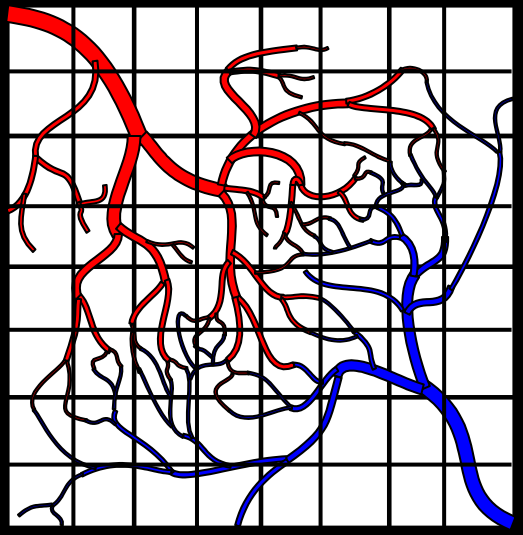
Squeezing Neuronal Information from Hemodynamics

Peter A. Bandettini, Ph.D

Unit on Functional Imaging Methods
&
3T Neuroimaging Core Facility

Laboratory of Brain and Cognition
National Institute of Mental Health

Neuronal Activation



Measured Signal

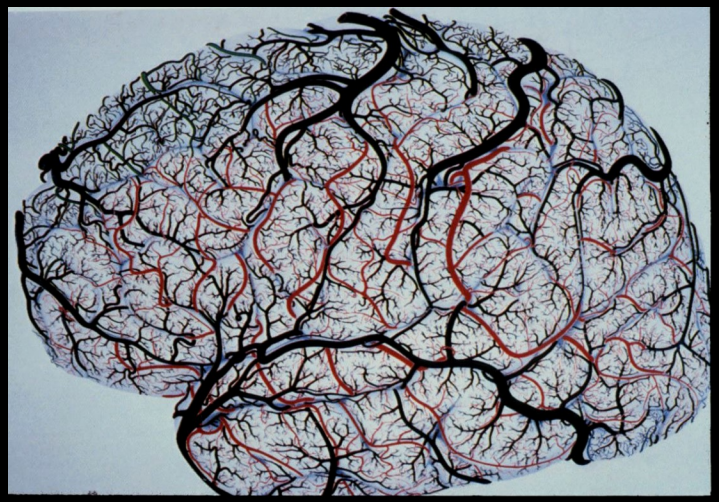
?

Hemodynamics

?

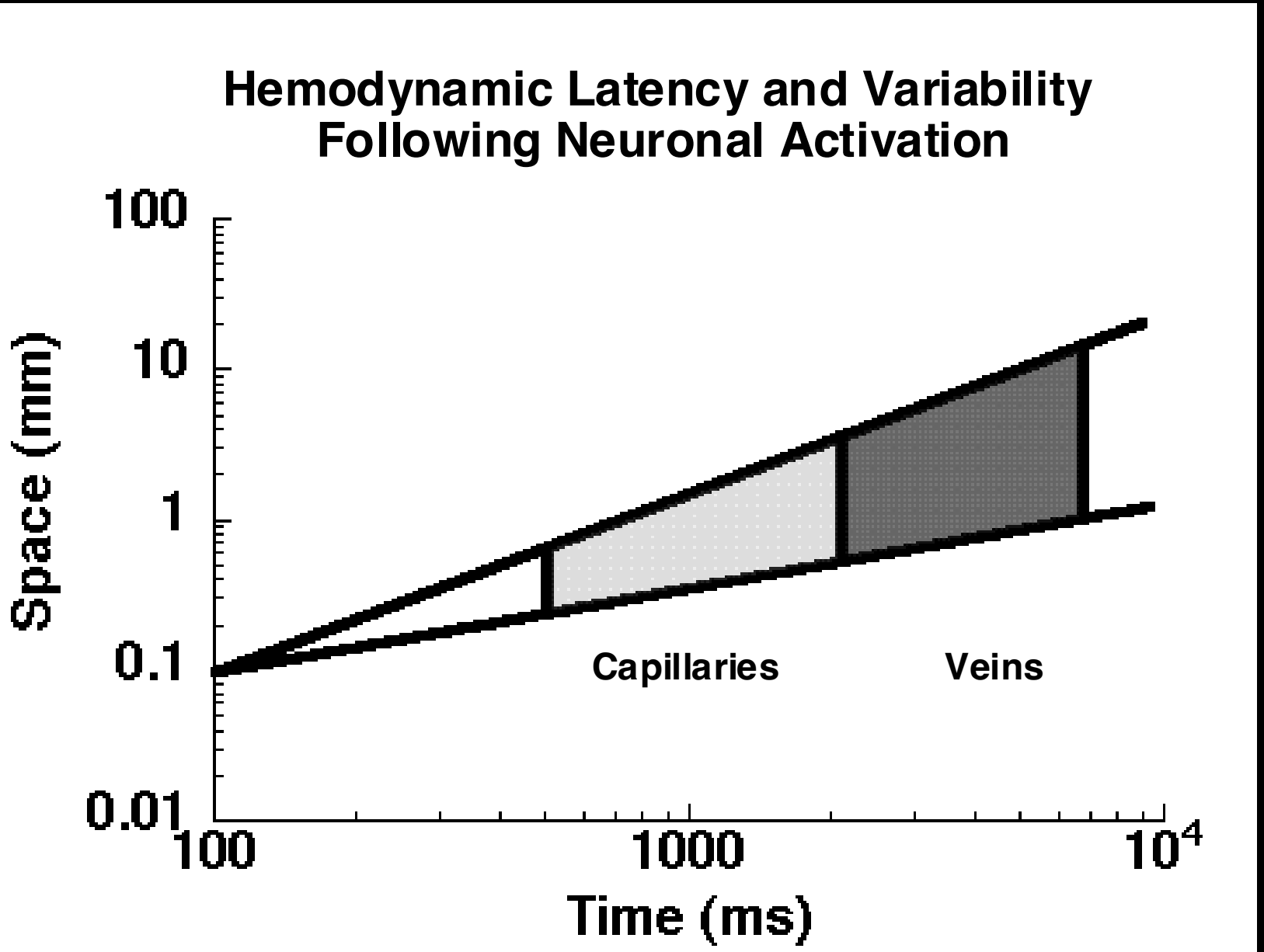
?

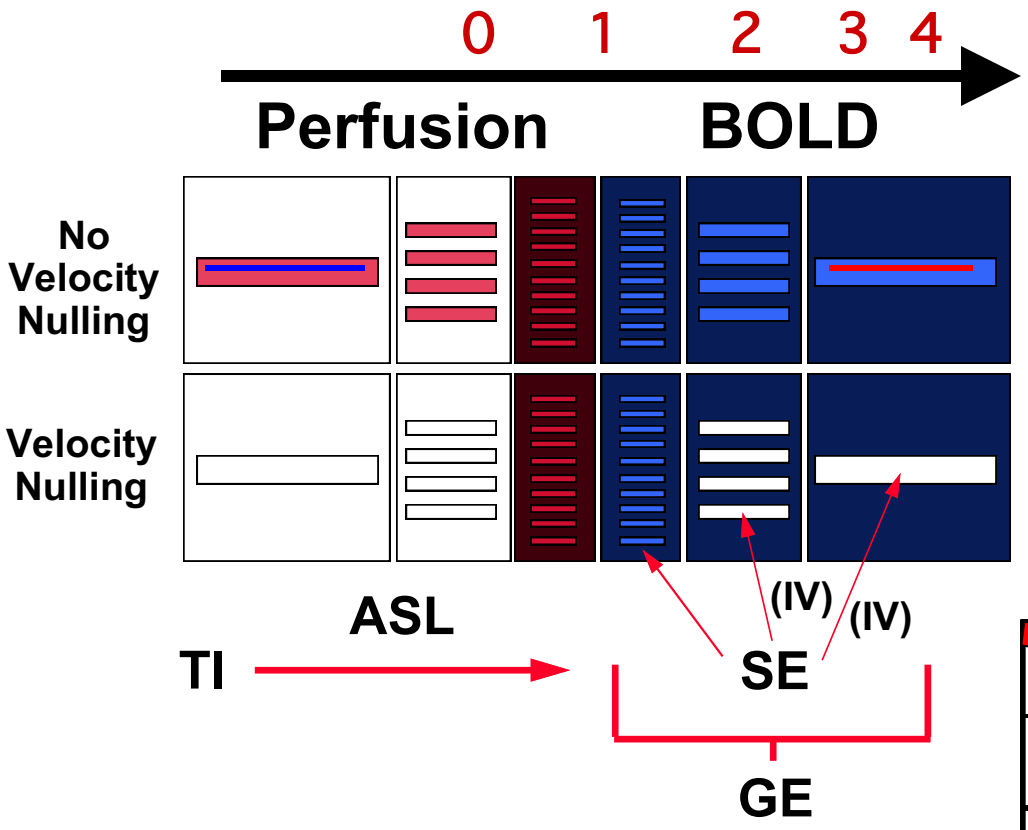
Noise



Systems Level
Neuronal Information Extraction

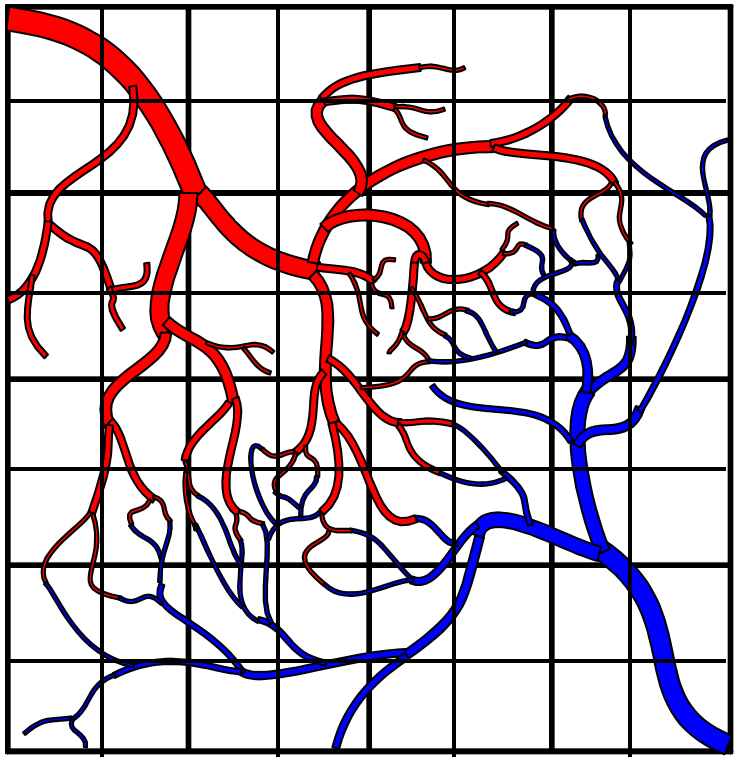
Latency
Magnitude


Hemodynamic Latency and Variability
Following Neuronal Activation
100
10
1
0.1
0.01
Space (mm)
Capillaries
Veins
100
1000
10^4
Time (ms)



Pulse Sequence Sensitivity

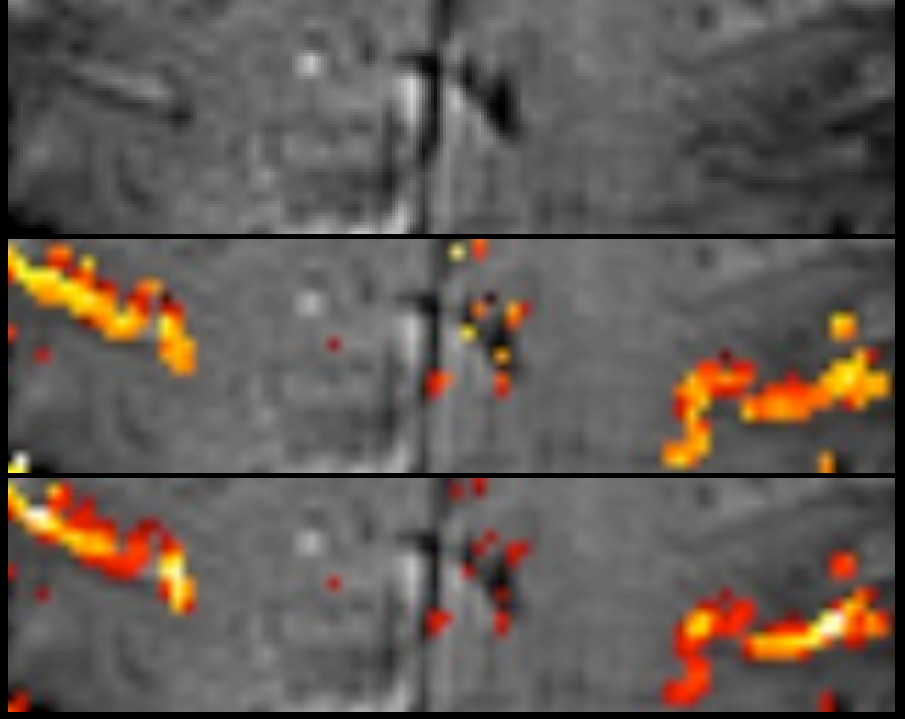
Spatial Heterogeneity

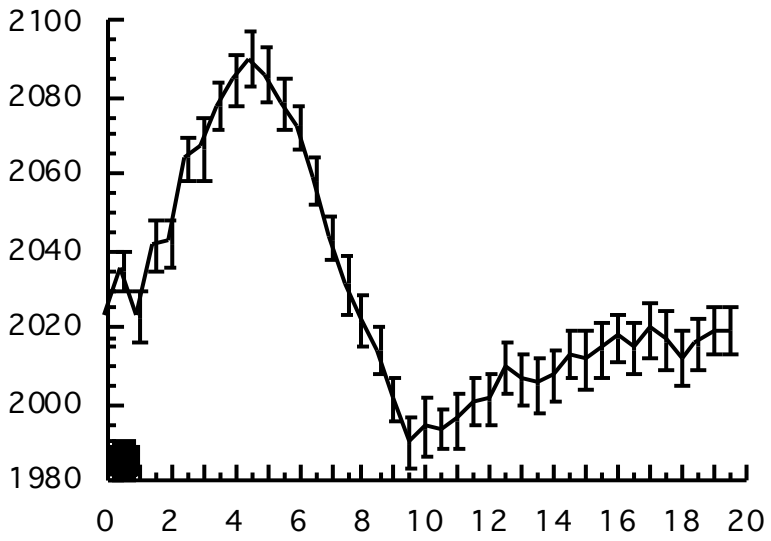


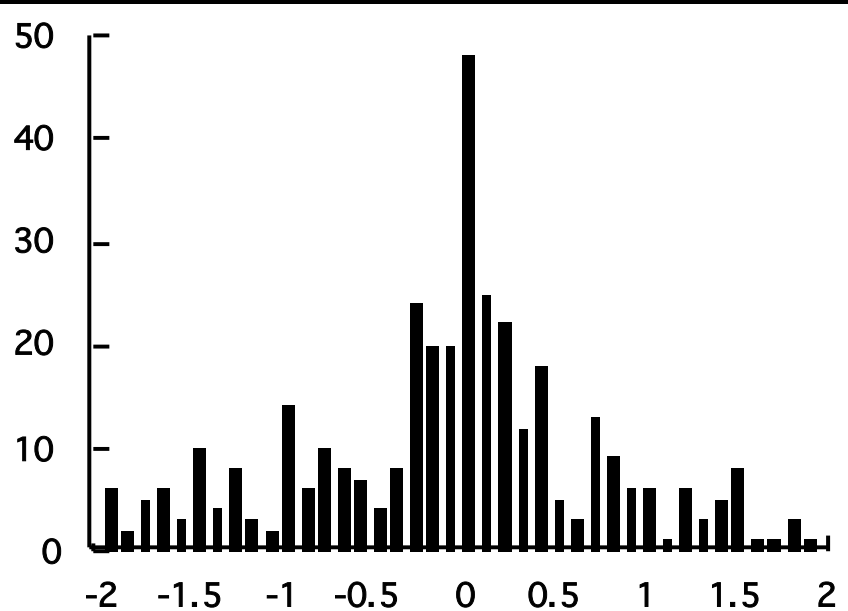
Temporal resolution factors	Values for each factor
Fastest image acquisition rate	≈64 images/s
Minimum time for signal to significantly deviate from baseline	≈3 s
Fastest on-off rate in which amplitude-is not compromised	≈8 s on, 8 s off
Fastest on-off rate in which hemodynamic response keeps up	≈2 s on, 2 s off
Minimum activation duration	≈30 ms (no limit determined yet, but the response behaves similarly below 500 ms)
Standard deviation of baseline signal	≈1% (less if physiological fluctuations and system instabilities are filtered out)
Standard deviation of onset time estimation	≈450 ms
Standard deviation of return to baseline time estimation	≈1250 ms
Standard deviation of entire on-off response time estimation	≈650 ms
Range of latencies over space	± 2.5 s

Latency

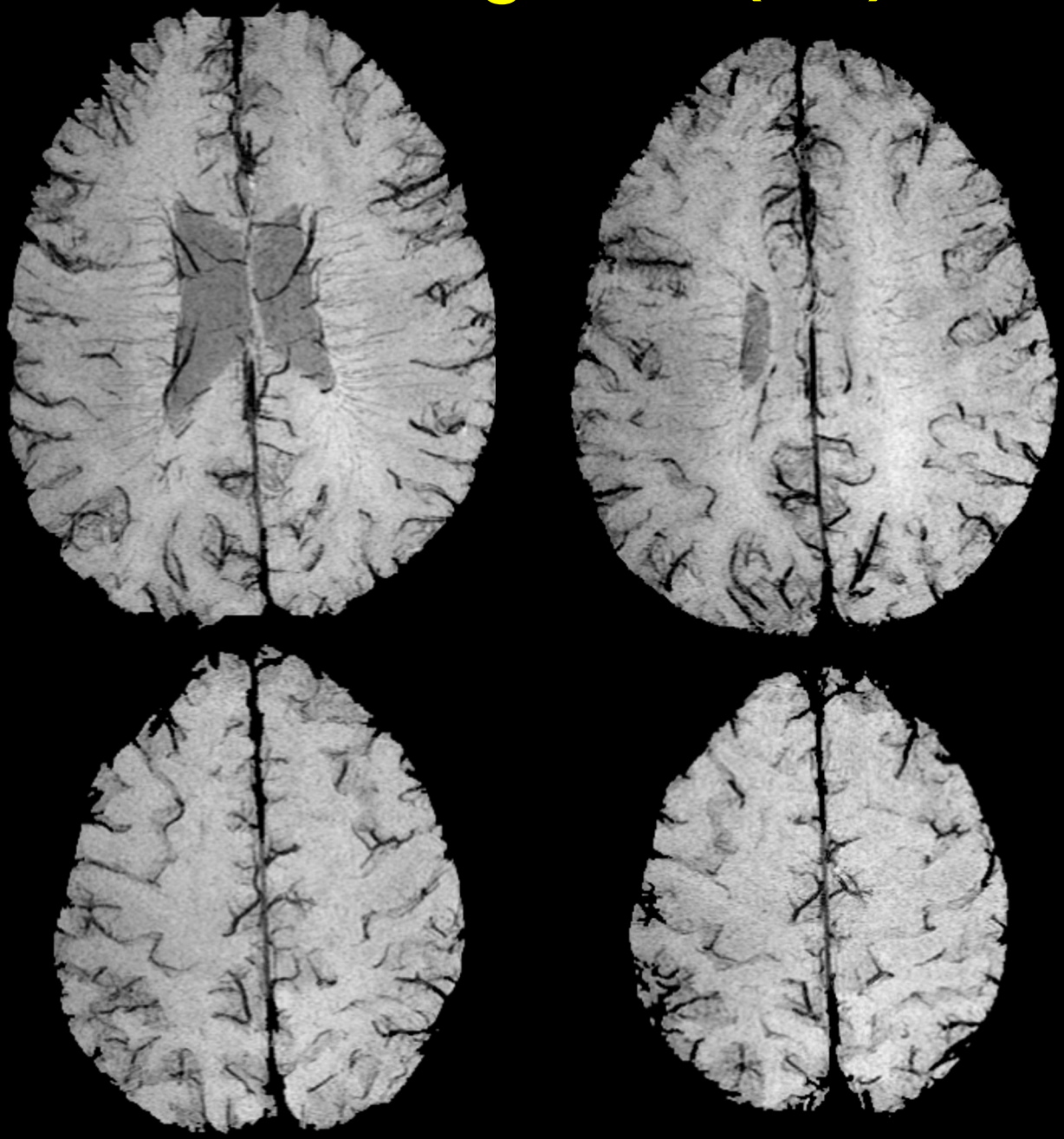
Magnitude

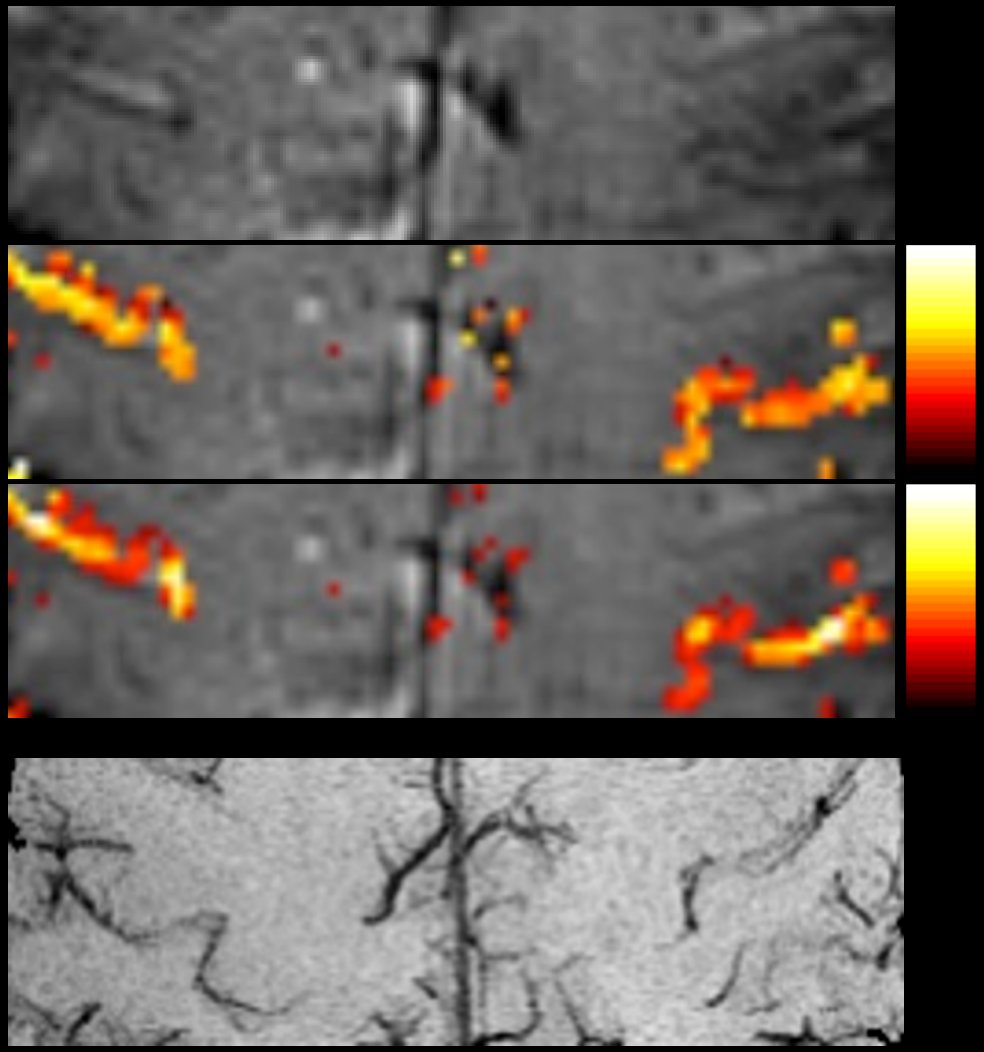






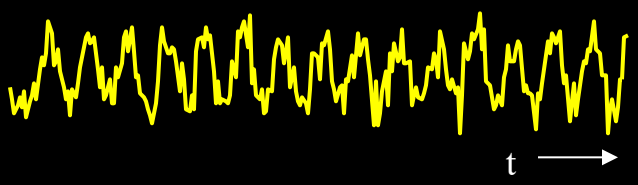
Venograms (3T)

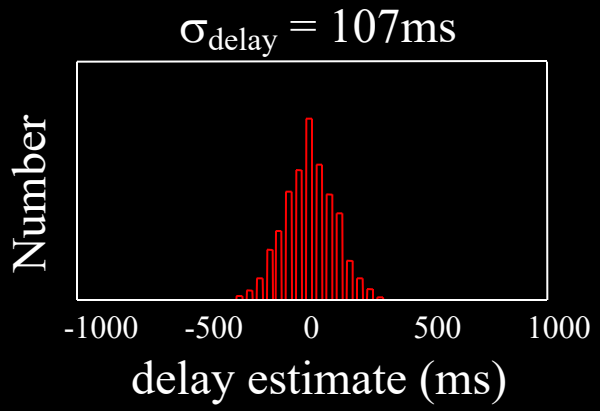




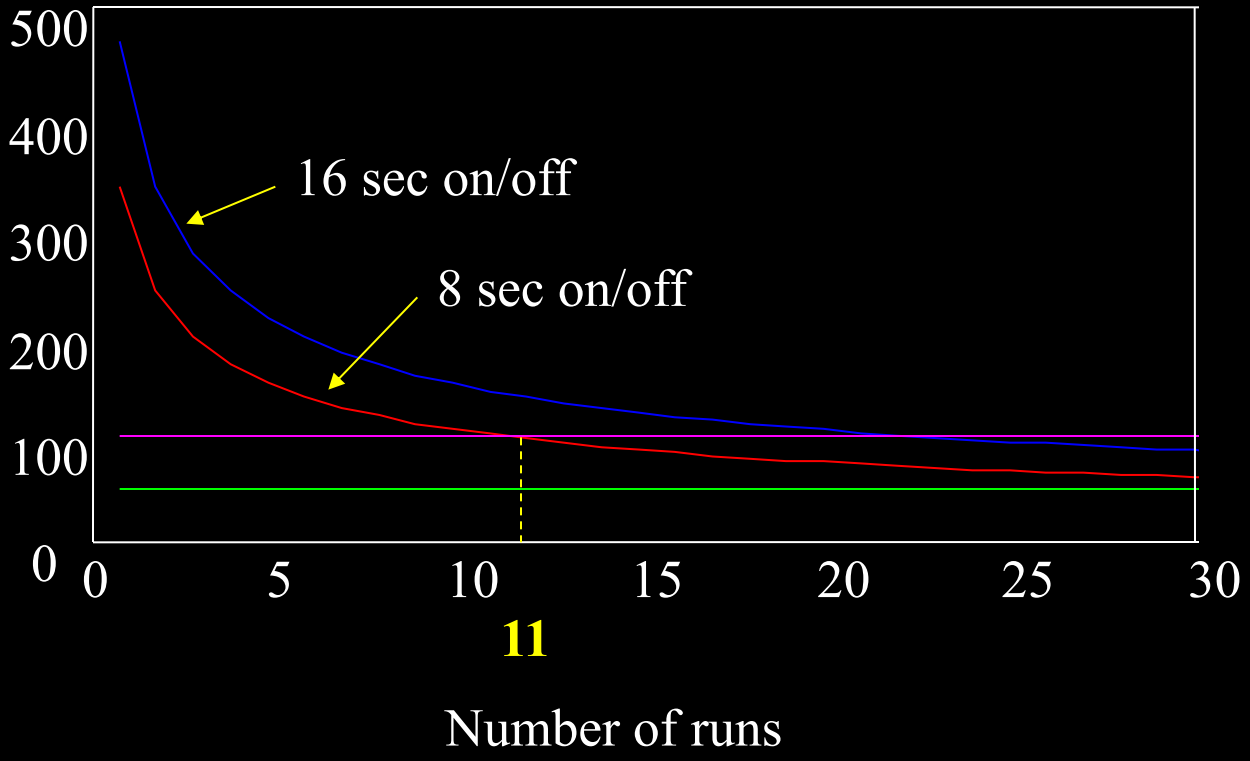
1 run:

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





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

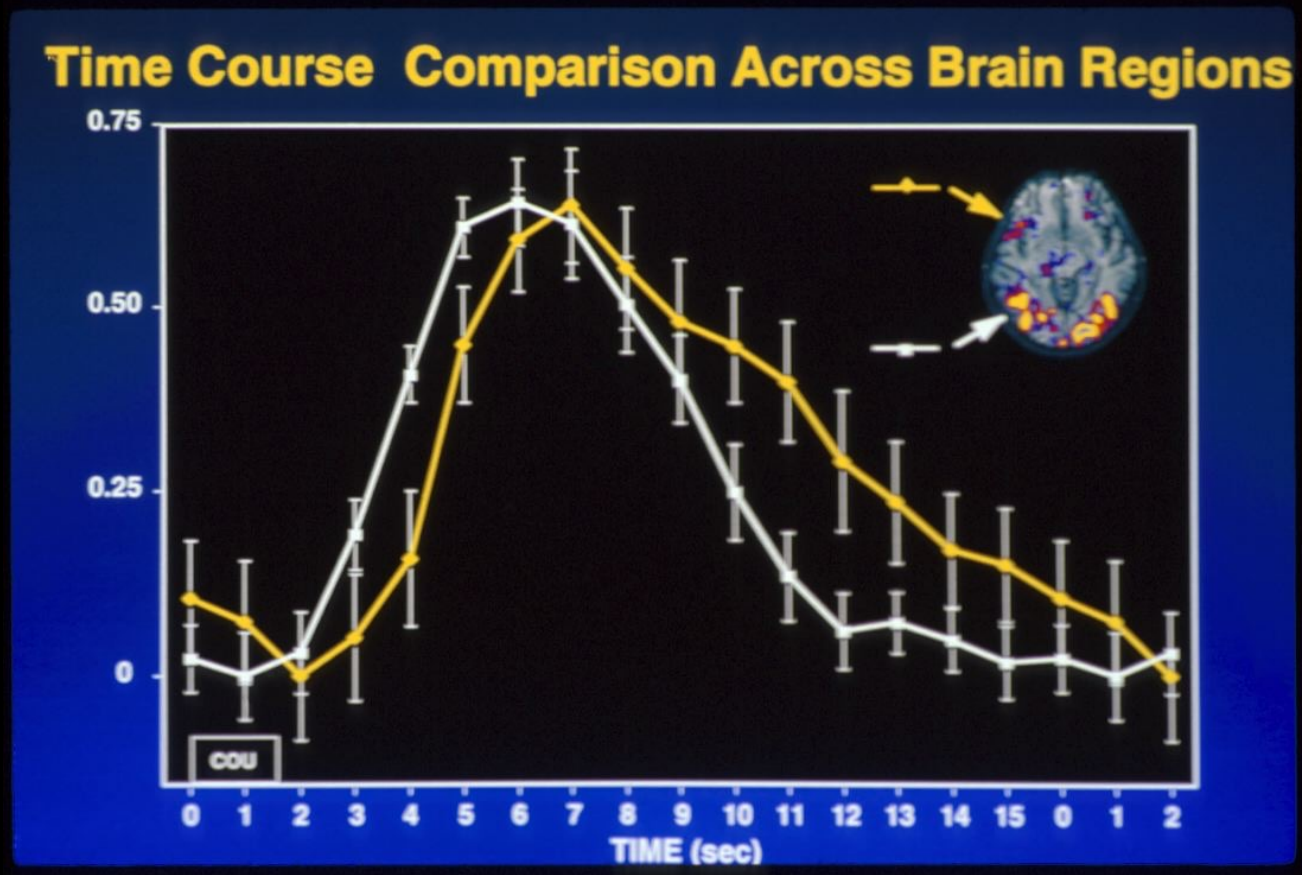


Proc. Natl. Acad. Sci. USA
Vol. 93, pp. 14878–14883, December 1996
Neurobiology

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

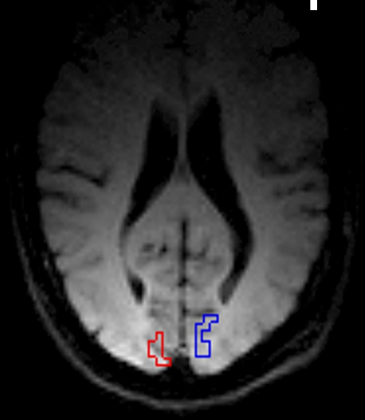
(neuroimaging/single trial/language/prefrontal)

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

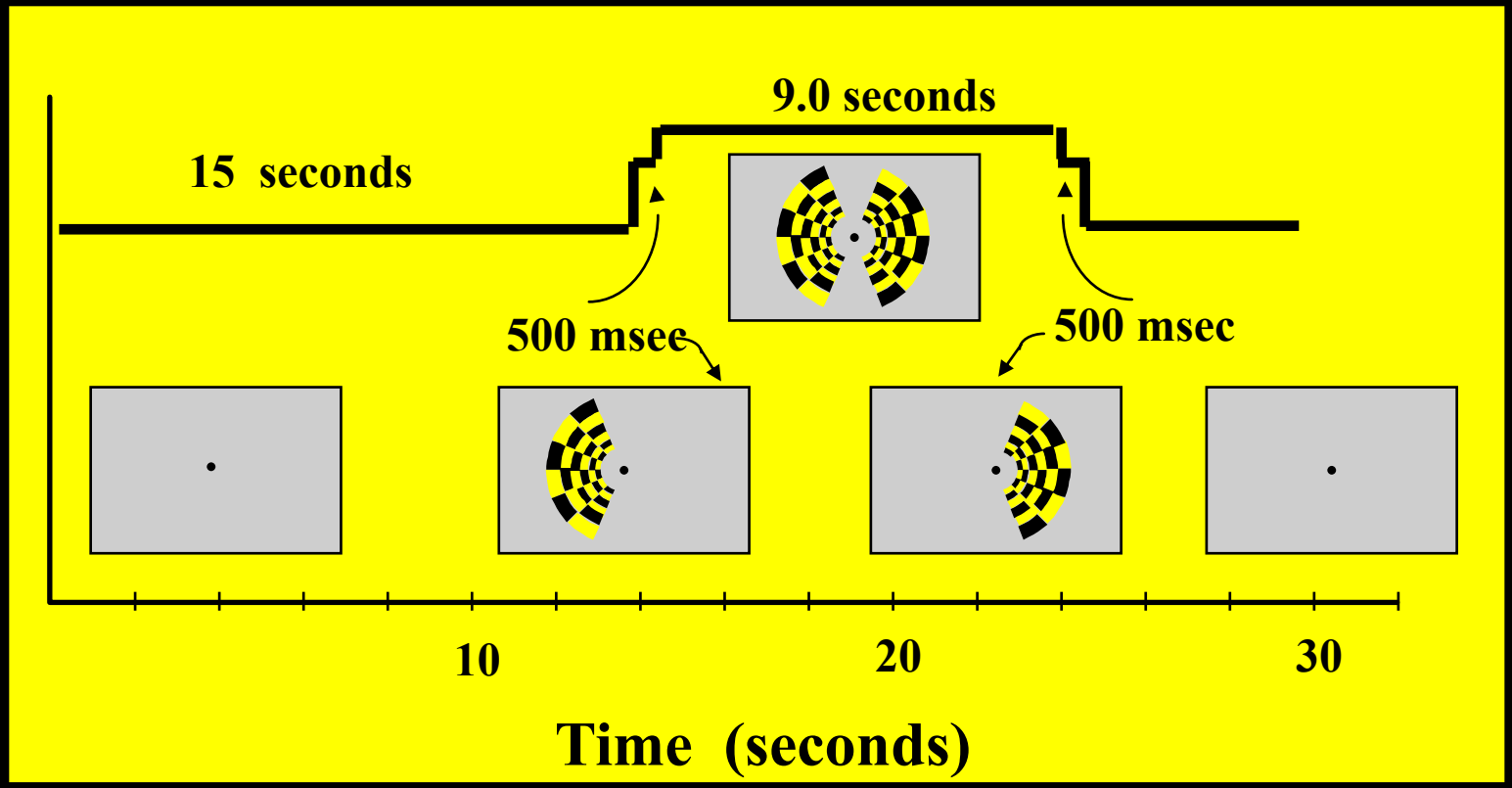


Hemi-Field Experiment

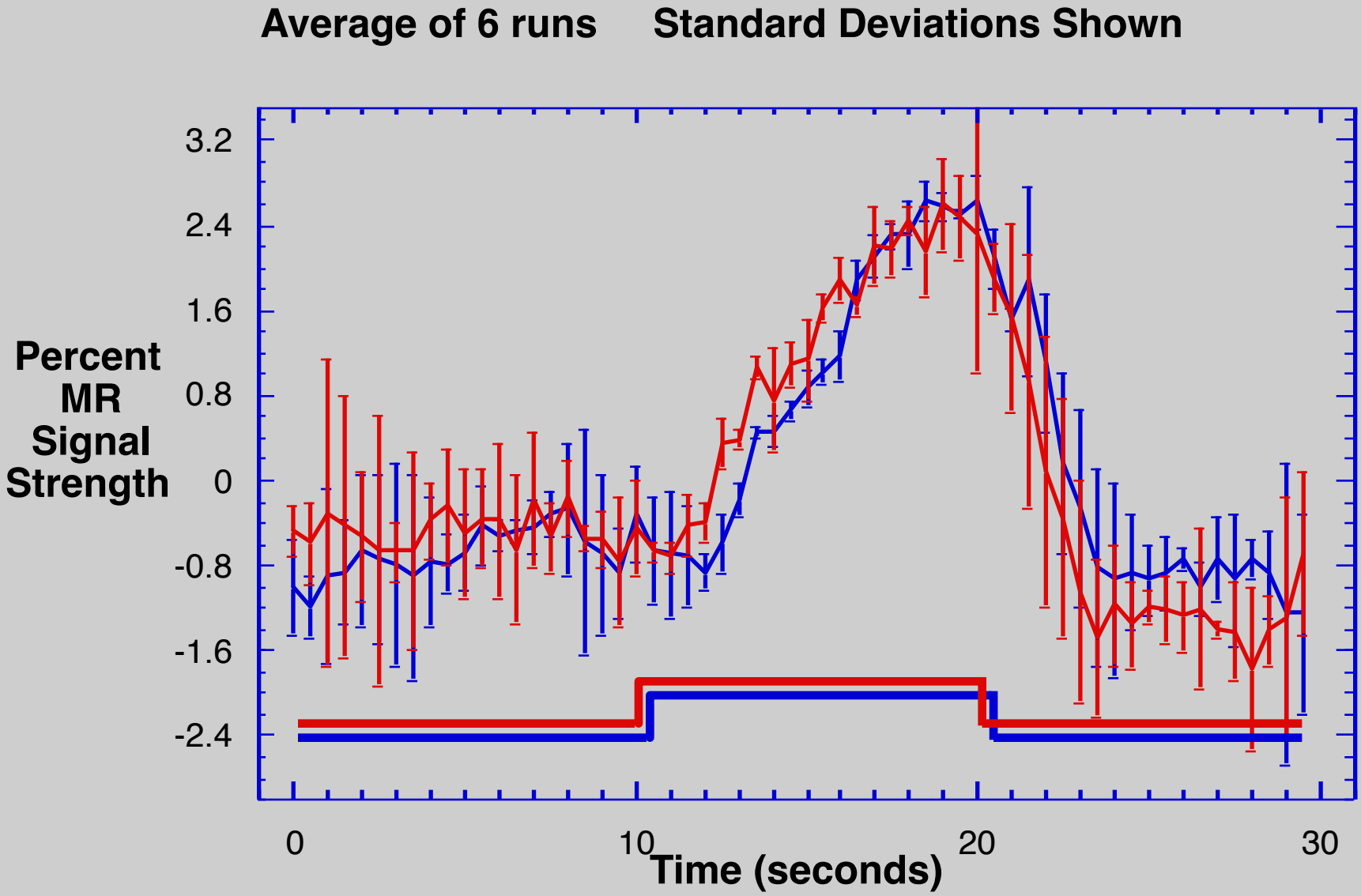
Left Hemisphere

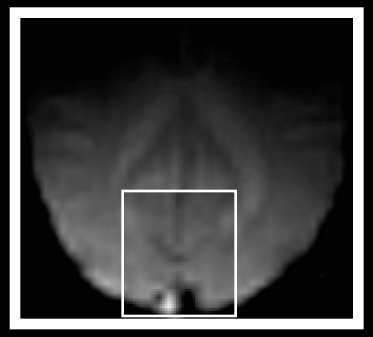


Right Hemisphere



Hemi-field with 500 msec asynchrony





500 ms

500 ms

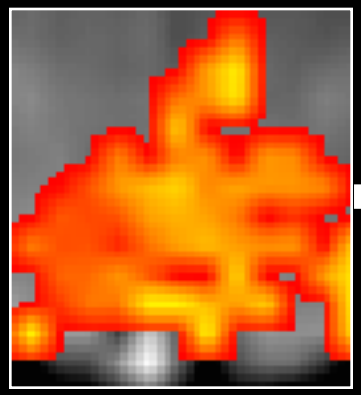
Right Hemifield

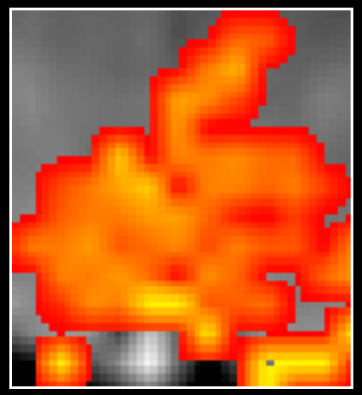
Left Hemifield

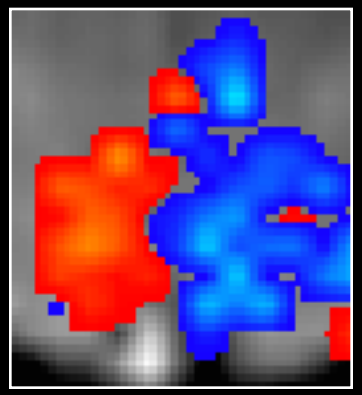
+ 2.5 s

0 s

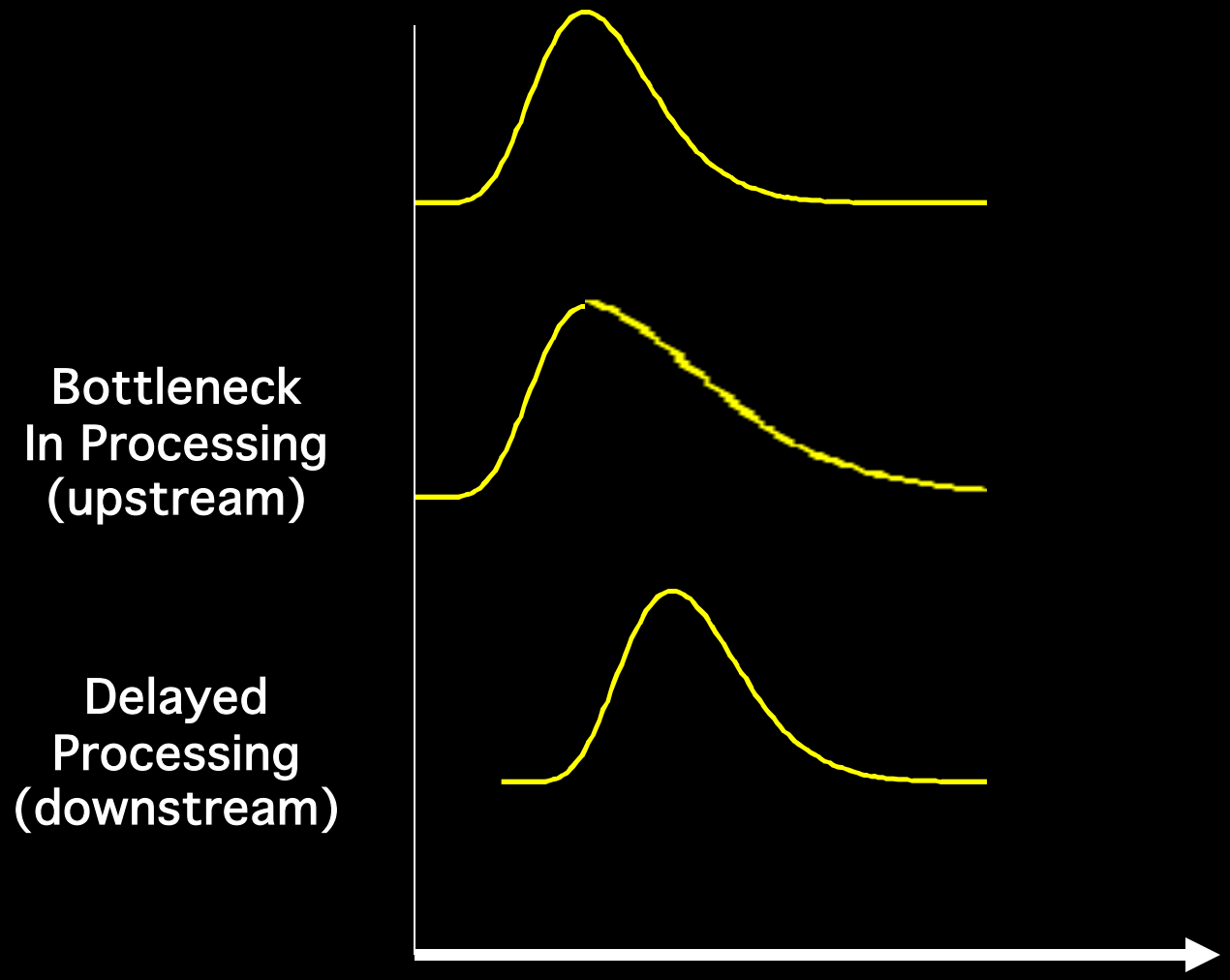
- 2.5 s







Hemodynamic Response Modulation



Use of Task Timing Modulation to Extract Processing Streams

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

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

Dependent Measures – Percent Correct and Reaction Time.

Hypotheses :

1) Stimulus rotation of 120 degrees will result in:

a) Longer Reaction Times

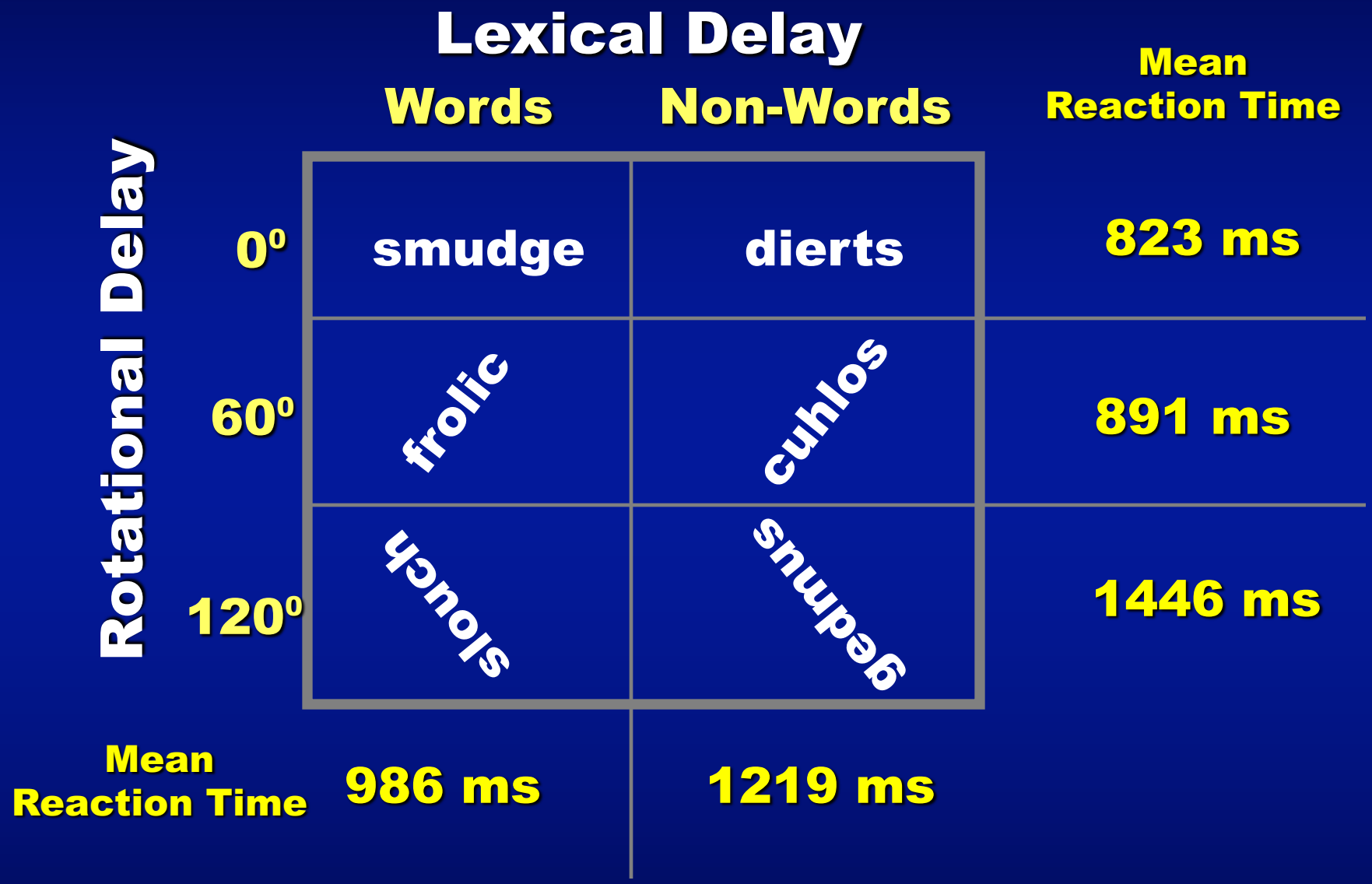
b) Stimulus rotation demands a change in perceptual perspective prior to linguistic processing. This will result in a delayed IRF onset in areas involved in Lexical and Pre-Lexical processing.

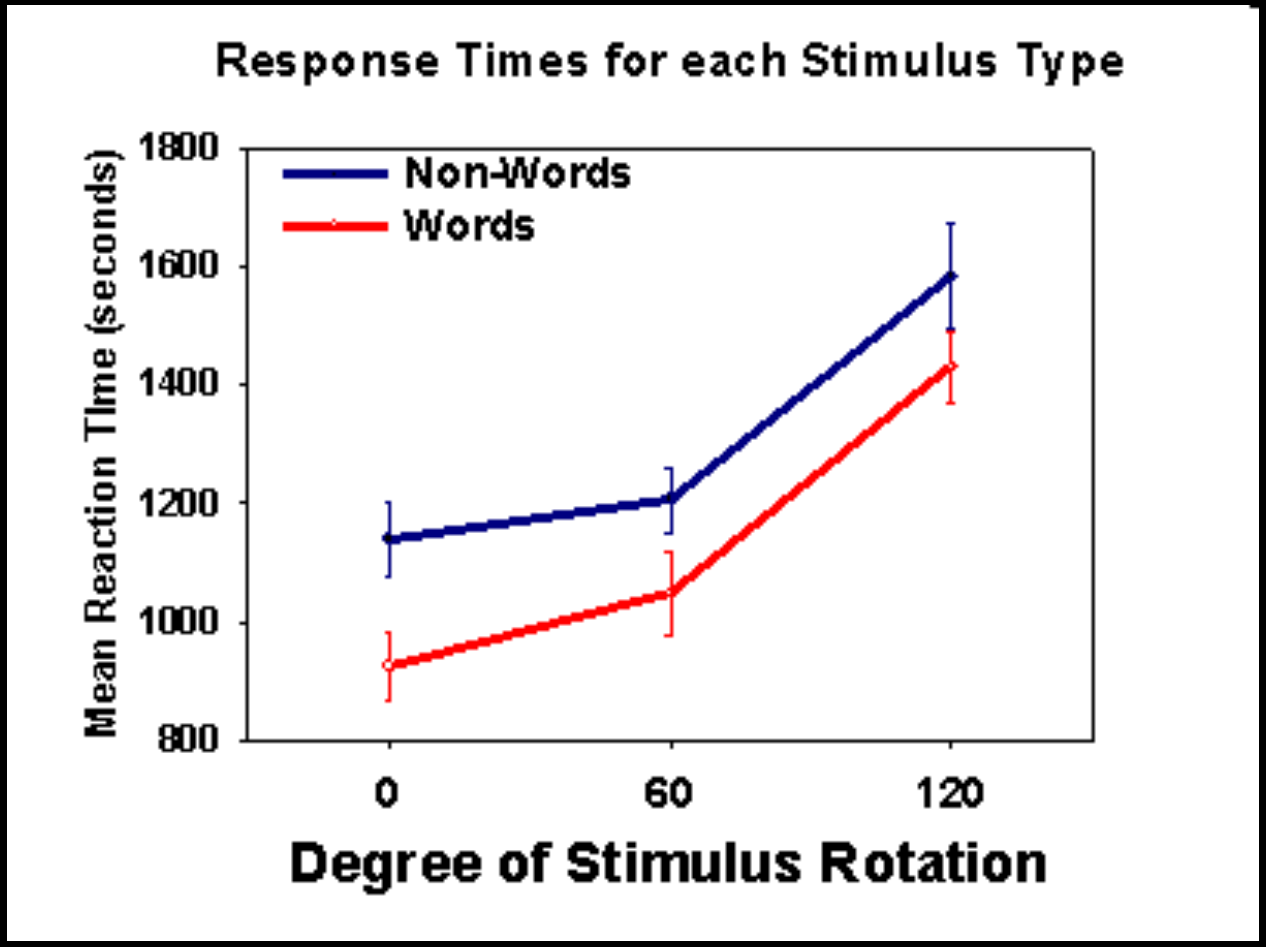
2) Lexical discrimination will result in :

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

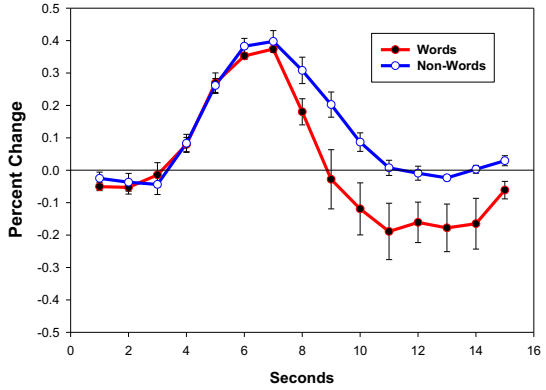
b) Wider IRF in Inferior Frontal cortex for non-words

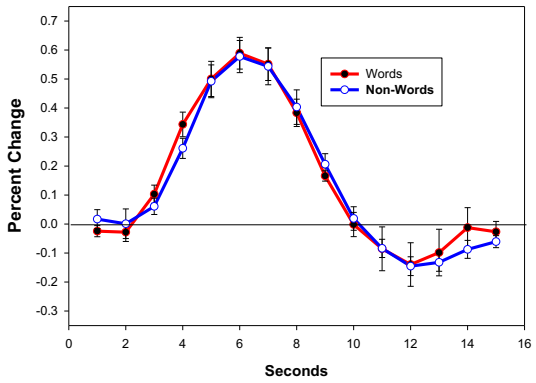
c) Delayed IRF onset in Left Middle Frontal Cortex

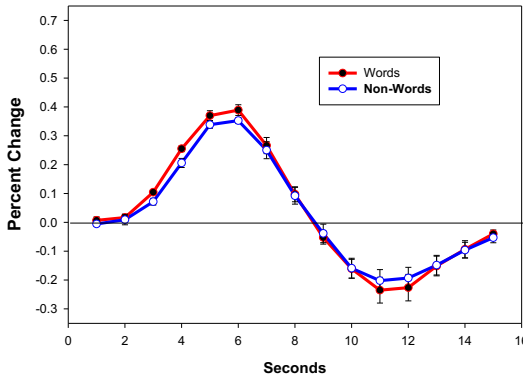

Lexical Delay
Words
Non-Words
Mean Reaction Time
Rotational Delay
0°
smudge
dierts
823 ms
60°
frolic
cuhlos
891 ms
120°
slouch
geamus
1446 ms
Mean Reaction Time
986 ms
1219 ms

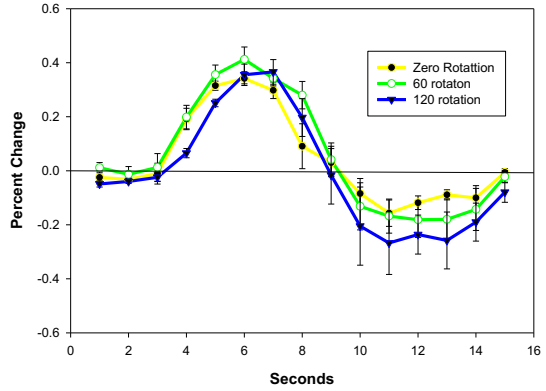

Response Times for each Stimulus Type
Mean Reaction Time (seconds)
1800
1600
1400
1200
1000
800
Non-Words
Words
0
60
120
Degree of Stimulus Rotation

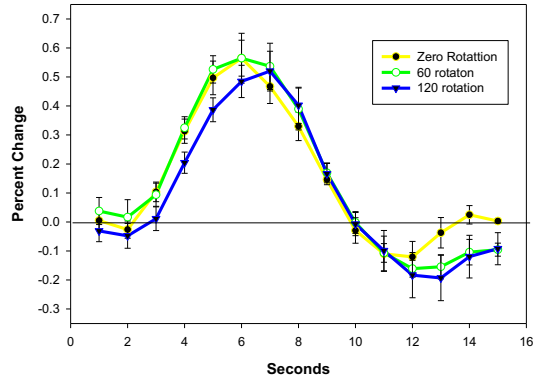
Inferior Frontal Gyrus Middle Temporal Gyrus Pre-Central Gyrus

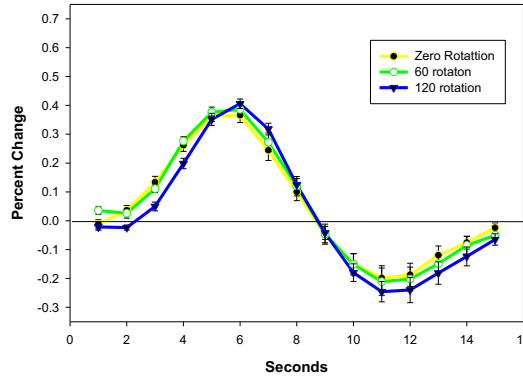






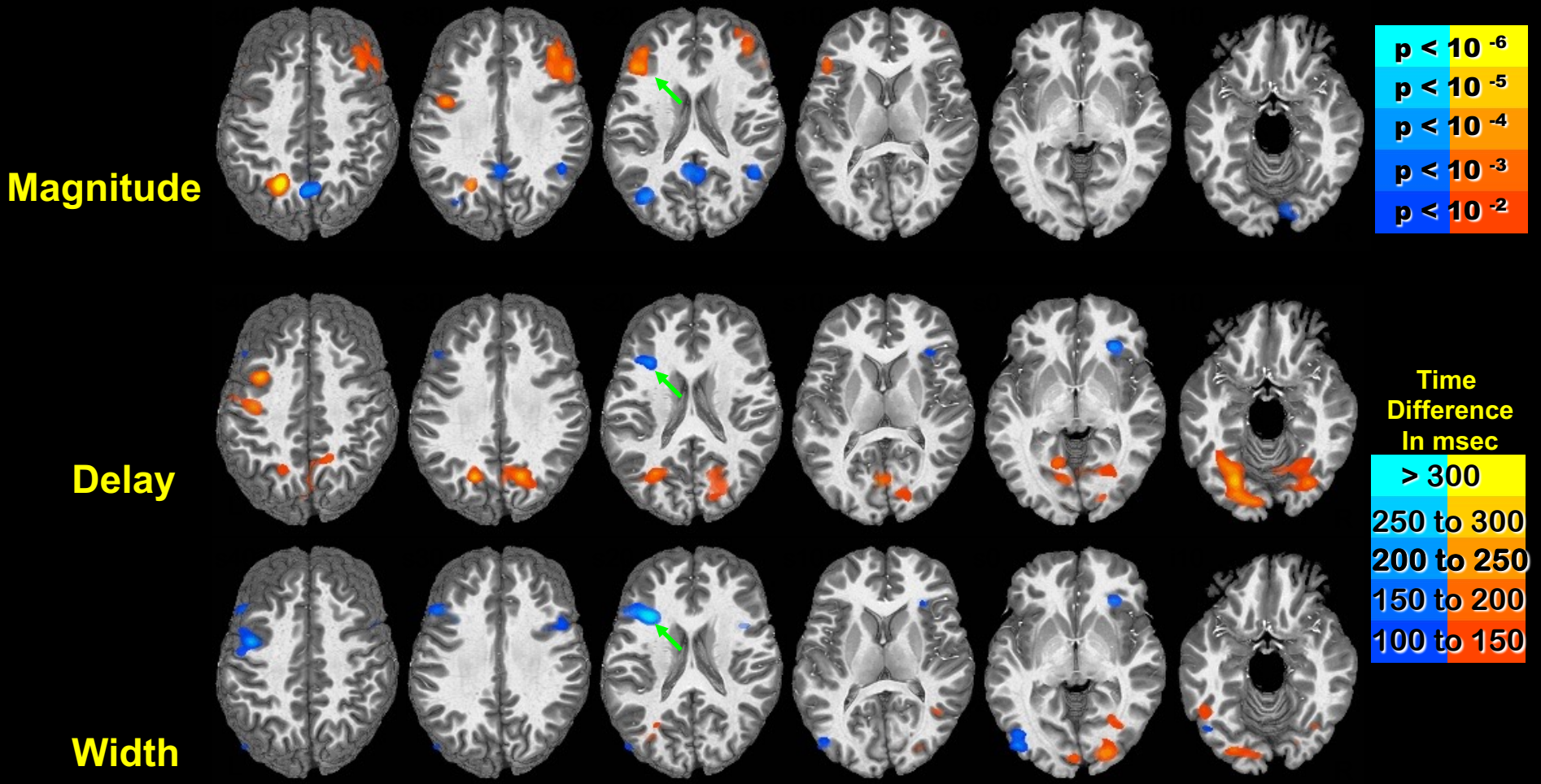






Graphs depicting the estimated Impulse Response Functions.

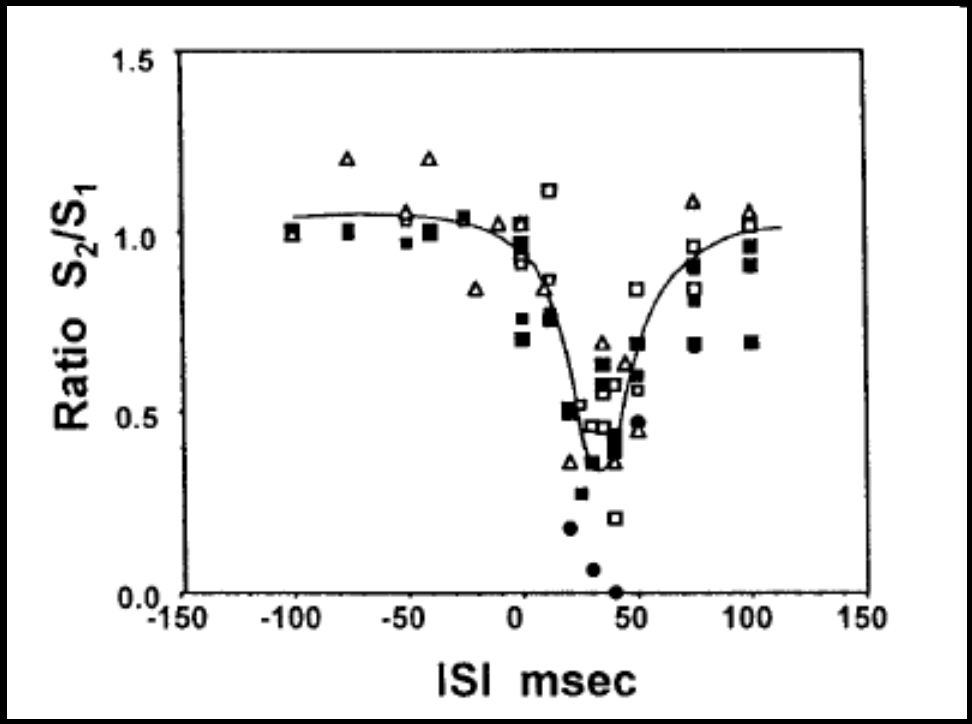
Lexical effect maps



Warm colors are areas where Words > Non-words. Cool colors (blues) are areas Where Non-words > words. The Left hemisphere is toward the left margin. The green arrows highlight the inferior frontal gyrus.

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[§]



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

Laminar Specificity of fMRI Onset Times During Somatosensory Stimulation in Rat

Afonso C. Silva and Alan P. Koretsky

Laboratory of Functional and Molecular Imaging

National Institute of Neurological Disorders and Stroke

Bethesda, Maryland, USA

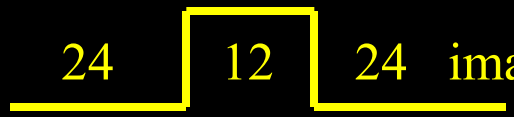
Can fMRI be used to distinguish neuronal signaling within laminar sub-regions of the brain?

fMRI Methods

- 11.7T/31cm magnet (Magnex Scientific, Ltd.)
- AVANCE electronics (Bruker-Biospin, Inc.)
- Conventional gradient-echo images
- FOV = 1.28 x 1.28 x 0.2 cm^3
- TE = 10 ms, TR = 40 ms, tip-angle ≈ 11°
- Matrix size:
  - 64 x 64 (200 x 200 x 2000 μm^3), 2.5 s/frame
  - 128 x 128 (100 x 100 x 2000 μm^3, 5.0 s/frame
  - 256 x 256 (50 x 50 x 2000 μm^3), 10 s/frame
- CBV: 20 mg/kg of AMI-227 (Advanced Magnetics, MA)

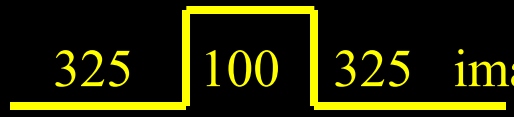
Somatosensory Stimulation

- Electrical stimulation of the forepaw:
  - Two needle electrodes inserted subcutaneously
  - Stimulation parameters: 2.0 mA; 3 Hz; 0.3 ms
  - Paradigm:
    1. Single stimulation **off – on – off** epoch



24	12	24	images	
60	30	60	seconds,	200 x 200 μm^2
240	120	240	seconds,	50 x 50 μm^2

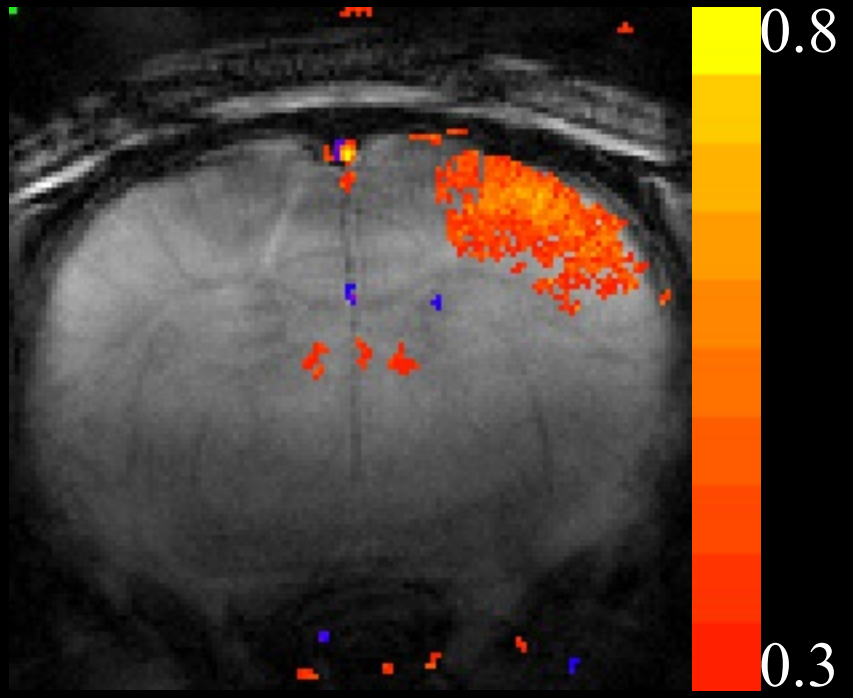
    2. Multiple stimuli block design



325	100	325	images	200 x 200 μm^2
13	4	13	seconds,	repeated 64 times

MRI of Functional Hemodynamics

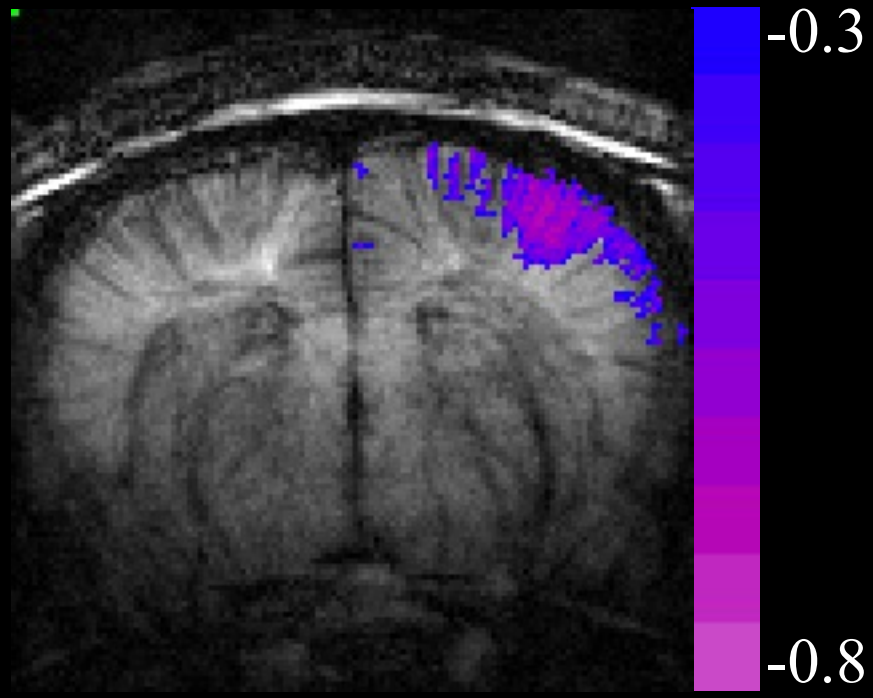
BOLD



Gradient-Echo Sequence

Resolution = 100x100x2000 μm^3

rCBV



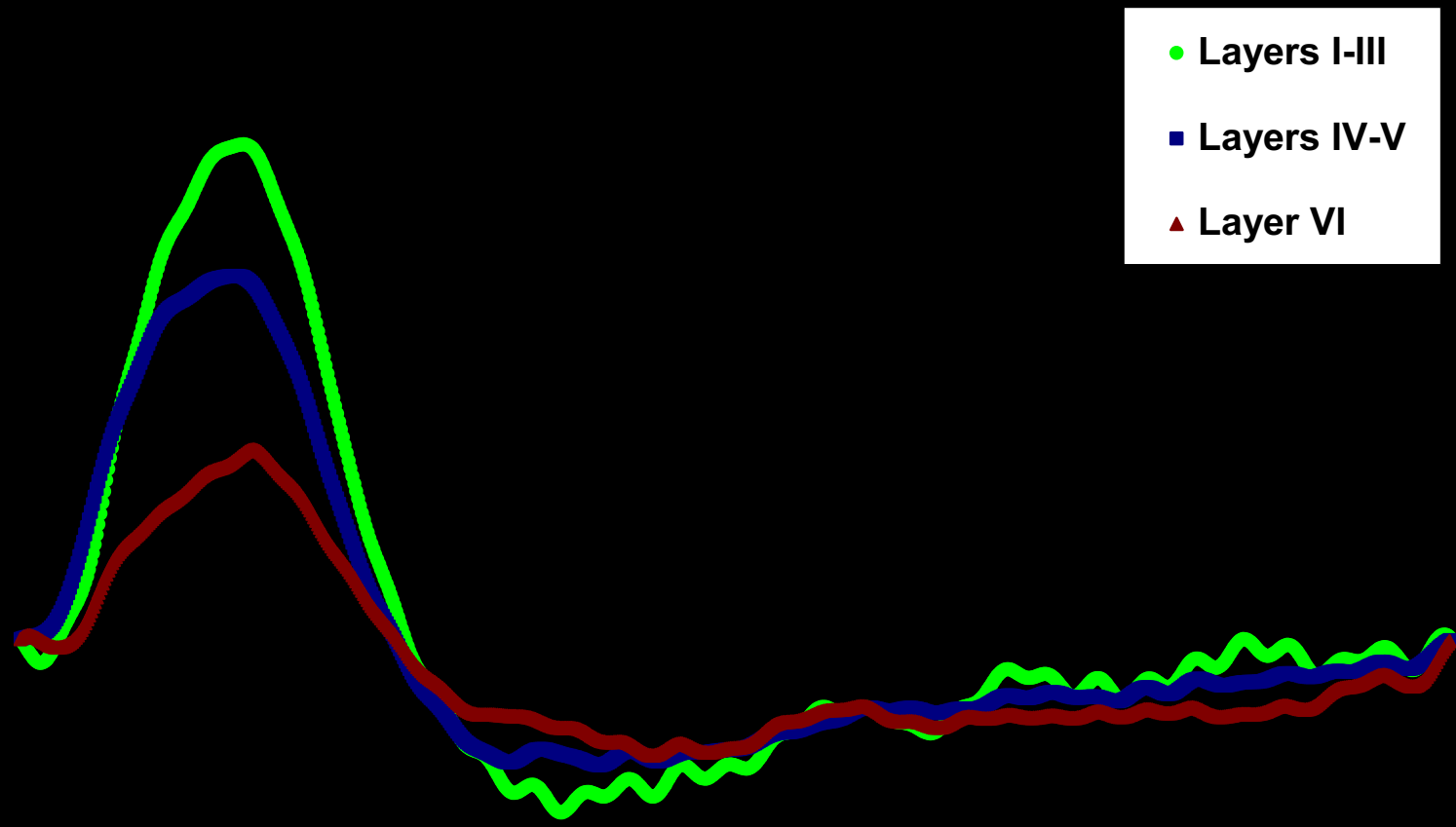
Iron Oxide Contrast Agent

Resolution = 100x100x2000 μm^3

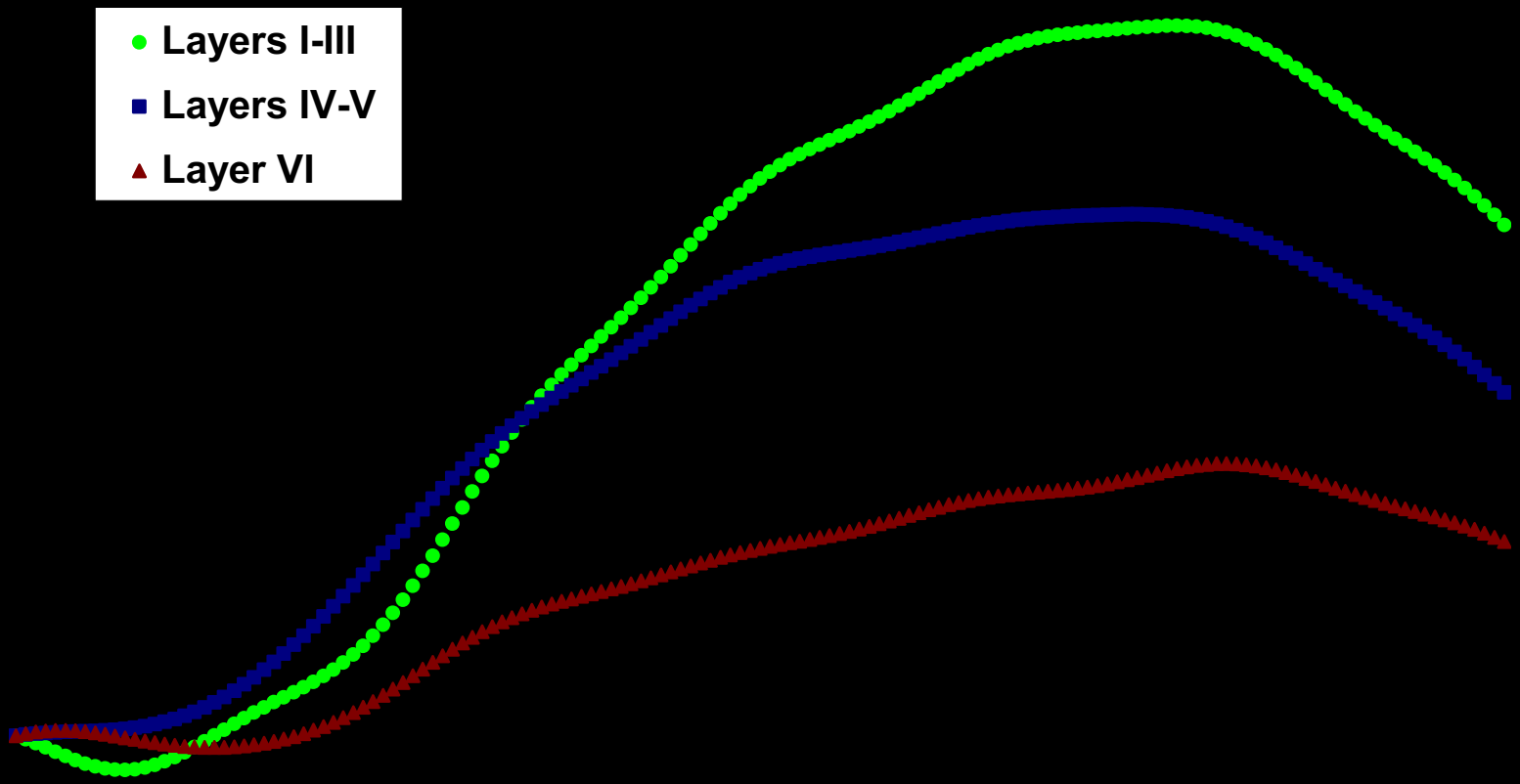
Mapping Onset Times of fMRI Response

- Hemodynamic response is stable if duty-cycle of repeated stimuli is low enough
- *Strategy*: to acquire multiple high-resolution images using conventional GRE-MRI, swapping phase-encode loop with image repetition loop to obtain one k-space line for all images per stimulus epoch
- Spatial in-plane resolution: 200 x 200 μm^2
- Temporal resolution: 40 ms

Averaged BOLD Time-Courses



Onset Time Detail

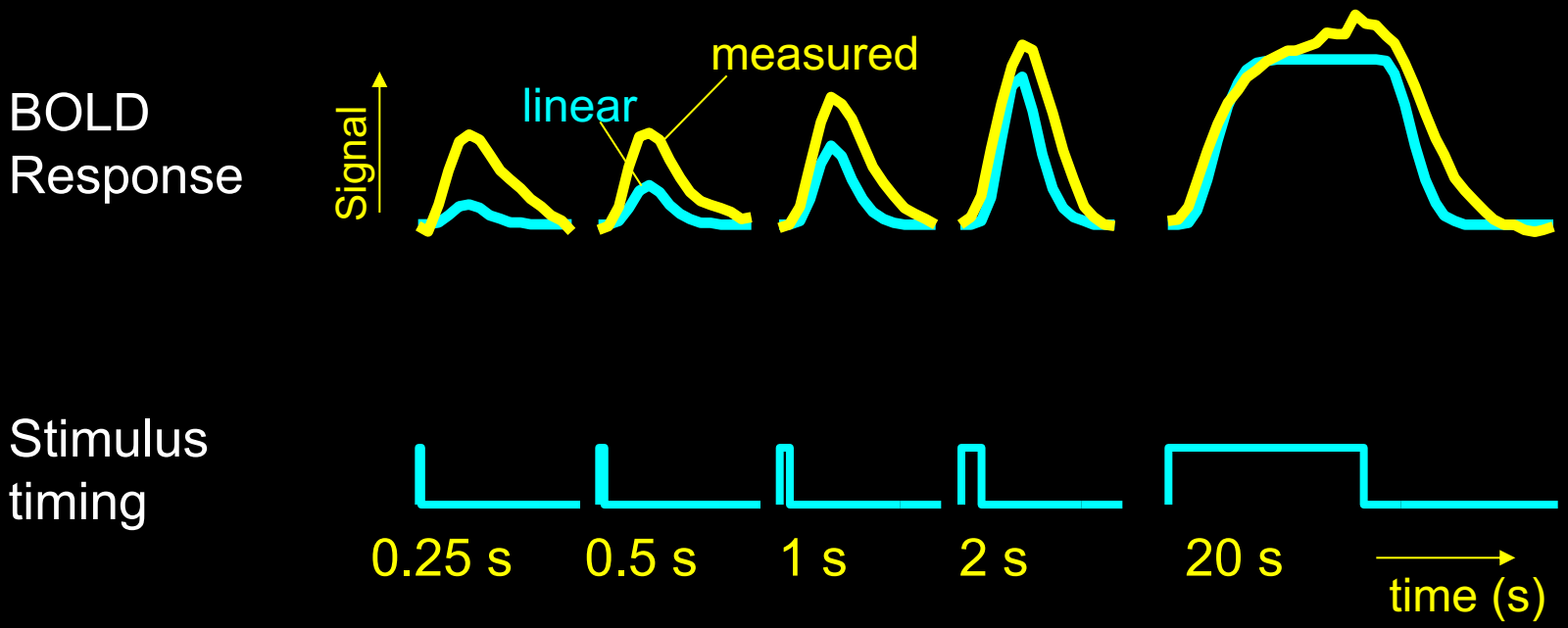


Systems Level
Neuronal Information Extraction

Latency
Magnitude

Dynamic Nonlinearity Assessment

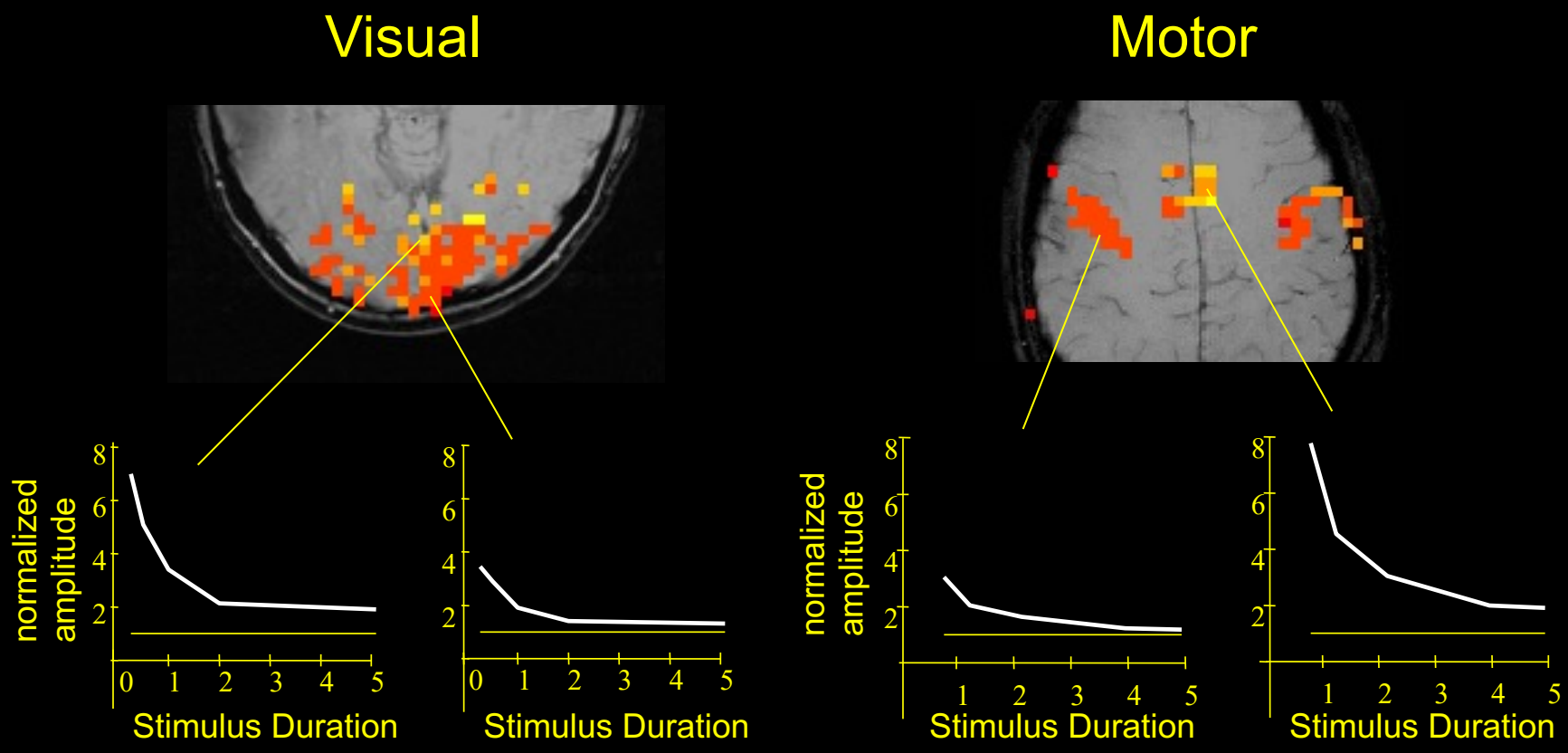
Different stimulus "ON" periods



Brief stimuli produce larger responses than expected

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

Spatial variation of linearity



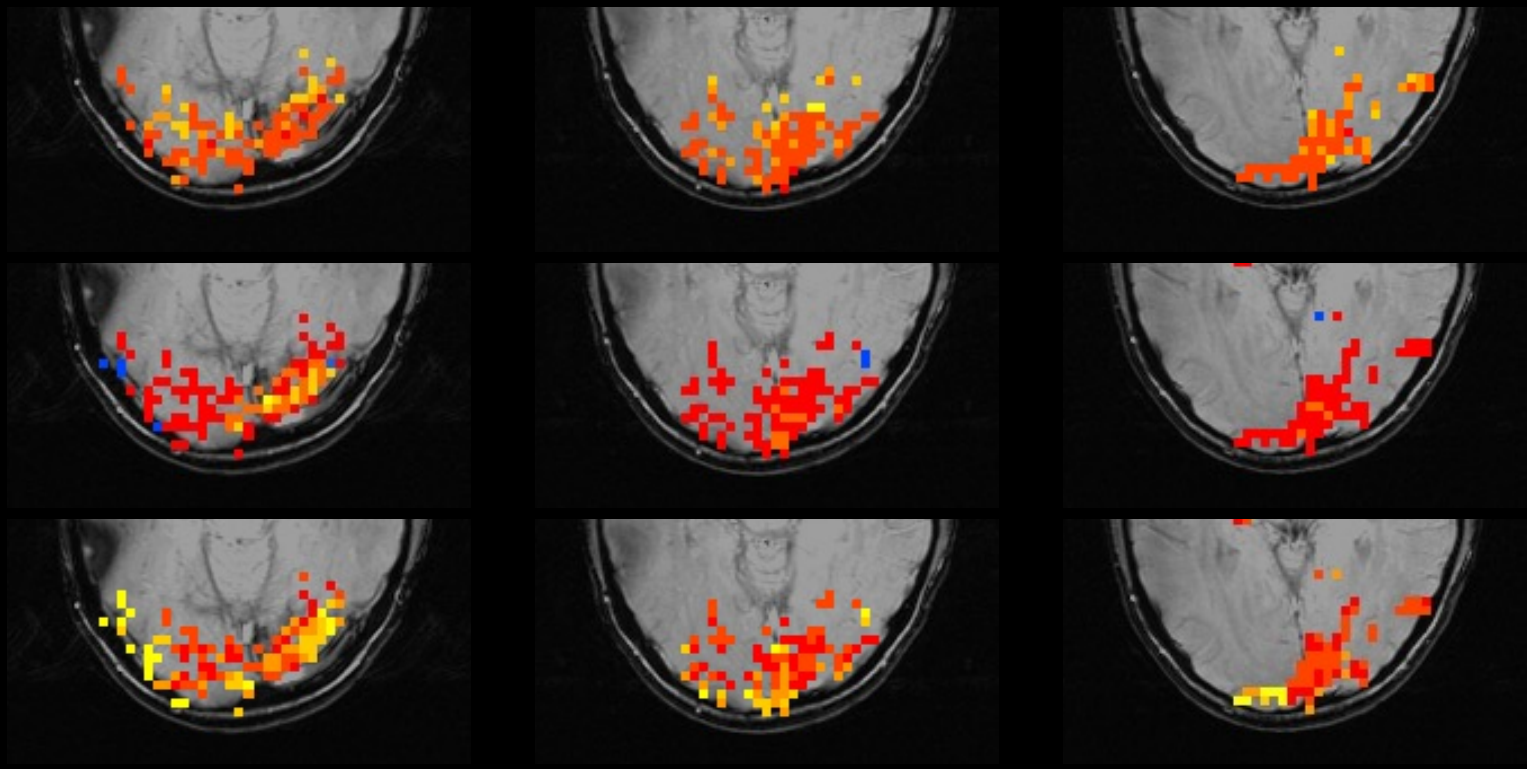
R.M. Birn, et al. Neuroimage 14, 817-26, 2001

Results – visual task

Nonlinearity

Magnitude

Latency



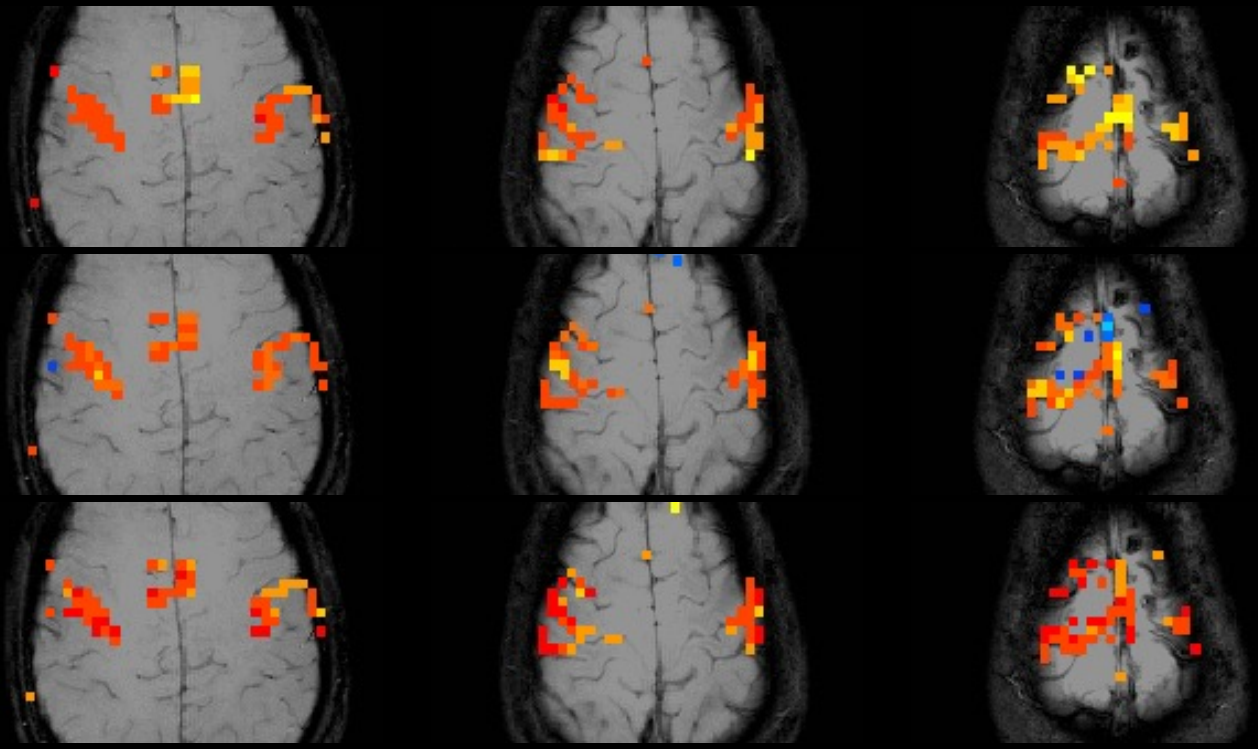
R. M. Birn, Z. Saad, P. A. Bandettini, (2001) "Spatial heterogeneity of the nonlinear dynamics in the fMRI BOLD response." *NeuroImage*, 14: 817-826.

Results – motor task

Nonlinearity

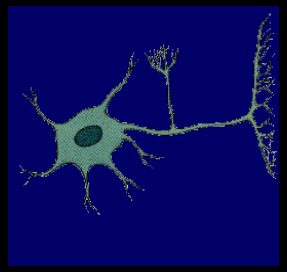
Magnitude

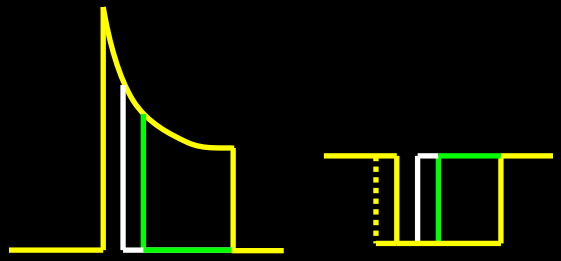
Latency



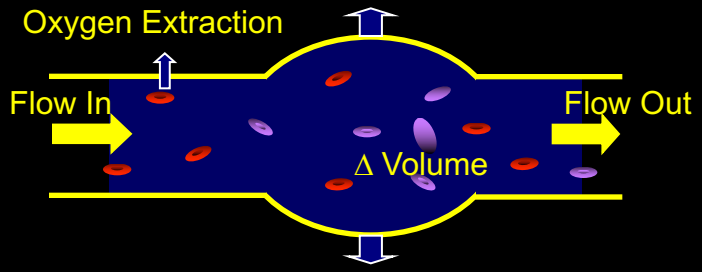
Sources of this Nonlinearity

- Neuronal



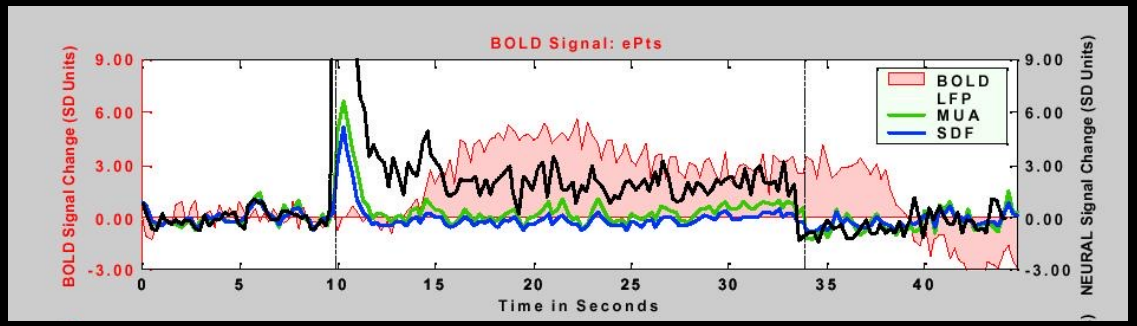


- Hemodynamic
  - Oxygen extraction
  - Blood volume dynamics

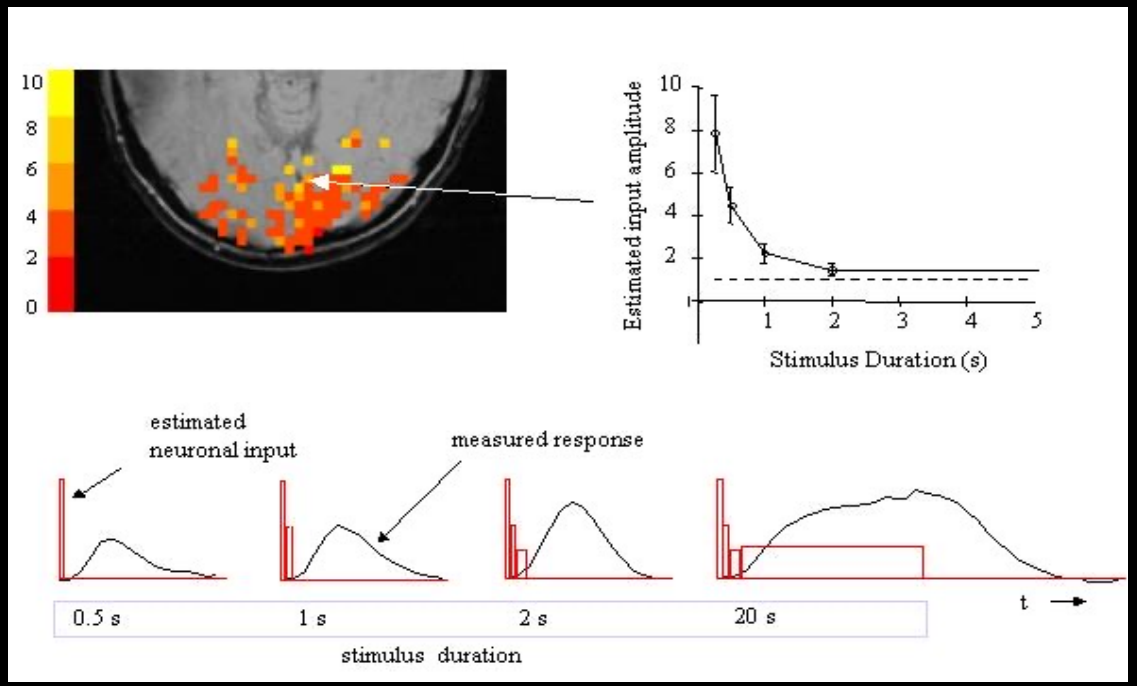


BOLD Correlation with Neuronal Activity

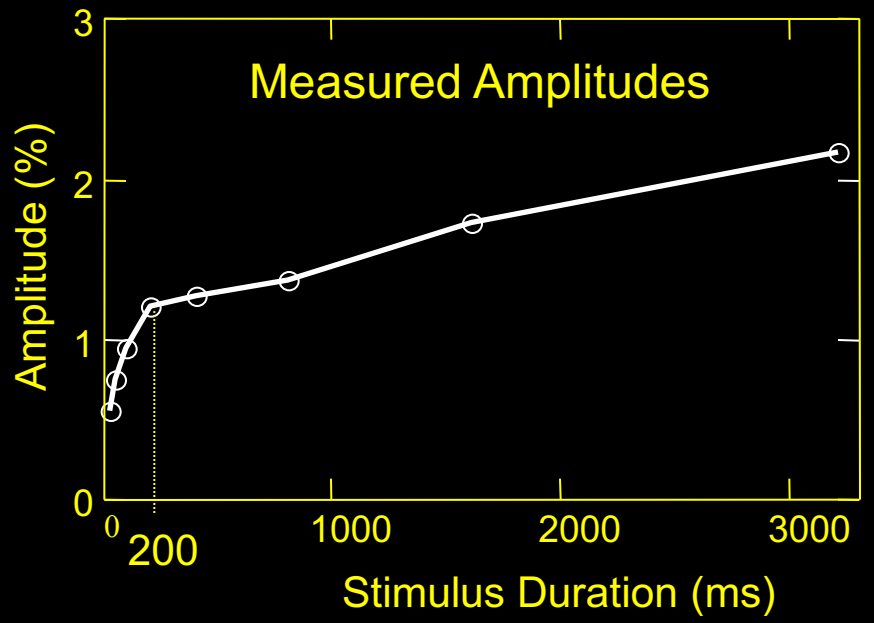
Logothetis et al. (2001) "Neurophysiological investigation of the basis of the fMRI signal" Nature, 412, 150-157.

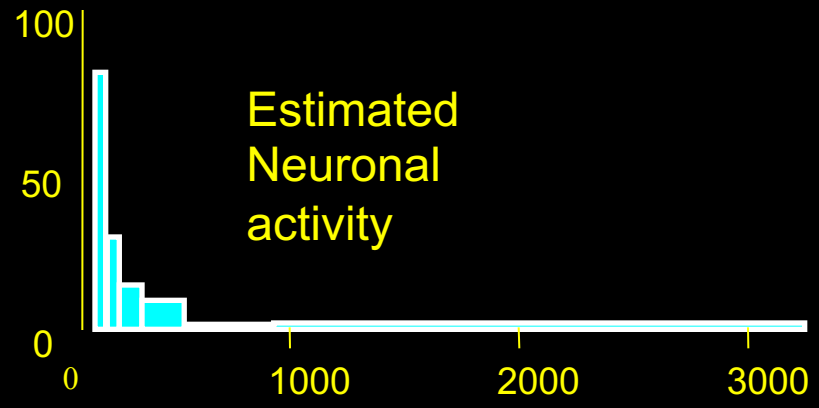


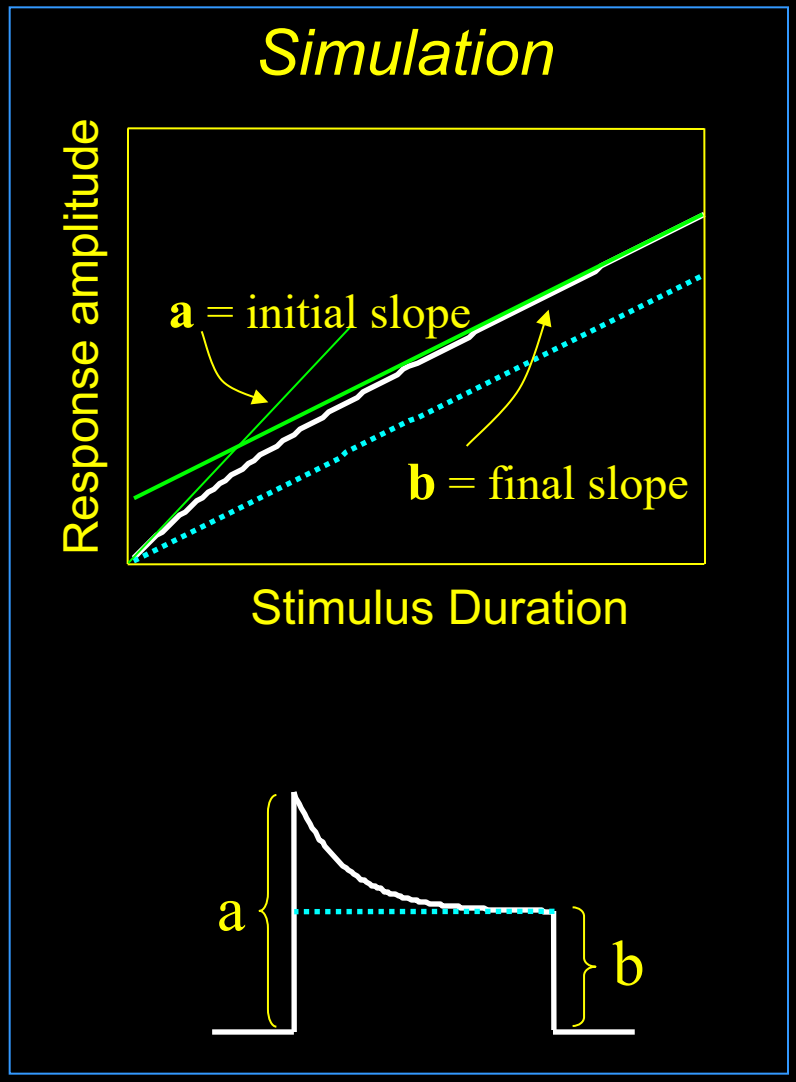
P. A. Bandettini and L. G. Ungerleider, (2001) "From neuron to BOLD: new connections." Nature Neuroscience, 4: 864-866.

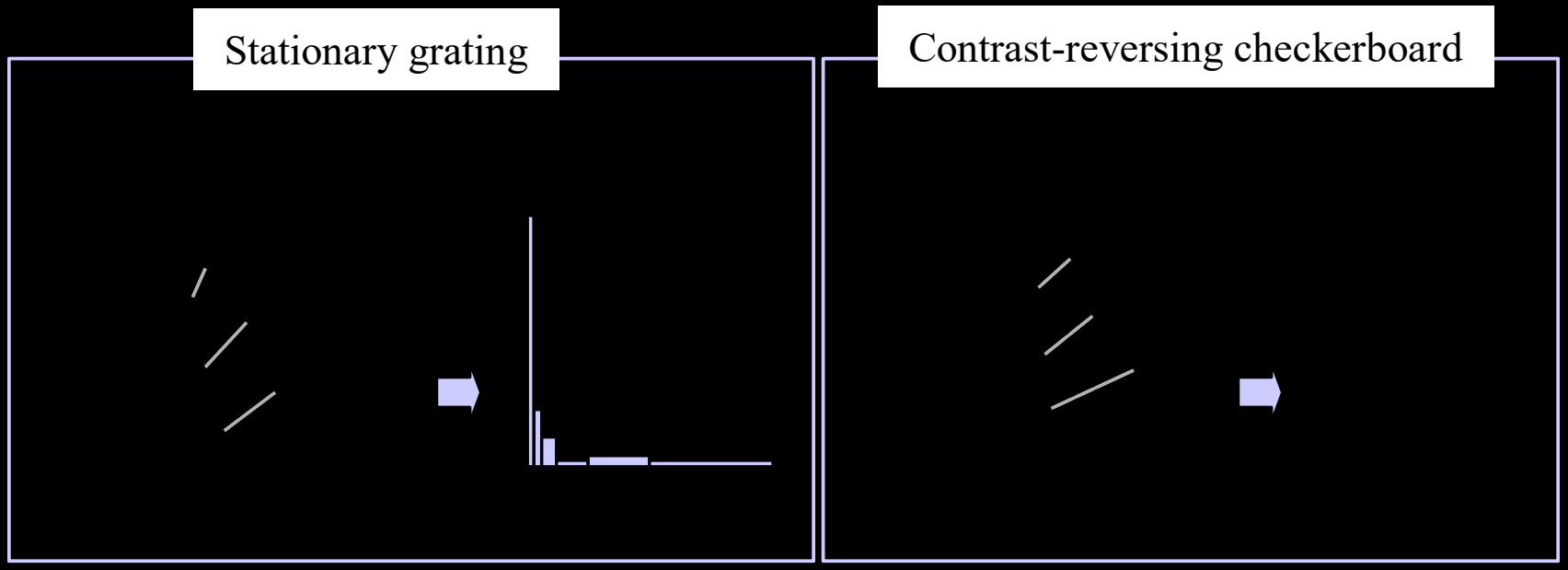


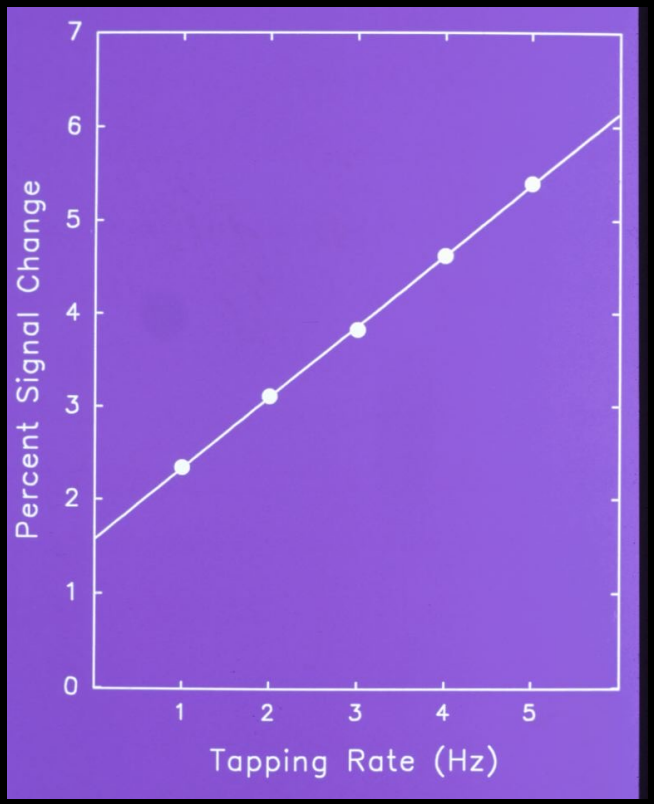
Results – constant gratings





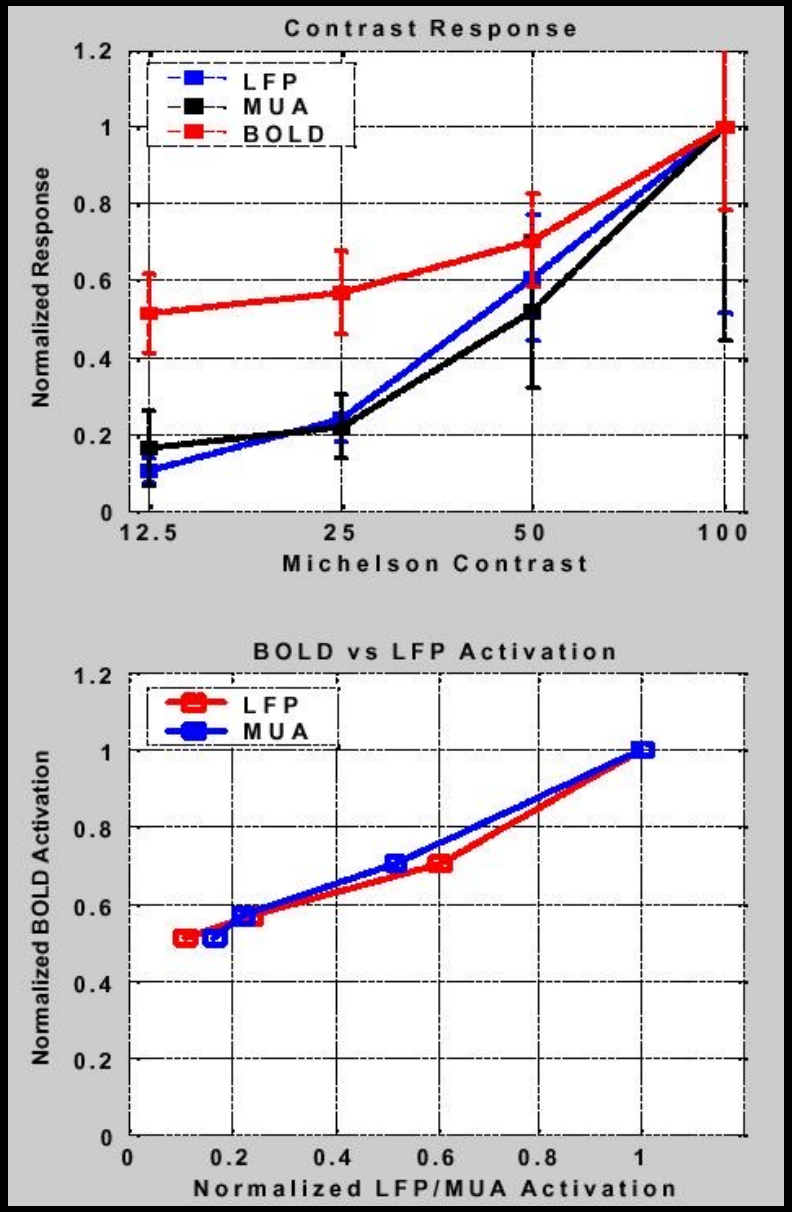



Stationary grating
Contrast-reversing checkerboard

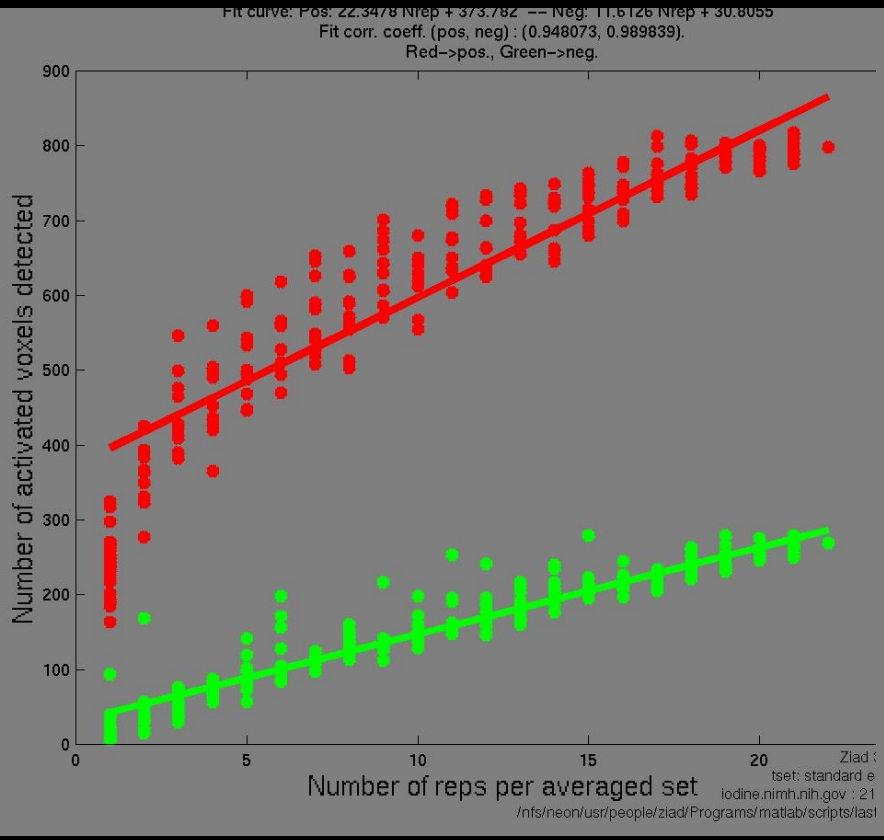


S. M. Rao et al, (1996) "Relationship between finger movement rate and functional magnetic resonance signal change in human primary motor cortex." *J. Cereb. Blood Flow and Met.* 16, 1250-1254.

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

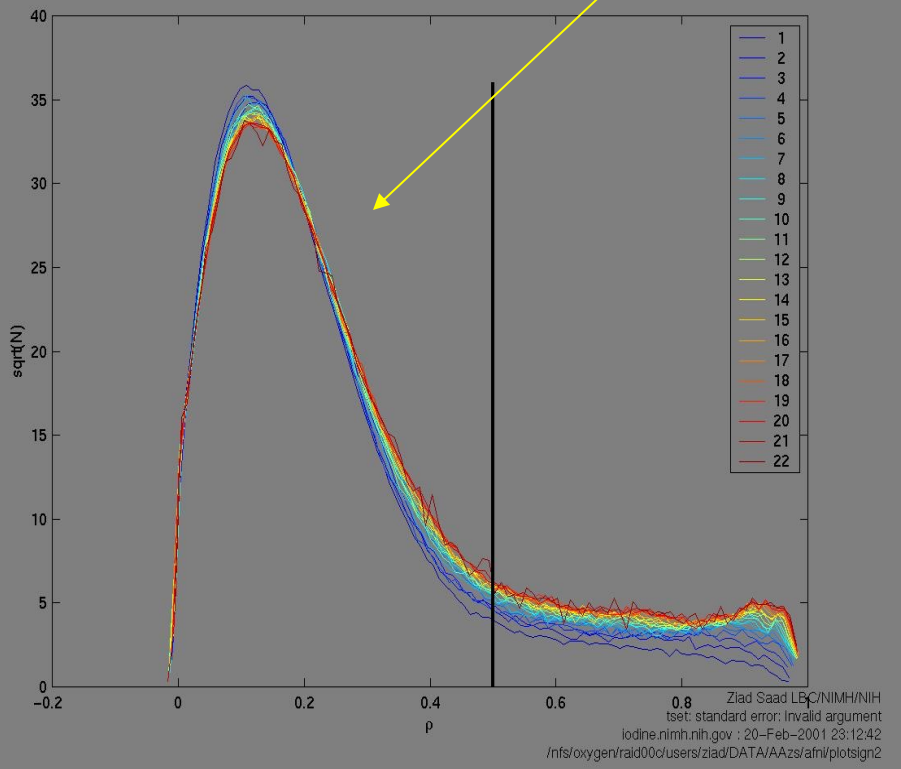


Continuously Growing Activation Area



CC Histogram

Inflection Point



Ziad Saad, et al (Submitted)

Systems Level
Neuronal Information Extraction

Latency
Magnitude

FIM Unit & FMRI Core Facility

Director:

Peter Bandettini

Staff Scientists:

Sean Marrett

Jerzy Bodurka

Frank Ye

Wen-Ming Luh

Computer Specialist:

Adam Thomas

Post Docs:

Rasmus Birn

Hauke Heekeren

David Knight

Patrick Bellgowan

Ziad Saad

Graduate Student:

Natalia Petridou

Post-Back. IRTA Students:

Elisa Kapler

August Tuan

Dan Kelley

Visiting Fellows:

Sergio Casciaro

Marta Maieron

Guosheng Ding

Clinical Fellow:

James Patterson

Psychologist:

Julie Frost

Summer Students:

Hannah Chang

Courtney Kemps

Douglass Ruff

Carla Wettig

Kang-Xing Jin

Program Assistant:

Kay Kuhns

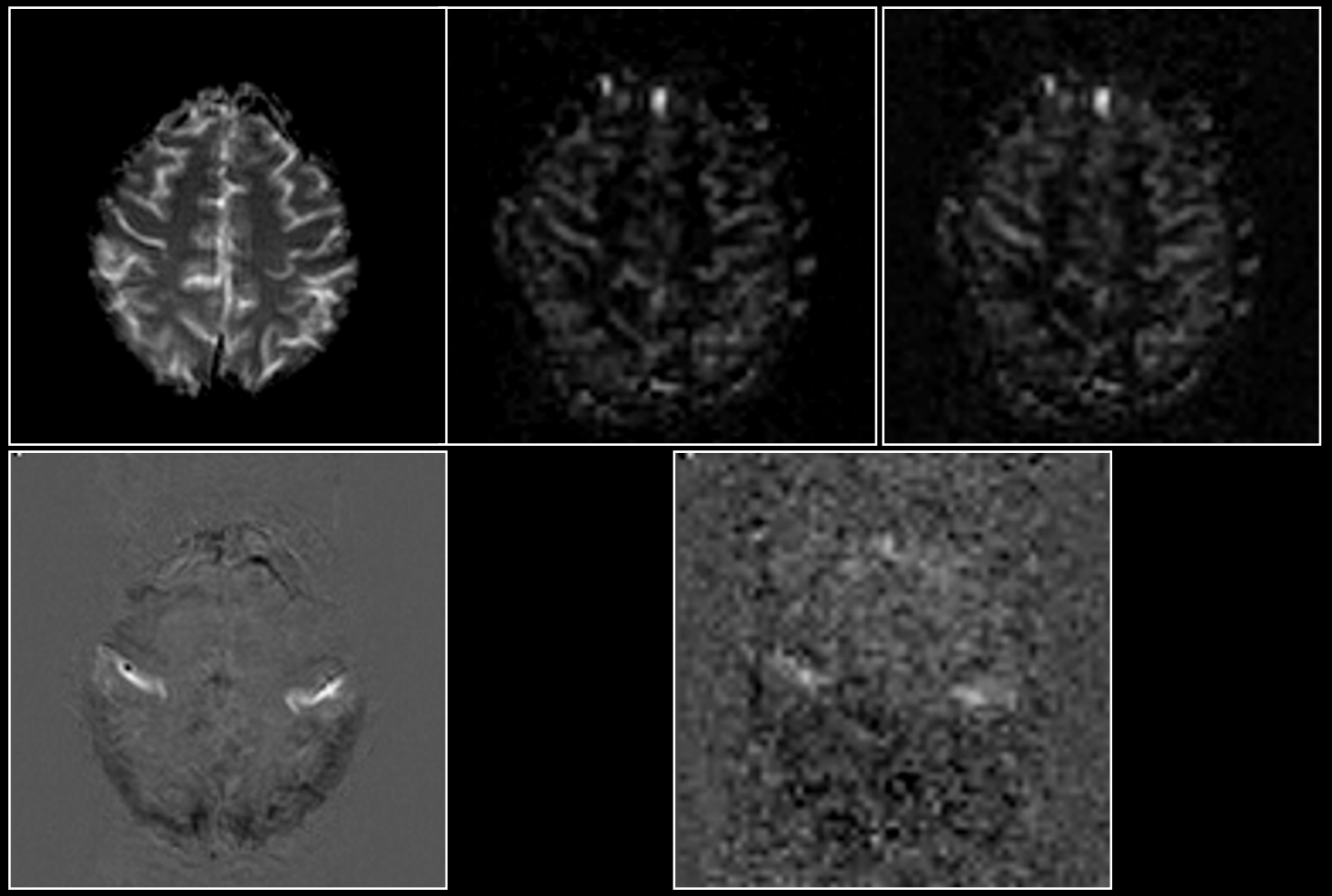
Scanning Technologists:

Karen Bove-Bettis

Paula Rowser

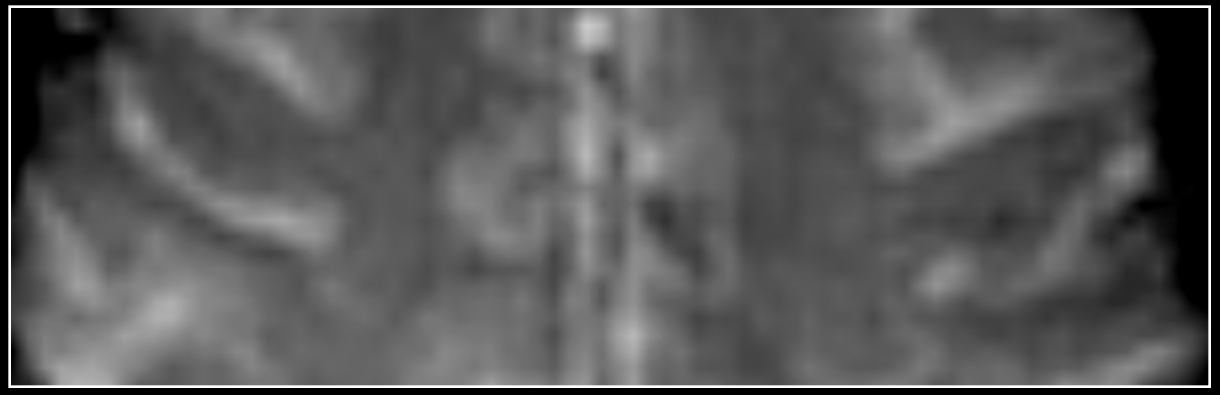
Perfusion

BOLD *Rest* *Activation*

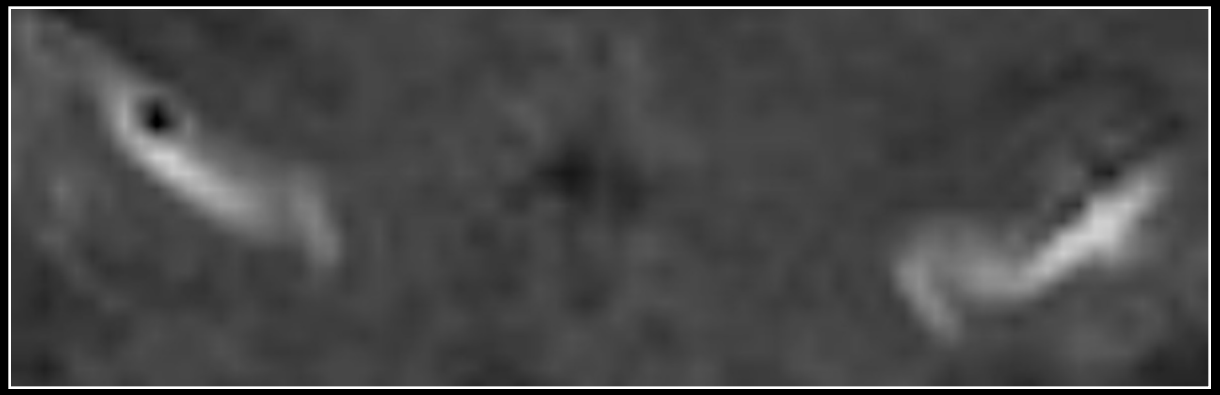


P. A. Bandettini, E. C. Wong, Magnetic resonance imaging of human brain function: principles, practicalities, and possibilities, *in* "Neurosurgery Clinics of North America: Functional Imaging" (M. Haglund, Ed.), p.345-371, W. B. Saunders Co., 1997.

Anatomy



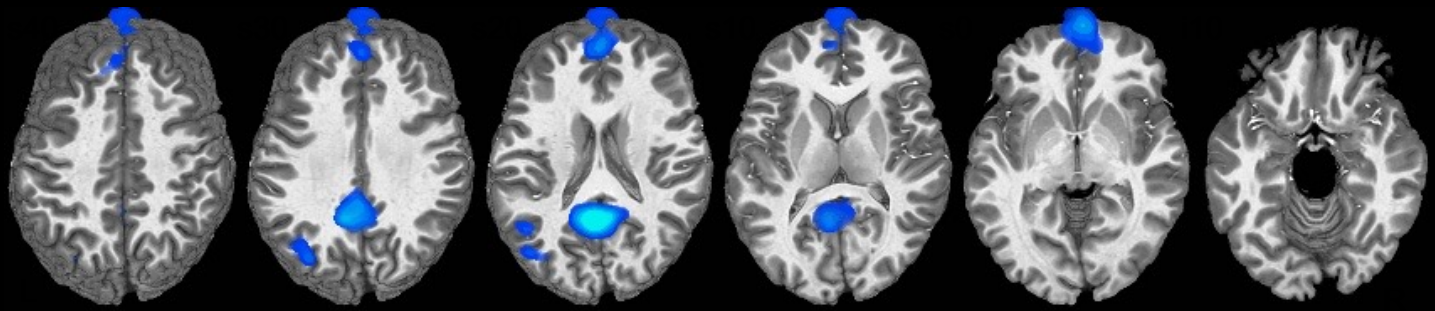
BOLD



Perfusion

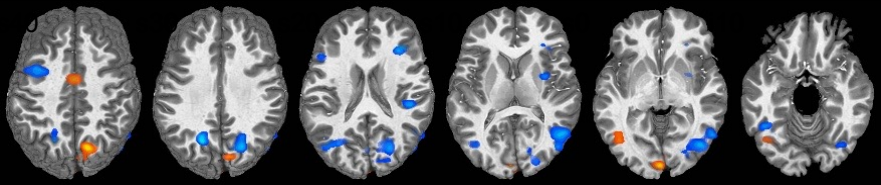
P. A. Bandettini, E. C. Wong, Magnetic resonance imaging of human brain function: principles, practicalities, and possibilities, *in* "Neurosurgery Clinics of North America: Functional Imaging" (M. Haglund, Ed.), p.345-371, W. B. Saunders Co., 1997.

Rotational effect maps

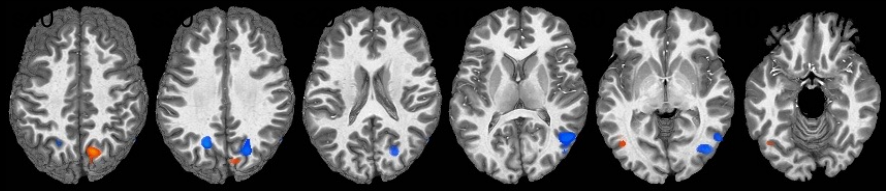


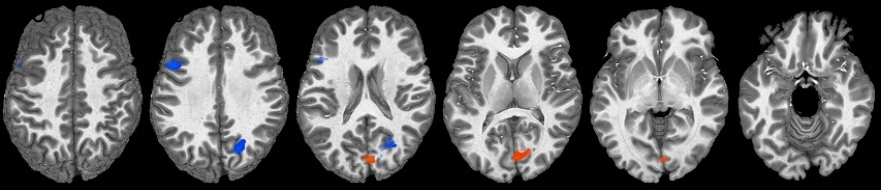
Non-rotated vs. 120° rotated

Non-rotated vs. 60° rotated

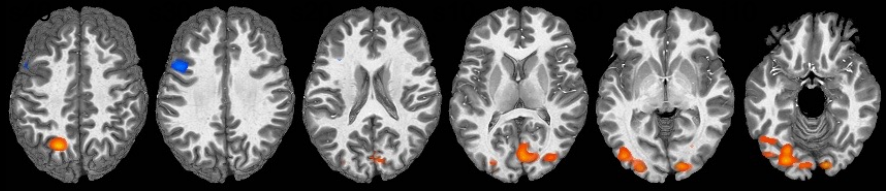


Delay





Width



Warm colors are areas where Non-rotated stimuli > rotated. Cool colors (blues) are areas where Rotated stimuli > Non-rotated. The Left hemisphere is toward the left margin.