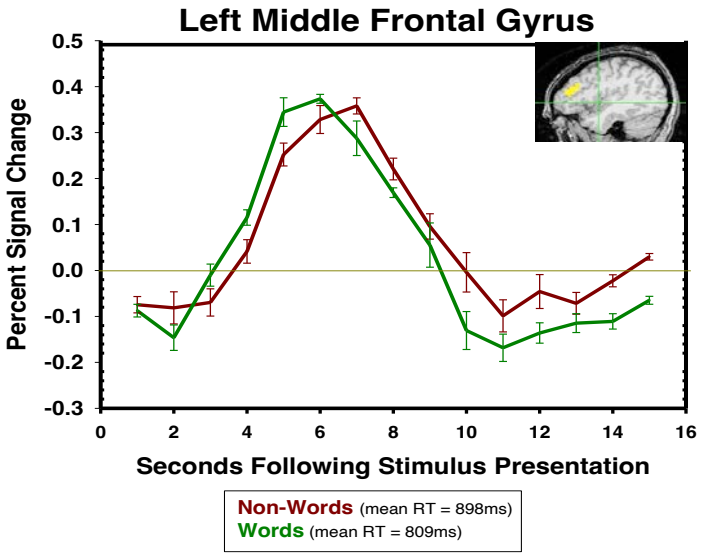
2) Lexical discrimination will result in :
   a) Longer Reaction Times for non-words
   b) Wider IRF in Inferior Frontal cortex for non-words
   c) Delayed IRF onset in Left Middle Frontal Cortex


Lexical Delay
Words
Non-Words
Mean Reaction Time
Rotational Delay
0°
smudge
dierts
823 ms
60°
frolic
cuhlos
891 ms
120°
slouch
geamus
1446 ms
Mean Reaction Time
986 ms
1219 ms

Mean Impulse Response Functions for Activated Voxels

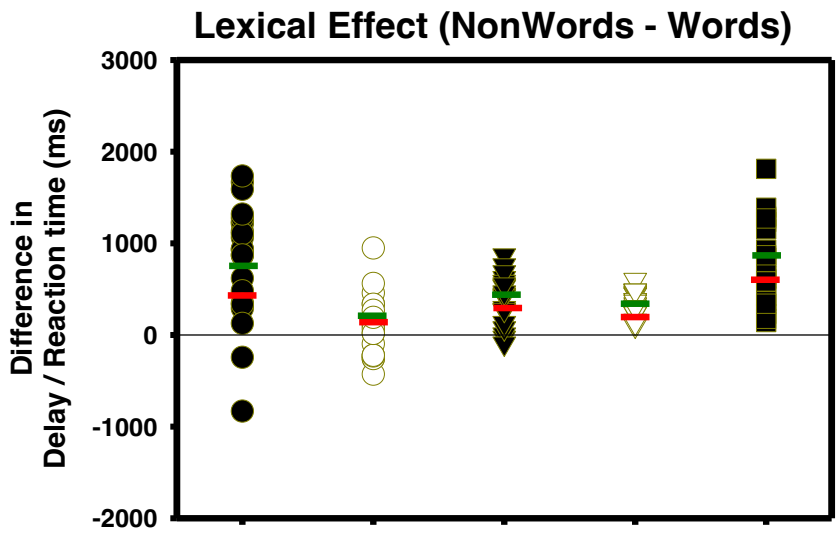


Rotation Effect

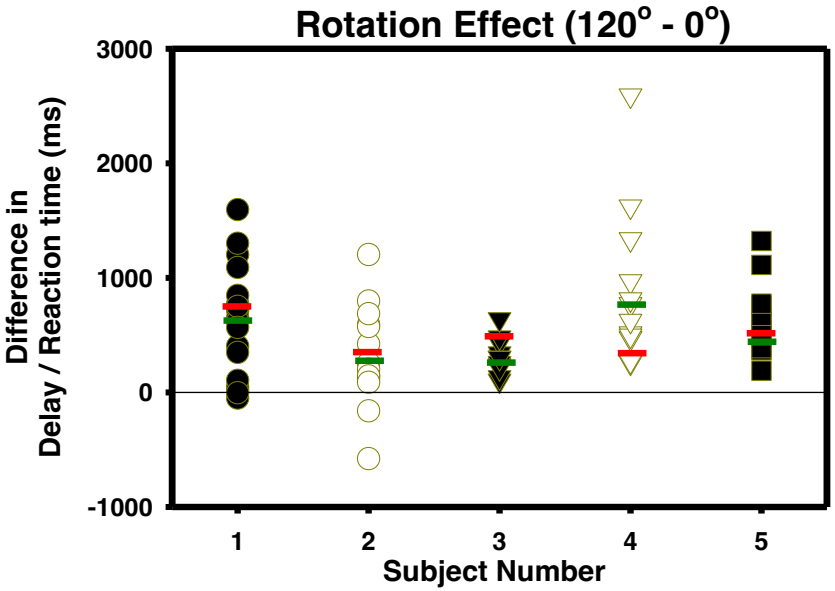


Lexical Effect

Delay Differences from Indivdual Voxels within the Above ROI's



Green lines depict the median Voxel Delay estimate



Red lines depict the mean RT difference

Speed

Temporal Resolution factors:

- Image acquisition rate (10 to 40 images/sec)
- Amount of signal averaging to make functional activation map

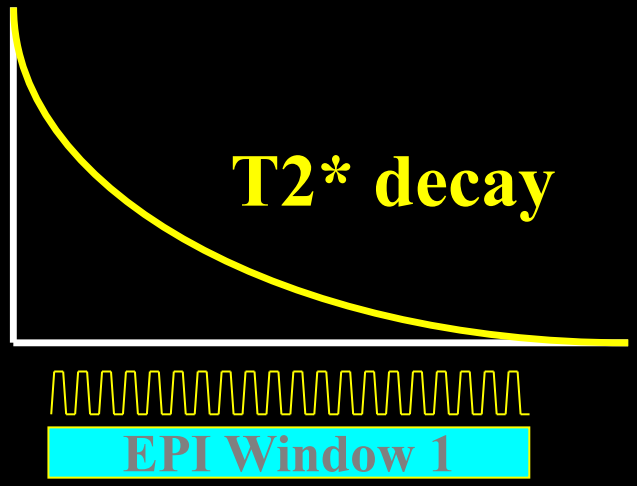
- Time for signal to deviate from baseline (3 sec)
- Fastest on-off rate in which amplitude is not compromised
  (8 sec on / 8 sec off)
- Fastest on-off rate in which hemodynamic response keeps up
  (2 sec on / 2 sec off)
- Minimum activation duration (no limit found)

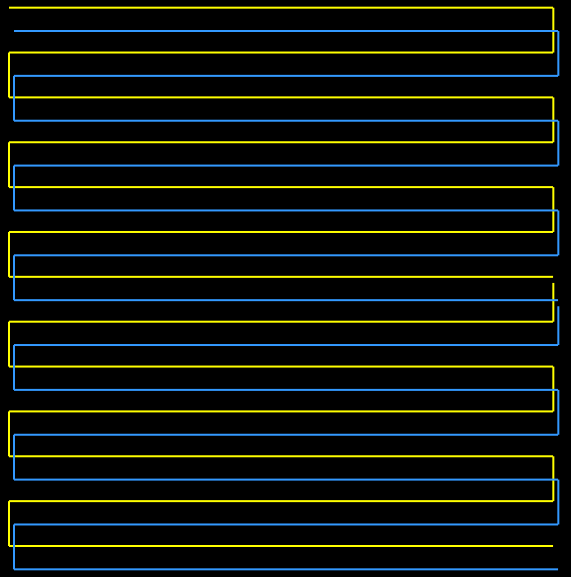
- Standard deviation of hemodynamic response measures per voxel
  (400 ms to 1 sec)
- Range of latencies over space (+ 2.5 sec, - 2.5 sec)

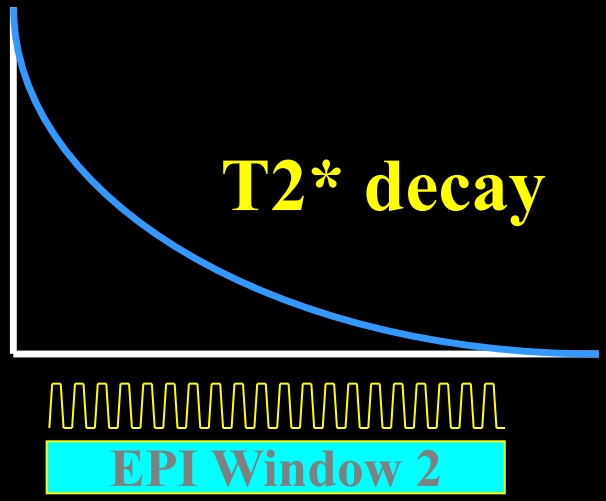
Variables to Optimize

- Information Content
- Sensitivity
- Acquisition Speed
- Resolution
- Image quality

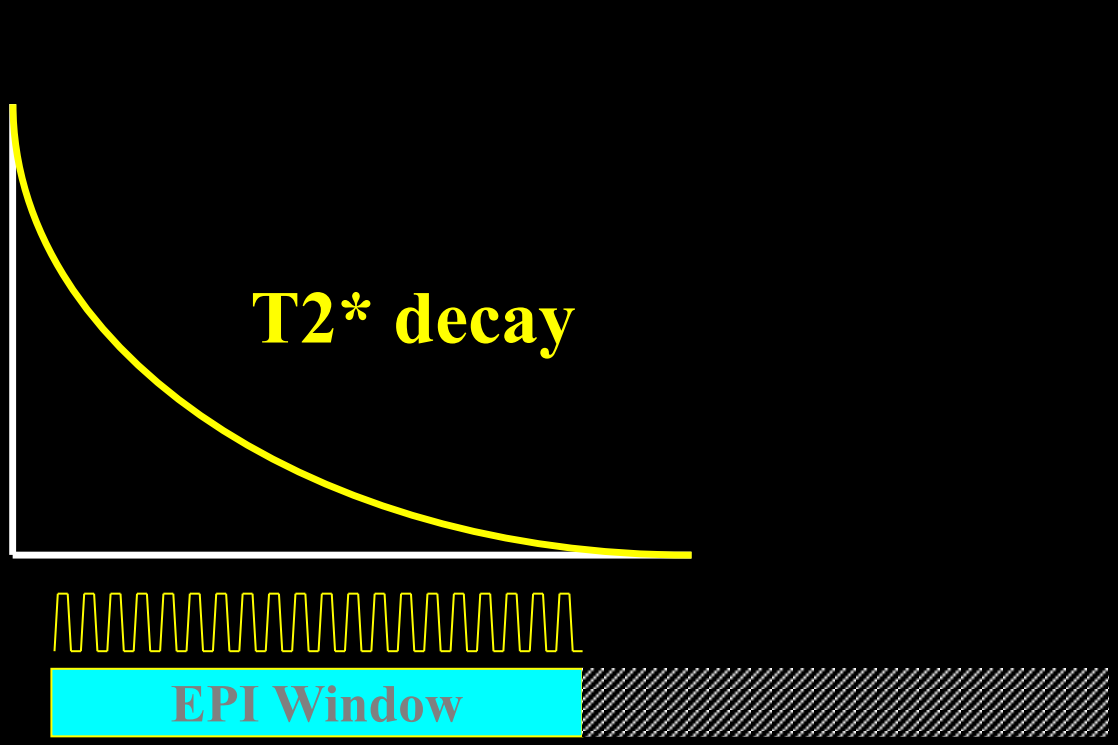
Multishot Imaging

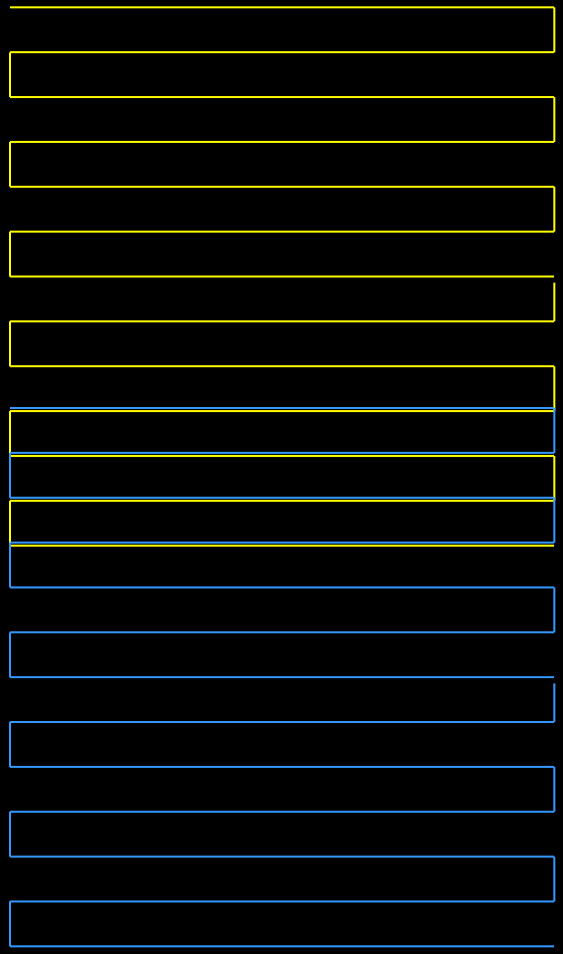




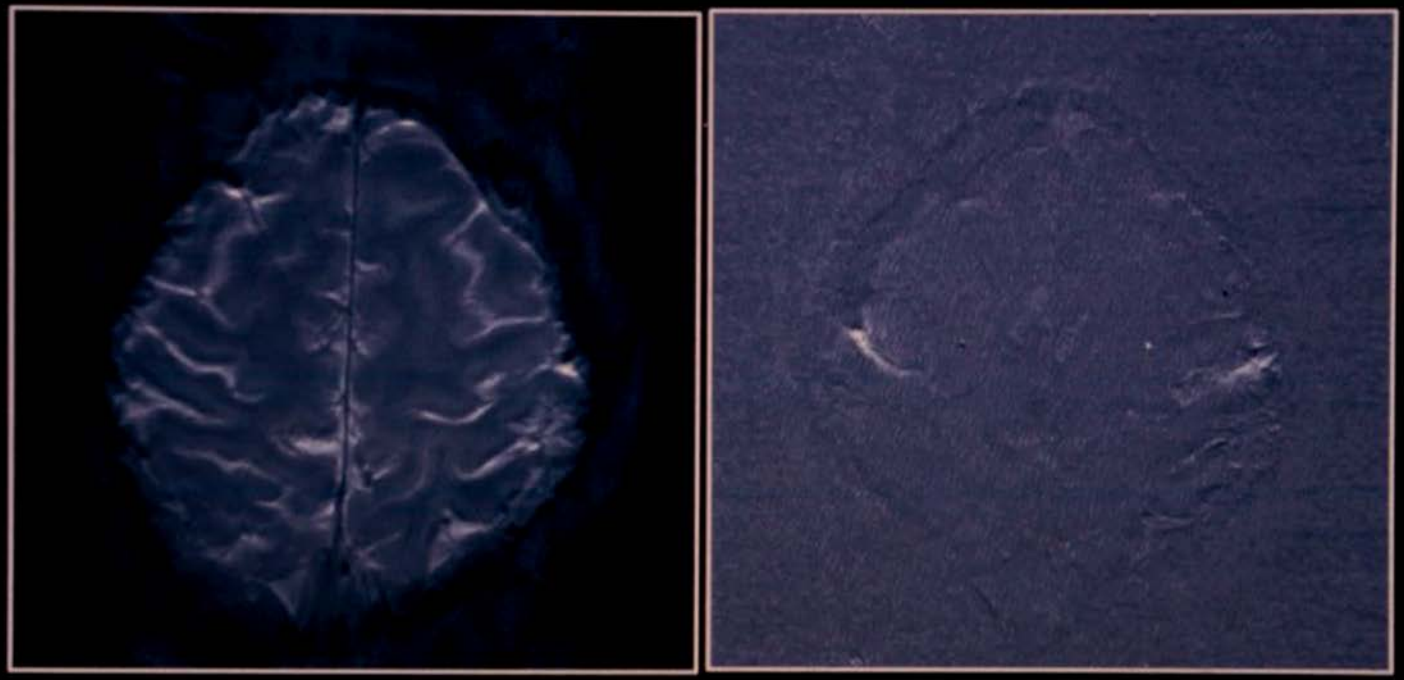


Partial k-space imaging

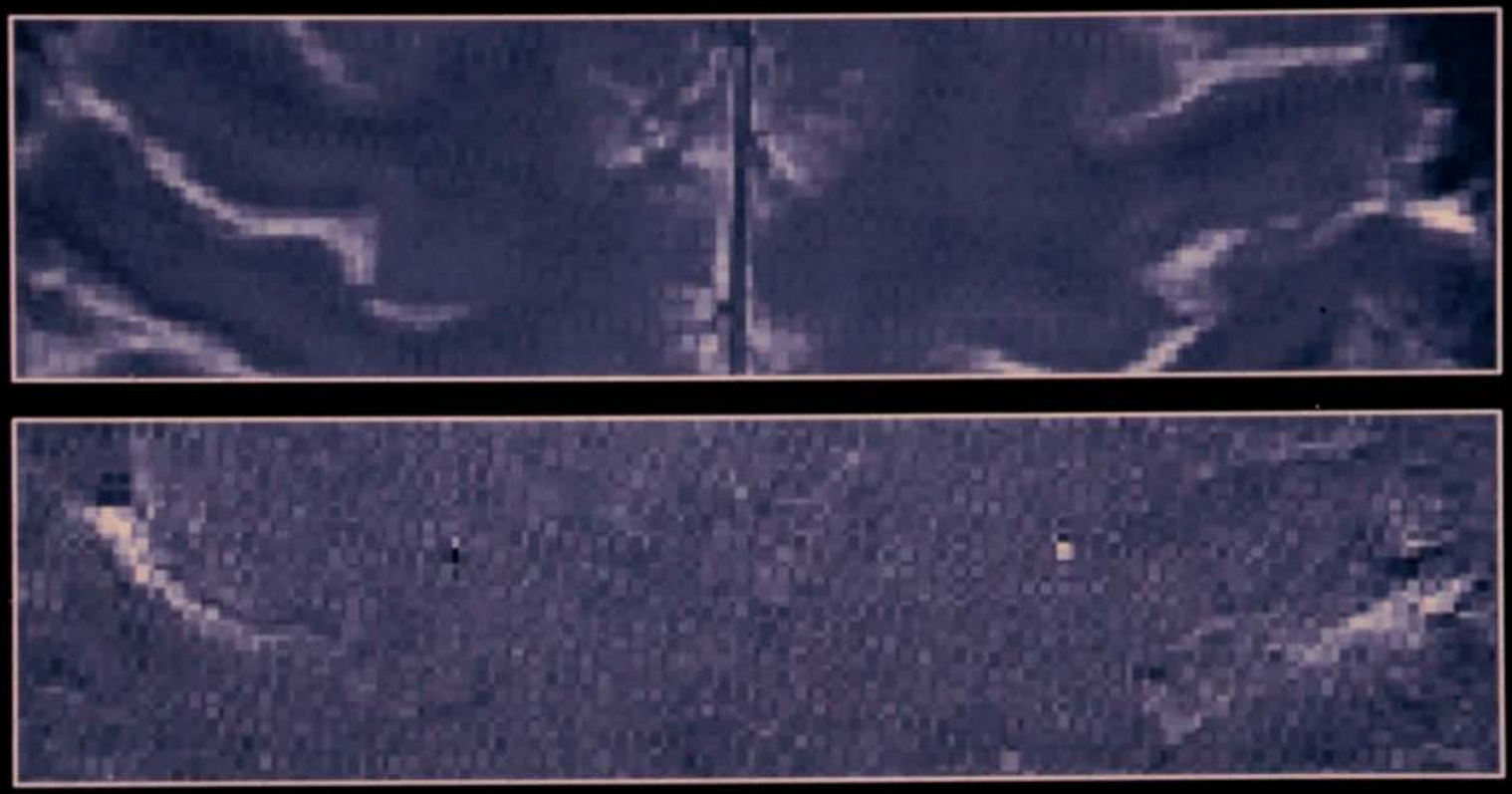




Single - Shot EPI at 3T:
Half NEX, 256 x 256, 16 cm FOV

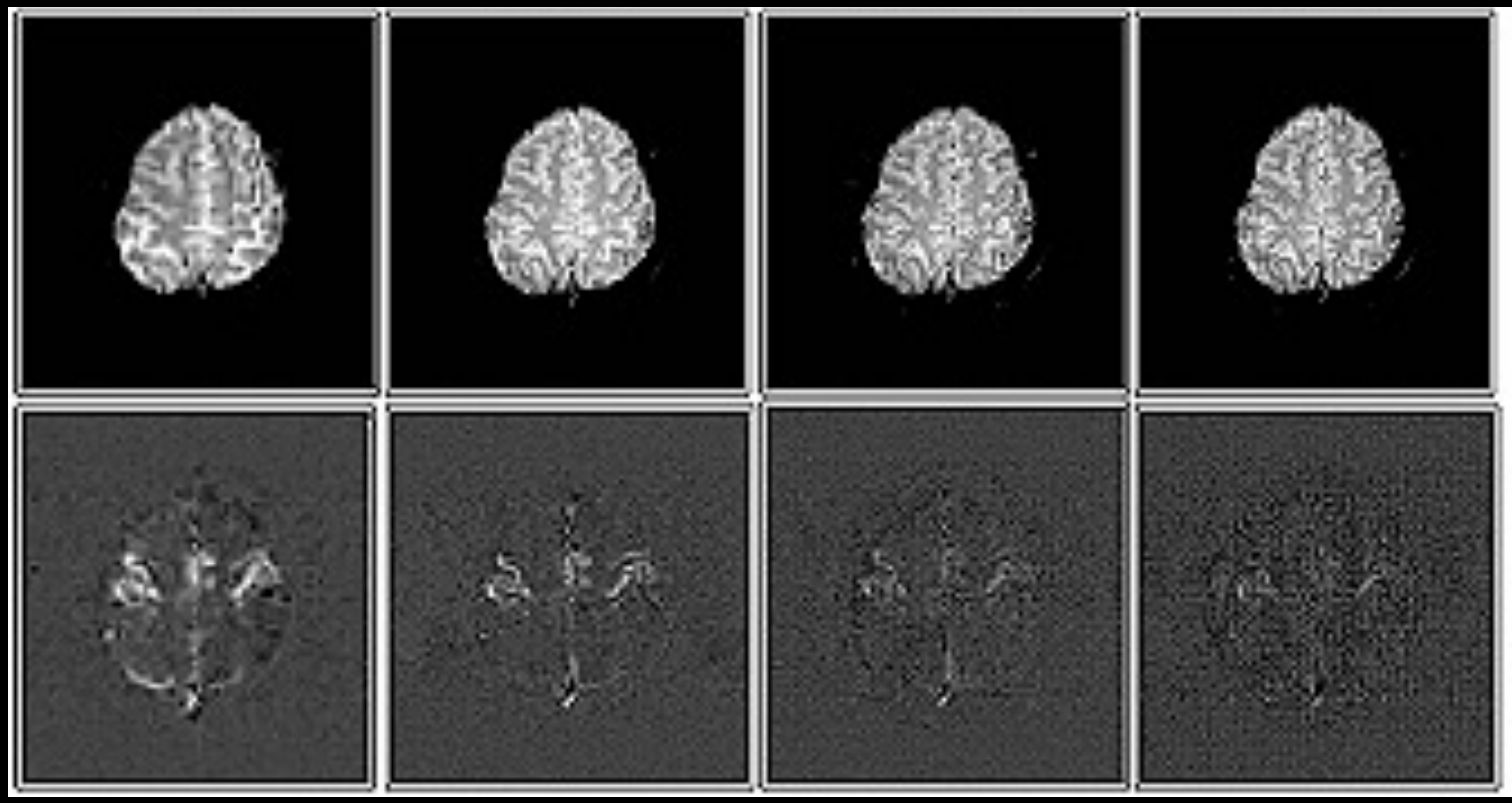


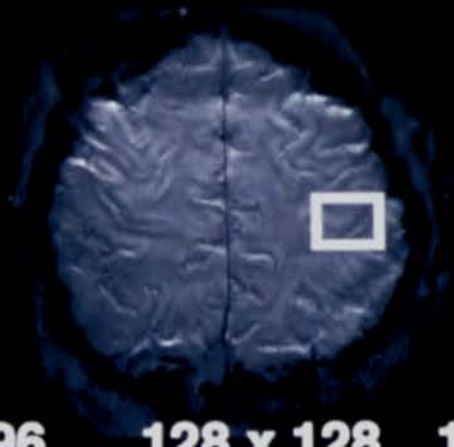
Single - Shot EPI at 3T:
Half NEX 256 x 256, 16 cm FOV



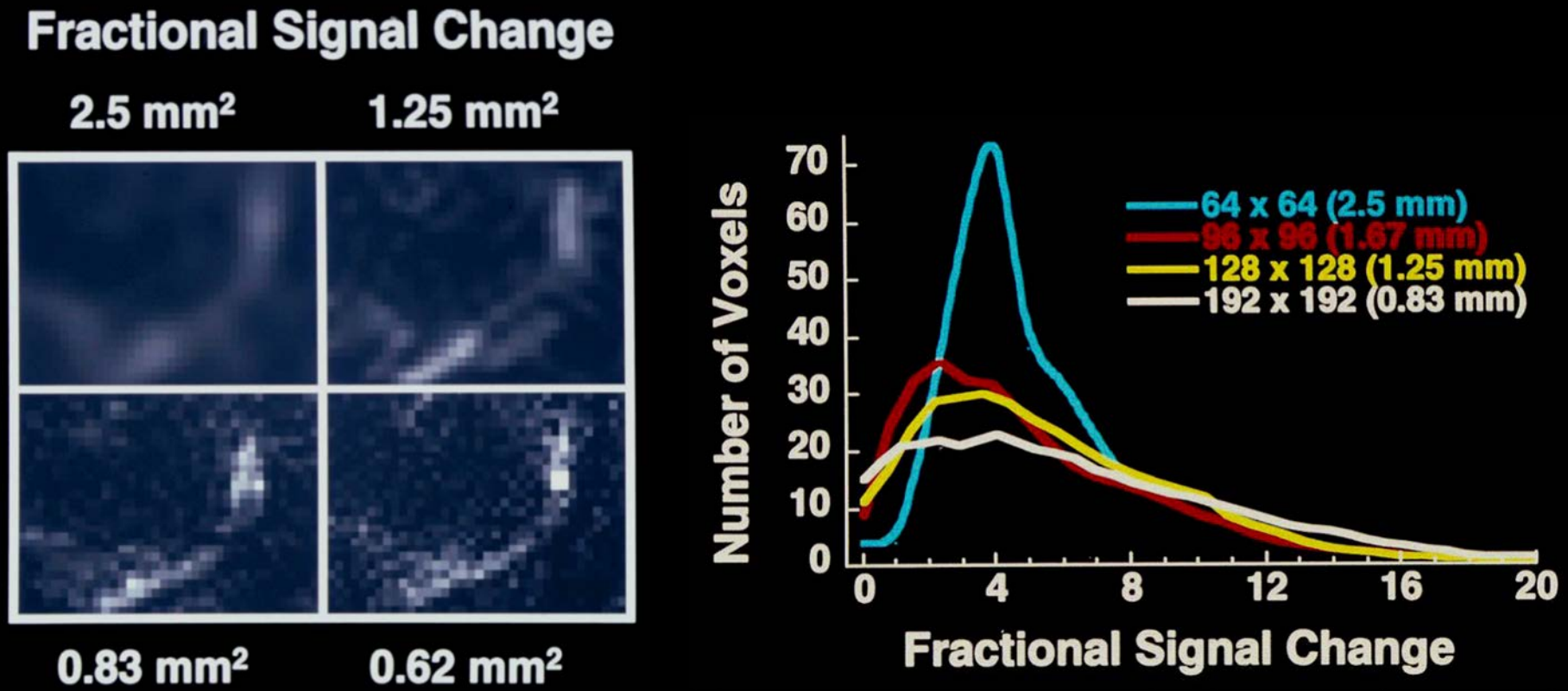
Multi Shot EPI

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

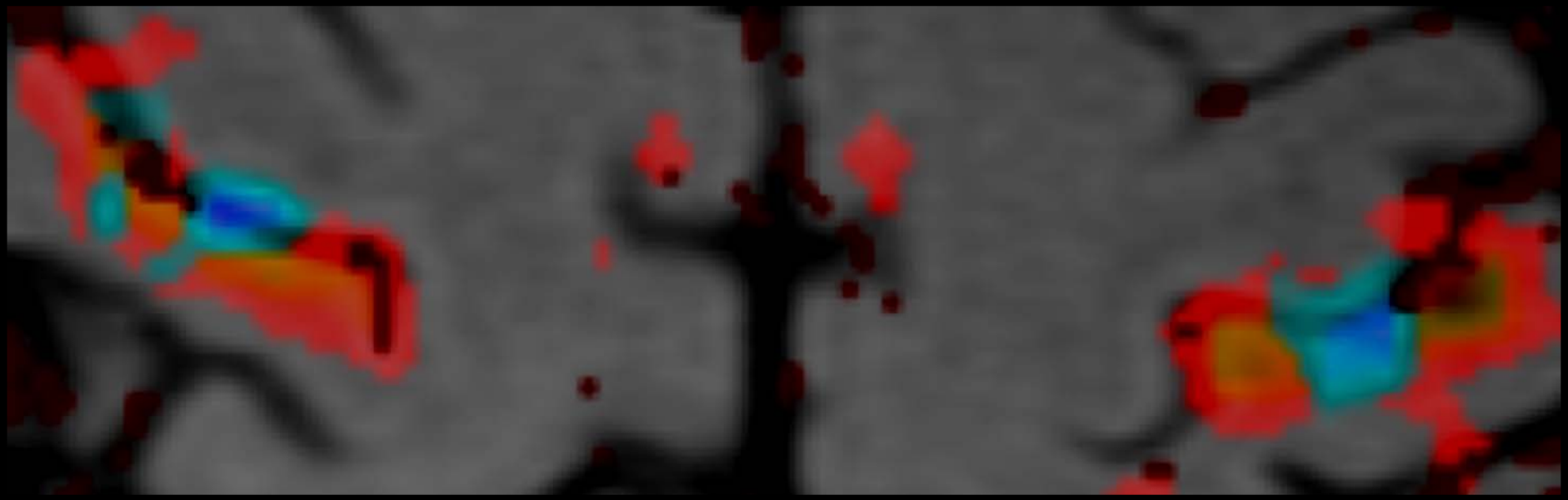




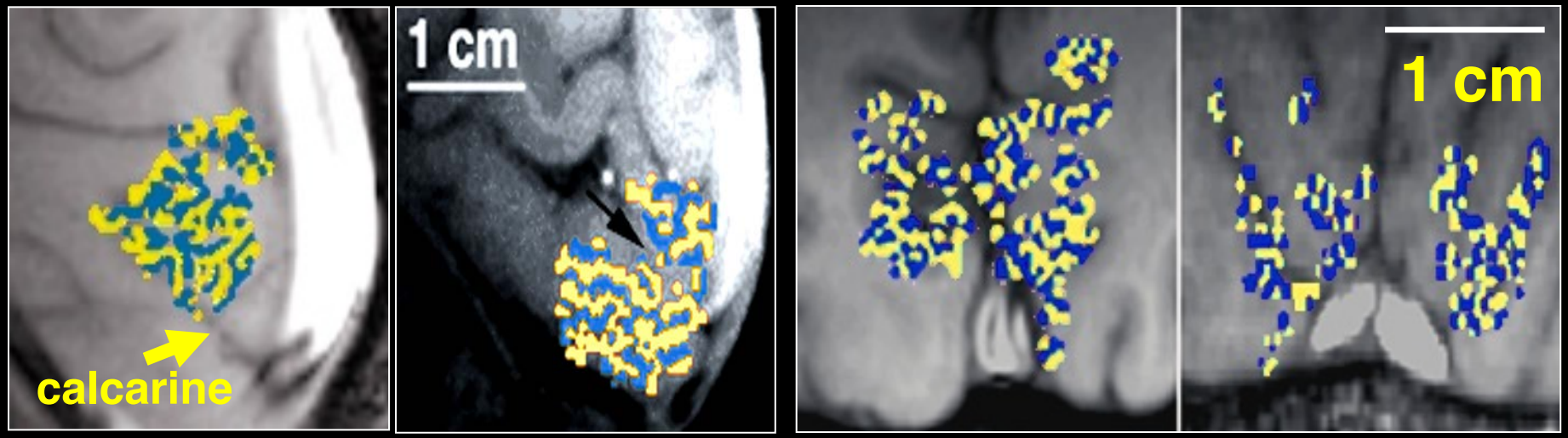
	64 x 64	96 x 96	128 x 128	192 x 192	256 x 256
%					
C/N					
	2.5 mm^2	1.67 mm^2	1.25 mm^2	0.83 mm^2	0.62 mm^2


Fractional Signal Change
2.5 mm²
1.25 mm²
0.83 mm²
0.62 mm²
Number of Voxels
0
10
20
30
40
50
60
70
0
4
8
12
16
20
Fractional Signal Change
64 x 64 (2.5 mm)
96 x 96 (1.67 mm)
128 x 128 (1.25 mm)
192 x 192 (0.83 mm)

Angiogram
Perfusion
BOLD



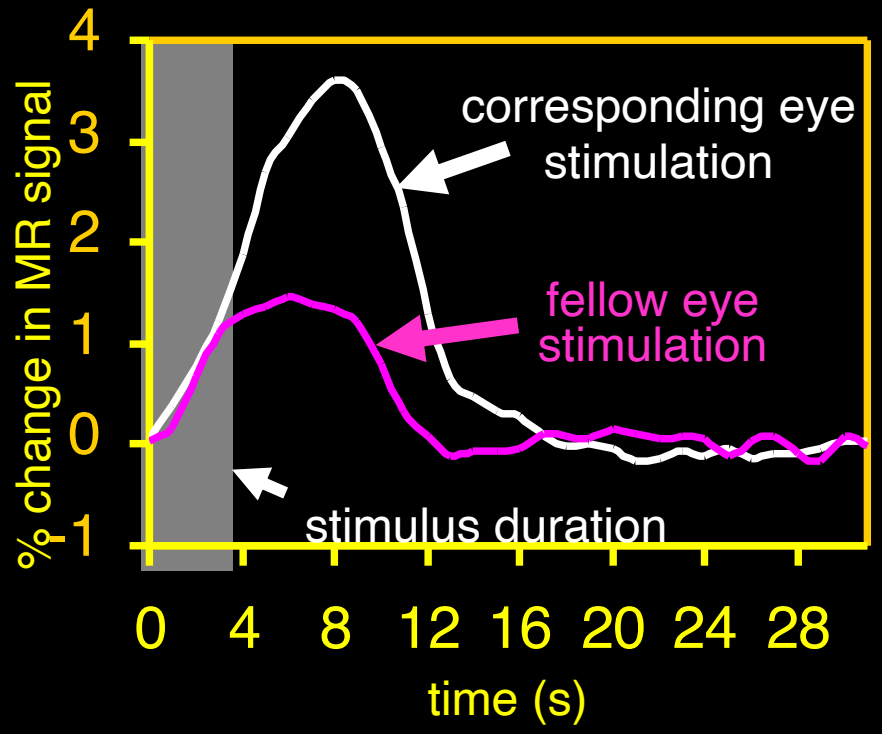
ODC Maps using fMRI



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

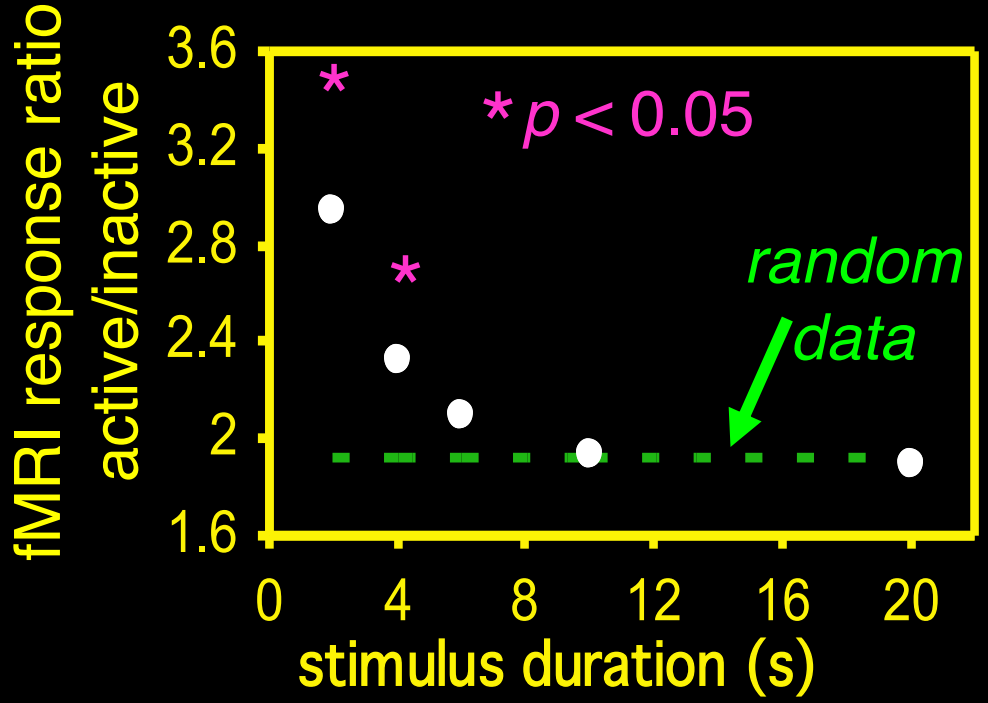
[1]Malonek D, Grinvald A. *Science* 272, 551-4 (1996).
[3]Horton JC, Hocking DR. *J Neurosci* 16, 7228-39 (1996).
[4]Horton JC, et al. *Arch Ophthalmol* 108, 1025-31 (1990).

fMRI Timecourse within an ODC



- For a 4 second stimulus, the hyperoxic response does not saturate (i.e., does not reach a plateau).
- The ratio of the peak magnitudes of the fMRI responses is nearly 3:1.

Experiment 2: Stimulus Duration



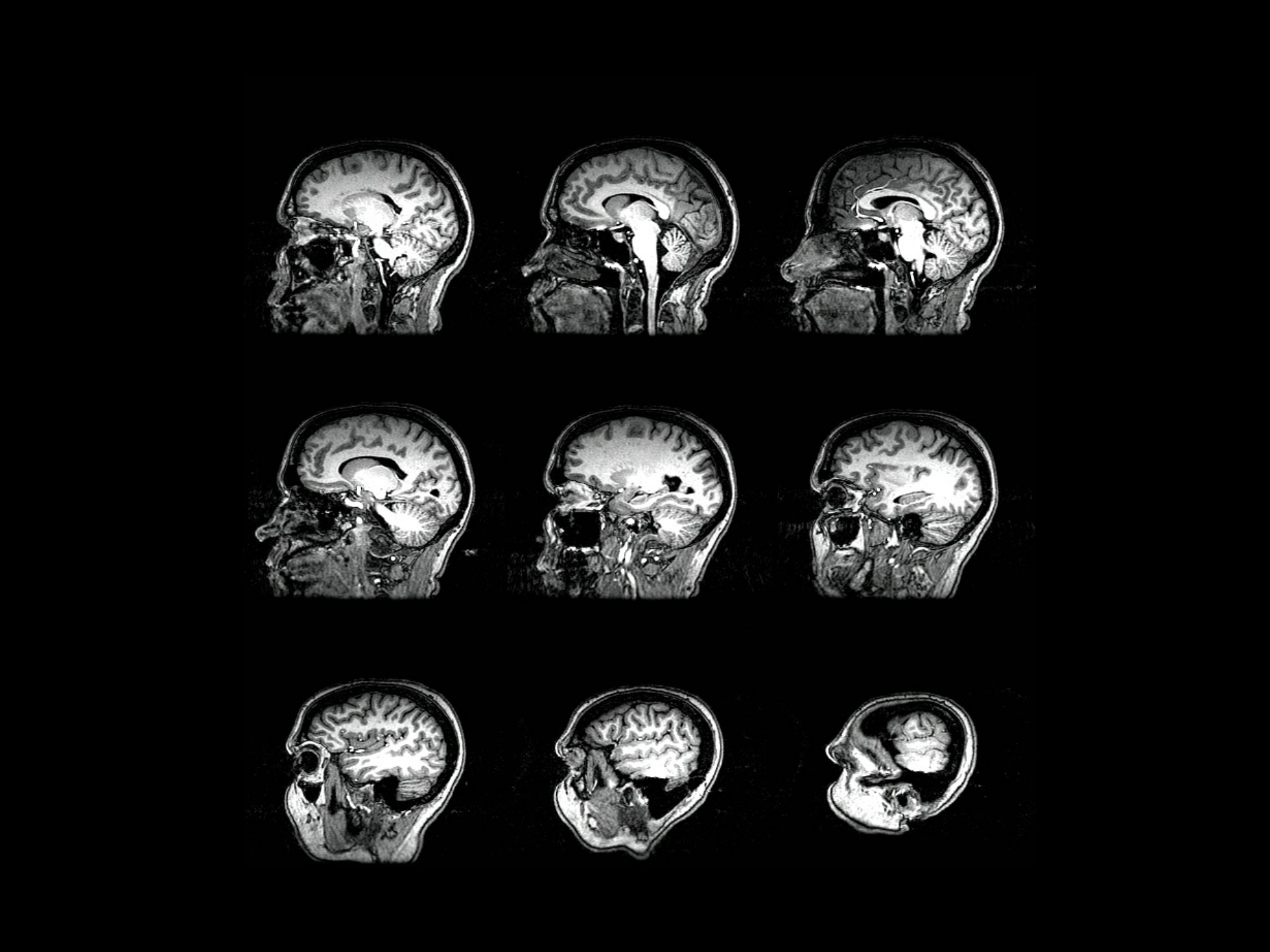
- The saturation of the hyperoxic response does not permit reliable mapping of ODCs.
- ODC maps obtained using the hyperoxic phase of the BOLD fMRI signal *are* reliable when stimulus duration is 4 seconds or less.

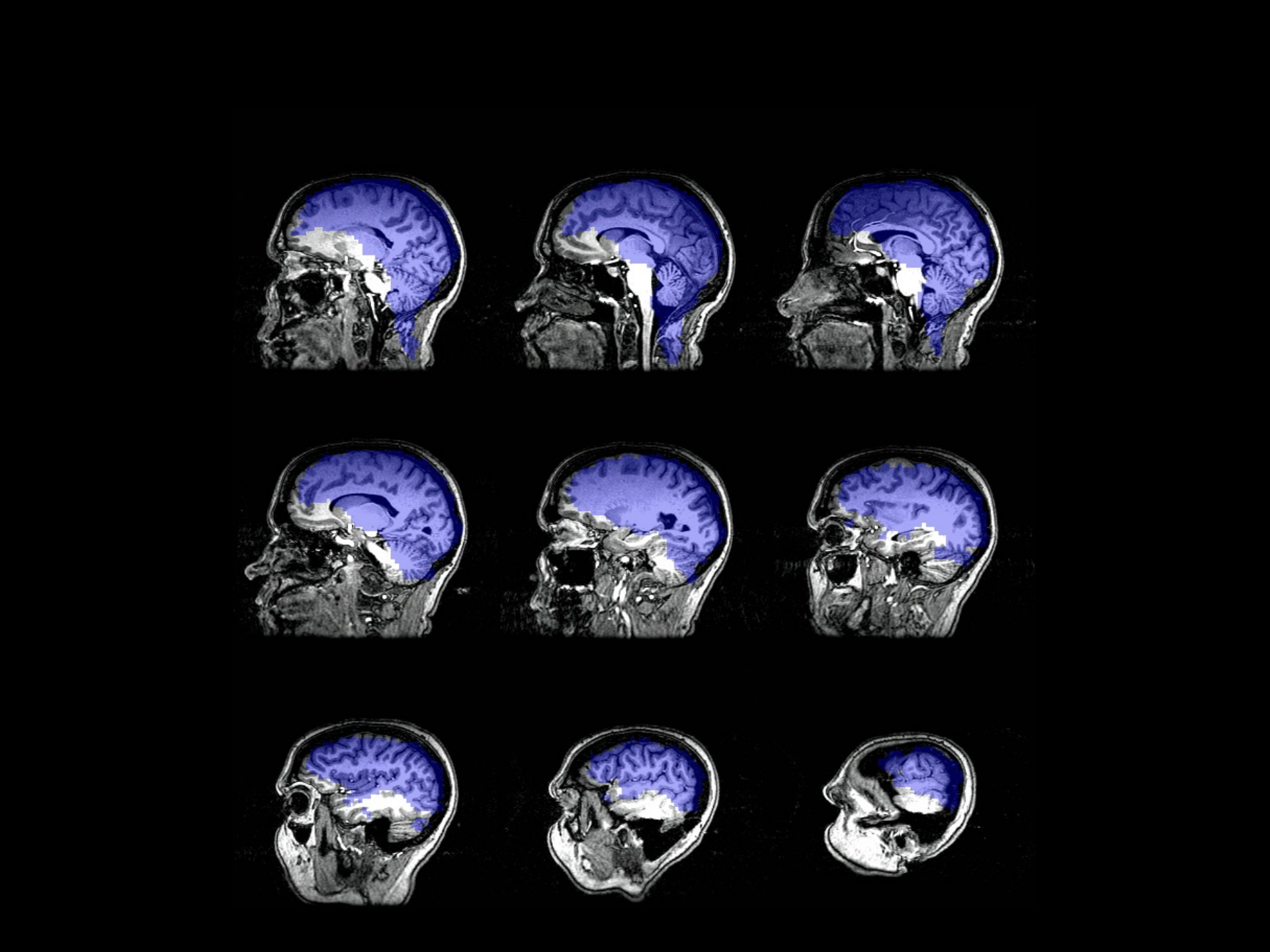
Variables to Optimize

- Information Content
- Sensitivity
- Speed
- Resolution
- Image quality

Image Quality

- Minimizing warping
  - Shimming
  - Reduced readout window duration
- Minimizing dropout
  - Shimming
  - Reduced TE
  - Adjust slice orientation
  - Increase resolution

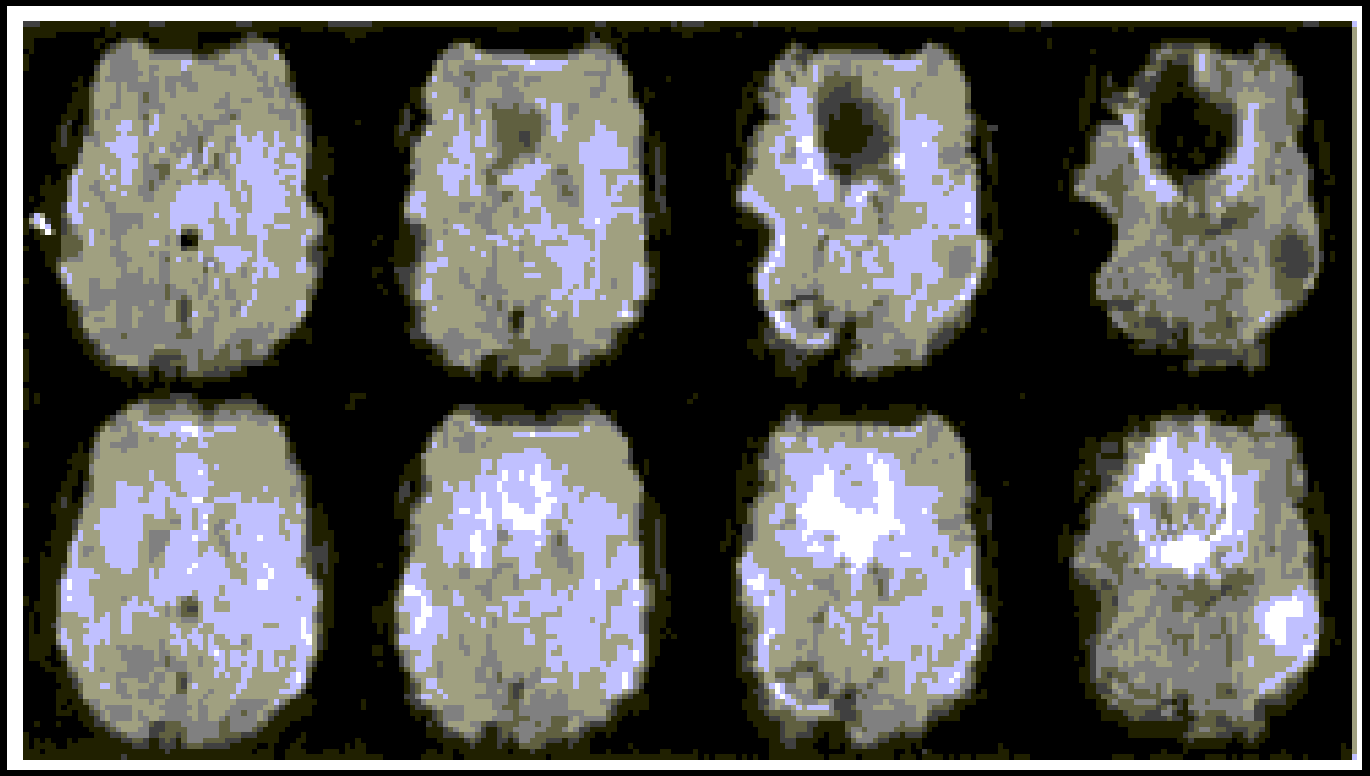




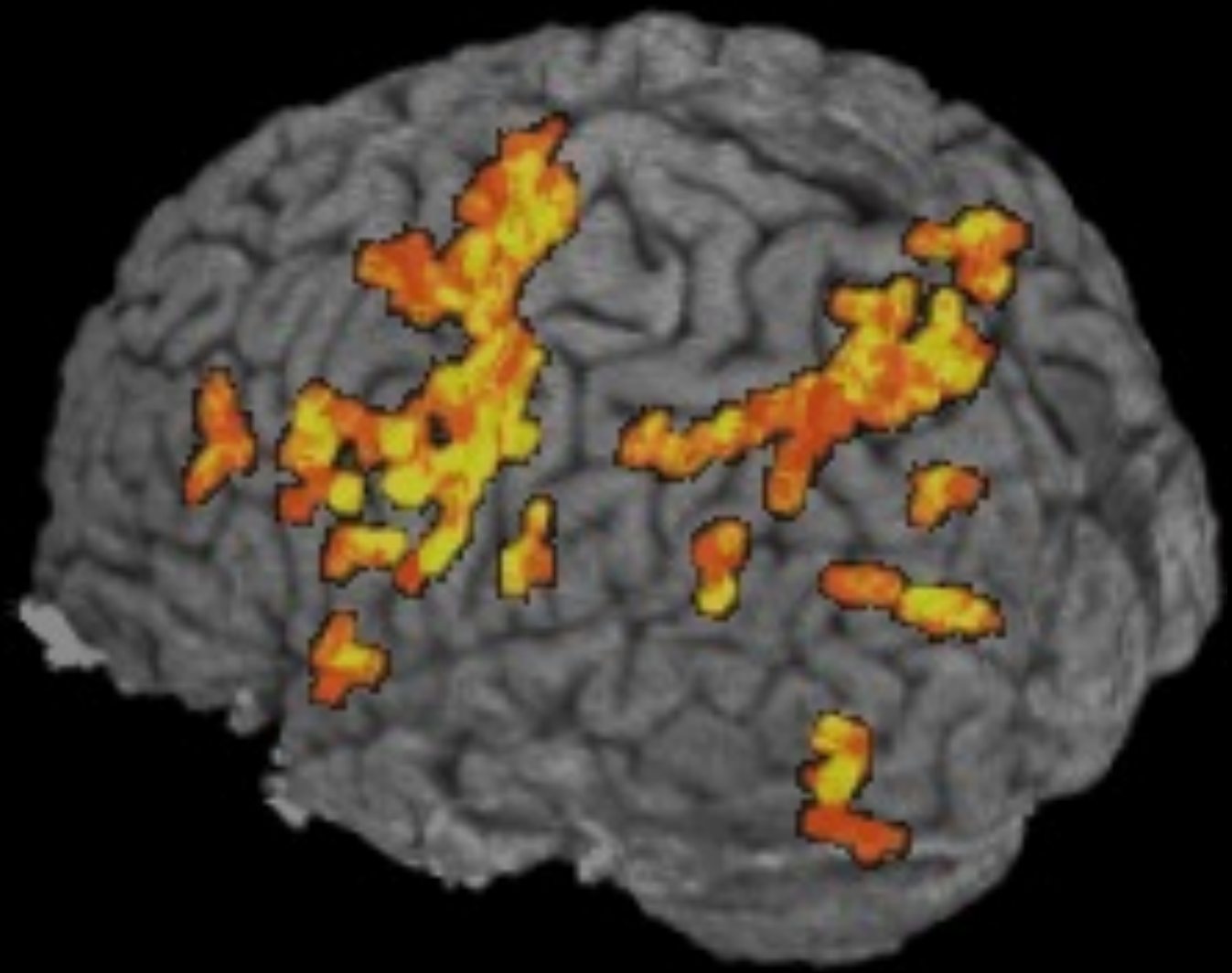
Magnetic Resonance in Medicine 42:290–299 (1999)

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

Gary H. Glover*



End of Acquisition



< 1 s to render

Blocked trials:
20 s on/20 s off
8 blocks

Blocks: 12345678

Color shows through brain

Correlation > 0.45

The End

Everything comes with a price...

Rasmus Birn
Patrick Bellgowan
Hauke Heekeren
Ziad Saad
Marta Maieron
Sergio Casciaro
James Patterson

Natalia Petridou

Wen-Ming Luh
Sean Marrett
Jerzy Bodurka
Frank Ye

Dan Kelley
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Hannah Chang

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Anders Dale, MGH
Ted DeYoe, MCW
Sue Courtney, Johns Hopkins U.
Jim Haxby, NIH
Bob Cox, NIH

唯实 求真 协力 创新

Honesty, Quest for Truth, Collaboration, Creativity

Parameters to Trade

-Time
-Pulse sequence (types of sequences)
-Resolution
-Coverage
-Image quality (types of artifacts, artifact correction)
-Sensitivity (factors that influence sensitivity)
-Information
-Quantification