Looking Into the "Noise" in Functional MRI

Peter A. Bandettini

Section on Functional Imaging Methods
Laboratory of Brain and Cognition
&
Functional MRI Facility

Section on Functional Imaging Methods

Rasmus Birn
David Knight
Anthony Boemio
Nikolaus Kriegeskorte
Kevin Murphy
Monica Smith
Najah Waters
Marieke Mur
Natalia Petridou
Jason Diamond

Functional MRI Facility

Kay Kuhns
Sean Marrett
Wen-Ming Luh
Jerzy Bodurka
Adam Thomas
Jon West

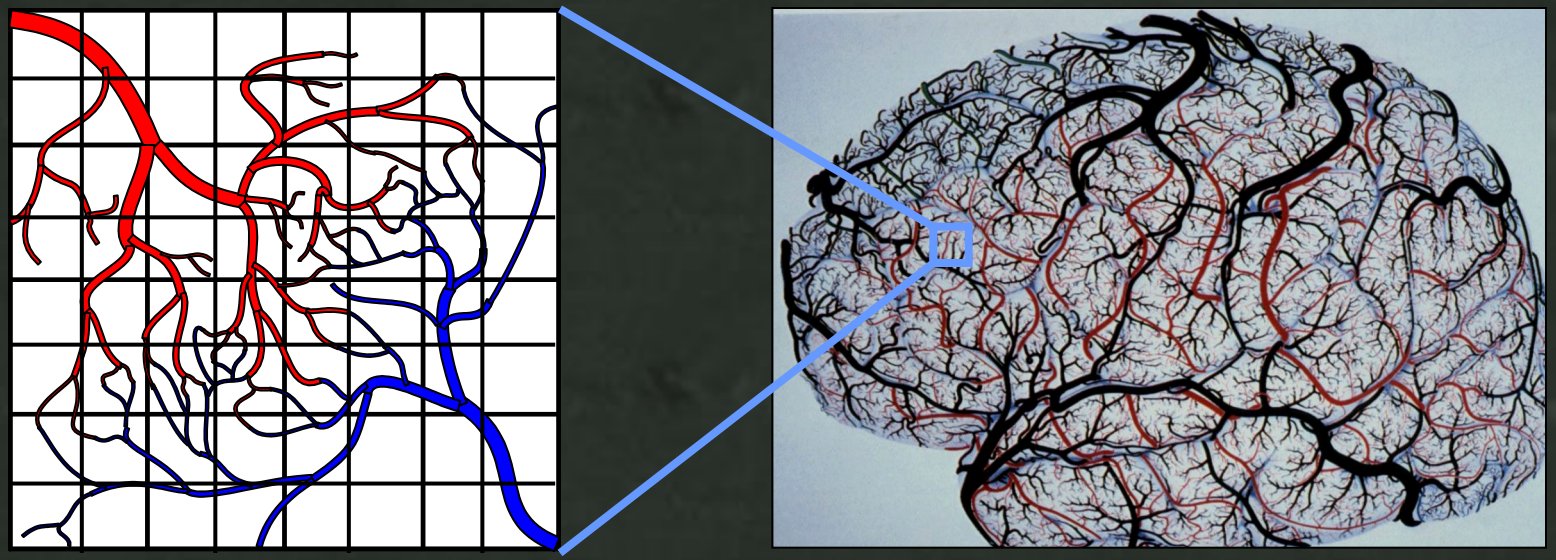
Karen Bove-Bettis
Ellen Condon
Sahra Omar
Alda Ottley
Paula Rowser
Janet Ebron

Neuronal Activation ⋯⋯▸ Measured Signal

?

? Hemodynamics ?

Noise ?



The Signal

The Hemodynamic Response Function
Spatial and Temporal Resolution
Interpretation

The "Noise"

Characteristics and Sources
Practical Issues

The Signal in the Noise

"Resting" State Connectivity
Physiologic Factors

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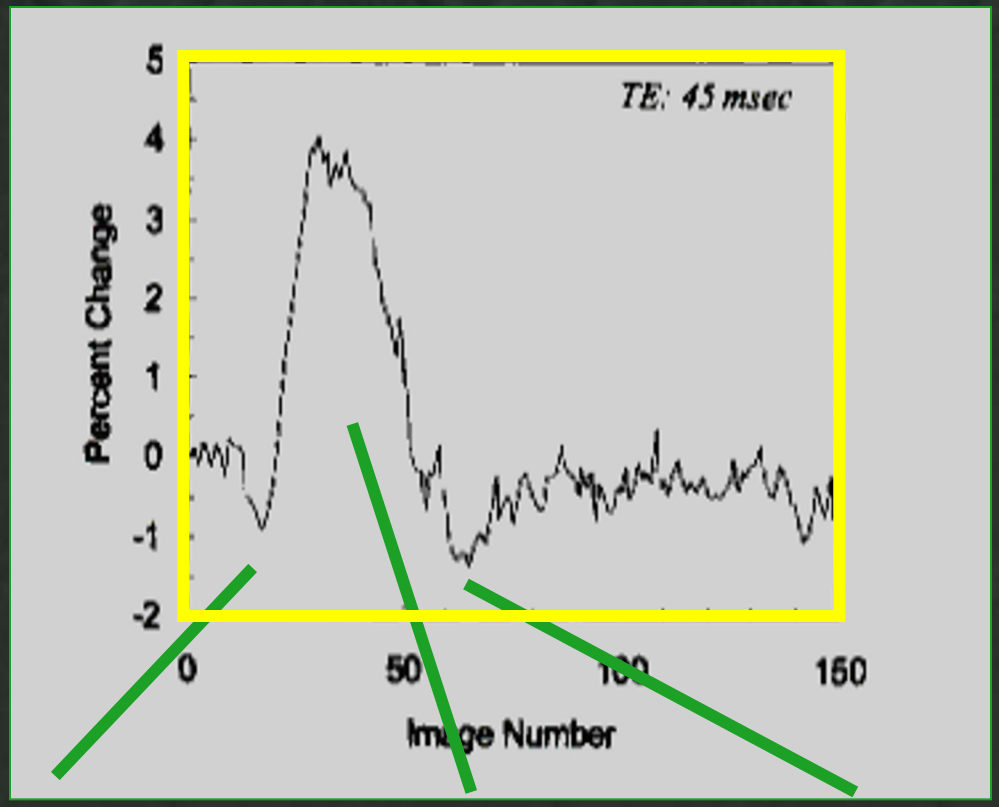
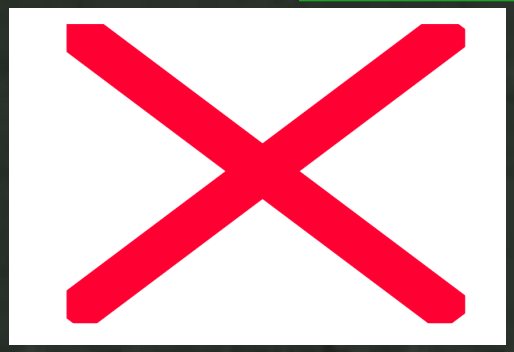
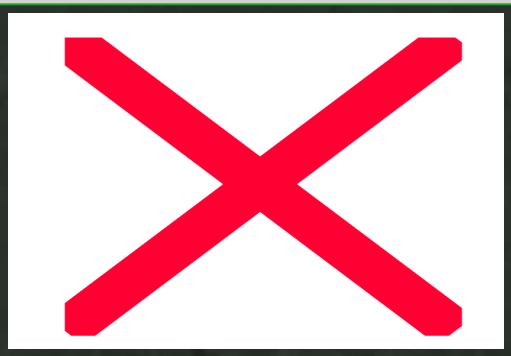
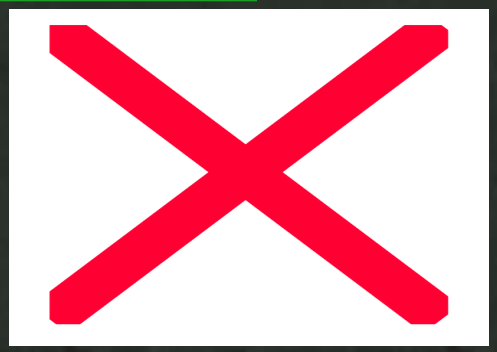
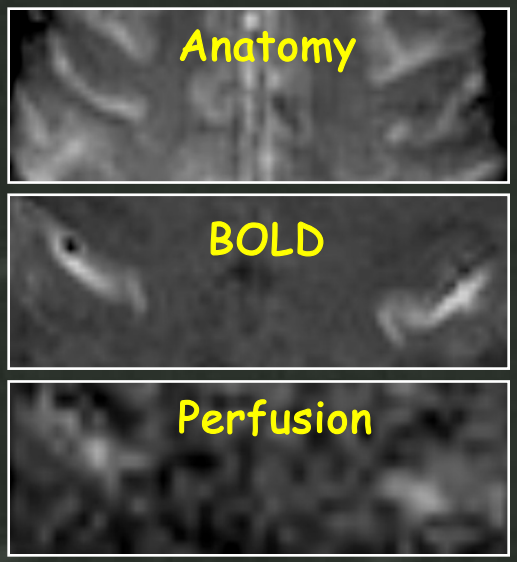






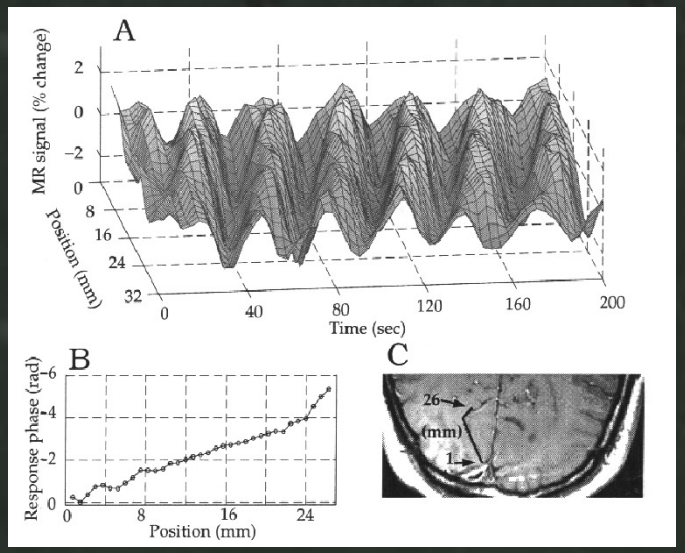


Spatial and Temporal Resolution



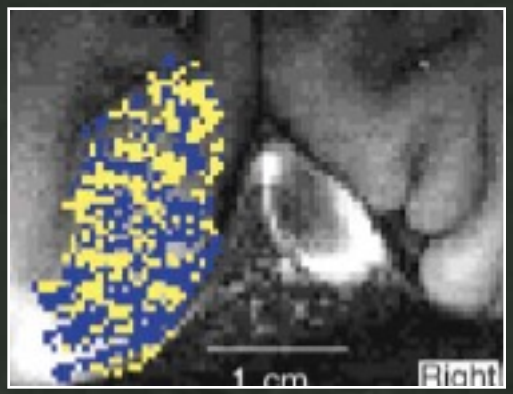
P. A. Bandettini, (1999) "Functional MRI" 205-220.

PSF FWHM = 3.5mm



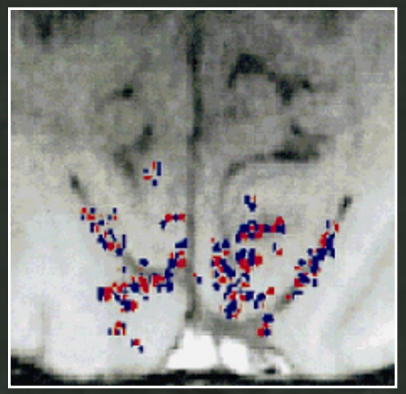
S.A. Engel, et al. Investigative Ophthalmology & Visual Science 35 (1994) 1977-1977.

0.47 x 0.47 in plane resolution



Cheng, et al. (2001) Neuron,32:359-374

0.54 x 0.54 in plane resolution



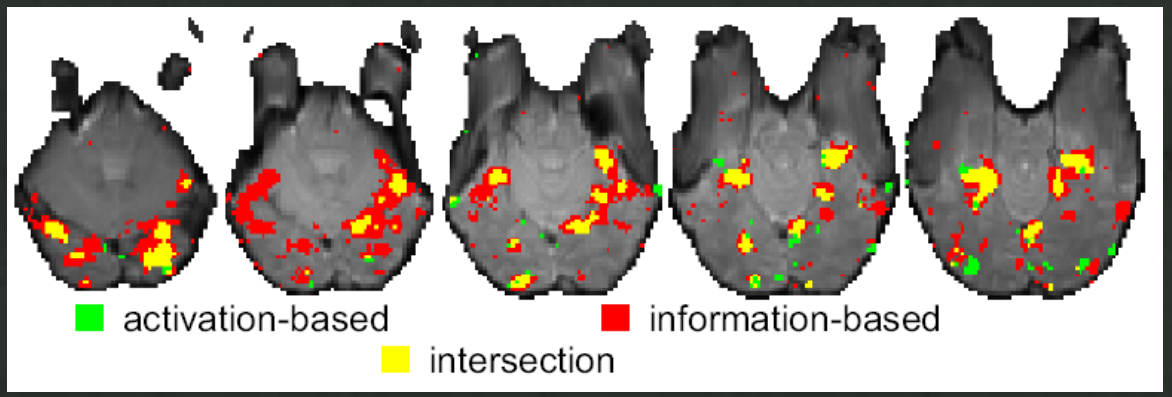
Menon et al, (1999) MRM 41 (2): 230-235

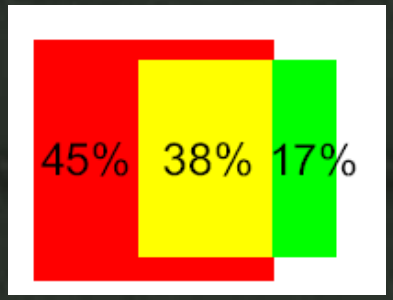
Multi-shot with navigator pulse

Activation-based **mapping: data smoothing**
(classical approach)

Information-based **mapping: local multivariate analysis**

volume scanned with MANCOVA searchlight→

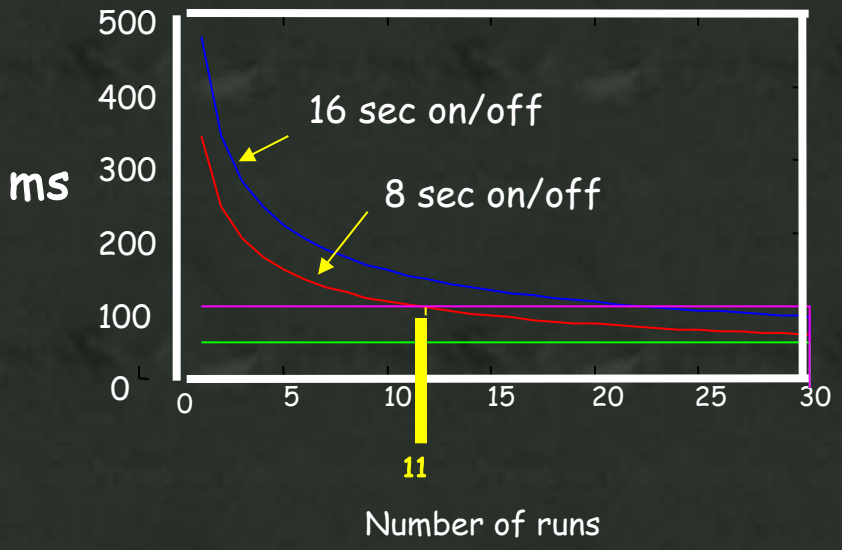




voxel sets

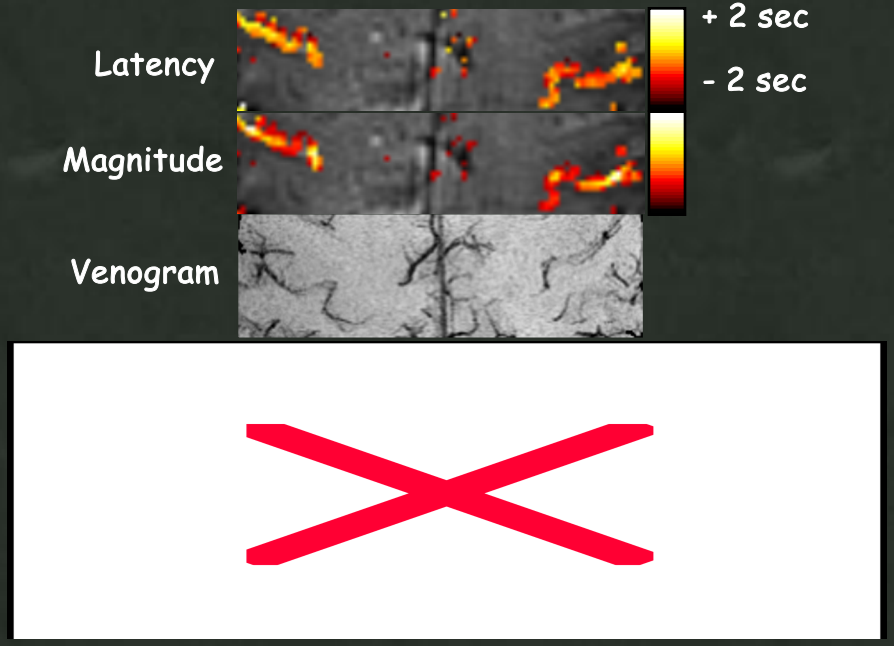
Spatial and Temporal Resolution

In an ideal world… no latency variation



R. Birn

Latency Variation…

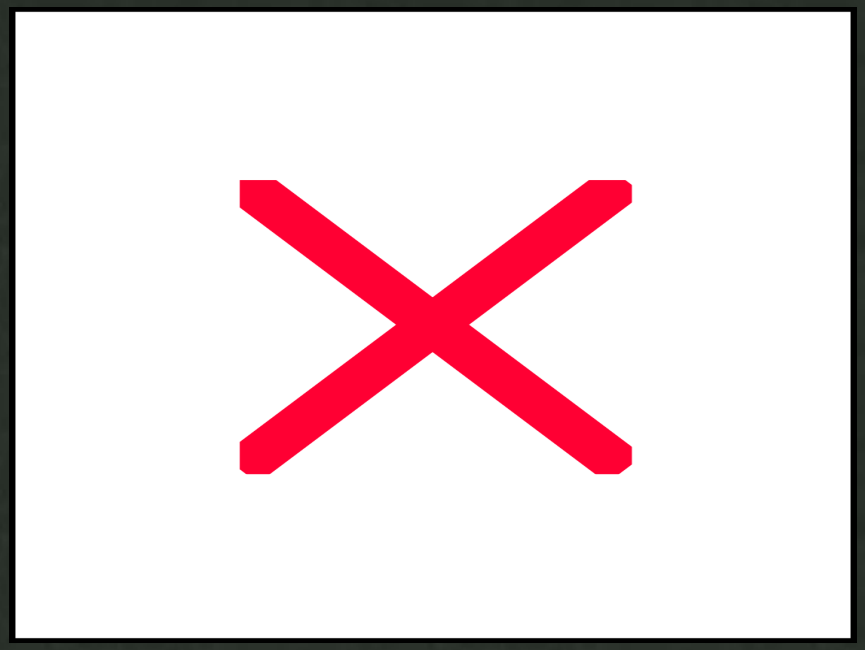


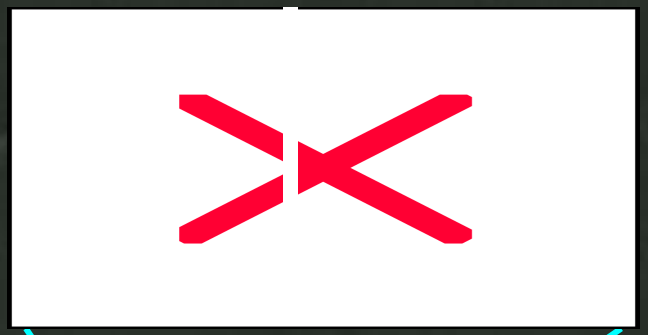
P. A. Bandettini, (1999) "Functional MRI" 205-220.

Spatial and Temporal Resolution

Word vs. Non-word

0°, 60°, 120° Rotation

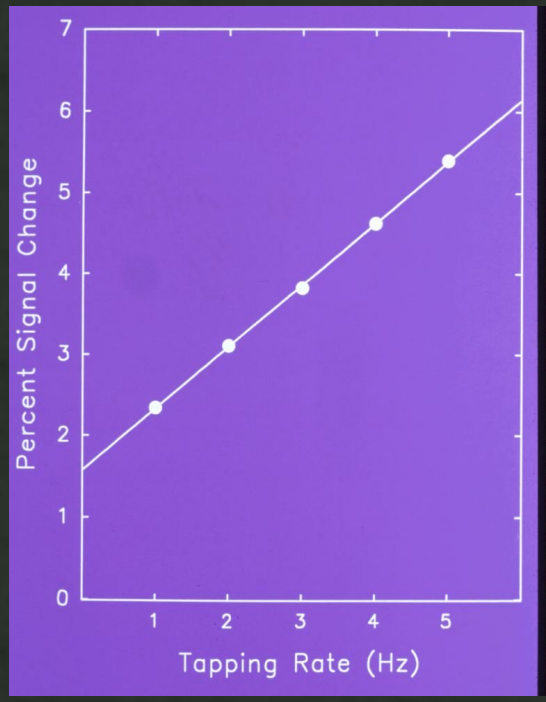




Bellgowan, et al (2003), PNAS 100, 15820–15283

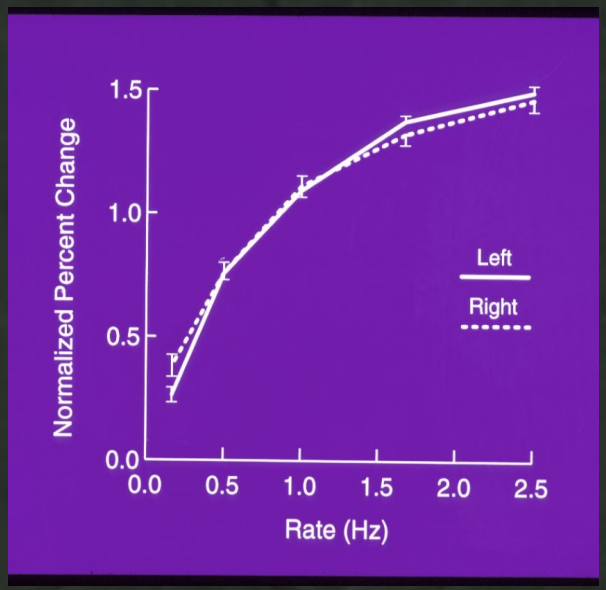
Interpretation

Motor Cortex

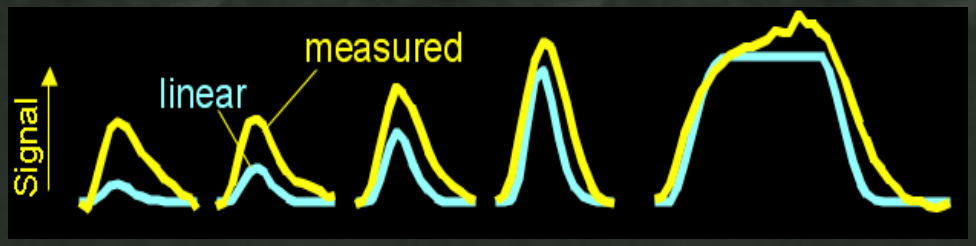


S. M. Rao et al, (1996) "Relationship between finger movement rate and functional magnetic resonance signal change in human primary motor cortex." *J. Cereb. Blood Flow and Met.* 16, 1250-1254.

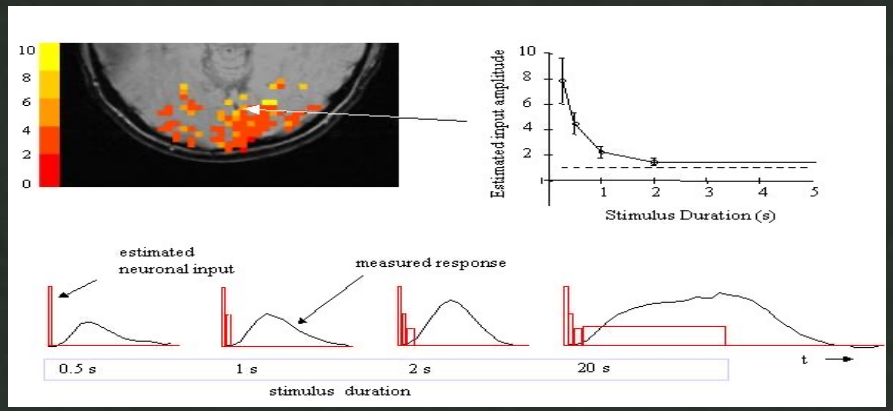
Auditory Cortex



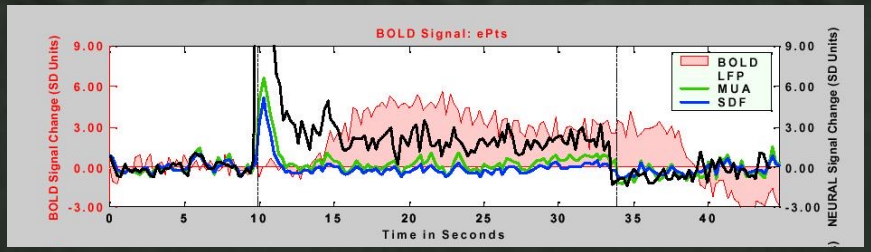
J. R. Binder, et al, (1994). "Effects of stimulus rate on signal response during functional magnetic resonance imaging of auditory cortex." *Cogn. Brain Res.* 2, 31-38



R. M. Birn, (2001) NeuroImage, 14: 817-826.



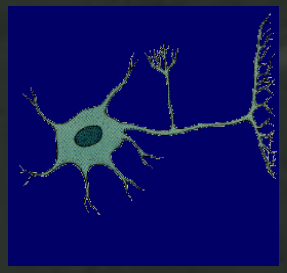
P. A. Bandettini et al, (2001) Nature Neuroscience, 4: 864-866.

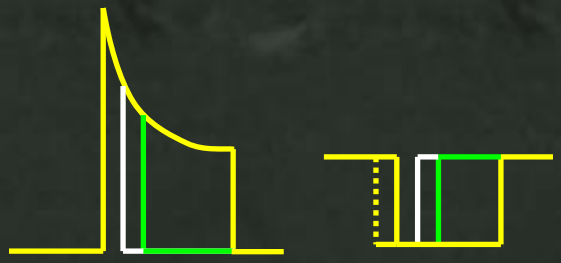


Logothetis et al. (2001) Nature, 412, 150-157.

Sources of this Nonlinearity

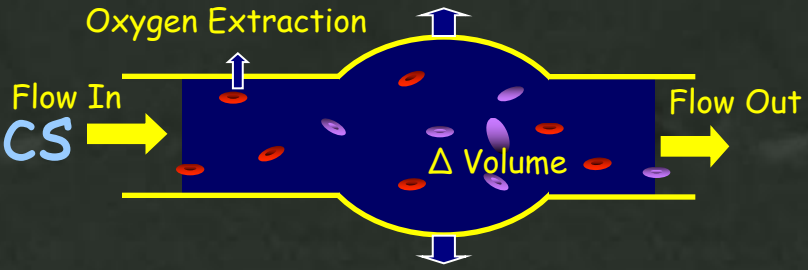
- Neuronal



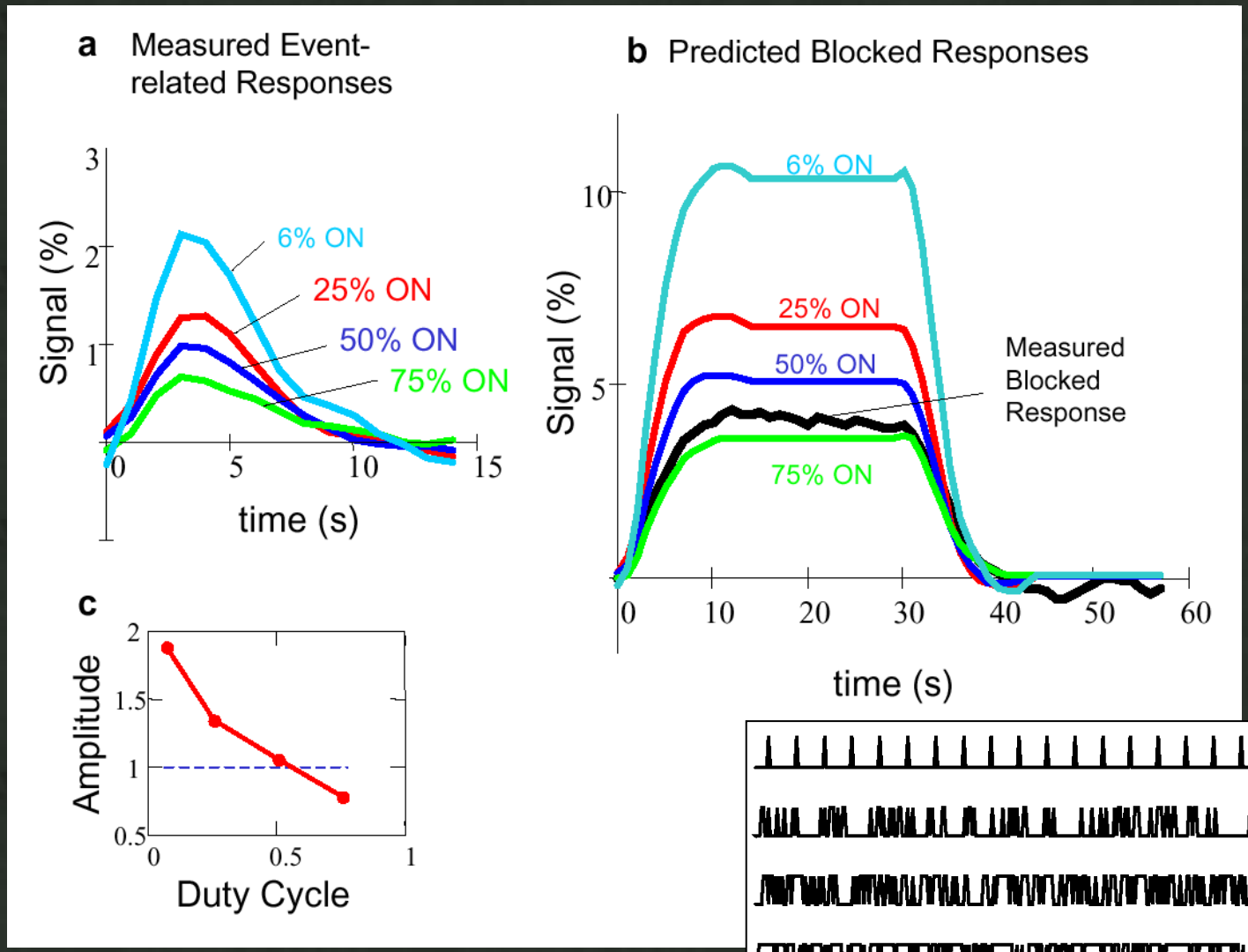


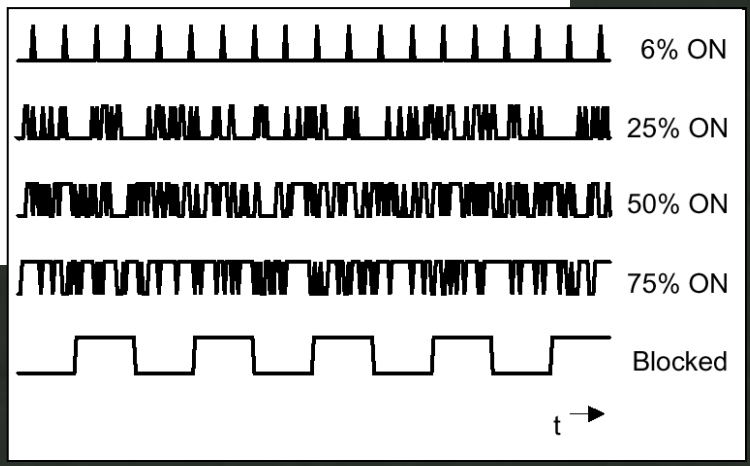
- Hemodynamic

  - Oxygen extraction
  - Blood volume dynamics



Interpretation





R.M. Birn, P. A. Bandettini. *NeuroImage, (in press)*

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"Resting" State Connectivity
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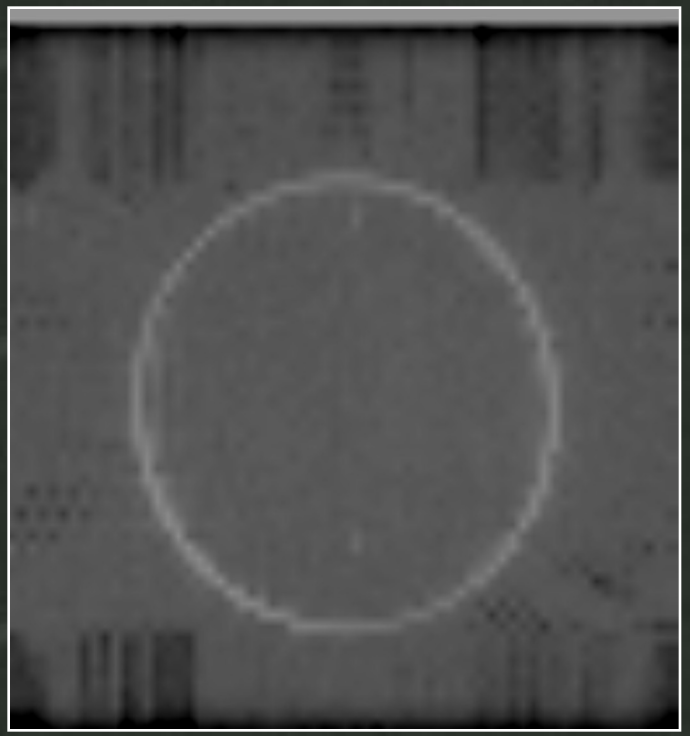
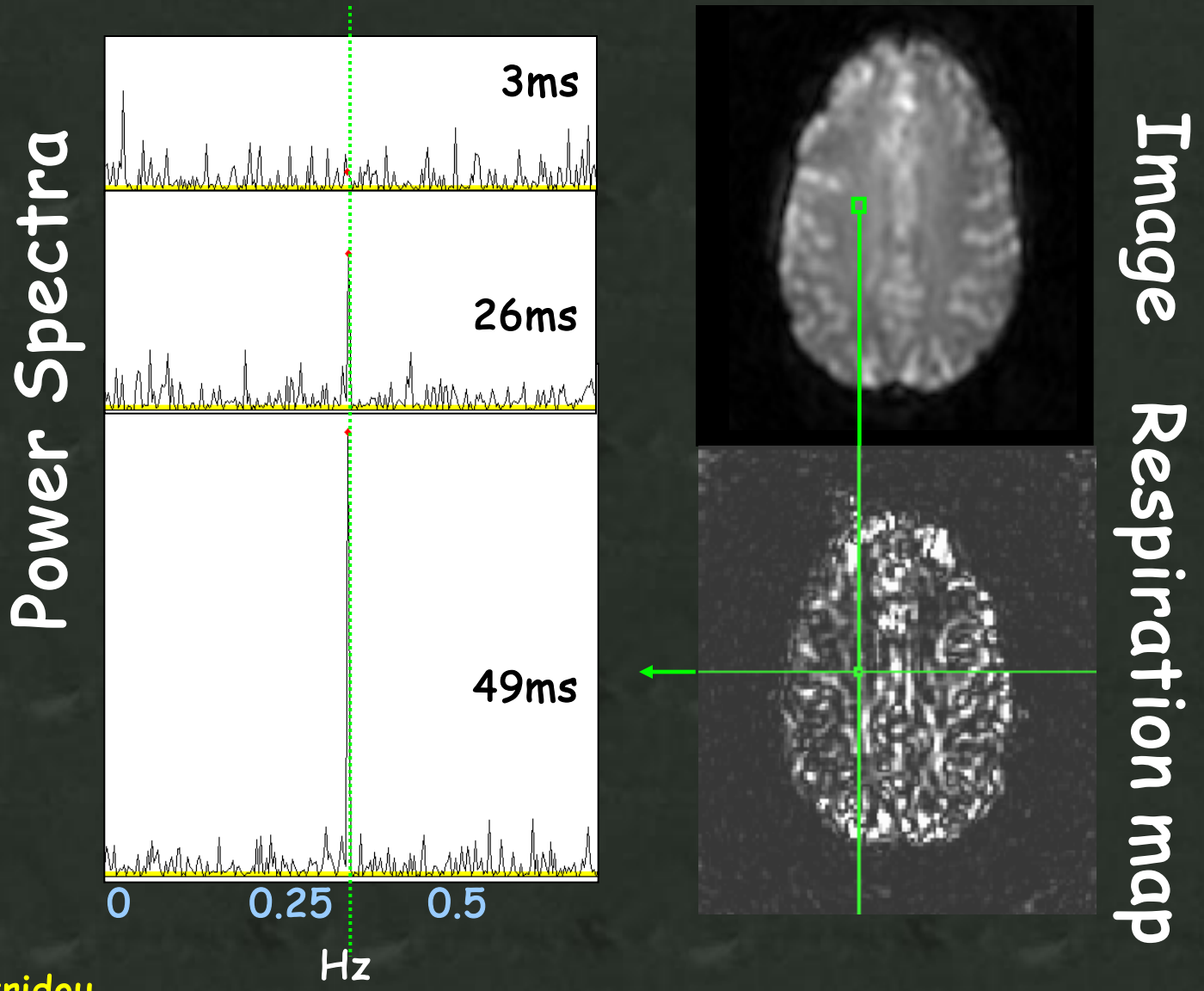
Characteristics and Sources

Phantom



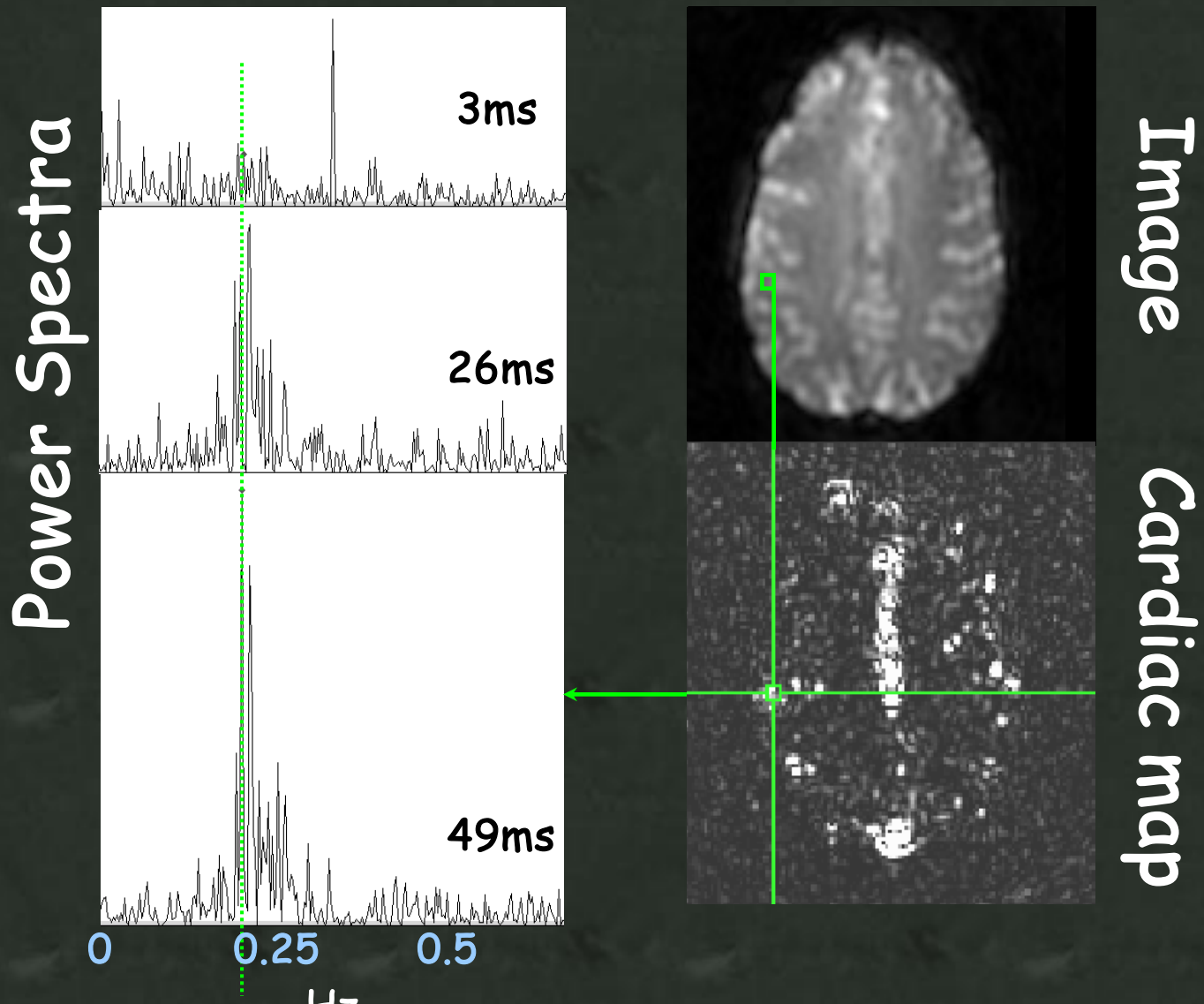
Brain

Direct Respiration Effects



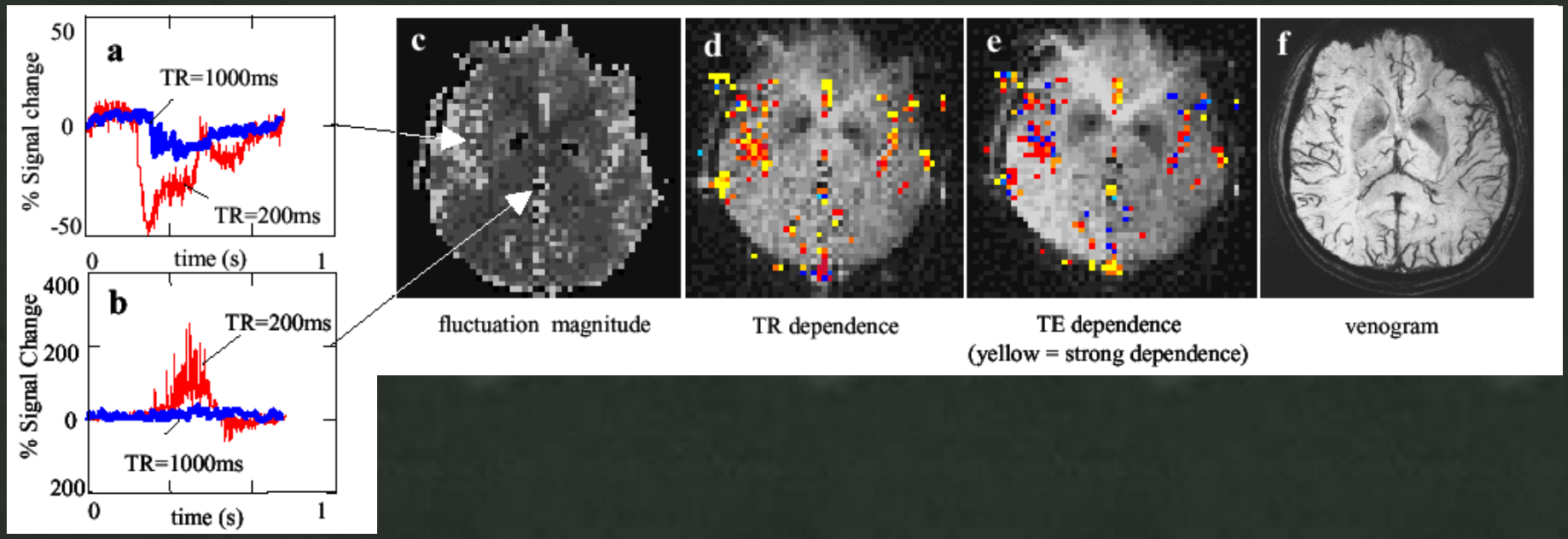
Characteristics and Sources

Direct Cardiac Effects



Characteristics and Sources

Cardiac "Transfer Function"



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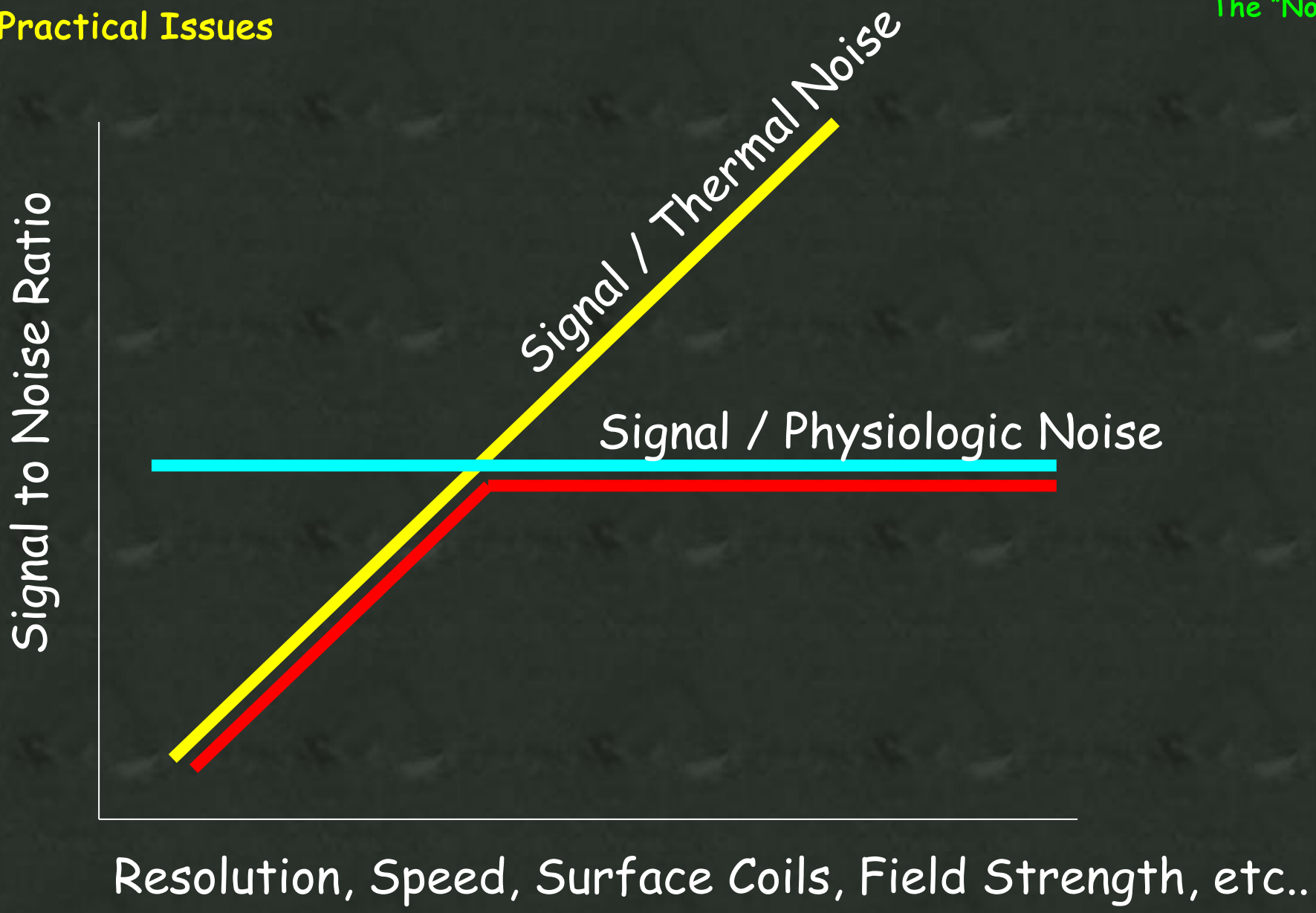
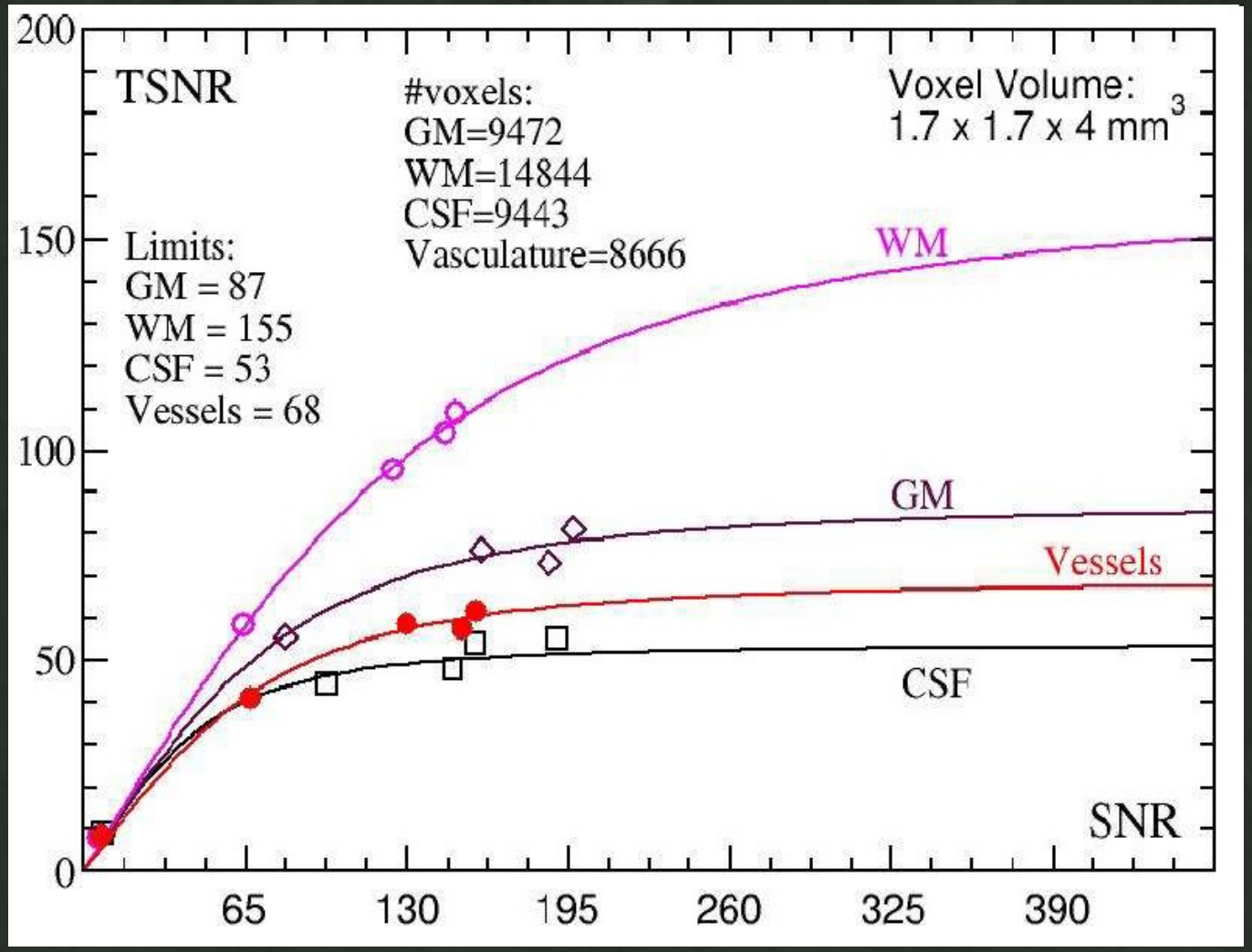
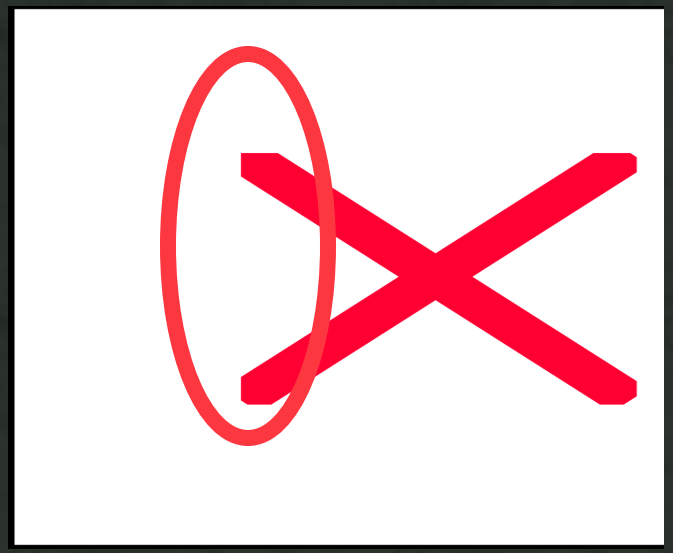
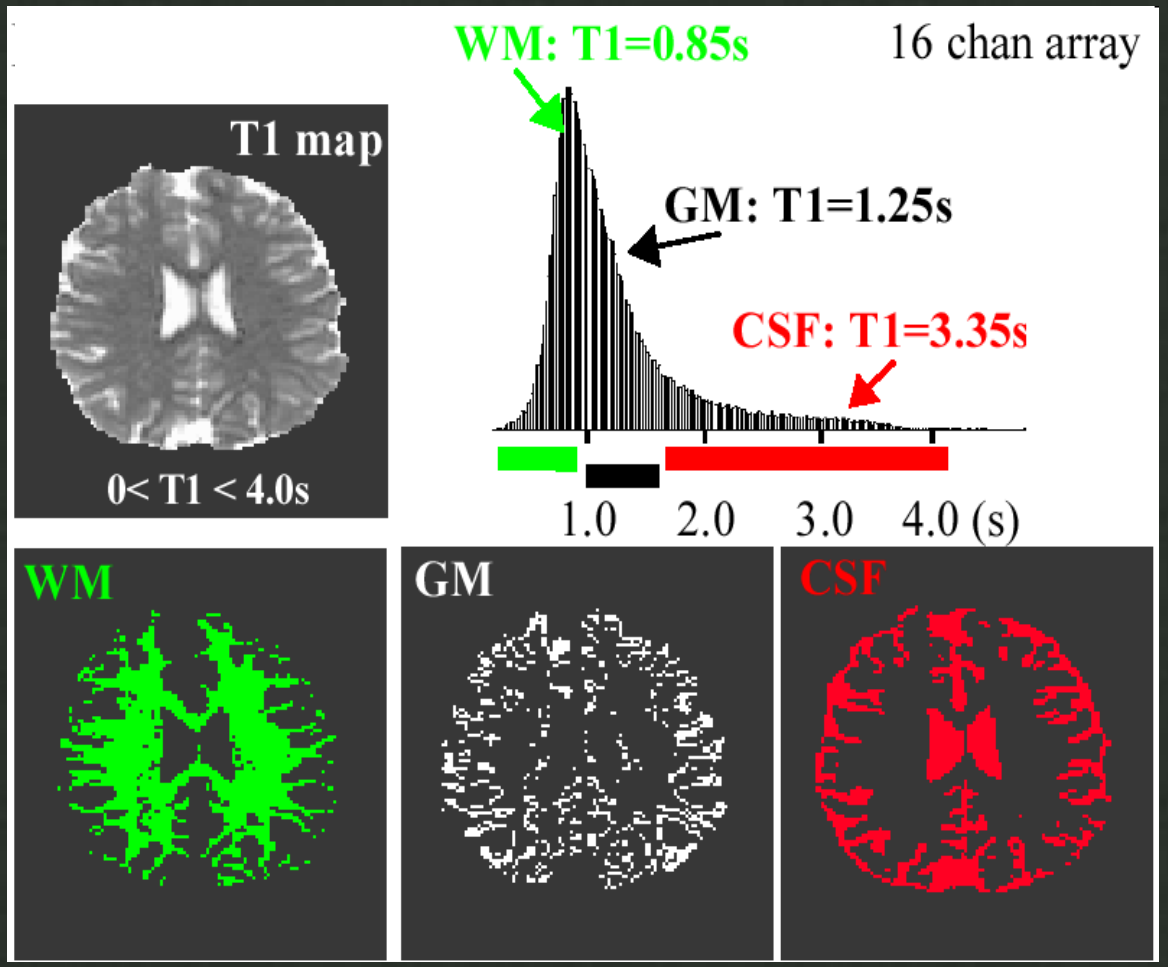

Signal to Noise Ratio
Signal / Thermal Noise
Signal / Physiologic Noise
Resolution, Speed, Surface Coils, Field Strength, etc..

Practical Issues



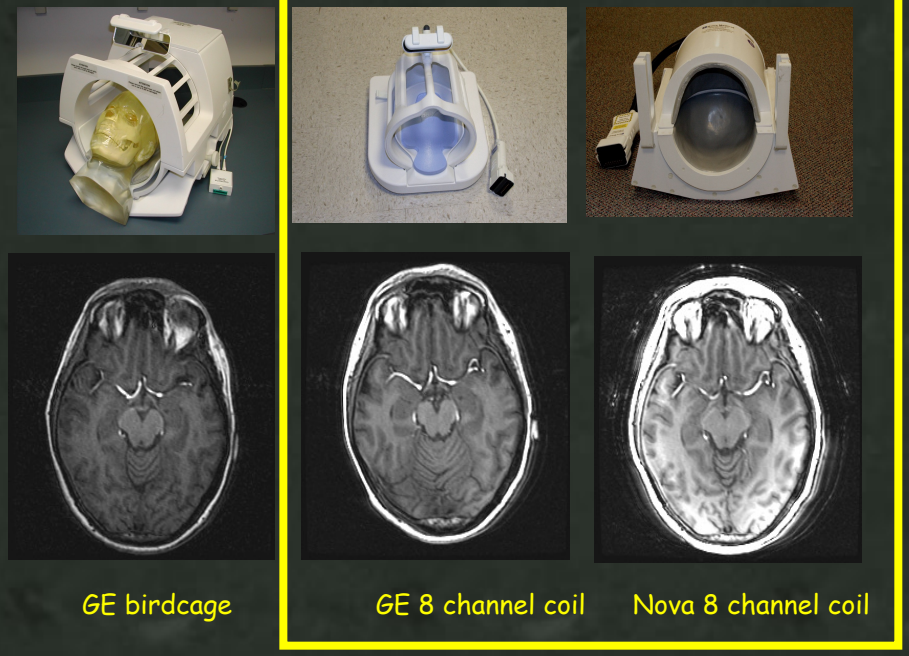
Segmentation using EPI Transient



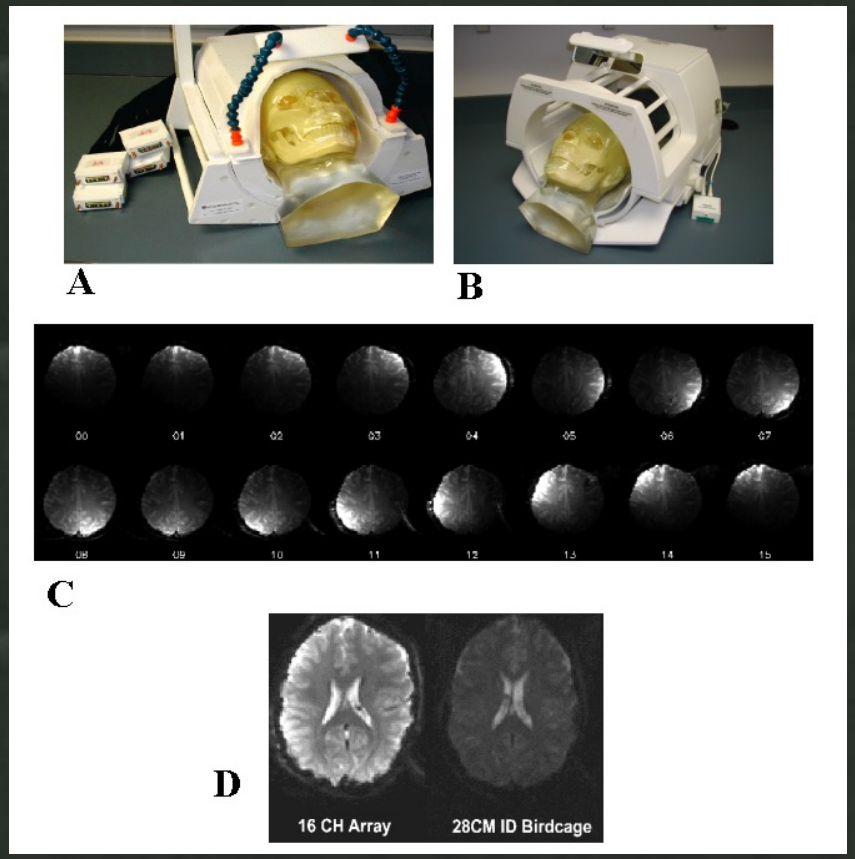


Practical Issues

8 channel parallel receiver coil

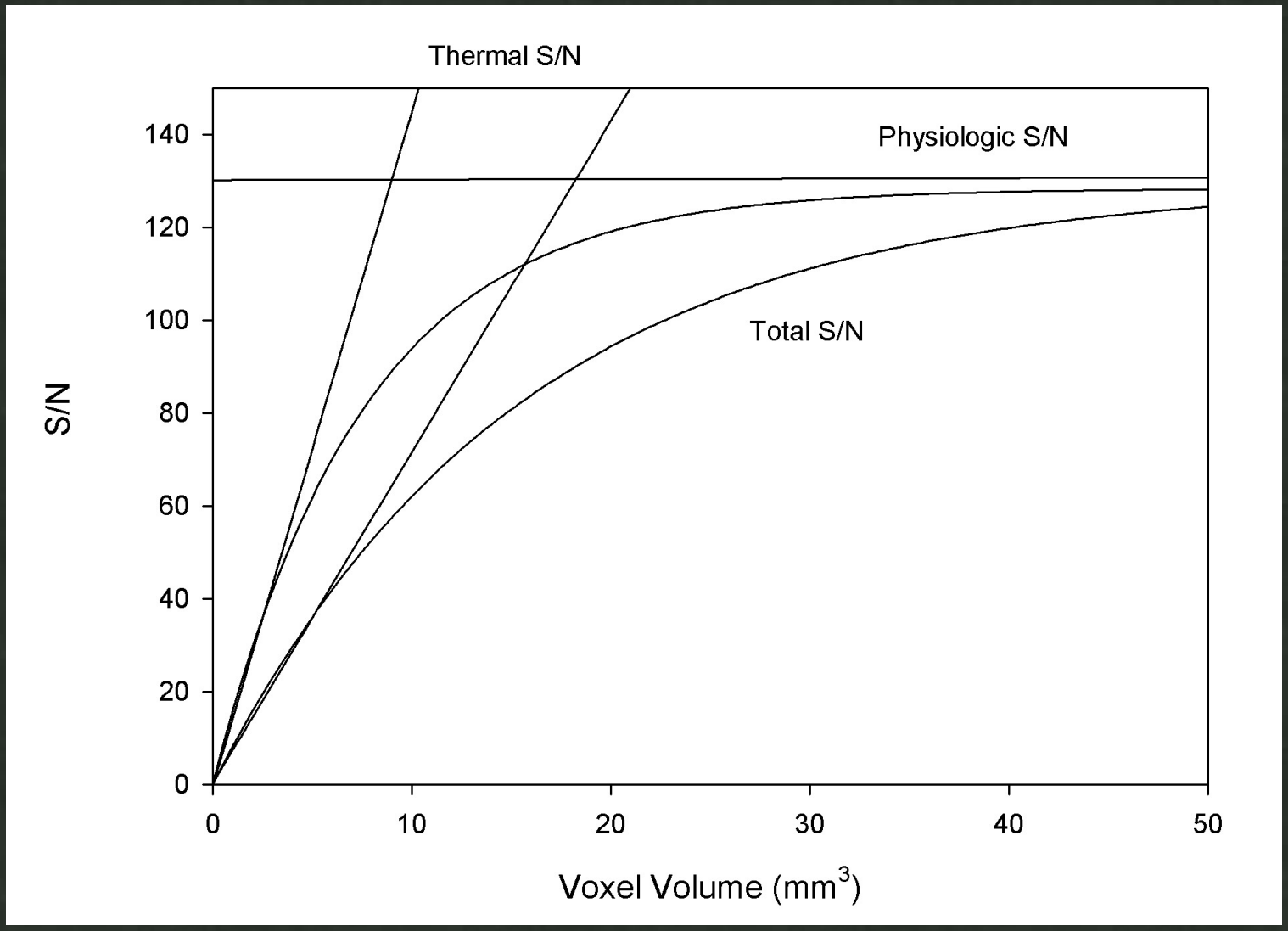


16 channel parallel receiver coil

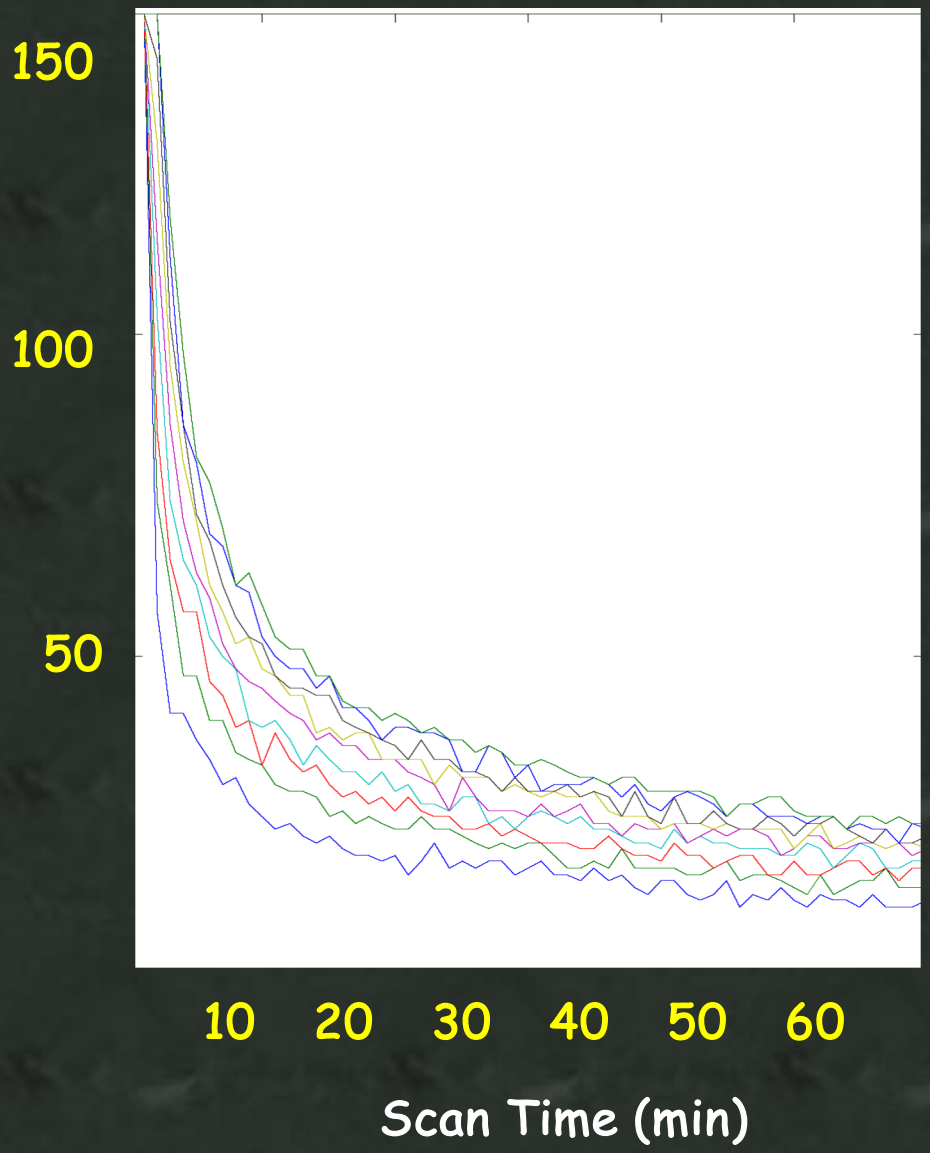


J. Bodurka, et al, Magnetic Resonance in Medicine 51 (2004) 165-171.

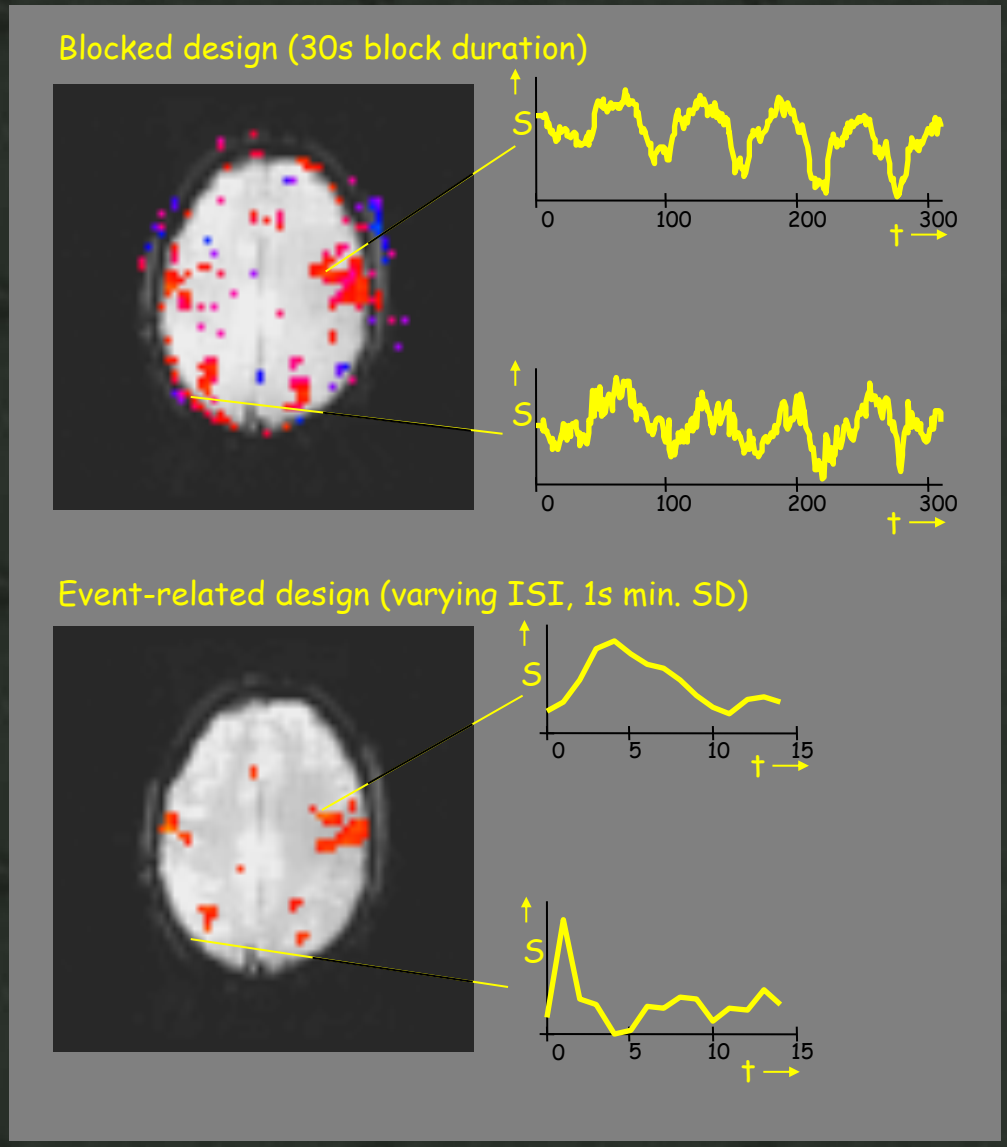
Simulated gains in TNSR with doubling sensitivity



Assuming a 2% signal change..

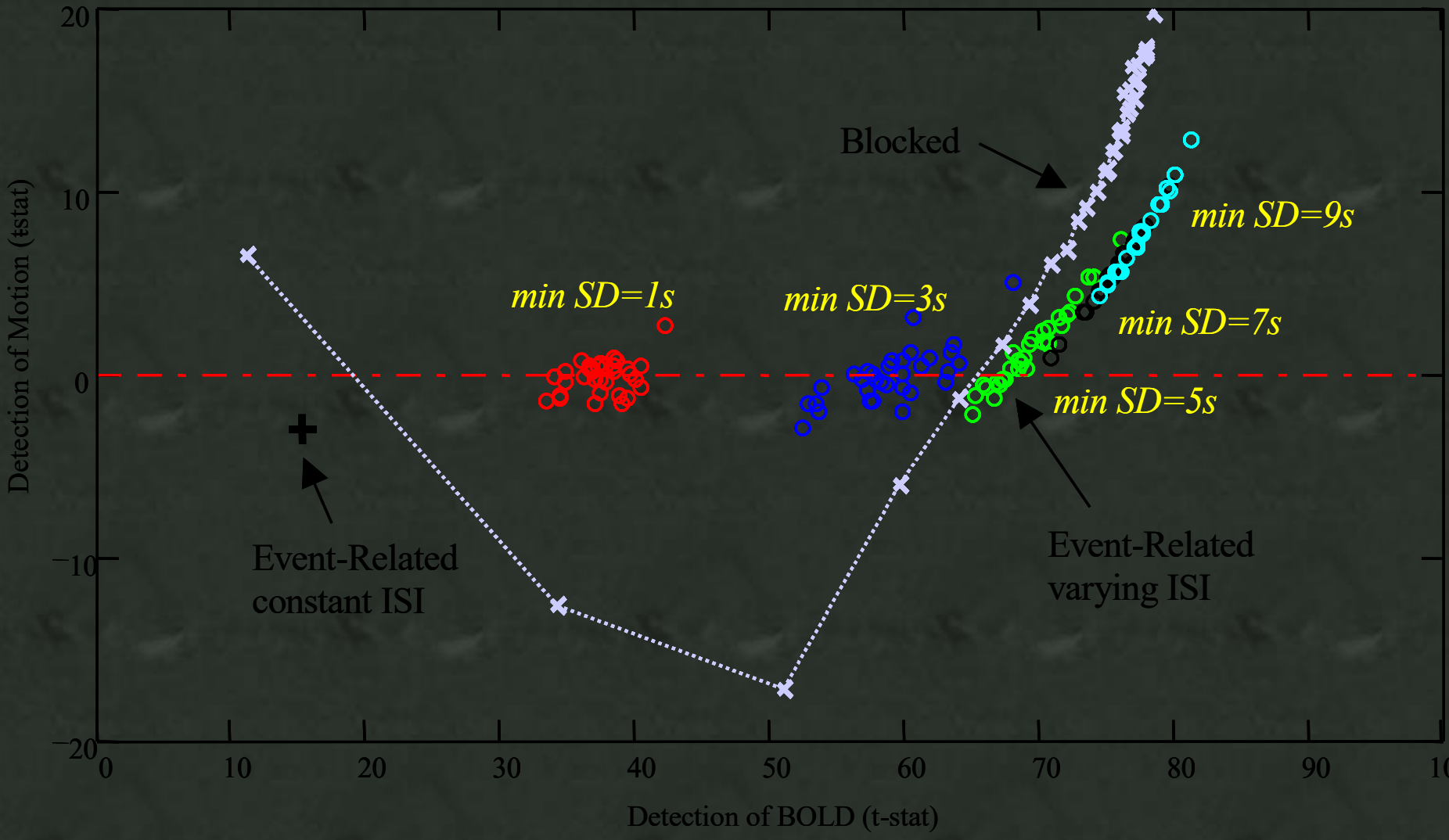


Stimulus Correlated Motion



R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

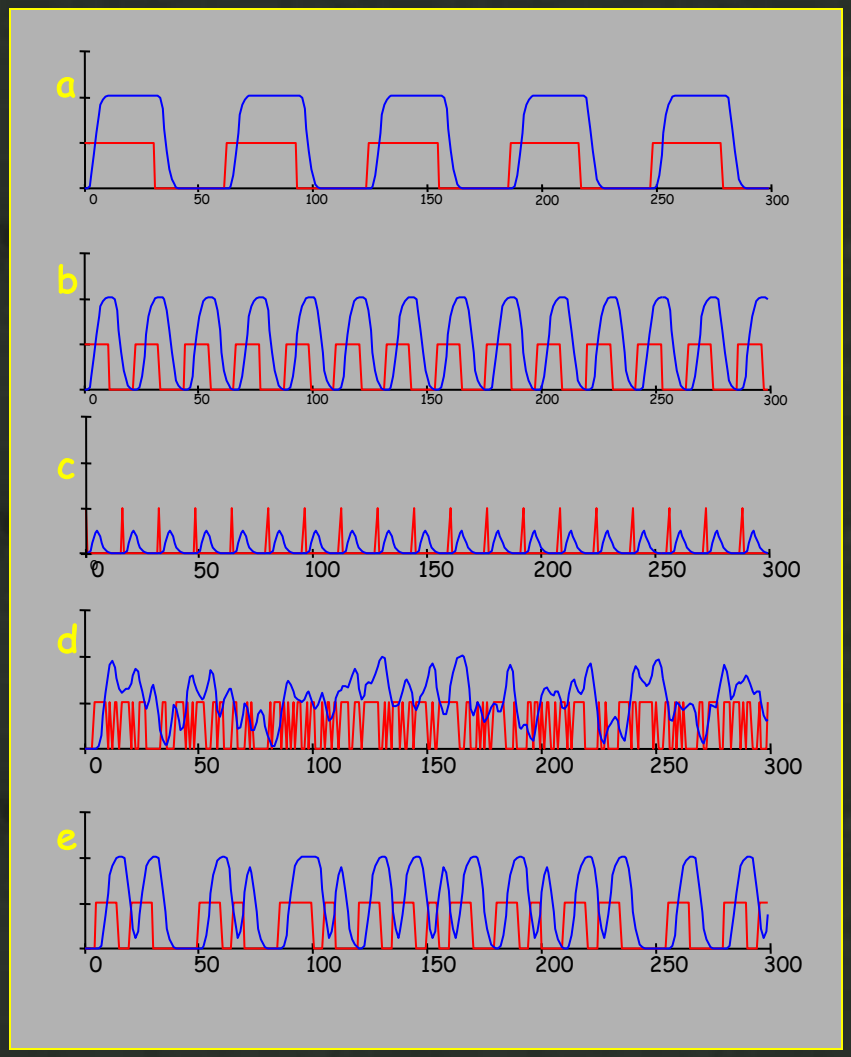
Stimulus Correlated Motion

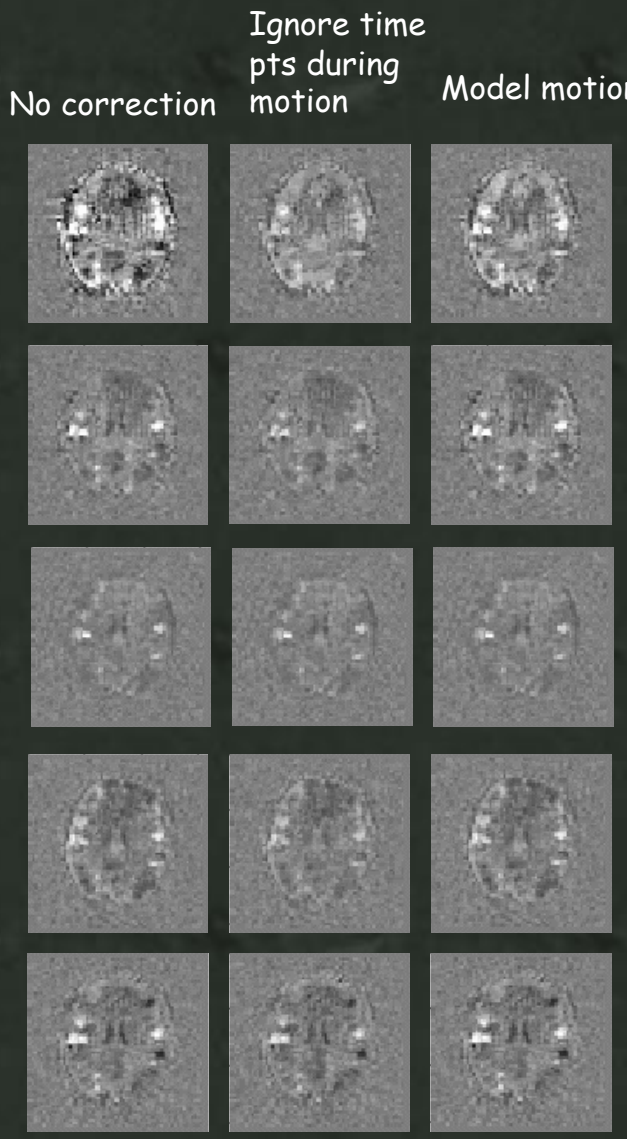


R.M. Birn, R. W. Cox, P. A. Bandettini. *NeuroImage,* 23 1046-1058 (2004)

Practical Issues

Working around stimulus correlated motion





R.M. Birn, R. W. Cox, P. A. Bandettini. *NeuroImage,* 23 1046-1058 (2004)

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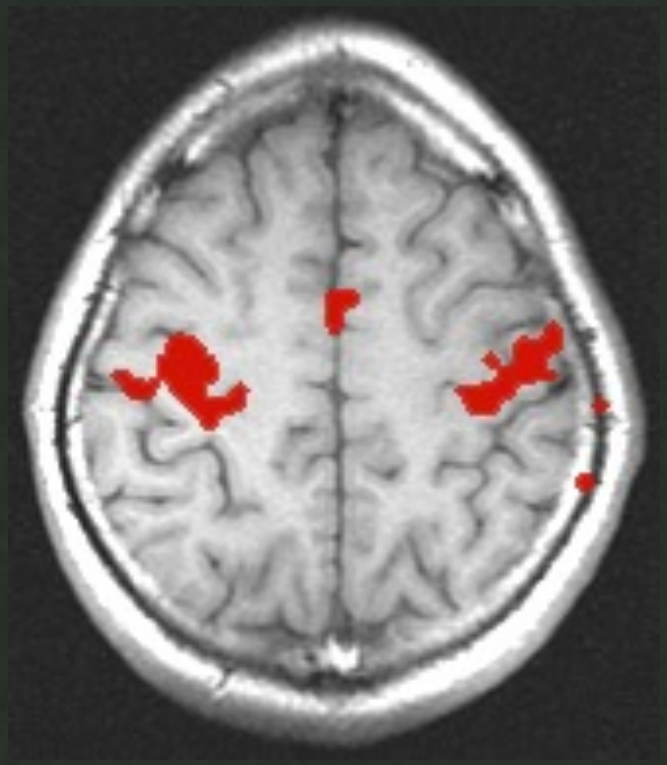
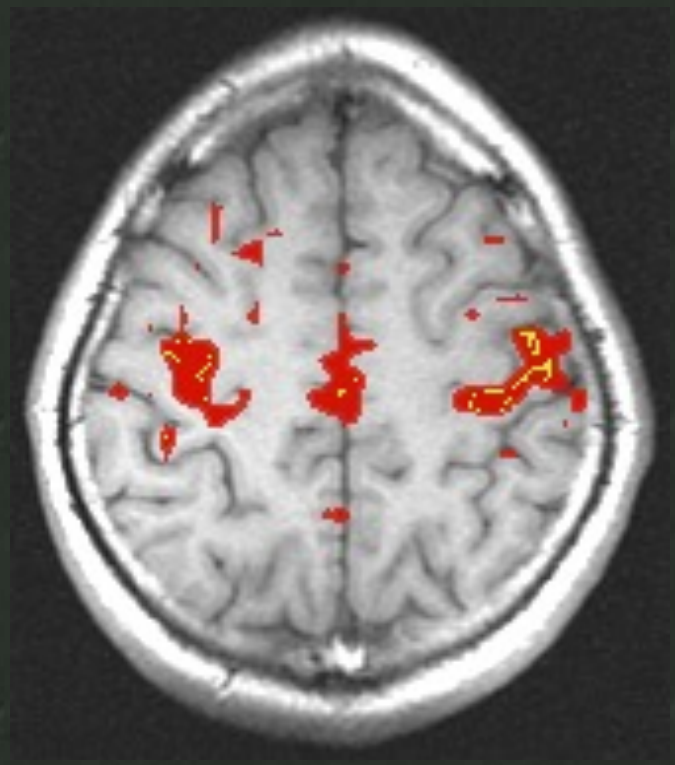
"Resting" State Connectivity

Resting State Correlations



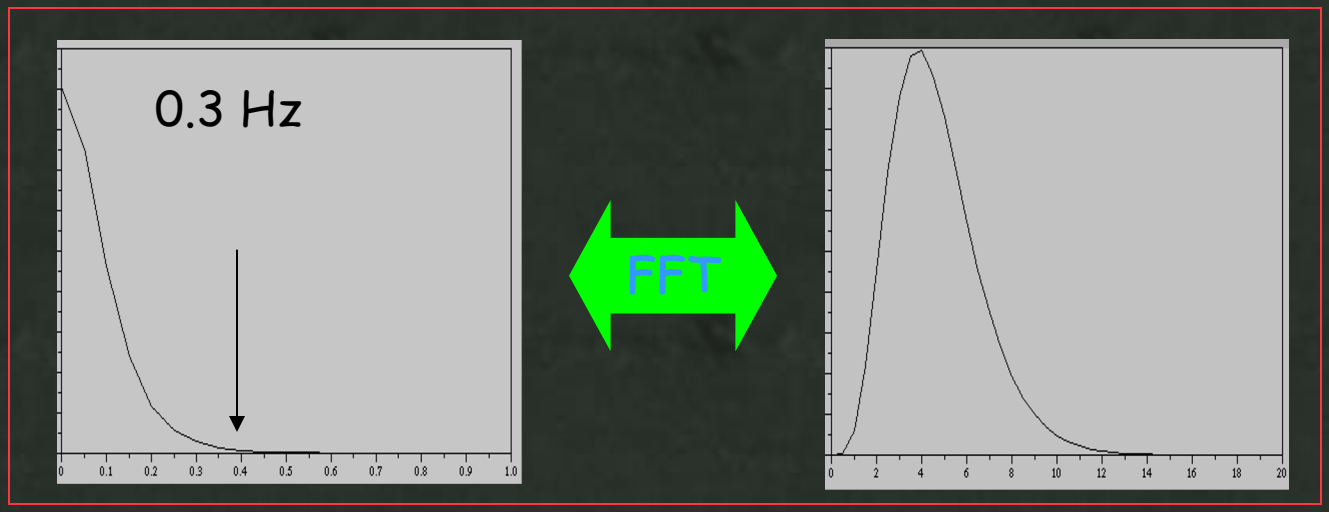
Activation:
correlation with reference function

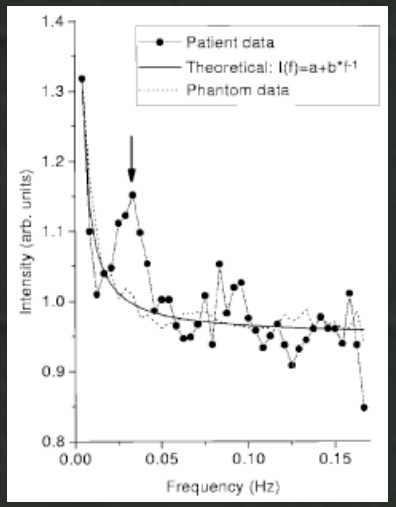


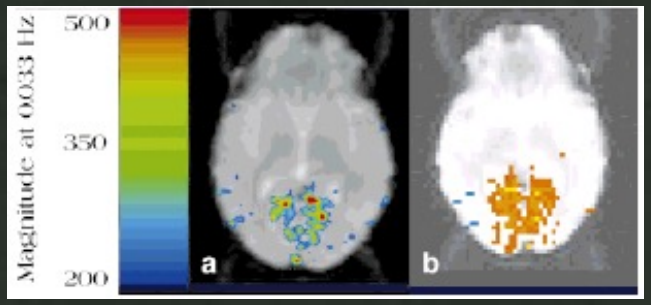
Rest:
seed voxel in motor cortex

B. Biswal *et al.*, MRM, 34:537 (1995)

"Resting" State Connectivity

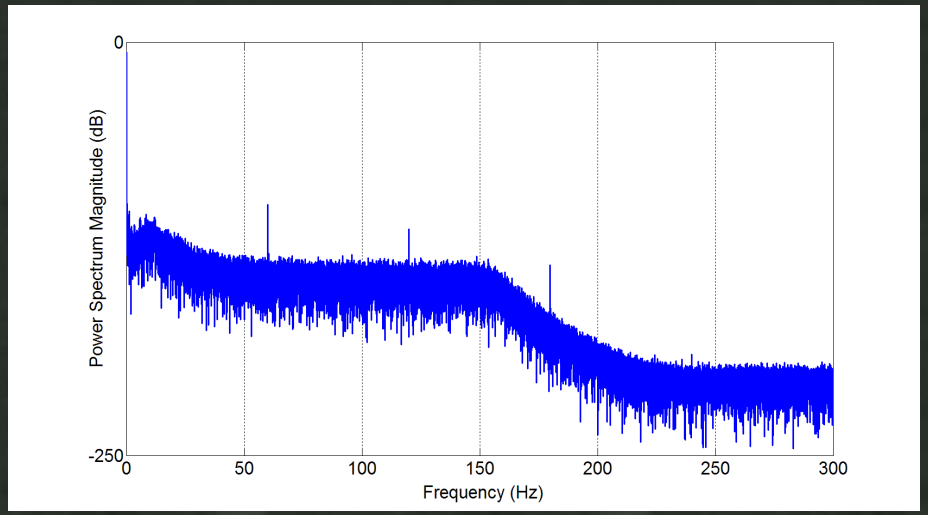






Kiviniemi, et al (2000), MRM 44, 373-378

MEG Power Spectrum



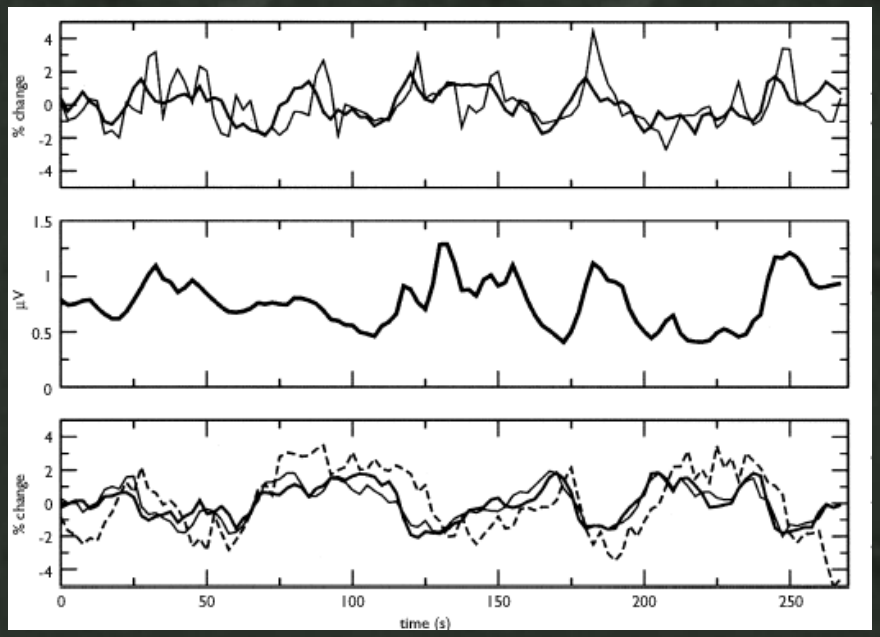
"Resting" State Connectivity

BOLD correlated with 10 Hz power during "Rest"

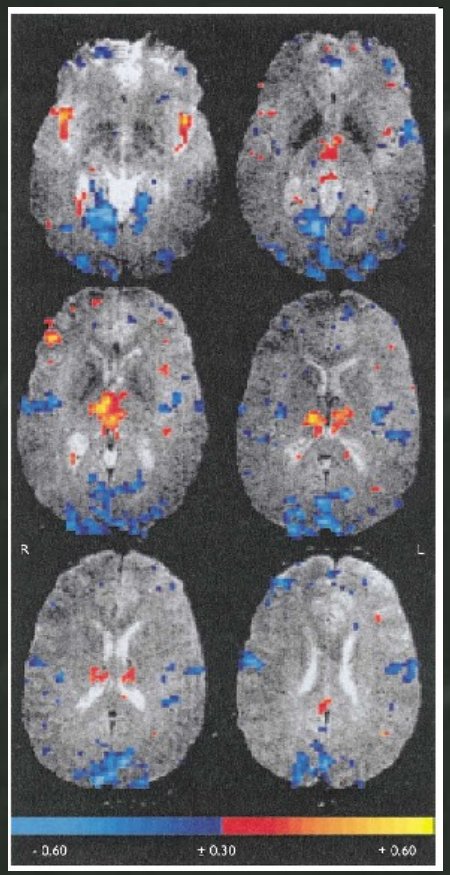
Positive

10 Hz power

Negative

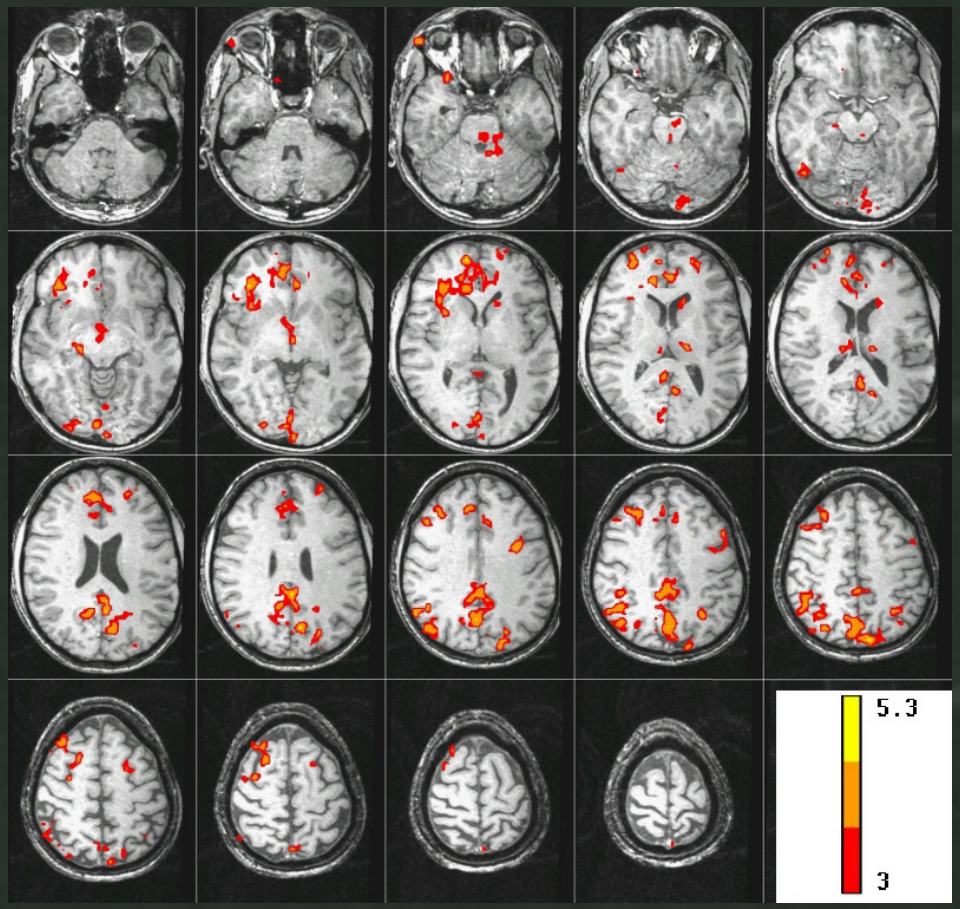


Goldman, et al (2002), Neuroreport



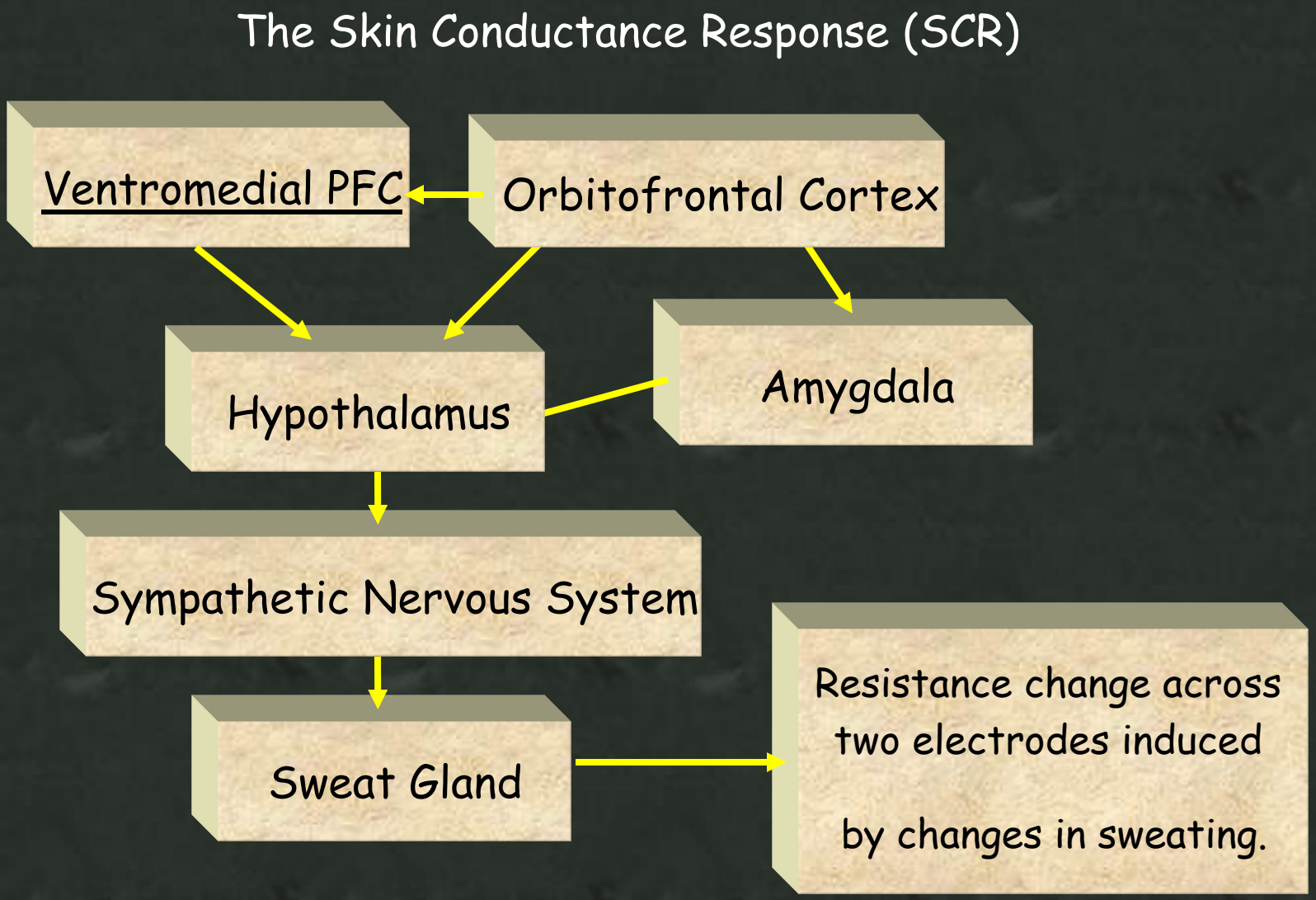
"Resting" State Connectivity

BOLD correlated with SCR during "Rest"



J. C. Patterson II, L. G. Ungerleider, and P. A Bandettini, *NeuroImage* **17**: *1787-1806, (2002).*

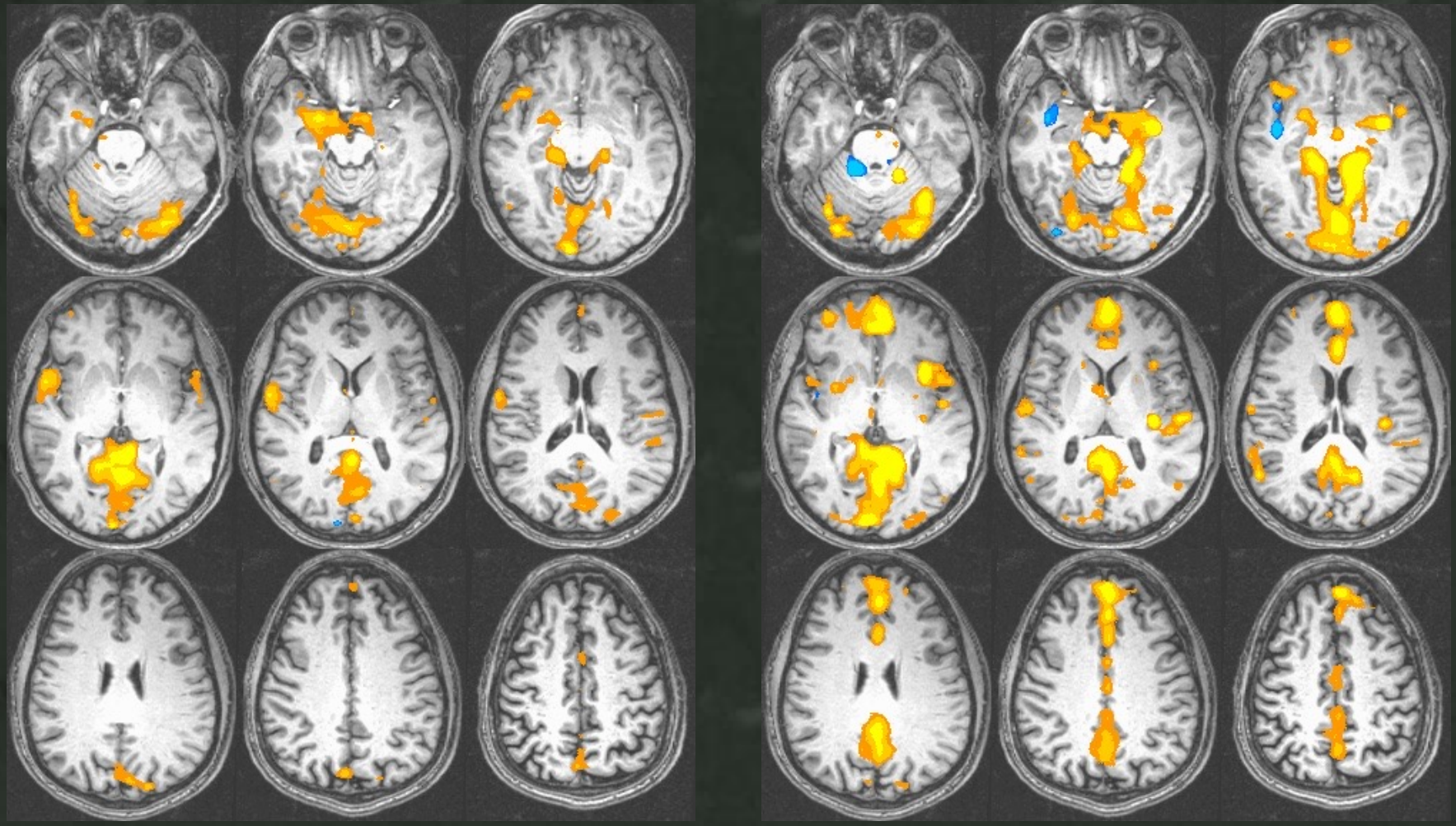
"Resting" State Connectivity



J. C. Patterson II, L. G. Ungerleider, and P. A Bandettini, *NeuroImage* **17**: *1787-1806, (2002).*

Right

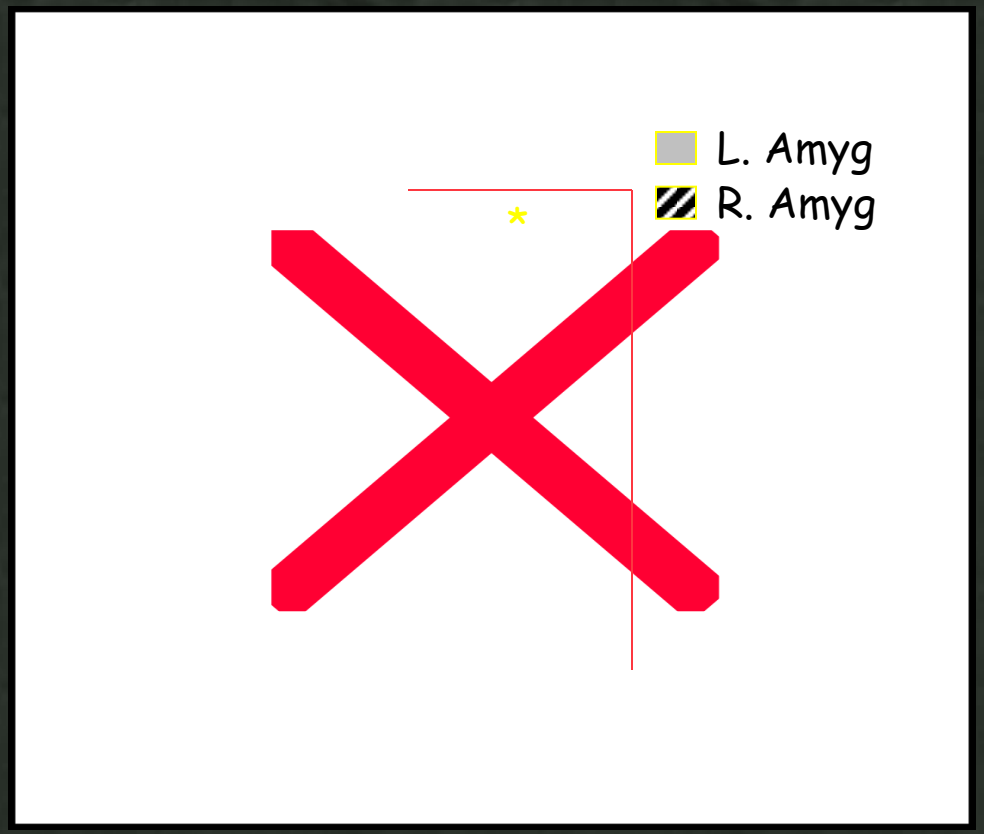
Left

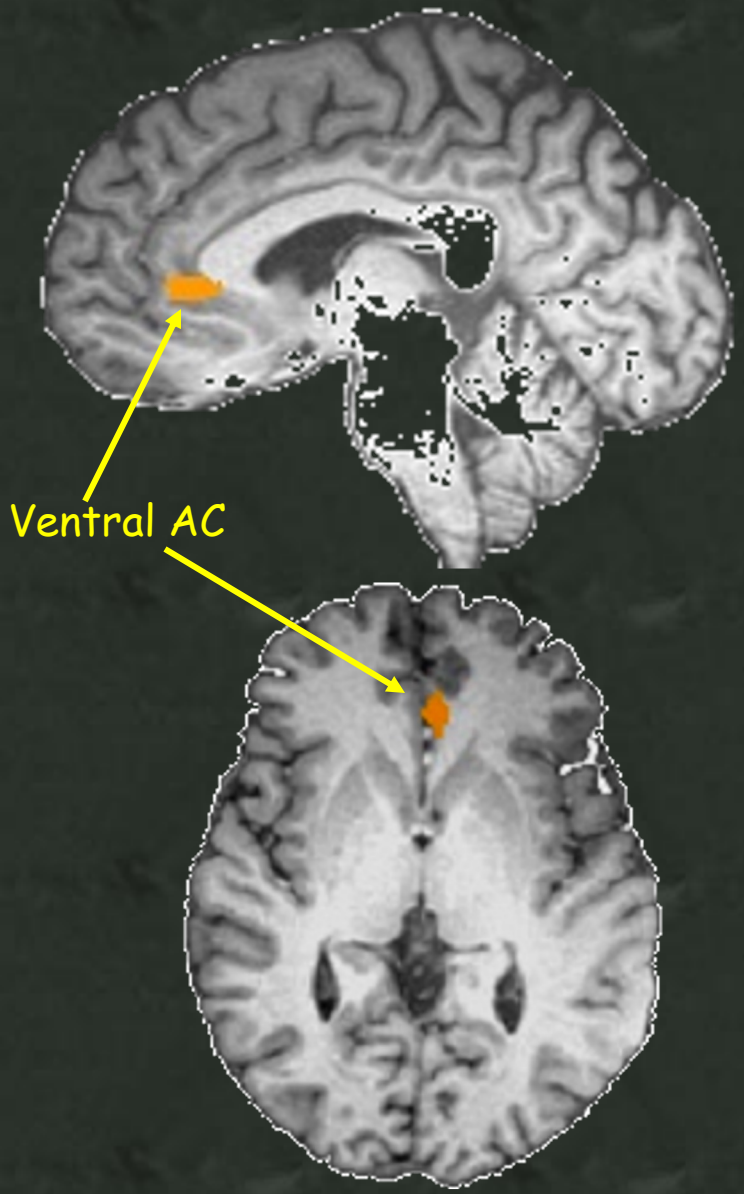


Brain regions showing strong correlation with left and right amygdala activity.

D. Knight, H. Nguyen

"Resting" State Connectivity





Fit coefficient comparing similarity of ventral AC activity with left and right amygdala activity. Activity within the ventral AC was more strongly associated with left than right amygdala activity.

D. Knight, H. Nguyen

Approaches to assessing spatial connectivity:

ICA, PCA, seed voxel…

Why not correlate every voxel with every other voxel?

For 64 x 64 resolution, 27 slices, 165 time points:
-160 voxel ROI = 5 min and 63 MB memory….

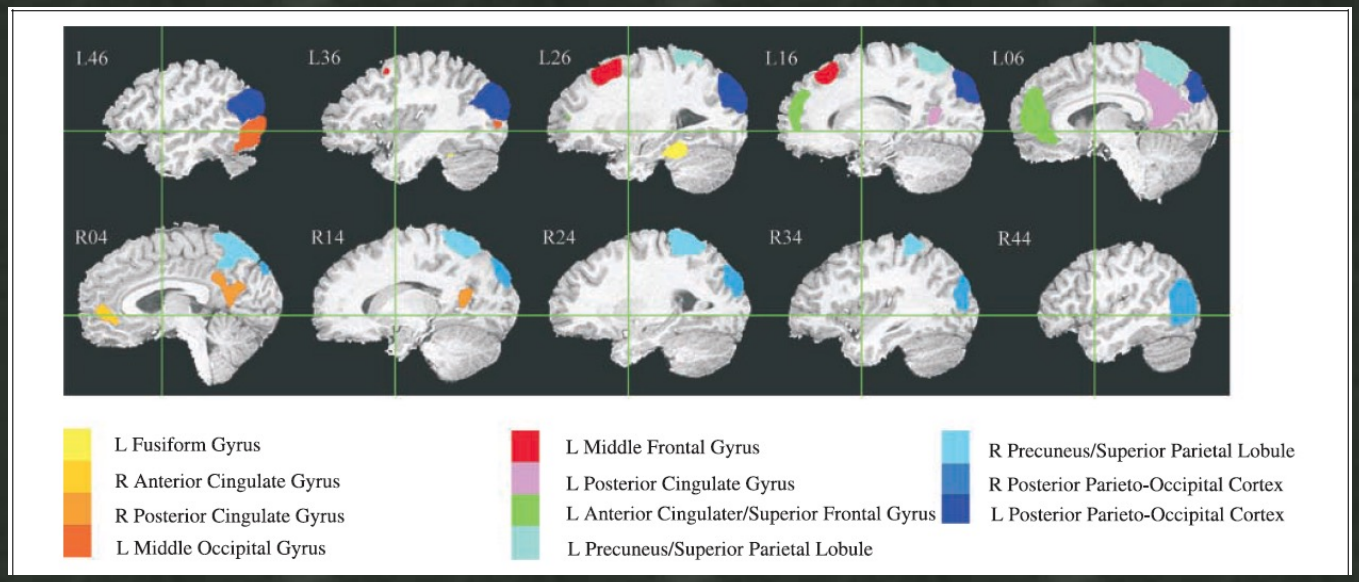
-Gray matter (10,000 voxels) = 5.32 hrs and 4.3 GB memory
-Entire volume (110,000 voxels) = 59 hrs and 47.5 GB memory

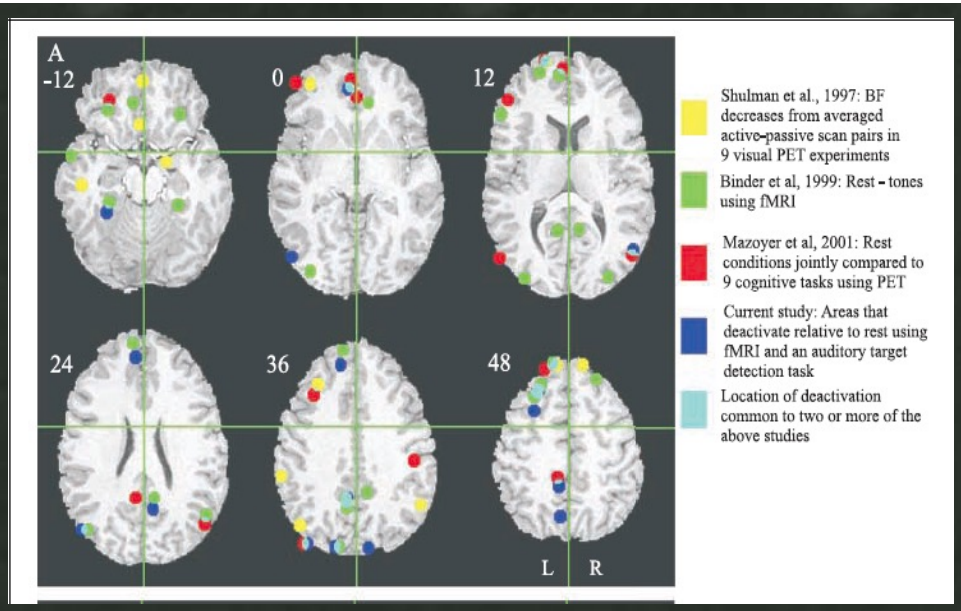
Resting state connectivity

Decreases during cognitive tasks

"Resting" State Connectivity

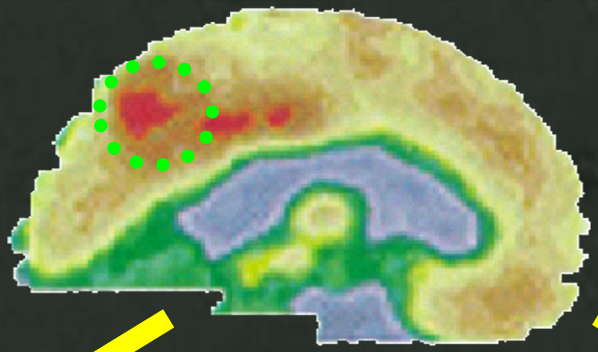
Regions showing decreases during cognitive tasks



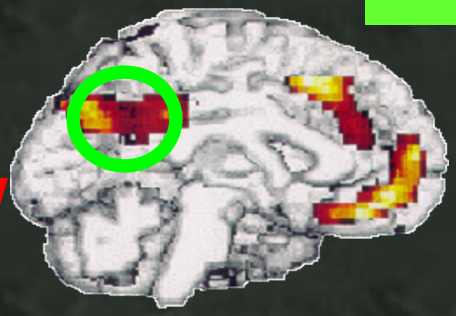


McKiernan, et al (2003), Journ. of Cog. Neurosci. 15 (3), 394-408

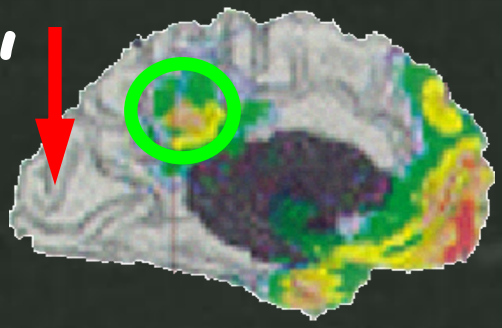
strongly reduced vigilance: ⟷ "rest" ⟷ perception + action



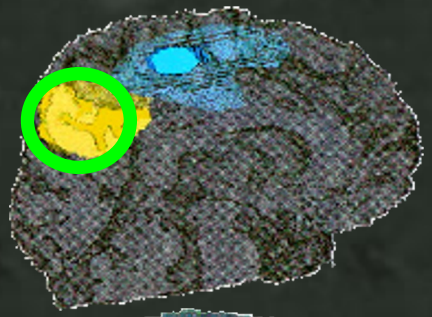
sleep



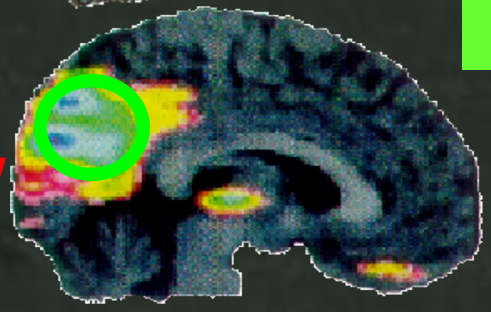
tasks



"default mode"



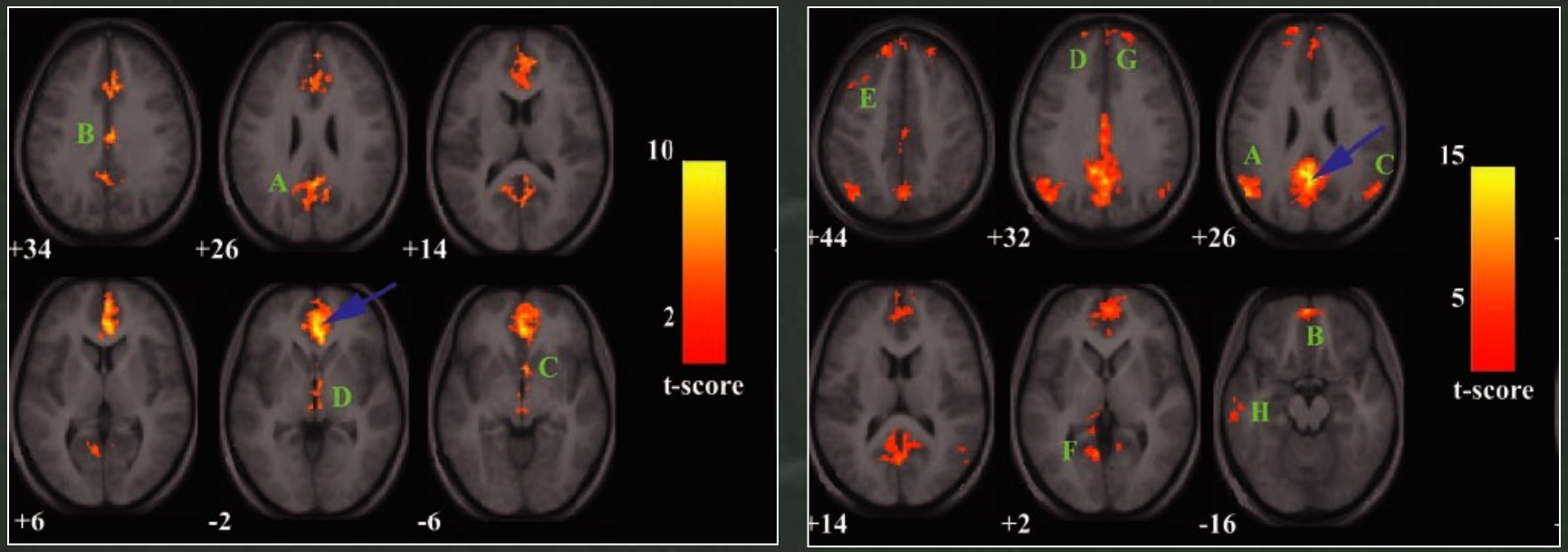
vegetative state



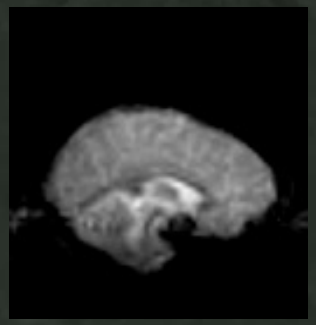
general anaesthesia

(Gusnard and Raichle 2001)

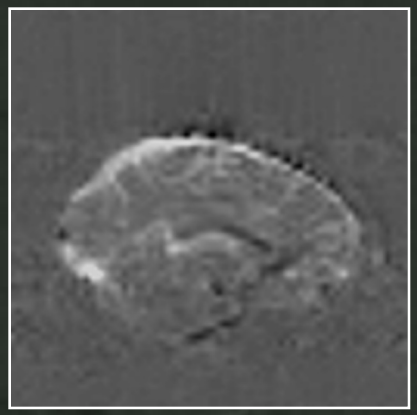
Spatial similarity of decreased signal change regions with regions showing resting state correlations.

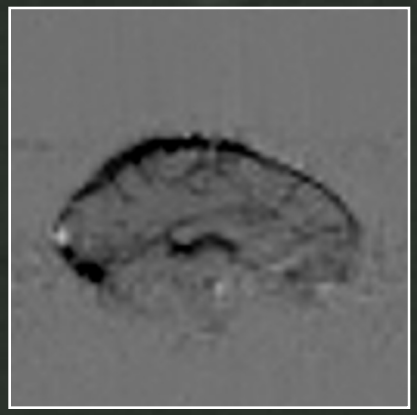


Greicius, et al (2003), PNAS 100 (1), 253-258



5% CO2



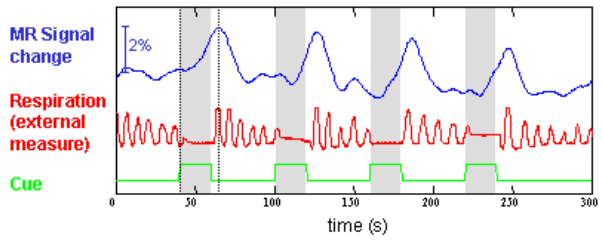


12% O2

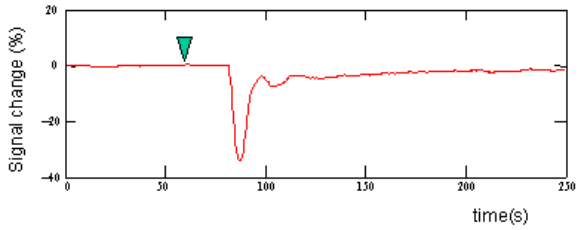
P. A. Bandettini, E. C. Wong, *NMR in Biomedicine* 10, 197-203 (1997).

Blood volume mapping by breath-hold

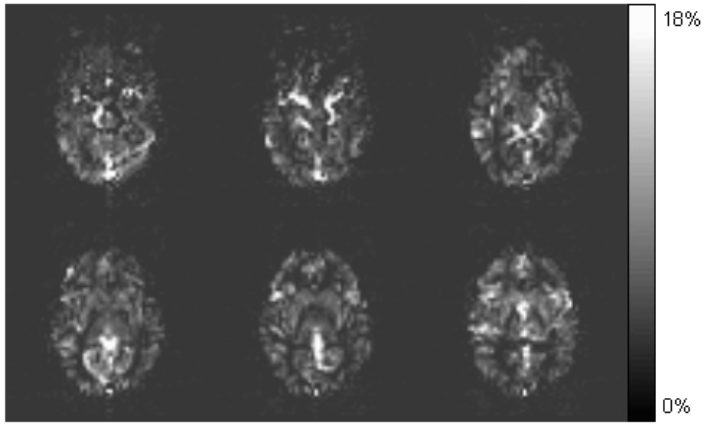
Breath-Holding



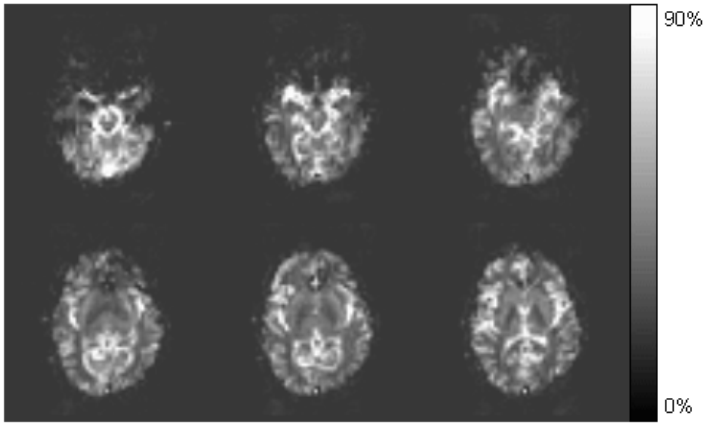
Gd-DTPA



BOLD Signal change resulting from breath holding

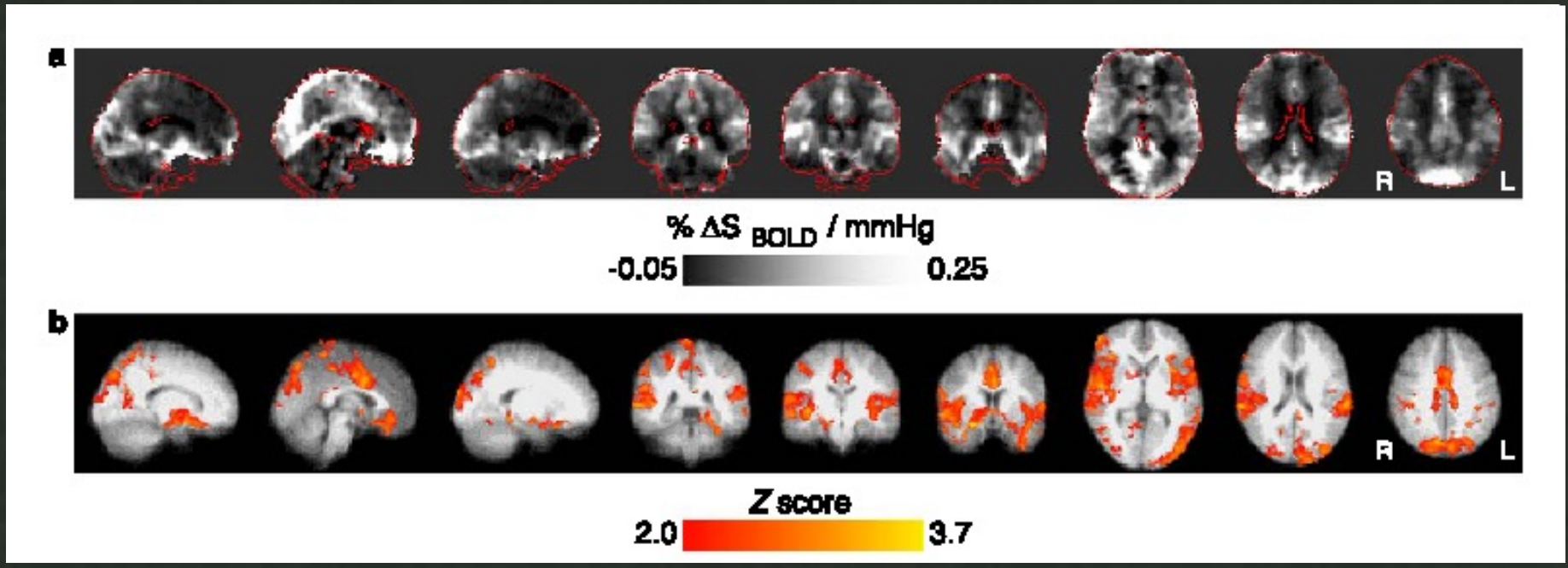


Signal change resulting bolus injection of Gd-DTPA



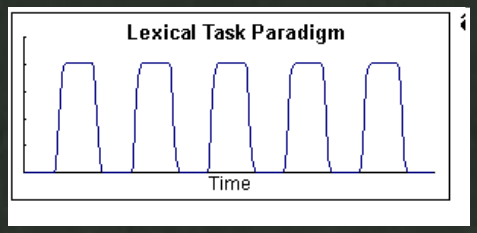
Note that although there are many similarities in the signal change amplitudes resulting from breath holding and exogenous contrast agent, there are several regions showing differences potentially indicating different contributions from arteries and veins.

Time Series Correlation with spontaneous changes in end tidal CO_2

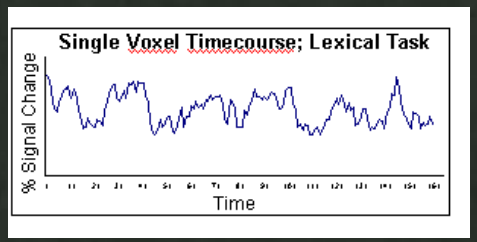


R. G. Wise, et al, NeuroImage 21 (2004), 1652-1664

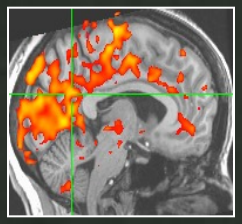
Lexical Task

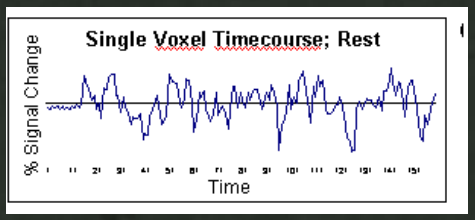


ROI

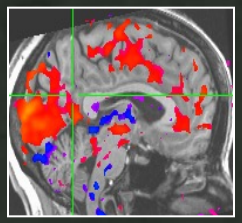


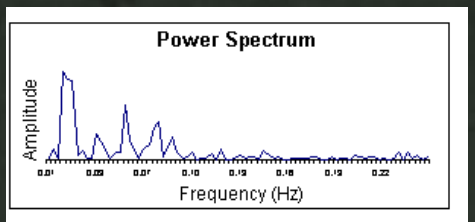
Functional Connectivity: Rest



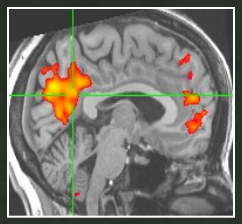


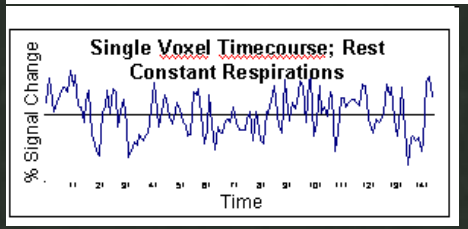
Correlation with Respiration Vol./Time



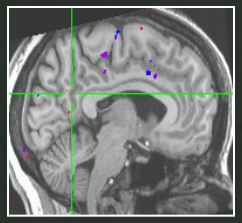


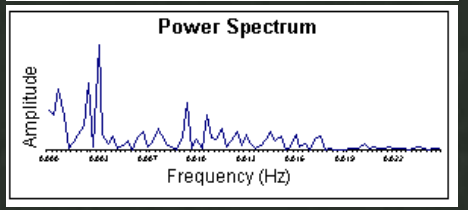
Functional Connectivity: Constant Resp.

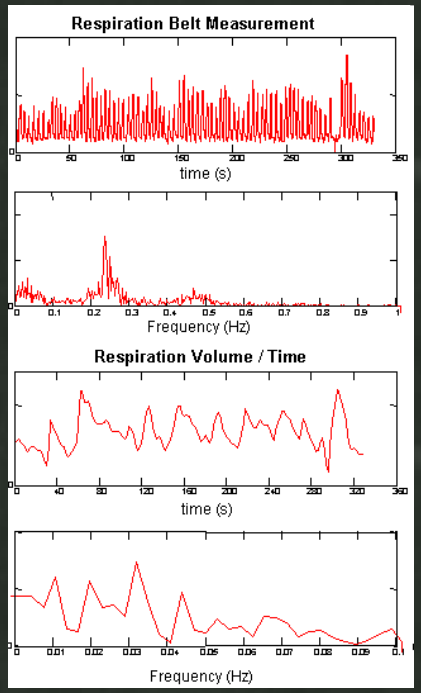


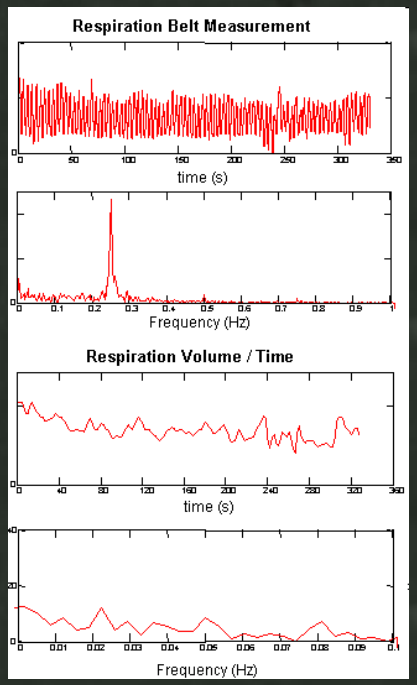


Correlation with Respiration Vol./Time: Constant Resp.

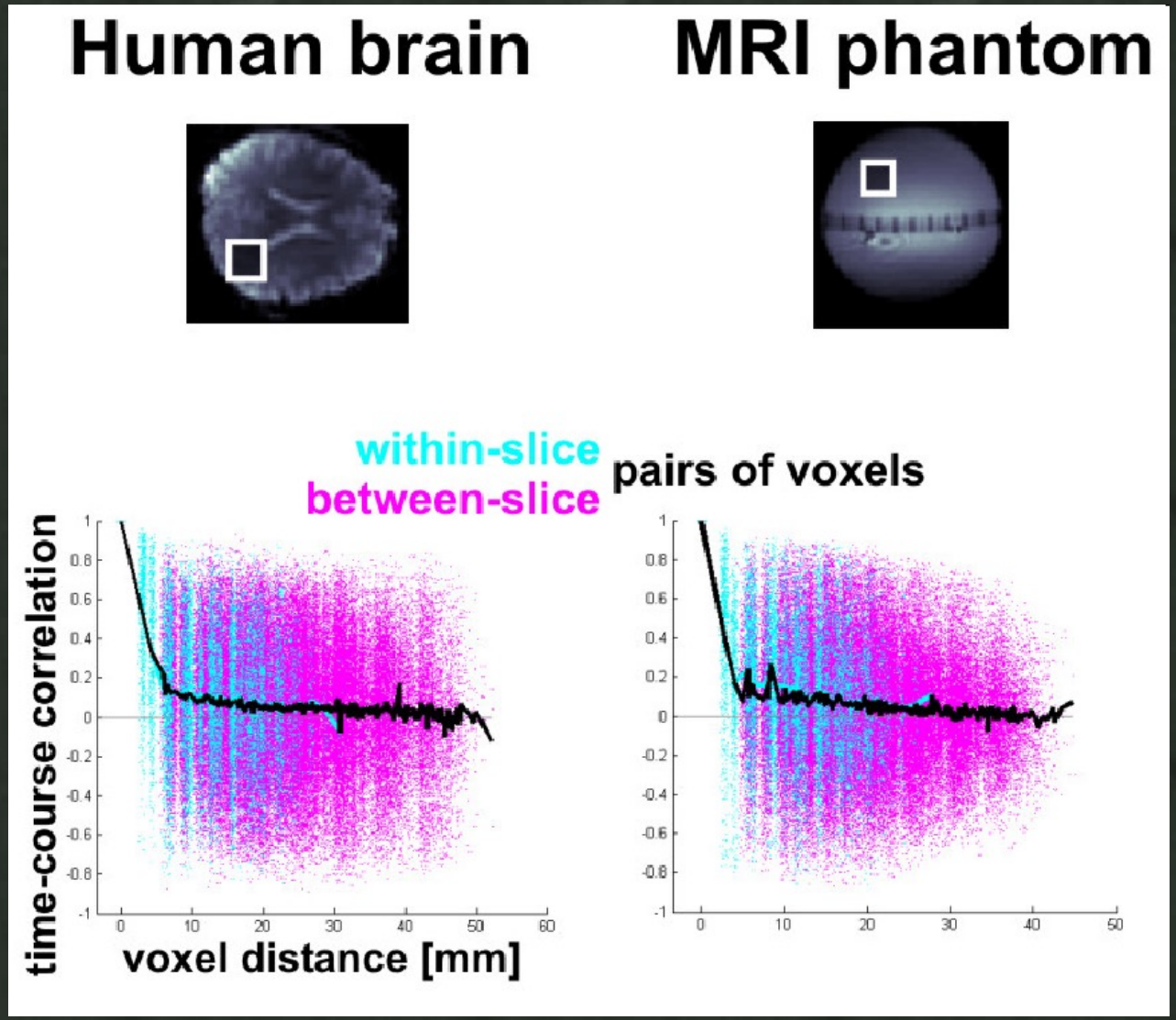








Local Correlations…



N. Kriegeskorte, J. Bodurka

The Signal

The Hemodynamic Response Function
Spatial and Temporal Resolution
Interpretation

The "Noise"

Characteristics and Sources
Practical Issues

The Signal in the Noise

"Resting" State Connectivity
Physiologic Factors