

Latest Developments in fMRI

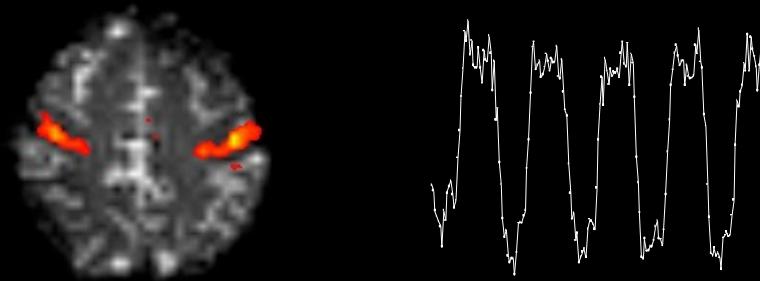
Peter A. Bandettini, Ph.D

Unit on Functional Imaging Methods
&
3T Neuroimaging Core Facility

Laboratory of Brain and Cognition
National Institute of Mental Health

The use of fMRI for the Investigation of Brain Function

Where?



When?

How much?

**How to get the brain to do what we want it to
do in the context of an fMRI experiment?**

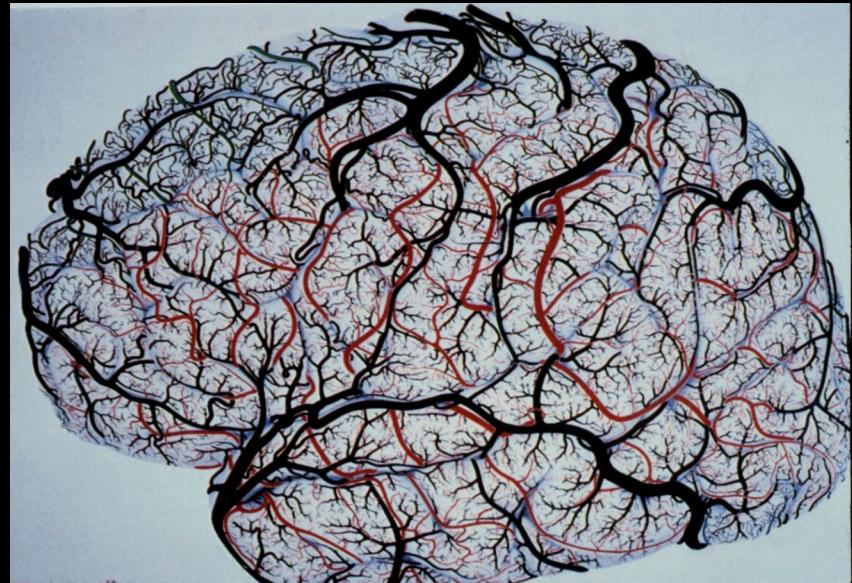
(limitations: limited time and signal to noise, motion, acoustic noise)

A Primary Challenge:

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



FIG. 43. Middle temporal gyrus. Female, 60 years. (1) Principal intracortical vein. The branches length regularly decreases from deep towards superficial cortical regions, thus the vascular territory of the principal vein has a conical appearance (dotted line) ($\times 28$).



Questions

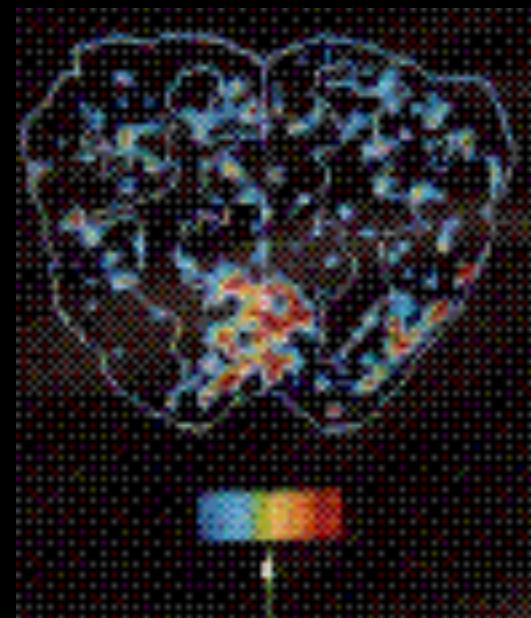
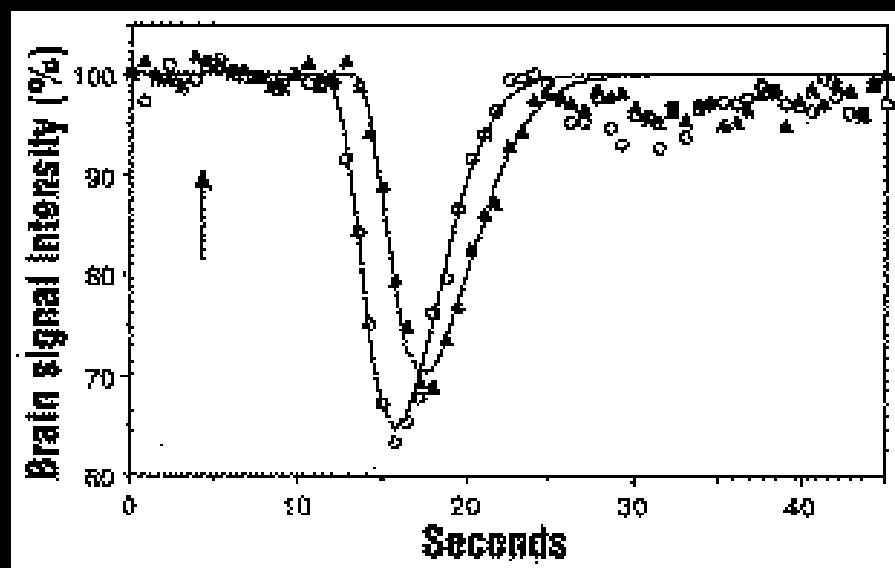
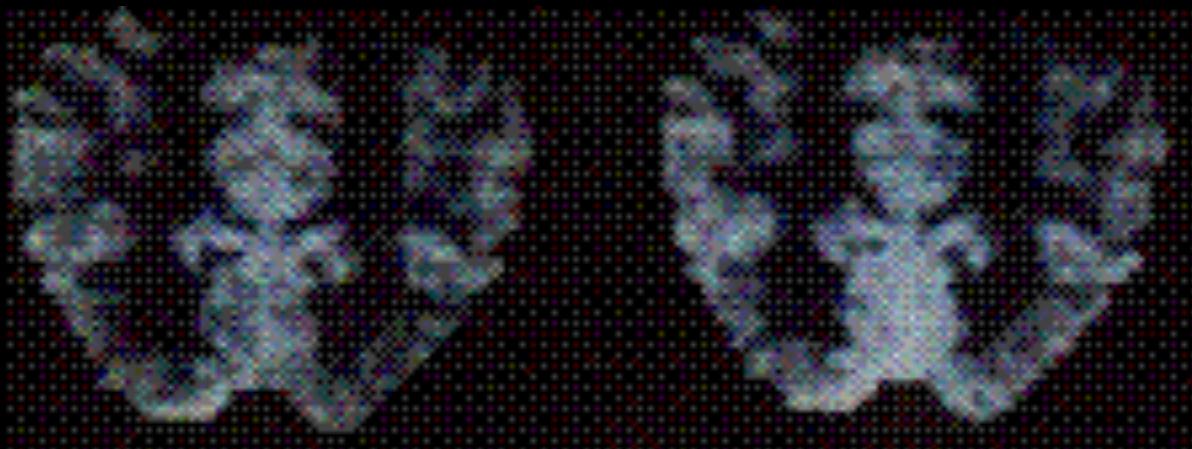
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2. What determines fMRI temporal resolution?
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4. What are the primary areas of fMRI methodology that require improvement?
5. How far can fMRI methodology improvement be taken?

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

Resting

Active

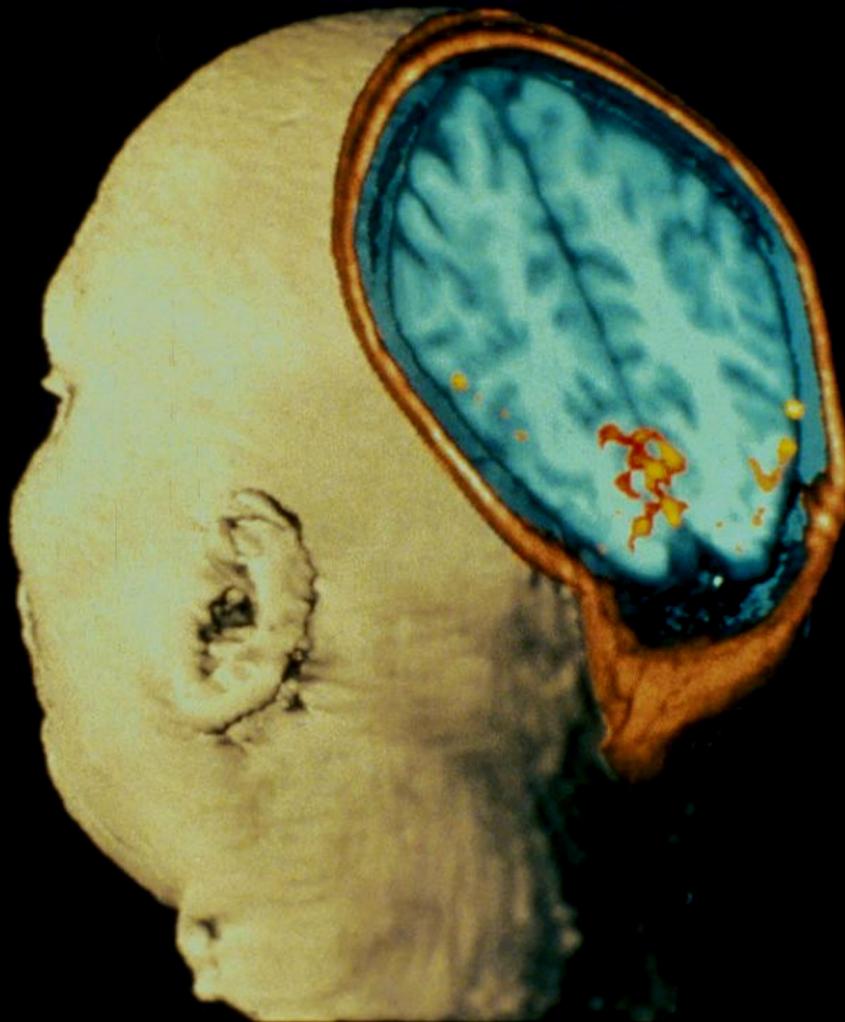


Photic Stimulation

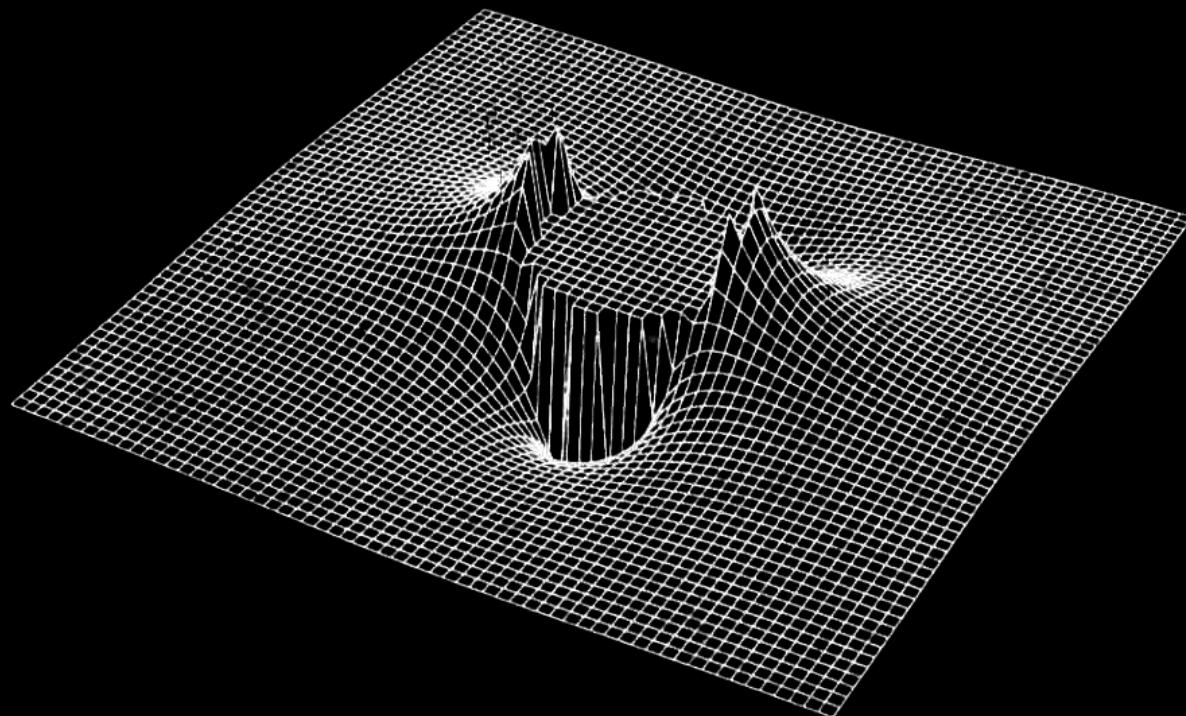
MRI Image showing
activation of the
Visual Cortex

From Belliveau, et al.
Science Nov 1991

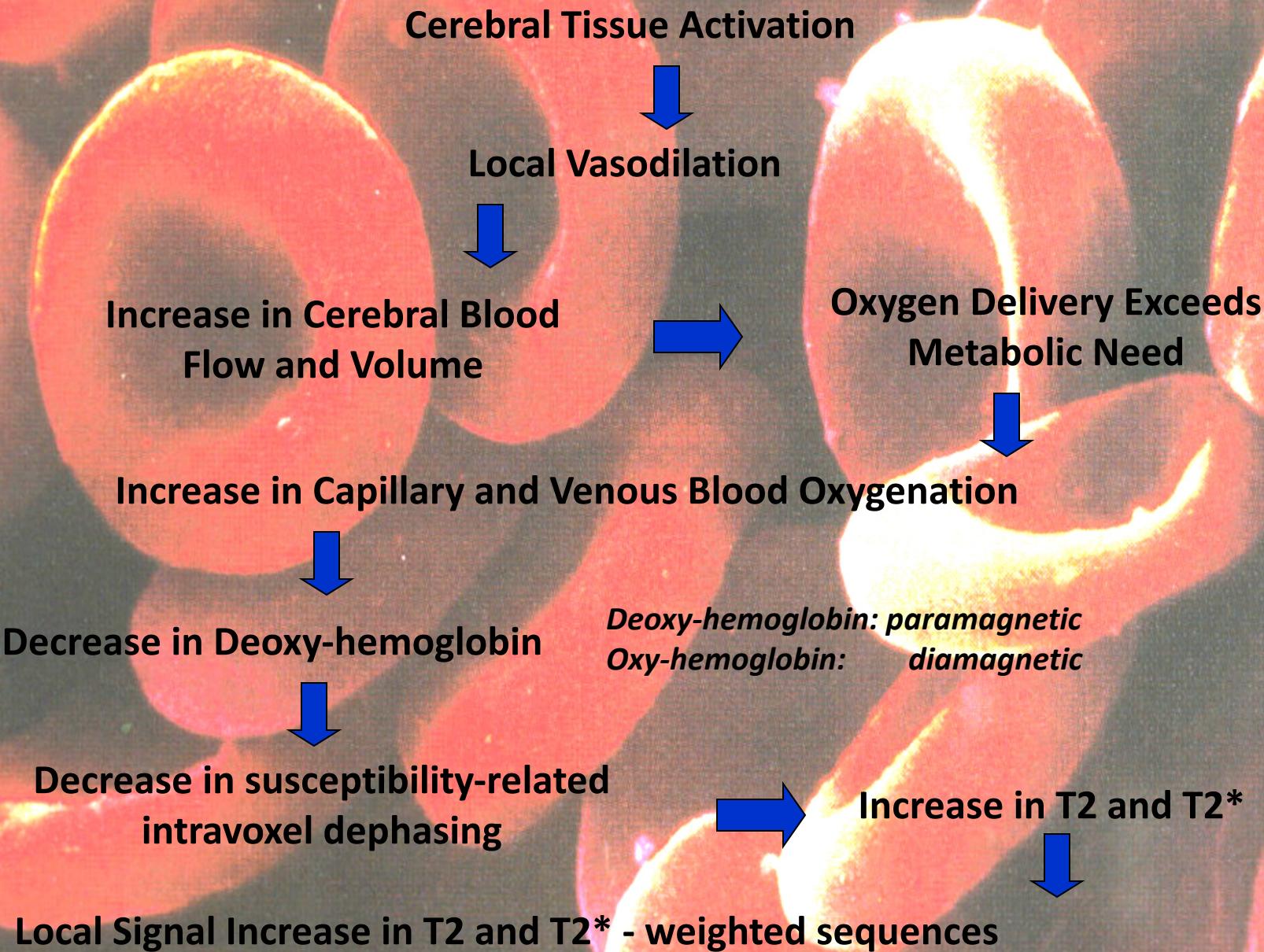
MSC - perfusion



Susceptibility-Induced Field Distortion in the
Vicinity of a Microvessel \perp to B_0 .

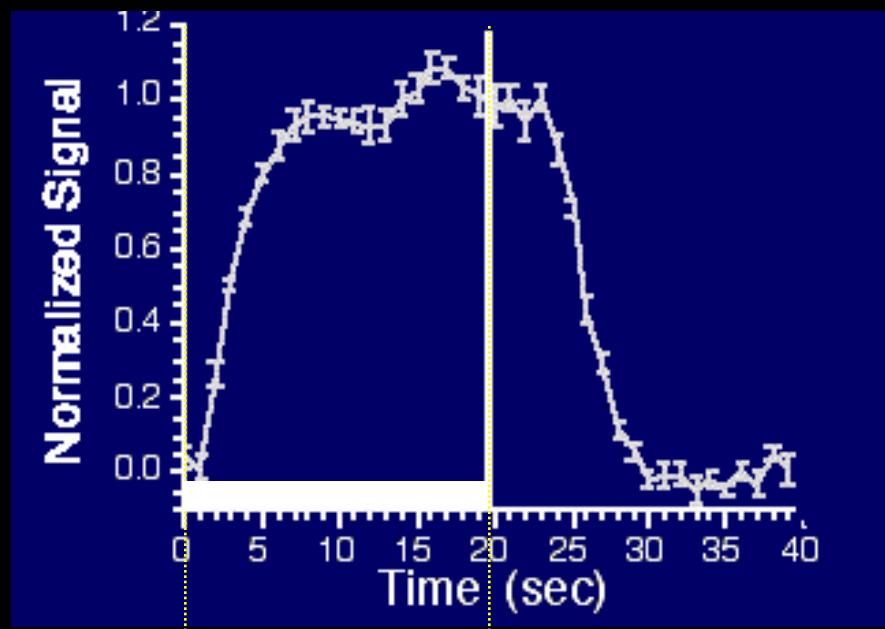


BOLD Contrast in the Detection of Neuronal Activity

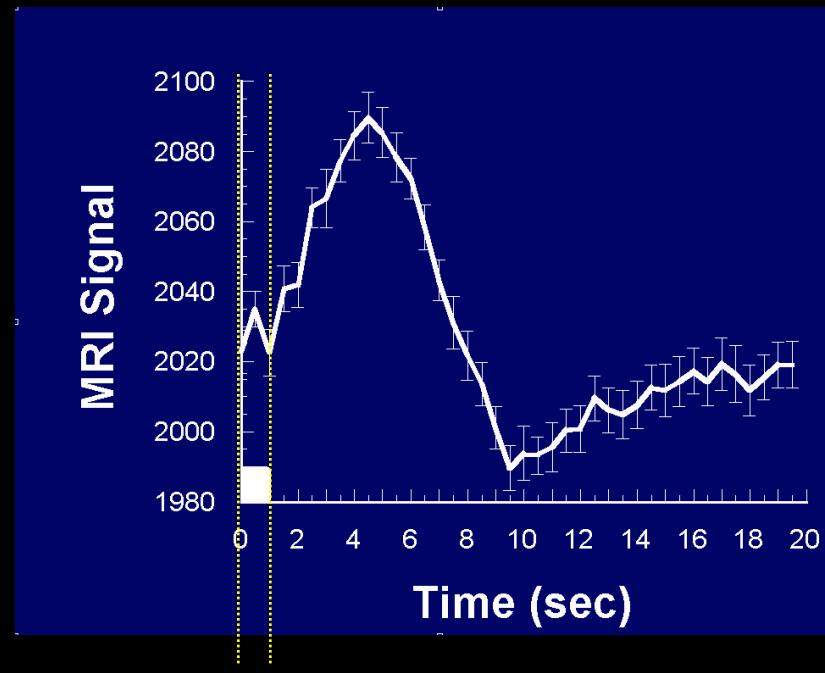


The BOLD Signal

Blood Oxxygenation Level Dependent (BOLD) signal changes



task

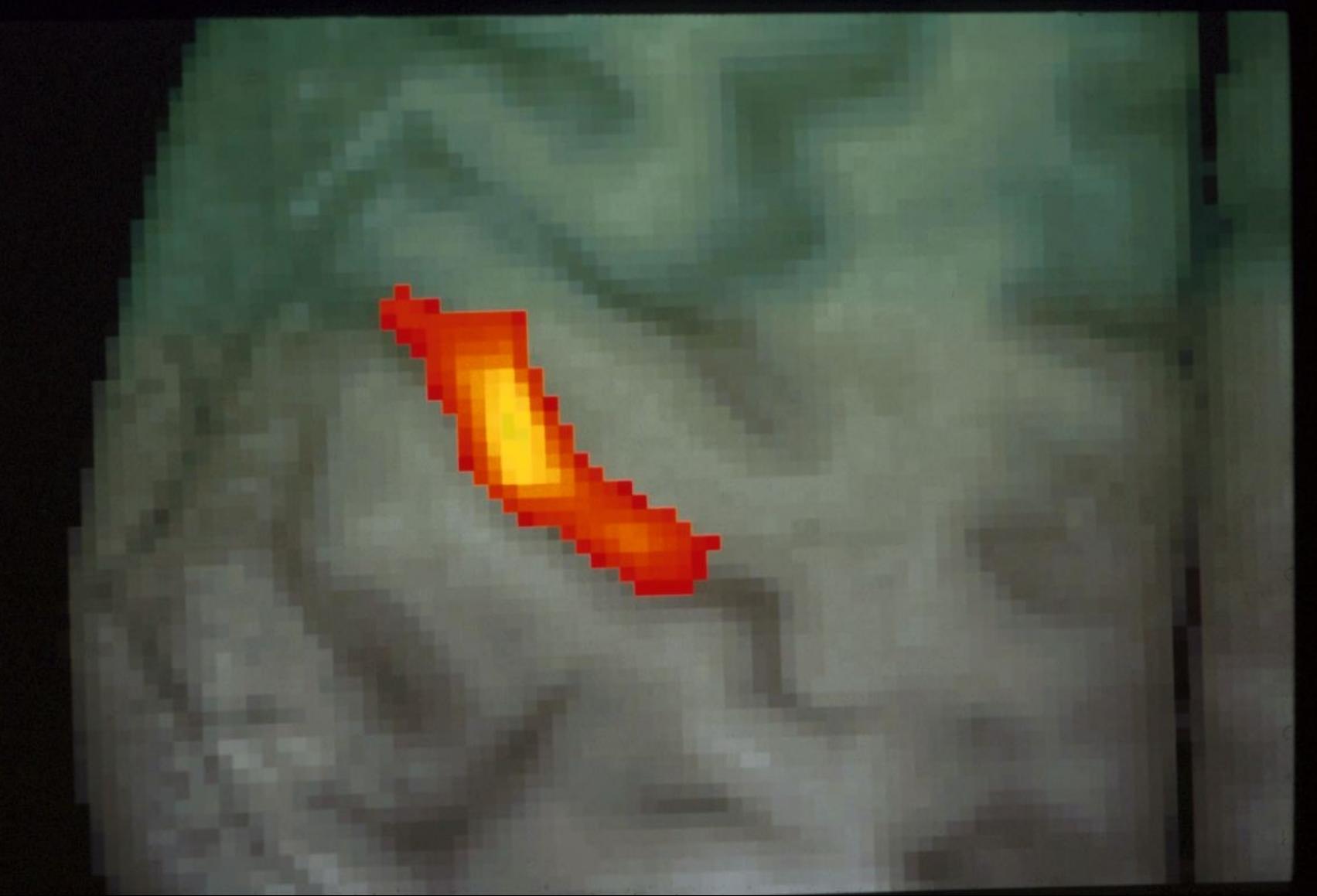


task

Alternating Left and Right Finger Tapping

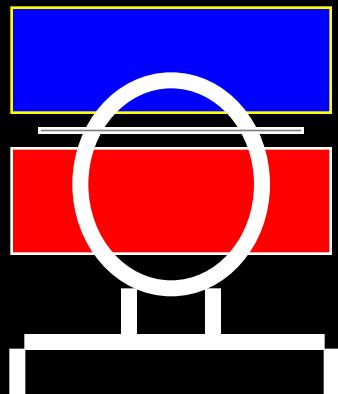


~ 1992

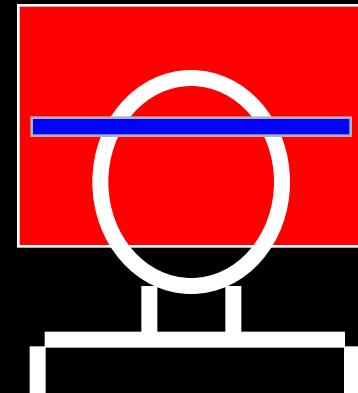


Perfusion / Flow Imaging

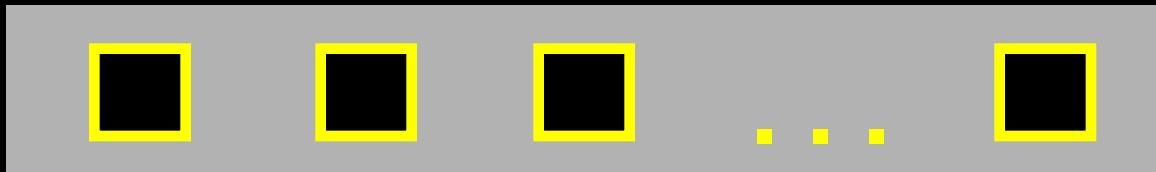
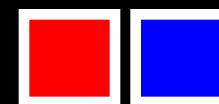
EPISTAR



FAIR

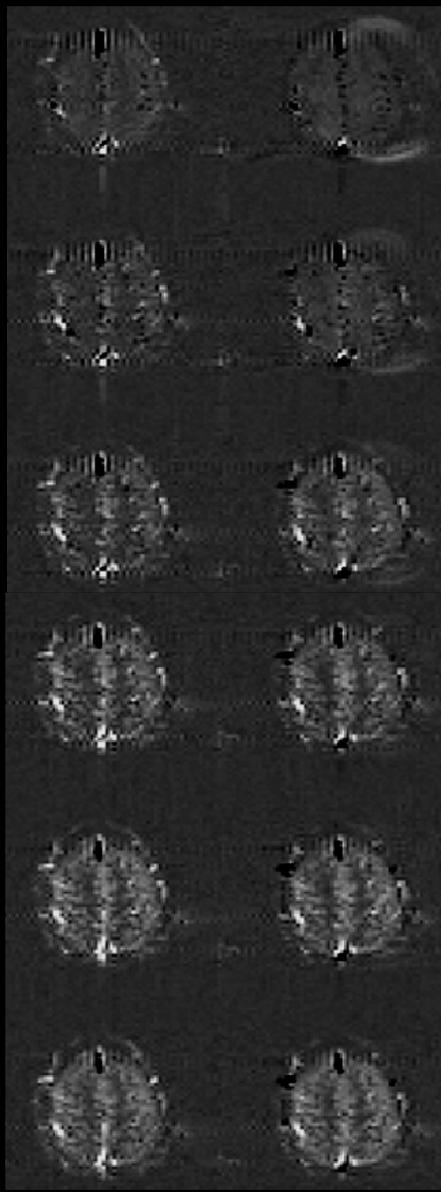


...



TI (ms) FAIR EPISTAR

200



400

600

800

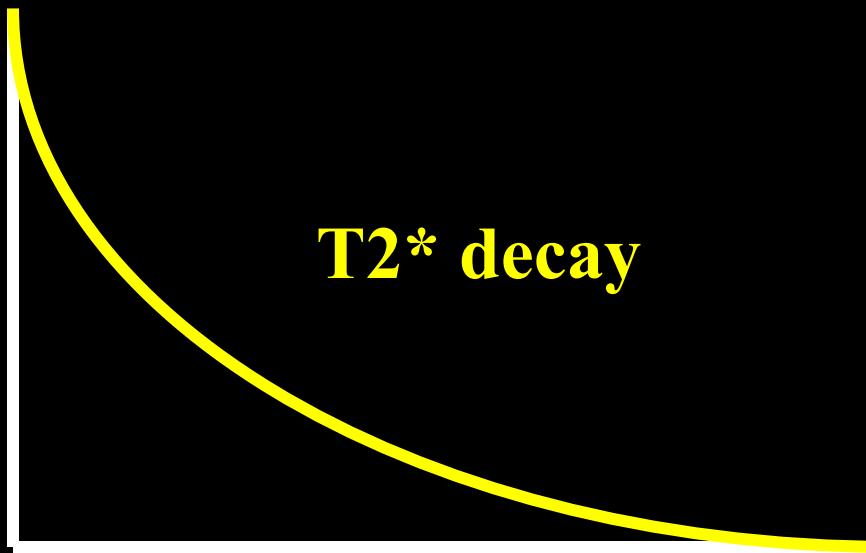
1000

1200

Questions

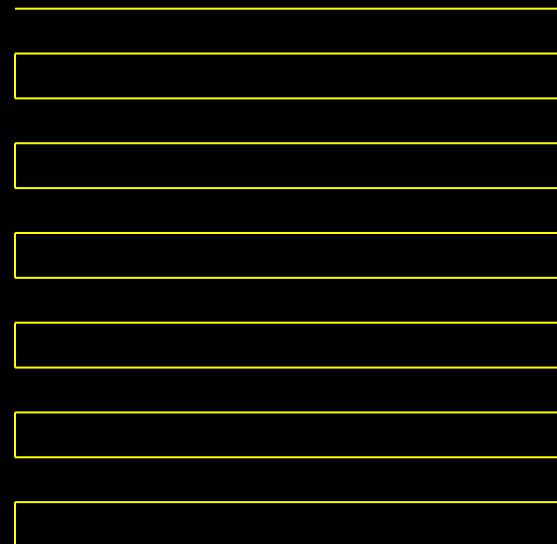
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Single Shot Imaging

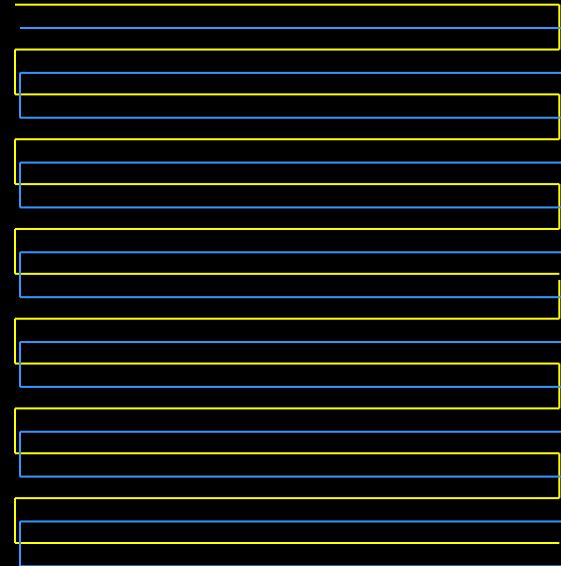


EPI Readout Window

≈ 20 to 40 ms



Multishot Imaging



Multi Shot EPI

Excitations

1

Matrix Size

64 x 64

2

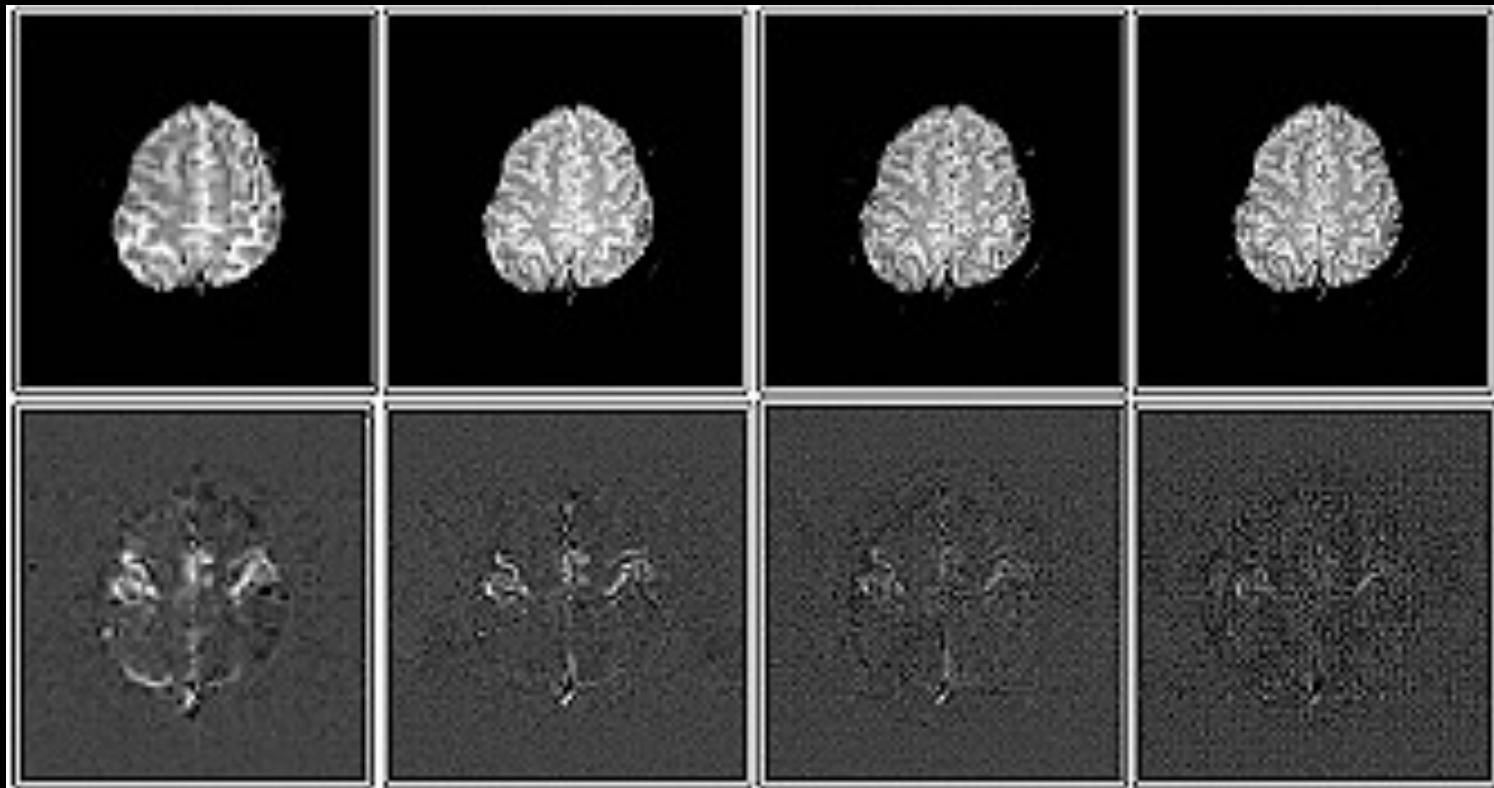
128 x 128

4

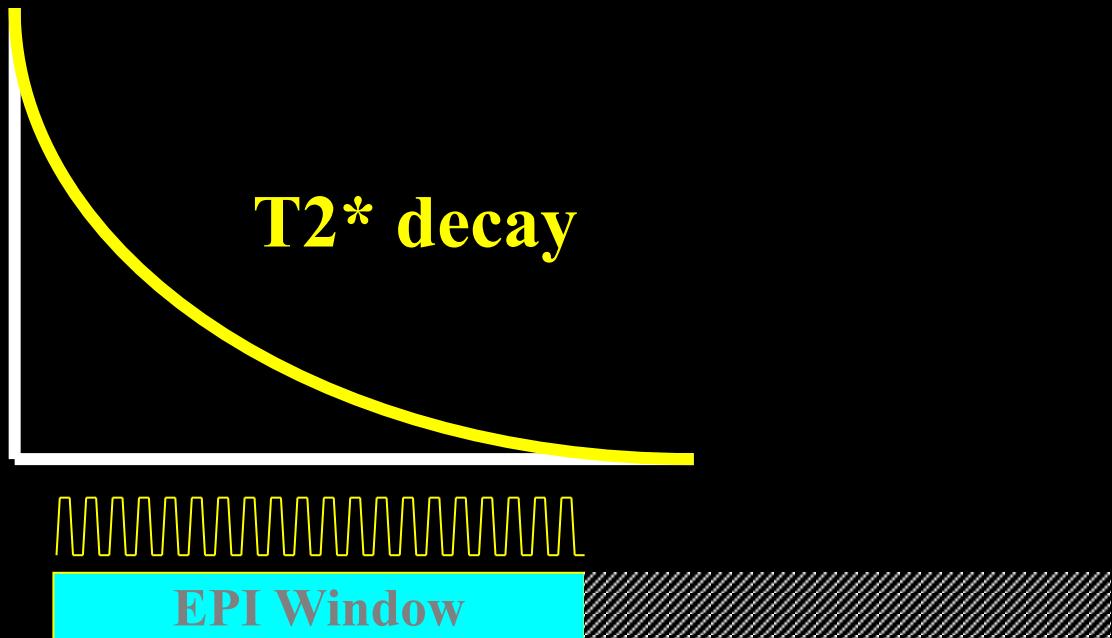
256 x 128

8

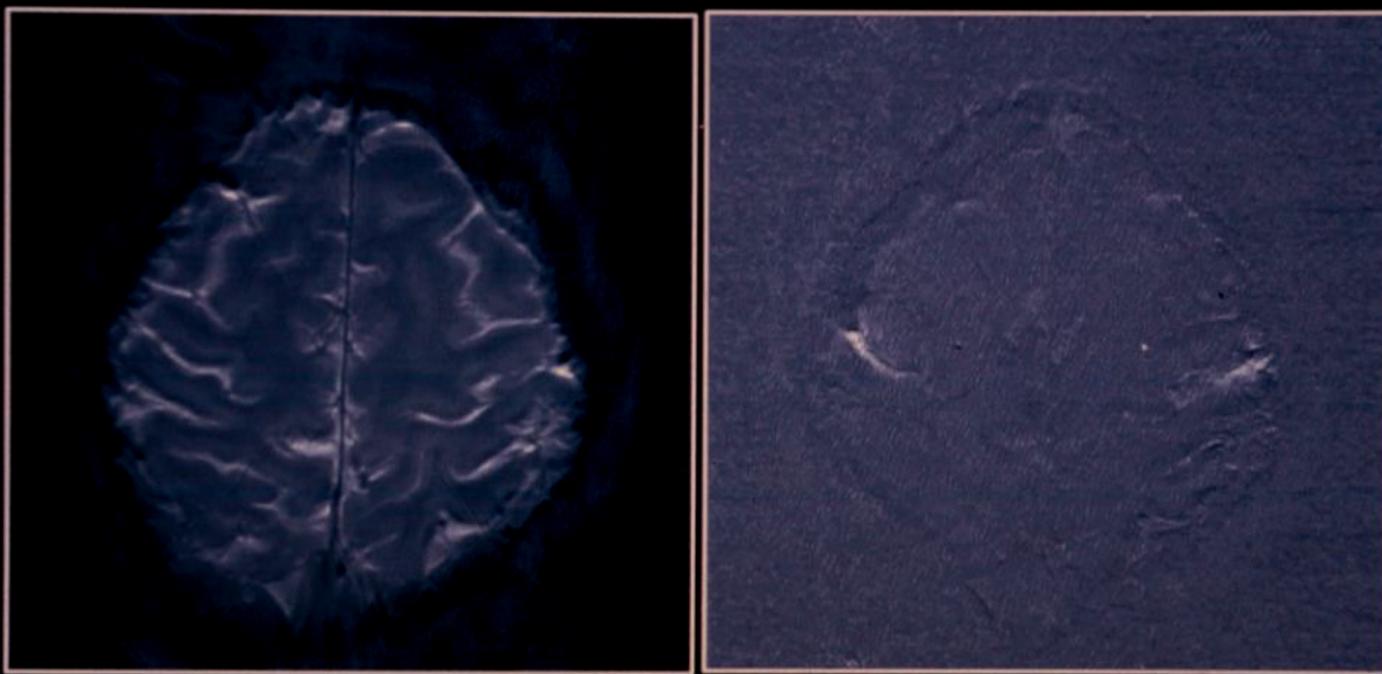
256



Partial k-space imaging

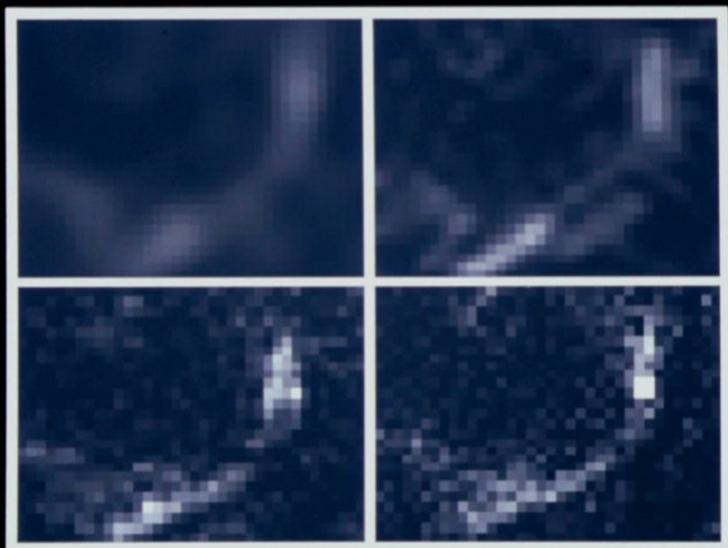


**Single - Shot EPI at 3T:
Half NEX, 256 x 256, 16 cm FOV**



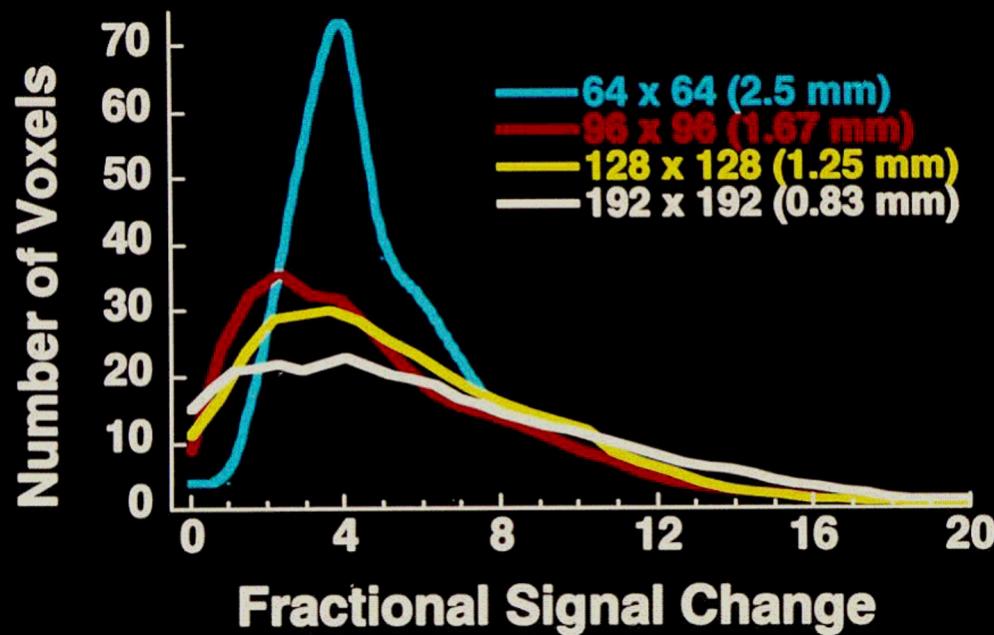
Fractional Signal Change

2.5 mm^2



1.25 mm^2

0.62 mm^2

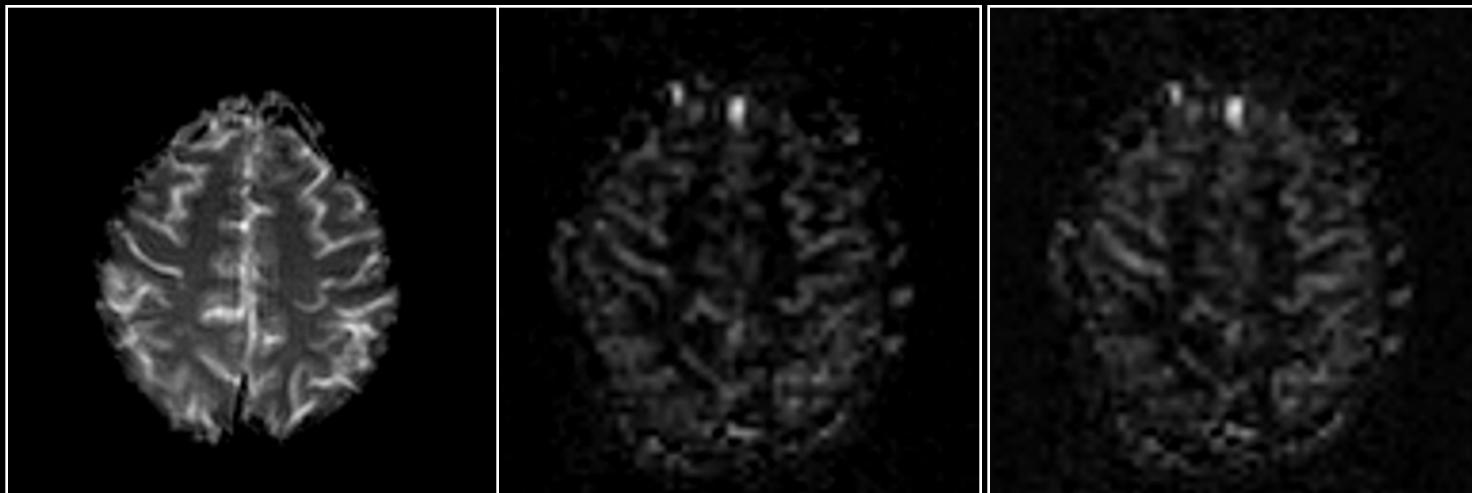


Perfusion

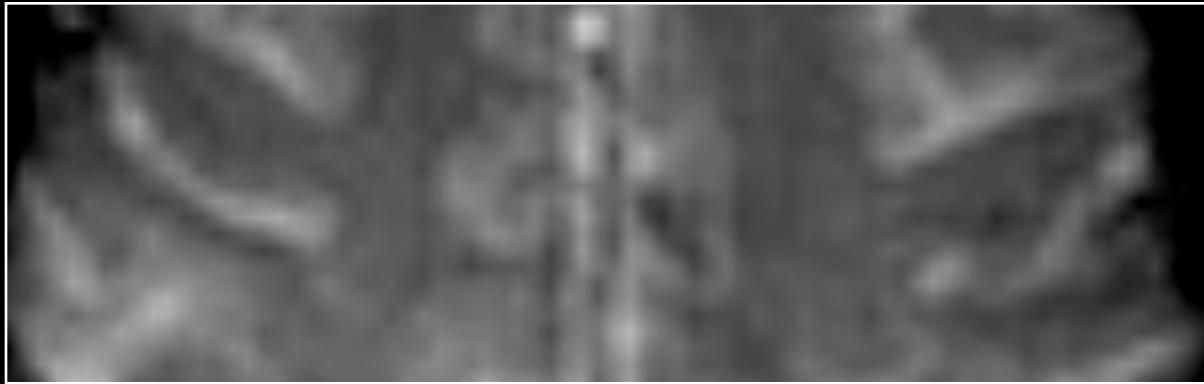
BOLD

Rest

Activation



Anatomy



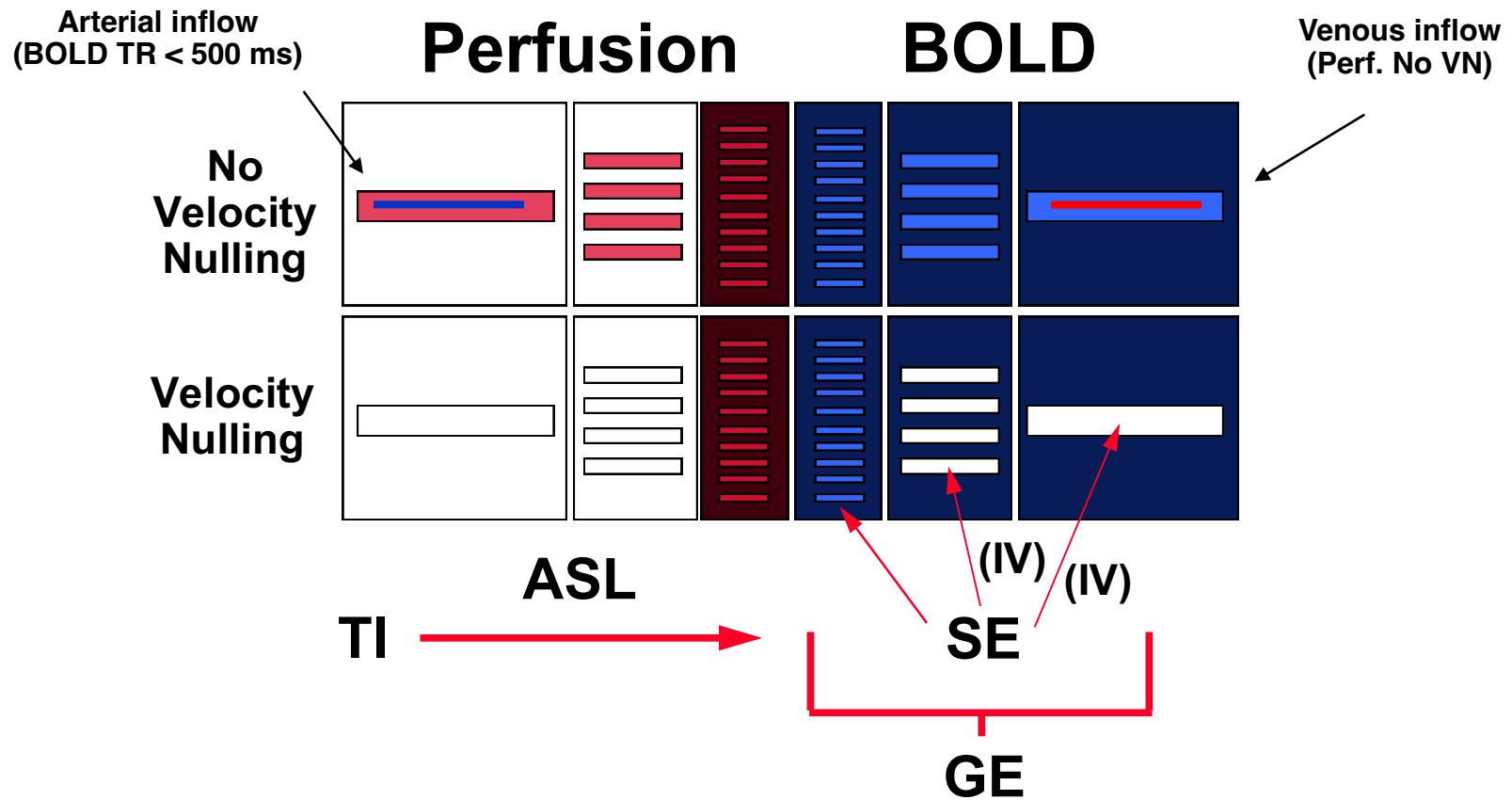
BOLD



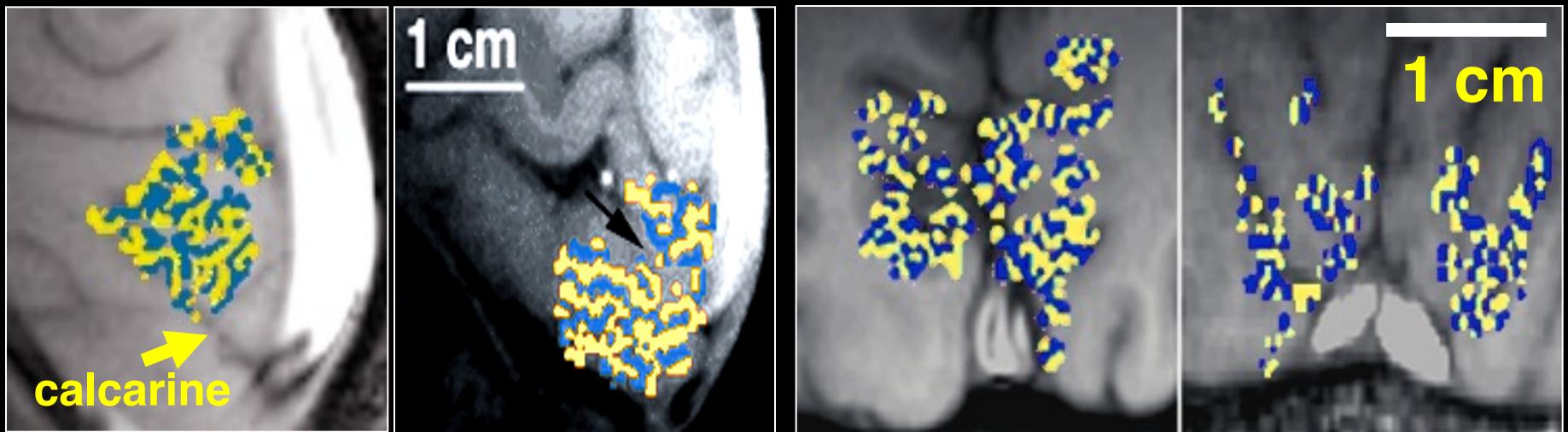
Perfusion



Hemodynamic Specificity



ODC Maps using fMRI



- Identical in size, orientation, and appearance to those obtained by optical imaging¹ and histology^{3,4}.

¹Malonek D, Grinvald A. *Science* 272, 551-4 (1996).

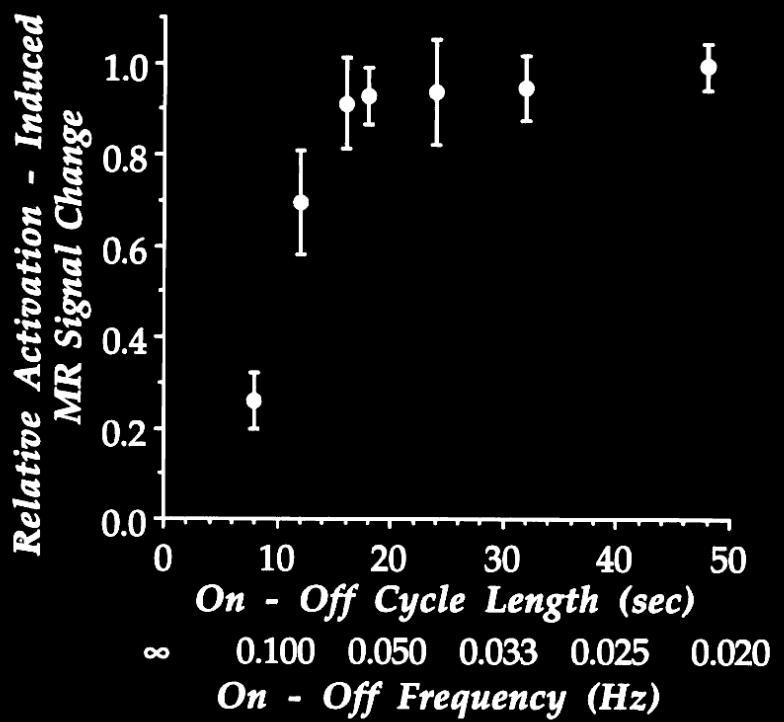
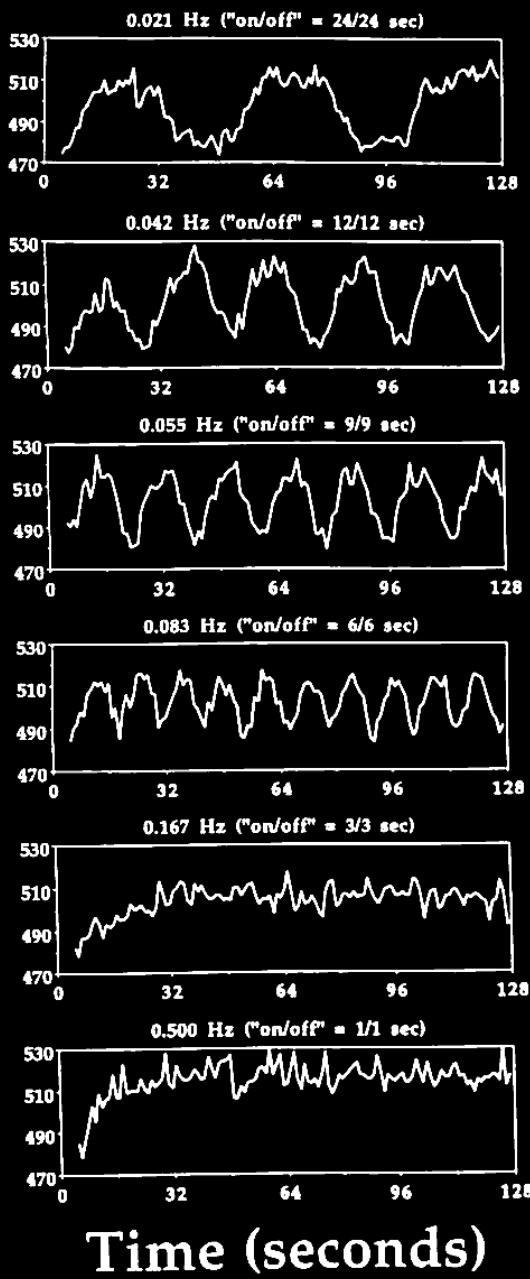
³Horton JC, Hocking DR. *J Neurosci* 16, 7228-39 (1996).

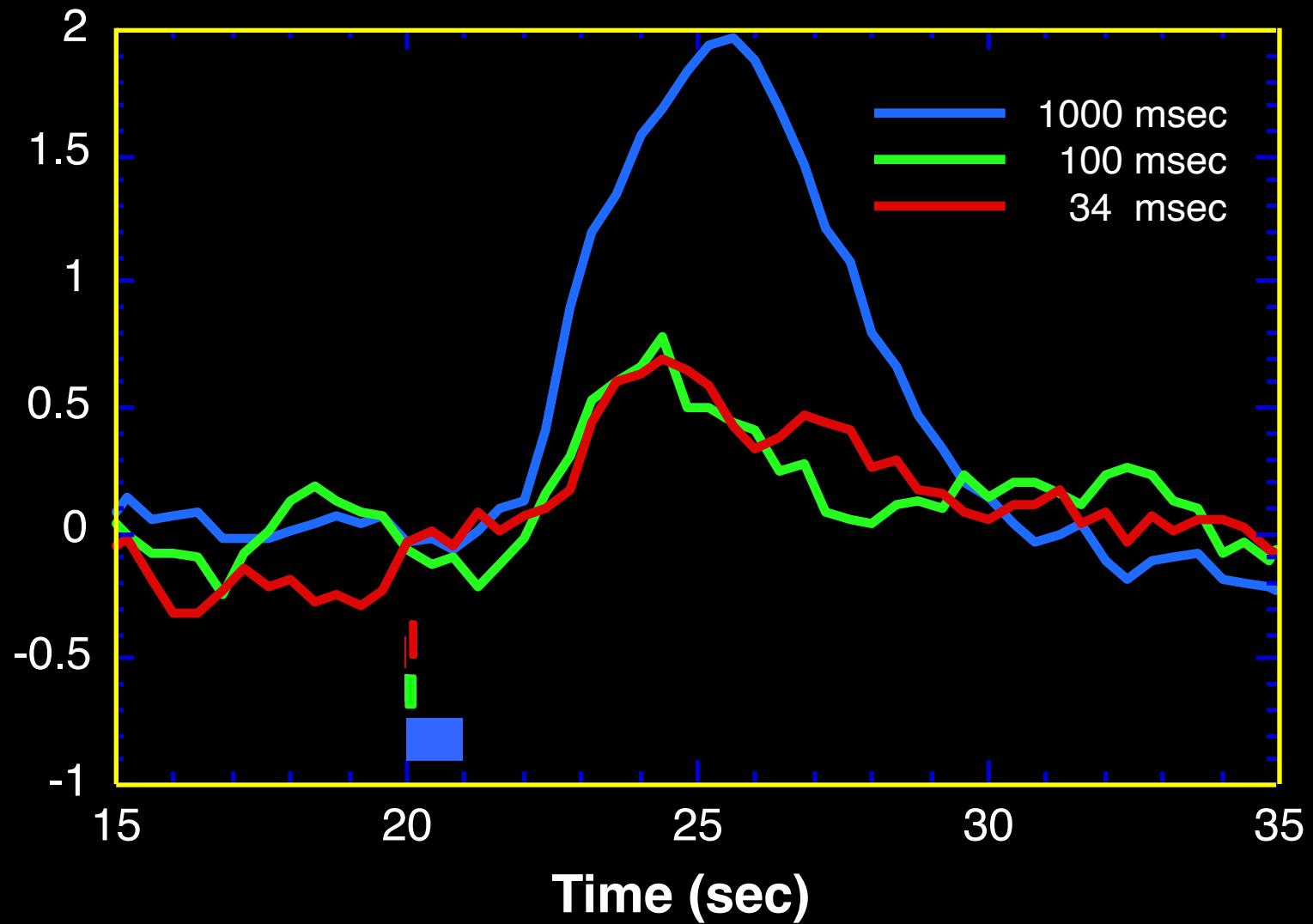
⁴Horton JC, et al. *Arch Ophthalmol* 108, 1025-31 (1990).

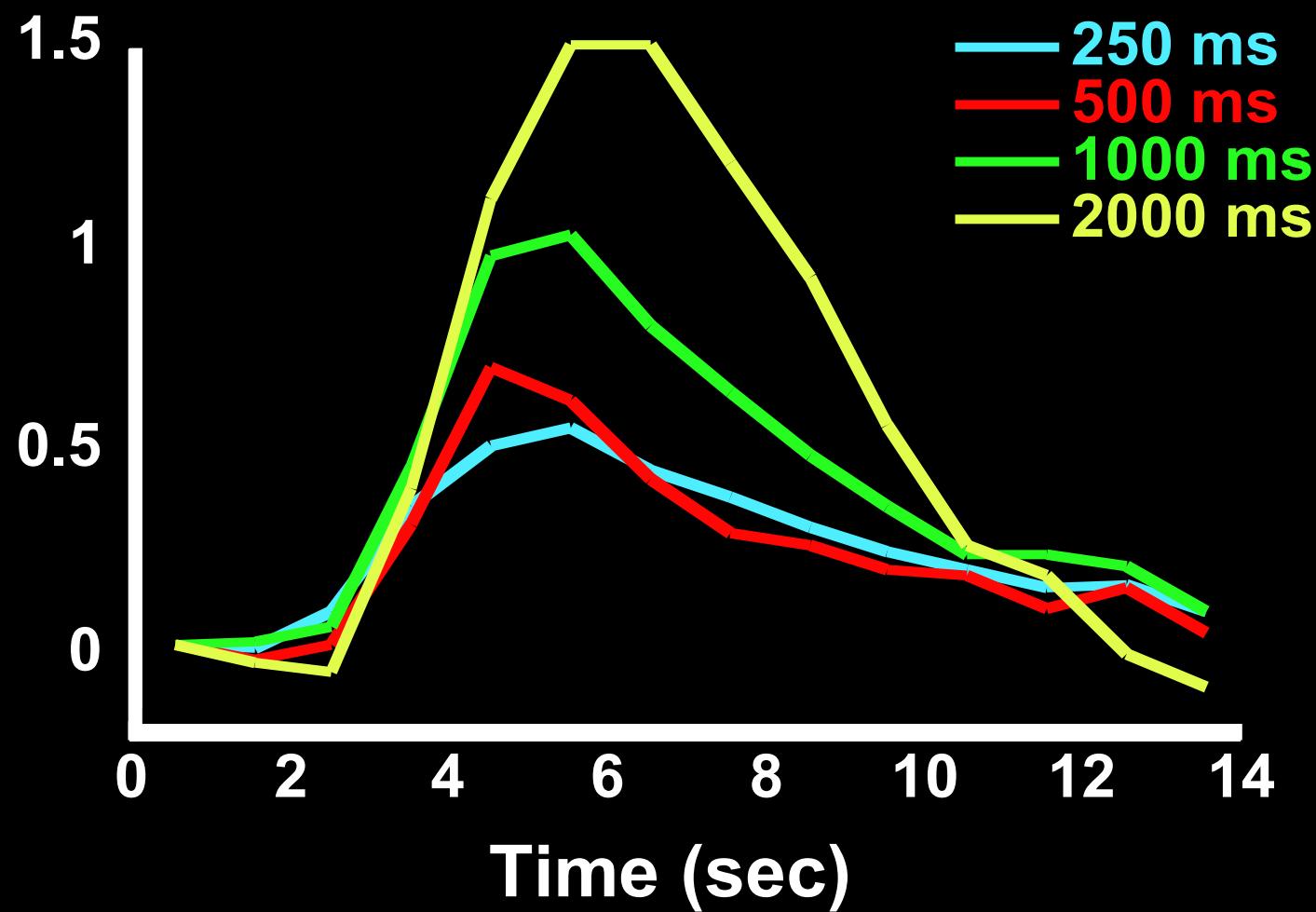
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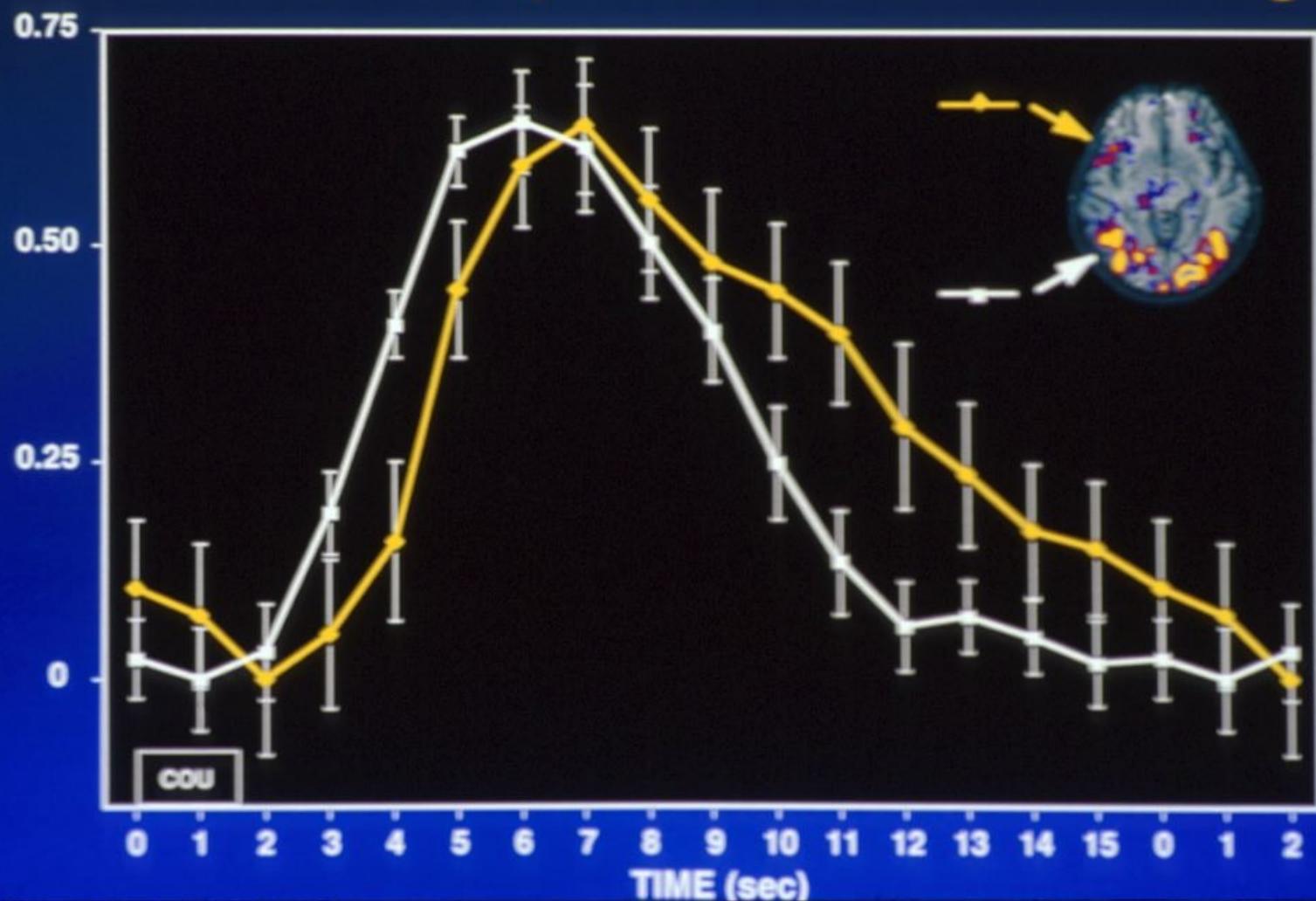
MRI Signal



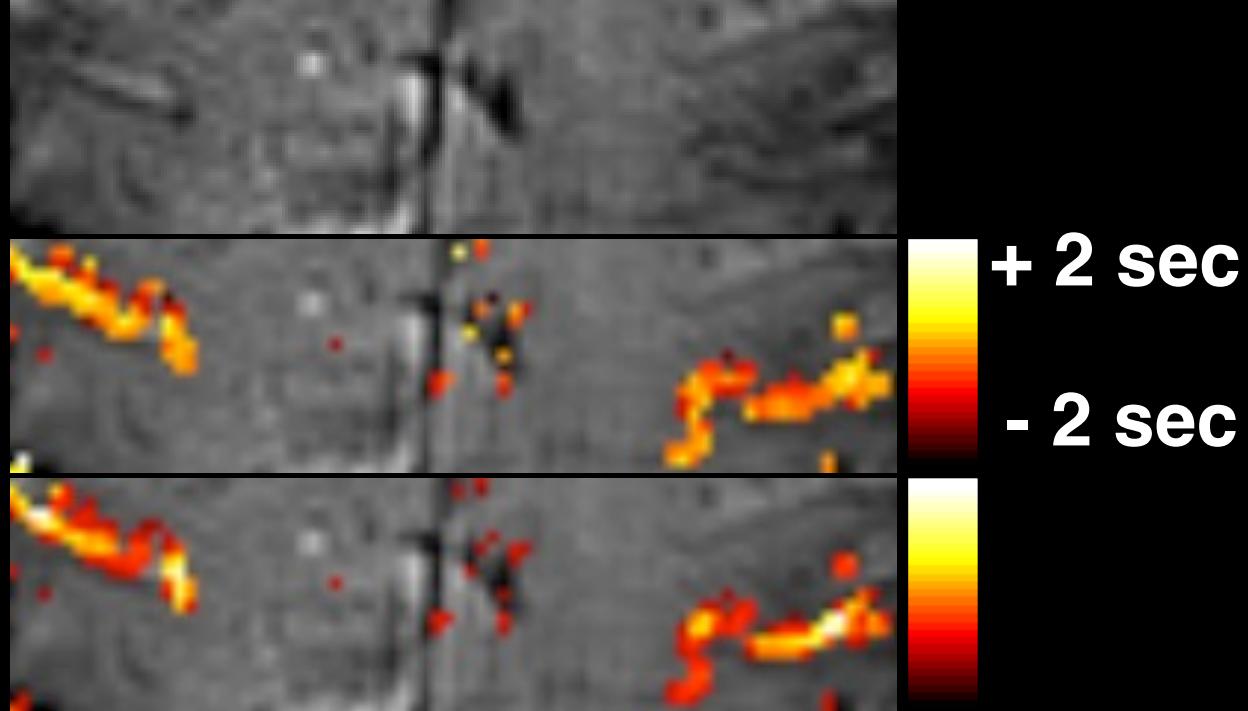




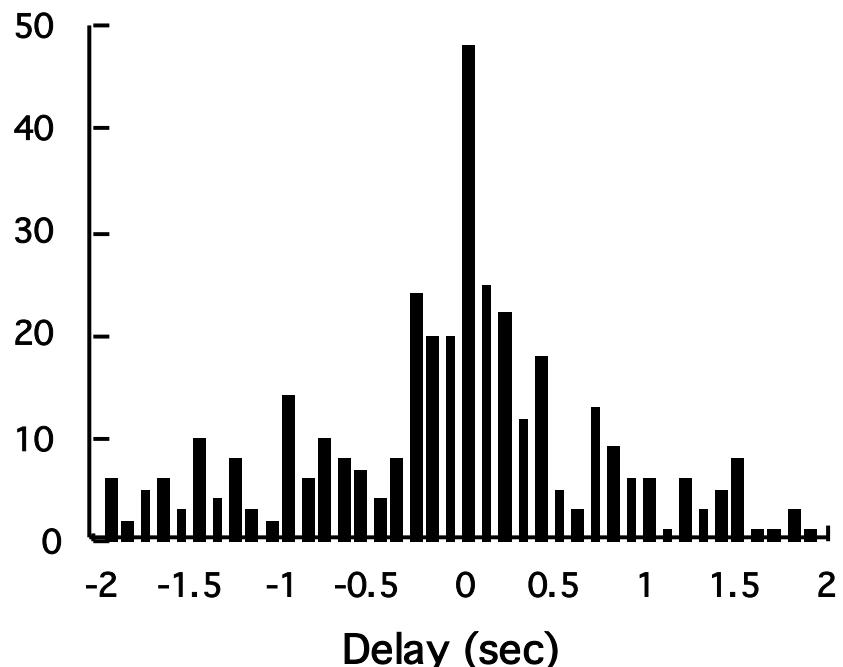
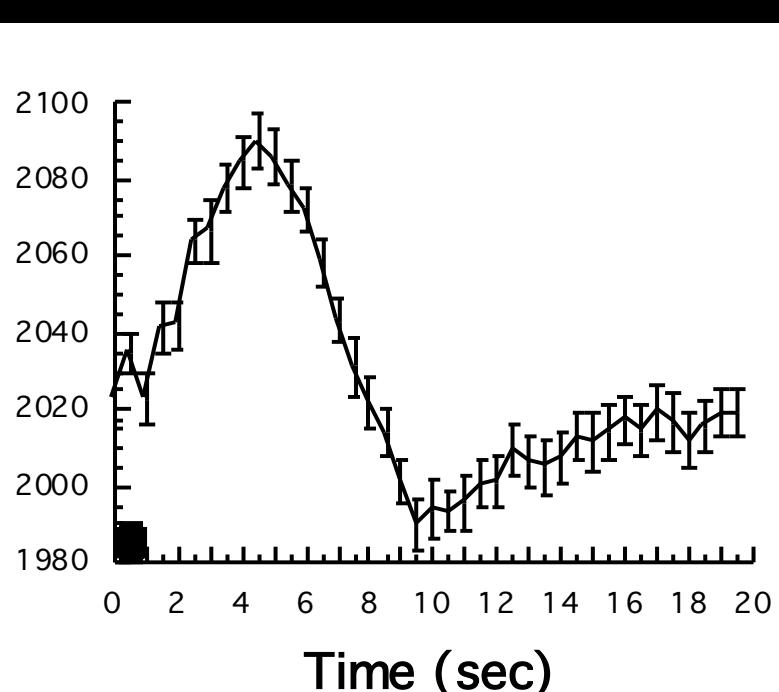
Time Course Comparison Across Brain Regions



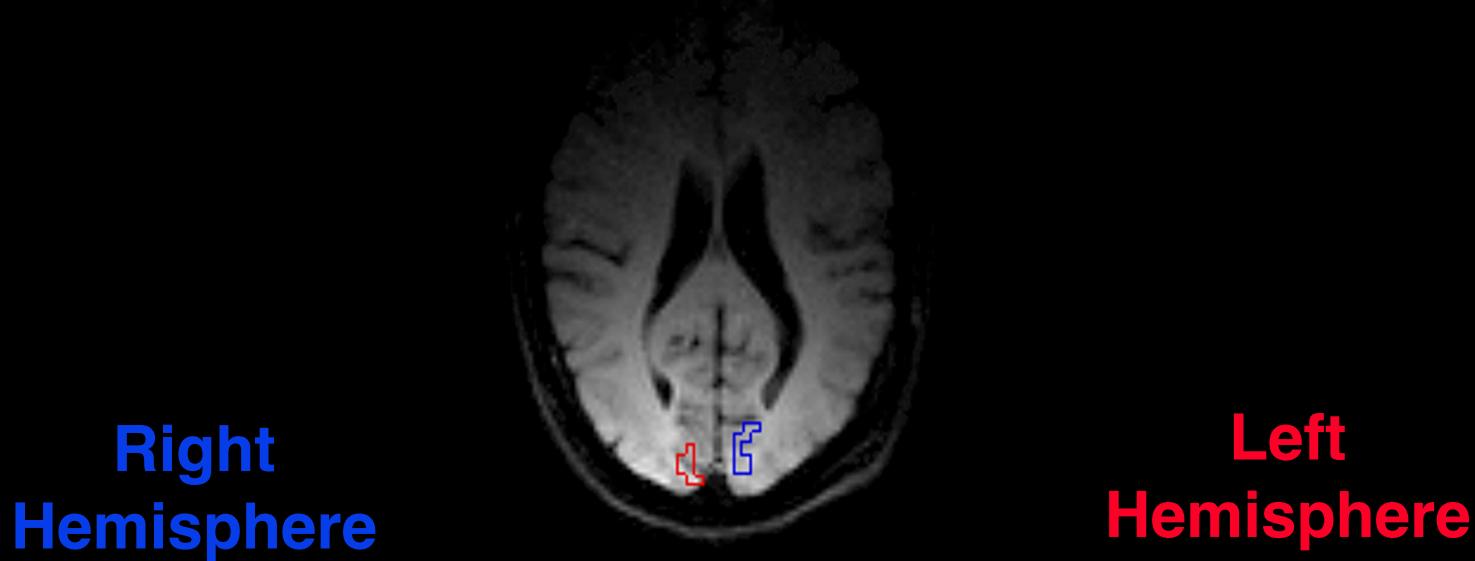
Latency

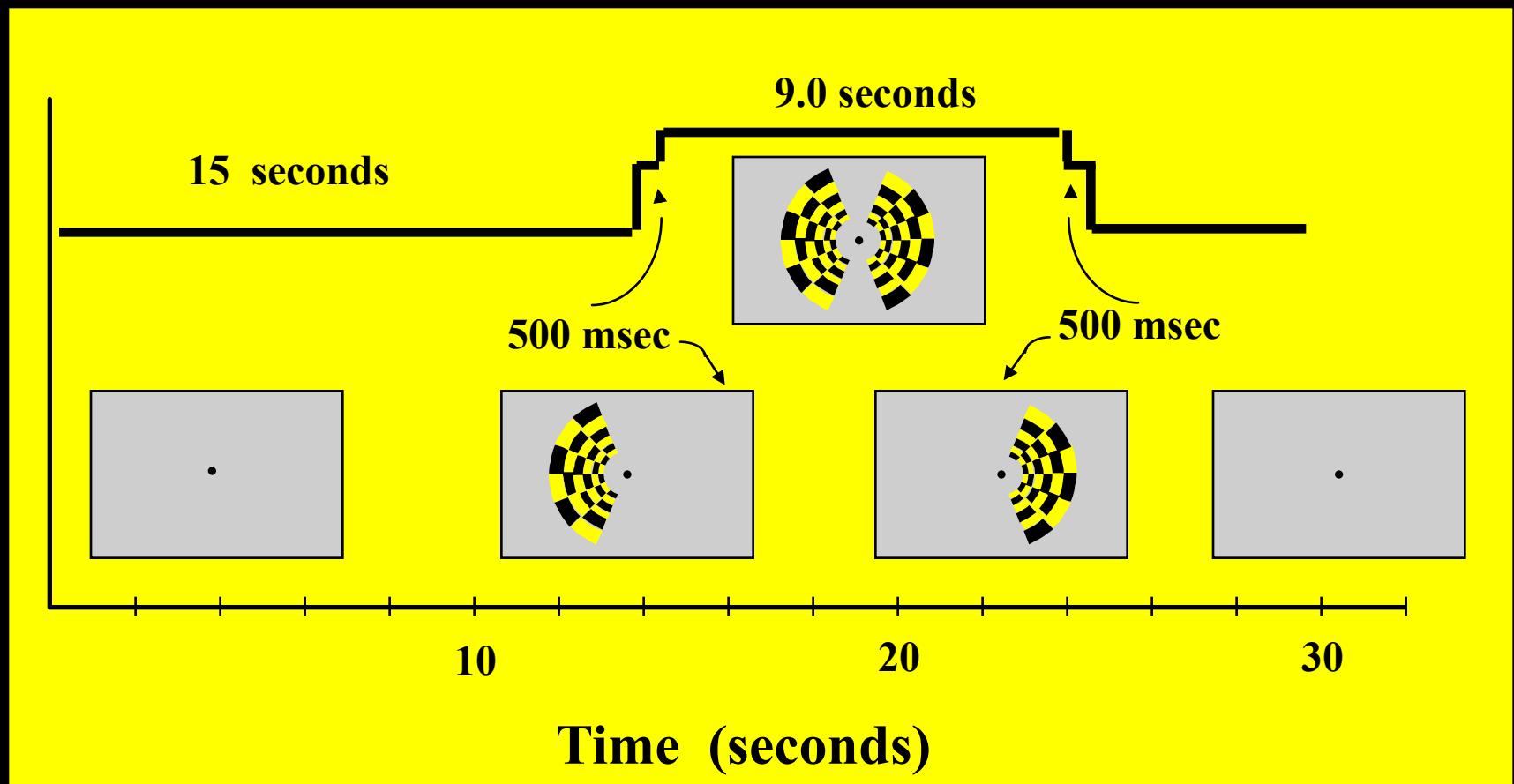


Magnitude



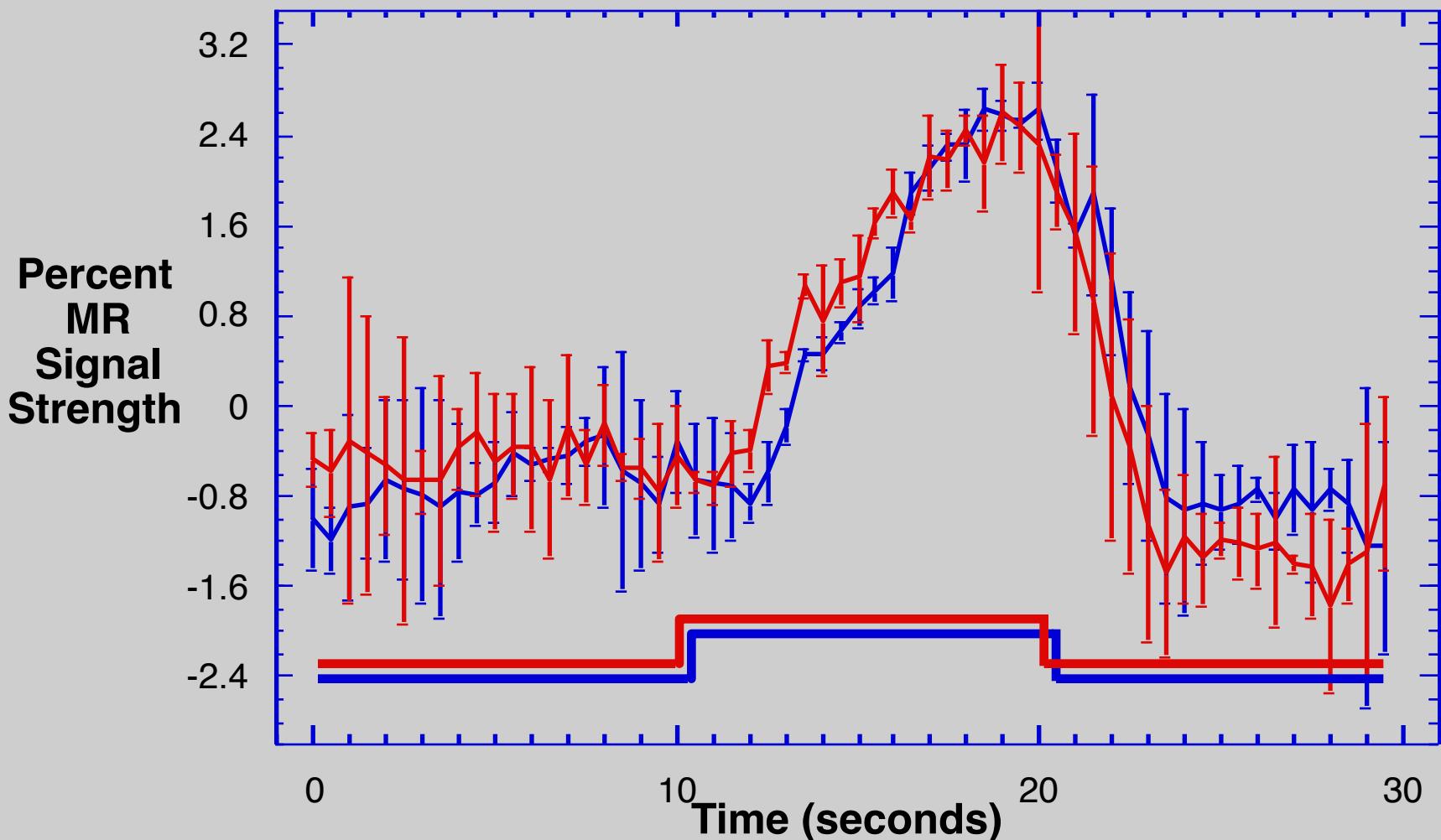
Regions of Interest Used for Hemi-Field Experiment

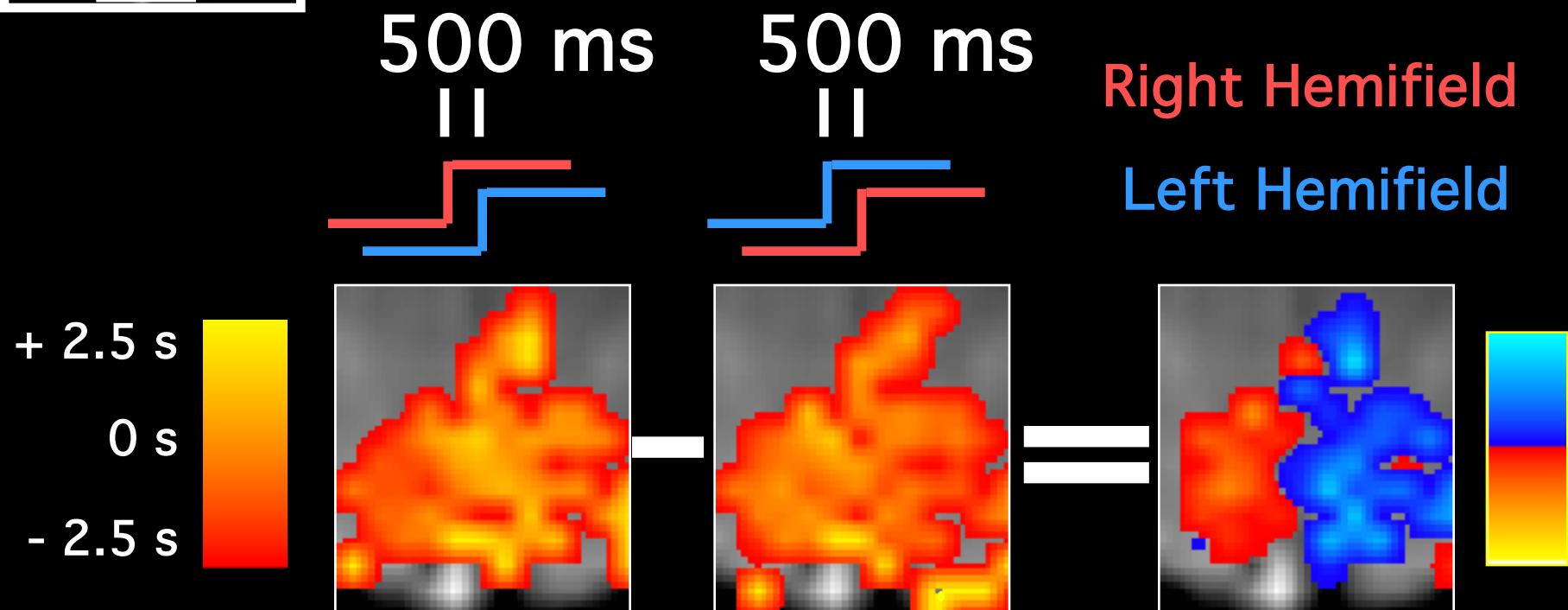
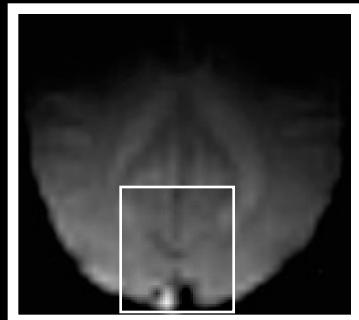




Hemi-field with 500 msec asynchrony

Average of 6 runs Standard Deviations Shown

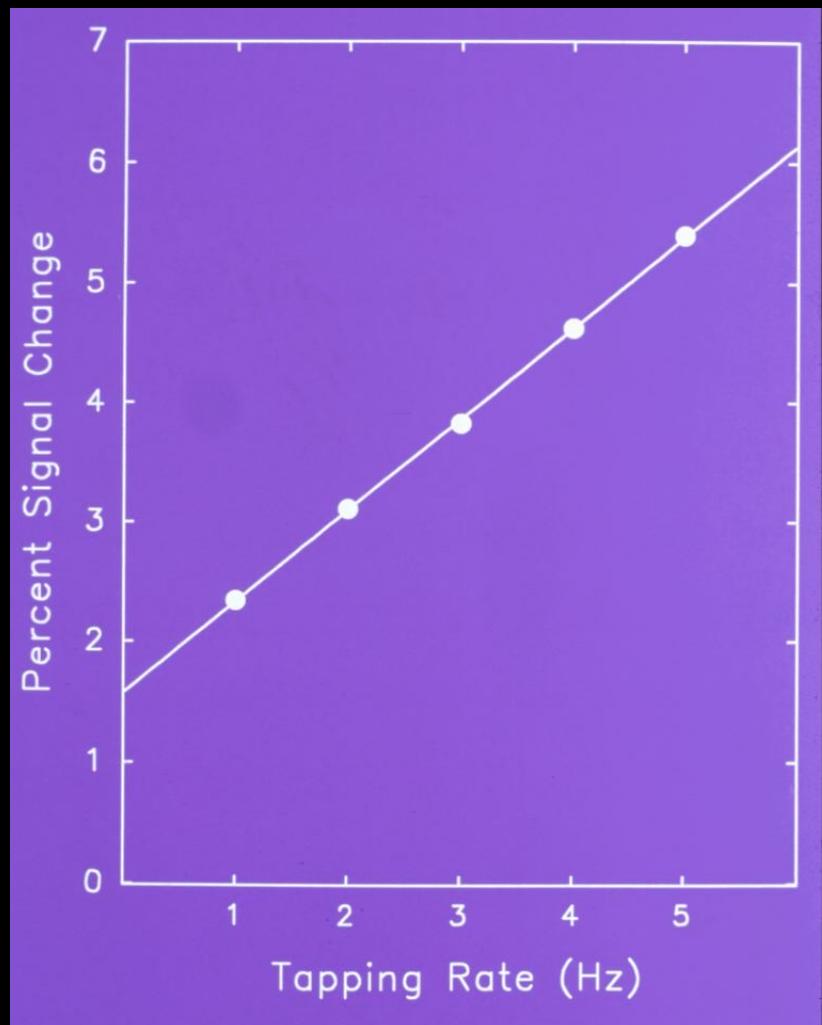




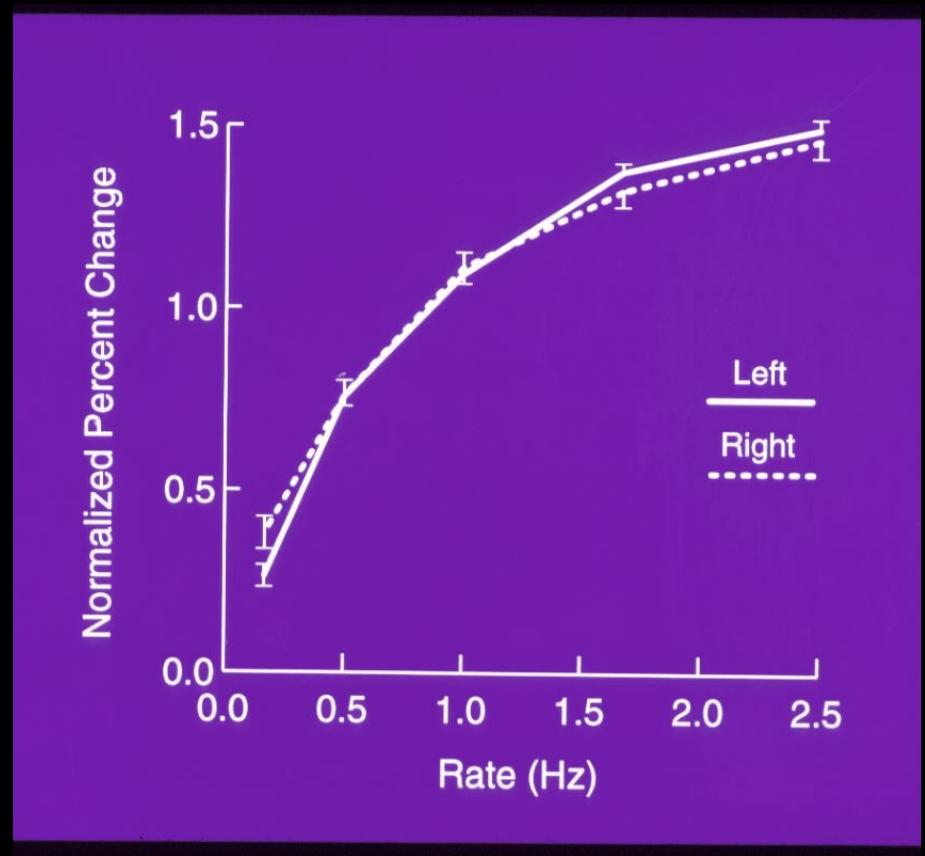
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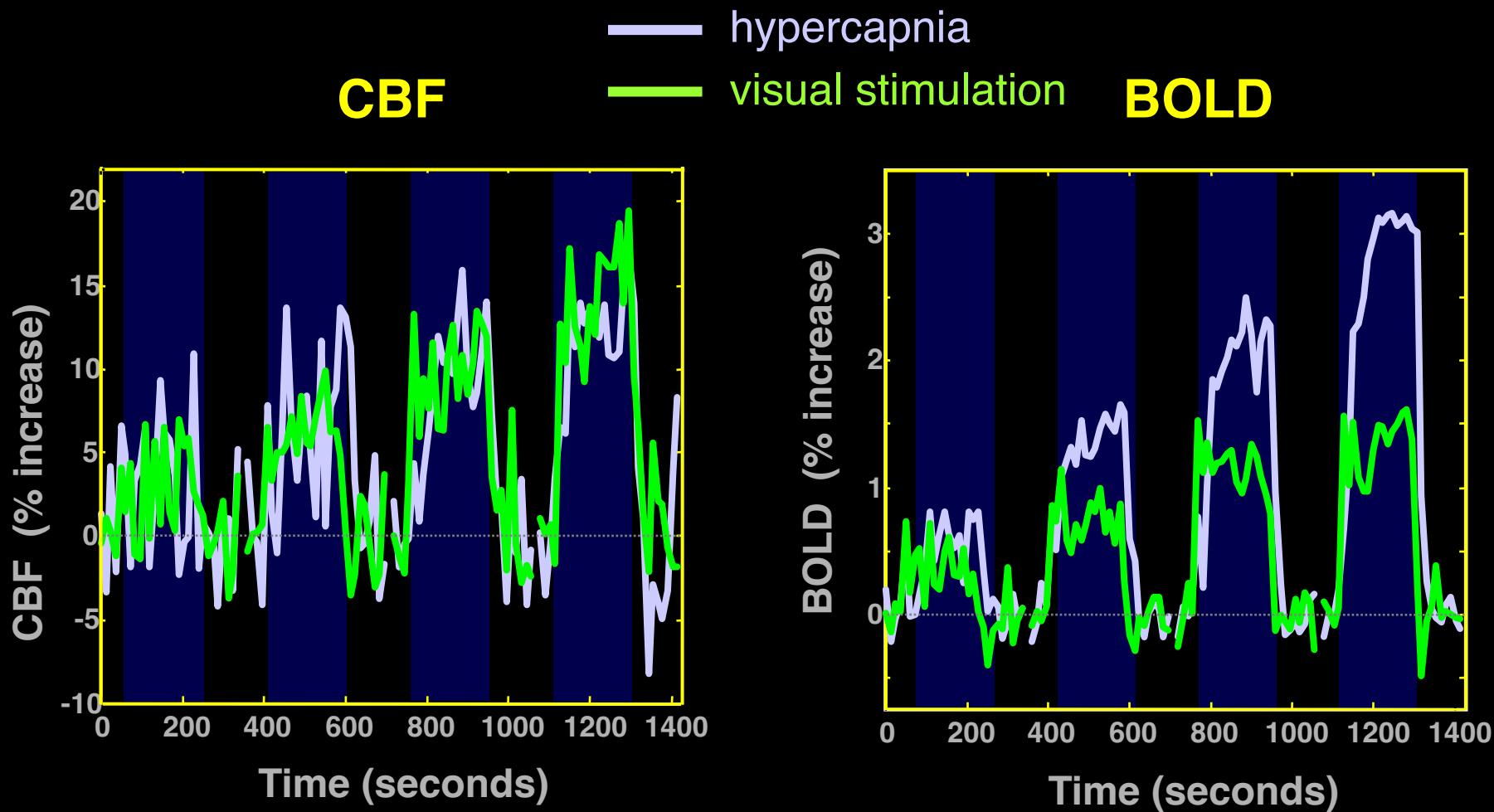
Motor Cortex



Auditory Cortex



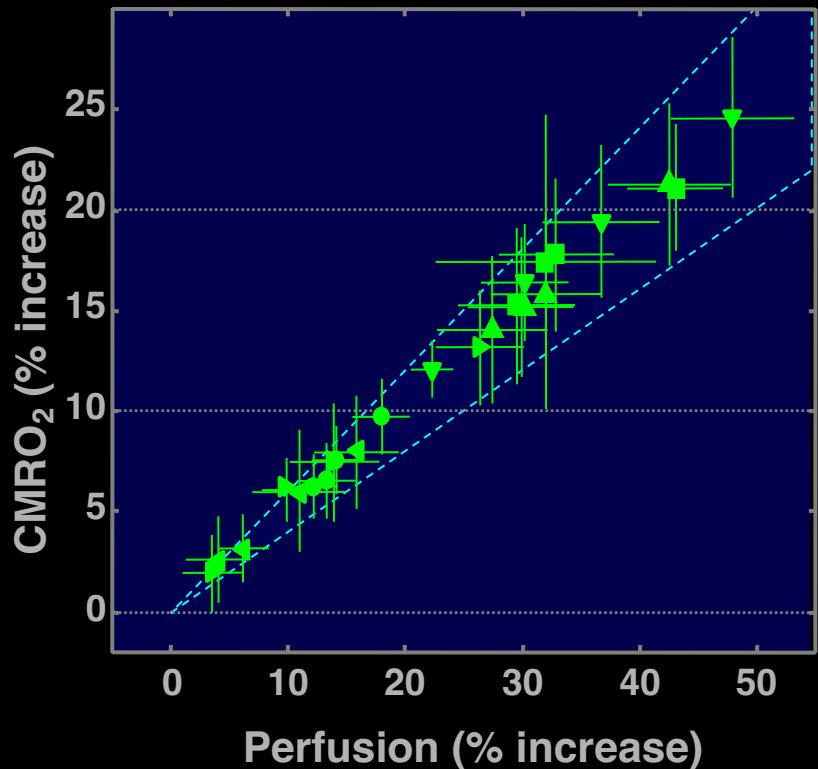
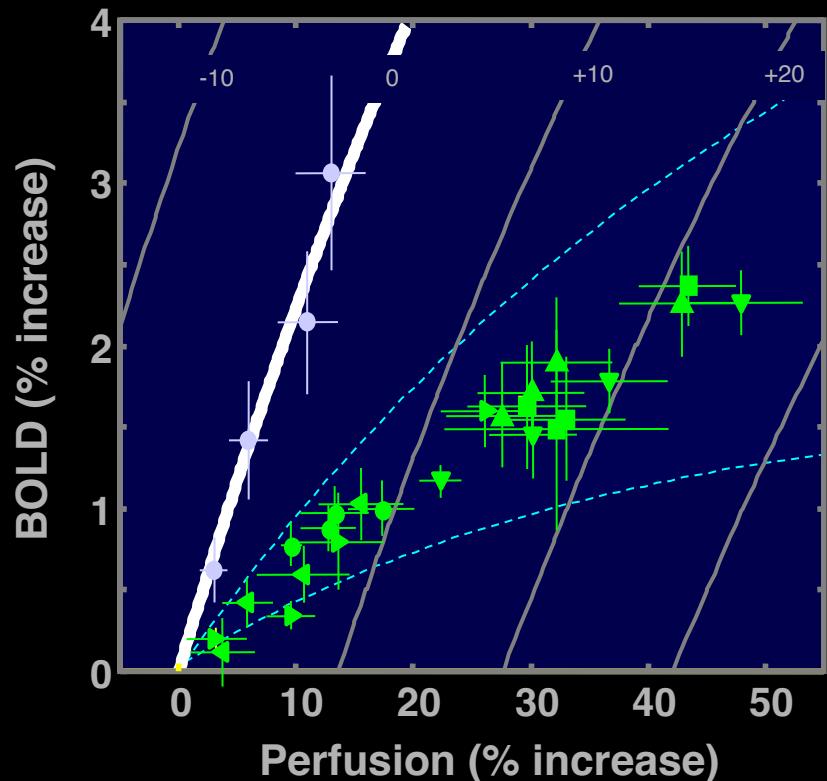
CMRO₂-related BOLD signal deficit:



Simultaneous Perfusion and BOLD imaging
during graded visual activation and hypercapnia

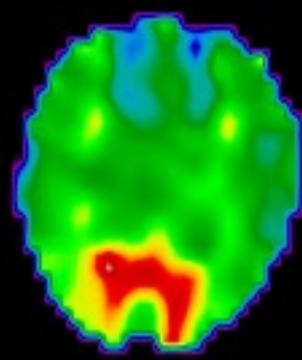
N=12

CBF-CMRO₂ coupling

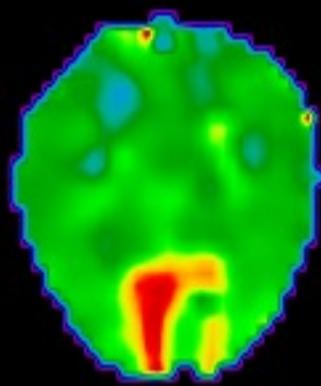


Characterizing Activation-induced CMRO₂ changes using calibration with hypercapnia

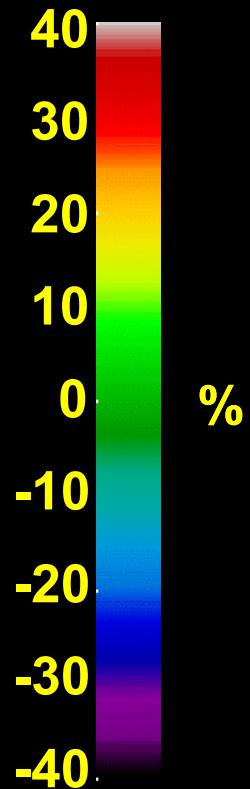
Computed CMRO₂ changes



Subject 1



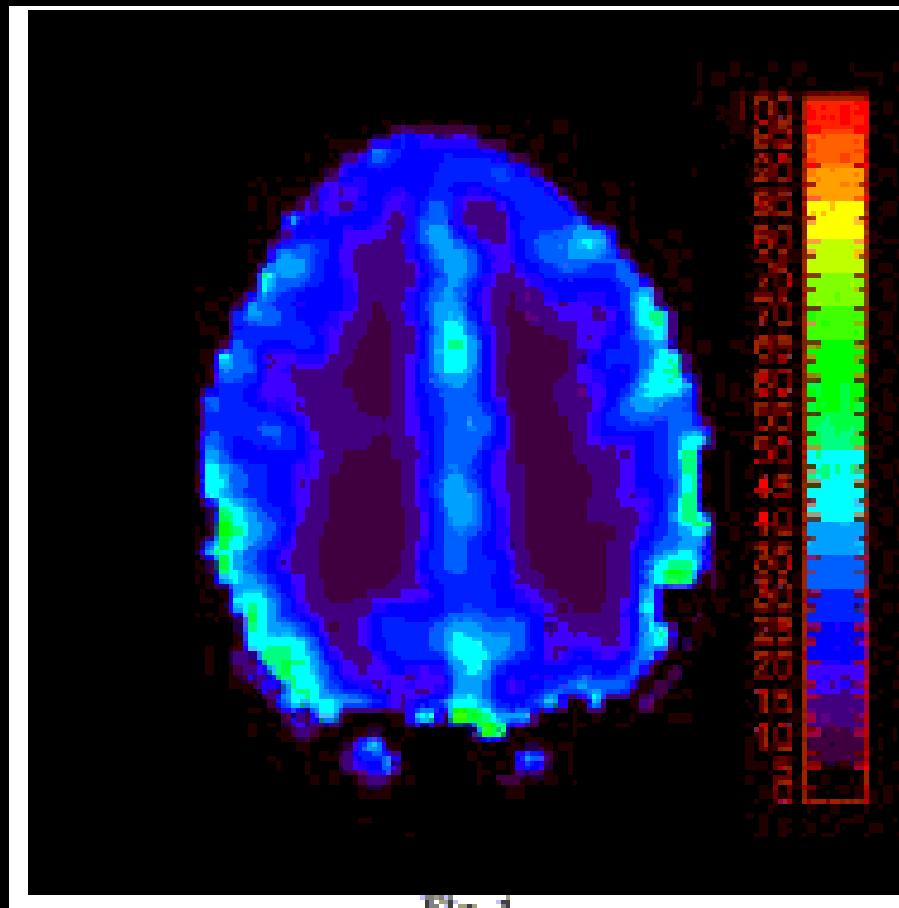
Subject 2



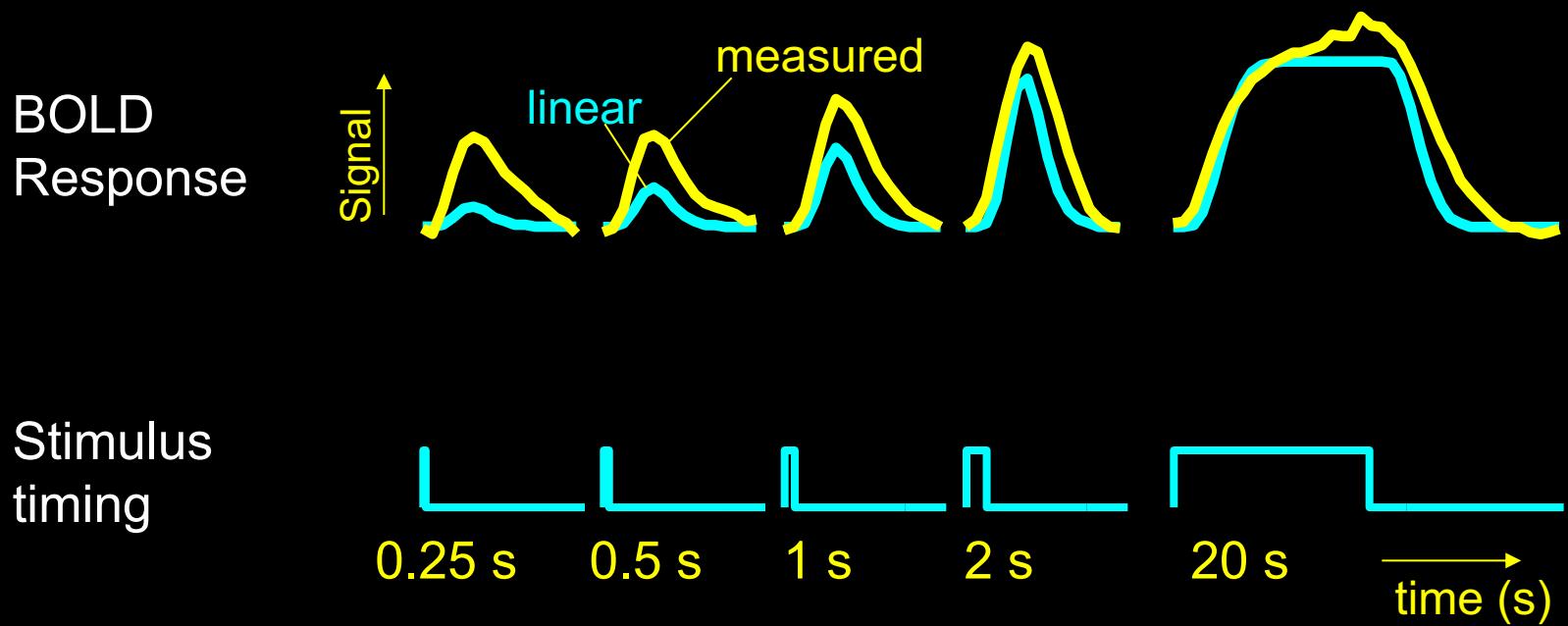
Quantitative Measurements of Cerebral Metabolic Rate of Oxygen (CMRO₂) Using MRI: A Volunteer Study

Honeyan AN¹, Weili LIN², Azim CELIK³, Yuesh Z. LEE⁴

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



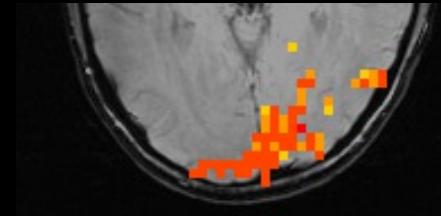
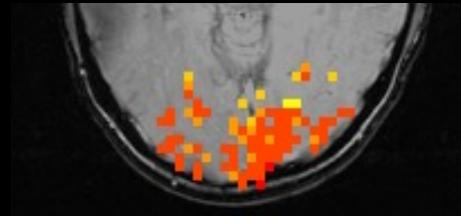
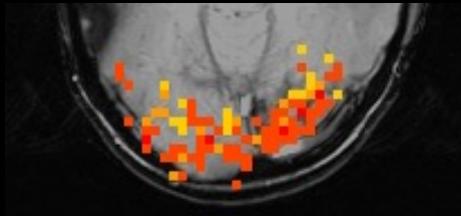
Different stimulus “ON” periods



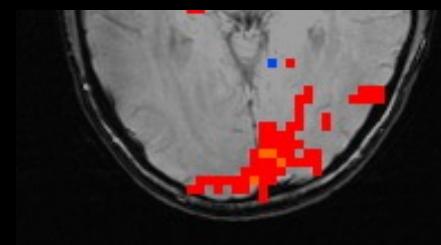
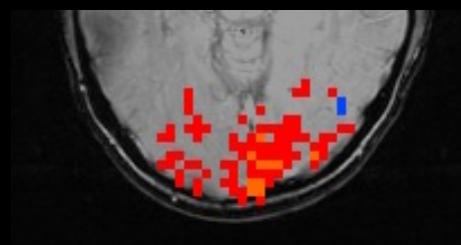
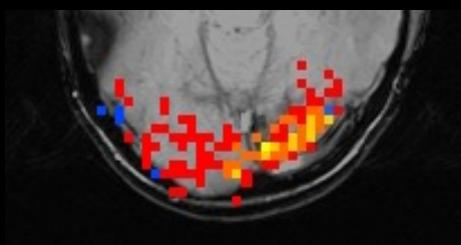
Brief stimuli produce larger responses than expected

Results – visual task

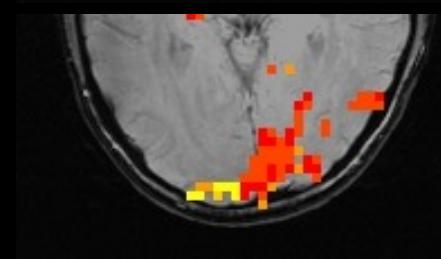
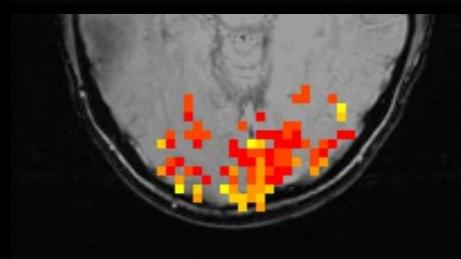
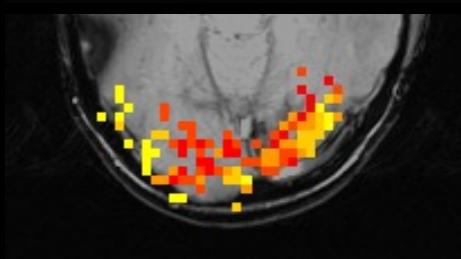
Nonlinearity



Magnitude

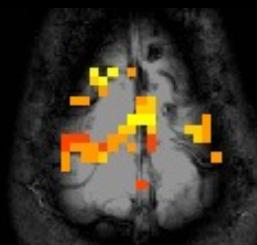
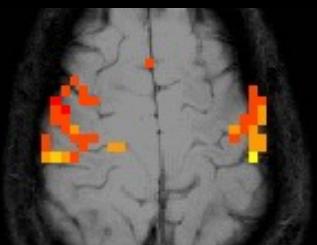
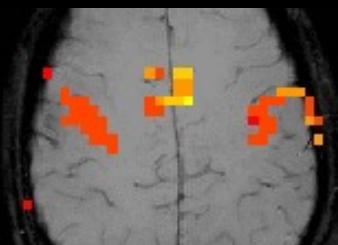


Latency

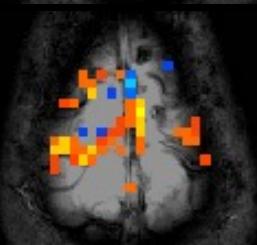
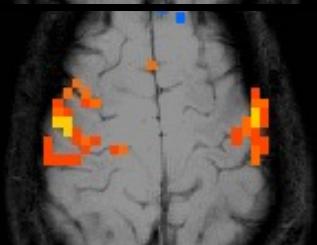
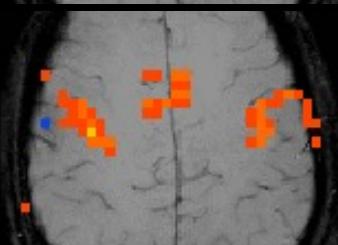


Results – motor task

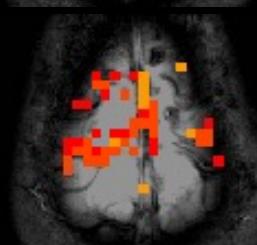
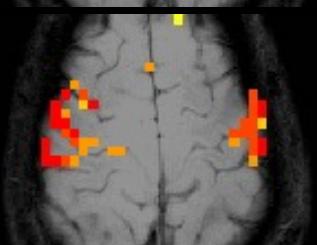
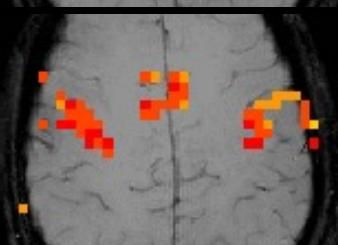
Nonlinearity



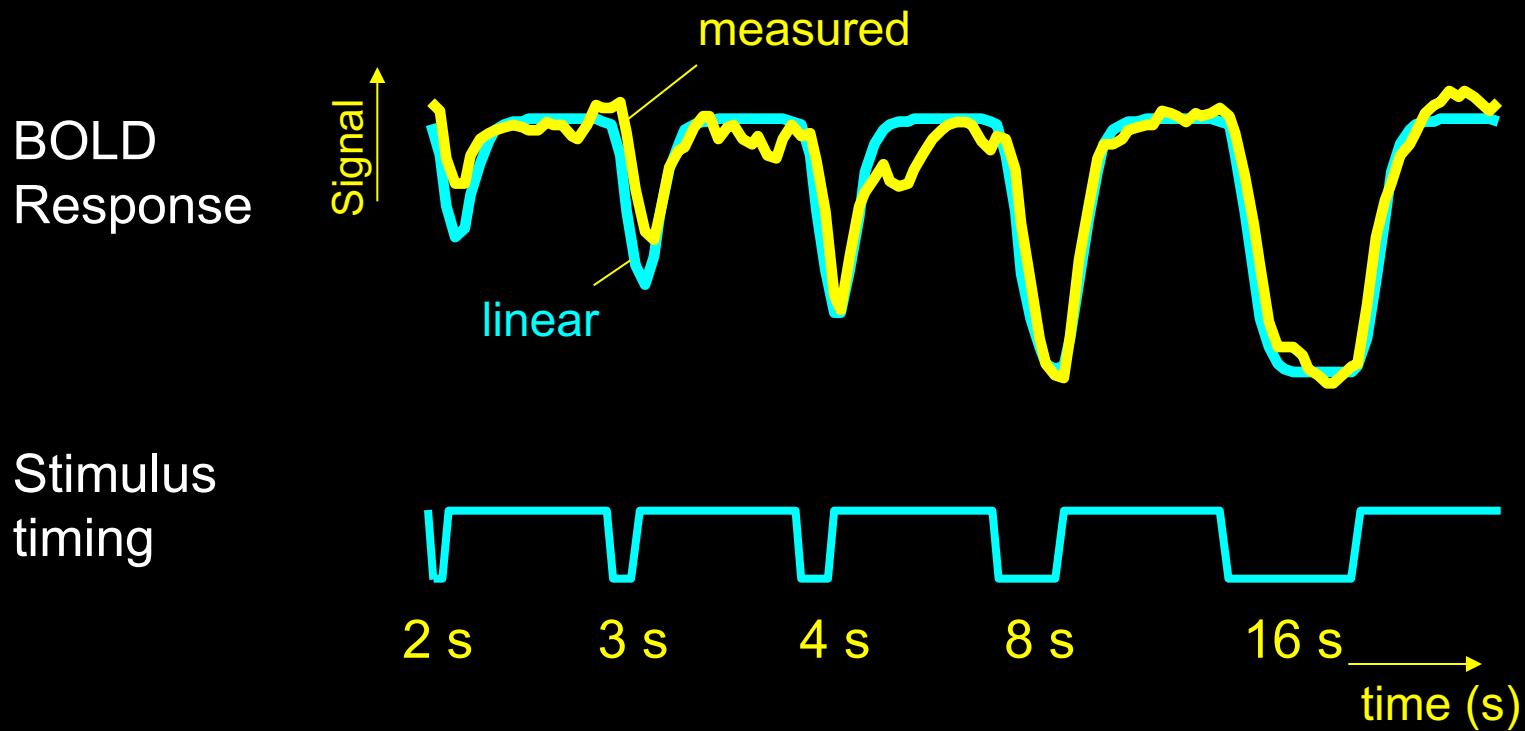
Magnitude



Latency



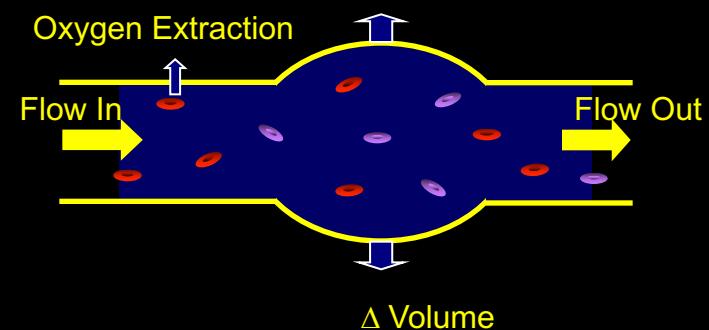
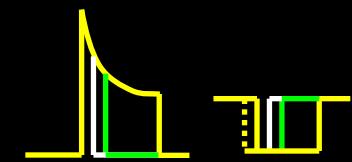
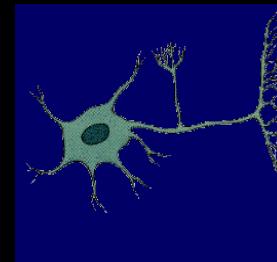
Different stimulus “ON” periods



Brief stimulus OFF periods produce smaller decreases than expected

Sources of this Nonlinearity

- Neuronal
- Hemodynamic
 - Oxygen extraction
 - Blood volume dynamics



Questions

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Improvement Needed...

**Neurovascular Coupling
Paradigm Design
Motion Reduction/Correction
Acoustic Noise
Sensitivity
Noise characterization
Image quality
Brain Coverage
Feedback Time/Information**

Improvement Needed...

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Neuronal Activation Input Strategies

1. Block Design

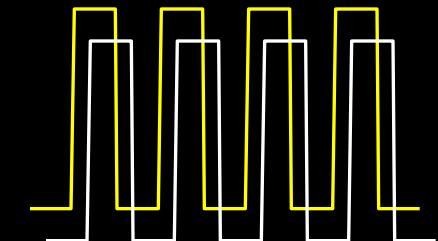
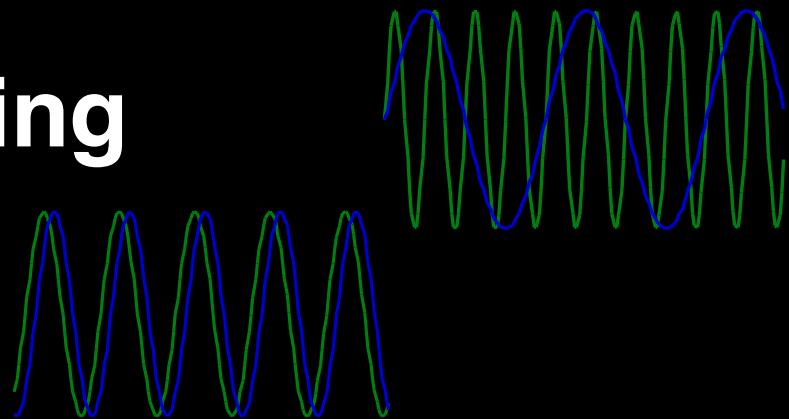
2. Frequency Encoding

3. Phase Encoding

4. Single Event

5. Orthogonal Block Design

6. Free Behavior Design.

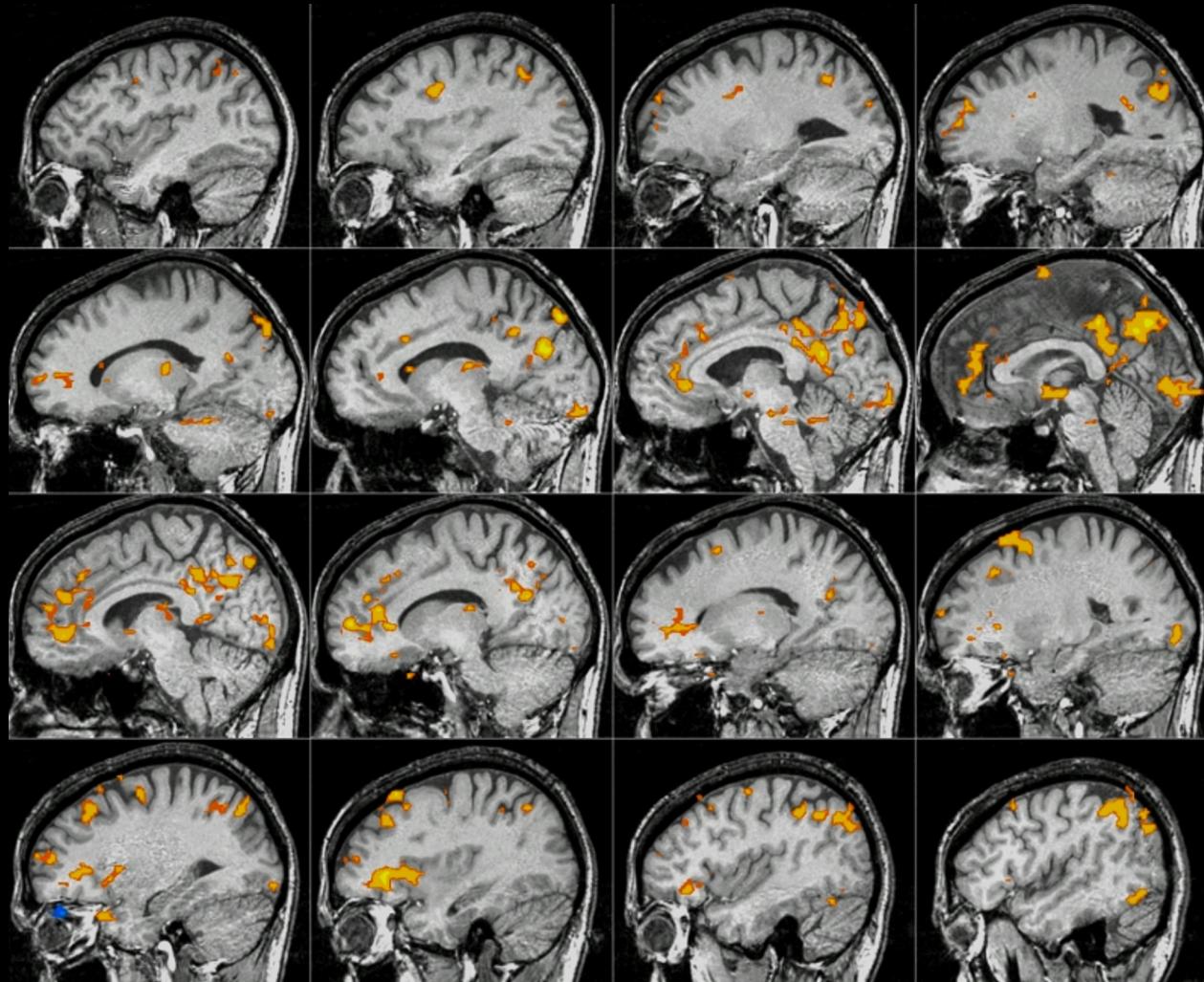


Free Behavior Design

Use a continuous measure as a reference function:

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

Brain activity correlated with SCR during “Rest”



Improvement Needed...

Neurovascular Coupling
Paradigm Design
Motion Reduction/Correction
Acoustic Noise
Sensitivity
Noise characterization
Image quality
Brain Coverage
Feedback Time/Information

Motion

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

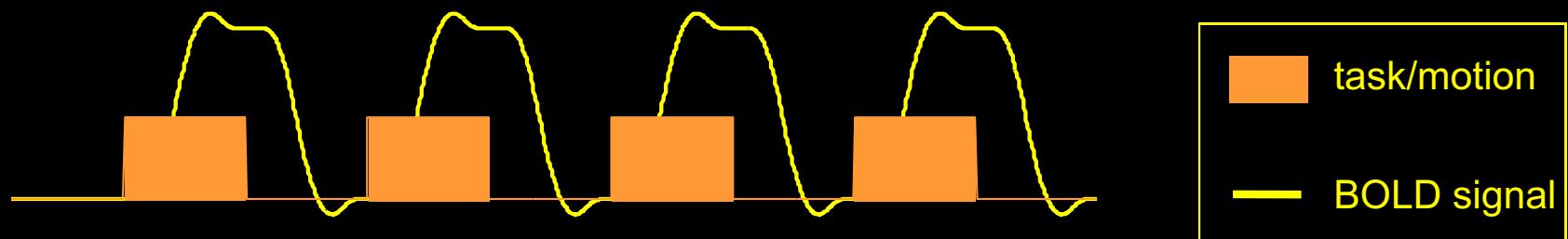
Bypass?

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

Suppress?

- Flatten image contrast
- Physical restraint
- Averaging, smoothing

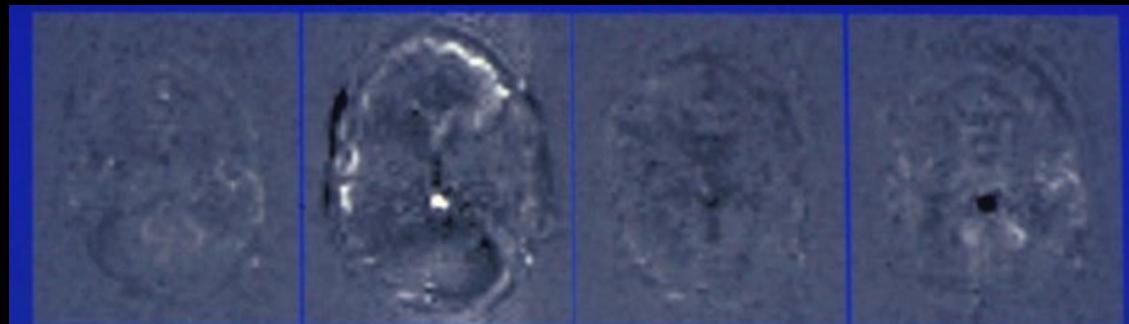
Block-trial



Single-trial (brief stimulus)



Overt Word Production



2

3

4

5



6

7

8

9



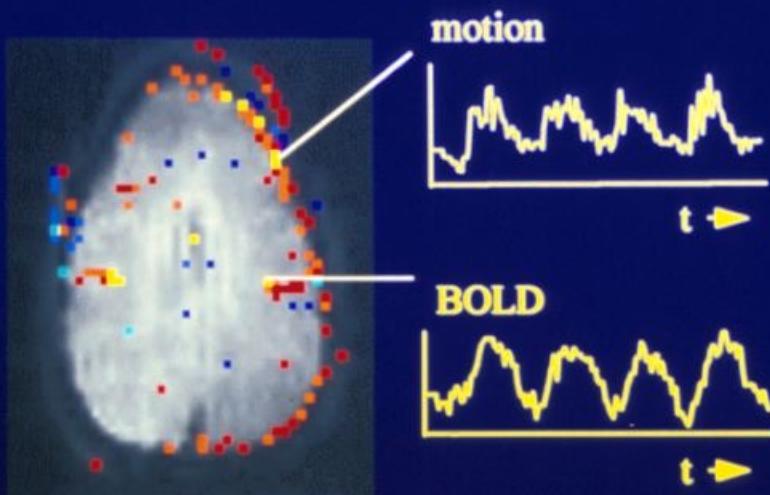
10

11

12

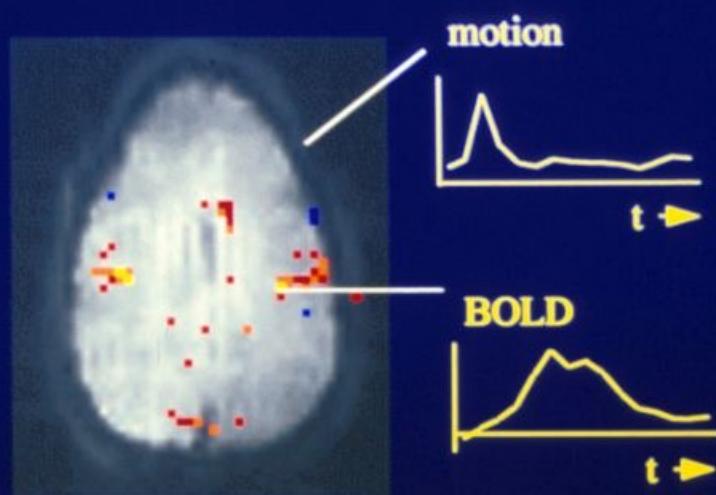
13

Motion-Decoupled fMRI: Functional MRI during overt word production



"block-trial" paradigm

Motion induced signal changes resemble functional (BOLD) signal changes

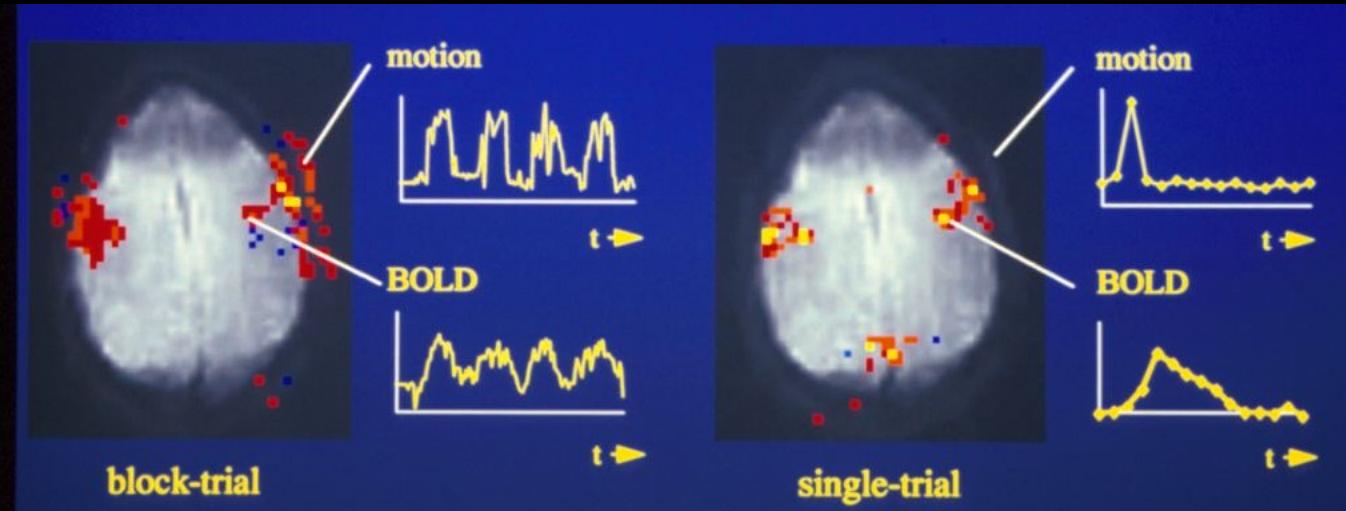


"single-trial" paradigm

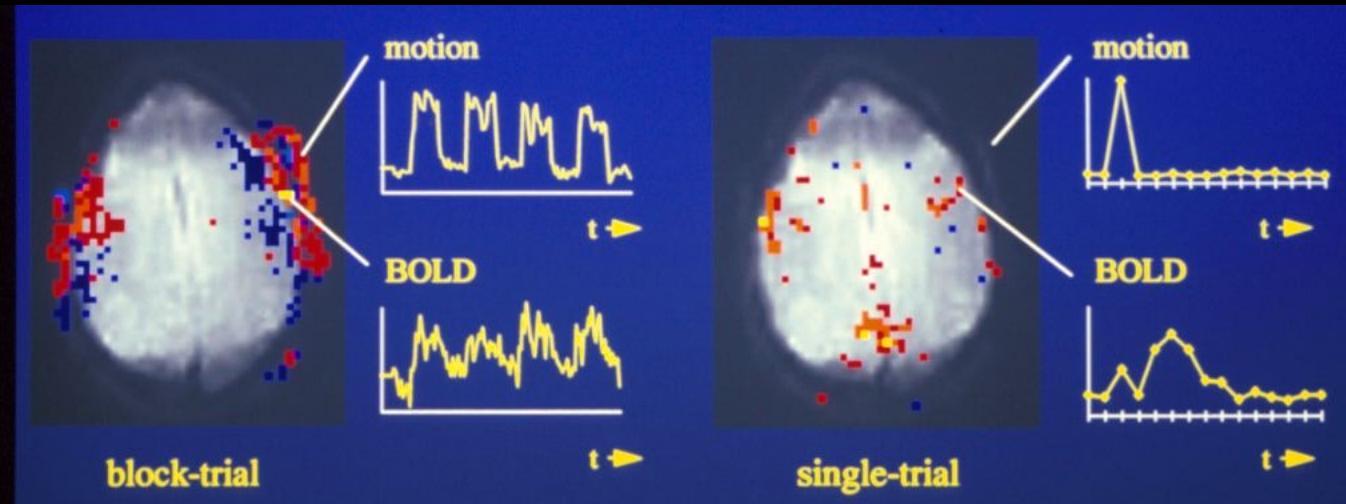
Motion induced and BOLD signal changes are separated in time

R.M. Birn, et al.

Tongue Movement

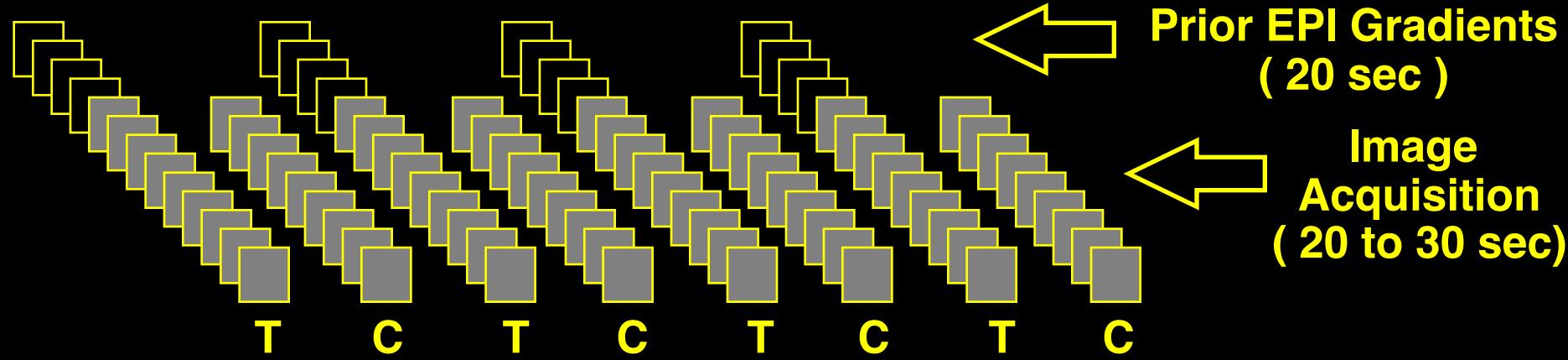


Jaw Clenching



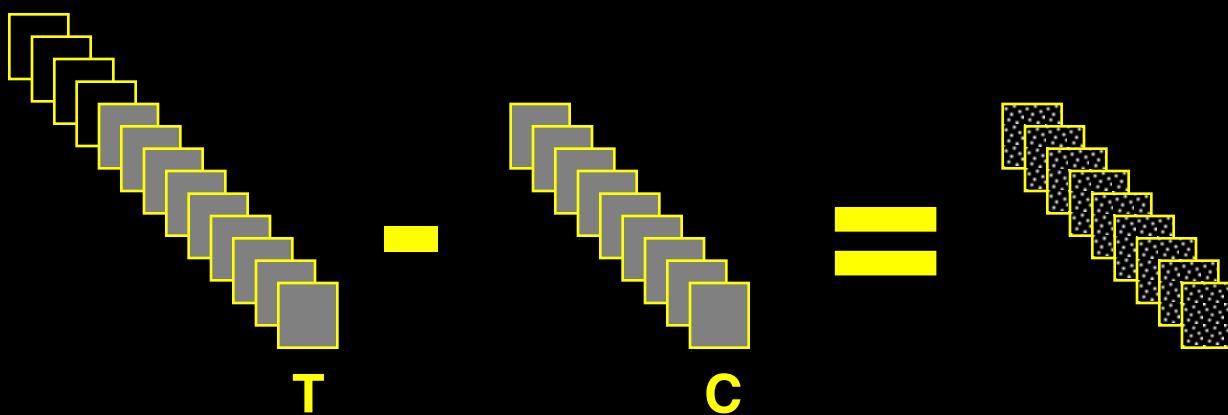
Improvement Needed...

Neurovascular Coupling
Paradigm Design
Motion Reduction/Correction
Acoustic Noise
Sensitivity
Noise characterization
Image quality
Brain Coverage
Feedback Time/Information



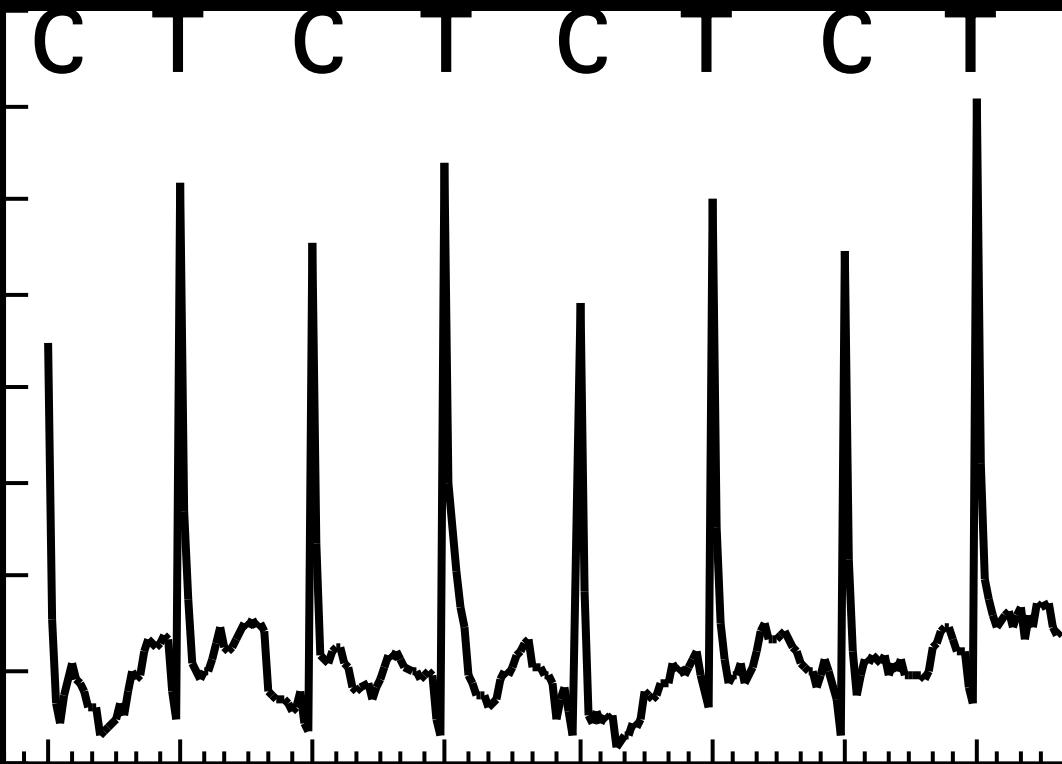
Prior EPI Gradients
(20 sec)

Image
Acquisition
(20 to 30 sec)

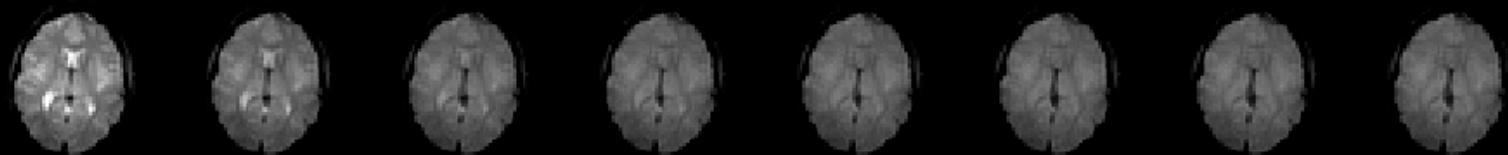


Average Time Series

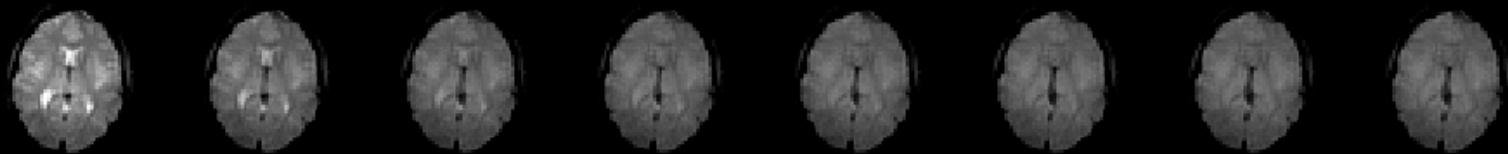
Difference Time Series



a.



b.



c.



0

1

2

3

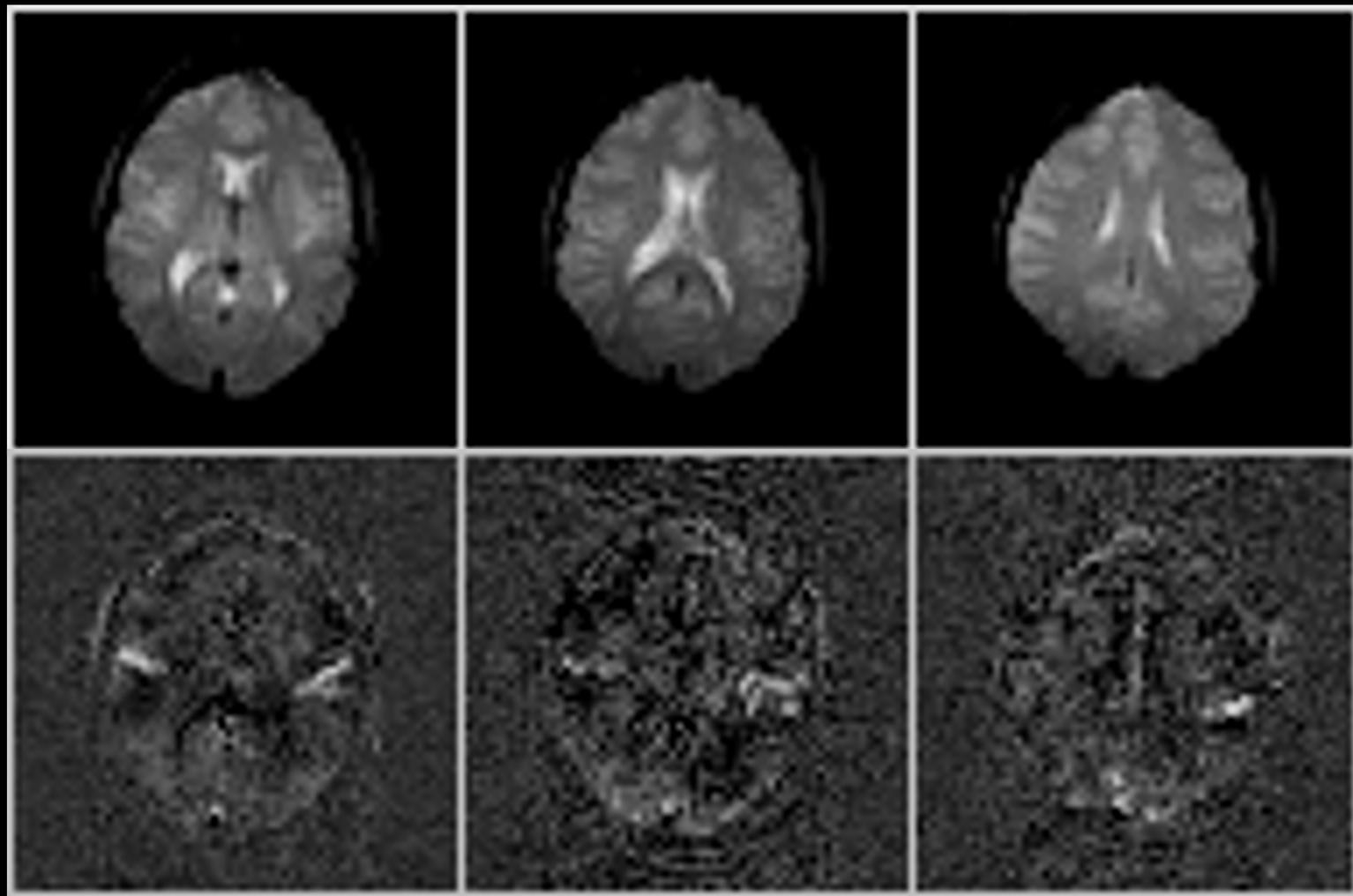
4

5

6

7

Time (sec)



How to deal with Scanner Noise?

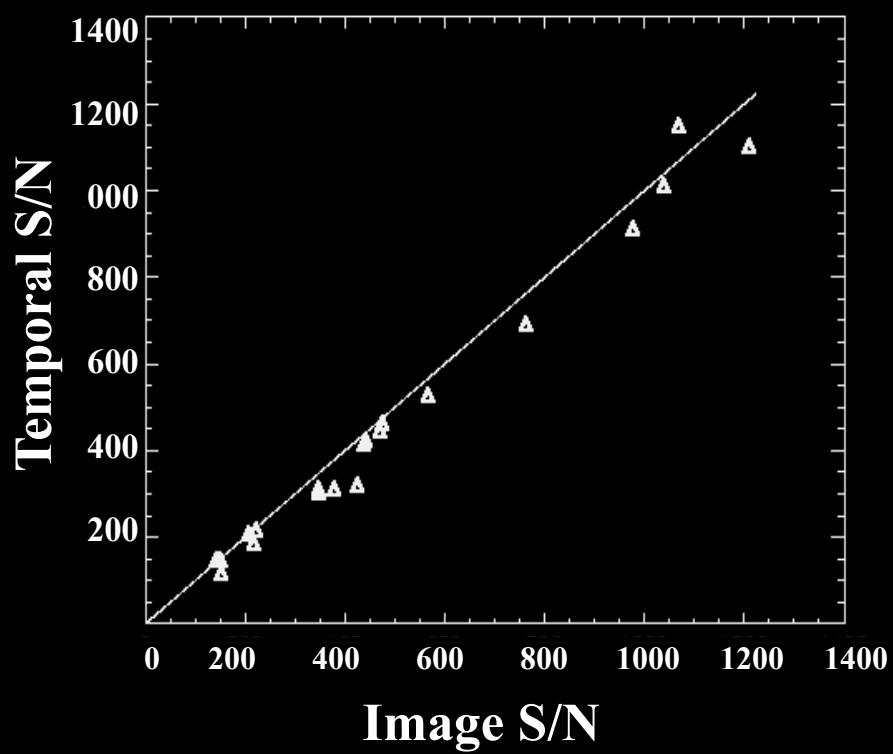
- Clustered volume acquisition
Talavage et al.
- Silent sequences

Improvement Needed...

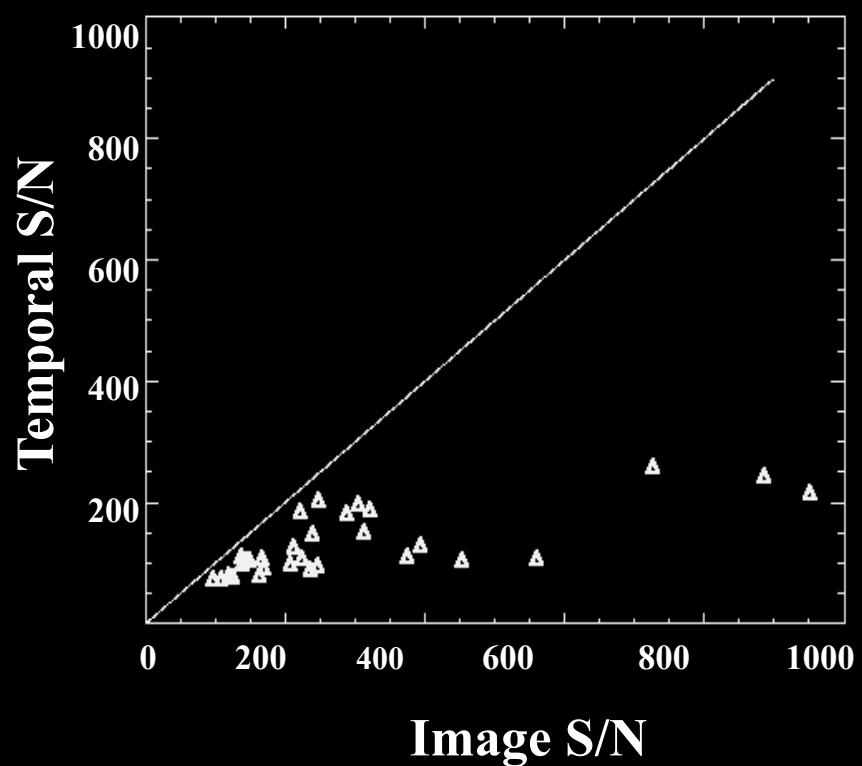
Neurovascular Coupling
Paradigm Design
Motion Reduction/Correction
Acoustic Noise
Sensitivity
Noise characterization
Image quality
Brain Coverage
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Temporal S/N vs. Image S/N

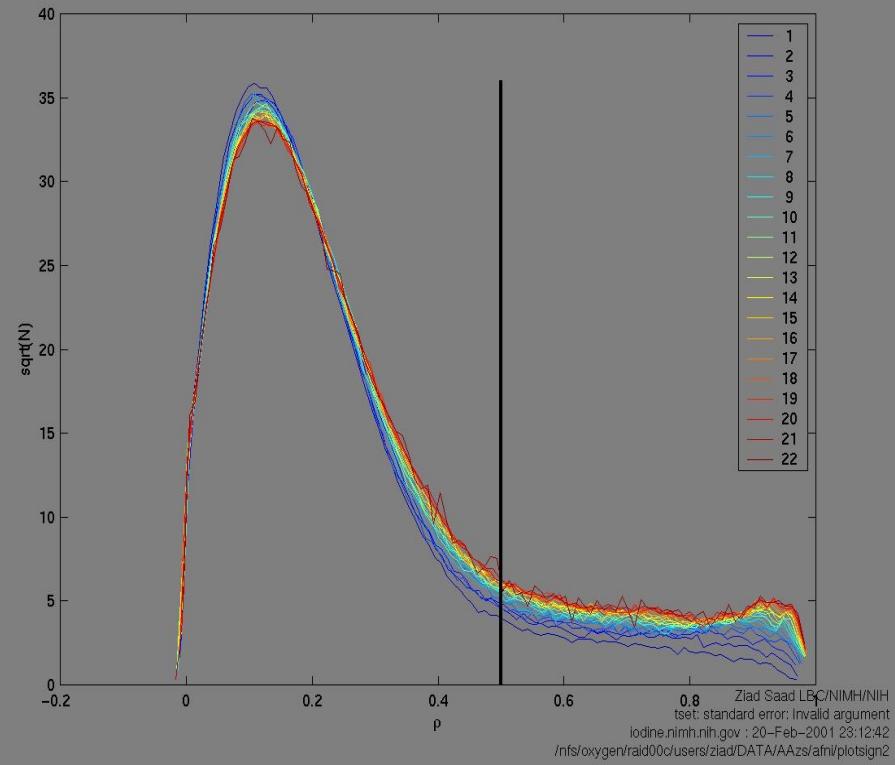
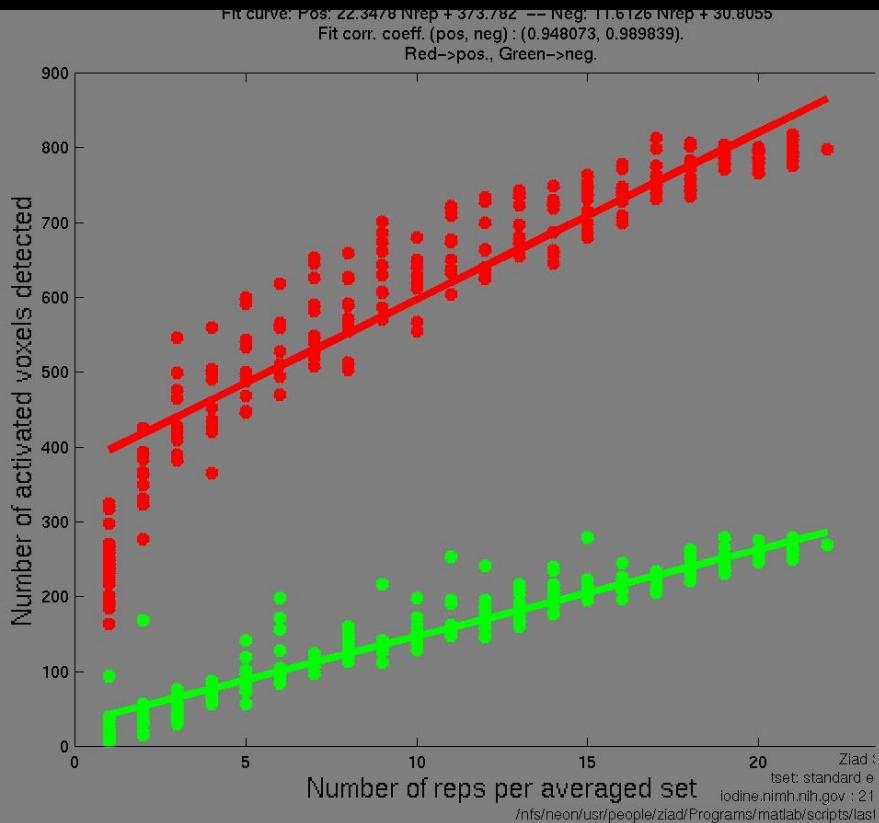
PHANTOMS



SUBJECTS



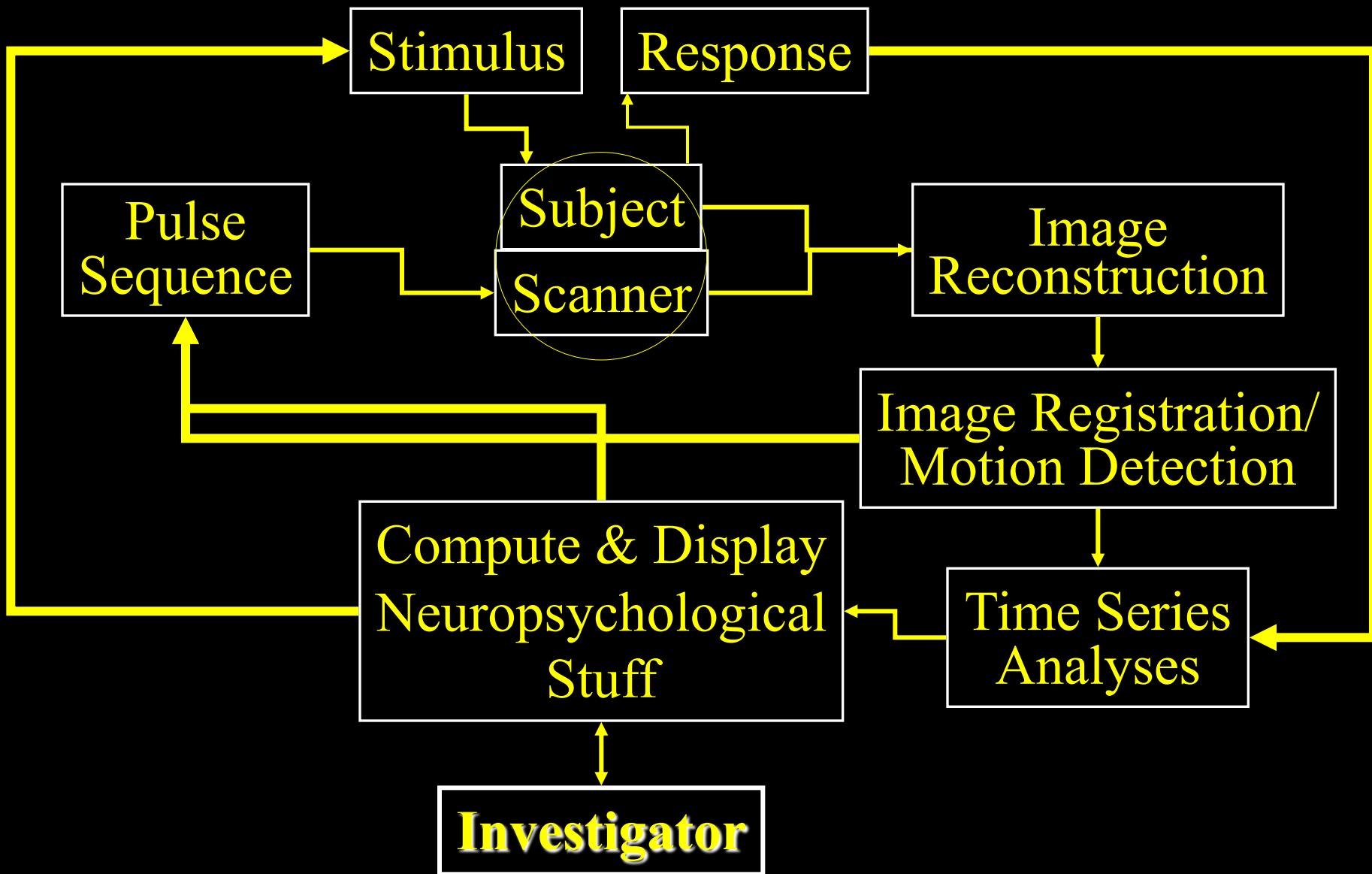
N. Petridou



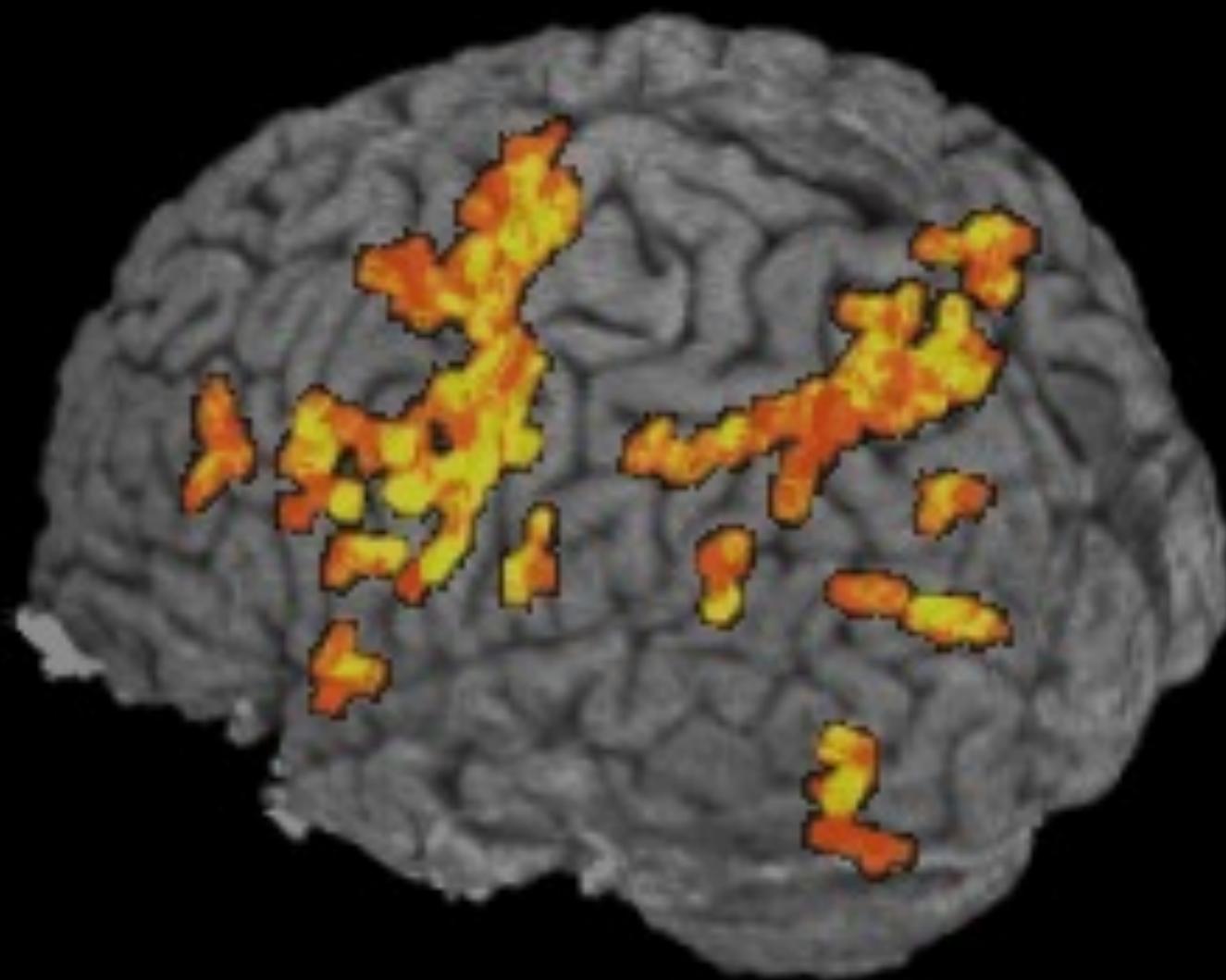
Questions

1. What determines fMRI spatial resolution?
2. What determines fMRI temporal resolution?
3. What determines fMRI interpretation and quantification?
4. What are the primary areas of fMRI methodology that require improvement?
5. How far can fMRI methodology improvement be taken?

Processing Stream with Real Time fMRI



End of Acquisition



< 1 s to render

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

Blocks: 1 2 3 4 5 6 7 8

Color shows
through brain

Correlation > 0.45



Functional Imaging Methods / 3T Group

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Rasmus Birn

Patrick Bellgowan

Ziad Saad

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August, 2000