

Latest Developments in fMRI

Peter A. Bandettini, Ph.D

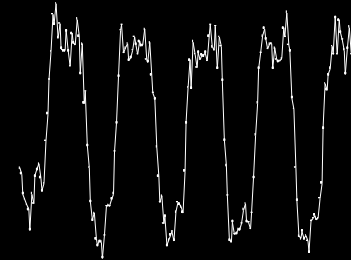
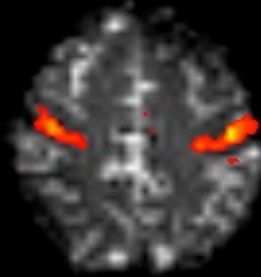
Unit on Functional Imaging Methods
&
3T Neuroimaging Core Facility

Laboratory of Brain and Cognition
National Institute of Mental Health

The use of fMRI for the Investigation of Brain Function

Where?

When?



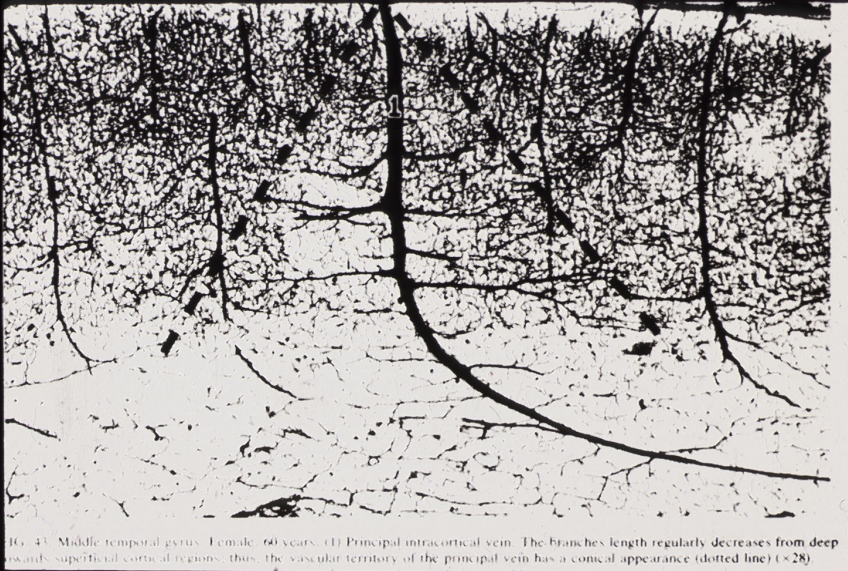
How much?

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.



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?

Contrast in Functional MRI

- **Blood Volume**

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

- **BOLD**

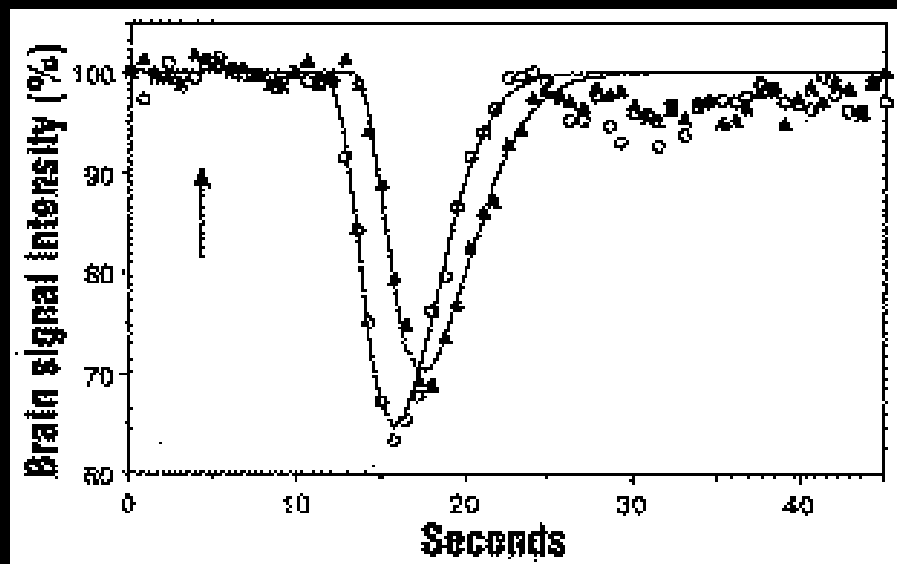
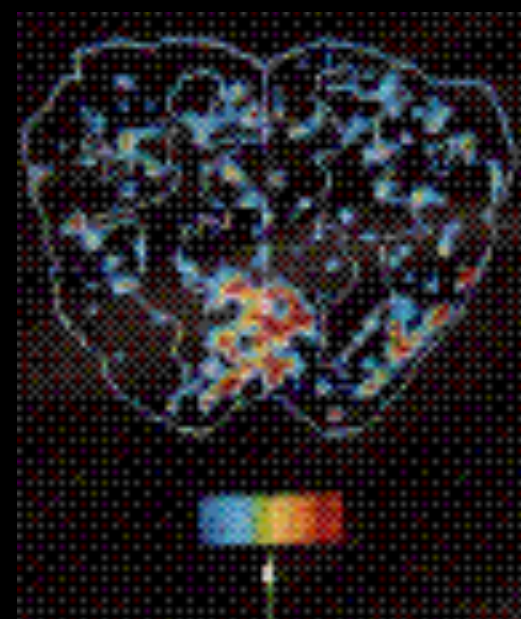
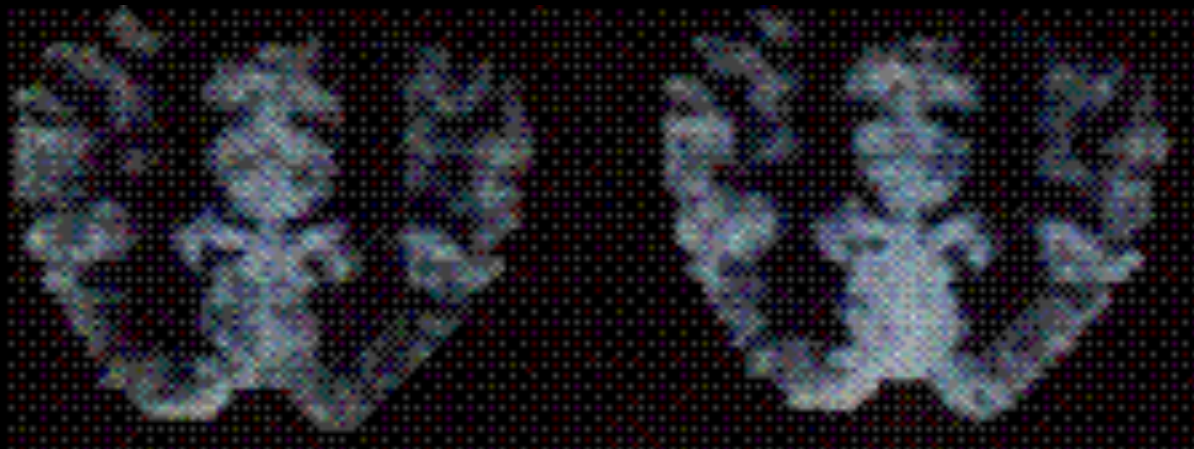
- Time series collection of T2* or T2 - weighted images

- **Perfusion**

- T1 weighting
- Arterial spin labeling

Resting

Active

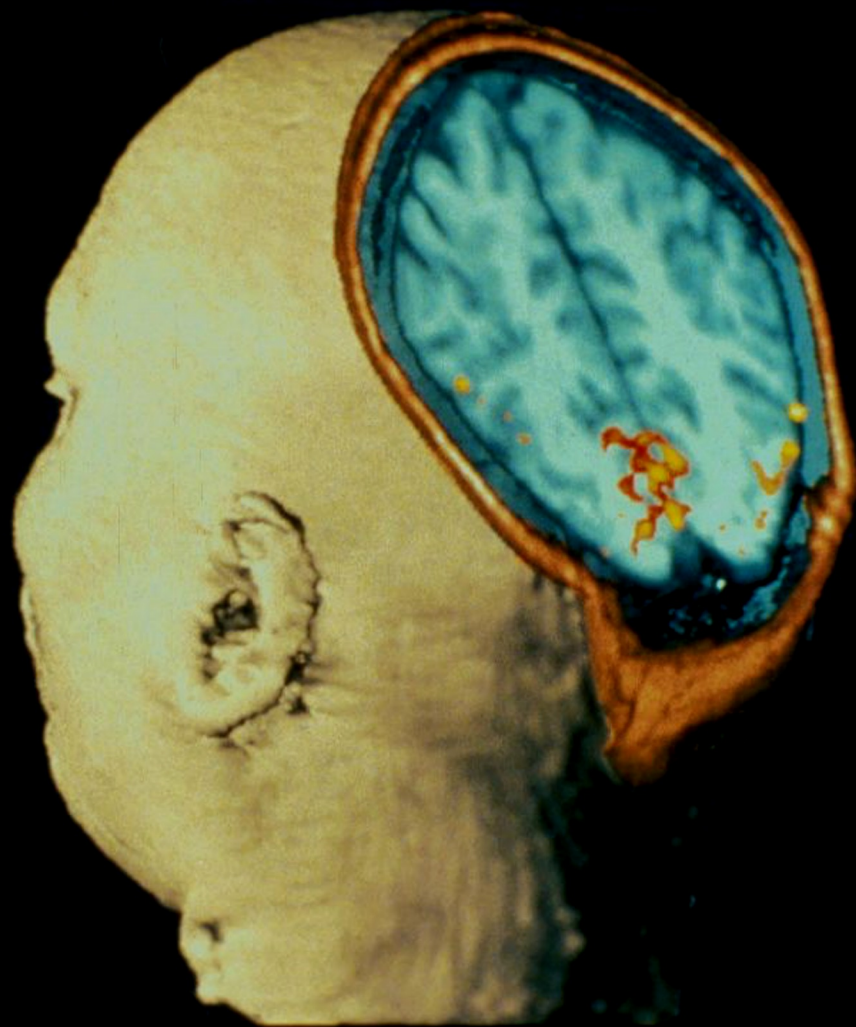


Photic Stimulation

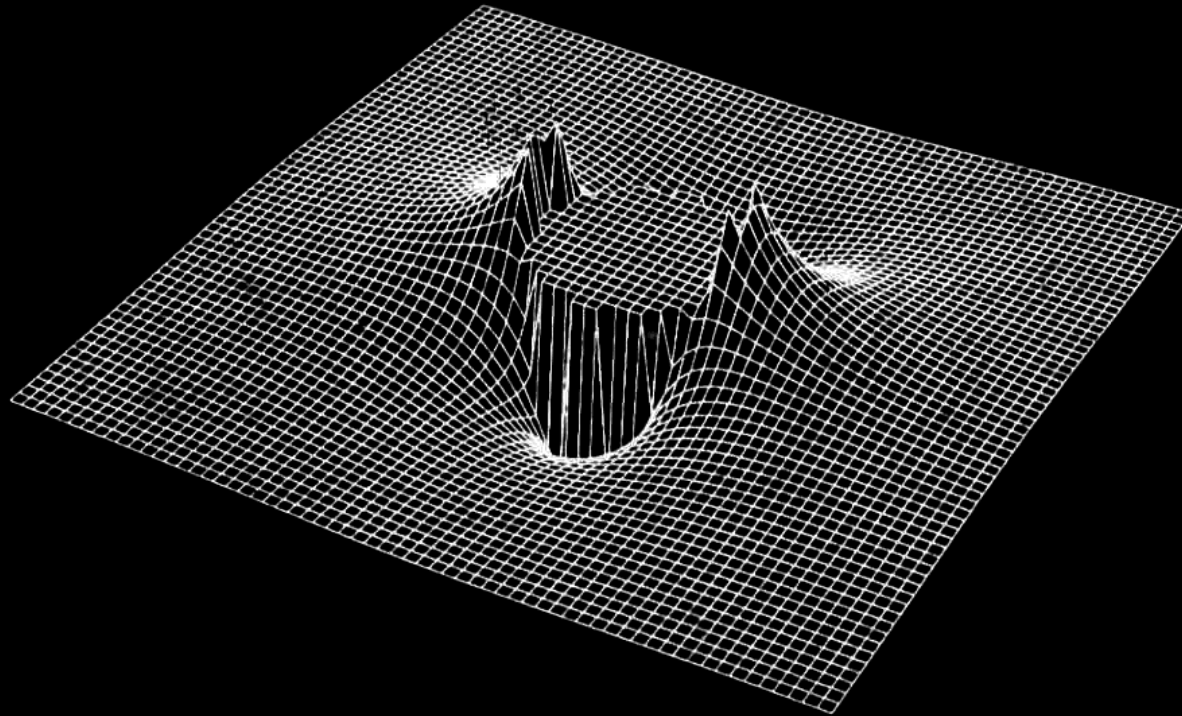
MRI Image showing
activation of the
Visual Cortex

From Belliveau, et al.
Science Nov 1991

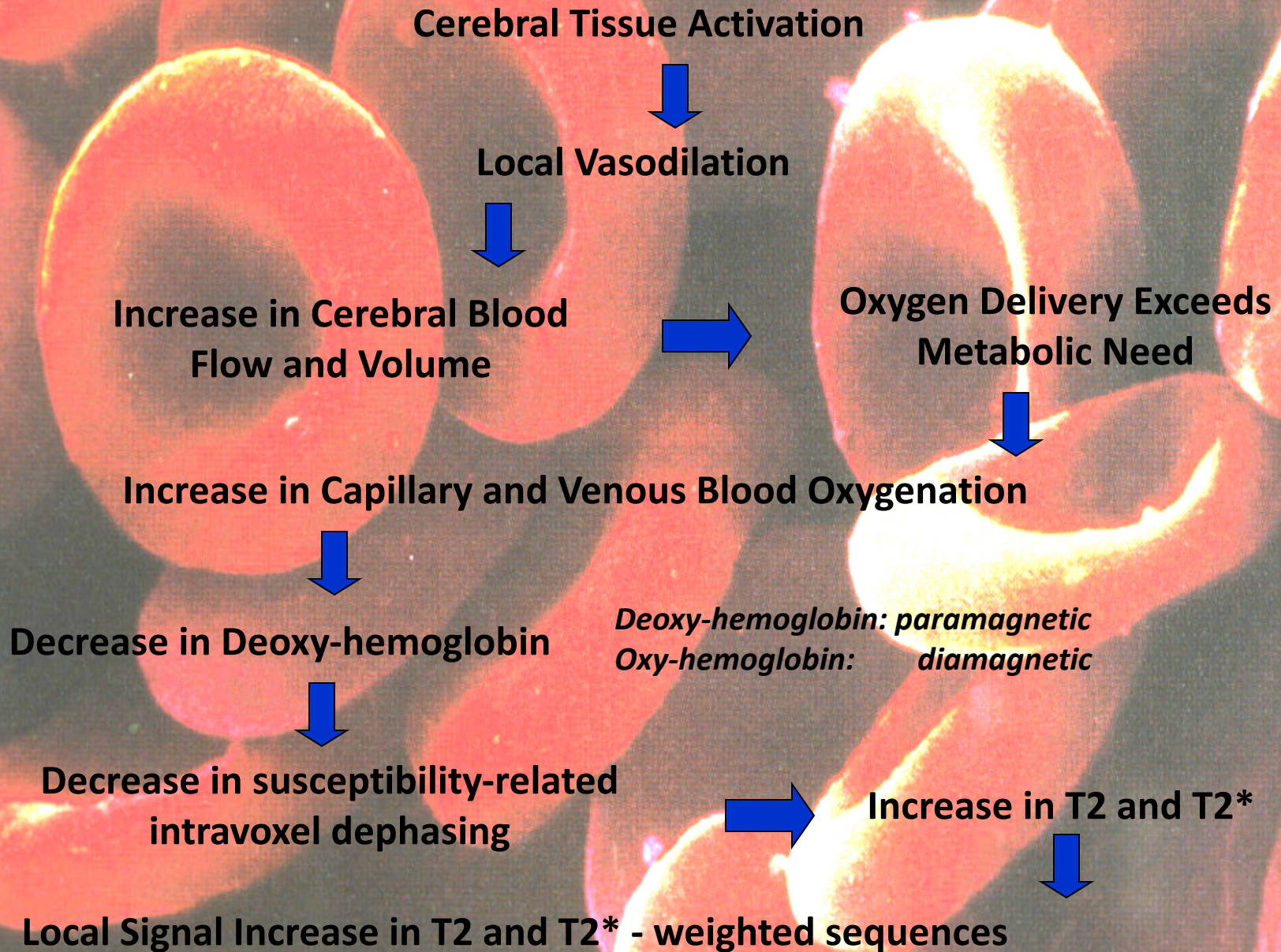
MSC - perfusion



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

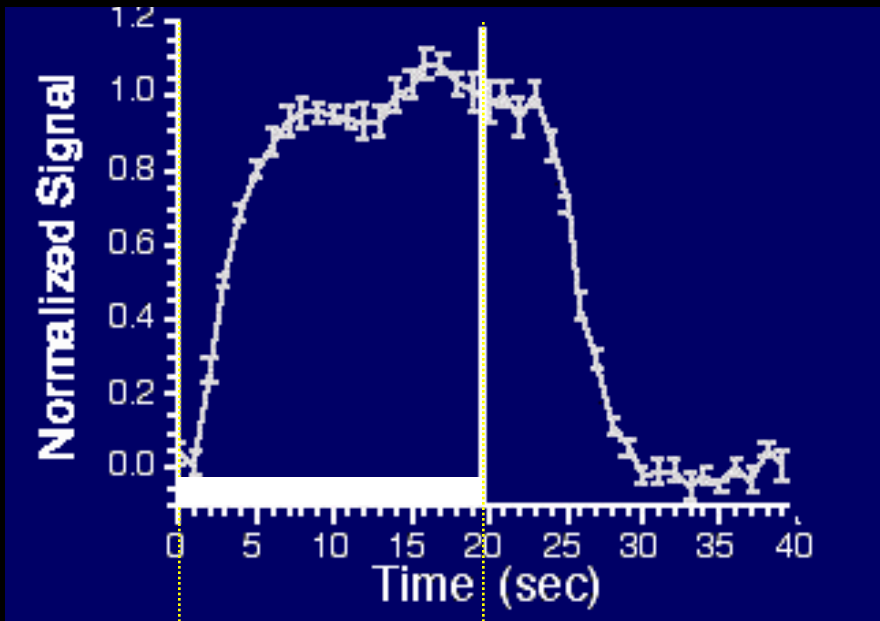


BOLD Contrast in the Detection of Neuronal Activity

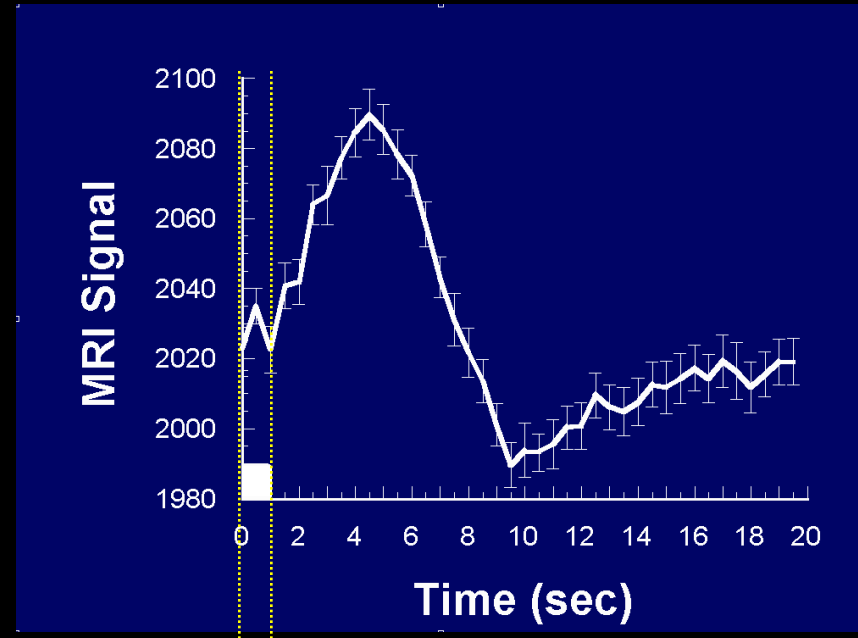


The BOLD Signal

Blood Oxygenation Level Dependent (BOLD) signal changes



task



task

Alternating Left and Right Finger Tapping

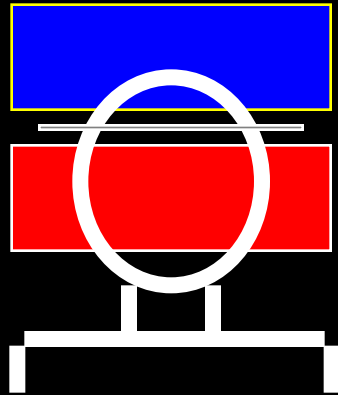


~ 1992

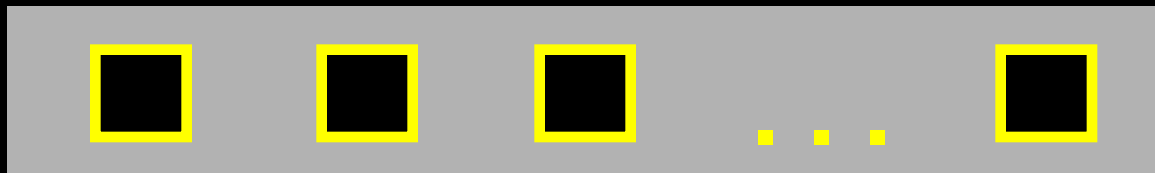
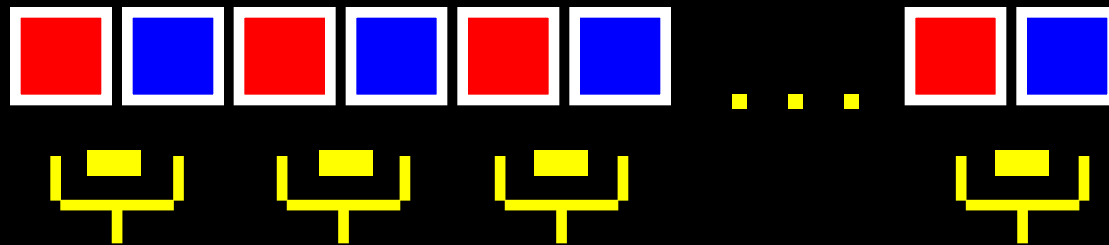
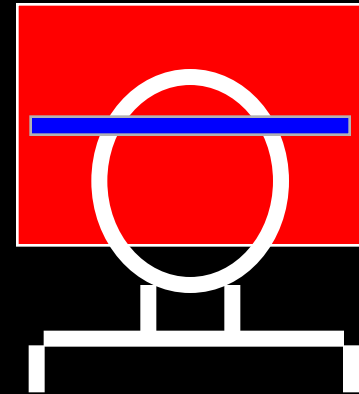


Perfusion / Flow Imaging

EPISTAR



FAIR



Perfusion
Time Series

TI (ms)

FAIR

EPISTAR

200

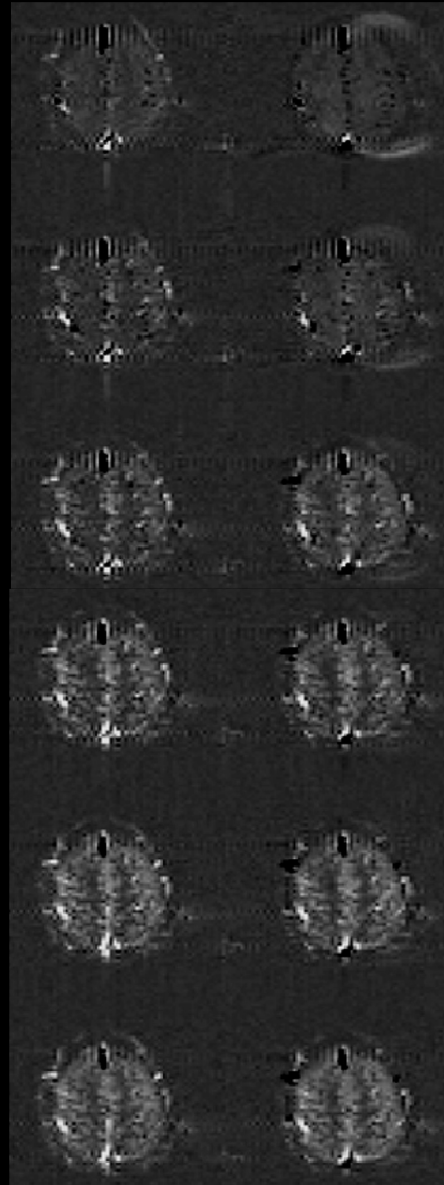
400

600

800

1000

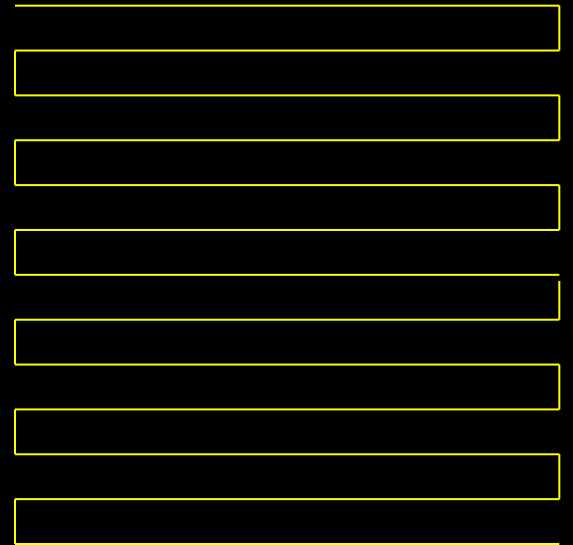
1200



Questions

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Single Shot Imaging



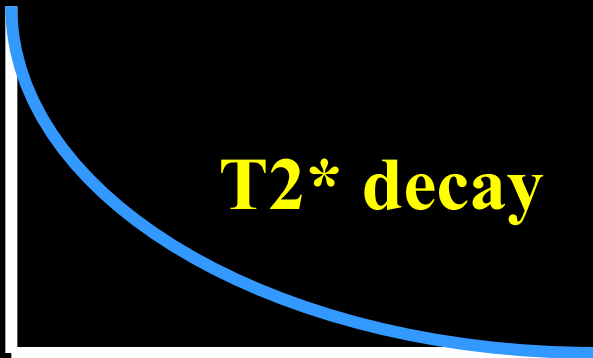
EPI Readout Window

≈ 20 to 40 ms

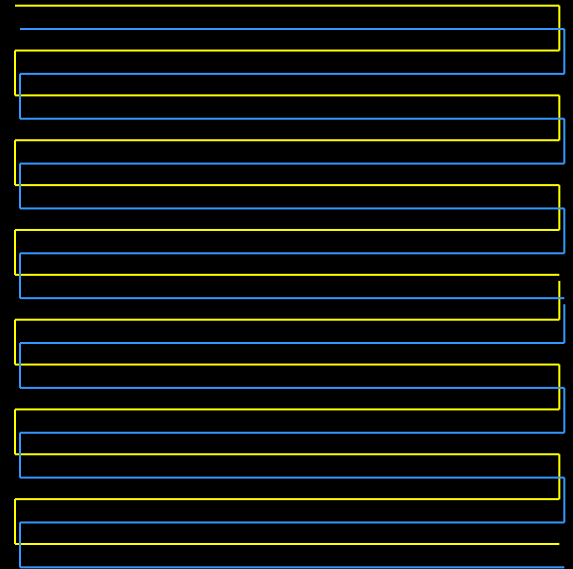
Multishot Imaging



EPI Window 1



EPI Window 2



Multi Shot EPI

Excitations
Matrix Size

1

64 x 64

2

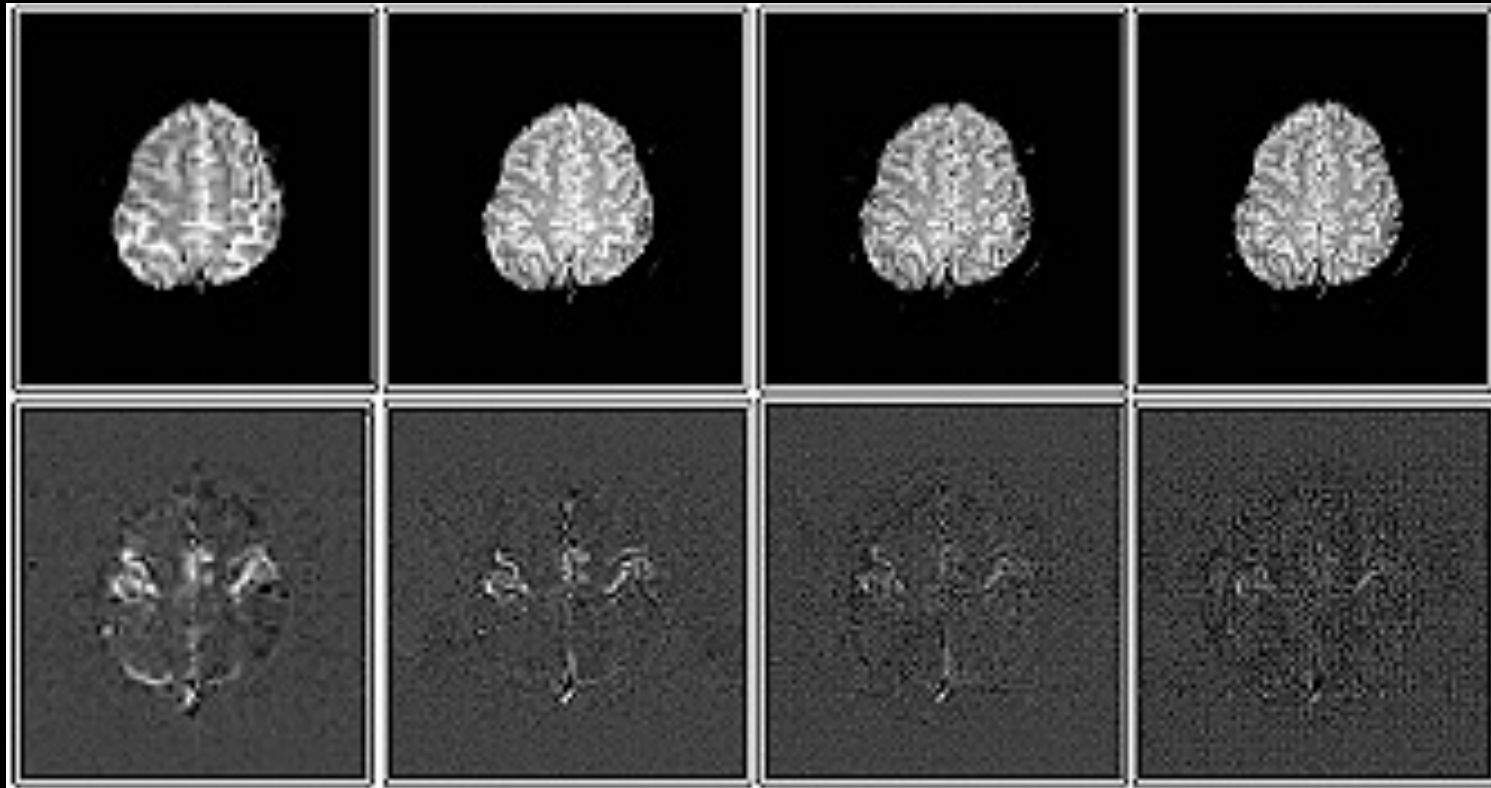
128 x 128

4

256 x 128

8

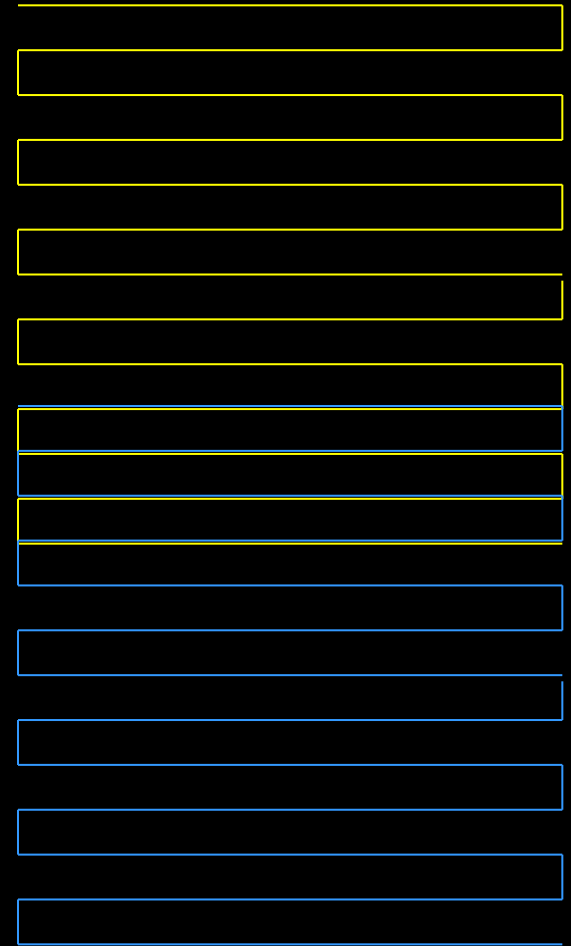
256



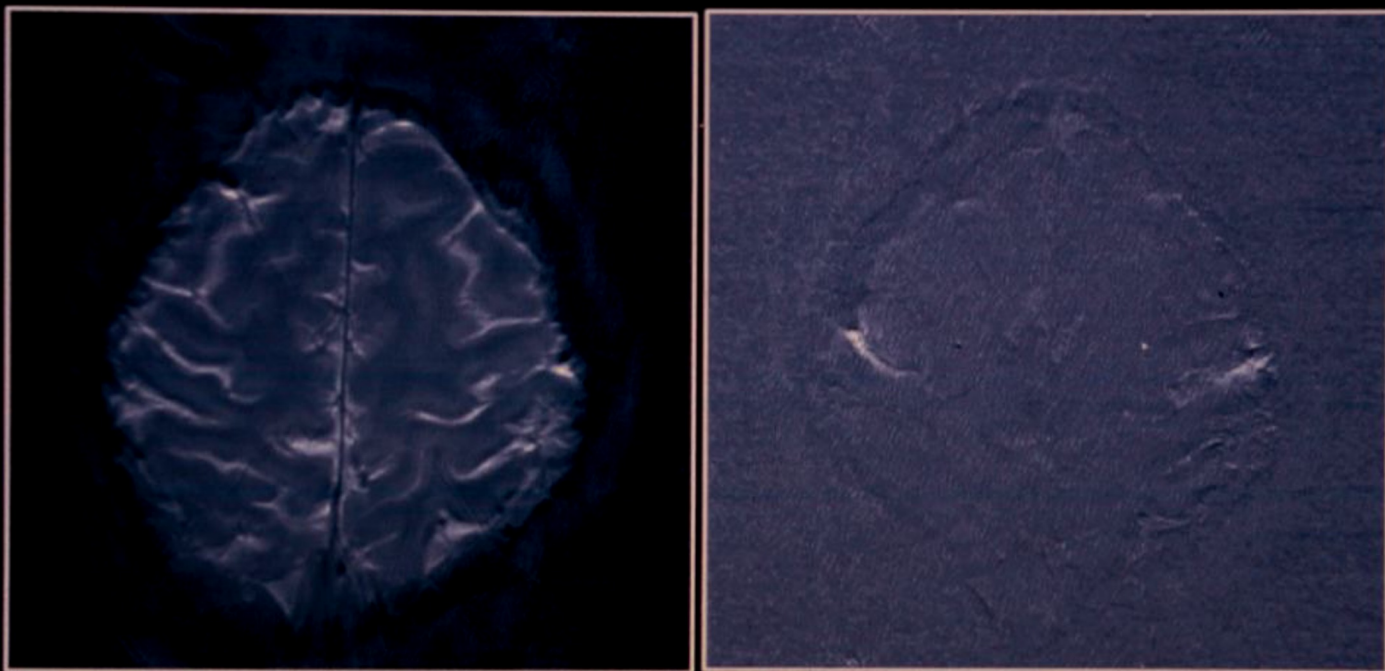
Partial k-space imaging



EPI Window



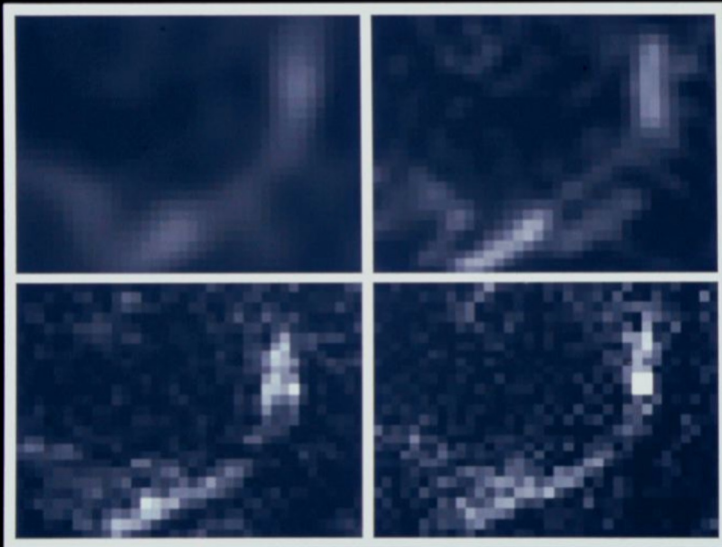
**Single - Shot EPI at 3T:
Half NEX, 256 x 256, 16 cm FOV**



Fractional Signal Change

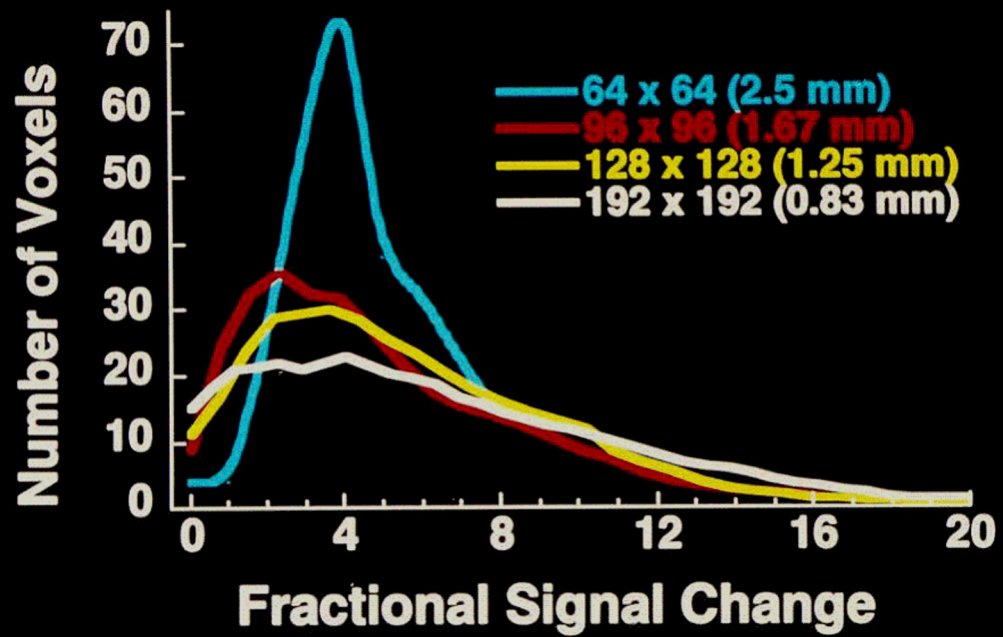
2.5 mm²

1.25 mm²



0.83 mm²

0.62 mm²

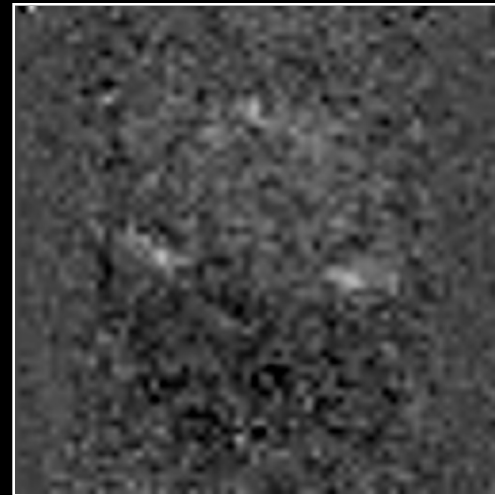
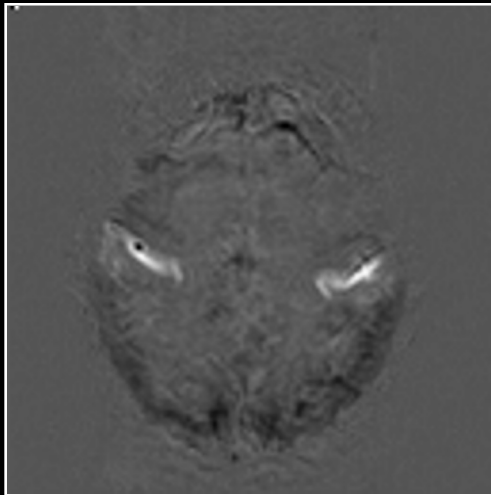
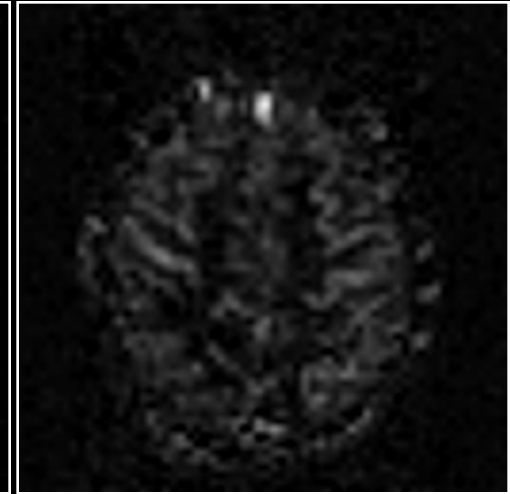
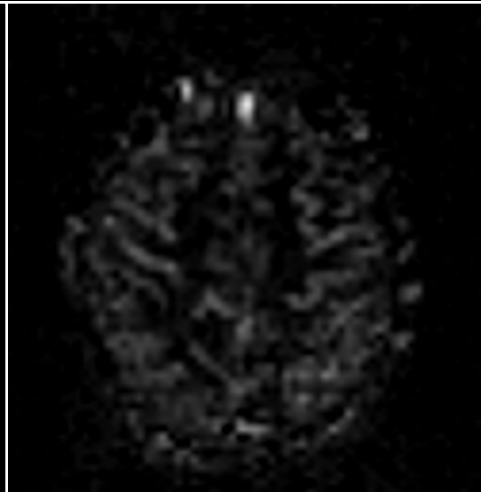
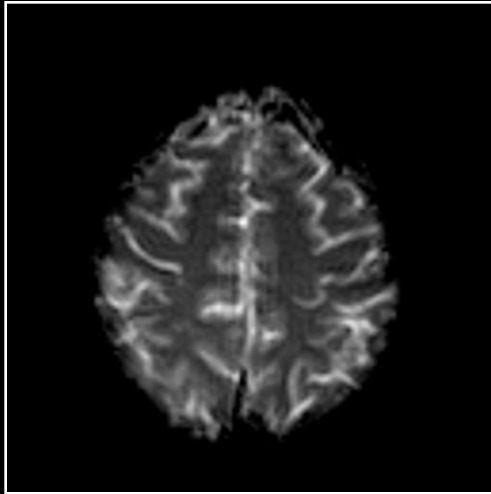


Perfusion

BOLD

Rest

Activation



Anatomy



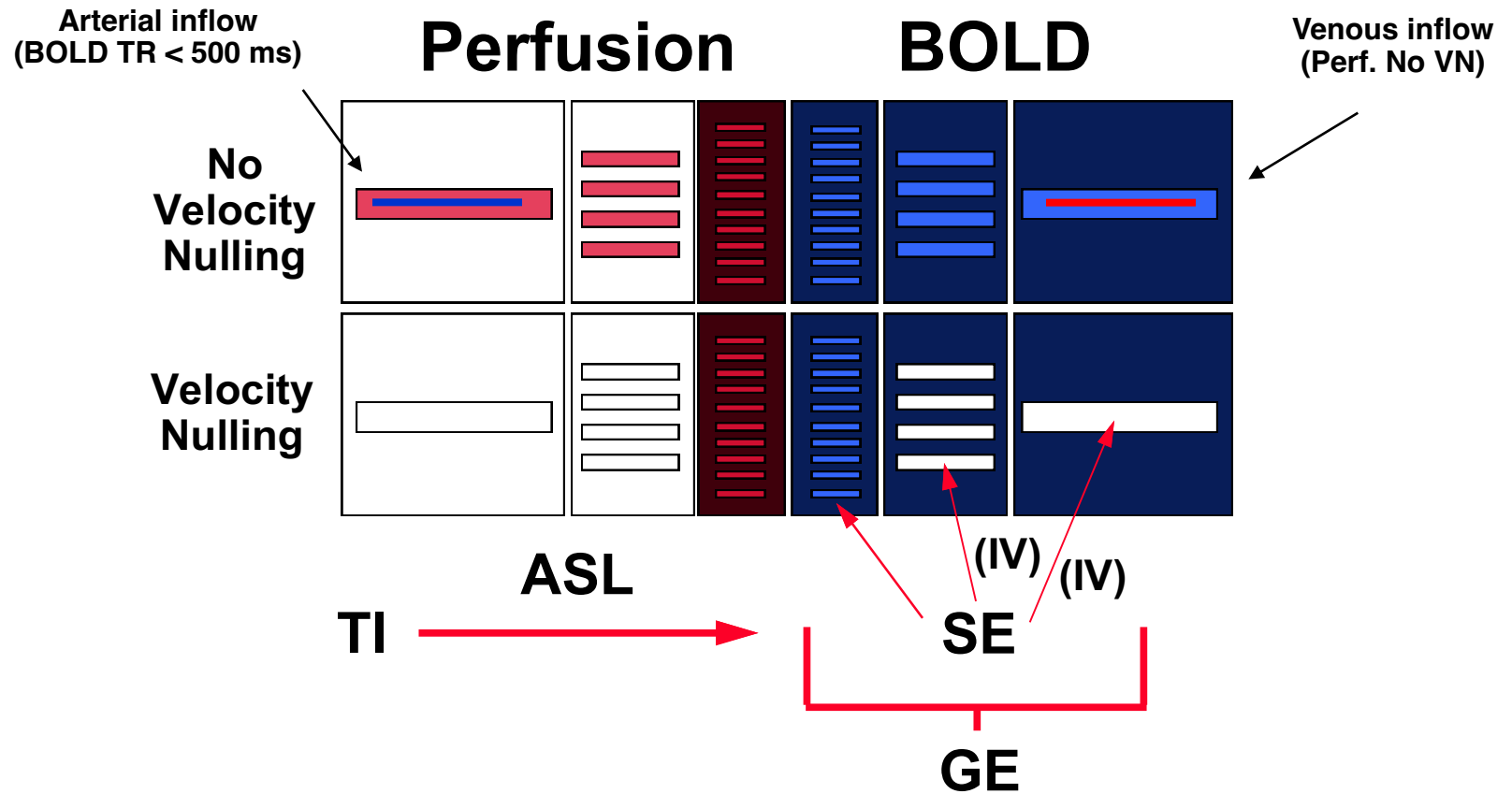
BOLD



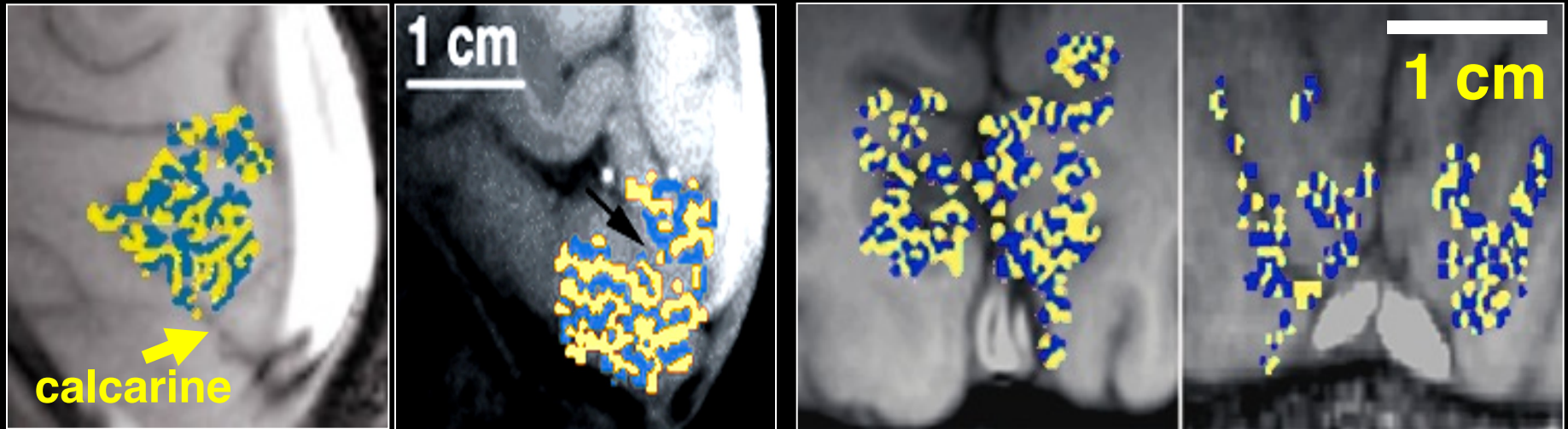
Perfusion



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).

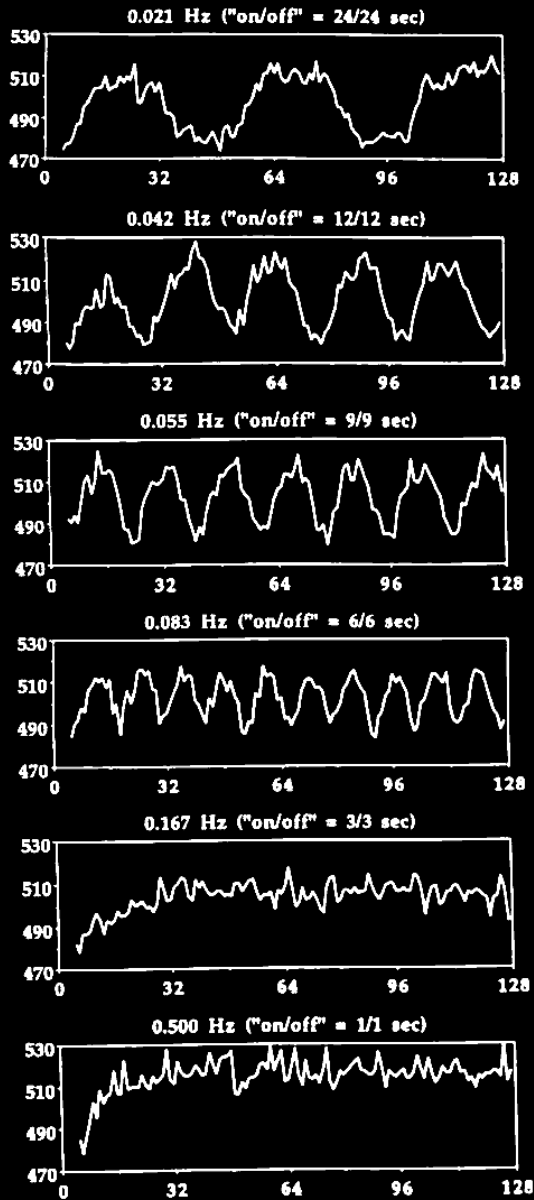
³Horton JC, Hocking DR. *J Neurosci* 16, 7228-39 (1996).

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

Questions

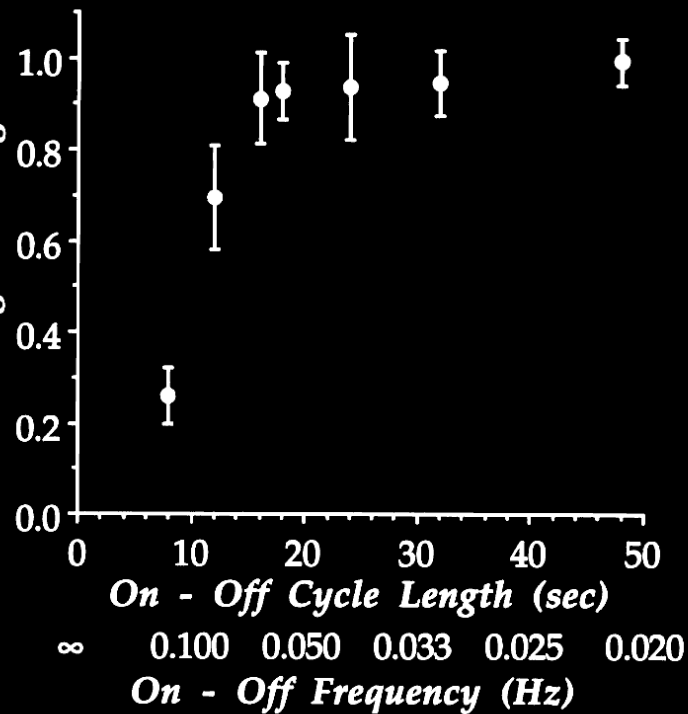
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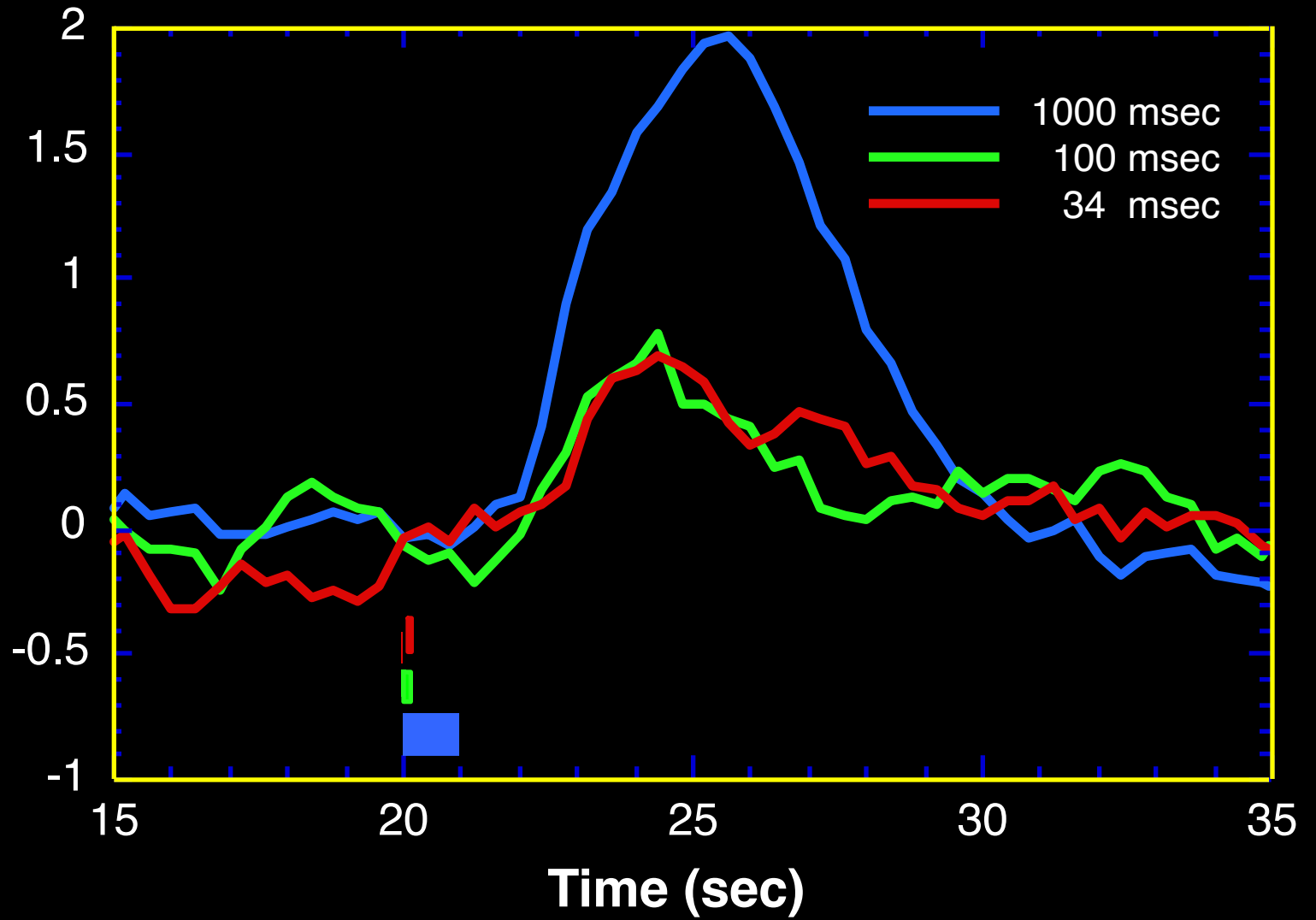
MRI Signal

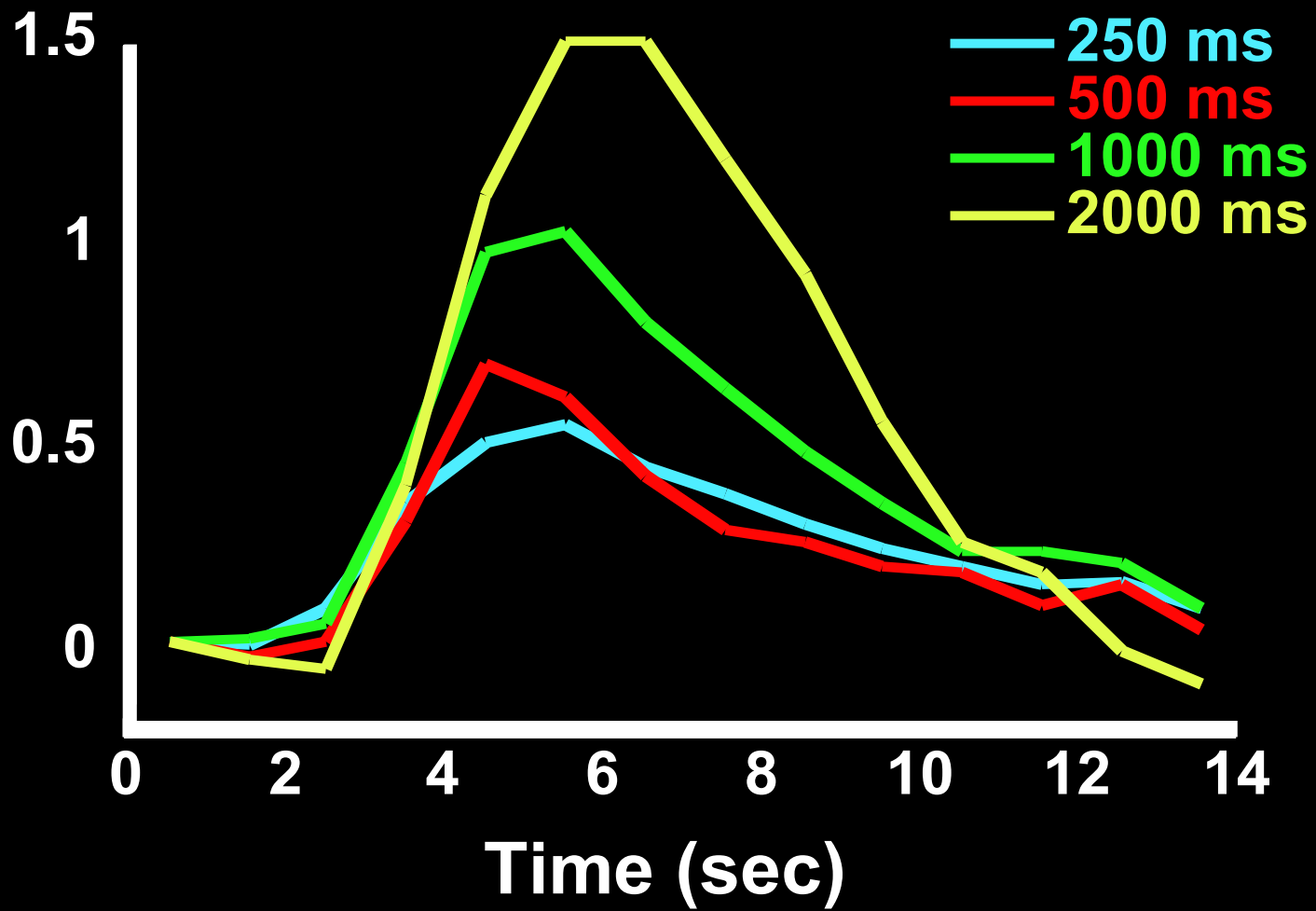


Time (seconds)

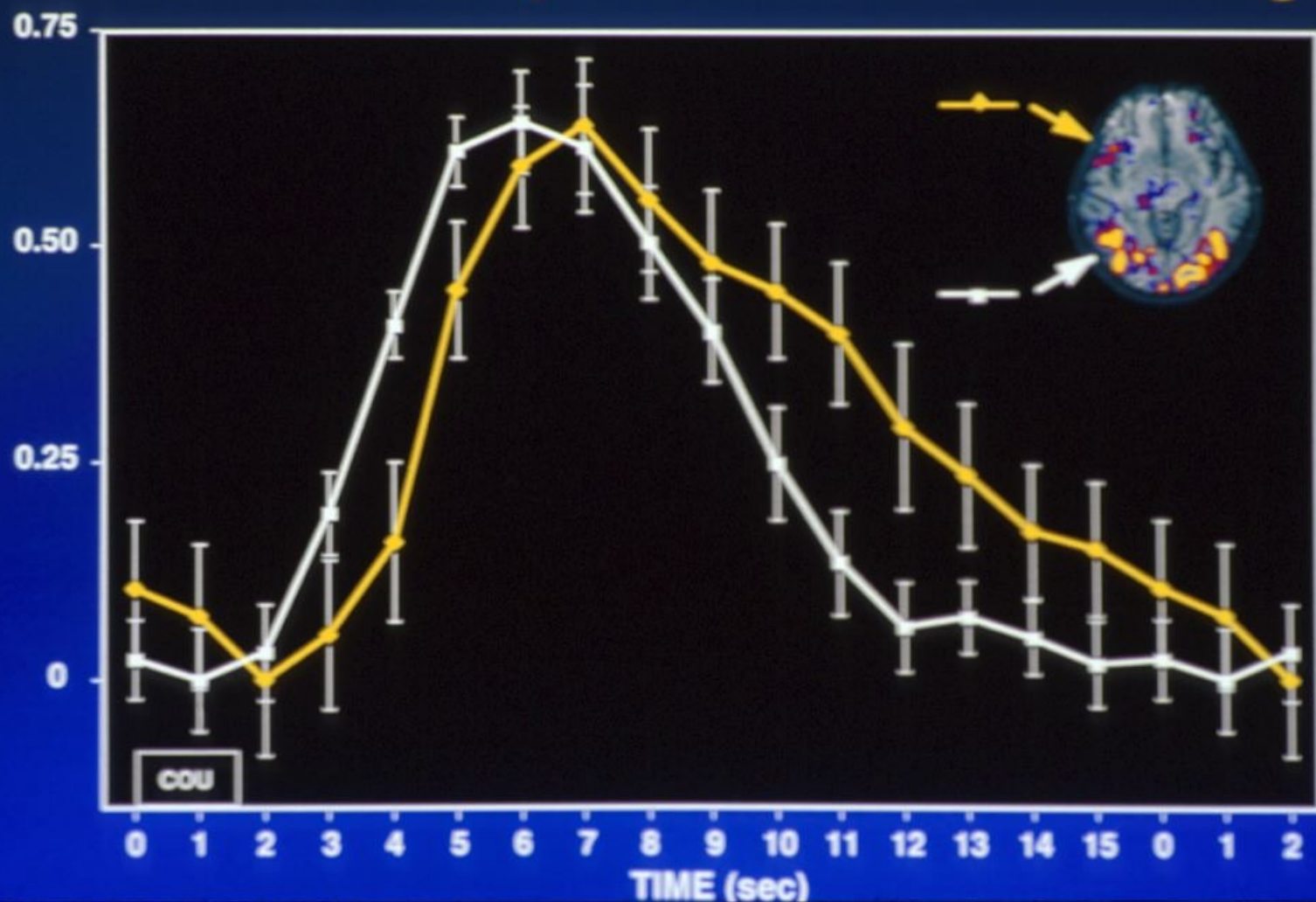
Relative Activation - Induced
MR Signal Change





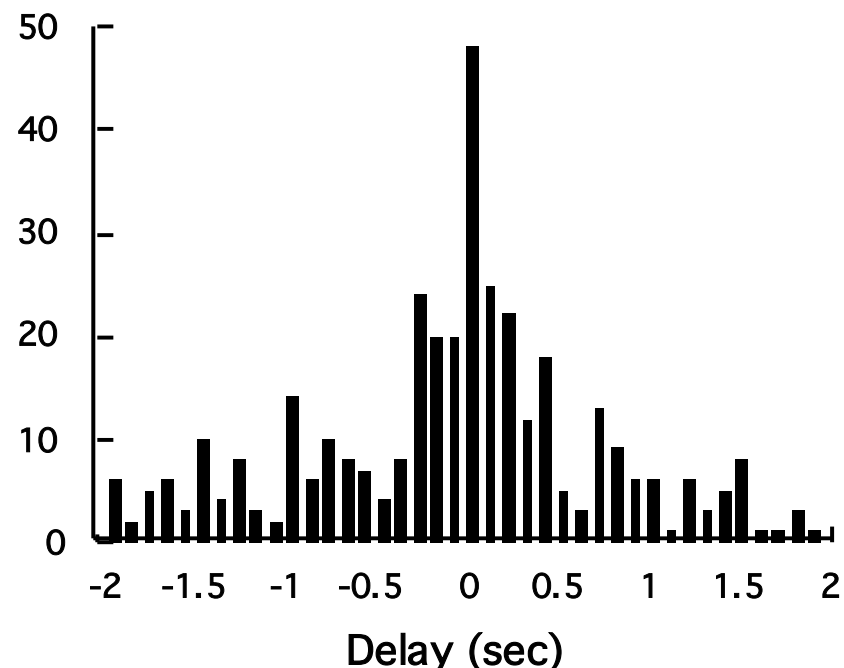
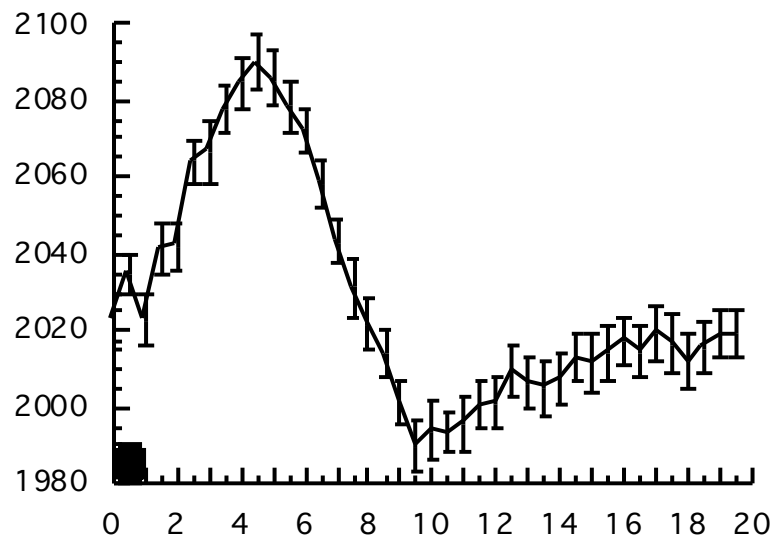
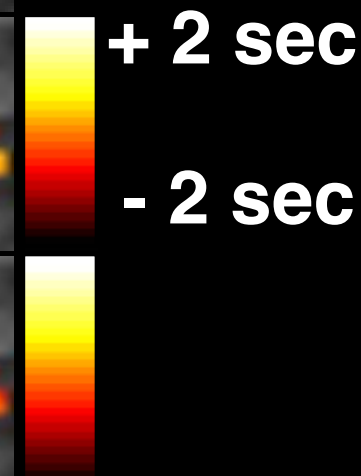
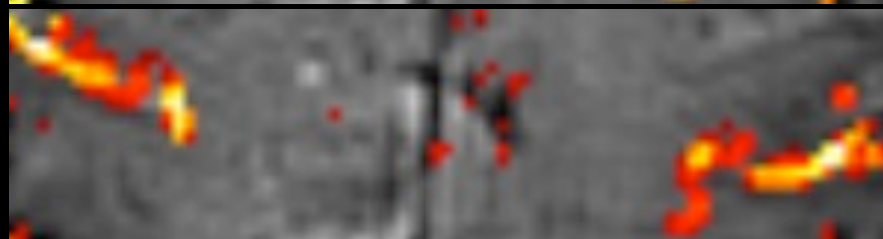
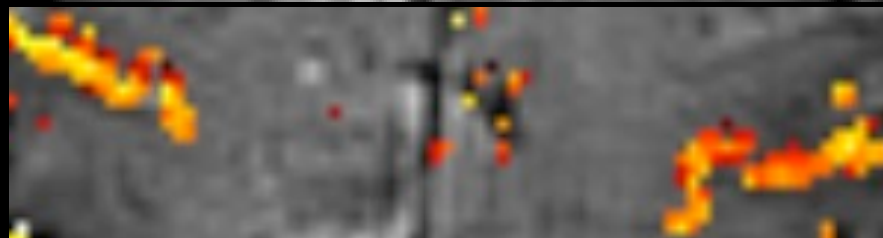


Time Course Comparison Across Brain Regions



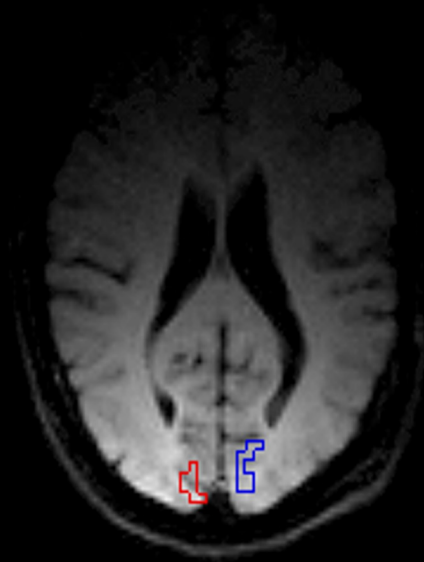
Latency

Magnitude

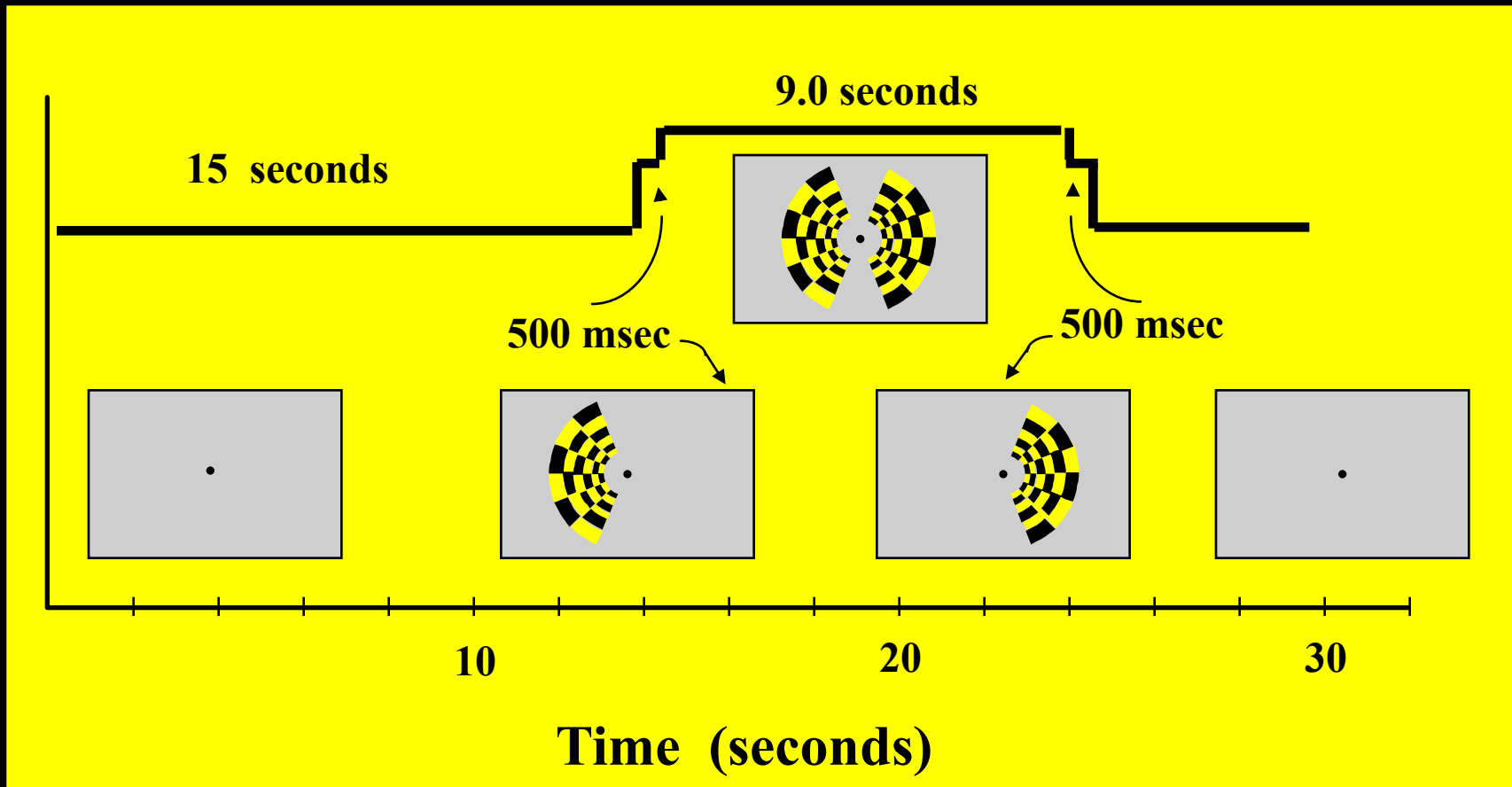


Regions of Interest Used for Hemi-Field Experiment

**Right
Hemisphere**

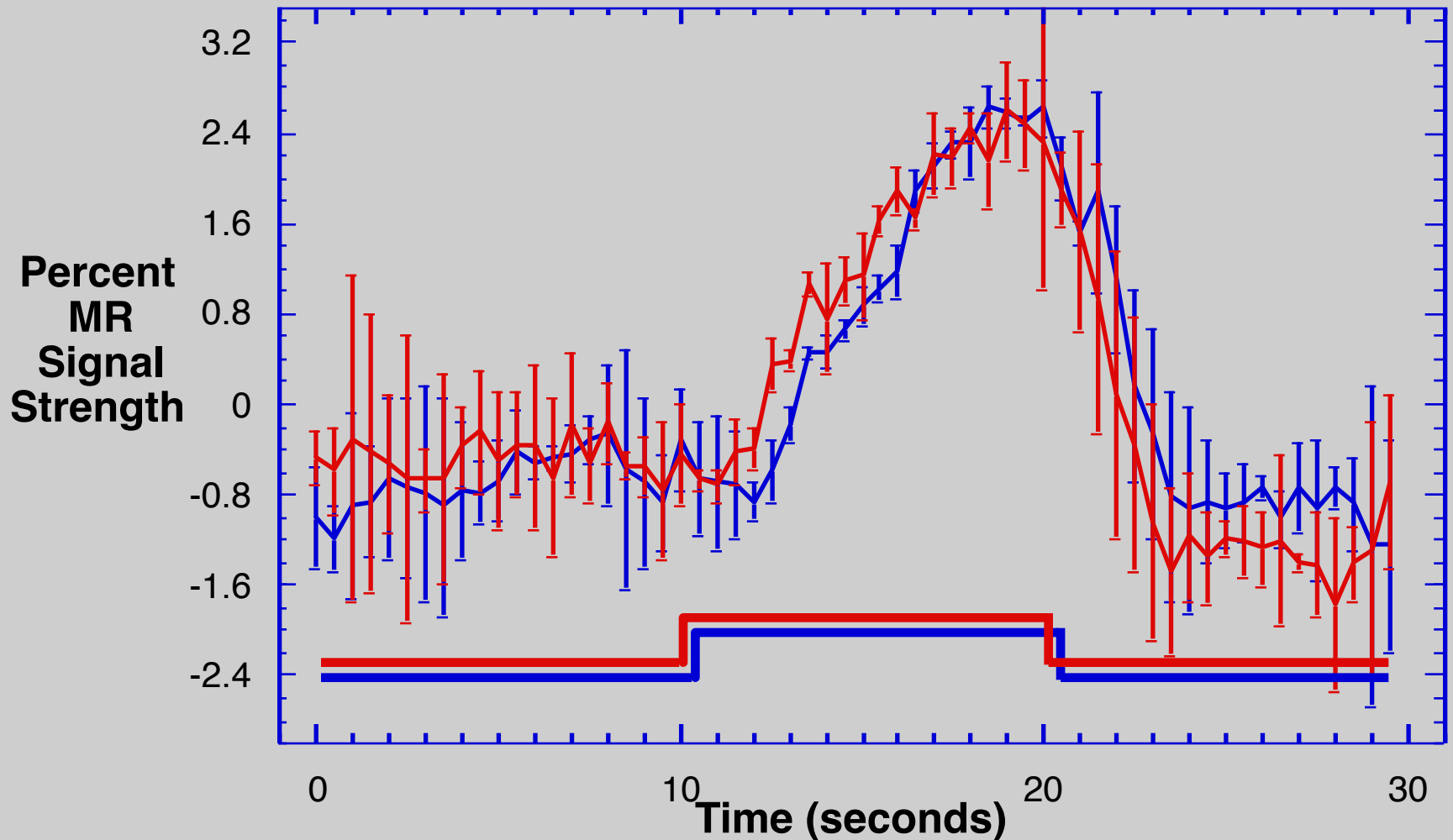


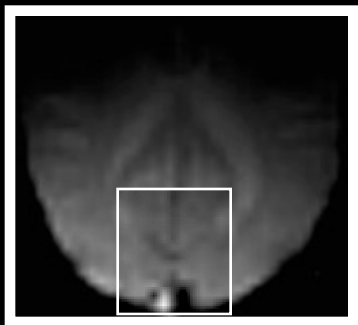
**Left
Hemisphere**



Hemi-field with 500 msec asynchrony

Average of 6 runs Standard Deviations Shown





500 ms



500 ms



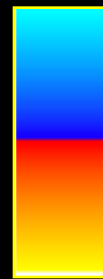
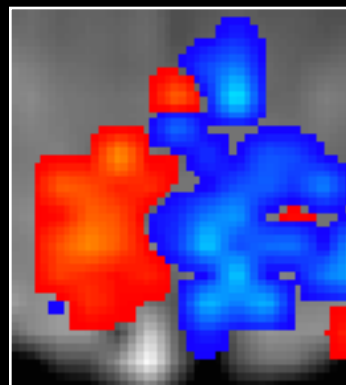
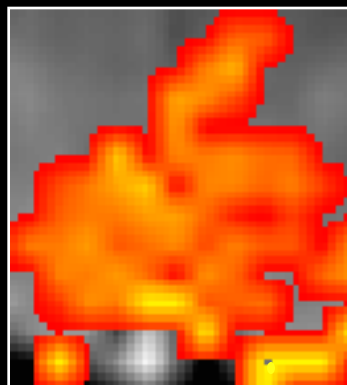
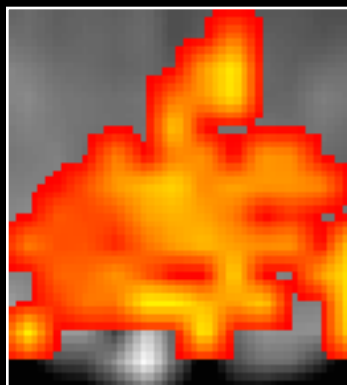
Right Hemifield

Left Hemifield

+ 2.5 s

0 s

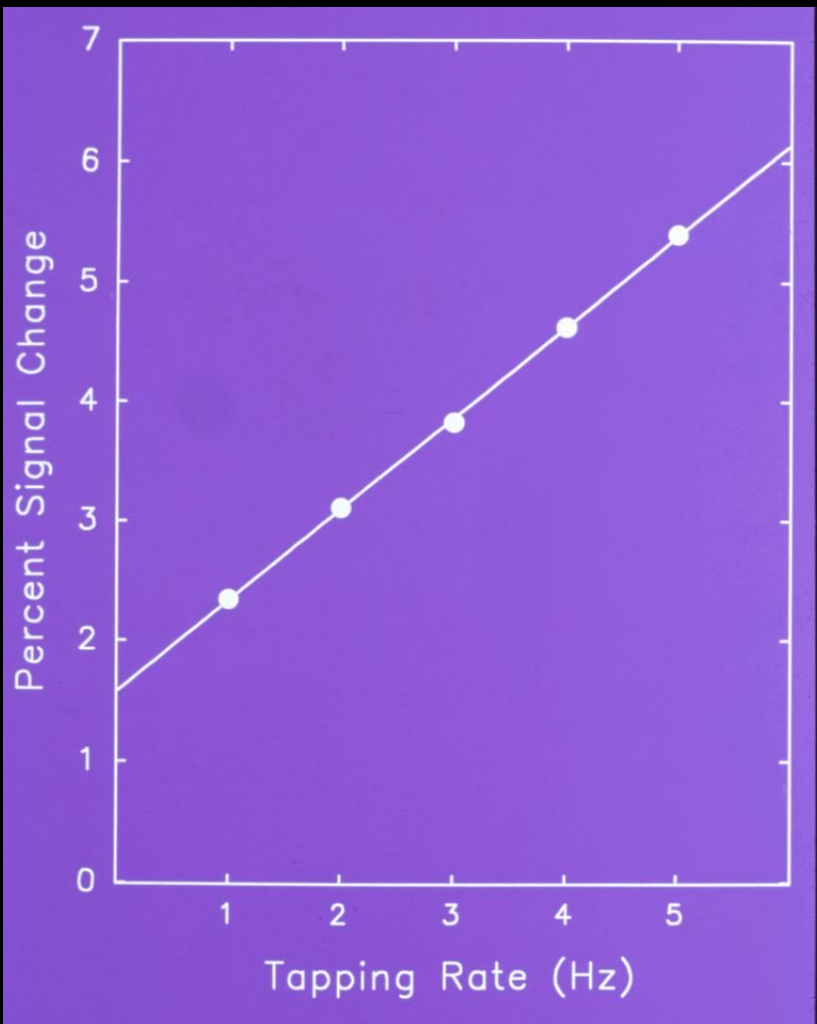
- 2.5 s



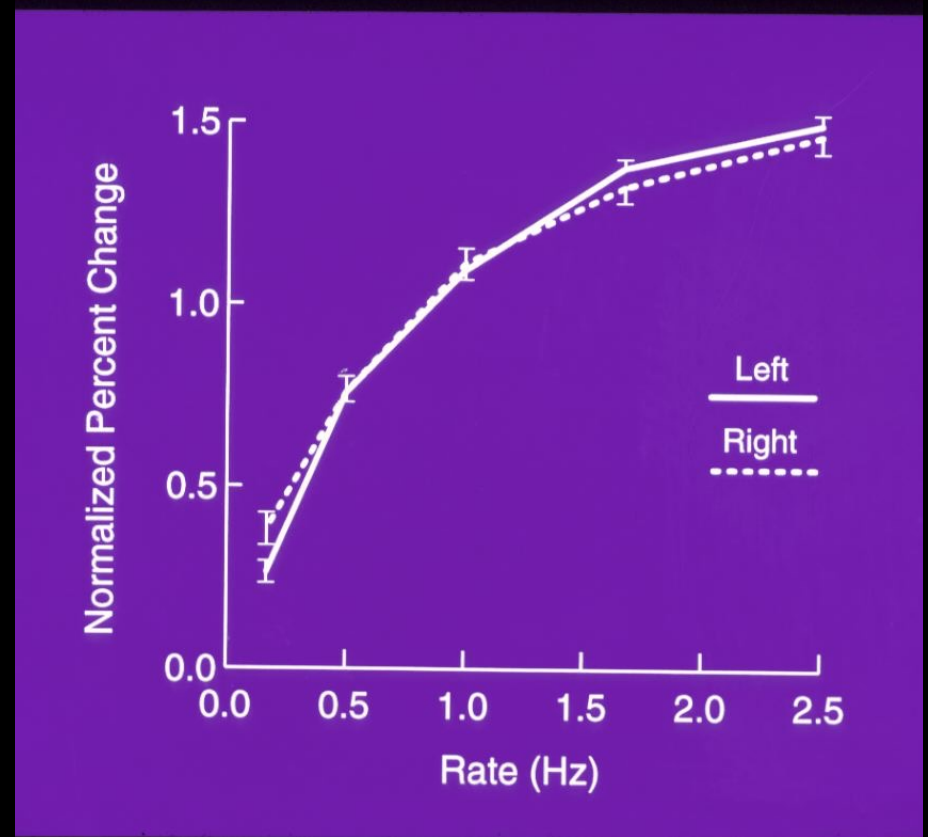
Questions

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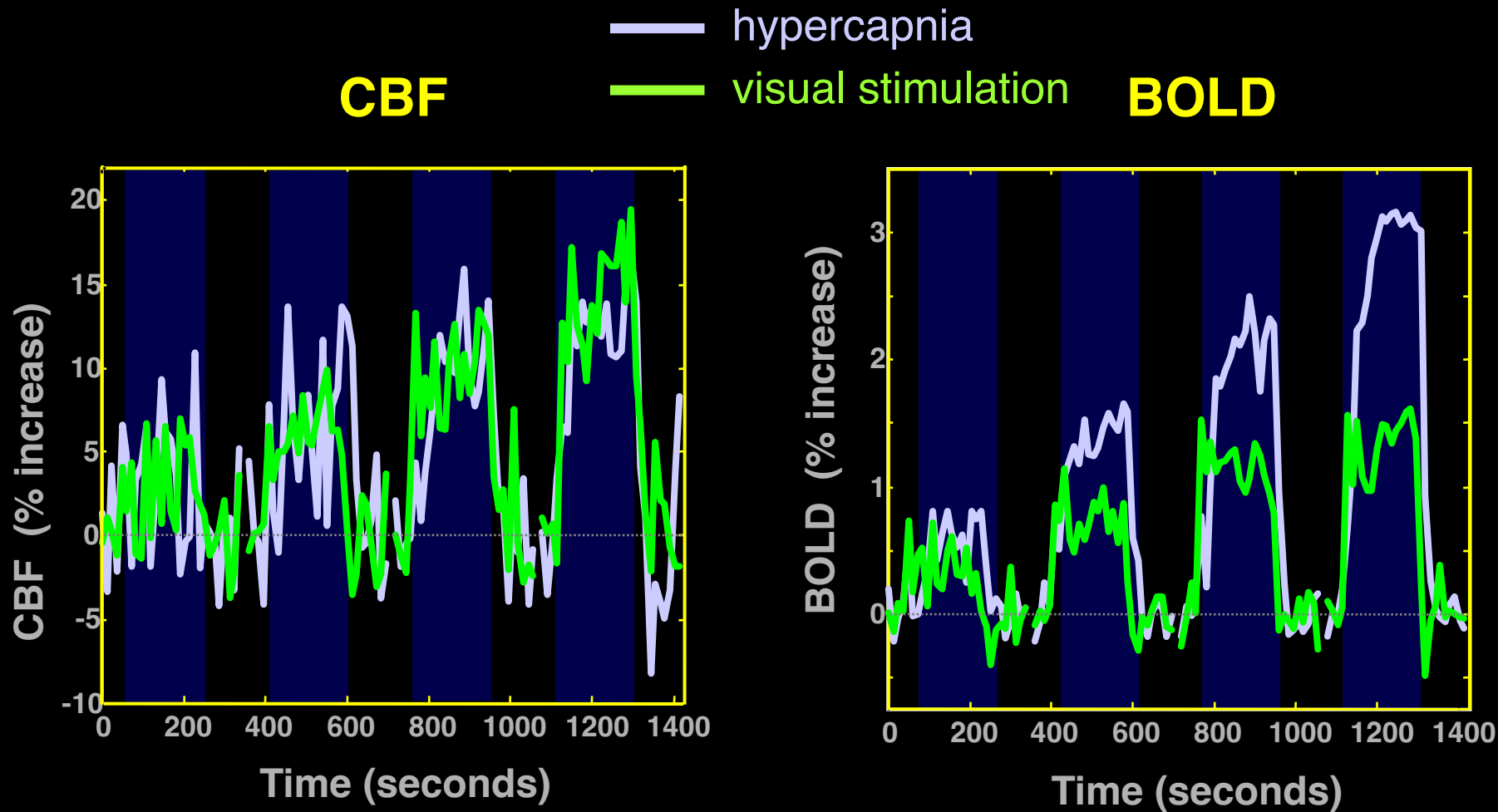
Motor Cortex



Auditory Cortex



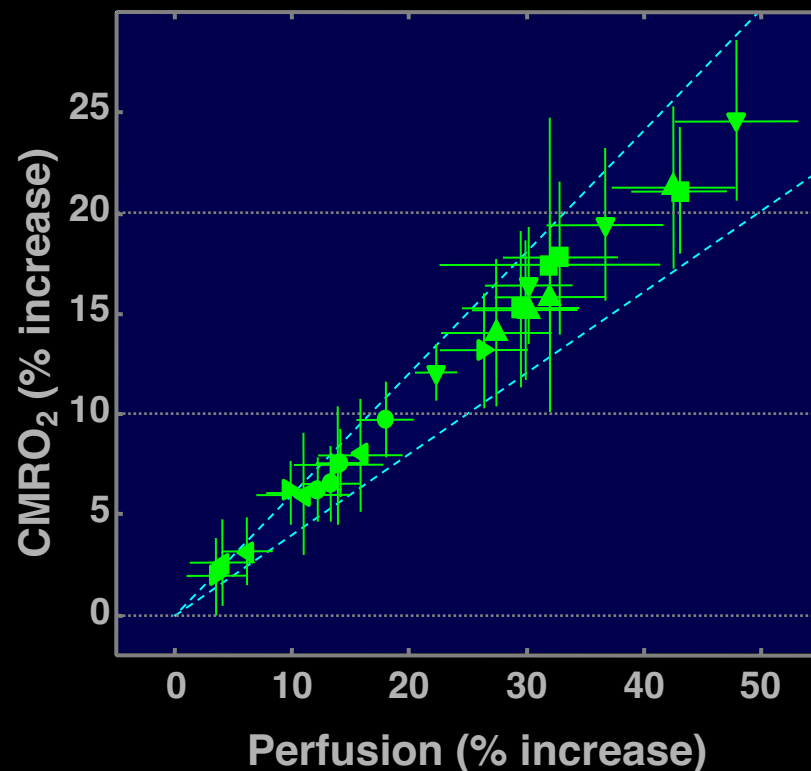
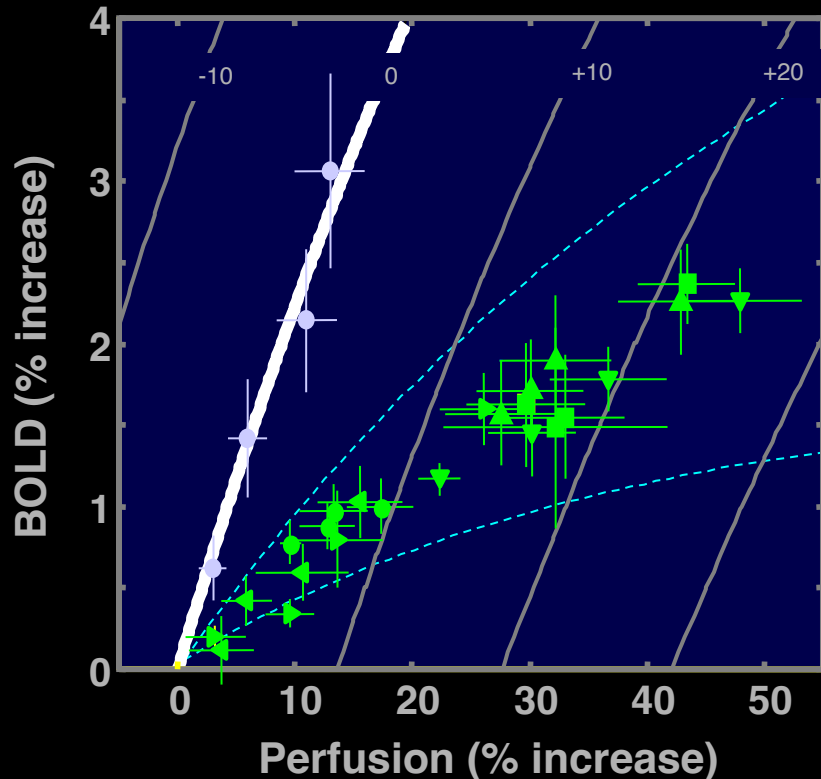
CMRO₂-related BOLD signal deficit:



Simultaneous Perfusion and BOLD imaging during graded visual activation and hypercapnia

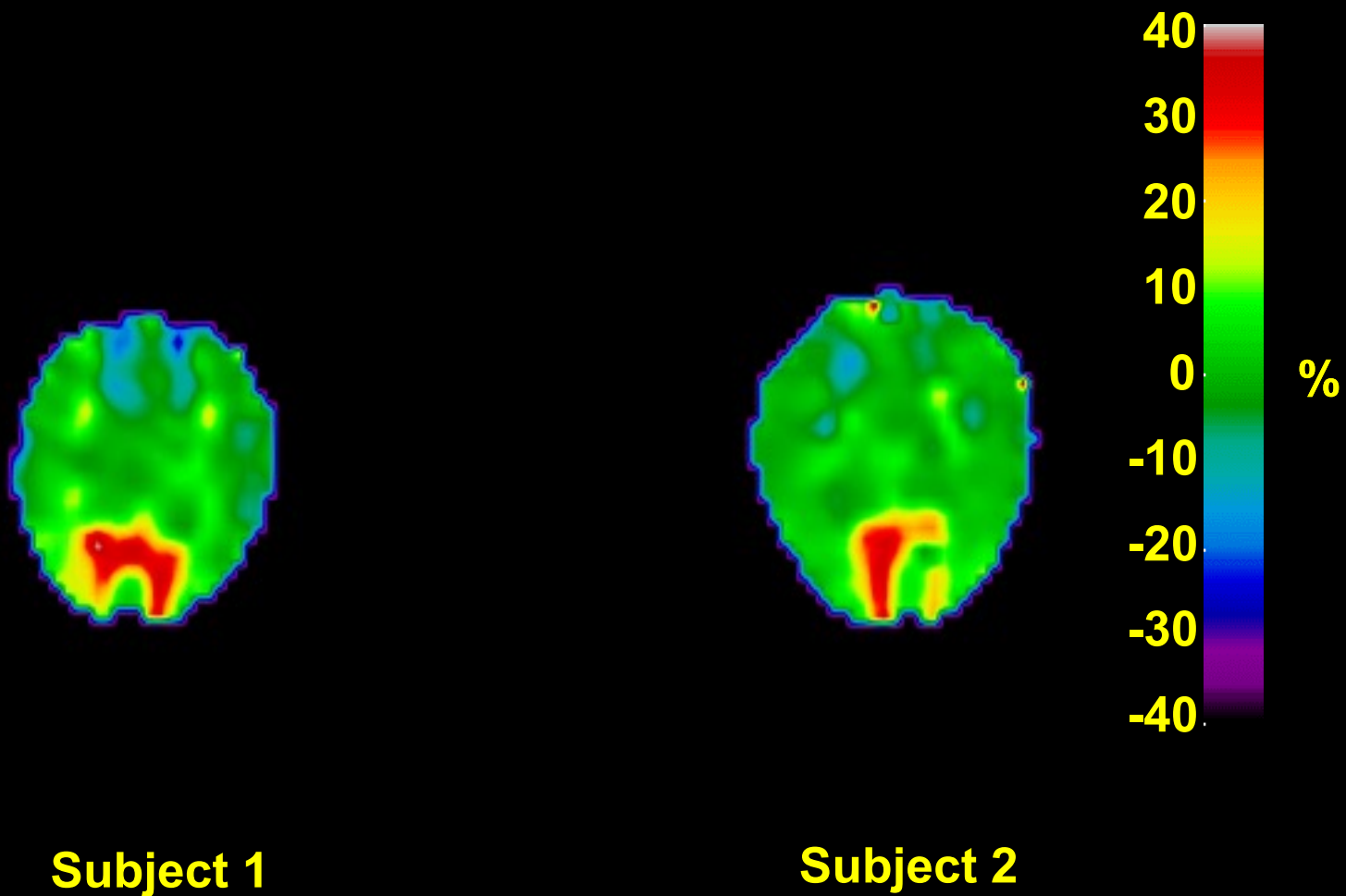
CBF-CMRO₂ coupling

Hoge, et al.



Characterizing Activation-induced CMRO₂ changes using calibration with hypercapnia

Computed CMRO₂ changes



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

Hongyu AN¹, Weili LIN², Azim CELIK³, Yueh 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;

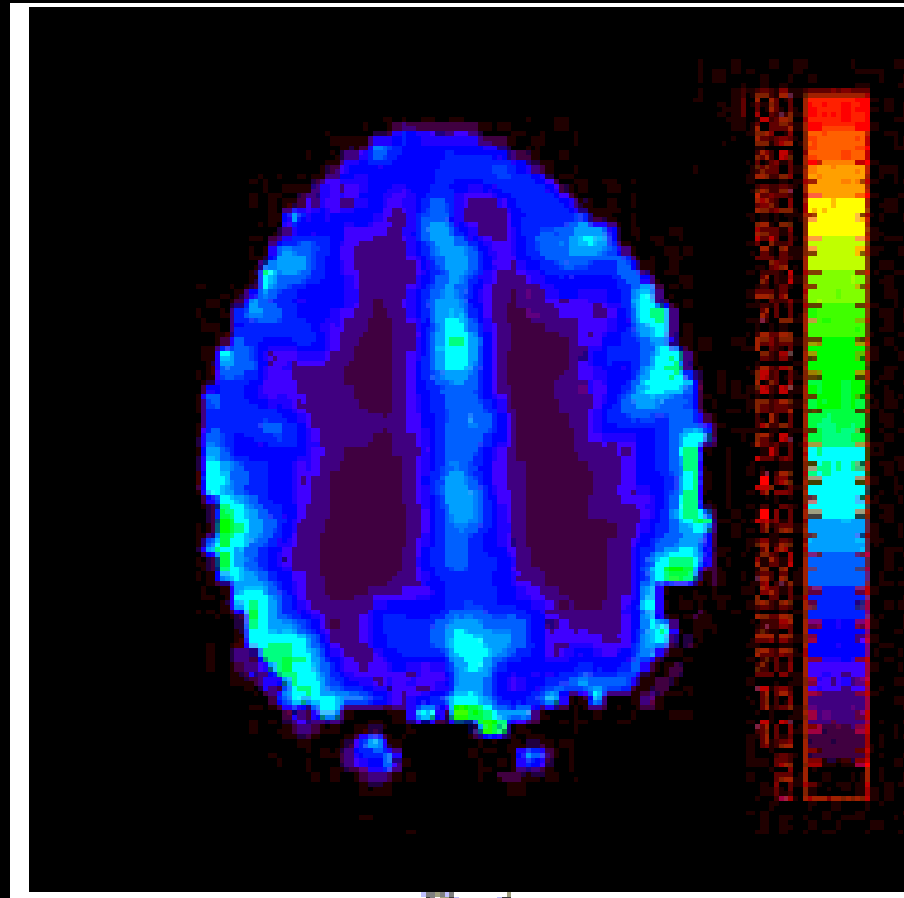
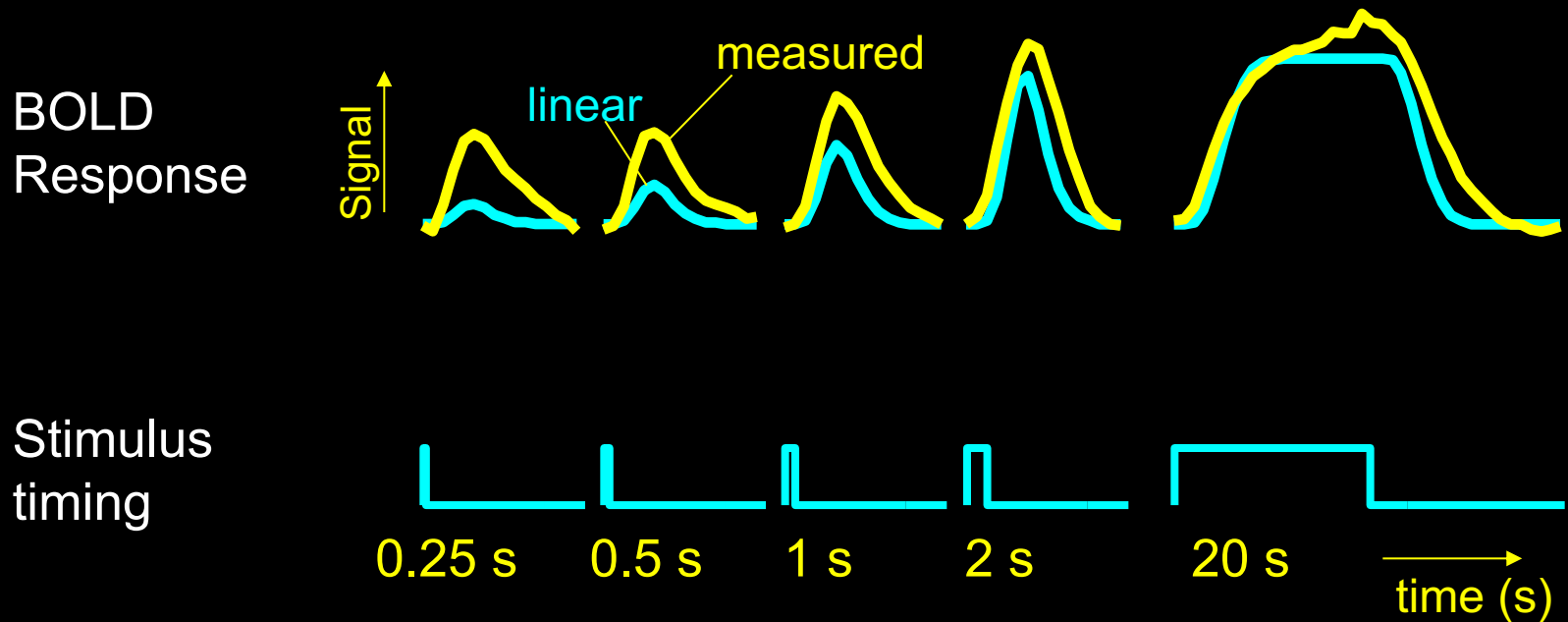


Figure 1

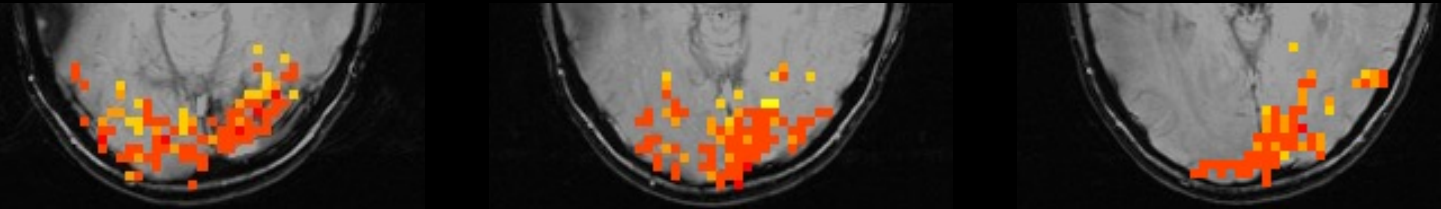
Different stimulus “ON” periods



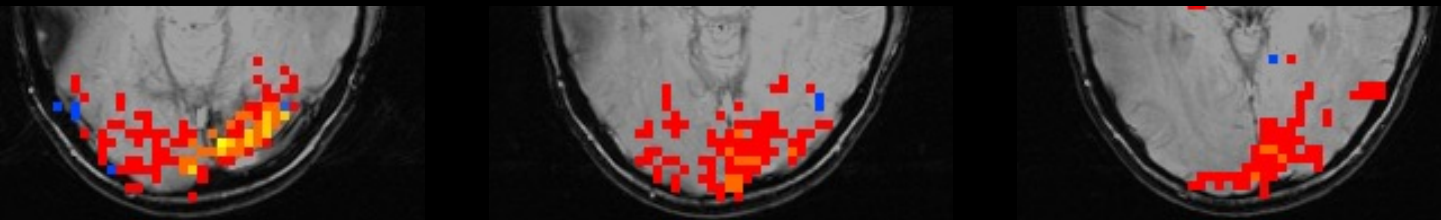
Brief stimuli produce larger responses than expected

Results – visual task

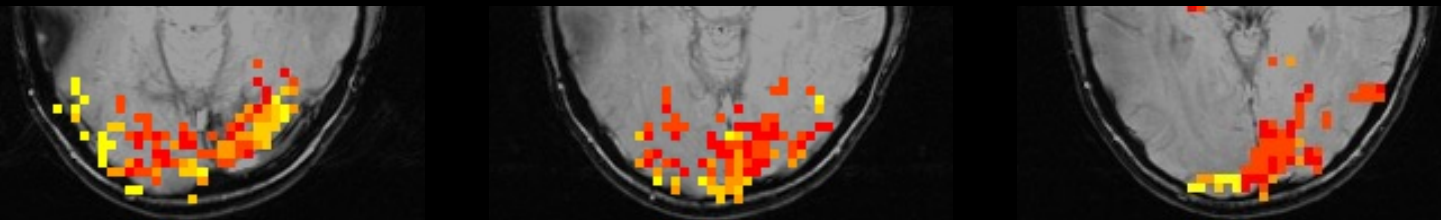
Nonlinearity



Magnitude

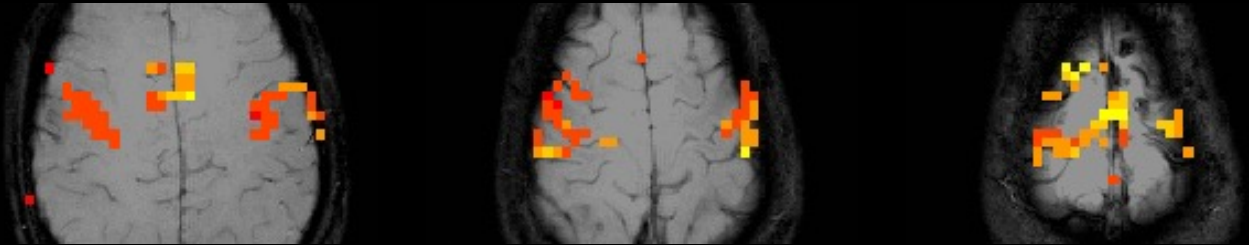


Latency

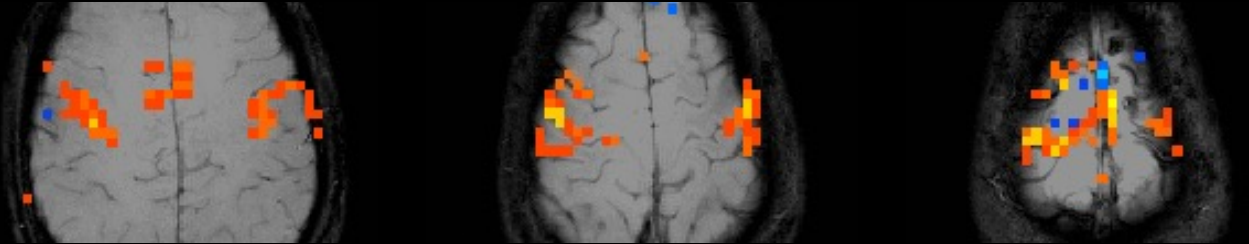


Results – motor task

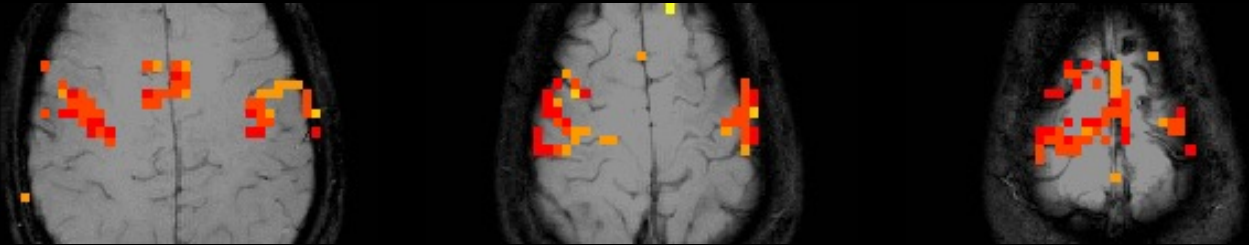
Nonlinearity



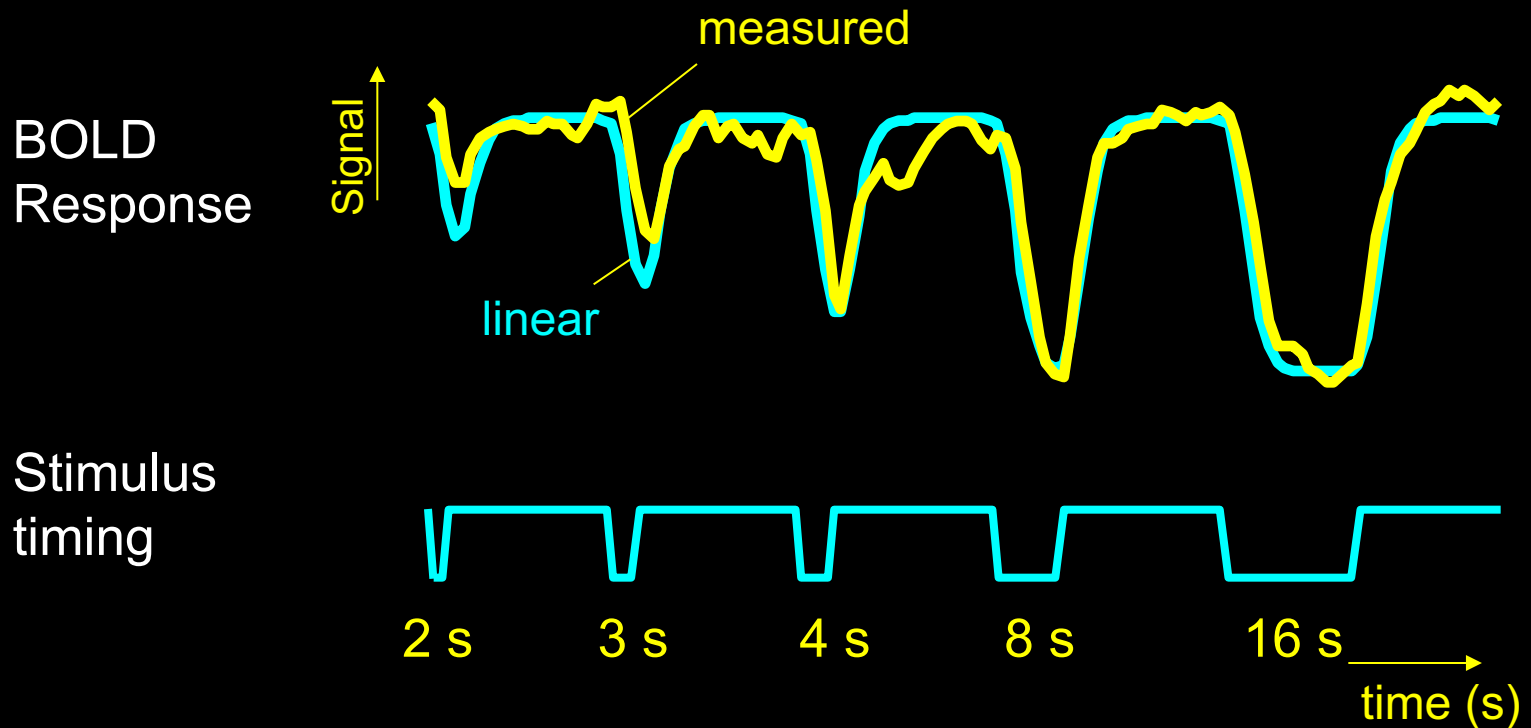
Magnitude



Latency



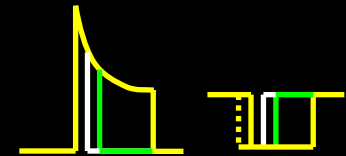
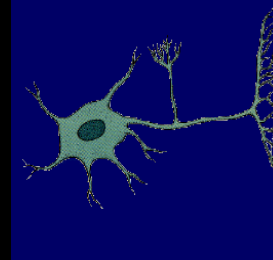
Different stimulus “ON” periods



Brief stimulus OFF periods produce smaller decreases than expected

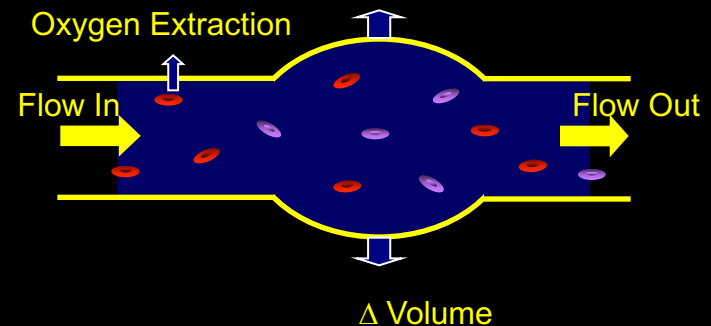
Sources of this Nonlinearity

- 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...

Neurovascular Coupling

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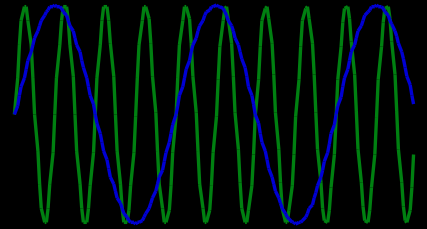
Brain Coverage

Feedback Time/Information

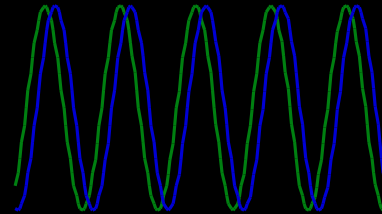
Neuronal Activation Input Strategies

1. Block Design

2. Frequency Encoding

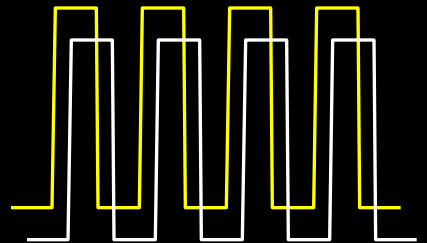


3. Phase Encoding



4. Single Event

5. Orthogonal Block Design



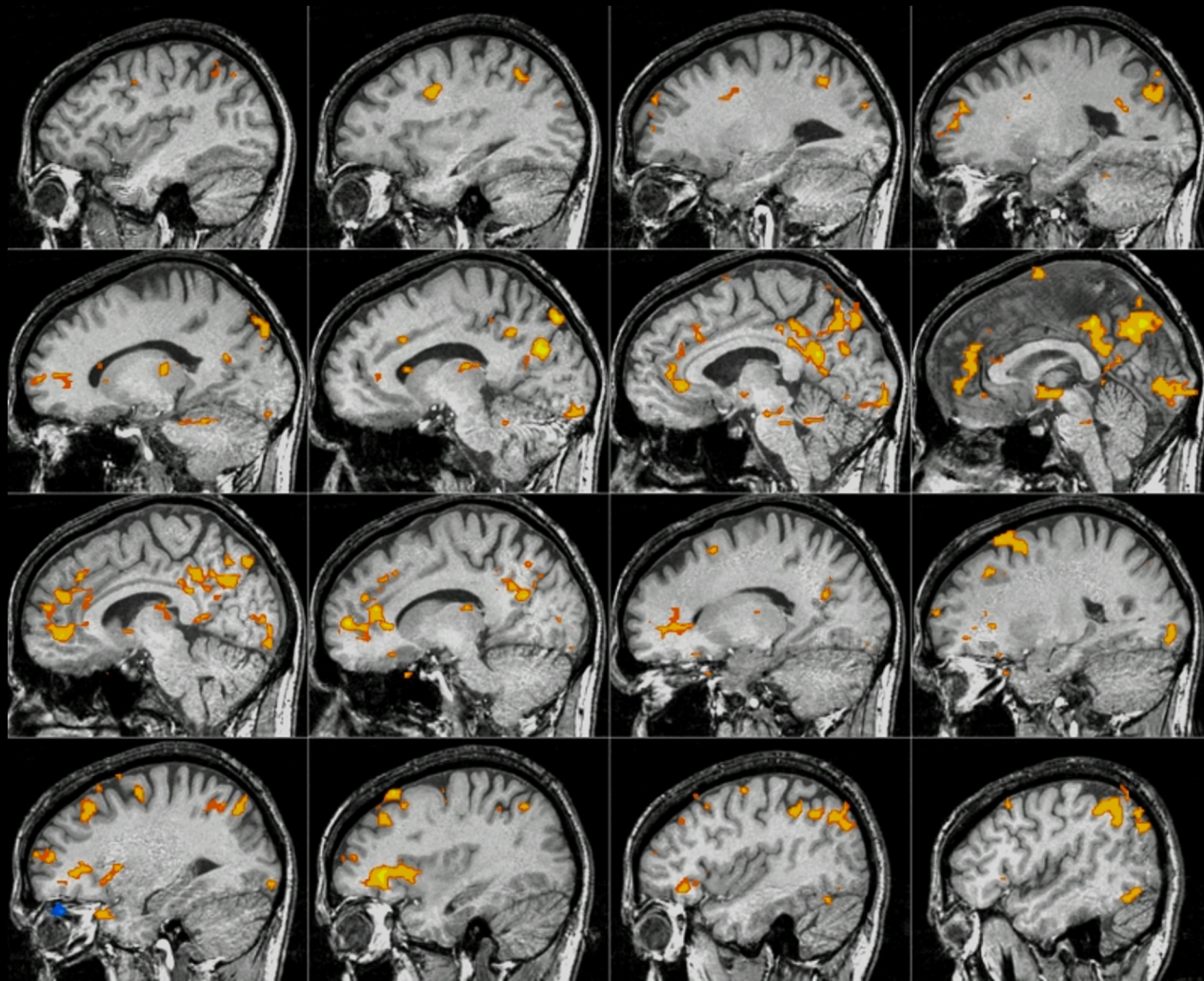
6. Free Behavior Design.

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

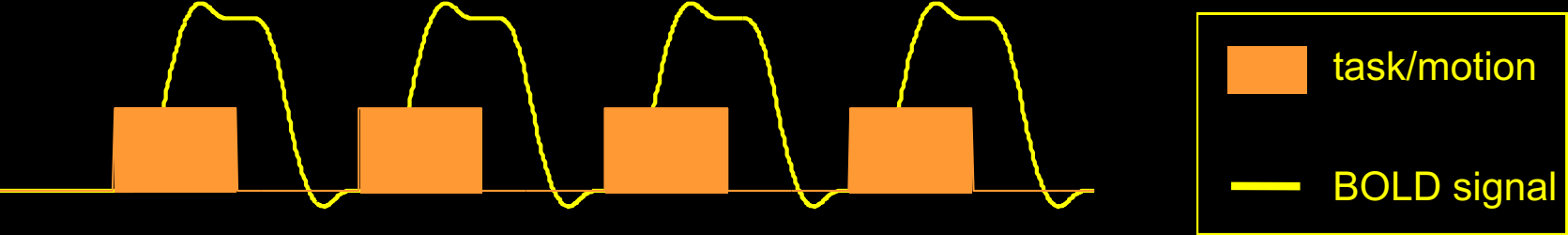
Bypass?

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

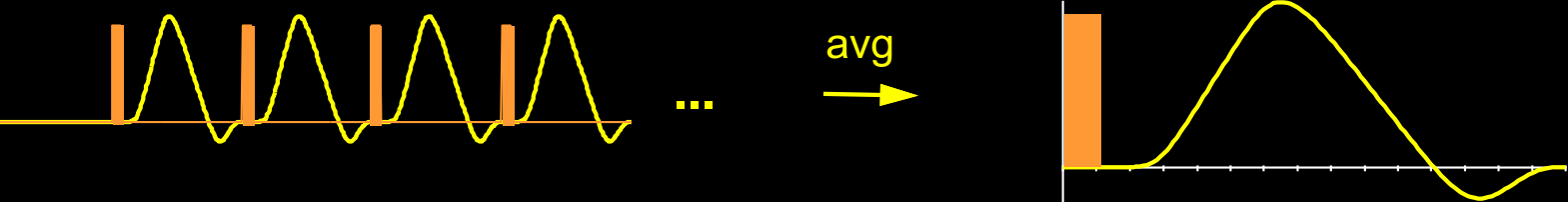
Suppress?

- Flatten image contrast
- Physical restraint
- Averaging, smoothing

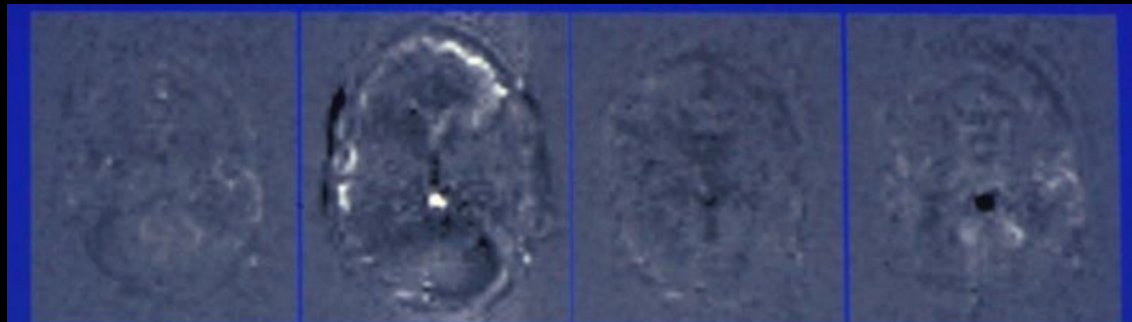
Block-trial



Single-trial (brief stimulus)



Overt Word Production



2

3

4

5

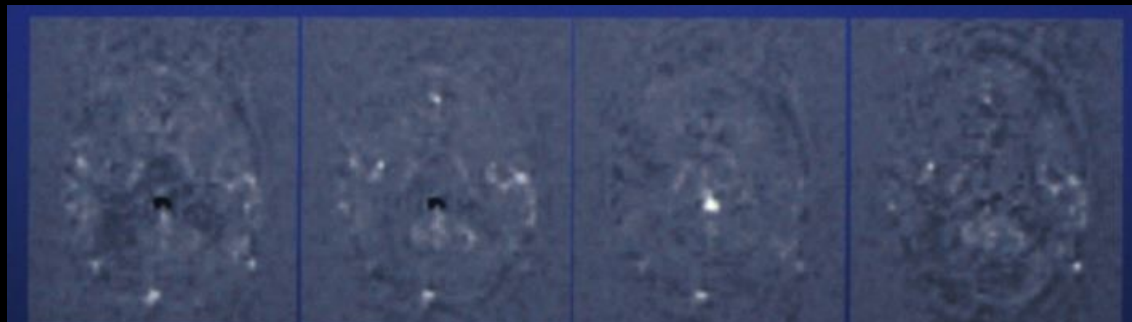


6

7

8

9



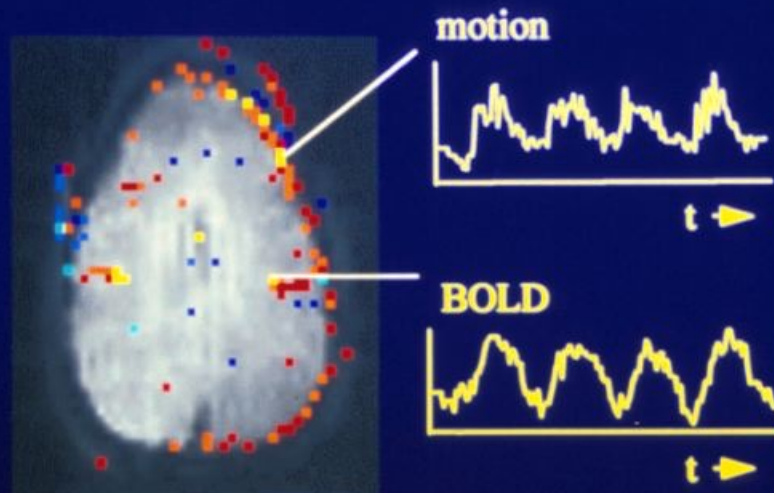
10

11

12

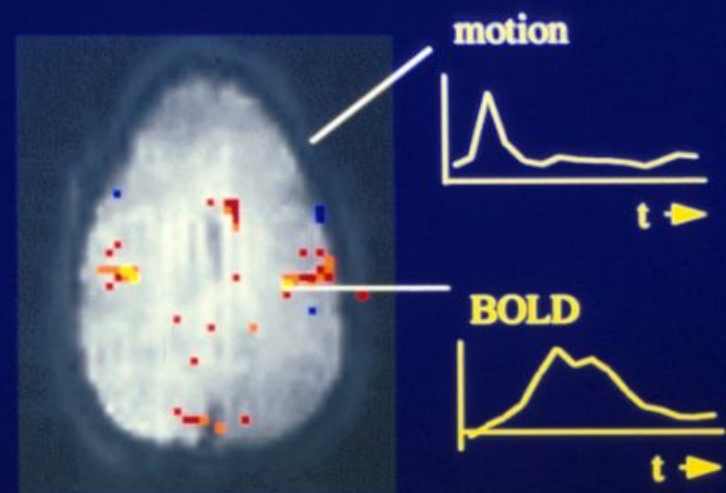
13

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



“block-trial” paradigm

Motion induced signal changes resemble functional (BOLD) signal changes

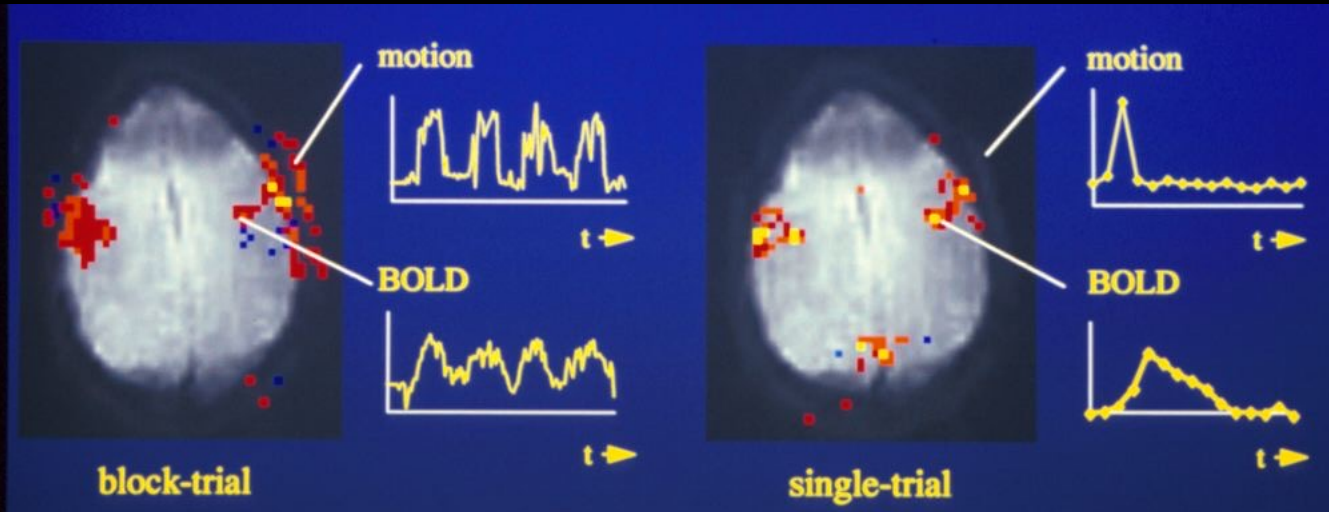


“single-trial” paradigm

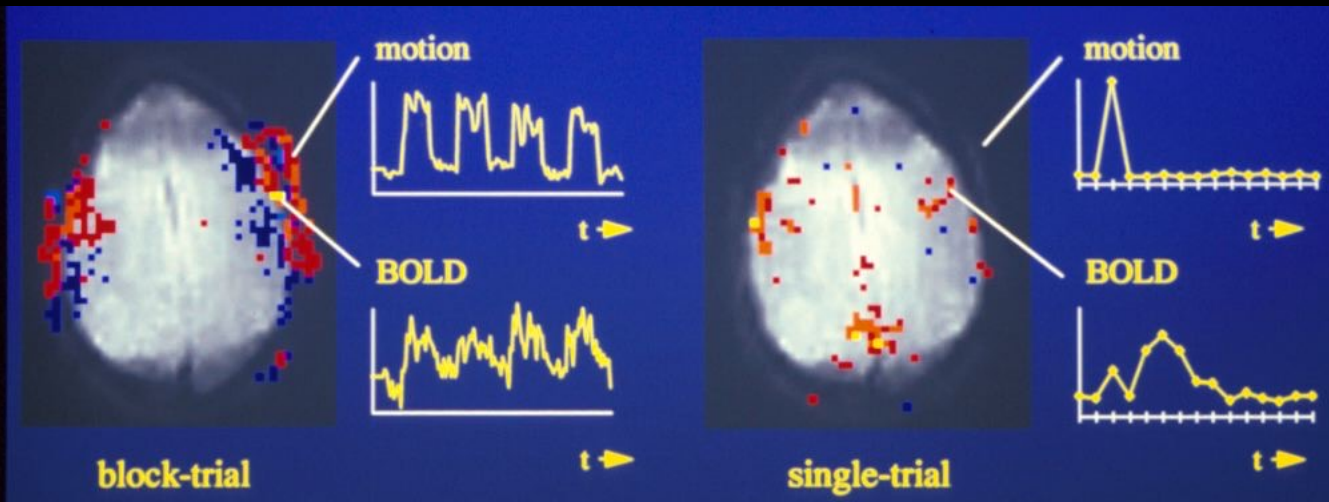
Motion induced and BOLD signal changes are separated in time

R.M. Birn, et al.

Tongue Movement



Jaw Clenching



Improvement Needed...

Neurovascular Coupling

Paradigm Design

Motion Reduction/Correction

Acoustic Noise

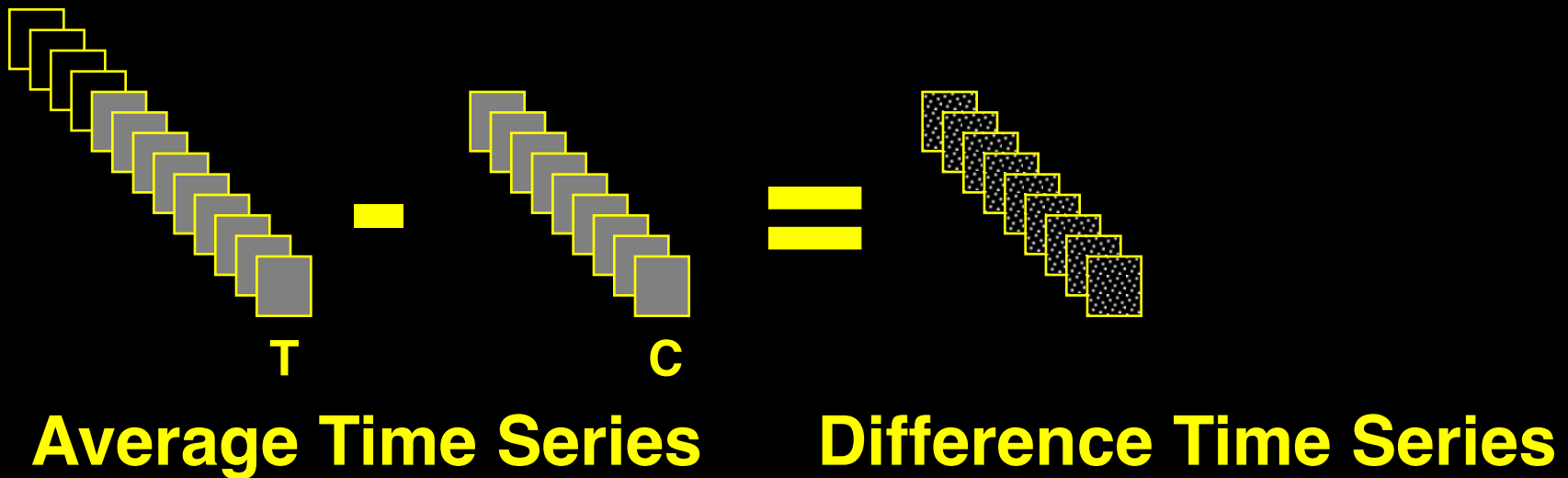
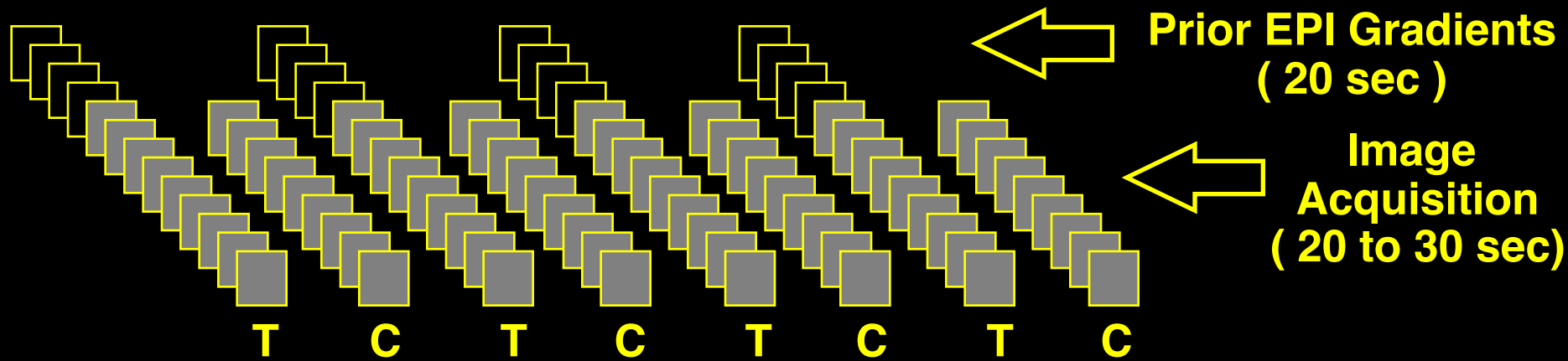
Sensitivity

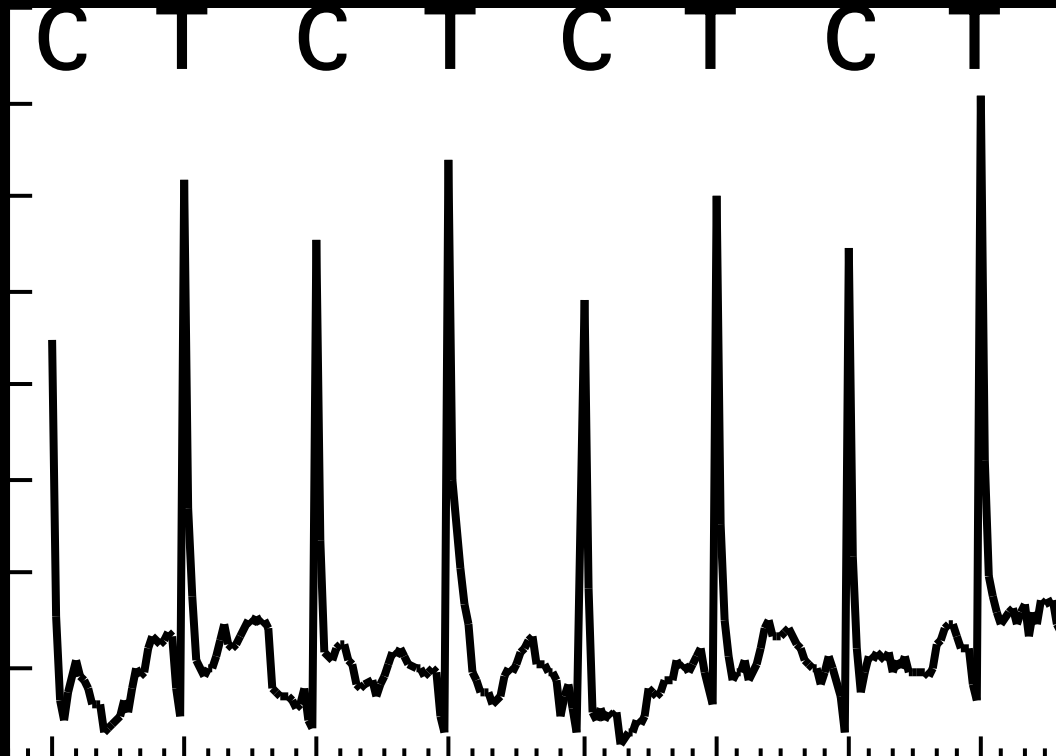
Noise characterization

Image quality

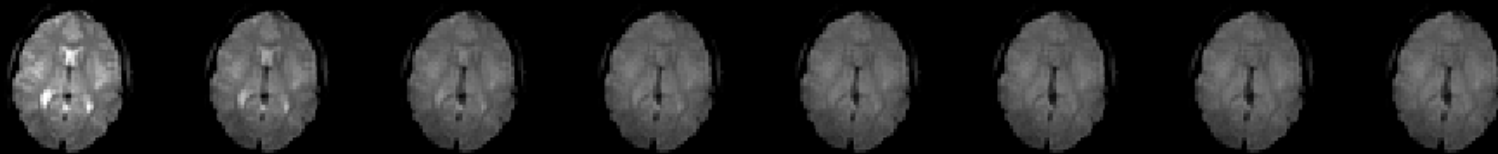
Brain Coverage

Feedback Time/Information

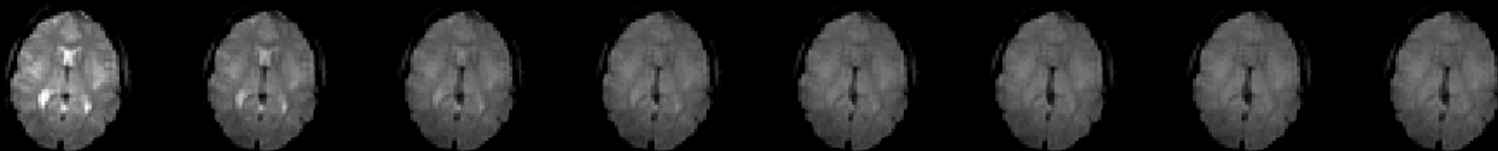




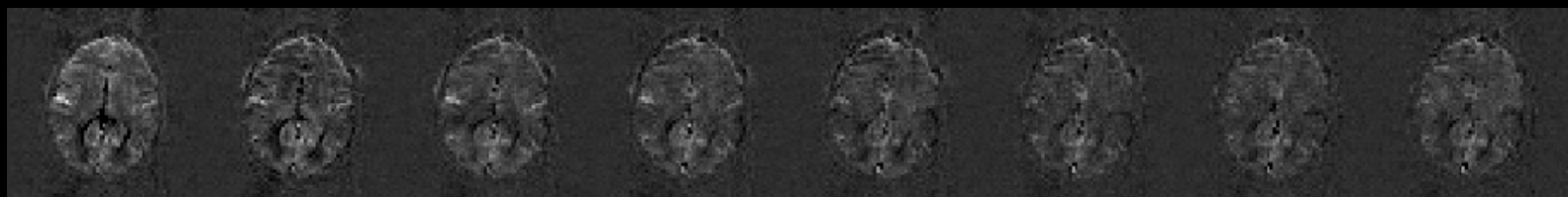
a.



b.



c.



0

1

2

3

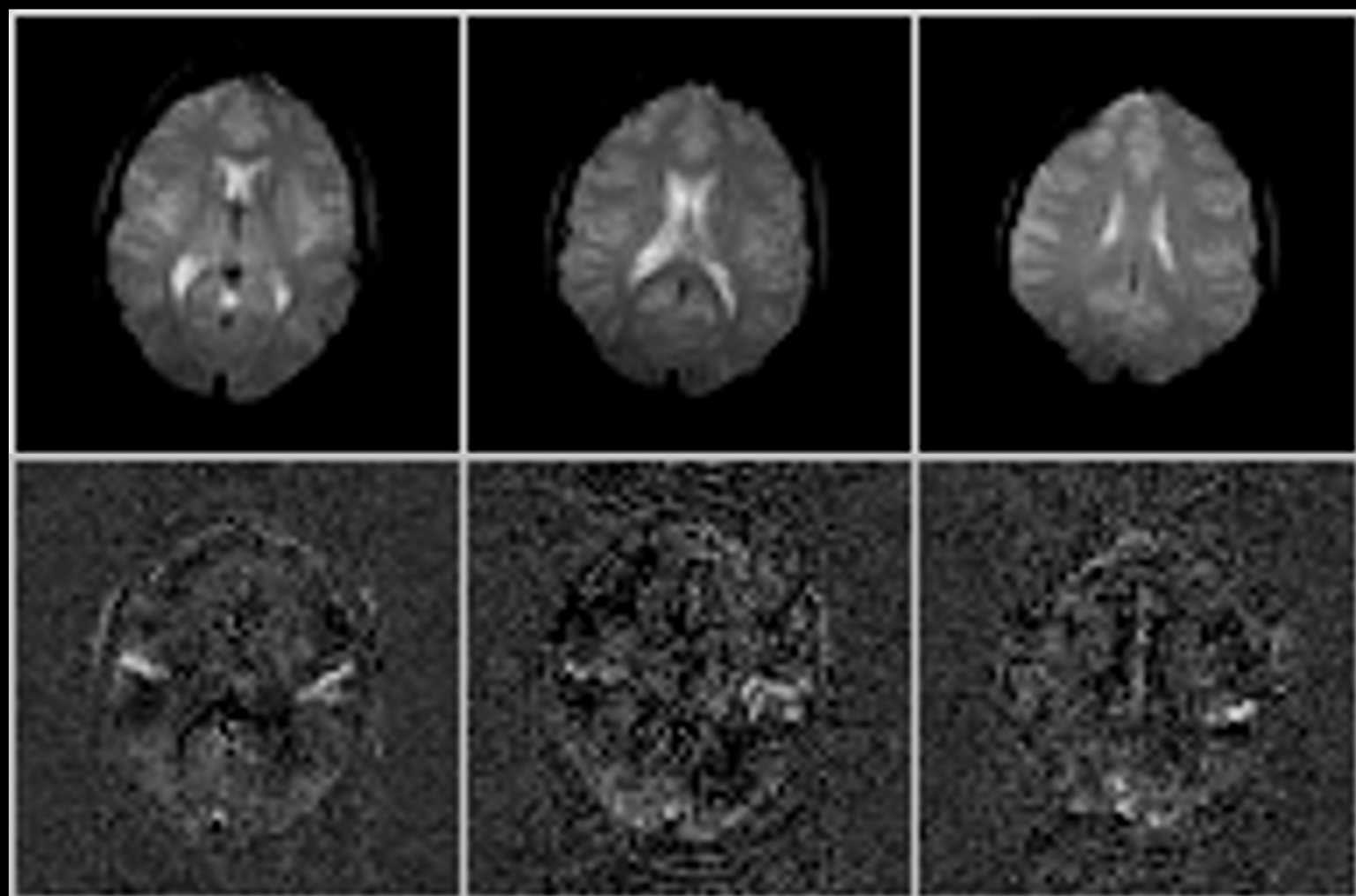
4

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

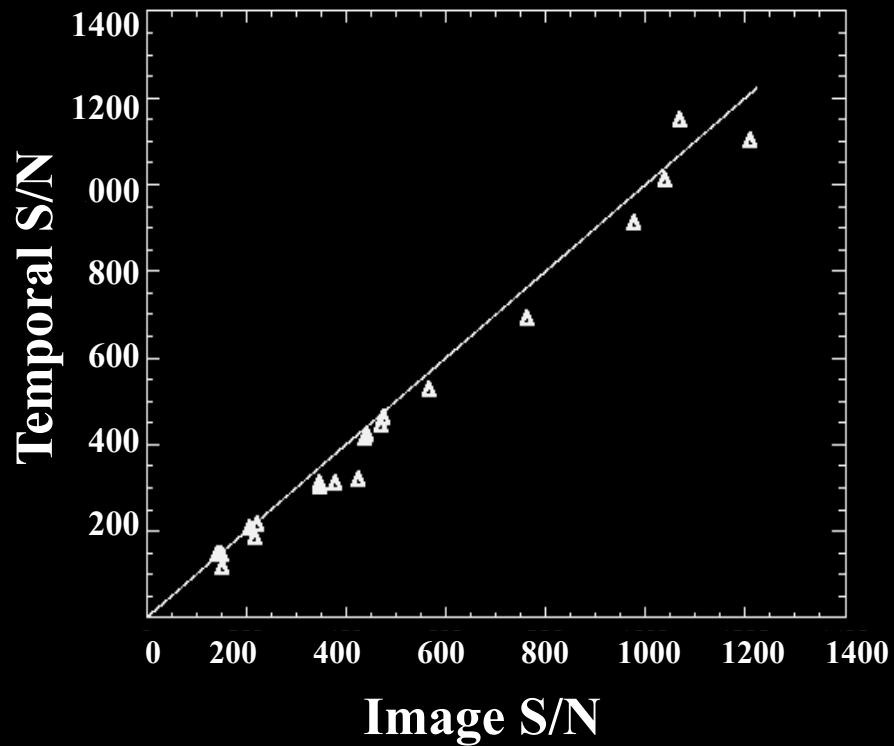
Image quality

Brain Coverage

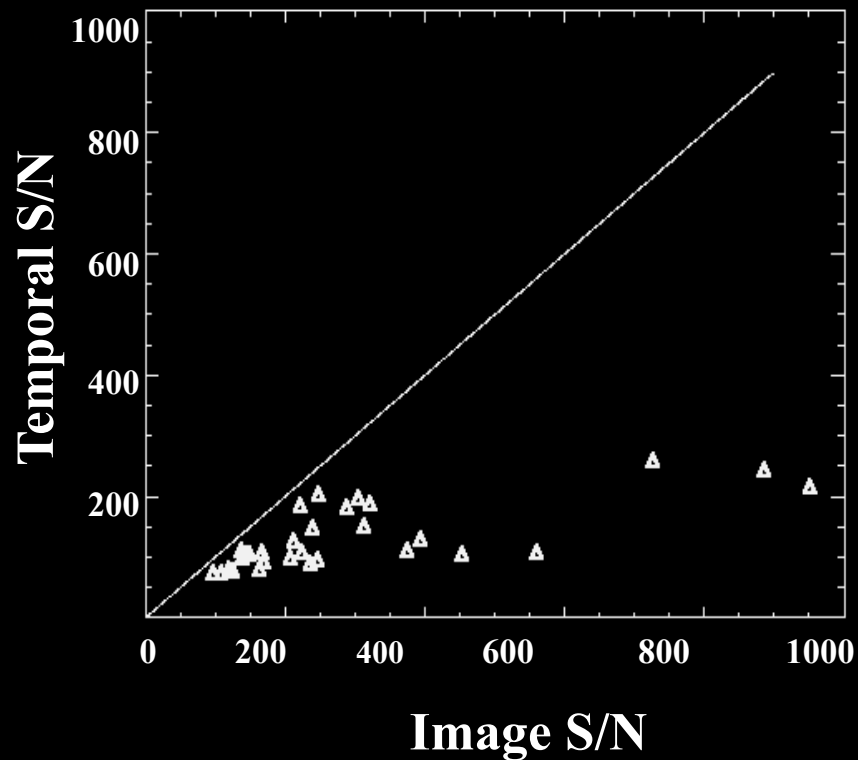
Feedback Time/Information

Temporal S/N vs. Image S/N

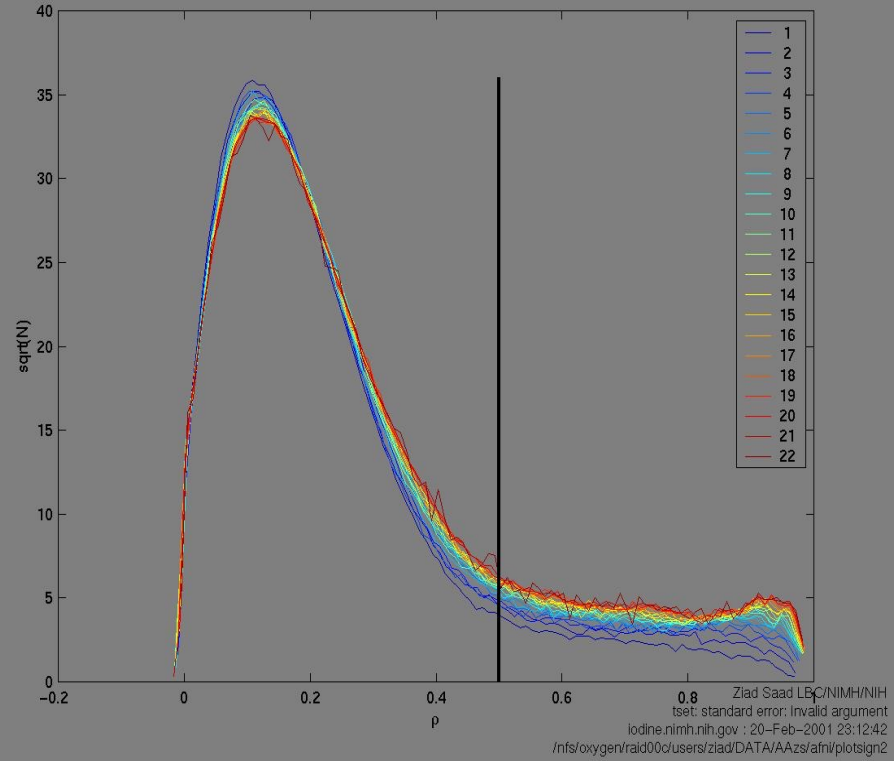
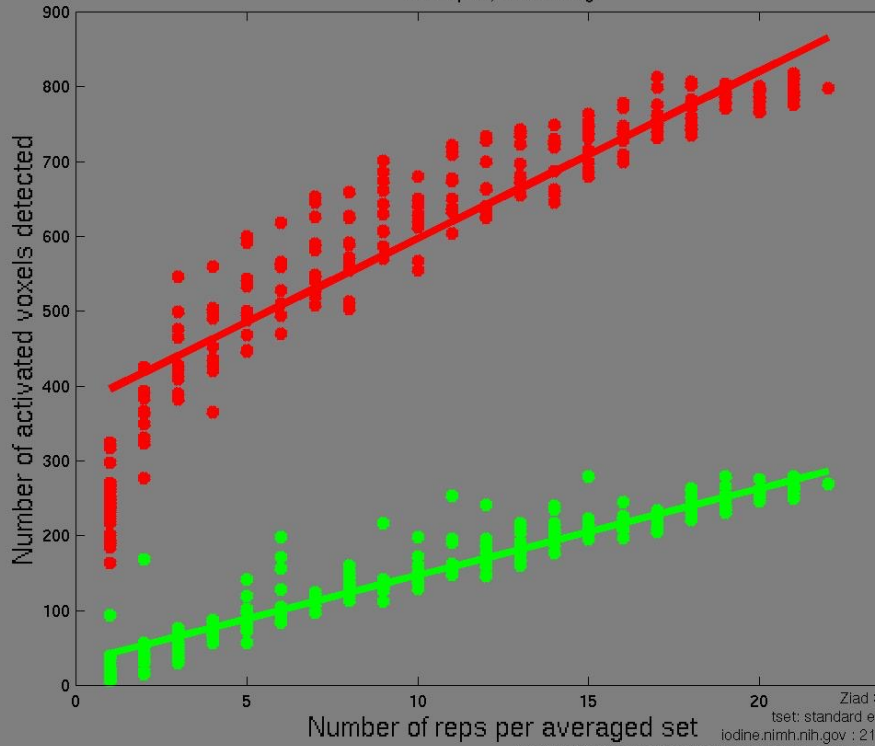
PHANTOMS



SUBJECTS



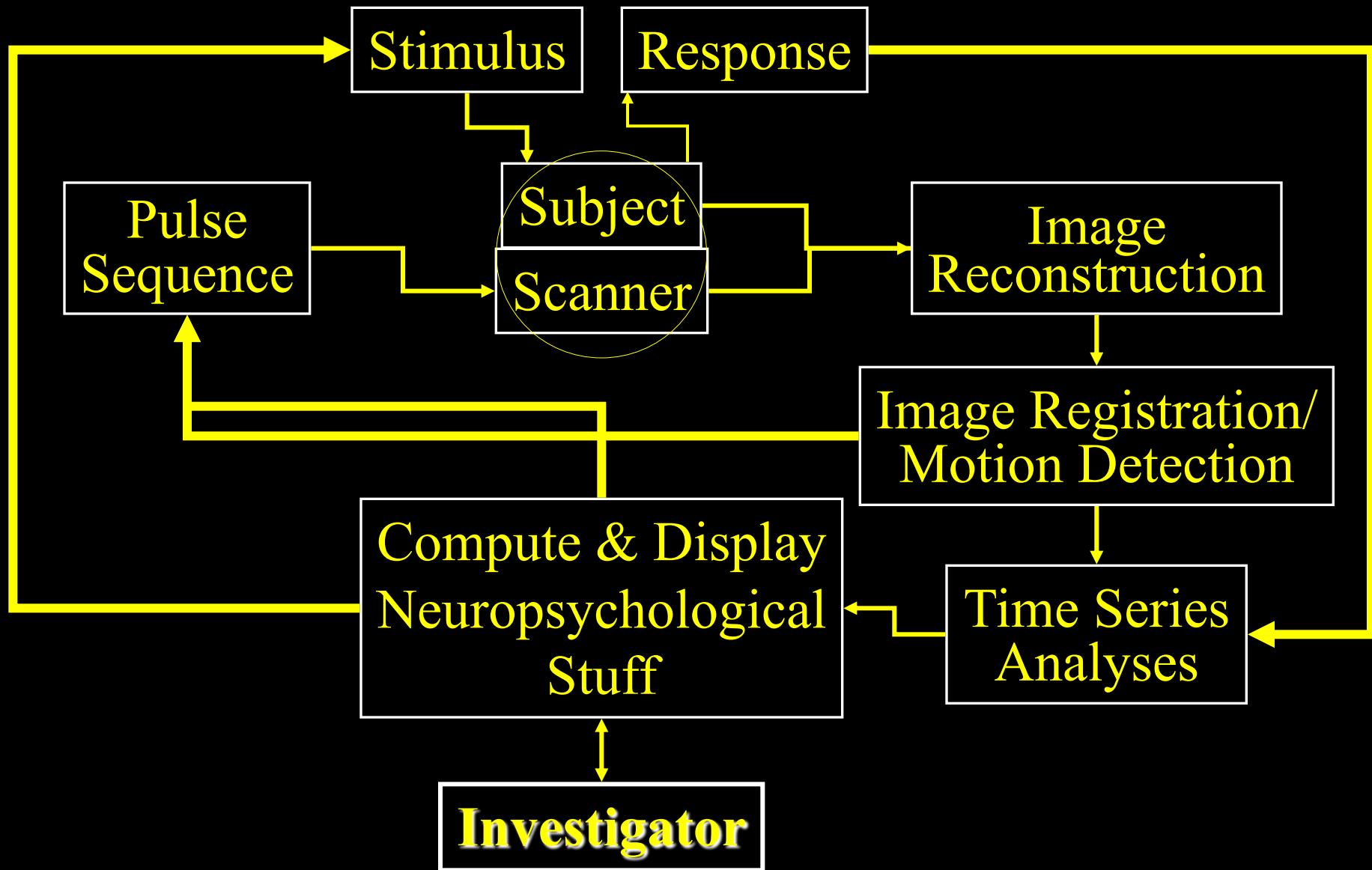
Fit curve: Pos: $22.3478 \cdot N_{rep} + 373.782$ --- Neg: $11.6126 \cdot N_{rep} + 30.8055$
 Fit corr. coeff. (pos, neg) : (0.948073, 0.989839).
 Red->pos., Green->neg.



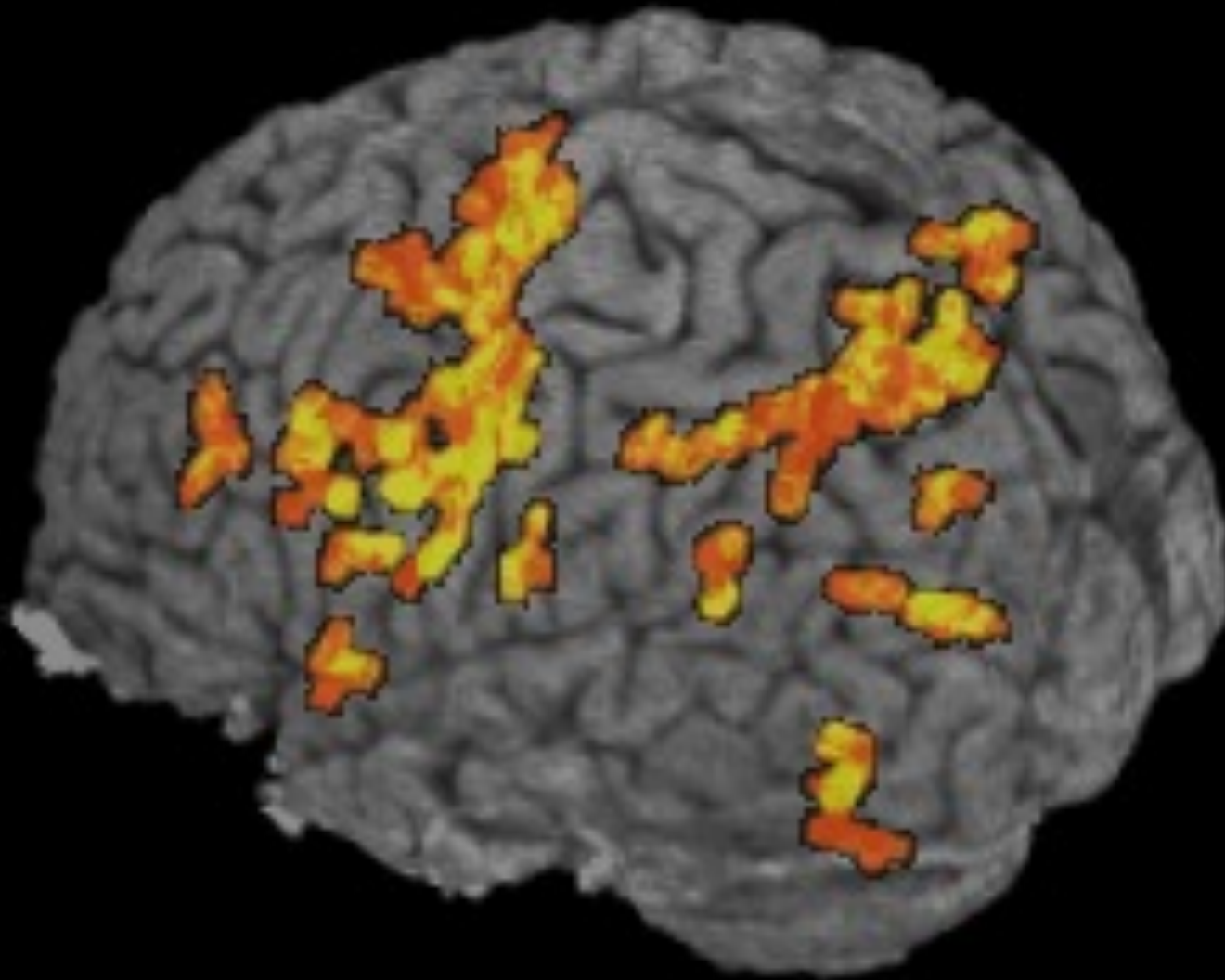
Questions

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: 12345678

**Color shows
through brain**

Correlation > 0.45

**The
End**

Functional Imaging Methods / 3T Group

Staff Scientists:

Sean Marrett

Jerzy Bodurka

Post Docs:

Rasmus Birn

Patrick Bellgowan

Ziad Saad

Graduate Student:

Natalia Petridou

Summer Student:

Dan Kelley

Program Assistant:

Kay Kuhns



August, 2000