# Latest Developments in fMRI

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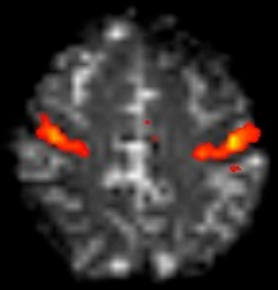
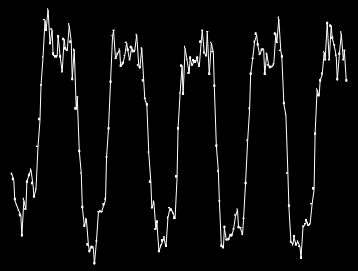
# Alternating Left and Right Finger Tapping

~ 1992

# The use of fMRI for the Investigation of Brain Function and Physiology

- **Where?**
- **When?**
- **How much?**



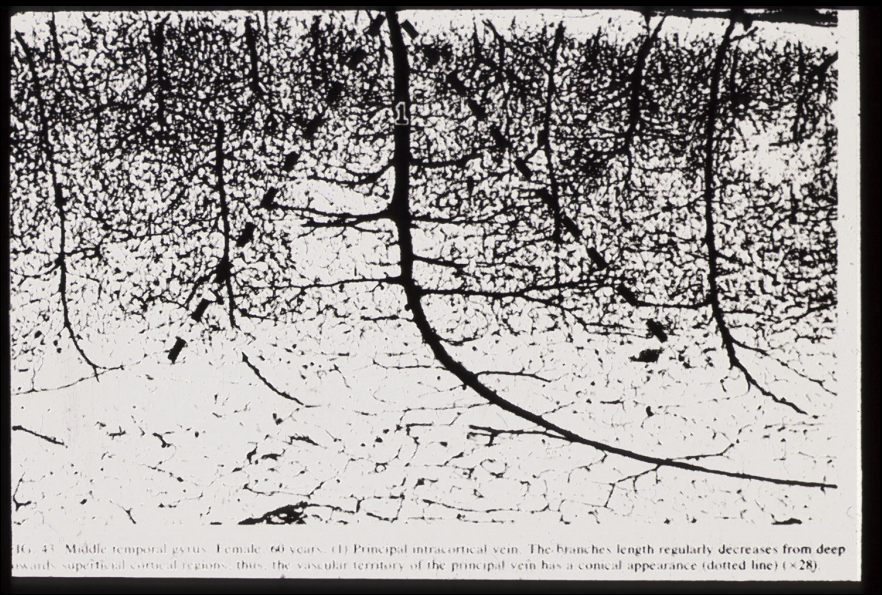


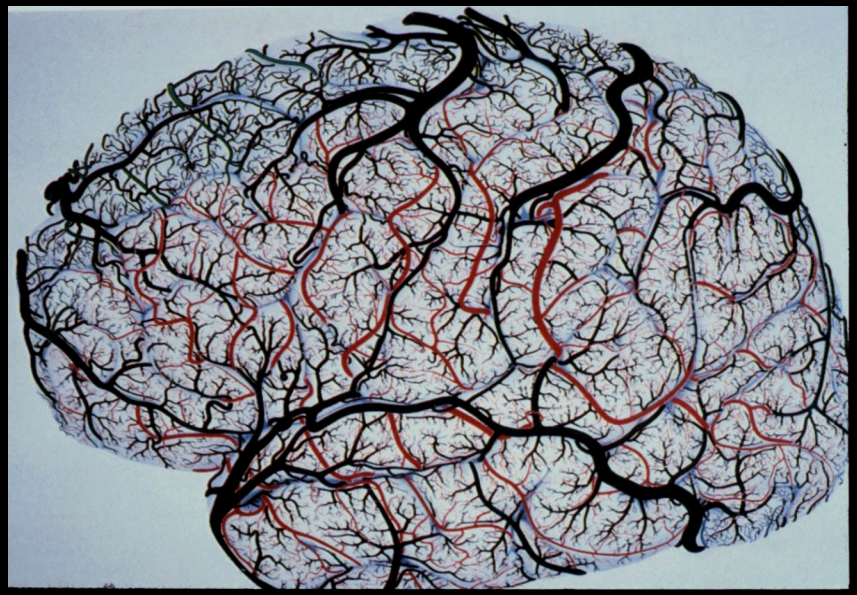
- **How to get the brain to do what we want it to do in the context of an fMRI experiment?**
  **(*limitations*: limited time and signal to noise, motion, acoustic noise)**

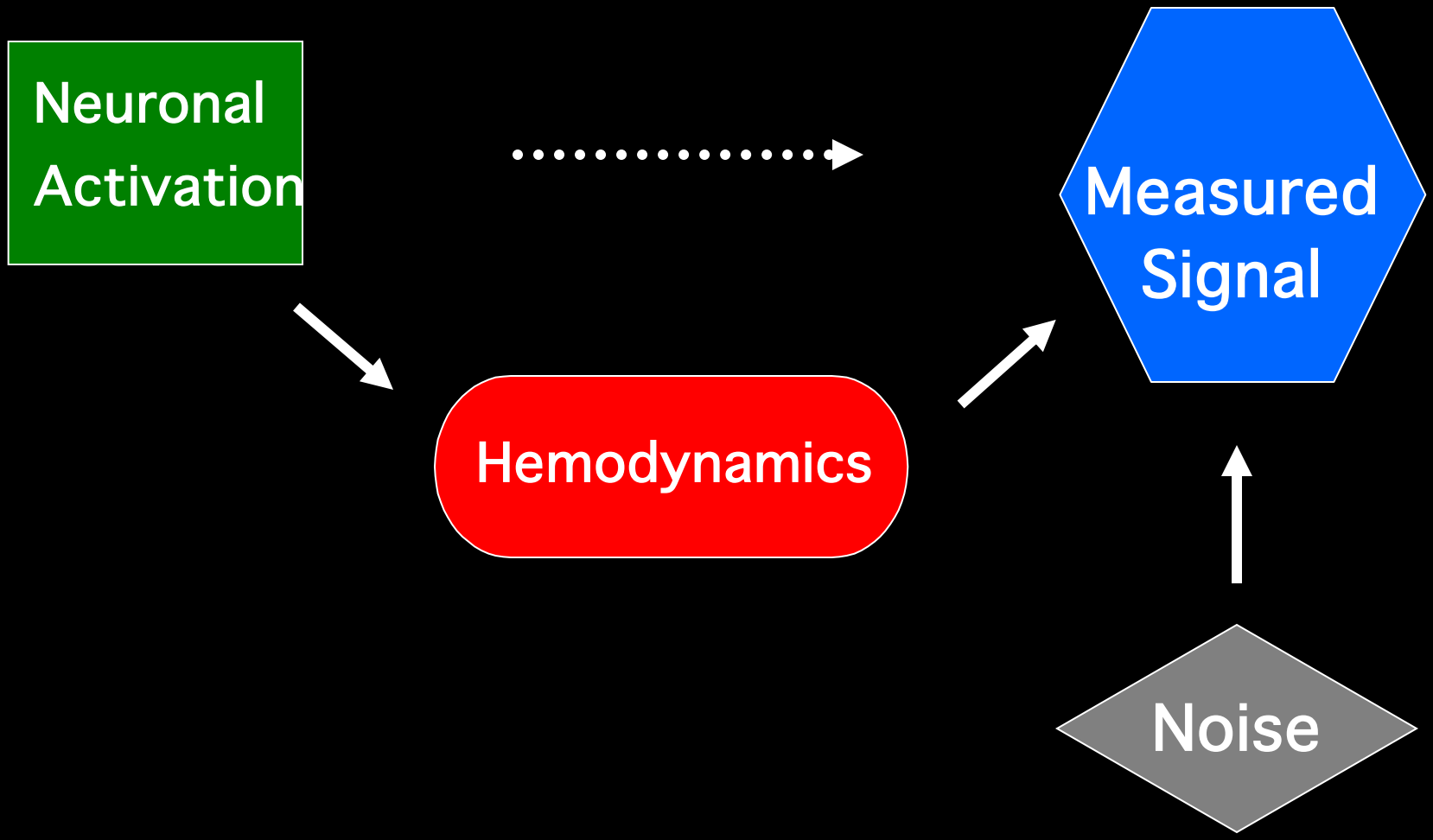
- **How much more information can we obtain?**

# A Primary Challenge for Observing Brain Activation:

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






Neuronal Activation
Measured Signal
Hemodynamics
Noise

# Latest Developments…

1. Temporal Resolution
2. Spatial Resolution
3. Sensitivity and Noise
4. Information Content
5. Implementation

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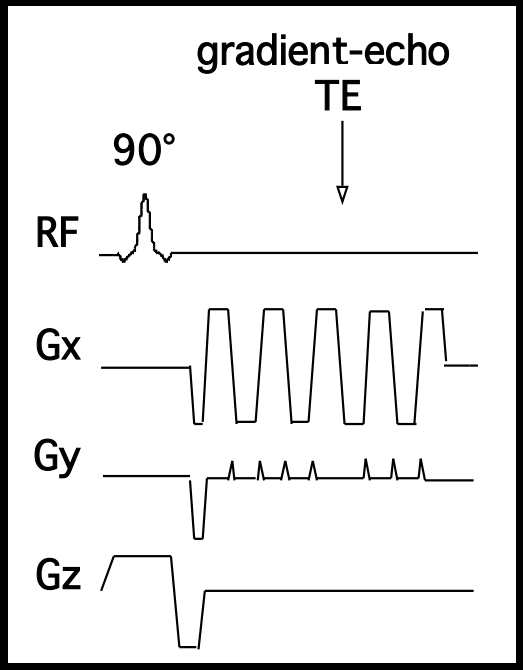
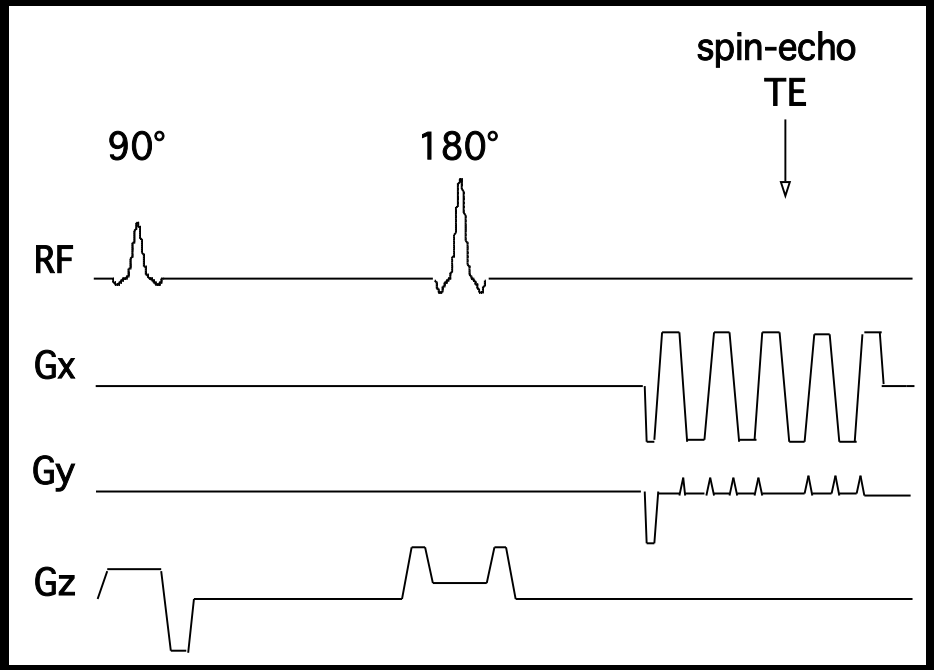
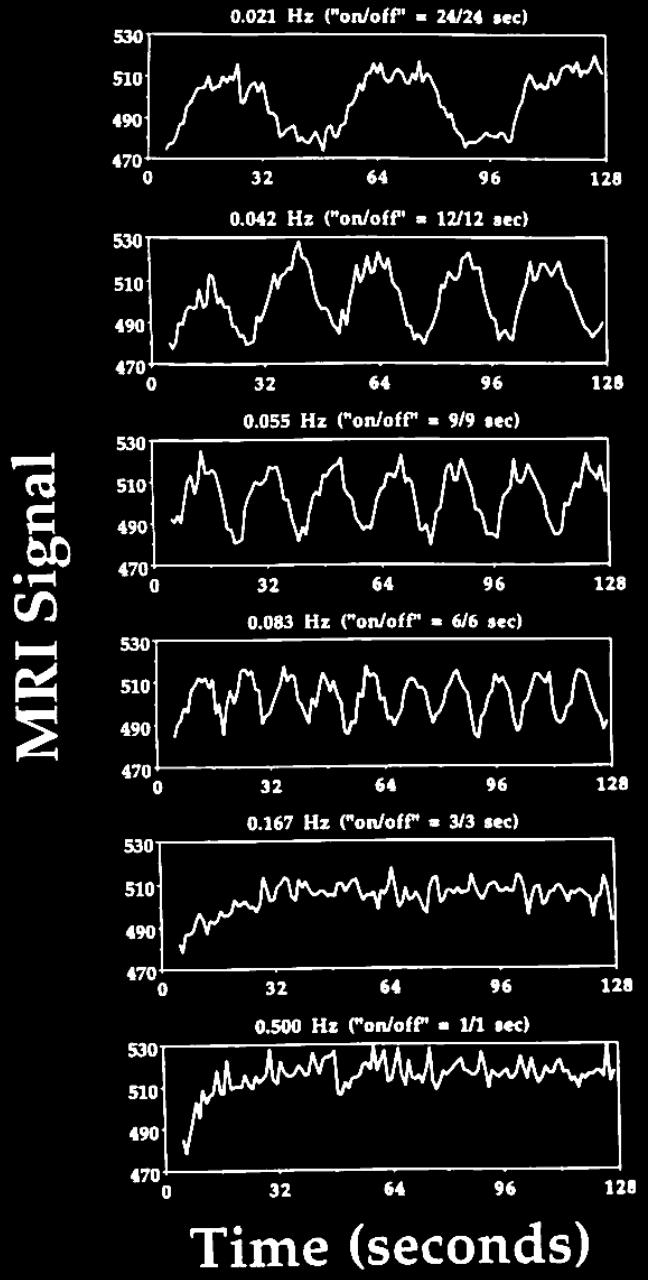
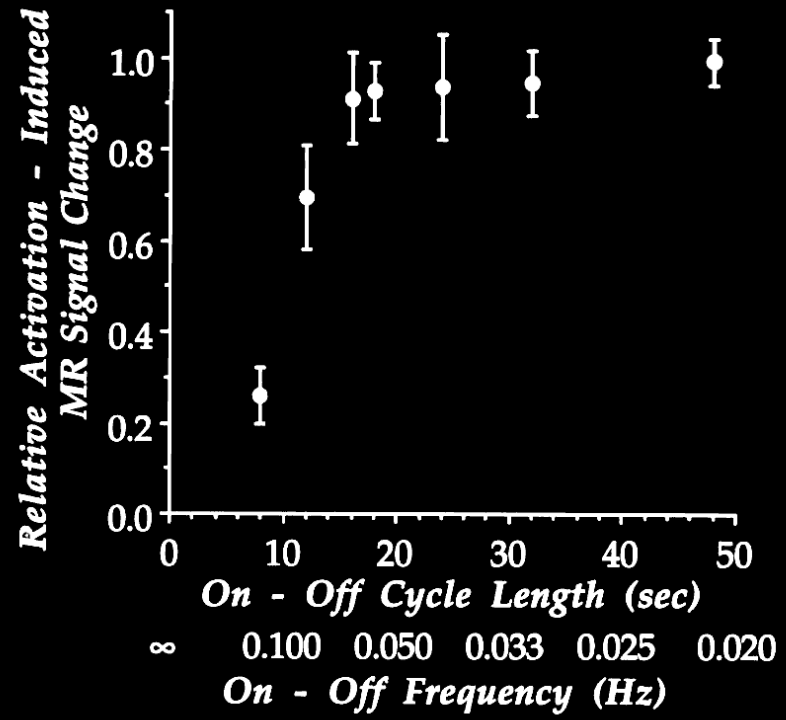
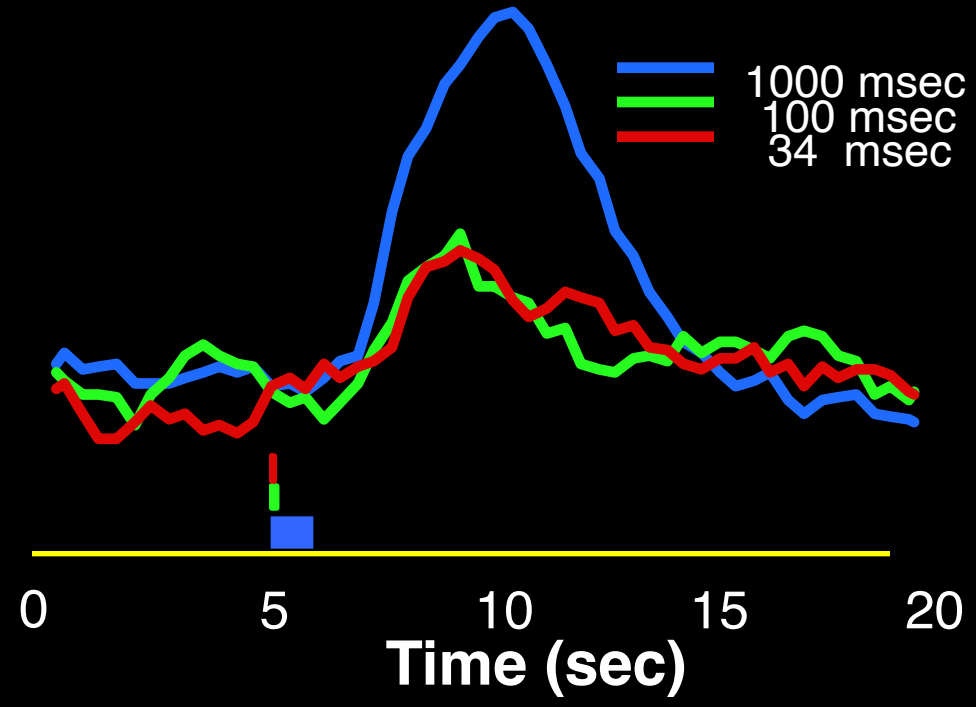
# Echo-Planar Imaging

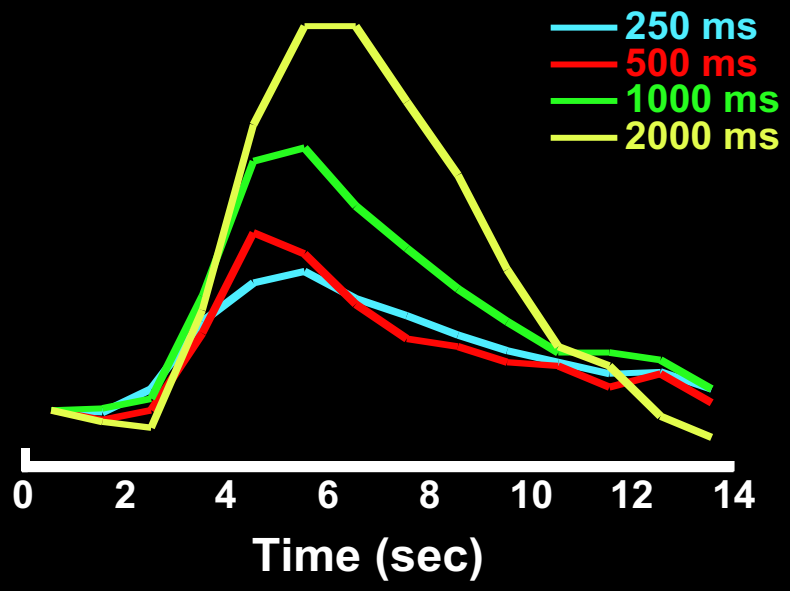


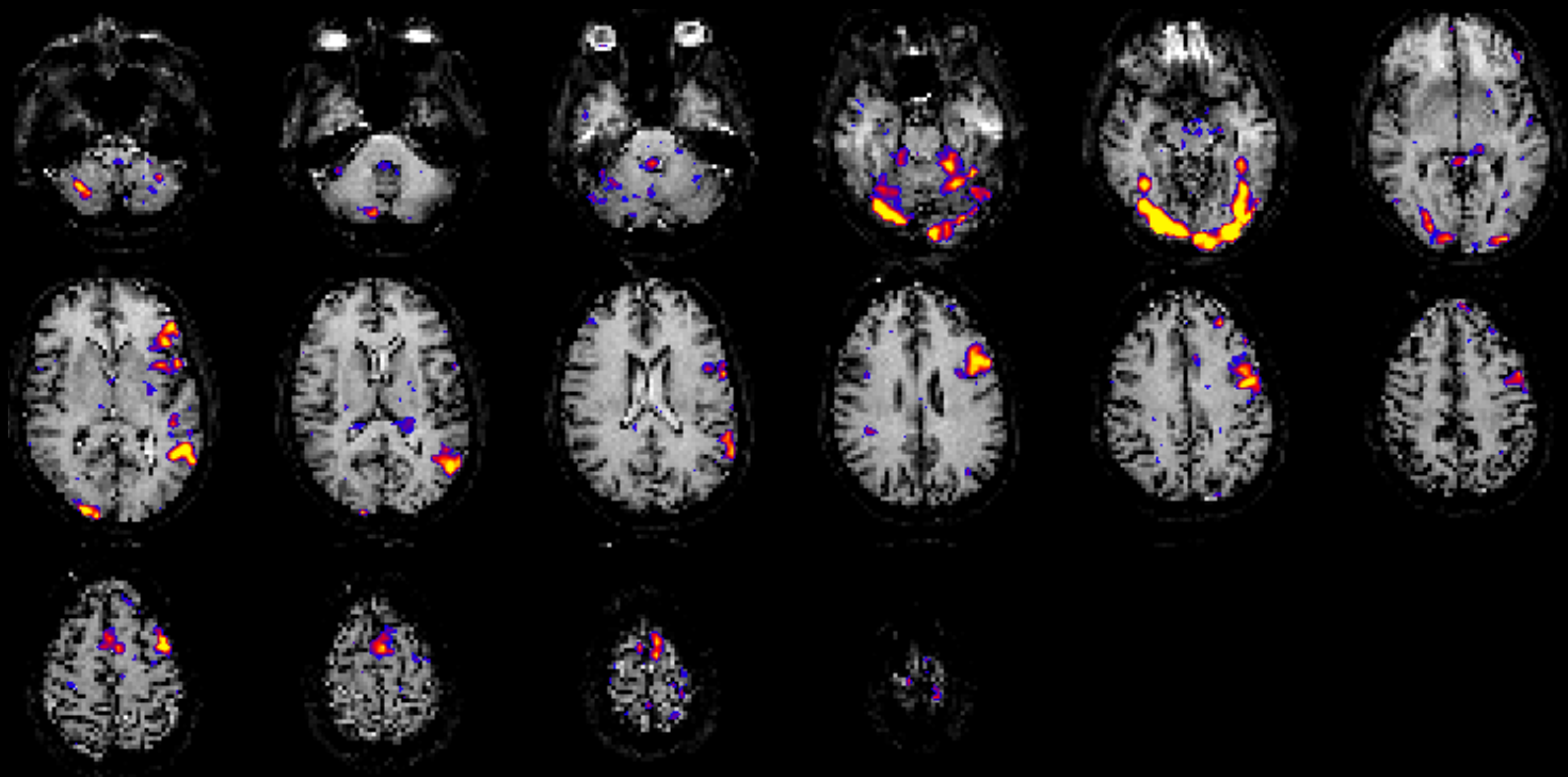

0.021 Hz ("on/off" = 24/24 sec)
0.042 Hz ("on/off" = 12/12 sec)
0.055 Hz ("on/off" = 9/9 sec)
0.083 Hz ("on/off" = 6/6 sec)
0.167 Hz ("on/off" = 3/3 sec)
0.500 Hz ("on/off" = 1/1 sec)
530
510
490
470
0
32
64
96
128
MRI Signal
Time (seconds)

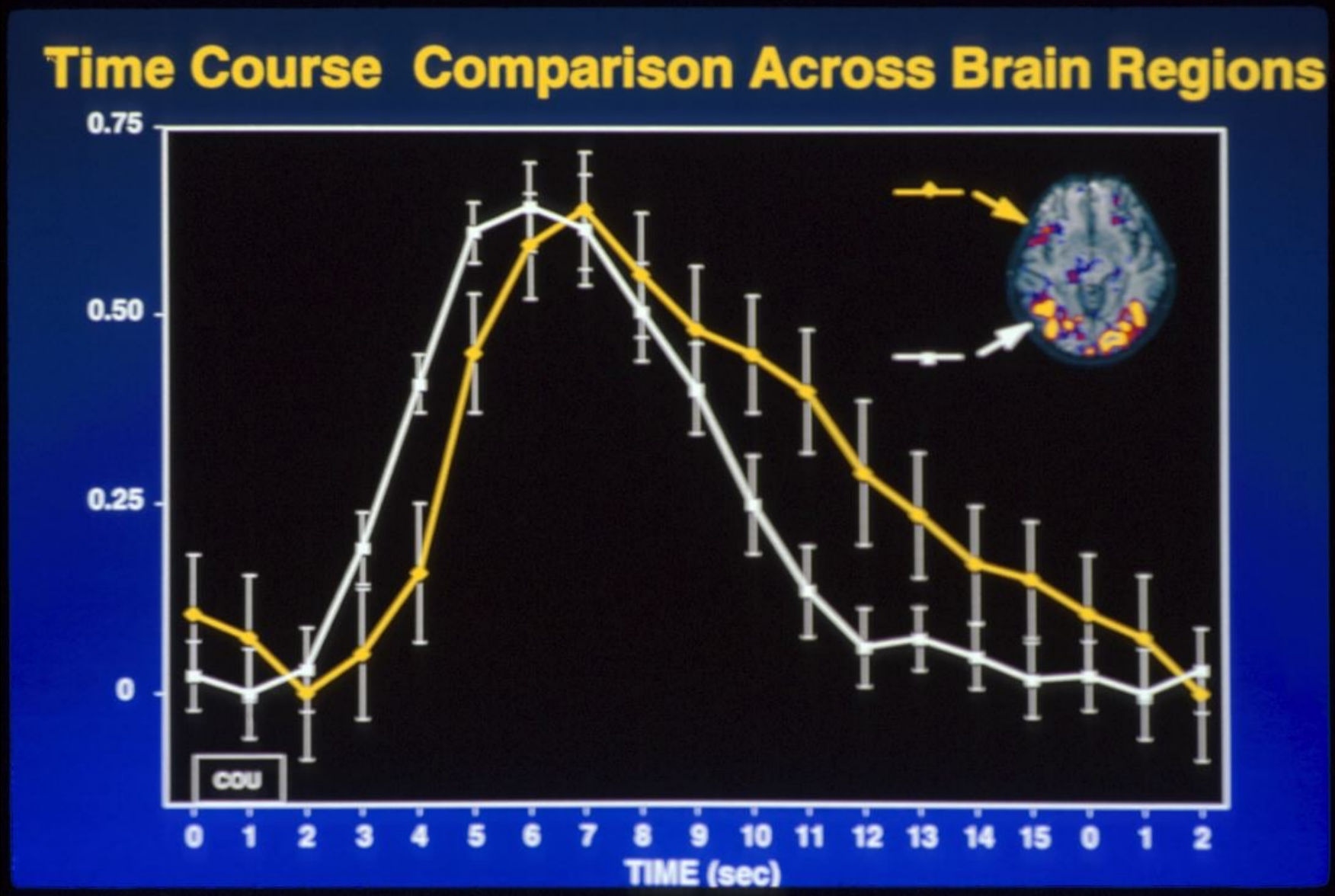

Relative Activation - Induced MR Signal Change
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
On - Off Cycle Length (sec)
∞
0.100
0.050
0.033
0.025
0.020
On - Off Frequency (Hz)


1000 msec
100 msec
34 msec
0
5
10
15
20
Time (sec)


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

# Word stem completion

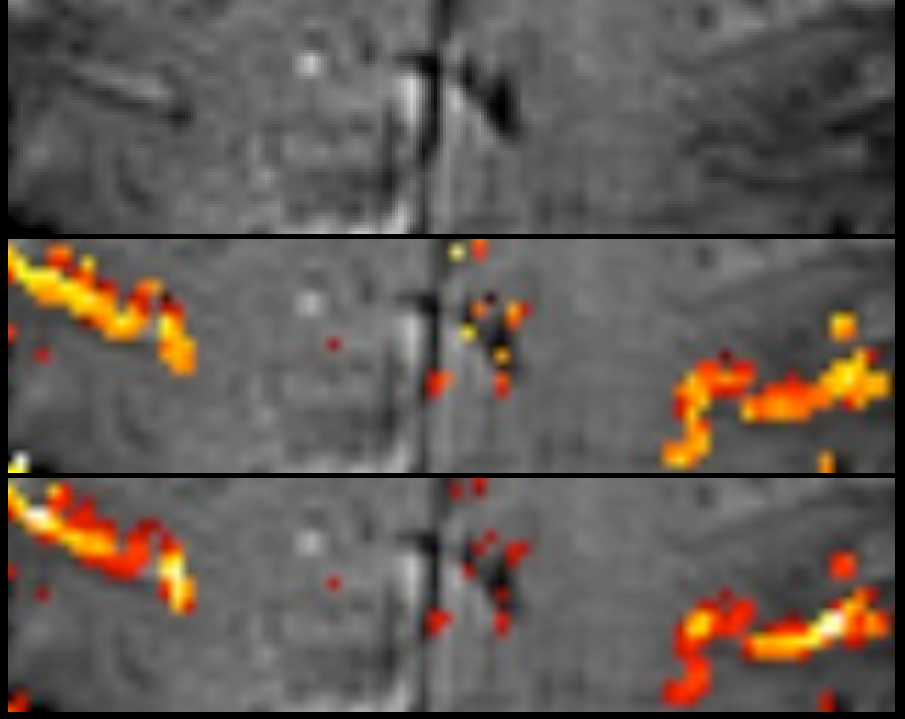


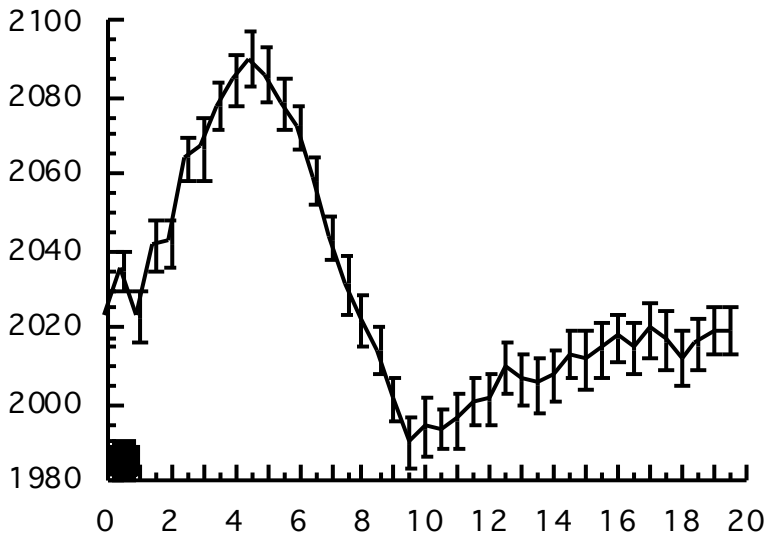


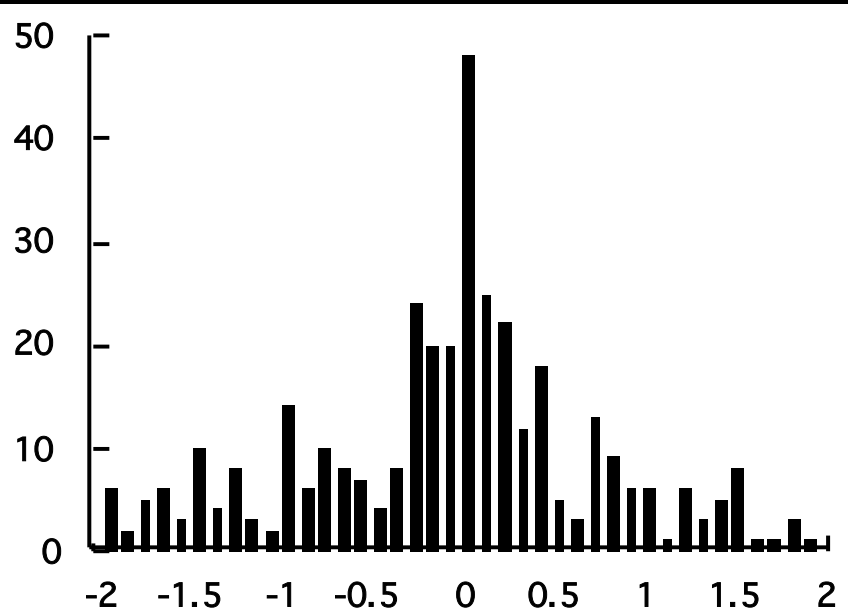

Buckner, R. L, Bandettini, P.A. et al. Detection of cortical activation during averaged single trials of a cognitive task using functional magnetic resonance imaging. *Proc. Natl. Acad. Sci. USA* **93**, 14878-83 (1996).

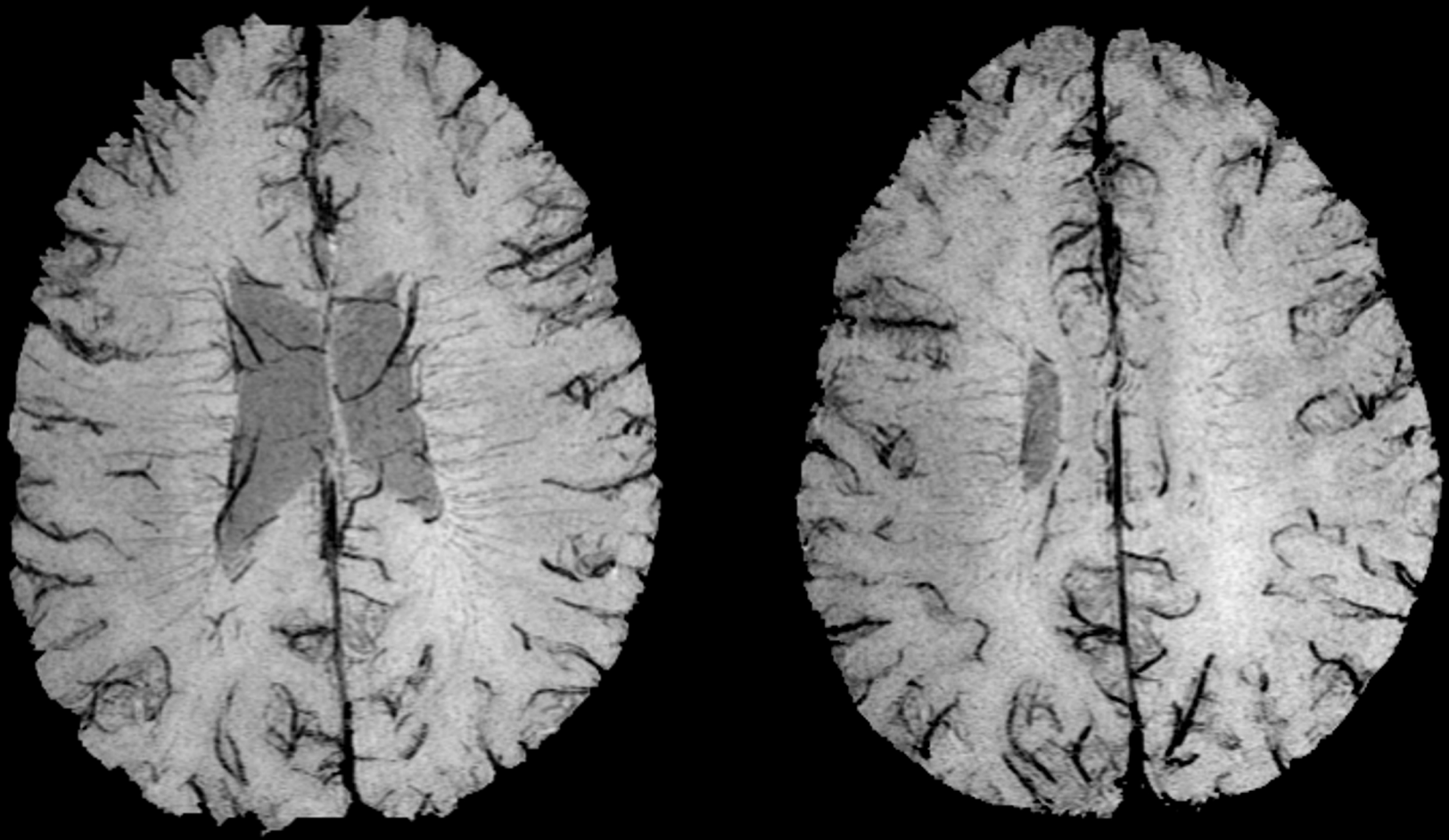
Latency

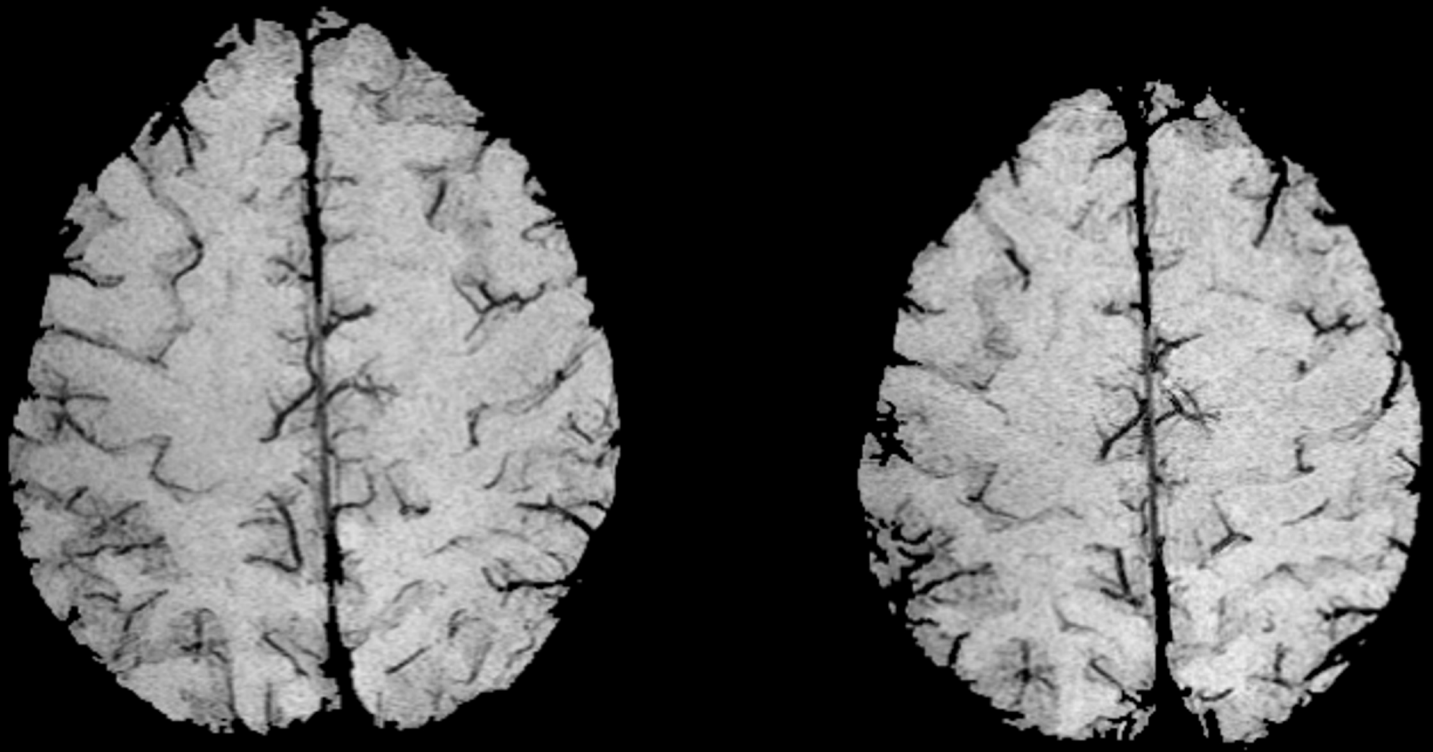
Magnitude

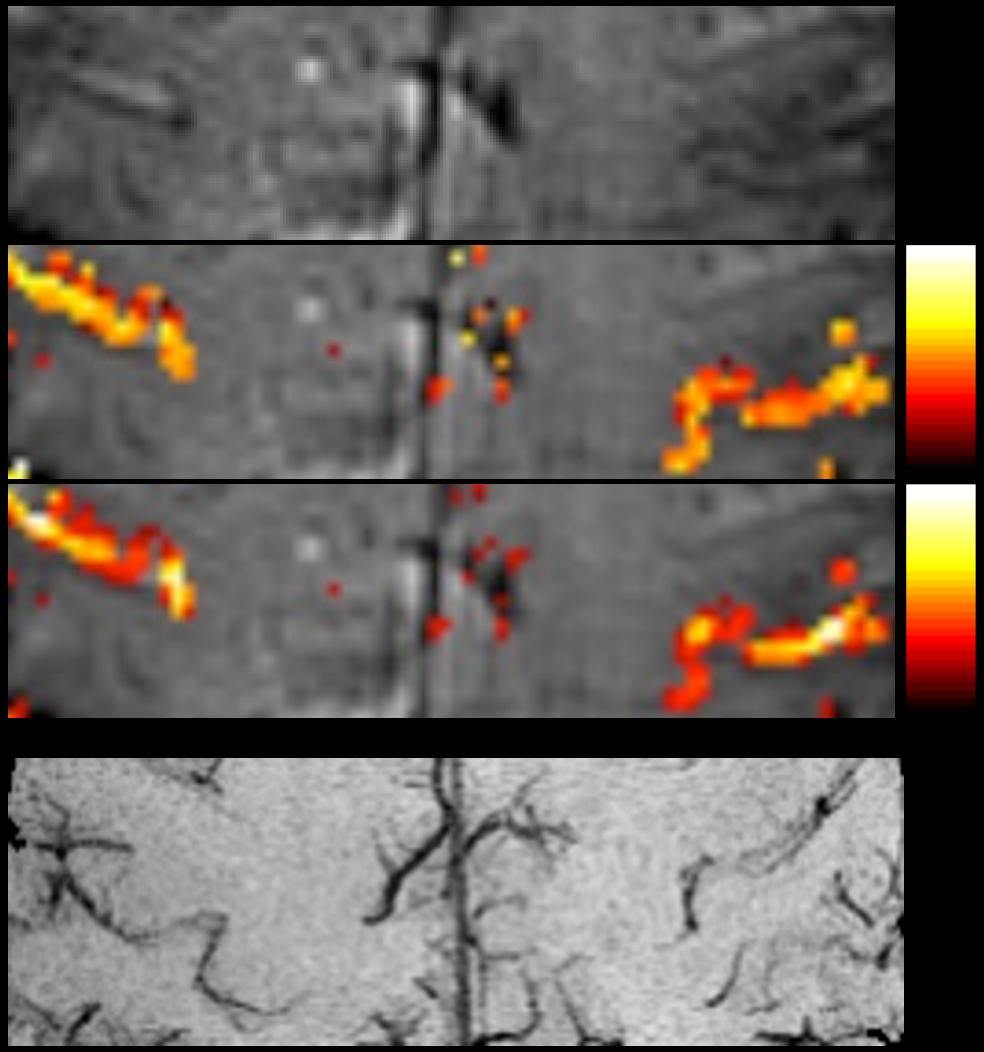


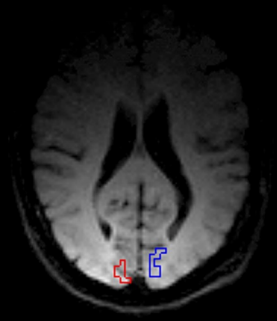







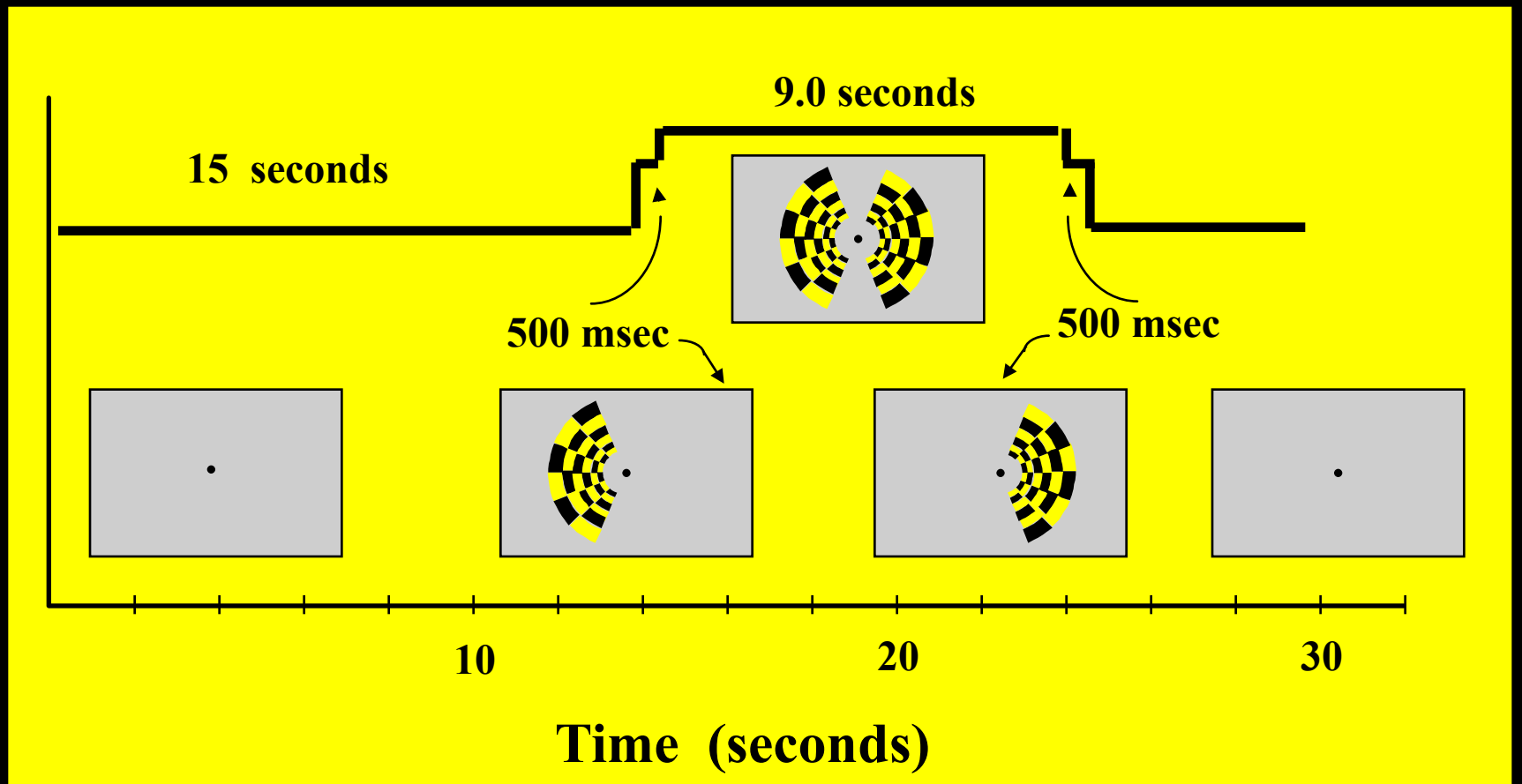


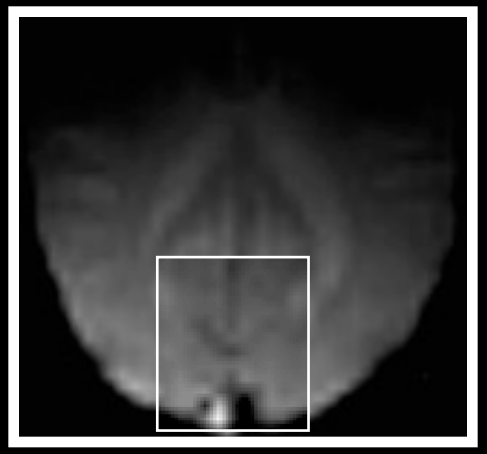
# Hemi-Field Experiment

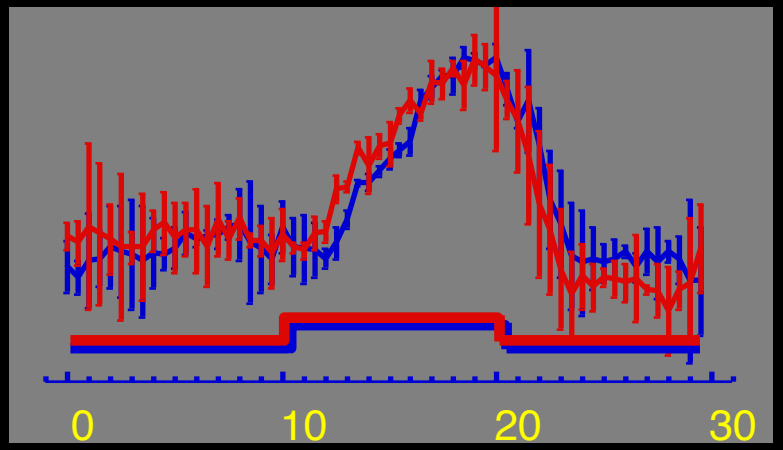


Right Hemisphere

Left Hemisphere








500 ms

500 ms

Right Hemifield

Left Hemifield

+ 2.5 s

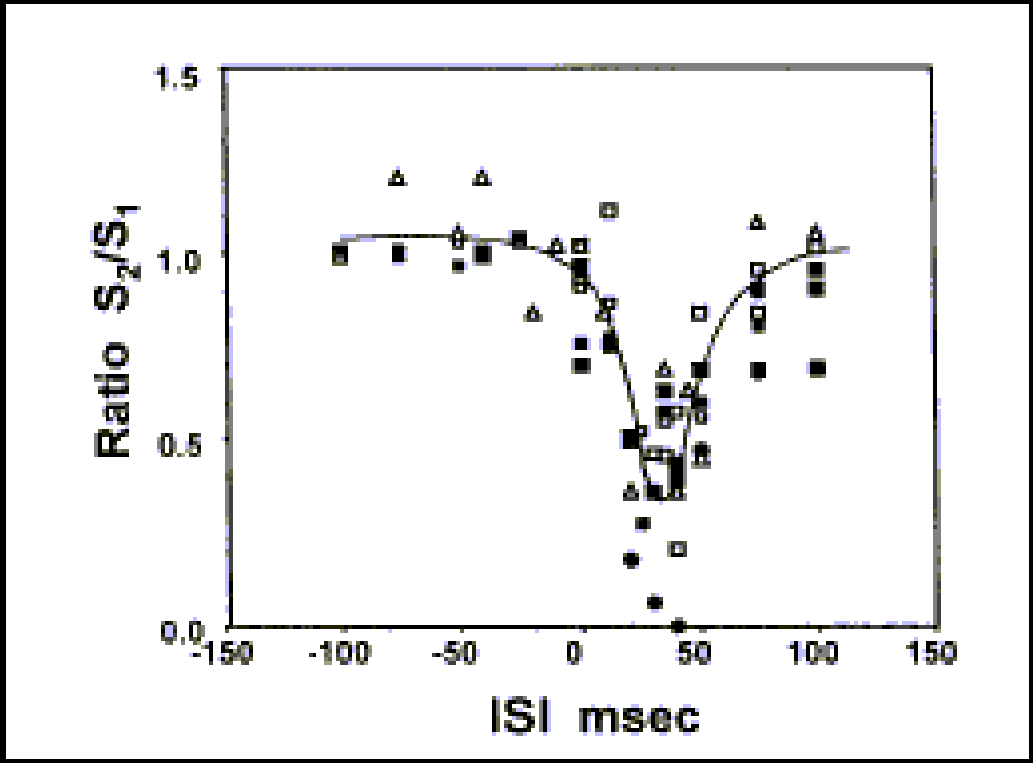
0 s

- 2.5 s

# An approach to probe some neural systems interaction by functional MRI at neural time scale down to milliseconds

Seiji Ogawa[†‡], Tso-Ming Lee[†], Ray Stepnoski[†], Wei Chen[§], Xiao-Hong Zhu[§], and Kamil Ugurbil[§]

[†]Bell Laboratories, Lucent Technologies, Murray Hill, NJ 07974; and [§]Center for Magnetic Resonance Research, University of Minnesota Medical School, Minneapolis, MN 55455




**11026–11031** PNAS **September 26, 2000** vol. 97 no. 20

# Latest Developments...

1. Temporal Resolution
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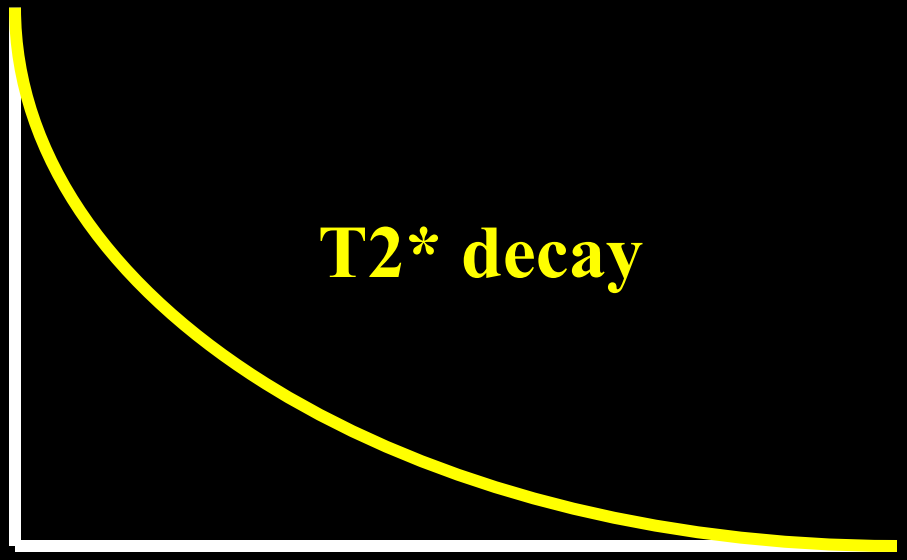
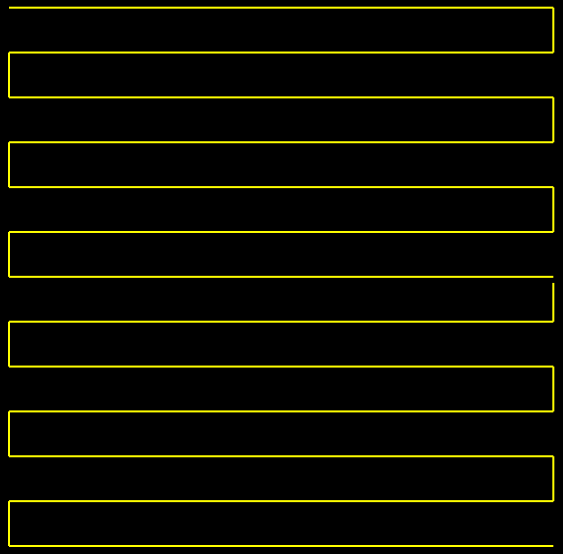
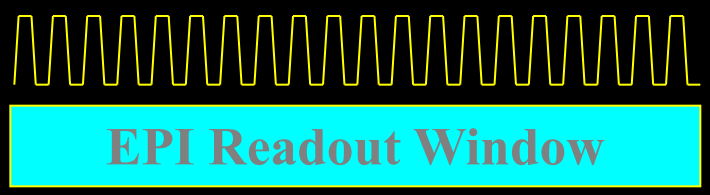
# Single Shot Imaging

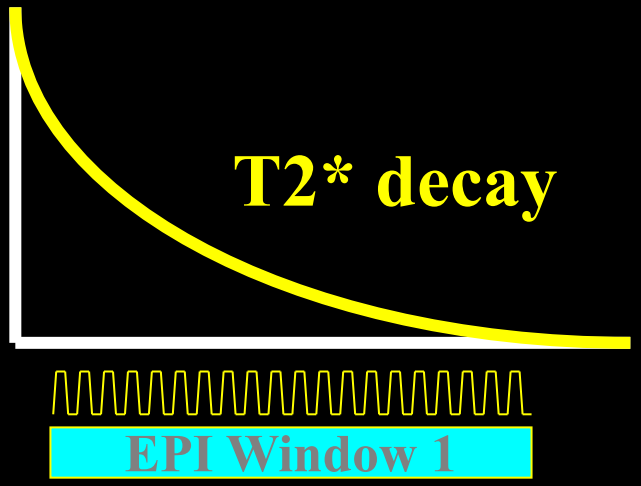


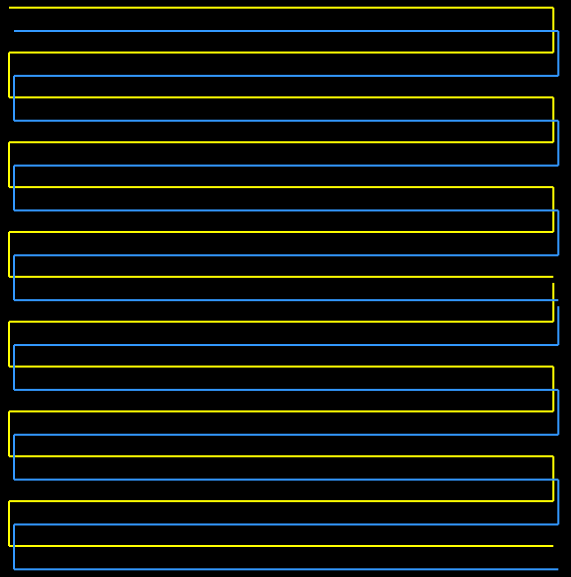



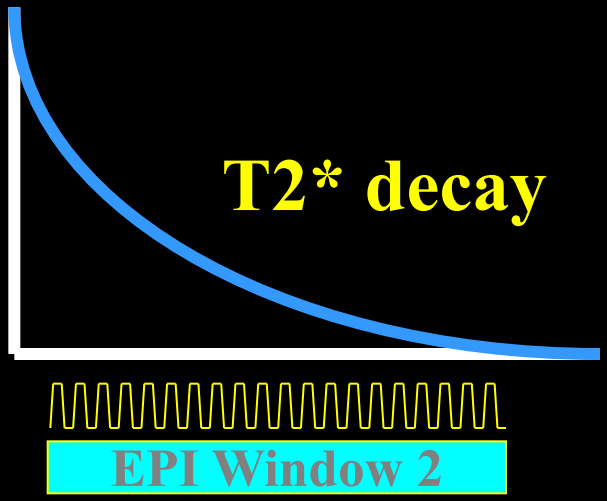



**≈ 20 to 40 ms**

# Multishot Imaging

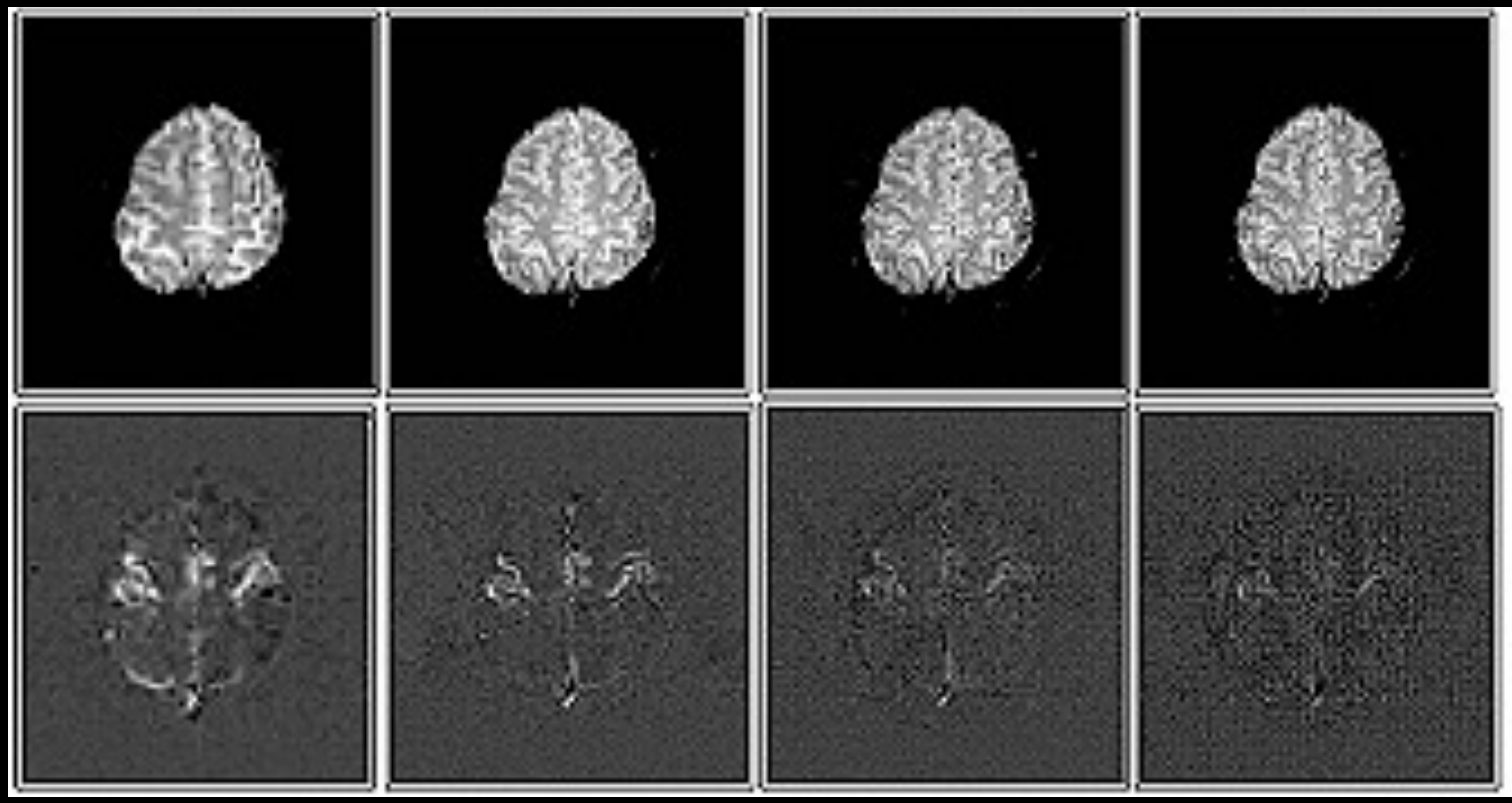


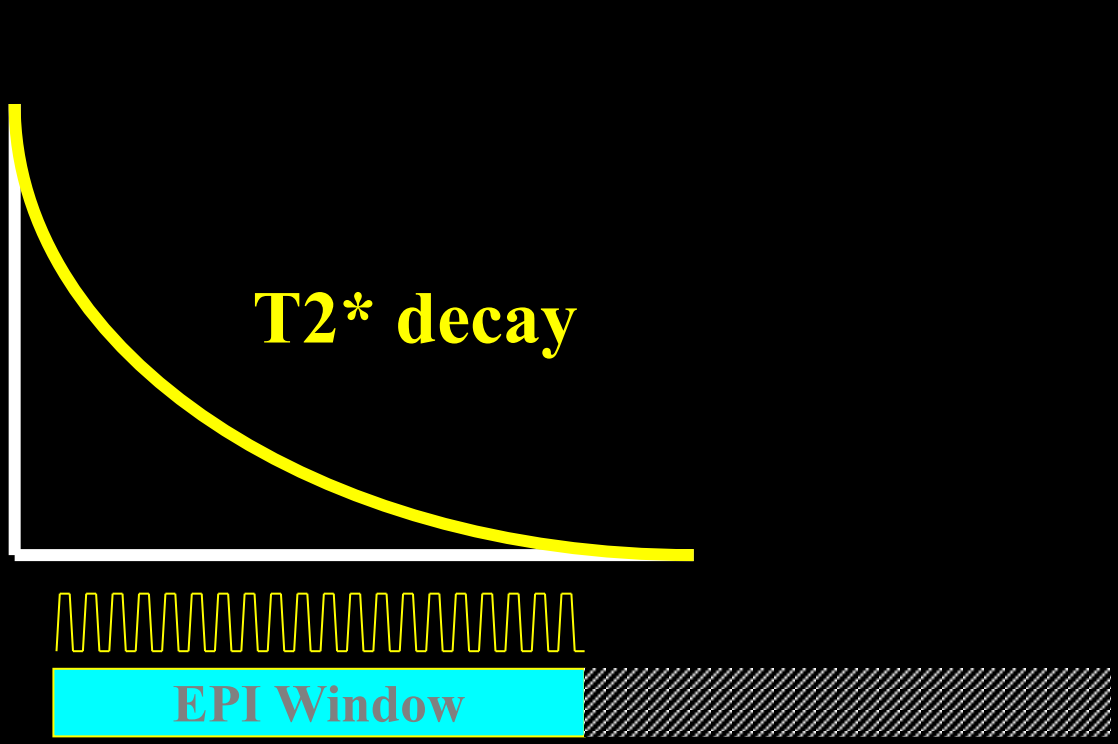


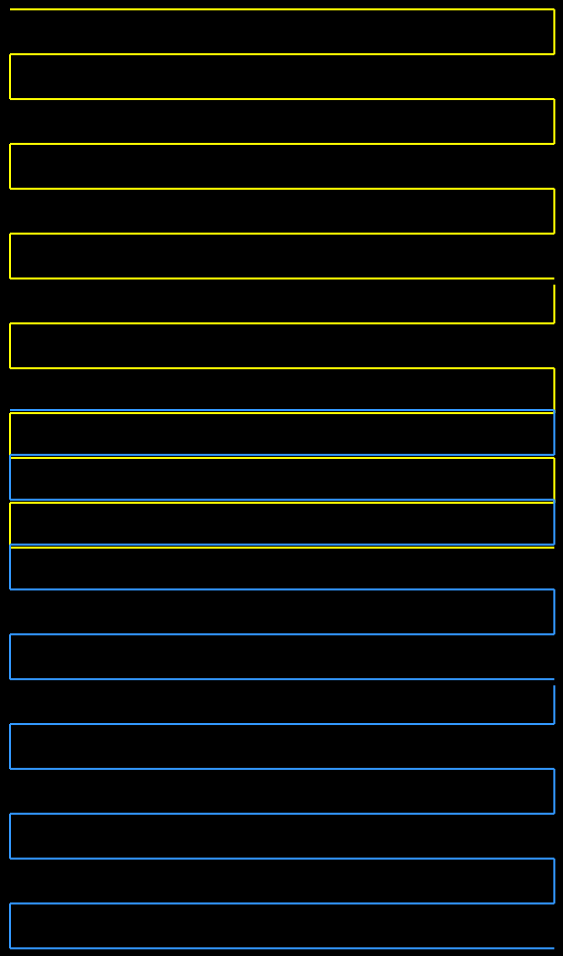
# Multi Shot EPI

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

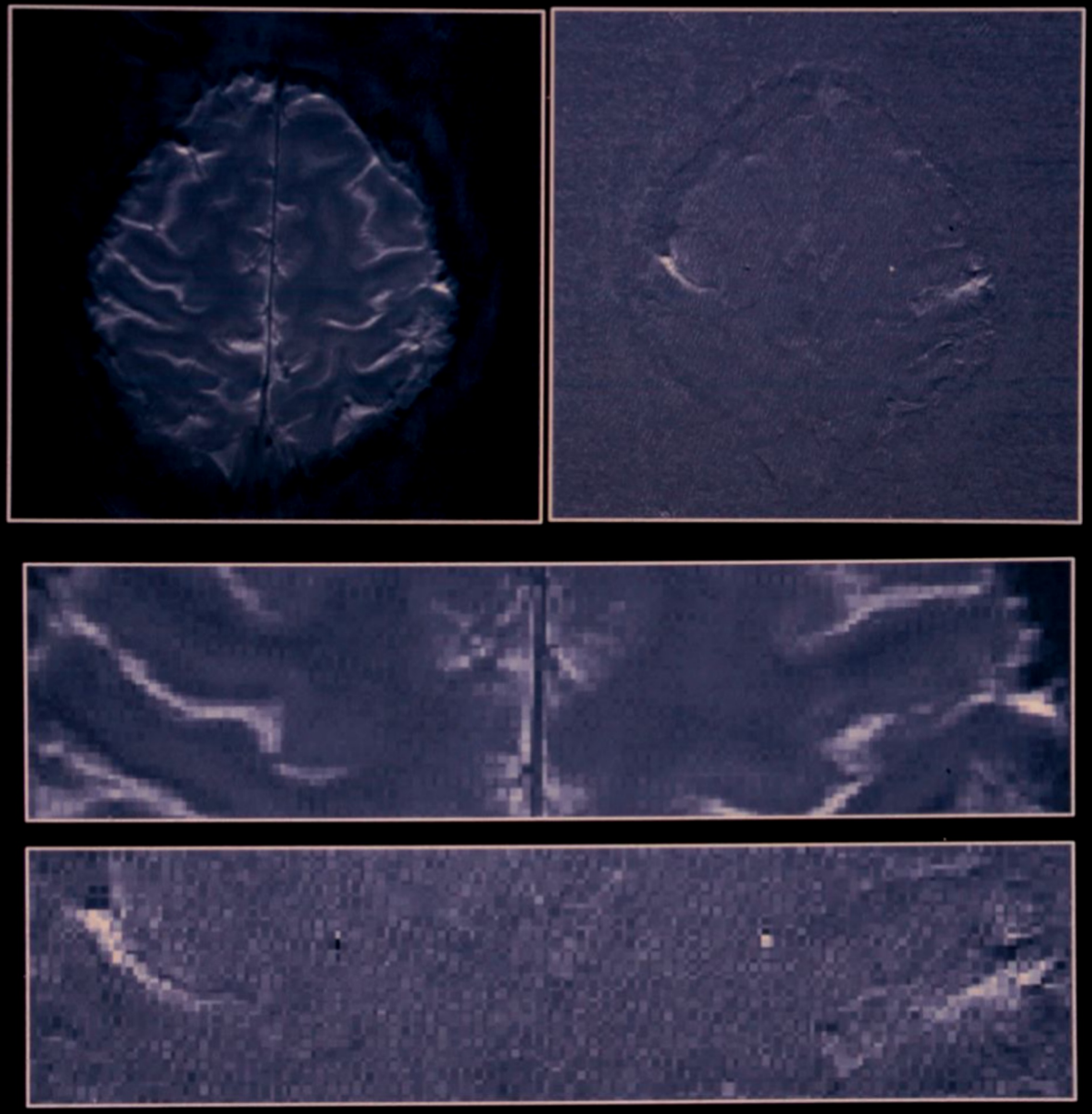


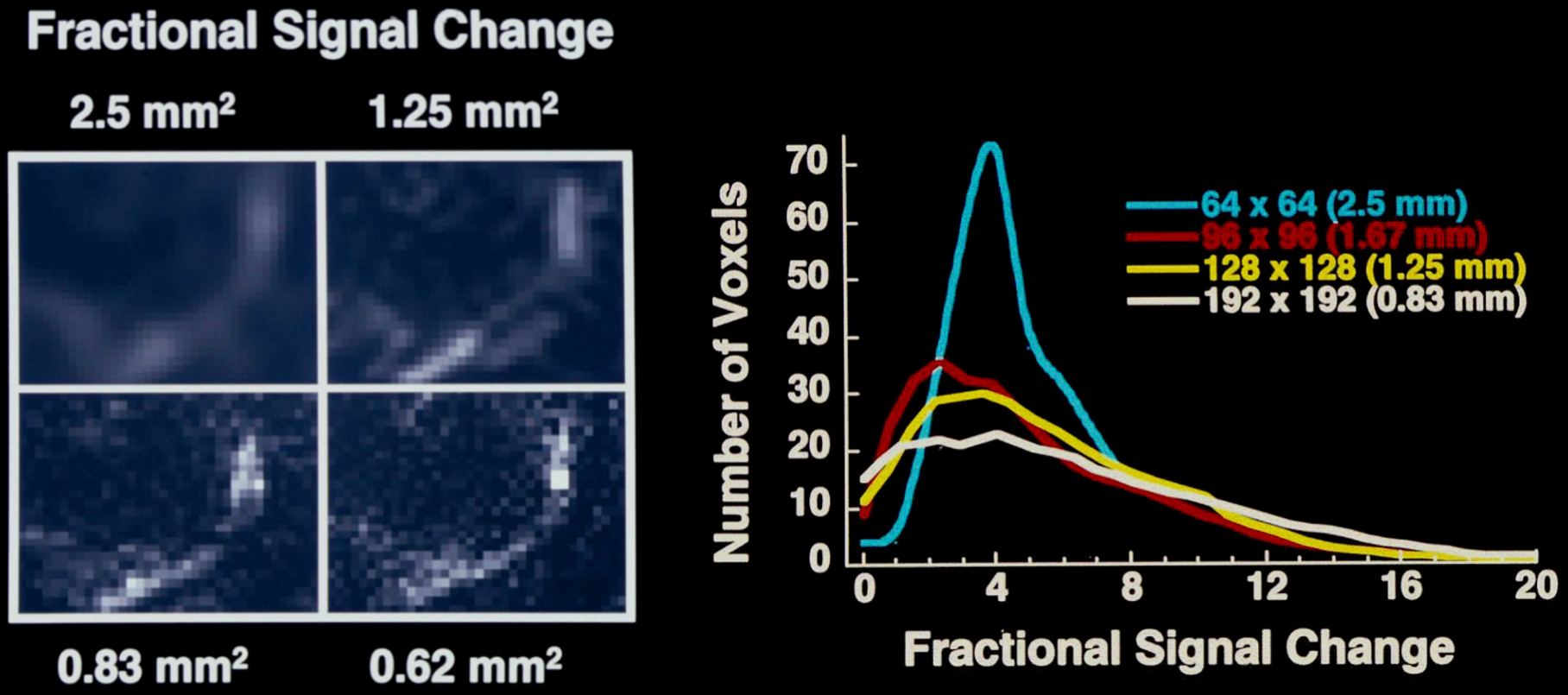
# Partial k-space imaging



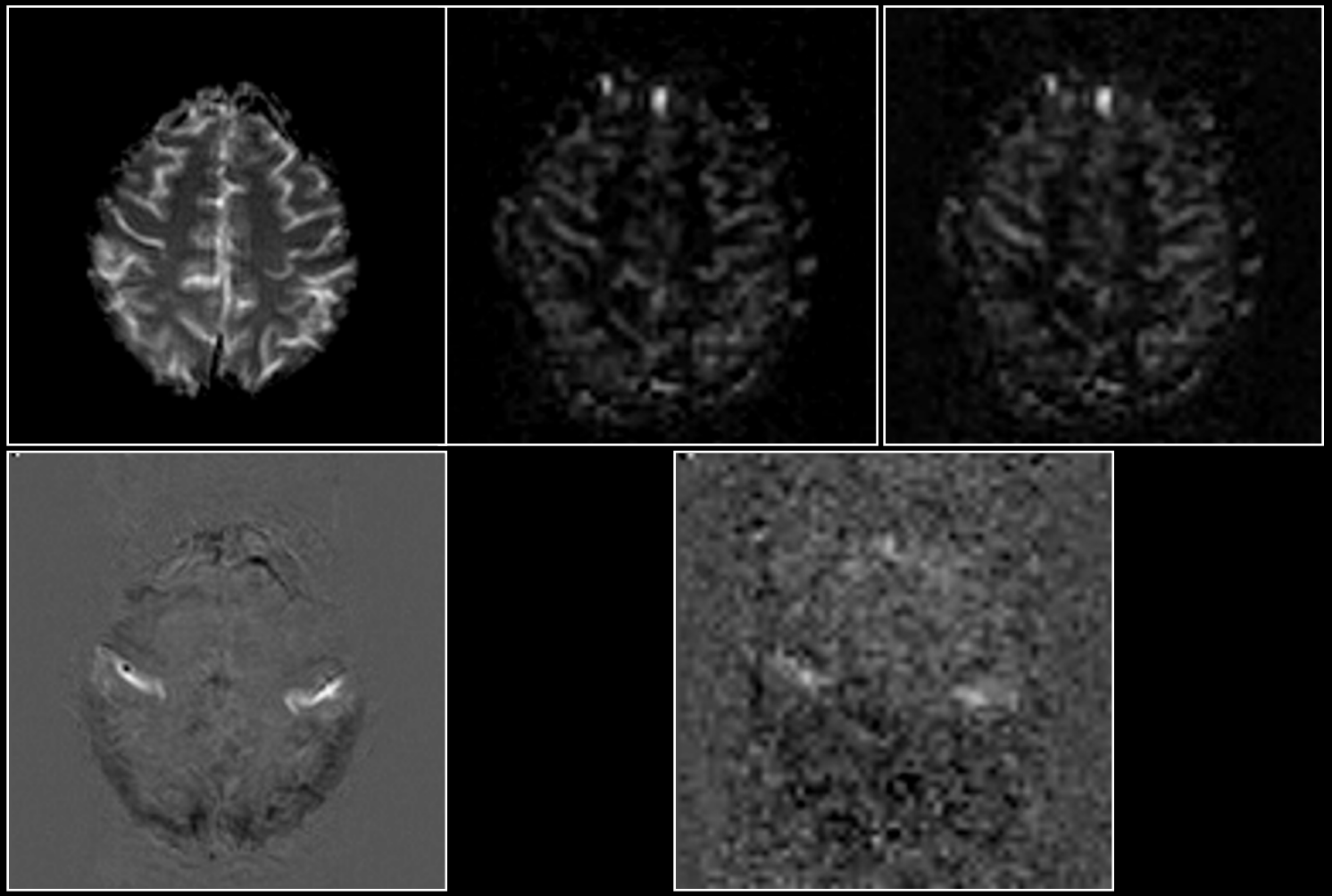
# Single - Shot EPI at 3T:
# Half NEX, 256 x 256, 16 cm FOV



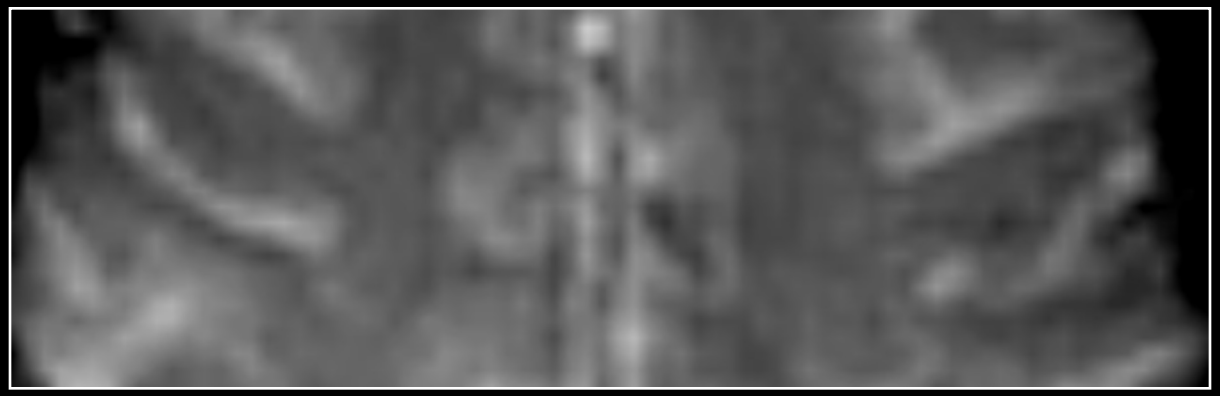

Fractional Signal Change
2.5 mm²
1.25 mm²
0.83 mm²
0.62 mm²
Number of Voxels
70
60
50
40
30
20
10
0
0
4
8
12
16
20
Fractional Signal Change
64 x 64 (2.5 mm)
96 x 96 (1.67 mm)
128 x 128 (1.25 mm)
192 x 192 (0.83 mm)

**Perfusion**

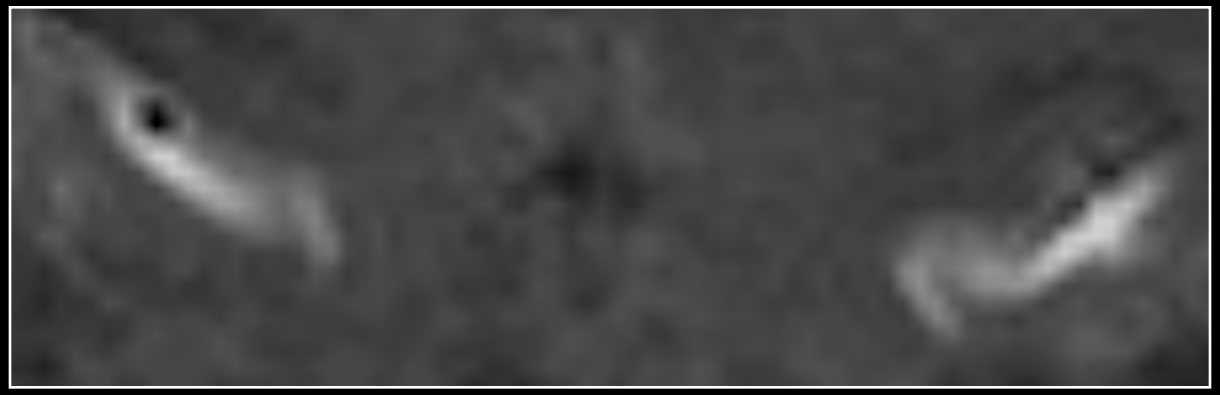
**BOLD** *Rest* *Activation*



Anatomy

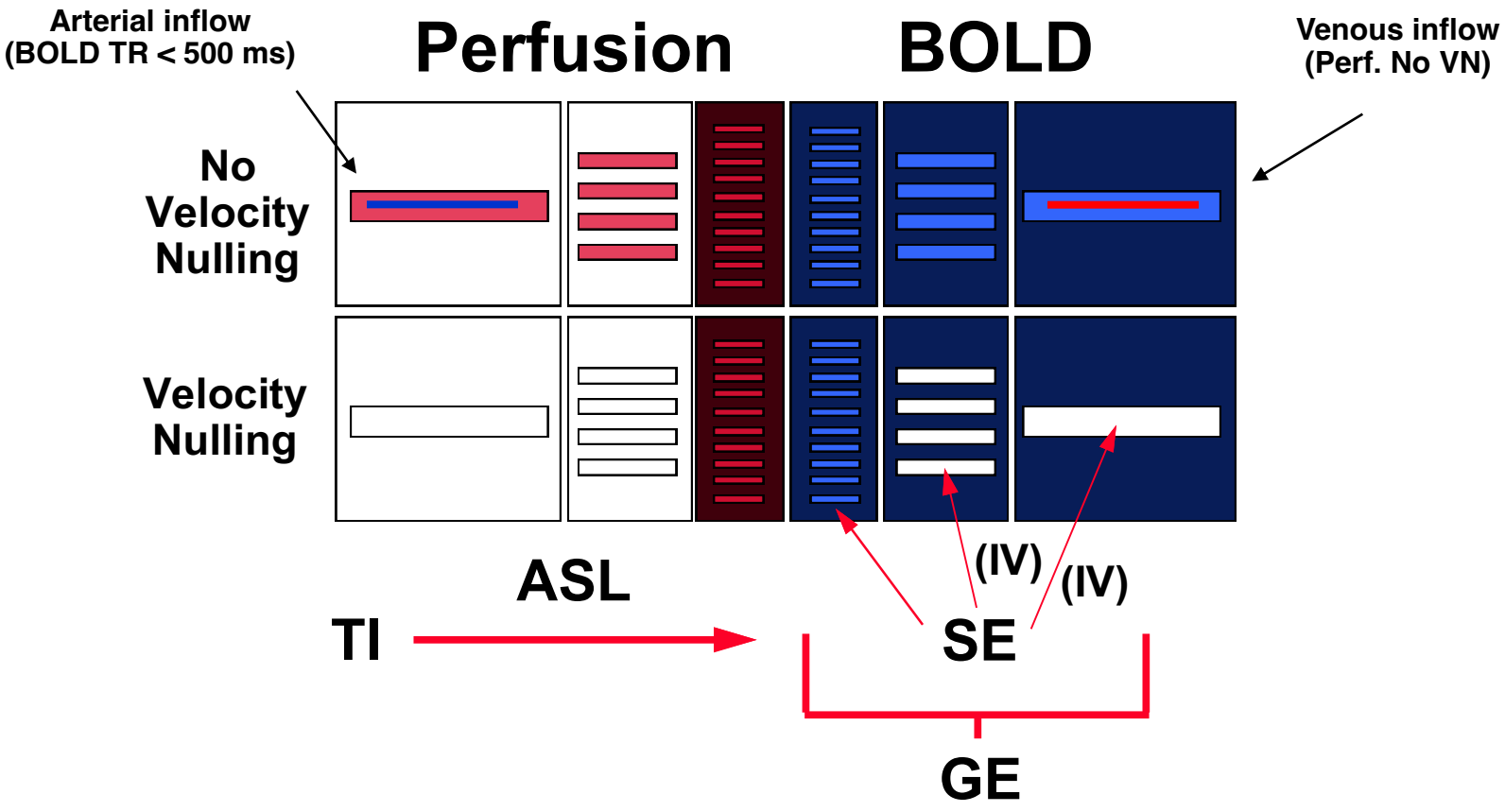


BOLD



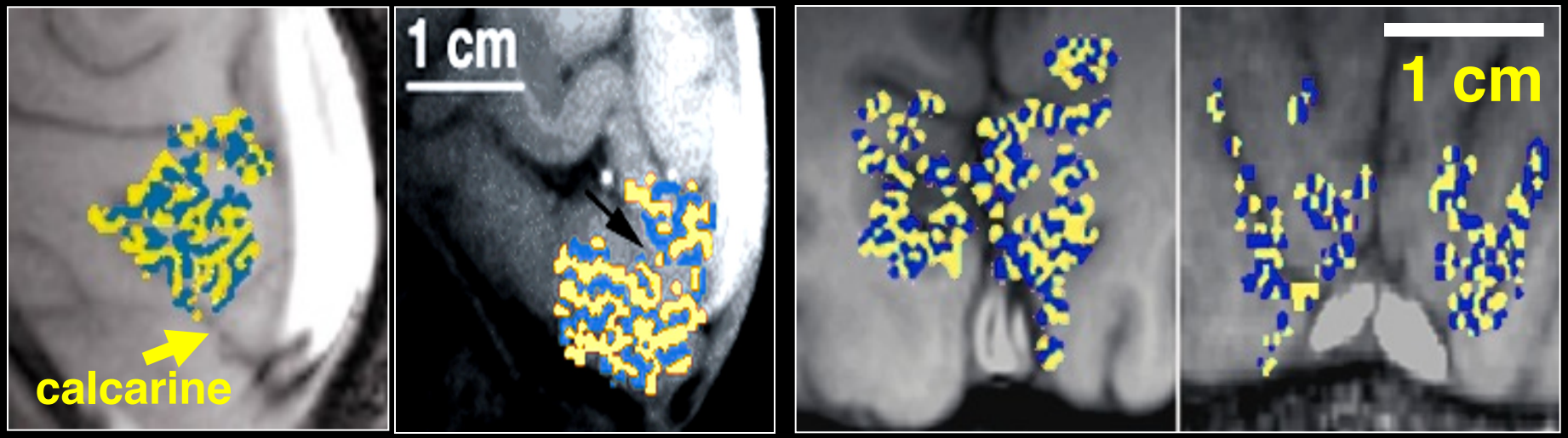
Perfusion

# Hemodynamic Specificity



Menon, et al

# 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).

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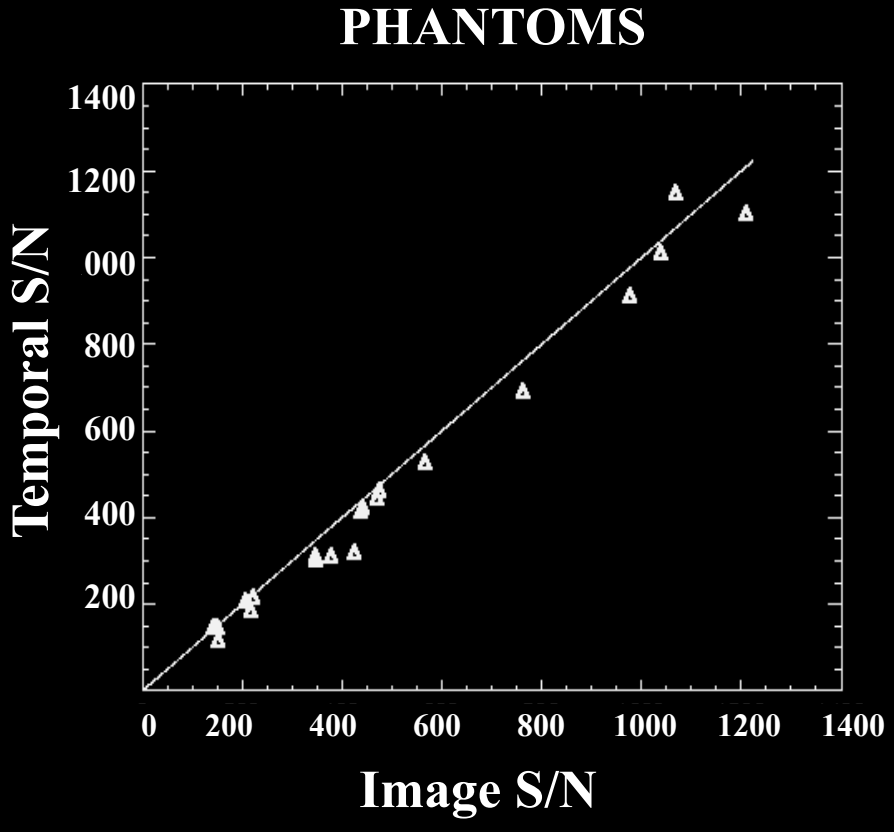
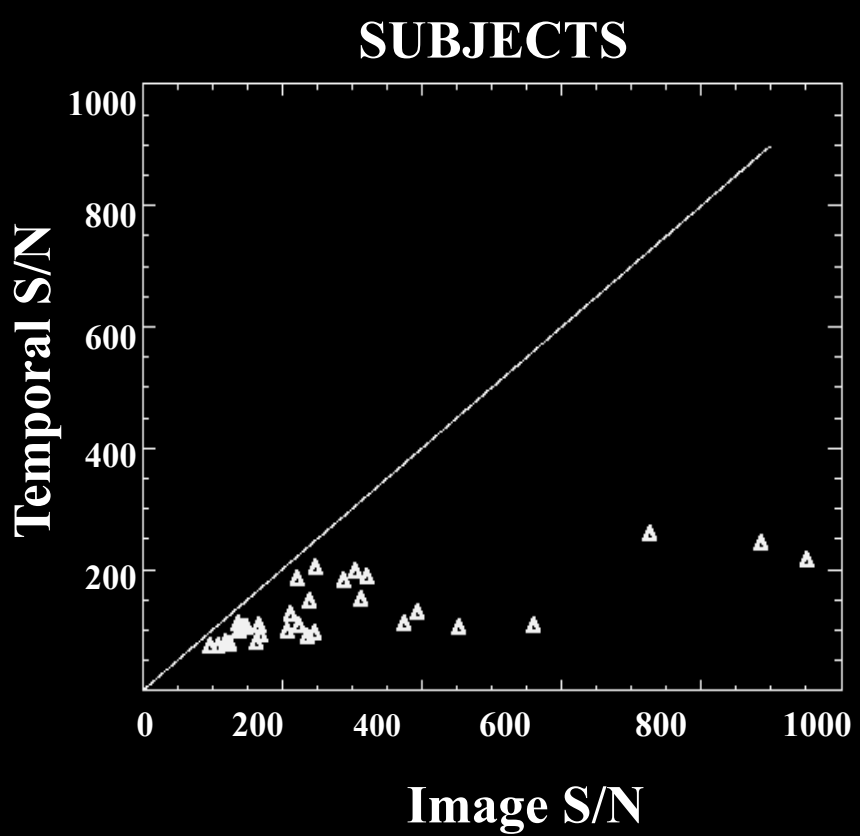
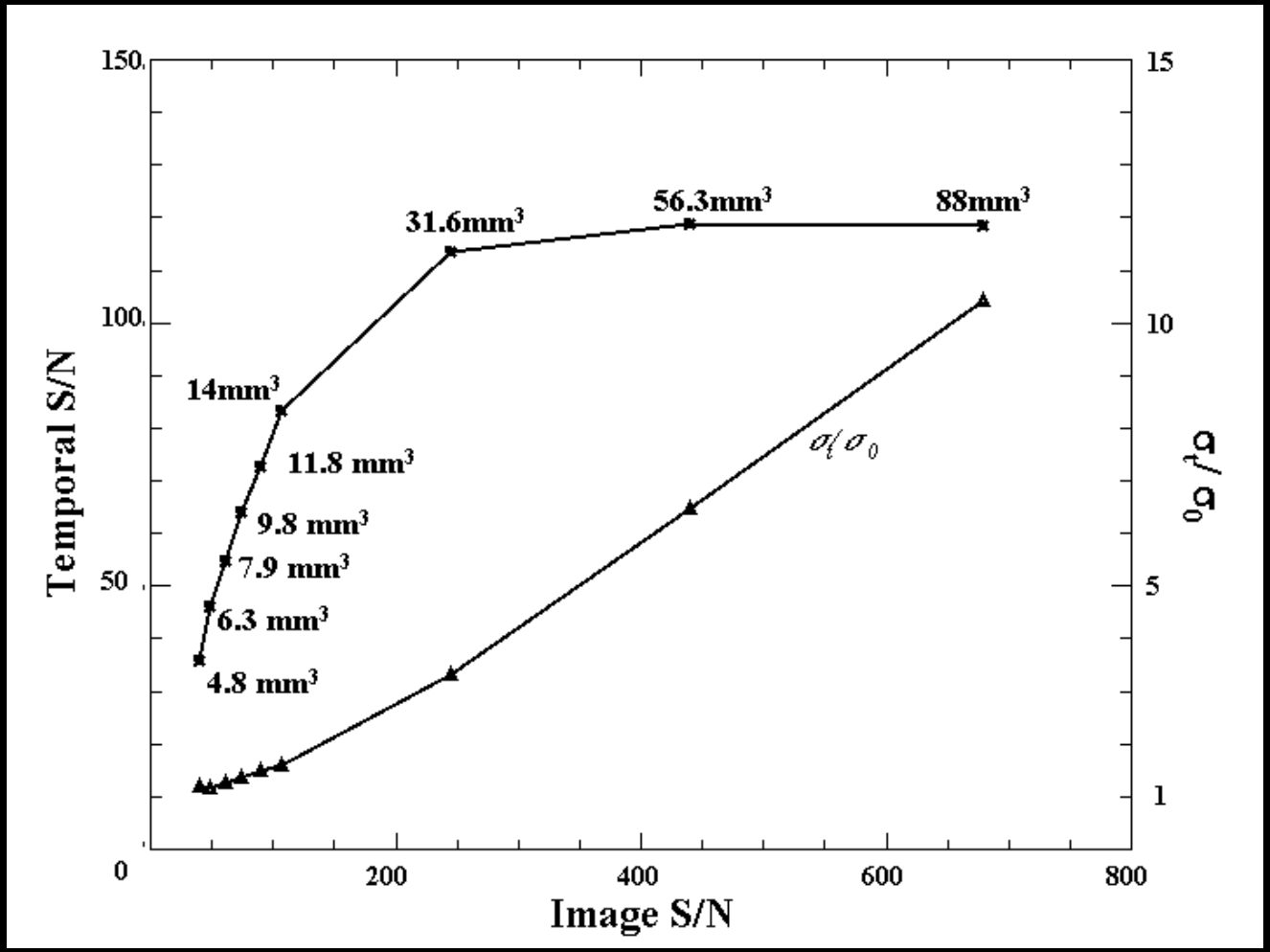
# Temporal S/N vs. Image S/N




N. Petridou

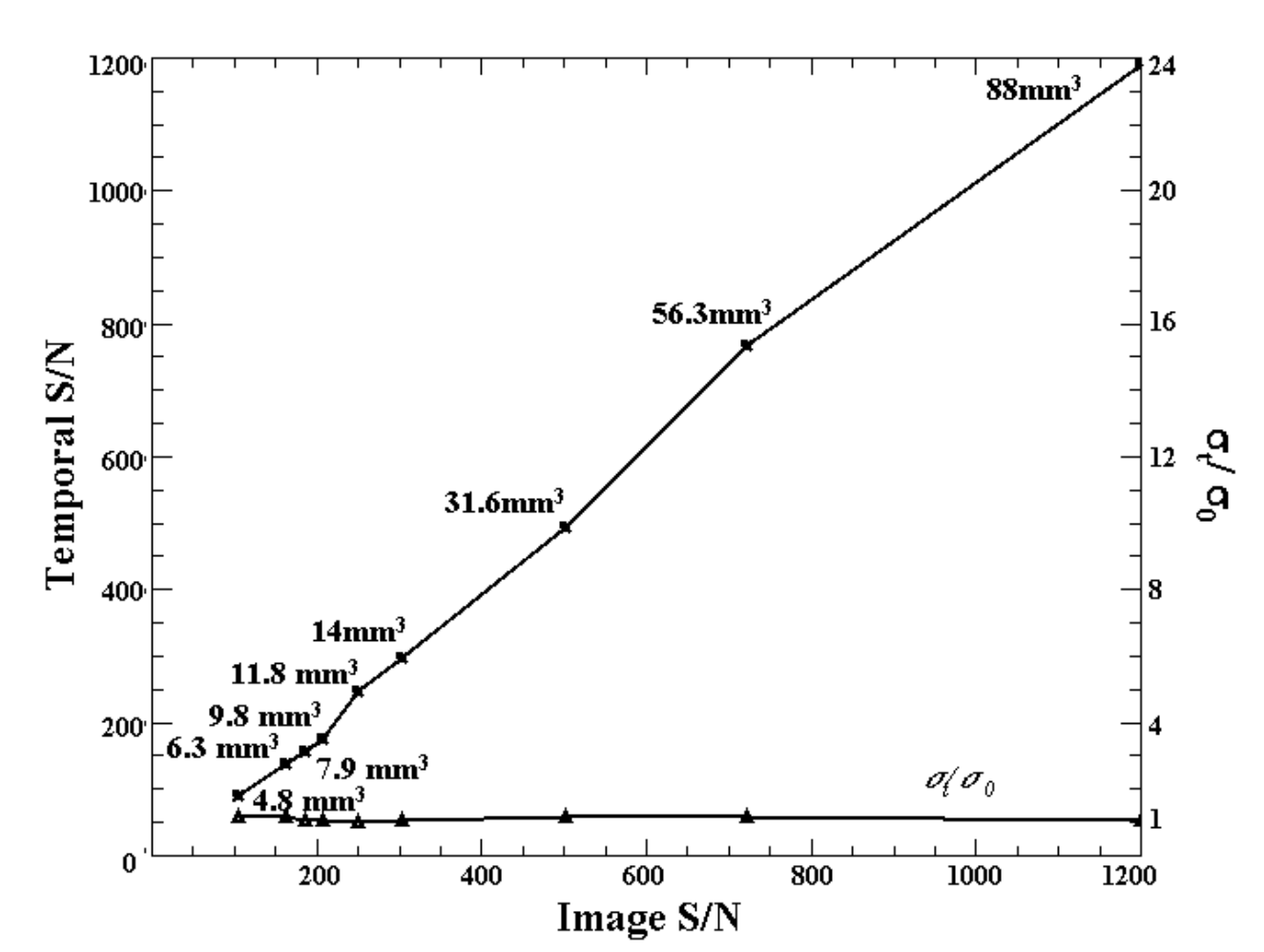
# Temporal vs. Image S/N
# Optimal Resolution Study




## Human data

Petridou et al

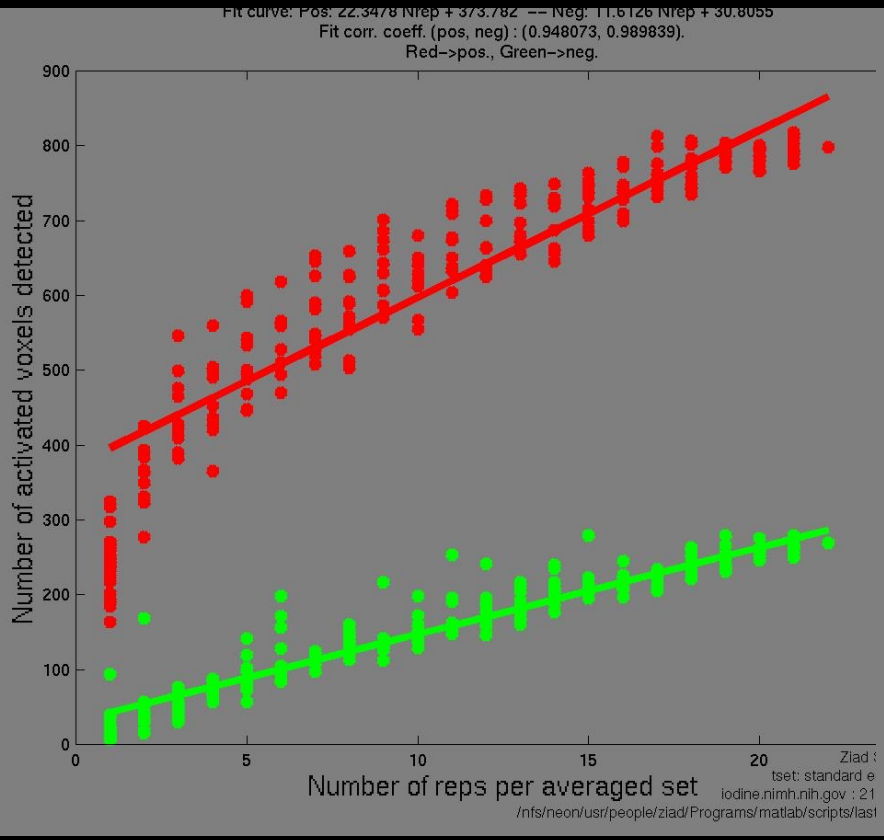
# Temporal vs. Image S/N
# Optimal Resolution Study




## Phantom data

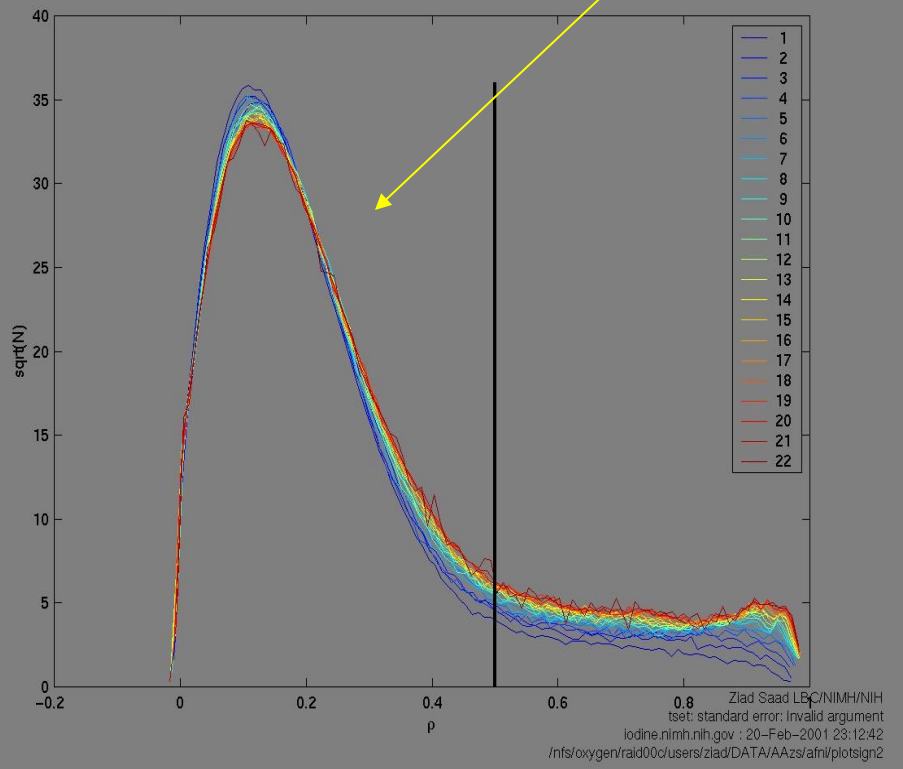
Petridou et al

# Continuously Growing Activation Area




# CC Histogram

Inflection Point




Ziad Saad, et al

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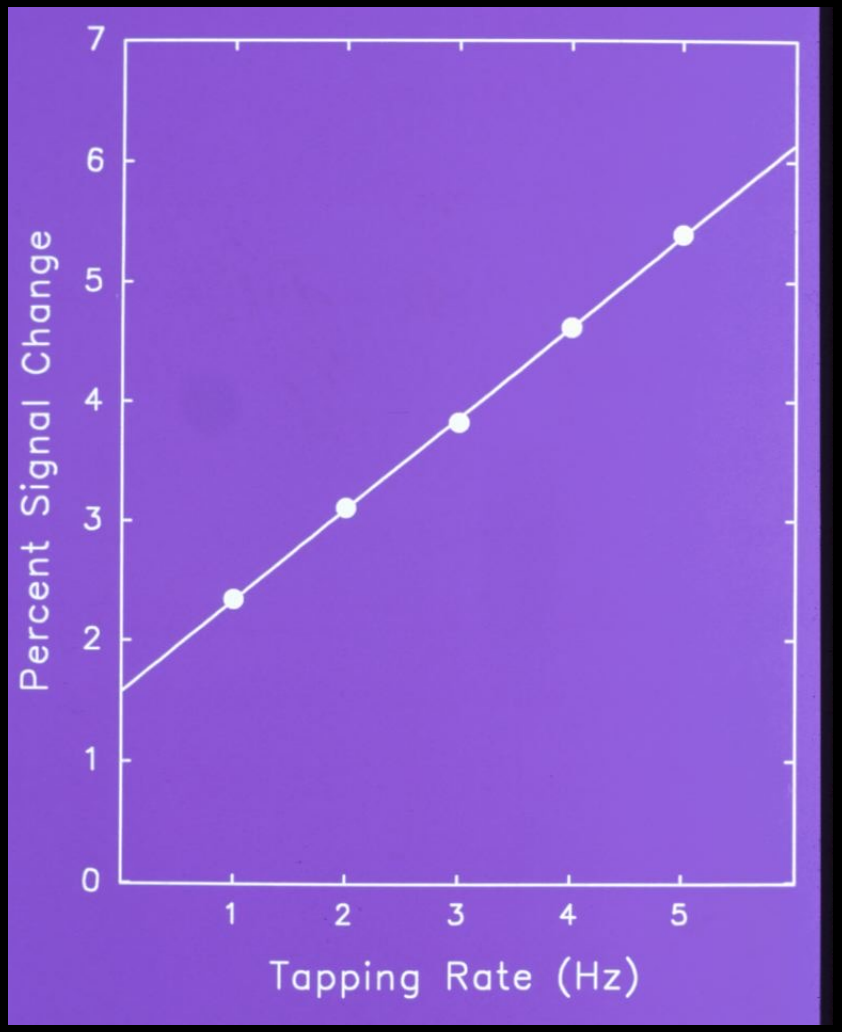
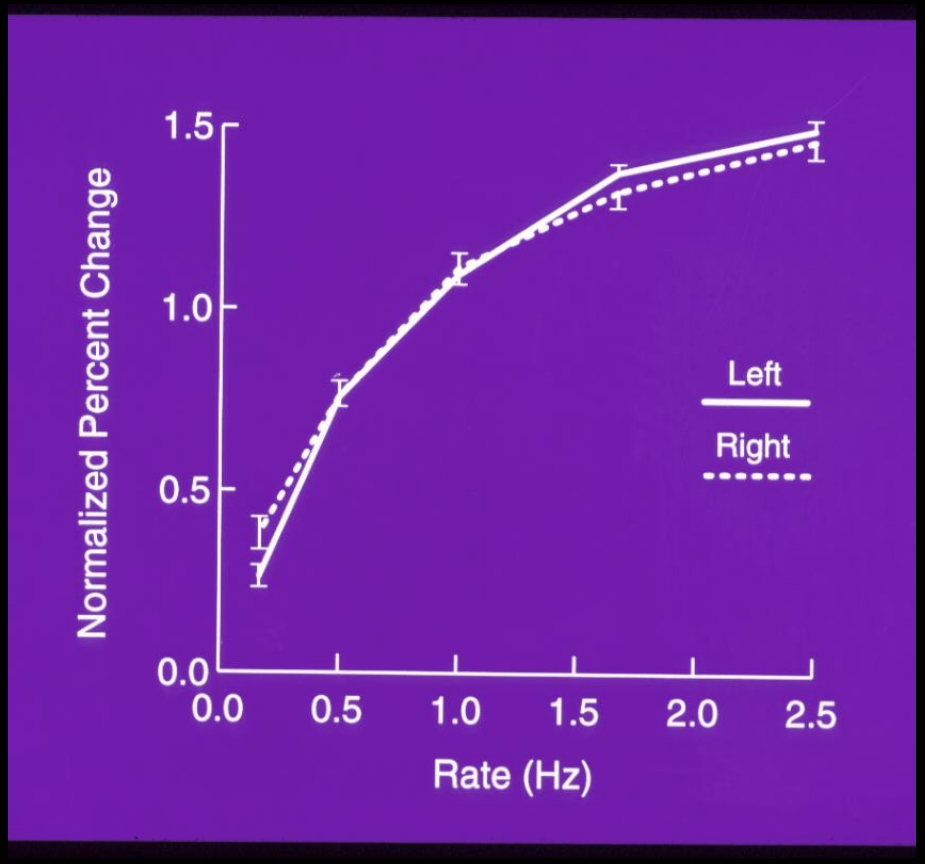
# Motor Cortex

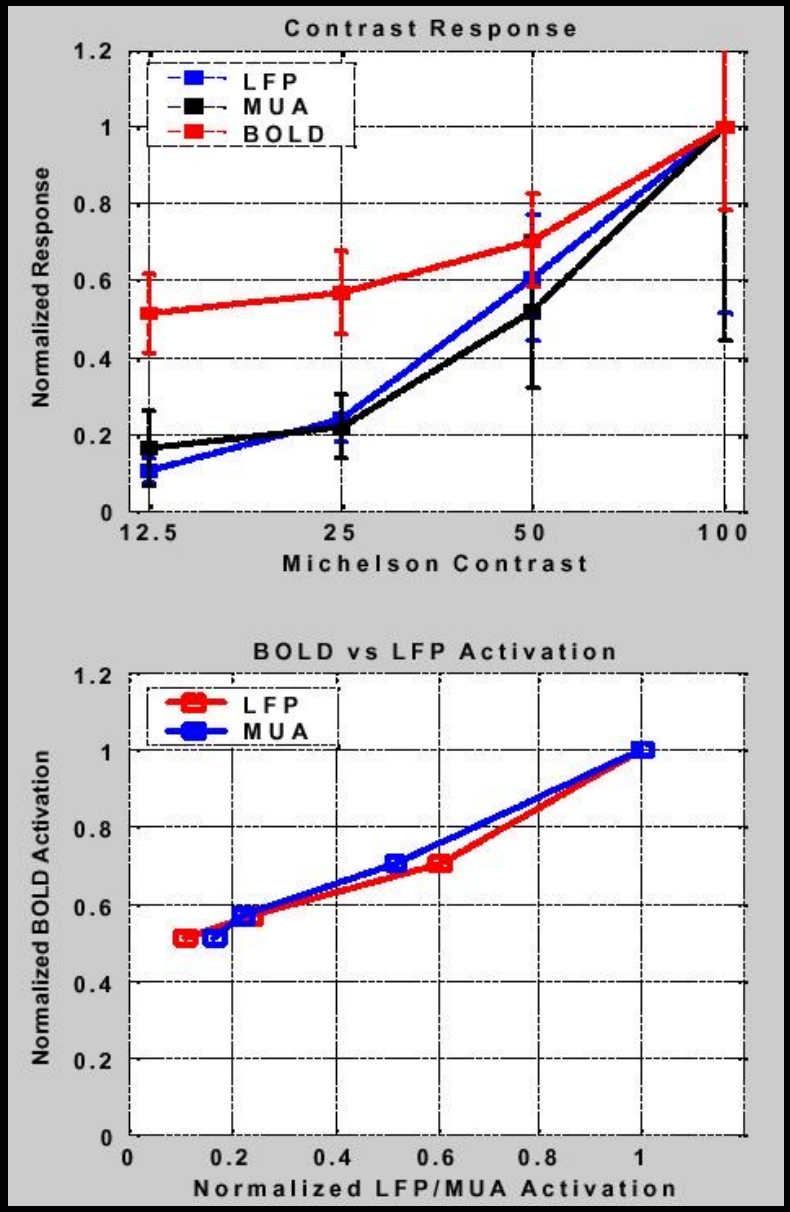



Rao, S. M. et al. *J. Cereb. Blood Flow and Metab.* **16**, 1250-1254 (1996).

# Auditory Cortex

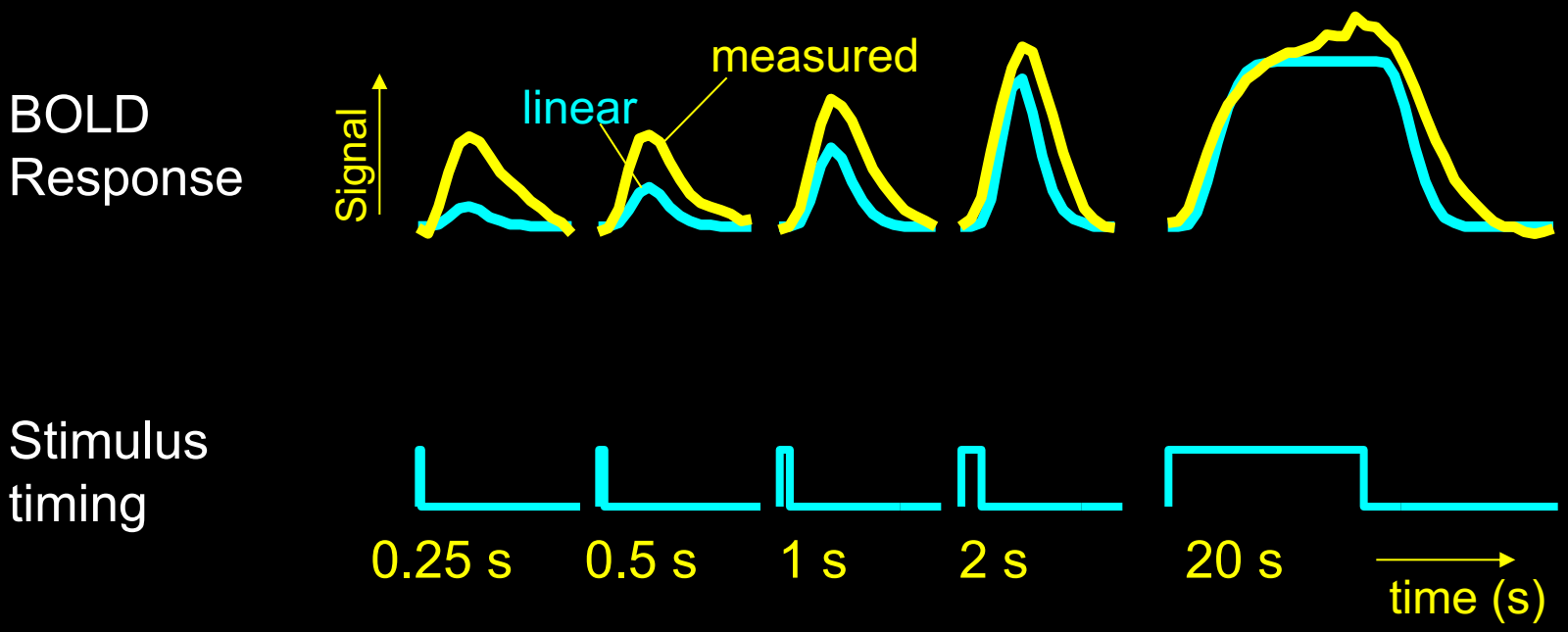



Binder, J. R. et al. *Cognitive Brain Research* **2**, 31-38 (1994).



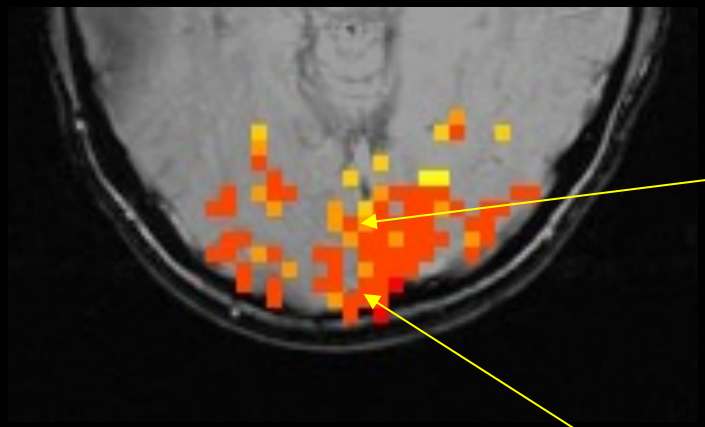

Logothetis et al. Nature, 412, 150-157

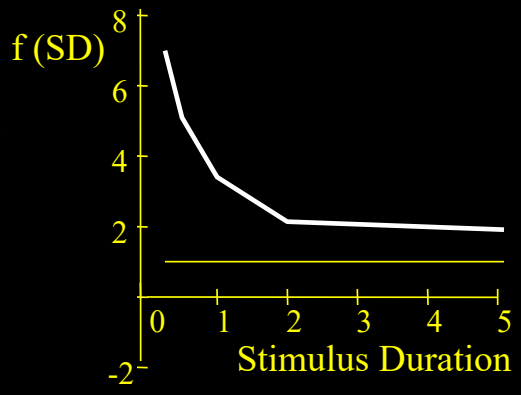
# Different stimulus “ON” periods

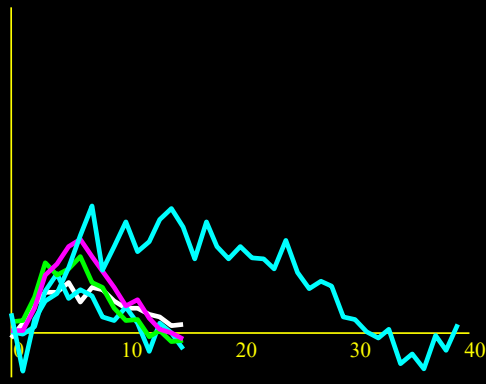


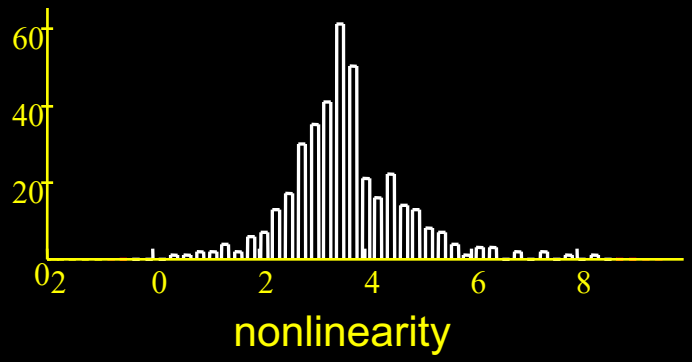

*Brief stimuli produce larger responses than expected*

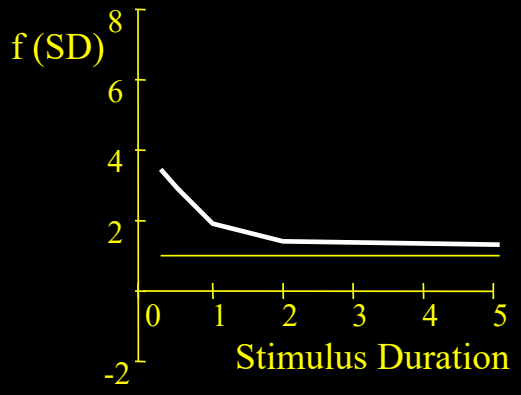
# Results – visual task

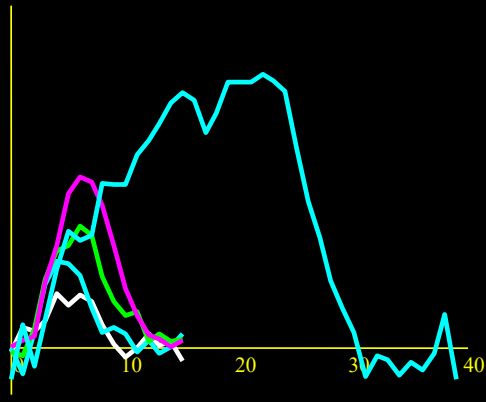




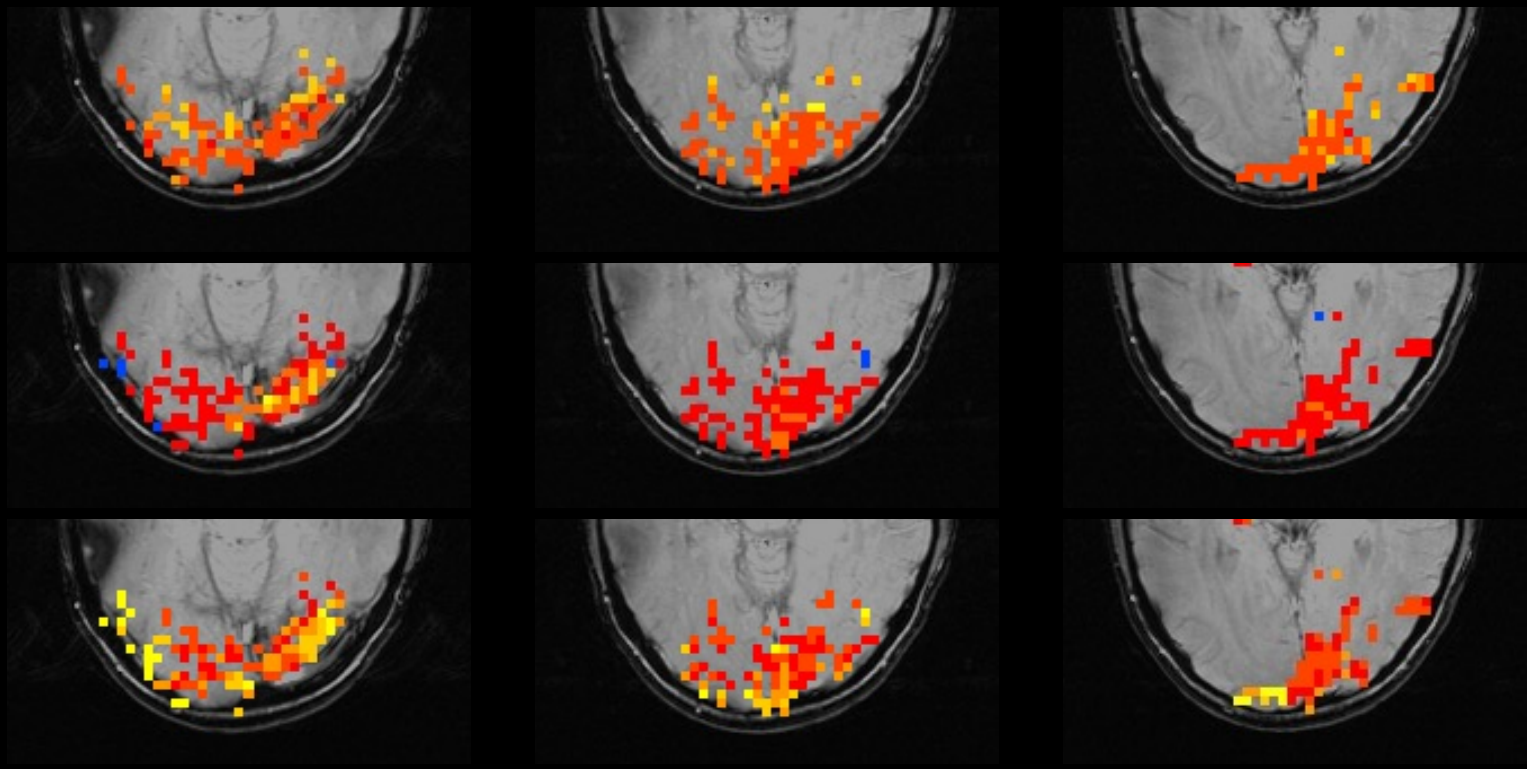



# Results – visual task

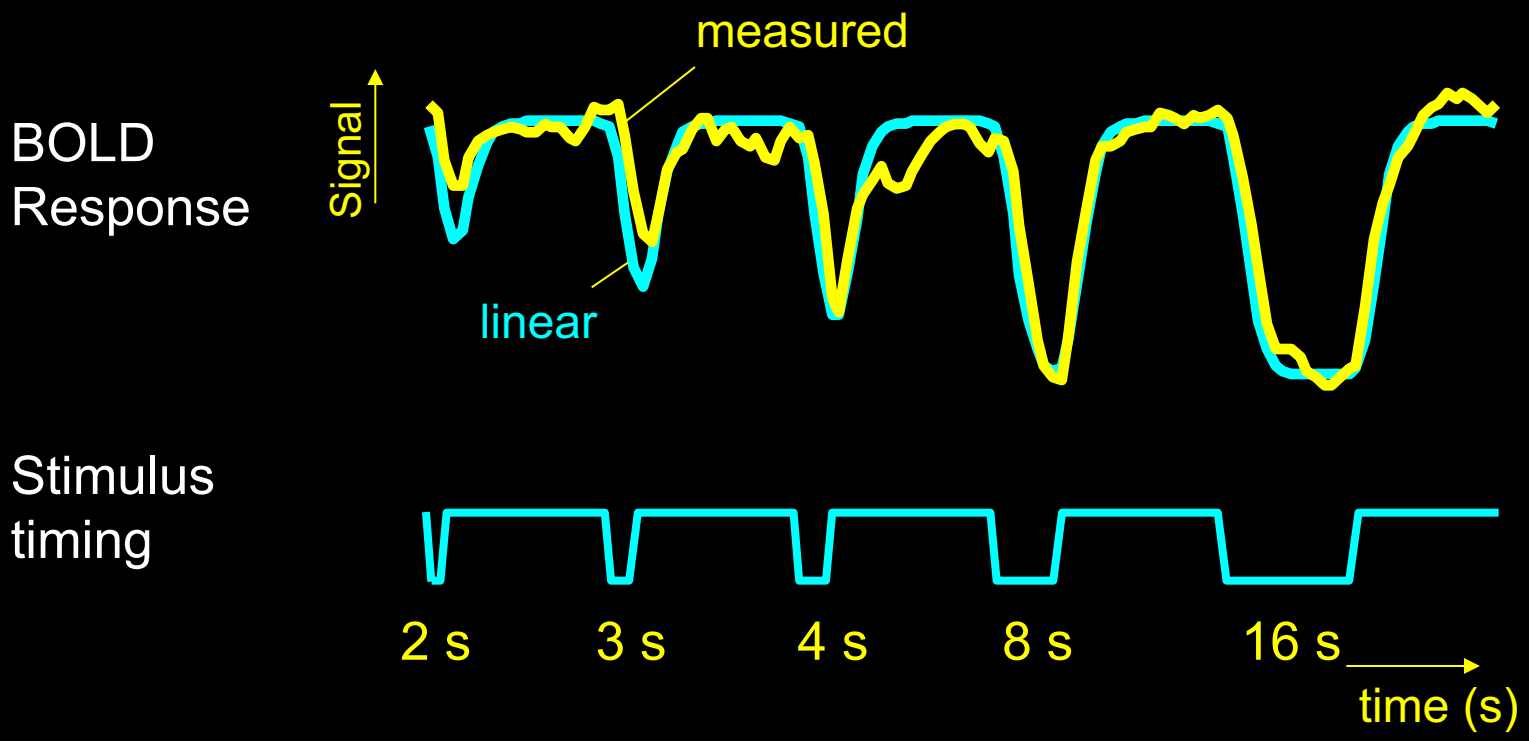
Nonlinearity

Magnitude

Latency



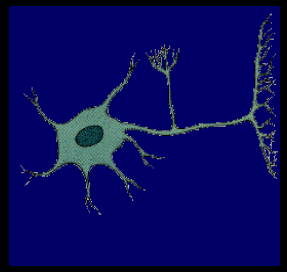
# Different stimulus “OFF” periods

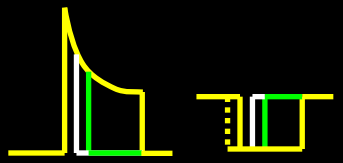



*Brief stimulus OFF periods produce smaller decreases than expected*

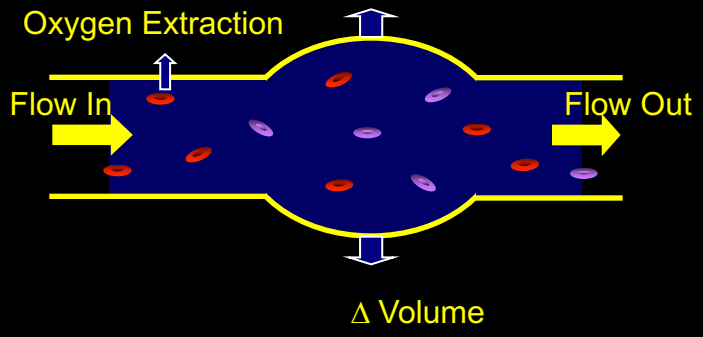
# Sources of this Nonlinearity

- Neuronal

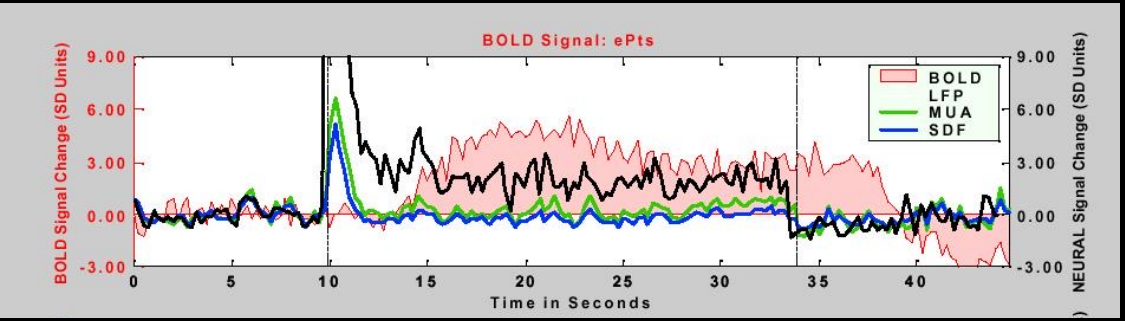




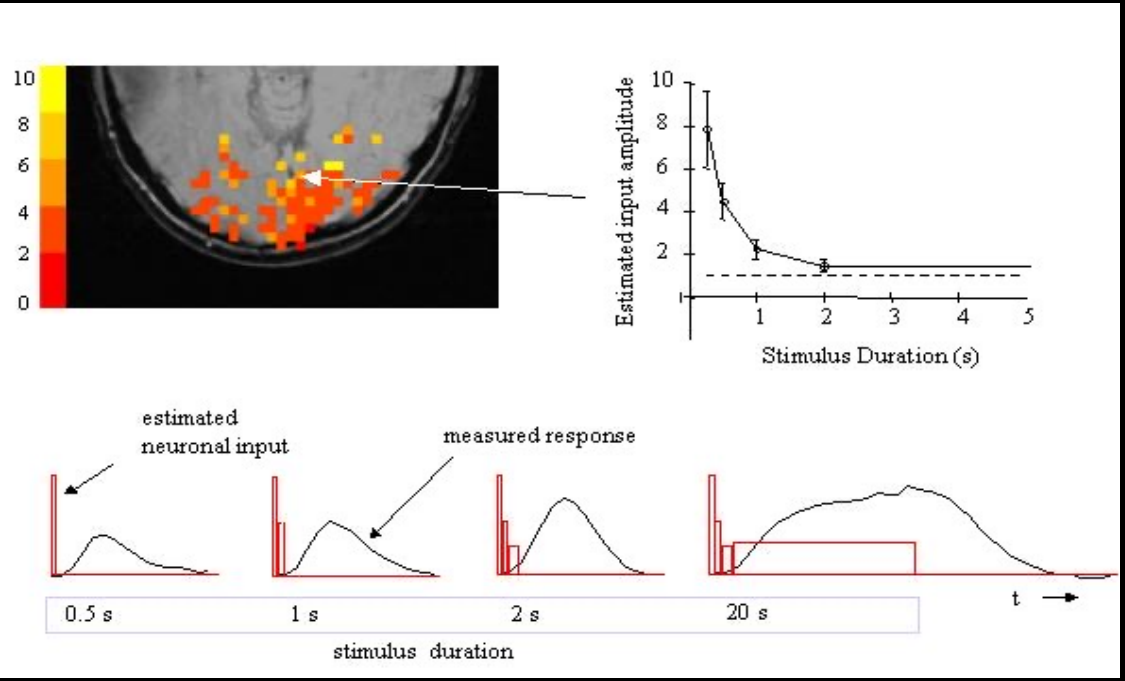
- Hemodynamic
  - Oxygen extraction
  - Blood volume dynamics



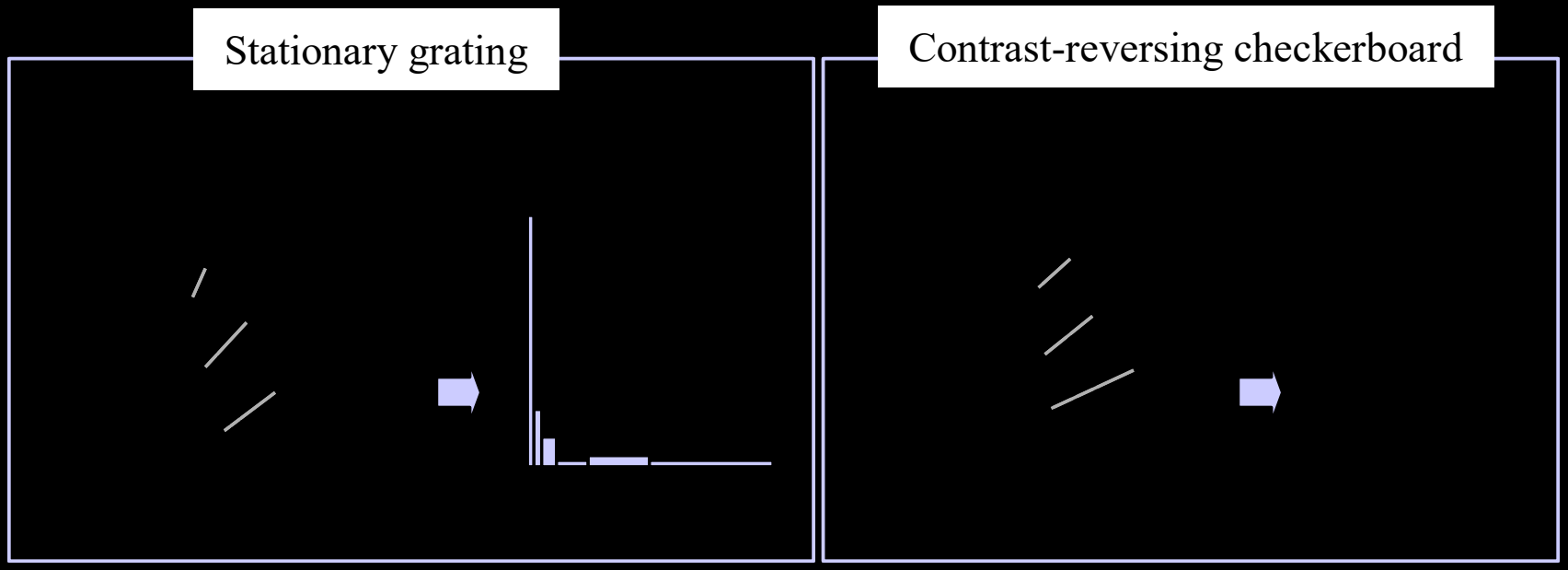
# BOLD Correlation with Neuronal Activity



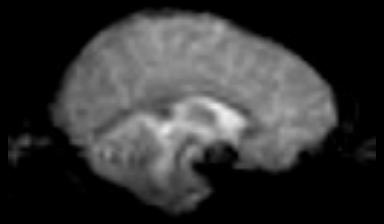

Logothetis et al. Nature, 412, 150-157

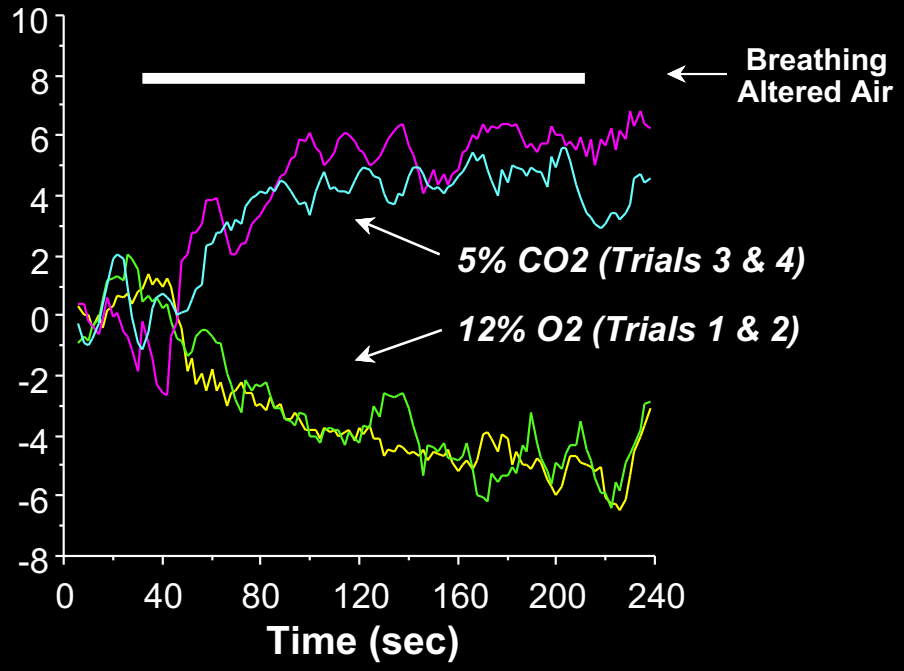



Bandettini and Ungerleider, Nature Neuroscience, 4, 864-866

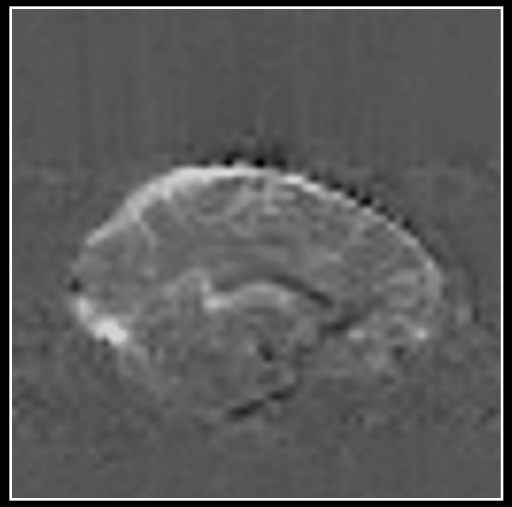

Stationary grating
Contrast-reversing checkerboard

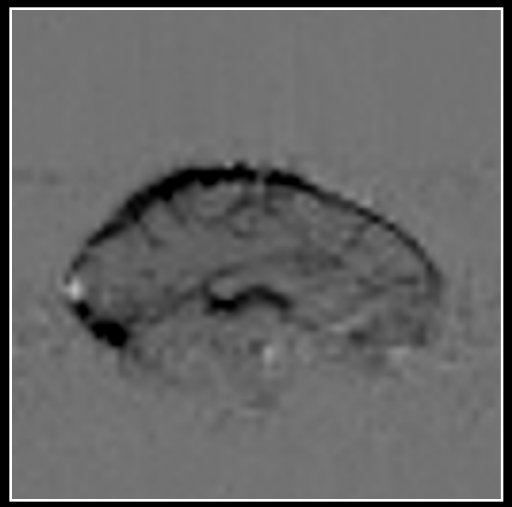
# Hemdodynamic Stress Calibration






5% CO2

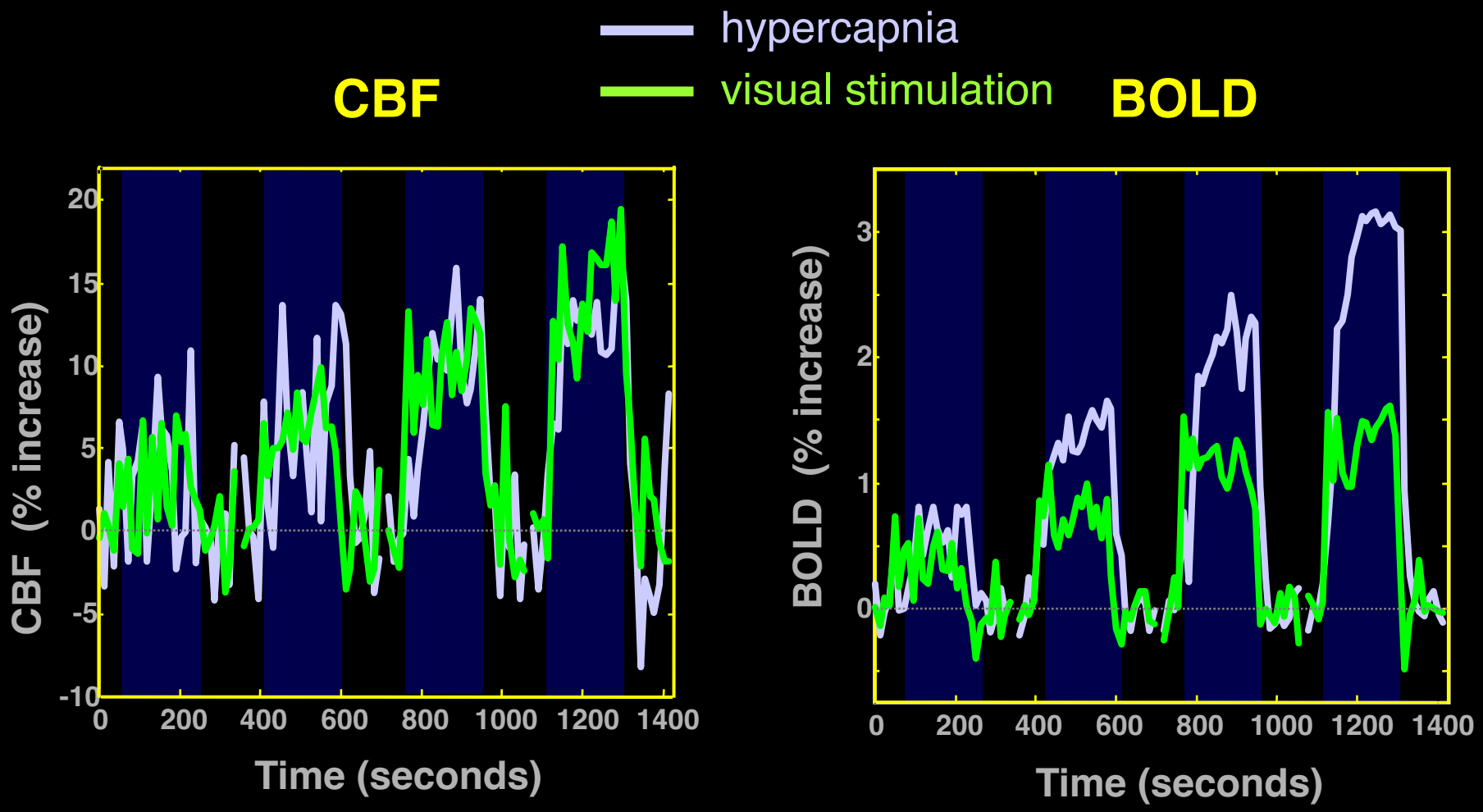




12% O2

# $CMRO_2$-related BOLD signal deficit:

*Hoge, et al.*

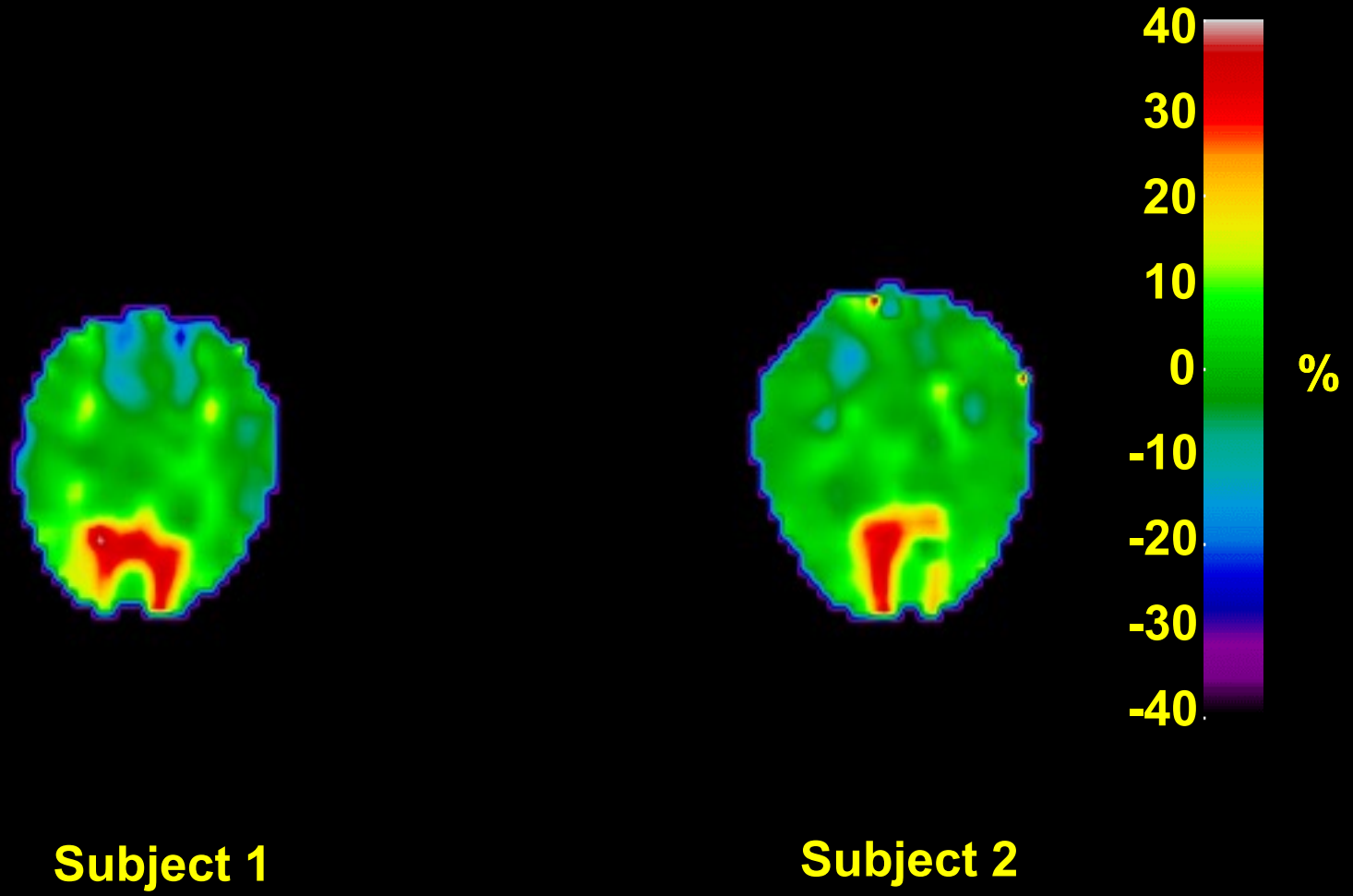



Simultaneous Perfusion and BOLD imaging during graded visual activation and hypercapnia

N=12

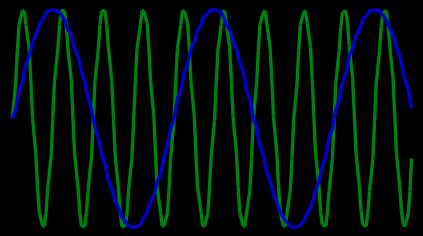
*Hoge, et al.*

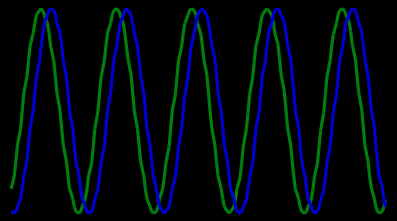
# Computed $CMRO_2$ changes

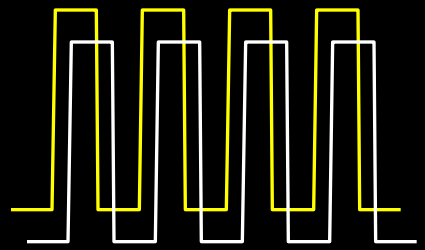


# Neuronal Activation Input Strategies

1. Block Design
2. Frequency Encoding
3. Phase Encoding
4. Single Event
5. Orthogonal Block Design
6. Free Behavior Design.





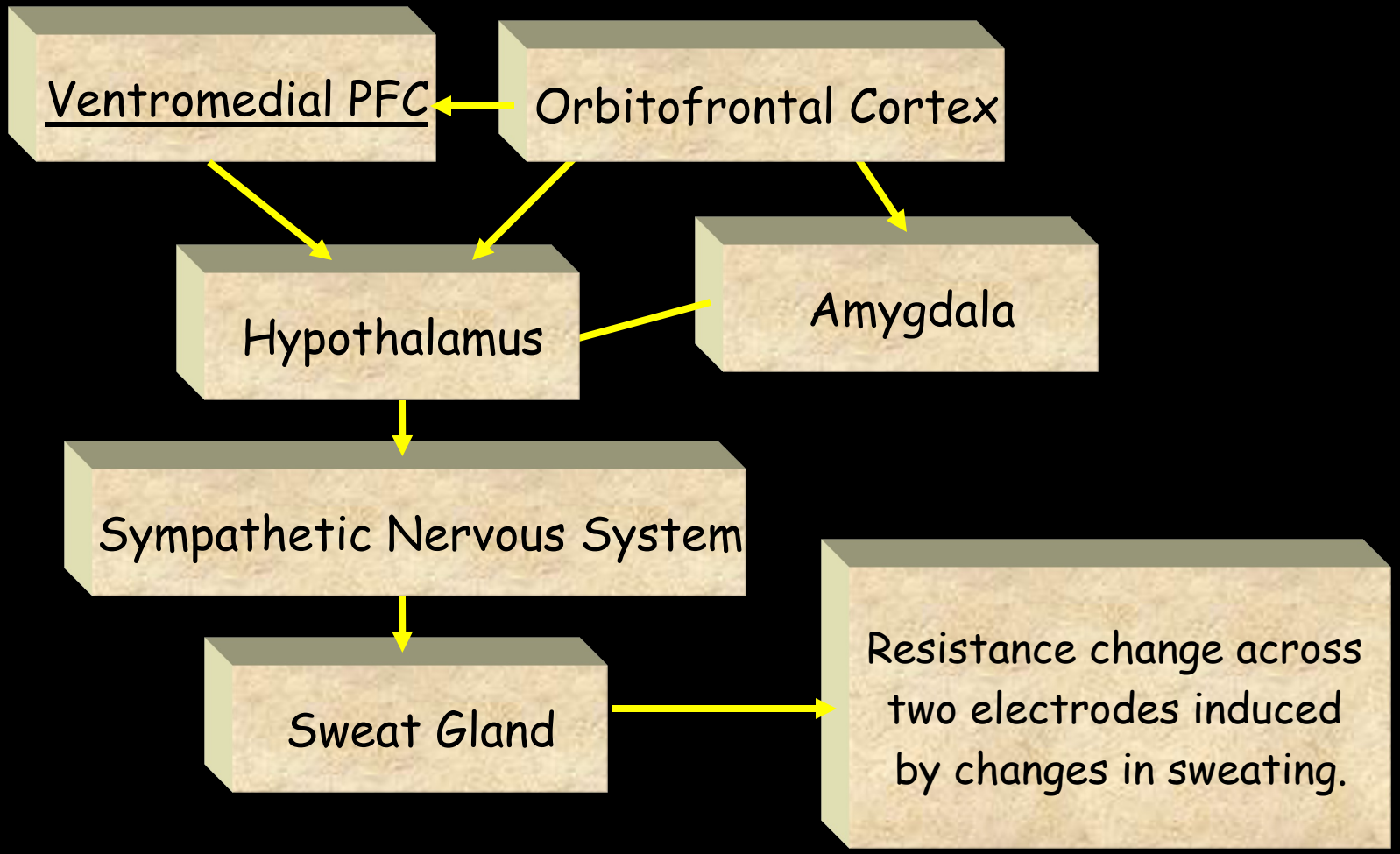


# Free Behavior Design

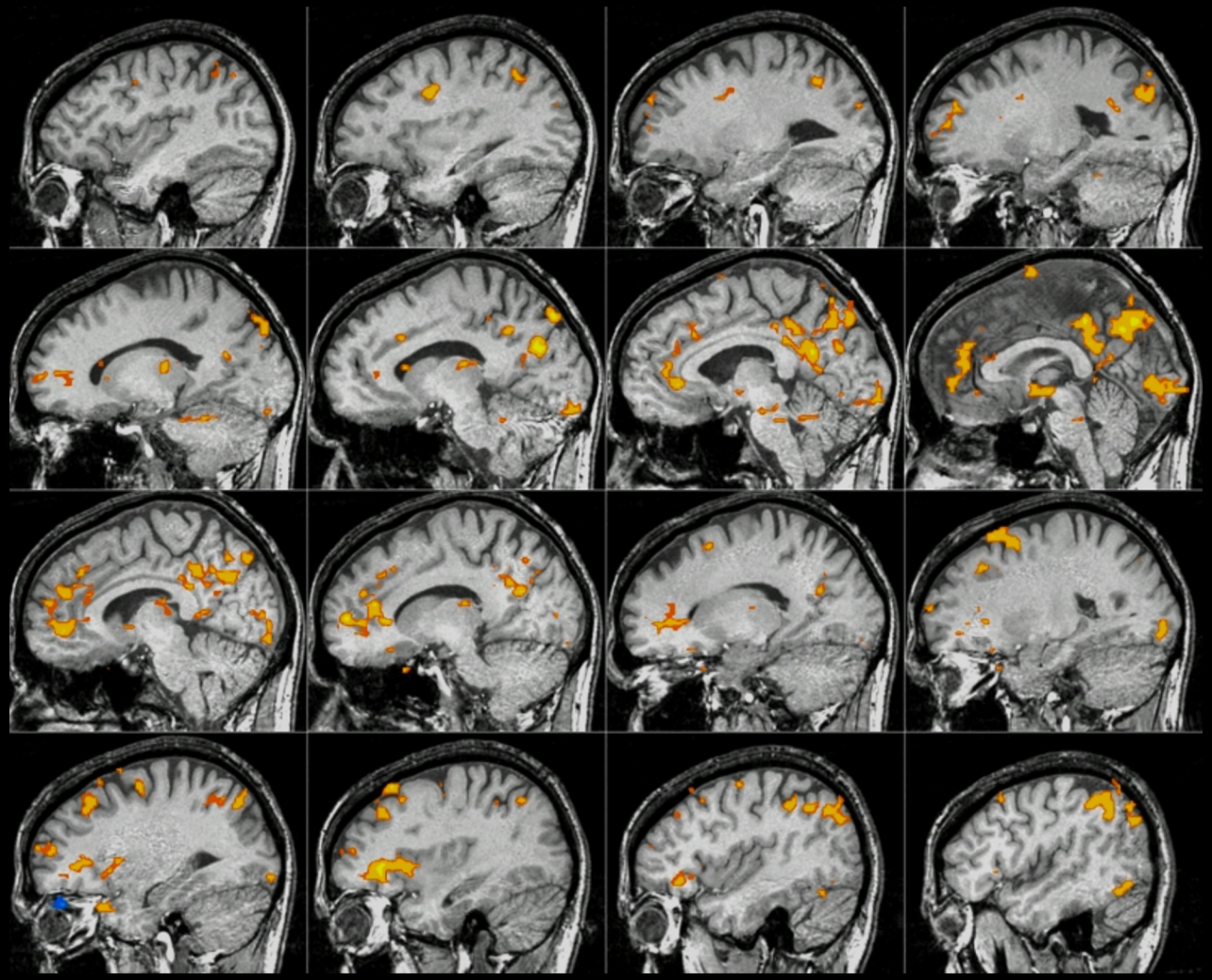
Use a continuous measure as a reference function:

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

# The Skin Conductance Response (SCR)

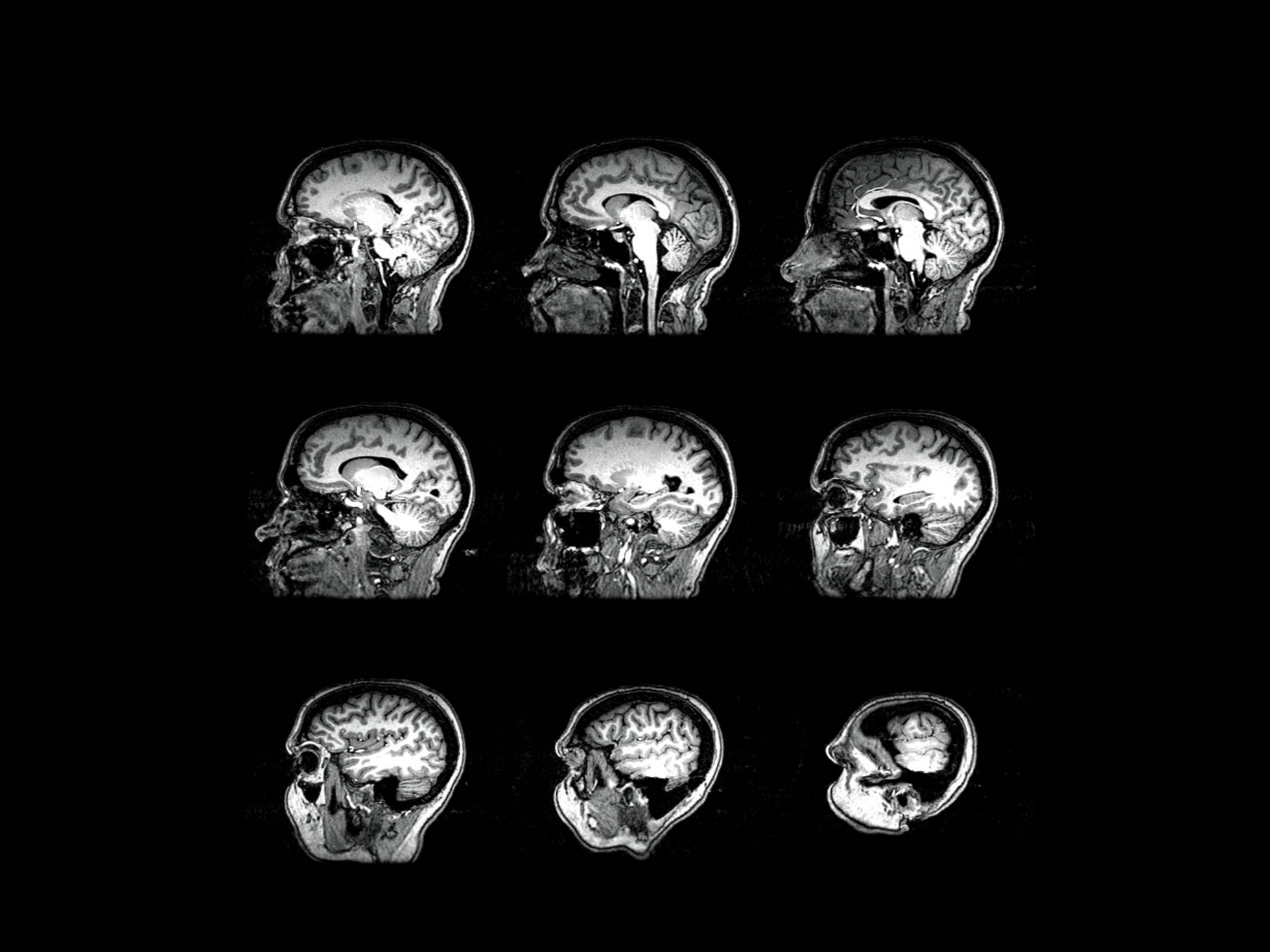


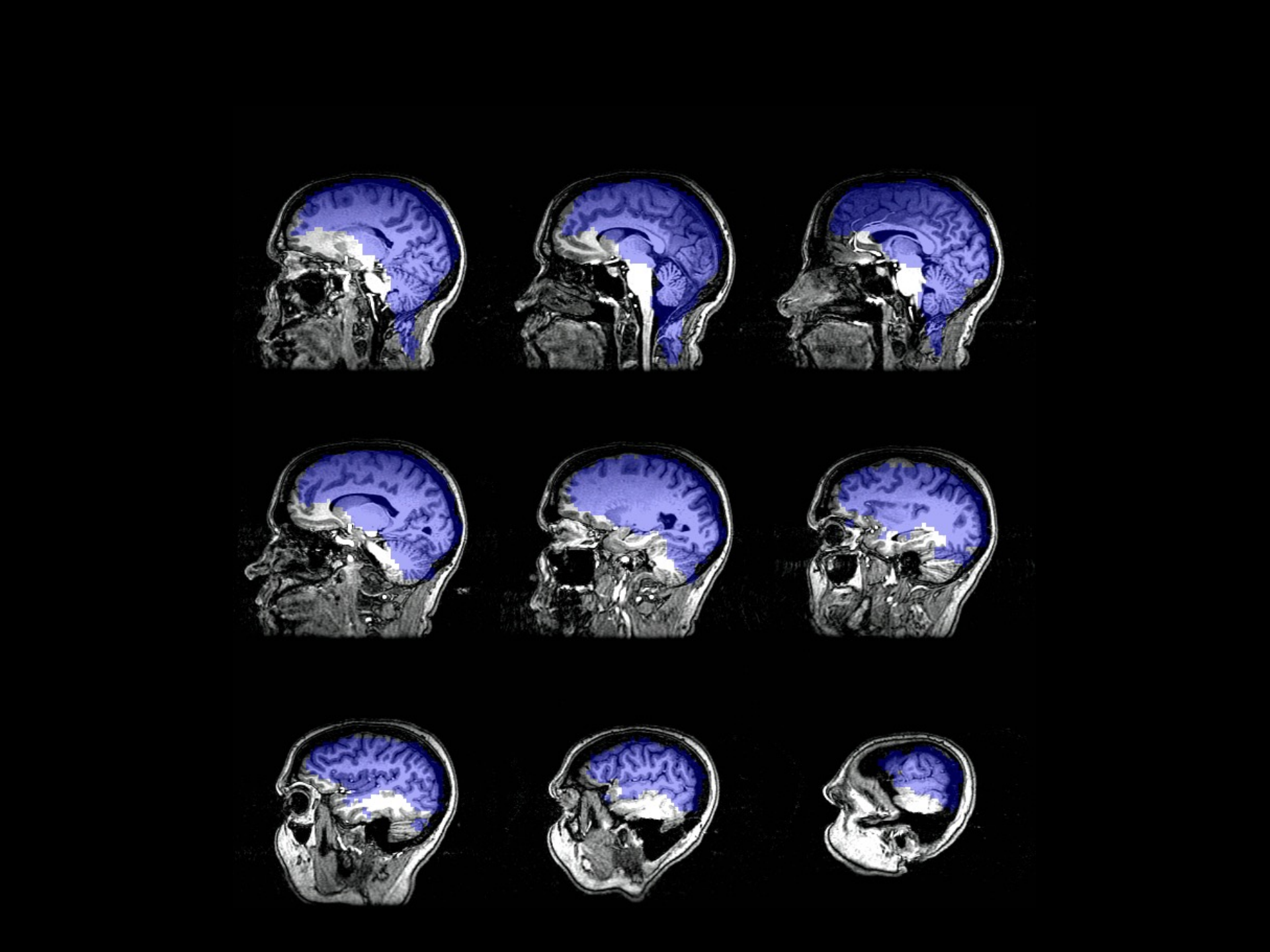
# Brain activity correlated with SCR during “Rest”



# Latest Developments...

1. Temporal Resolution
2. Spatial Resolution
3. Sensitivity and Noise
4. Information Content
5. Implementation

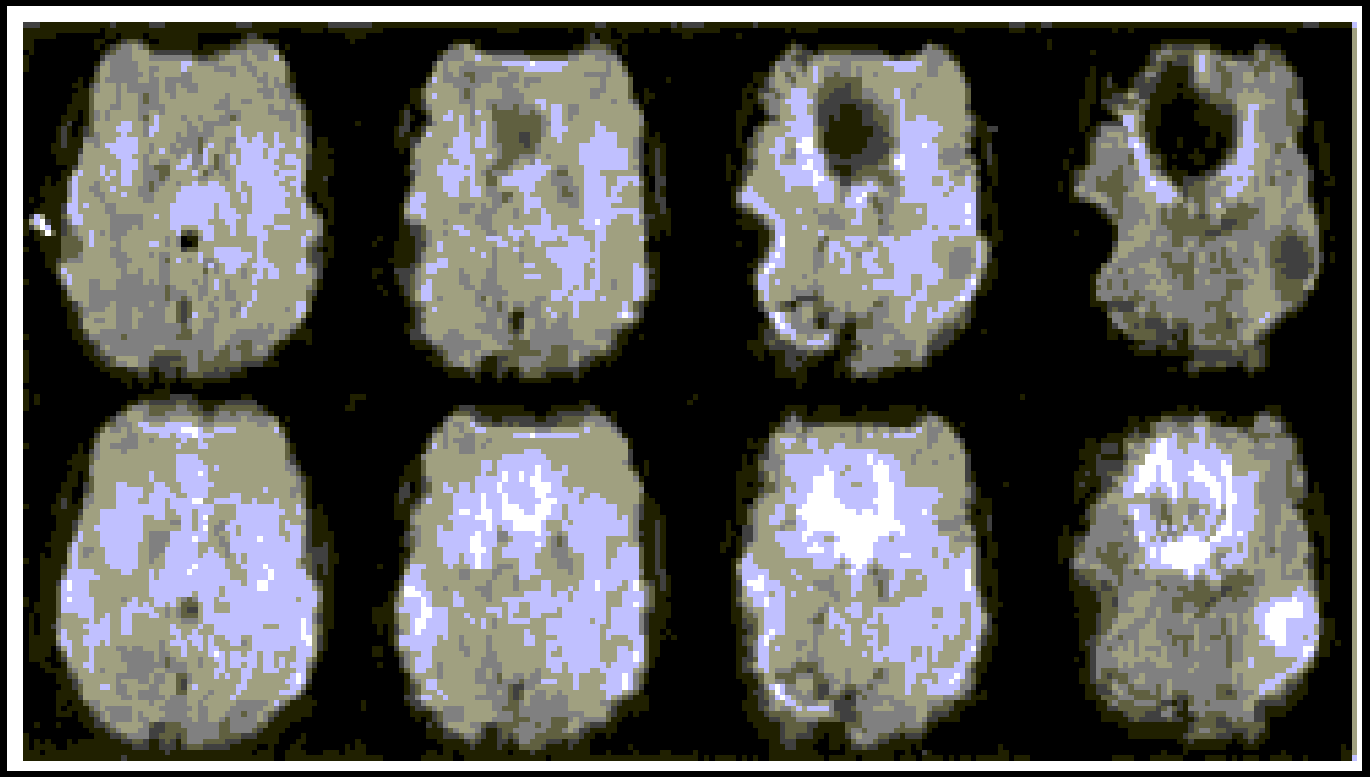




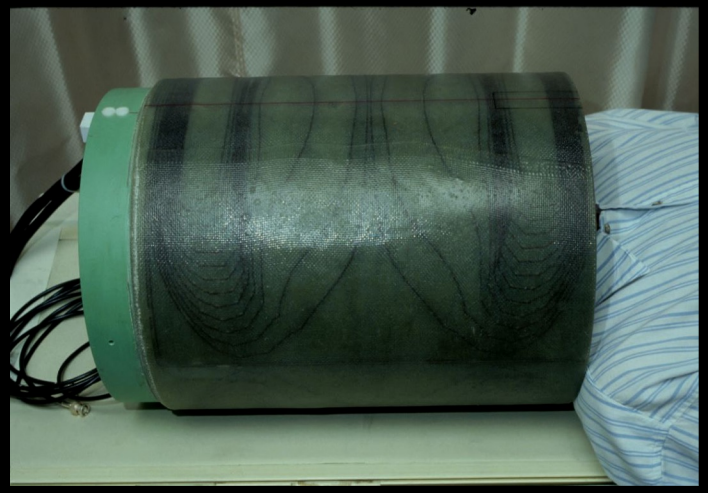
Magnetic Resonance in Medicine 42:290–299 (1999)

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

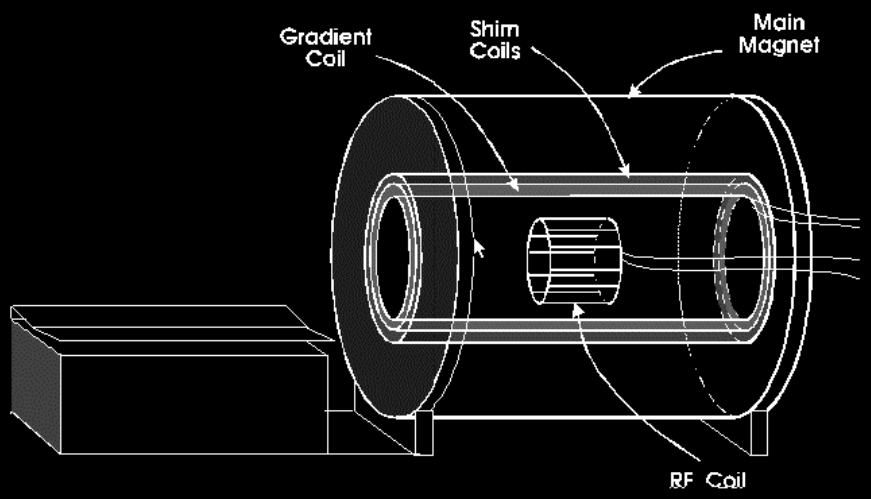
Gary H. Glover*



2 G/cm, 350 T/m/s



4 G/cm, 150 T/m/s




10 G/cm, 1000 T/m/s

Diffusion imaging
Faster imaging
Higher resolution

# Functional Imaging Methods / 3T Group

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Patrick Bellgowan

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August, 2000