Functional MRI Patterns, Connections, Dynamics, and Noise.

Peter A. Bandettini, Ph.D.

Section on Functional Imaging Methods

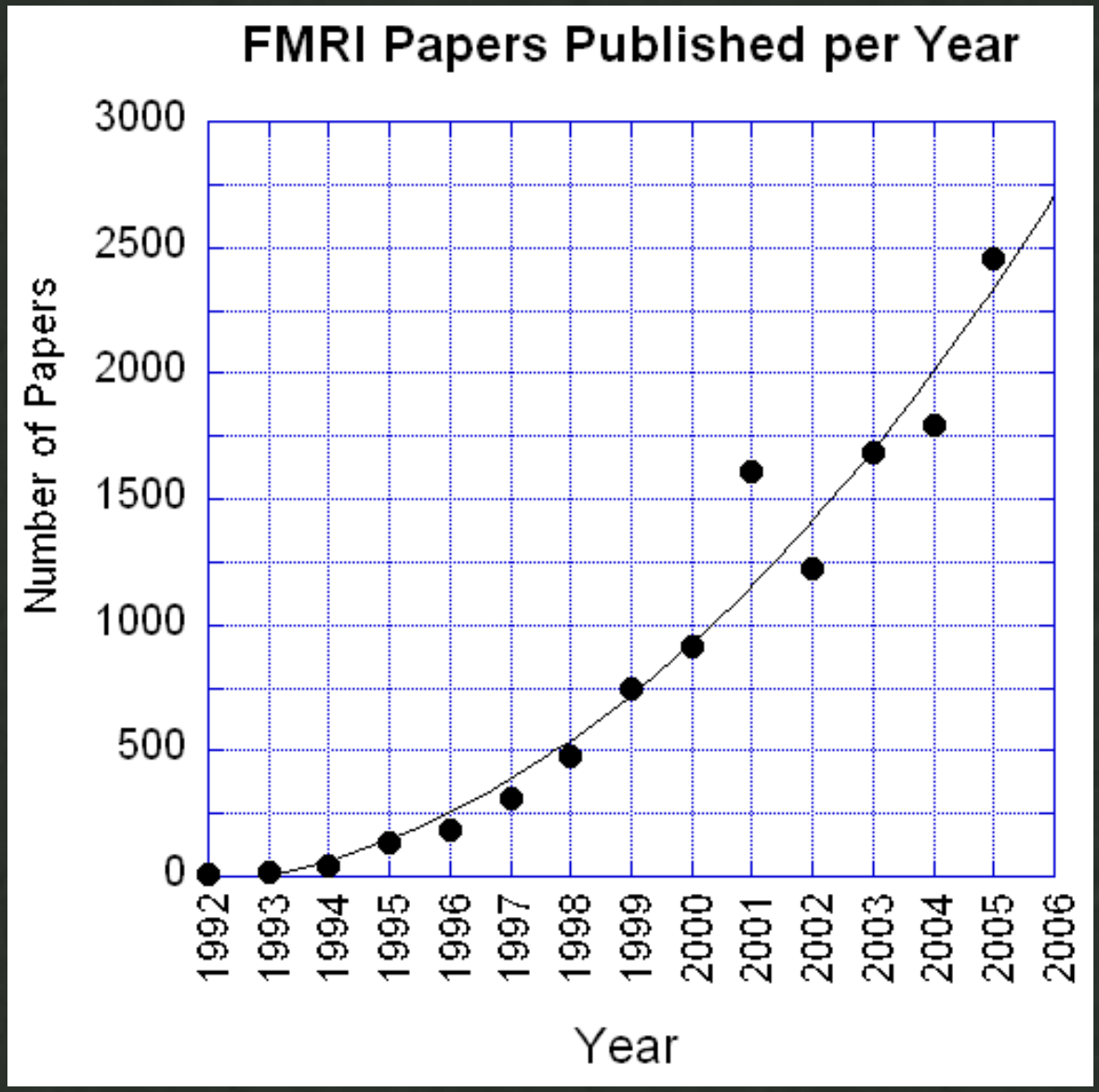
http://fim.nimh.nih.gov

Laboratory of Brain and Cognition

&

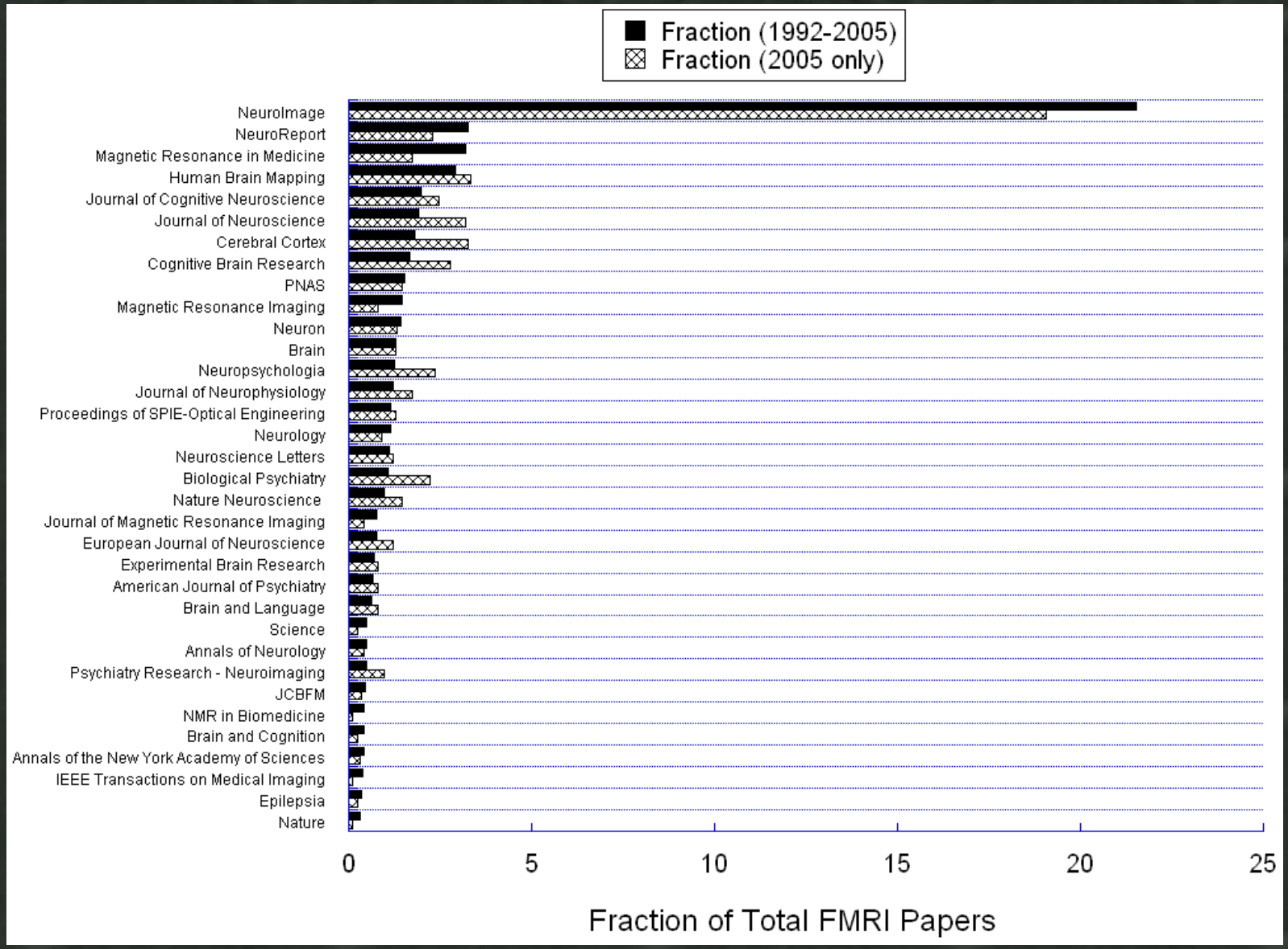
Functional MRI Facility

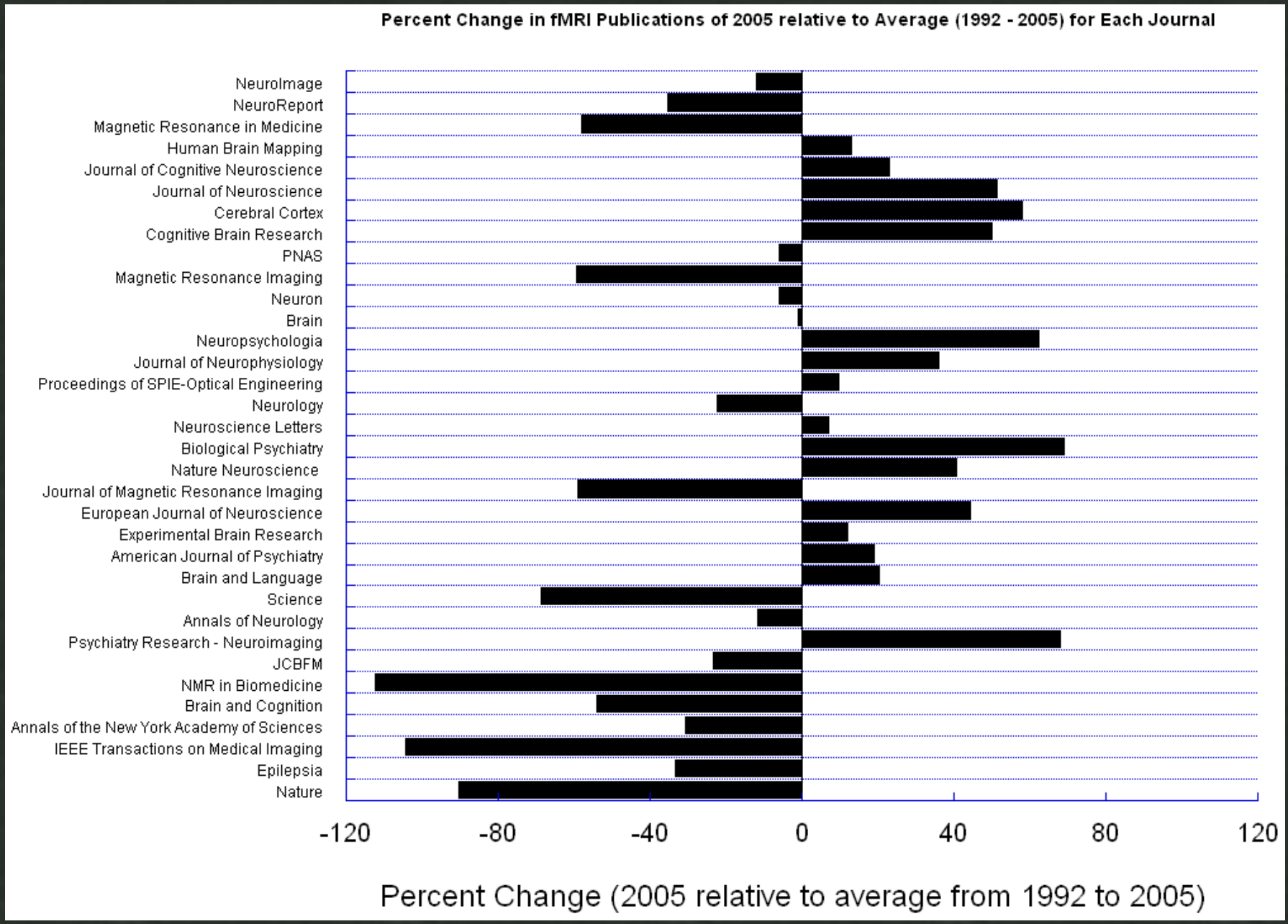
http://fmrif.nimh.nih.gov



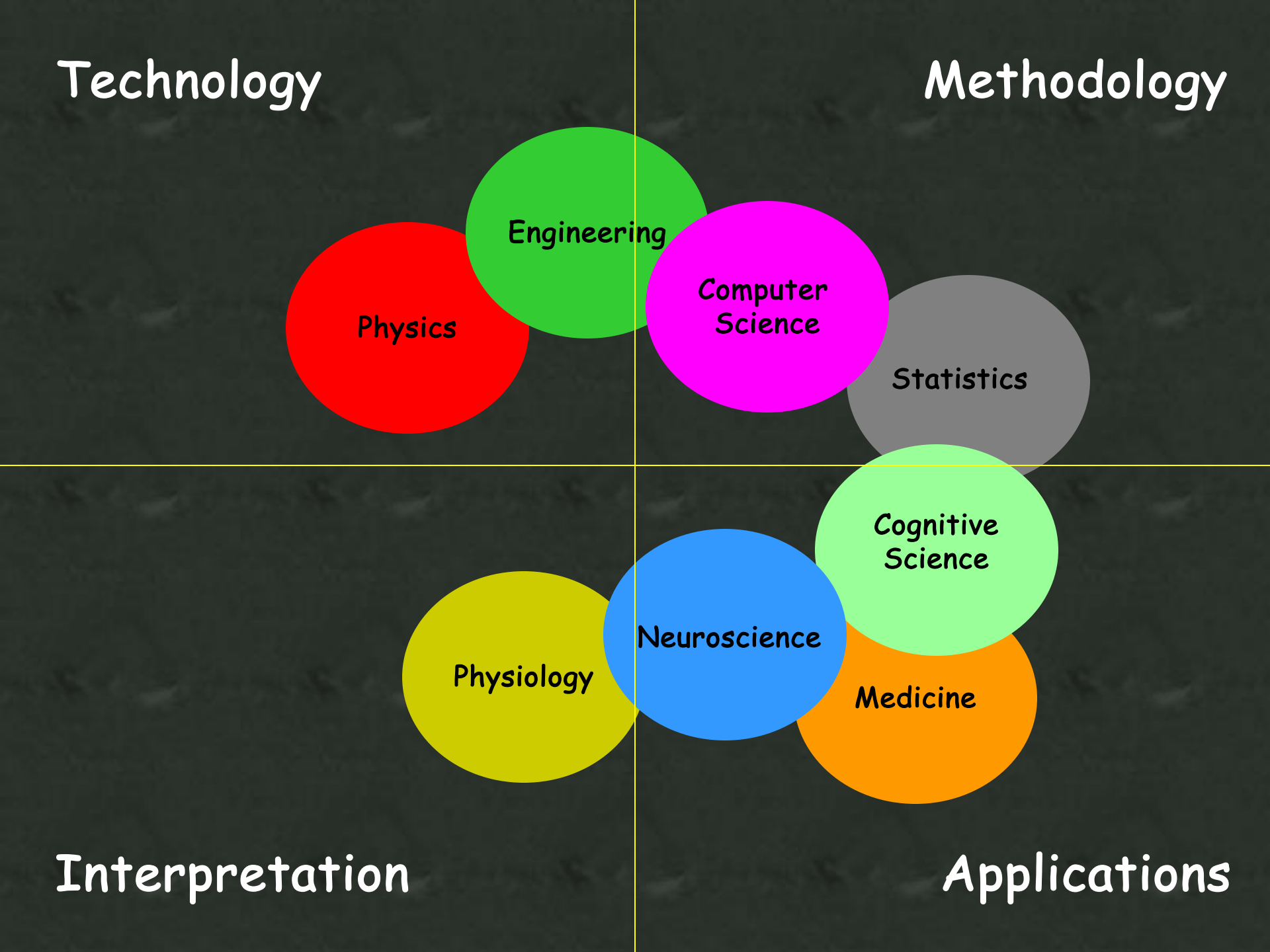
"fMRI" or "functional MRI"

Breakdown of fMRI papers by Journal




Percent Change in fMRI Publications of 2005 relative to Average (1992 - 2005) for Each Journal
NeuroImage
NeuroReport
Magnetic Resonance in Medicine
Human Brain Mapping
Journal of Cognitive Neuroscience
Journal of Neuroscience
Cerebral Cortex
Cognitive Brain Research
PNAS
Magnetic Resonance Imaging
Neuron
Brain
Neuropsychologia
Journal of Neurophysiology
Proceedings of SPIE-Optical Engineering
Neurology
Neuroscience Letters
Biological Psychiatry
Nature Neuroscience
Journal of Magnetic Resonance Imaging
European Journal of Neuroscience
Experimental Brain Research
American Journal of Psychiatry
Brain and Language
Science
Annals of Neurology
Psychiatry Research - Neuroimaging
JCBFM
NMR in Biomedicine
Brain and Cognition
Annals of the New York Academy of Sciences
IEEE Transactions on Medical Imaging
Epilepsia
Nature
-120
-80
-40
0
40
80
120
Percent Change (2005 relative to average from 1992 to 2005)

1991


Technology
Methodology
Engineering
Physics
Computer Science
Statistics
Cognitive Science
Neuroscience
Physiology
Medicine
Interpretation
Applications

Technology

Coil arrays
Higher field strength
Higher resolution

Methodology

"Resting state"
Fluctuation assessment
Multi-modal integration
Pattern classification
Novel Functional Contrasts

Interpretation

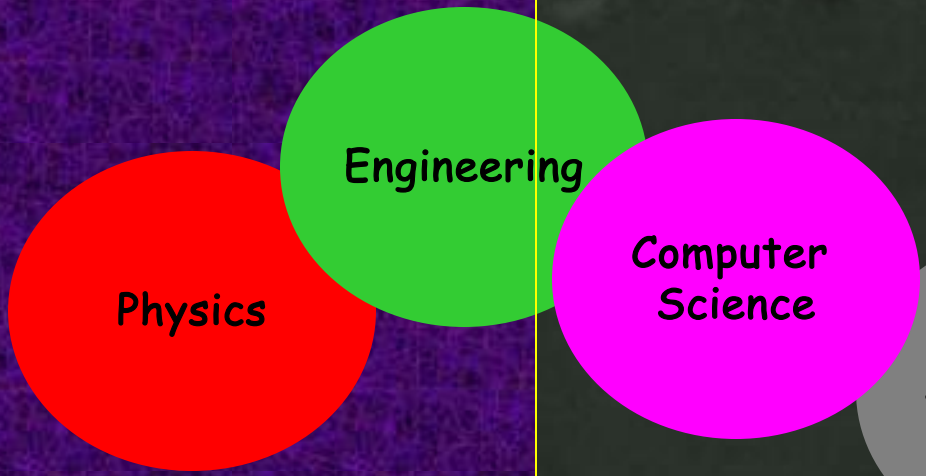
Fluctuations
Dynamics
Cross - modal comparison

Applications

Basic Neuroscience
Behavior correlation/prediction
Pathology correlation

Technology

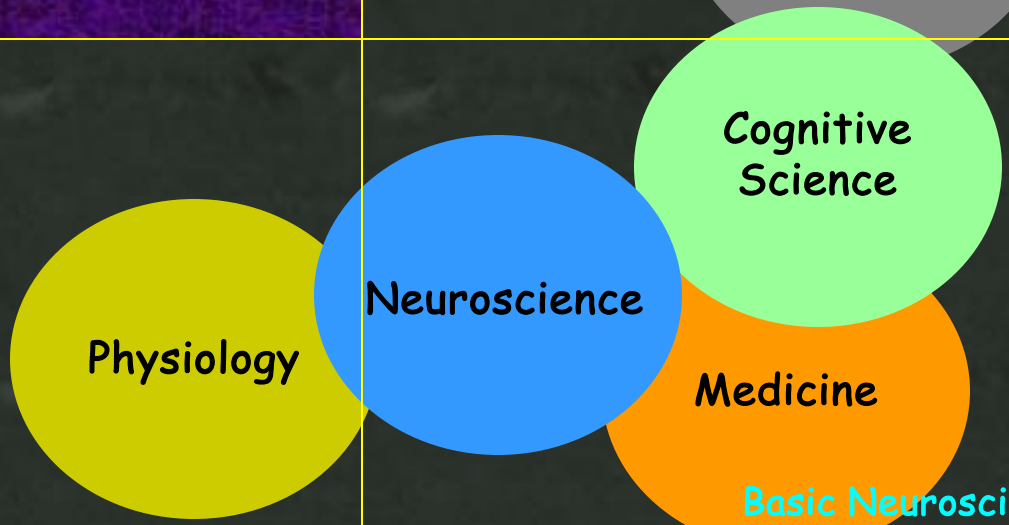
Coil arrays
Higher field strength
Higher resolution



Methodology

"Resting state"
Fluctuation assessment
Multi-modal integration
Pattern classification
Novel Functional Contrasts

Statistics



Fluctuations
Dynamics
Cross - modal comparison

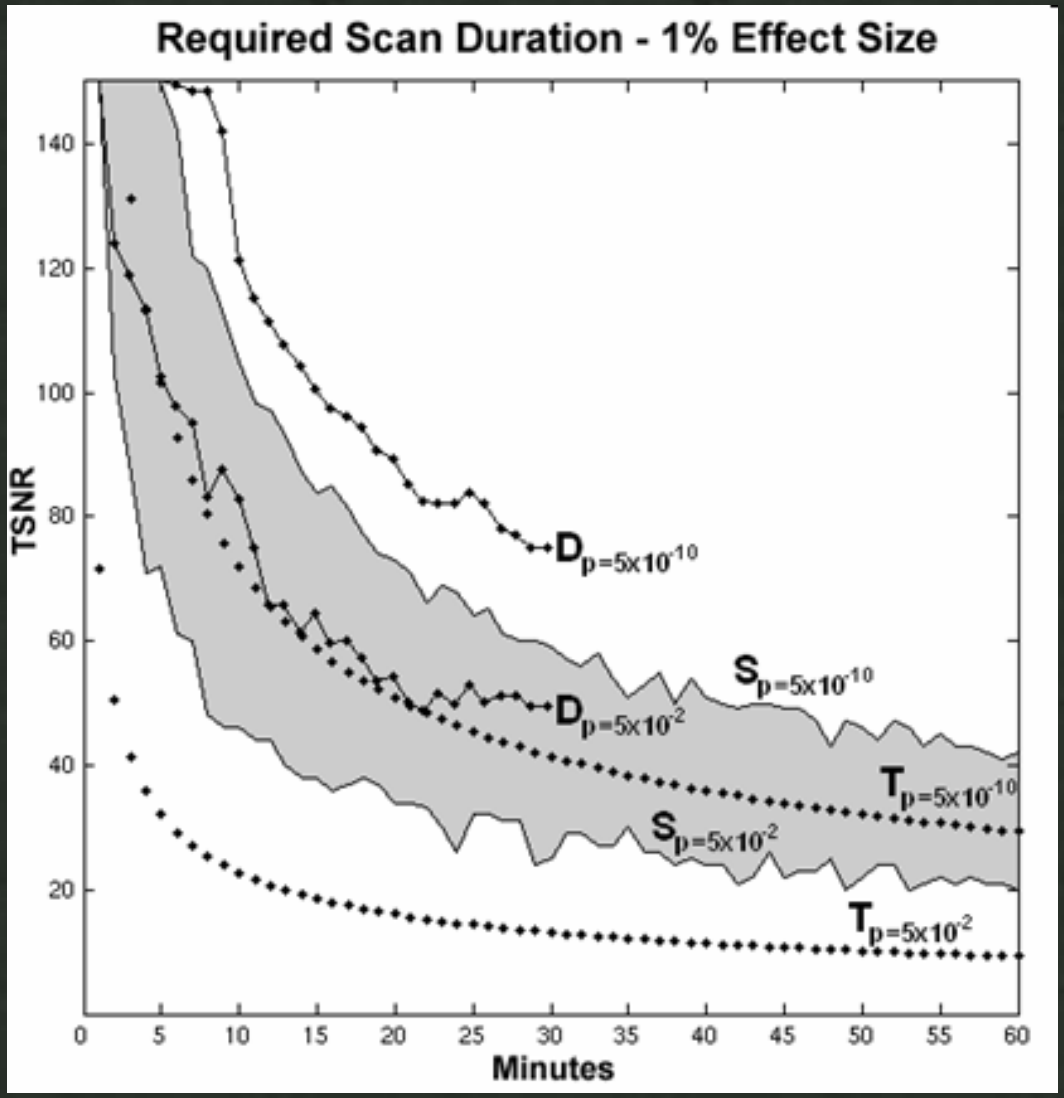
Interpretation

Basic Neuroscience
Behavior correlation/prediction
Pathology correlation

Applications

Technology

Parallel Acquisition



Reasons for higher SNR

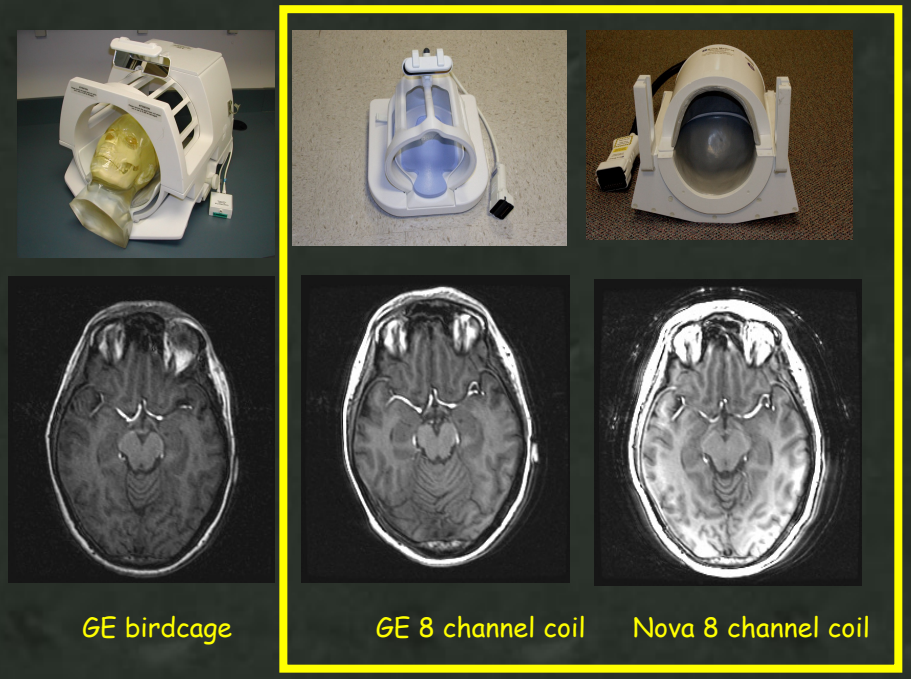
-Shorter scan duration
-Higher Resolution
-More subtle comparisons

Murphy et al.

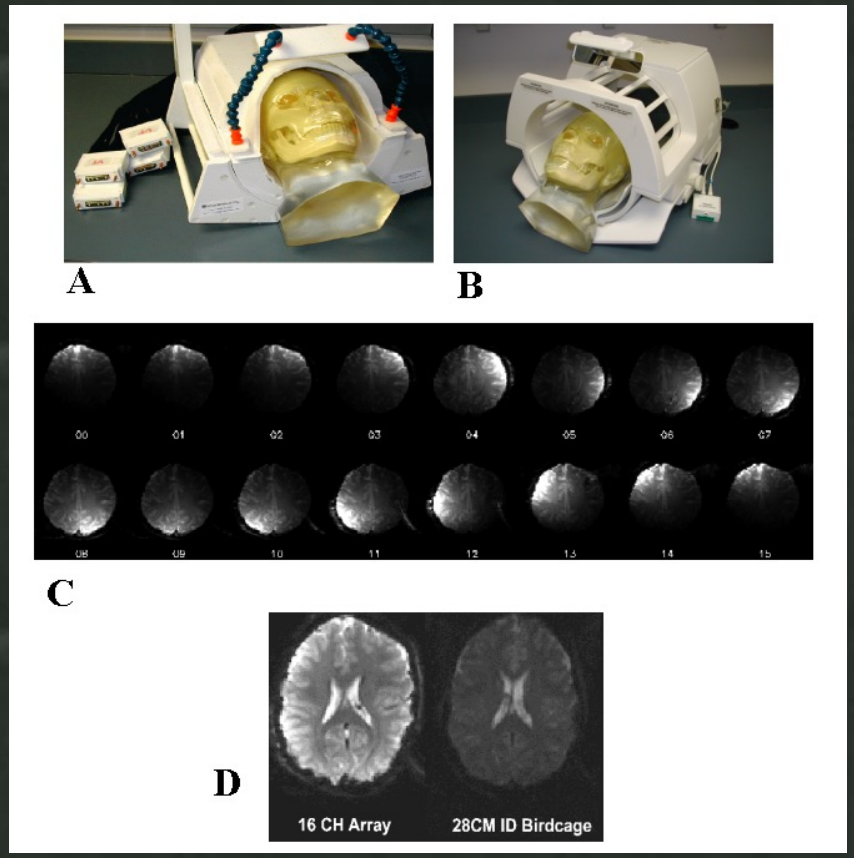
Technology

Parallel Acquisition

8 channel parallel receiver coil



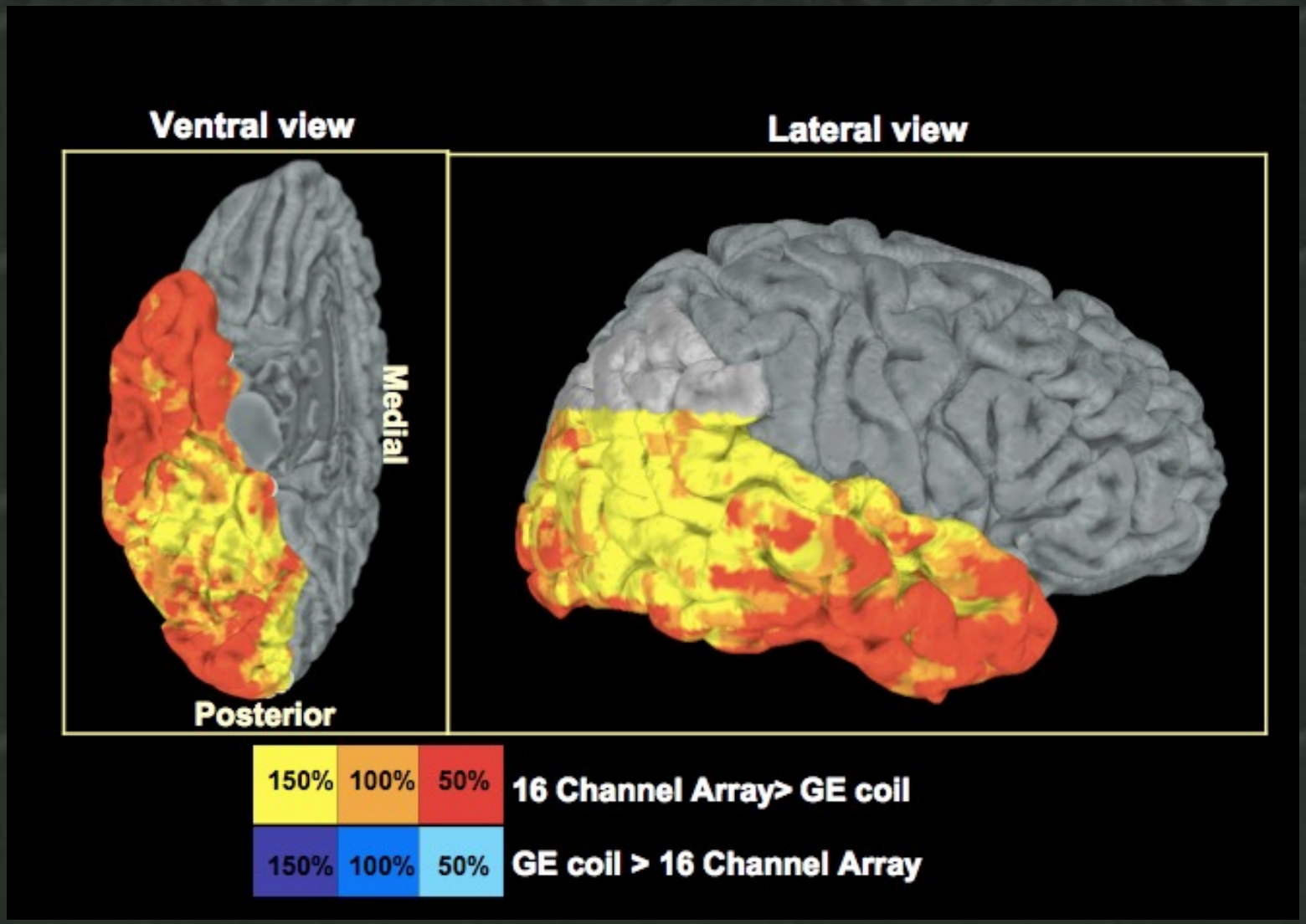
16 channel parallel receiver coil



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

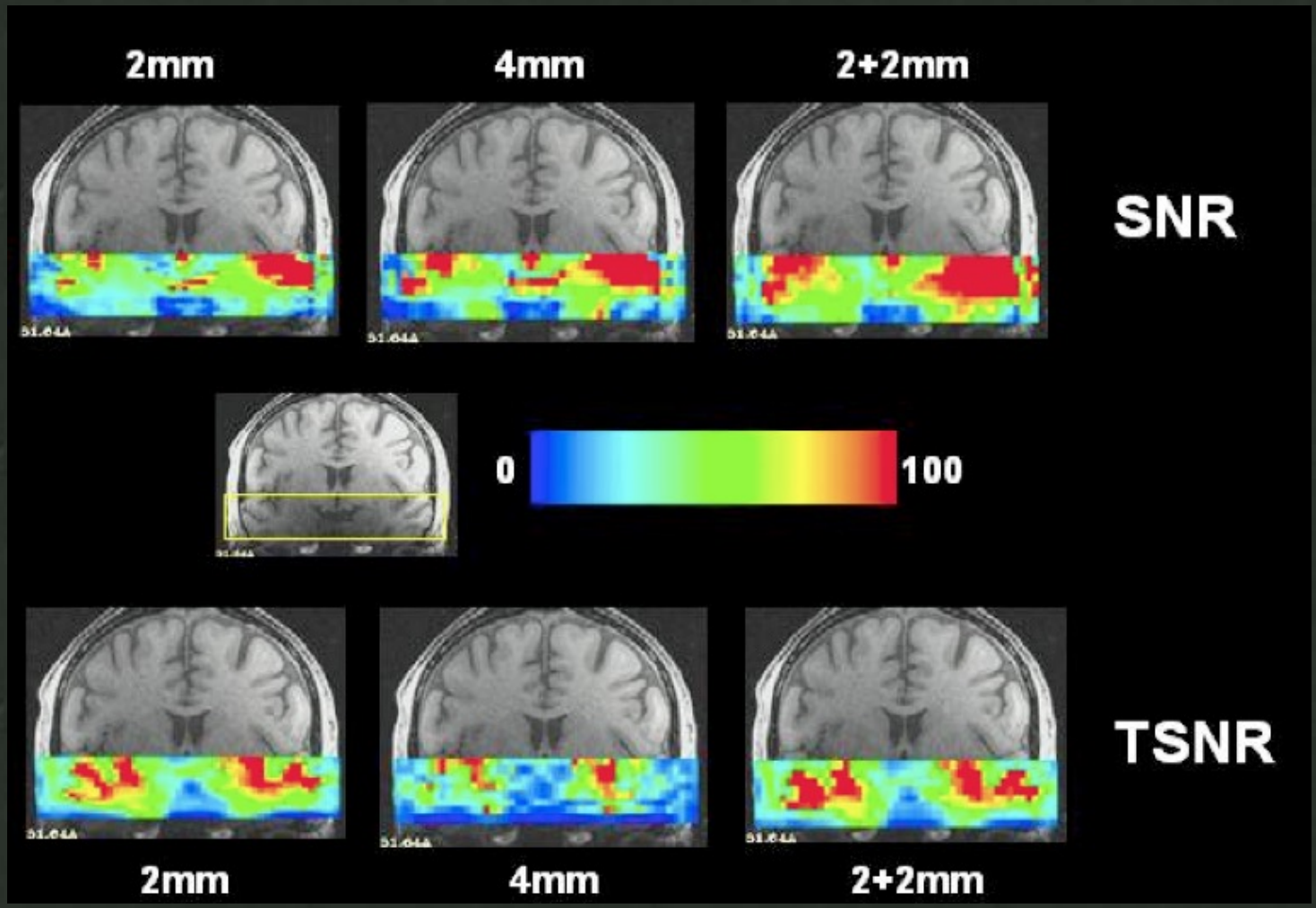
Technology

Parallel Acquisition



P. S. F. Bellgowan, P. A. Bandettini, P. van Gelderen, A. Martin, J. Bodurka, Improved BOLD detection in the medial temporal region using parallel imaging and voxel volume reduction. *NeuroImage*, 29, 1244-1251 (2006)

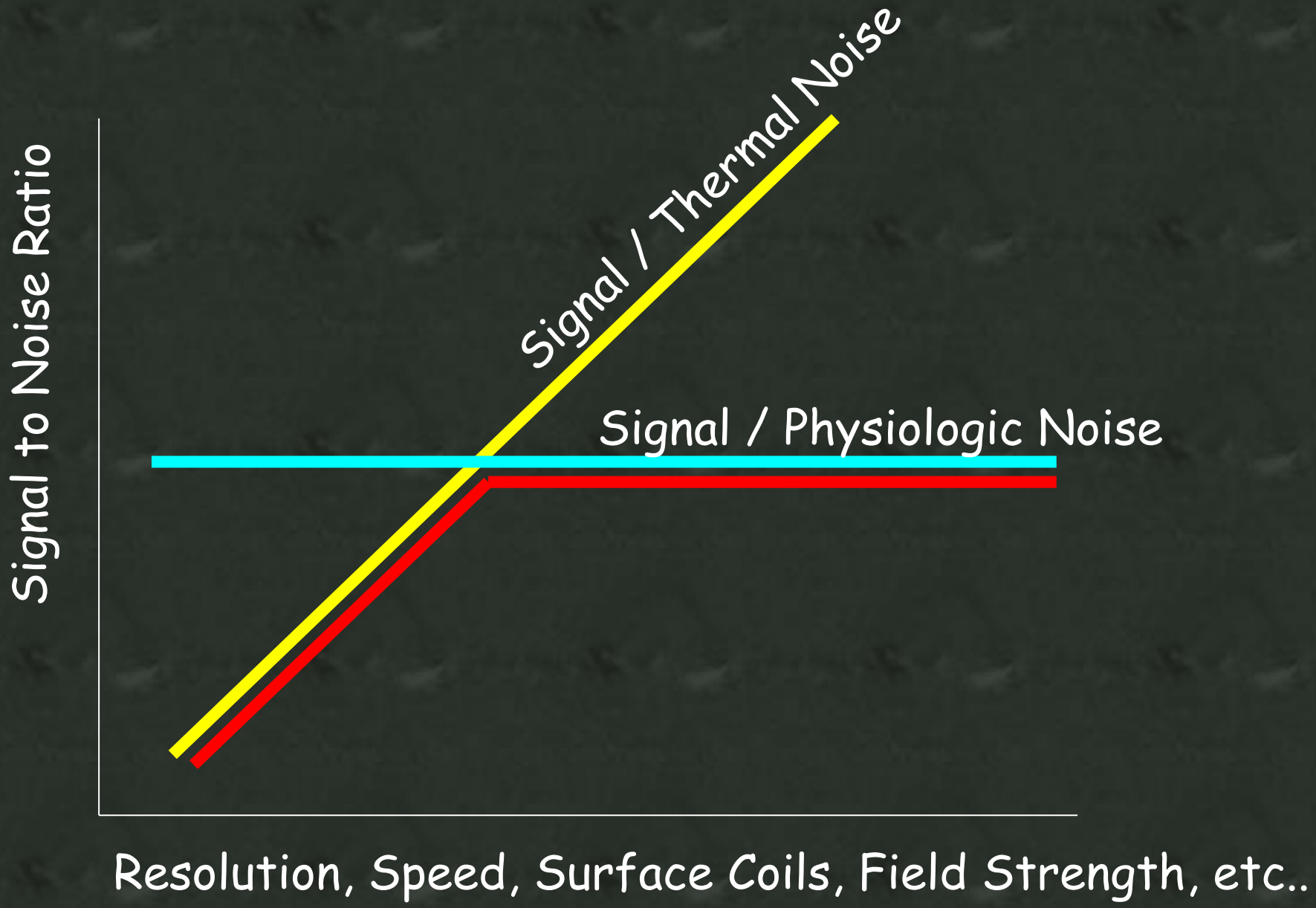
Advantage of Thinner Slices



P. S. F. Bellgowan, P. A. Bandettini, P. van Gelderen, A. Martin, J. Bodurka, Improved BOLD detection in the medial temporal region using parallel imaging and voxel volume reduction. *NeuroImage*, 29, 1244-1251 (2006)

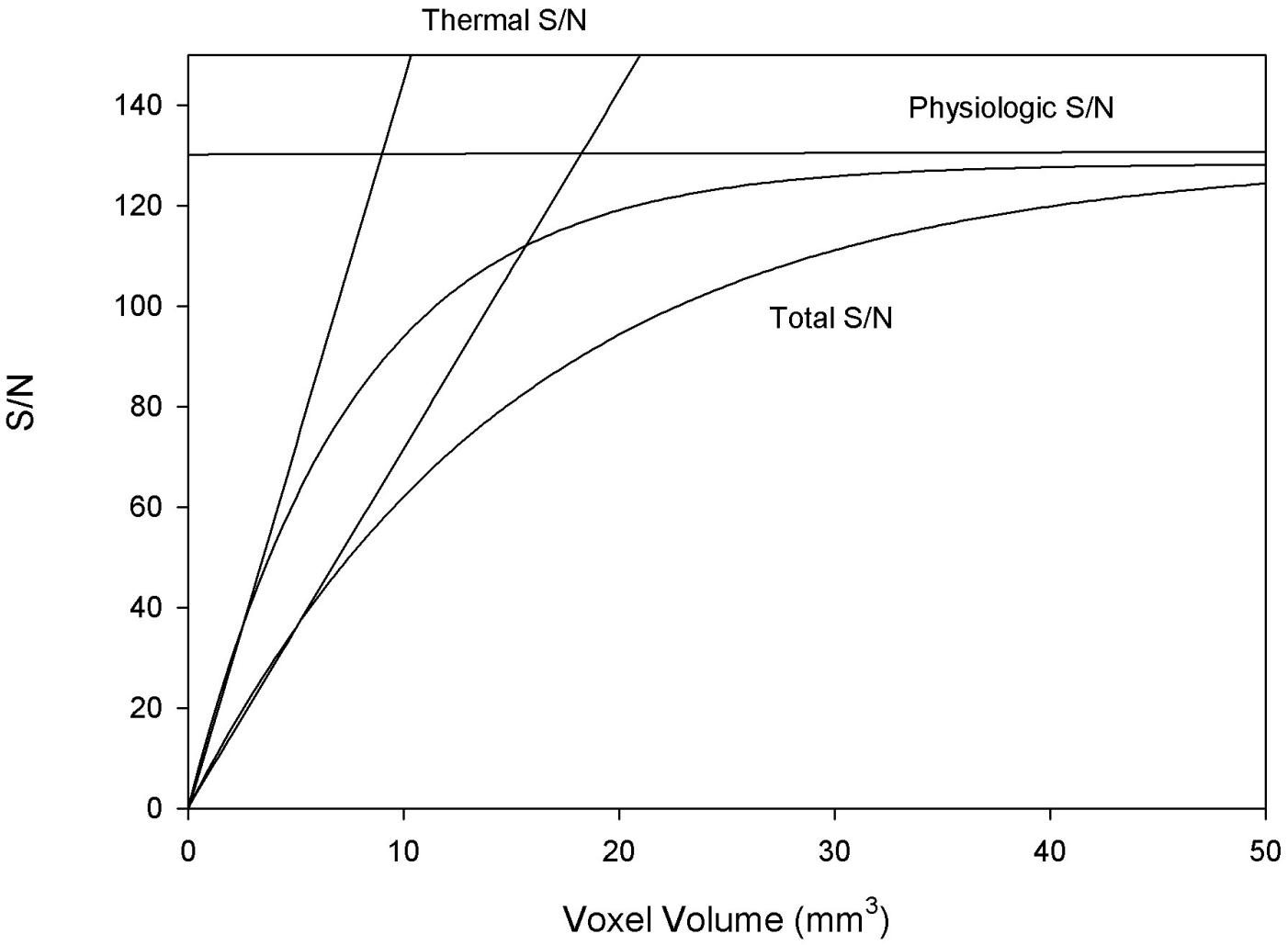
Technology

Parallel Acquisition

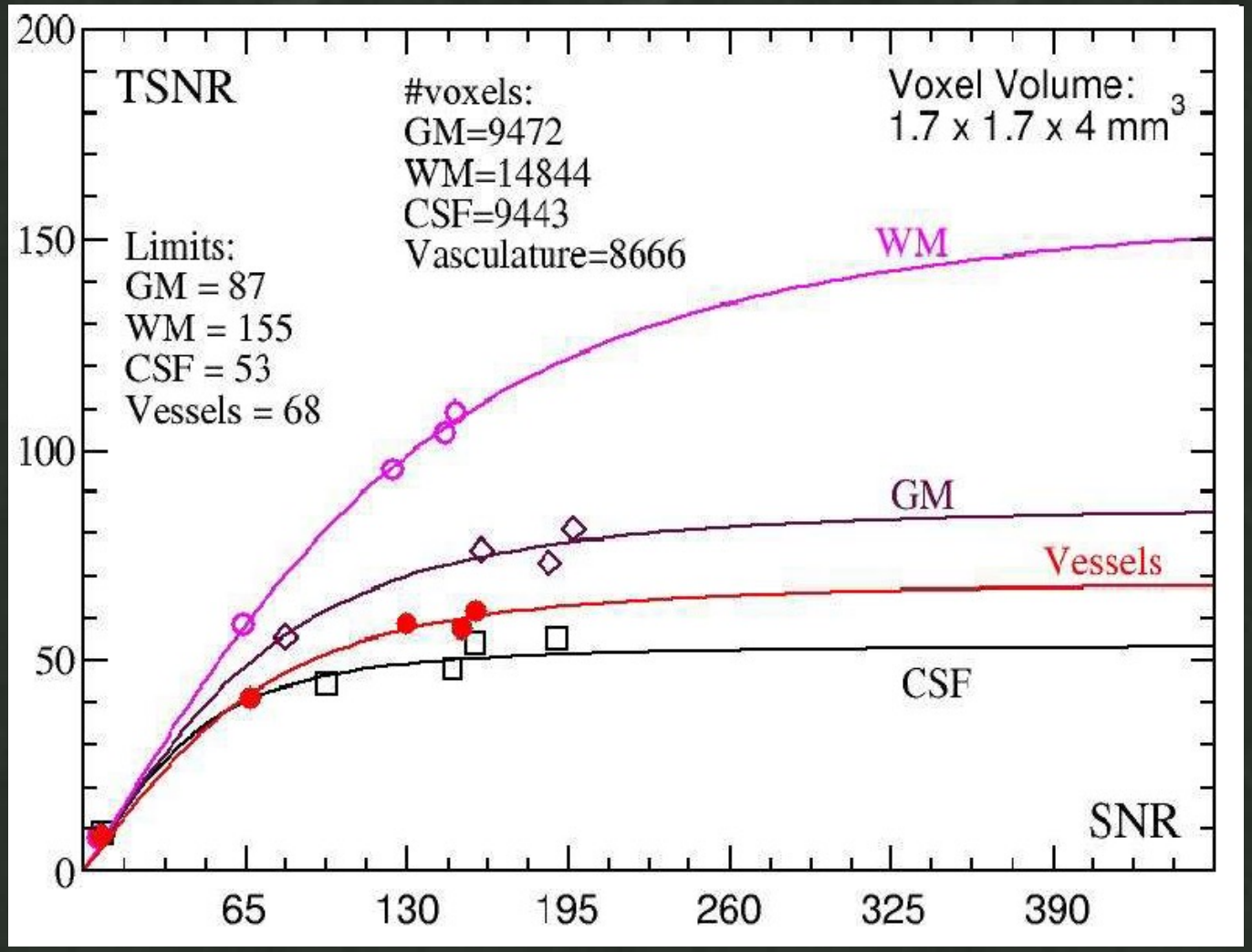


Simulated gains in TNSR with doubling sensitivity

Temporal SNR

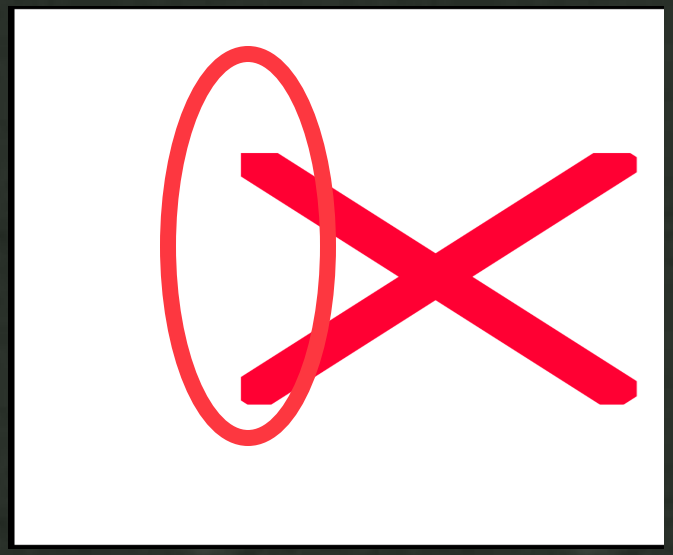


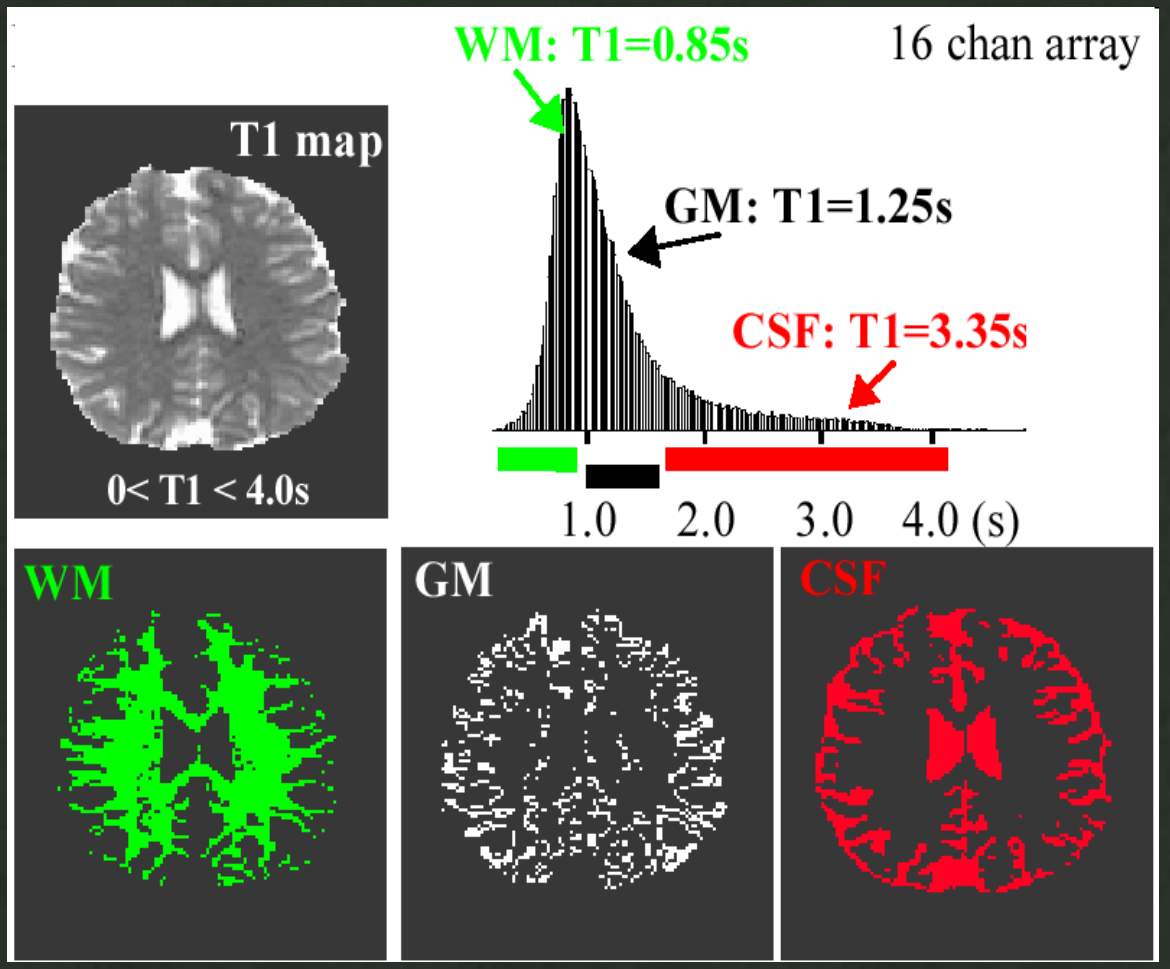
Parallel Acquisition



J. Bodurka

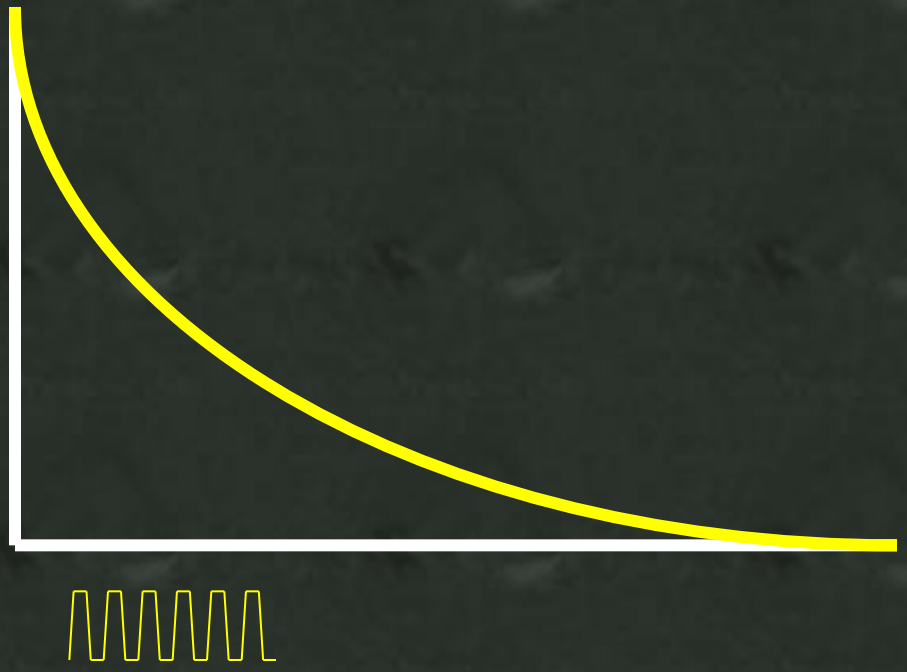
Segmentation using EPI Transient



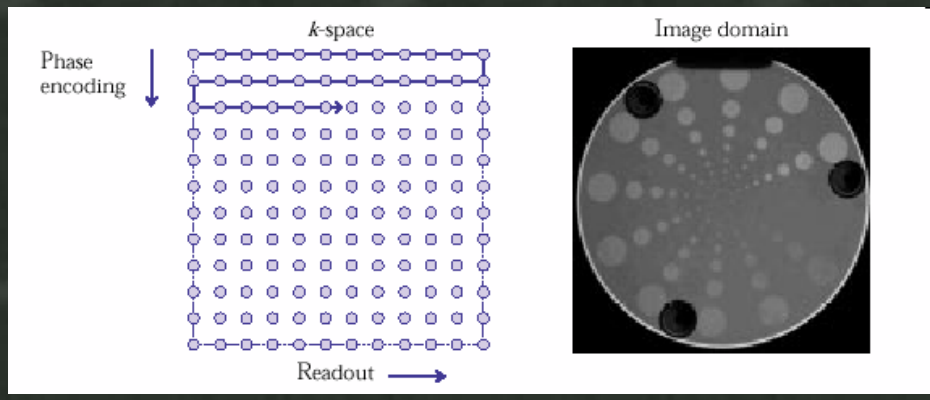


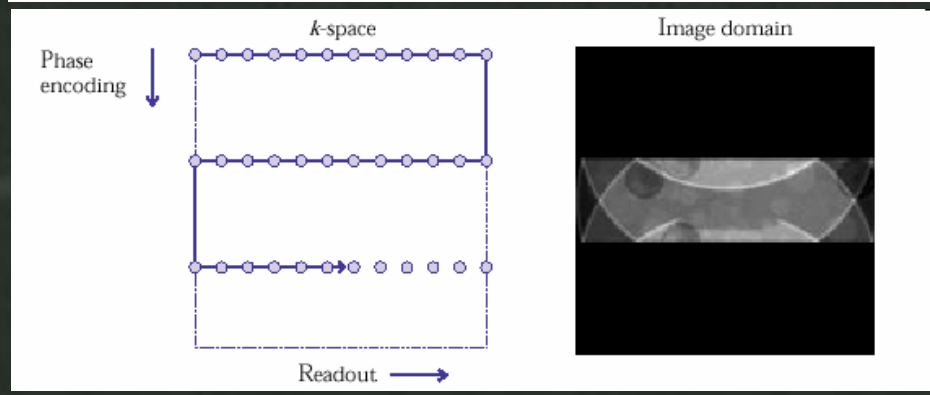
Technology

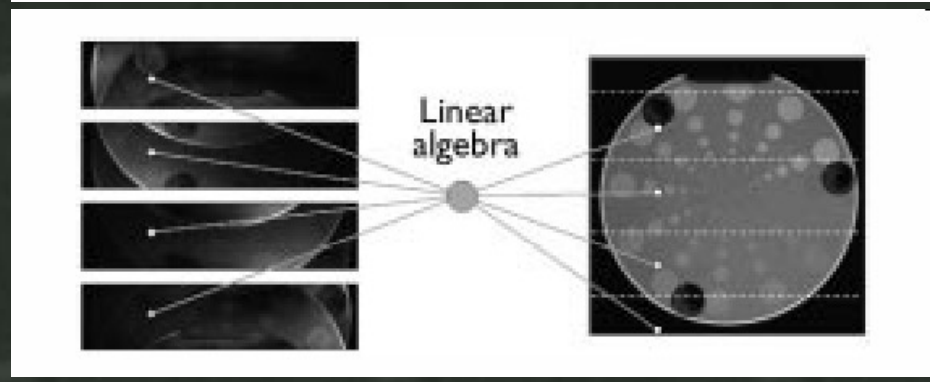
SENSE Imaging



≈ 5 to 30 ms







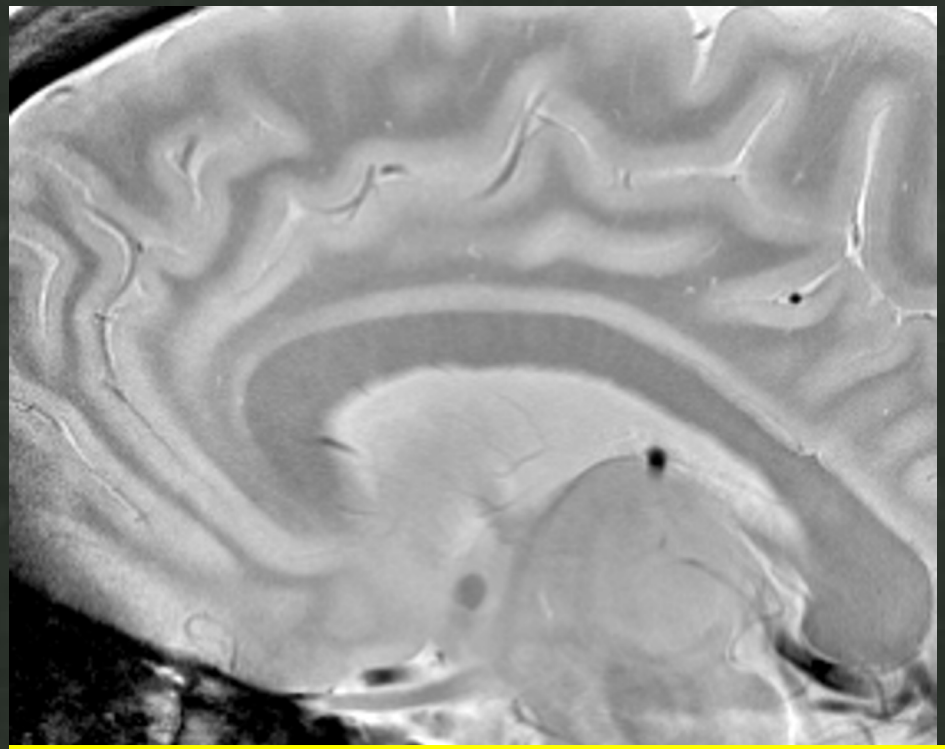
Pruessmann, et al.

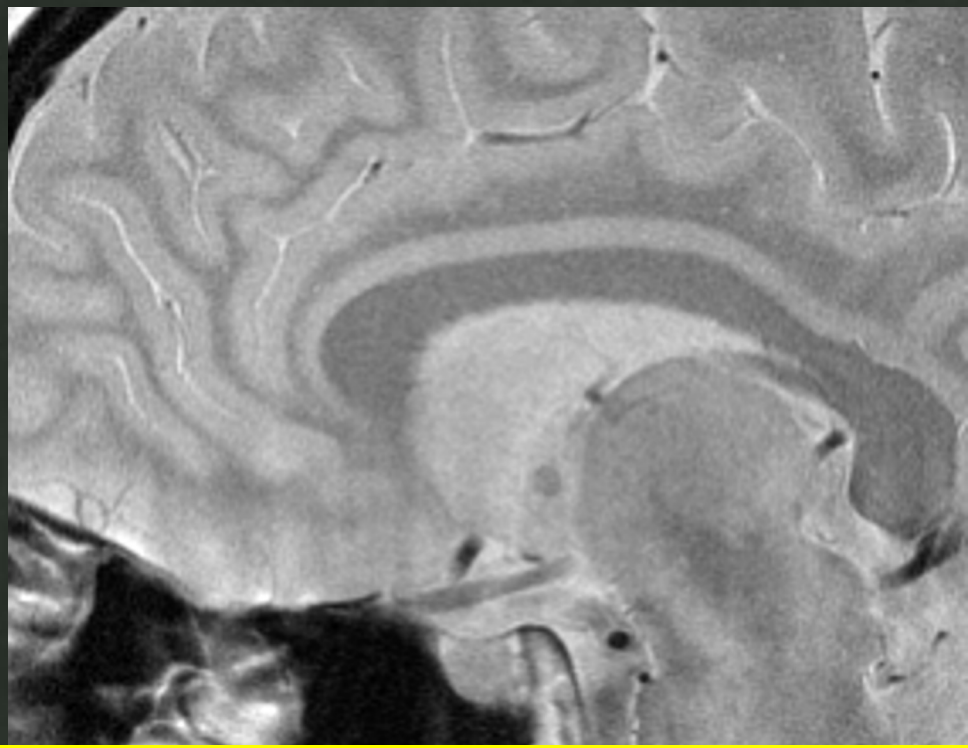
SENSE Imaging

3T single-shot SENSE EPI using 16 channels: 1.25x1.25x2mm

7T head coil

3T head coil



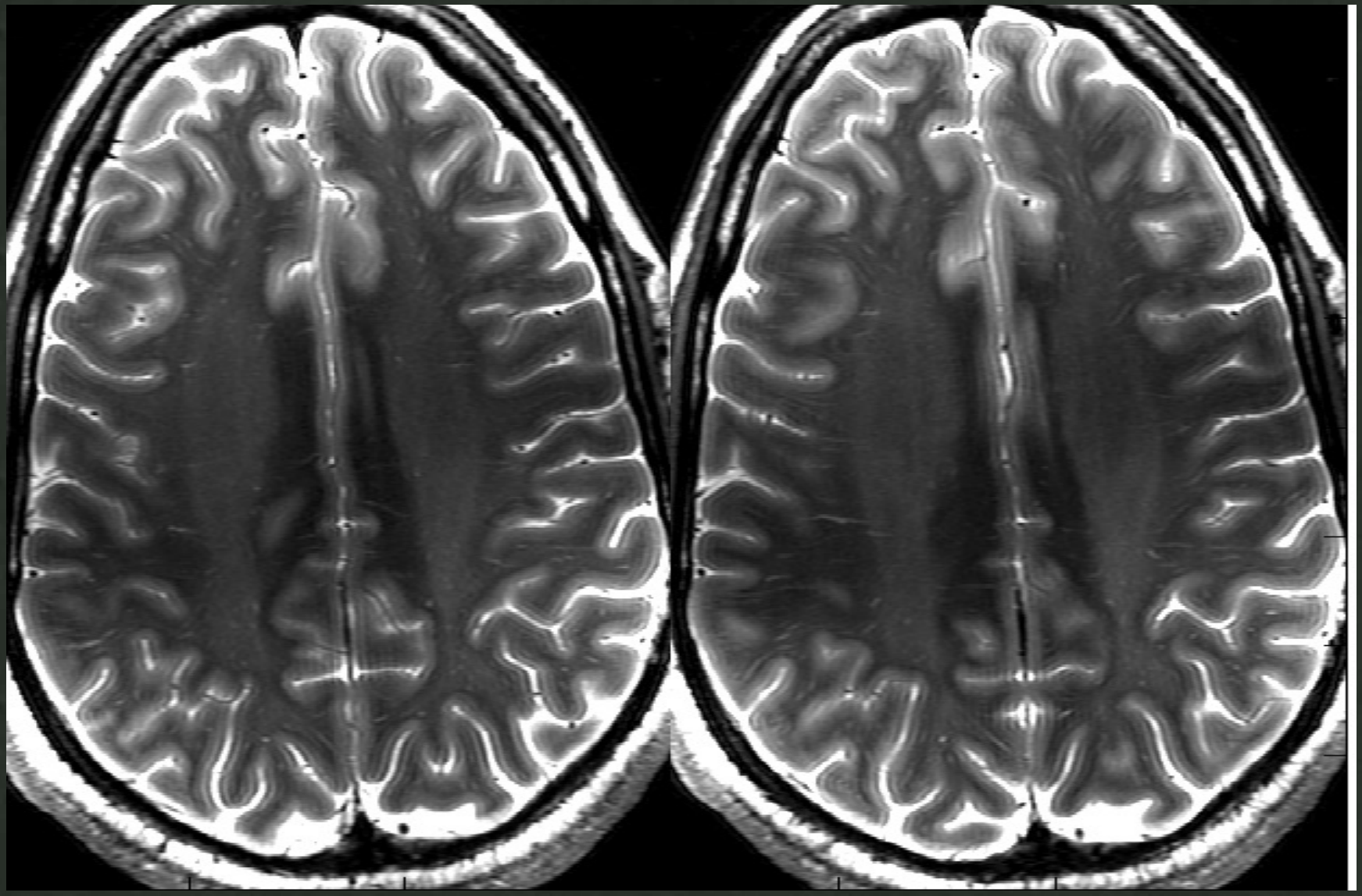


TSE, 11 echoes, 7 min exam, 20cm FOV, 512x512 (0.4mm x 0.4mm), 3mm thick slices.

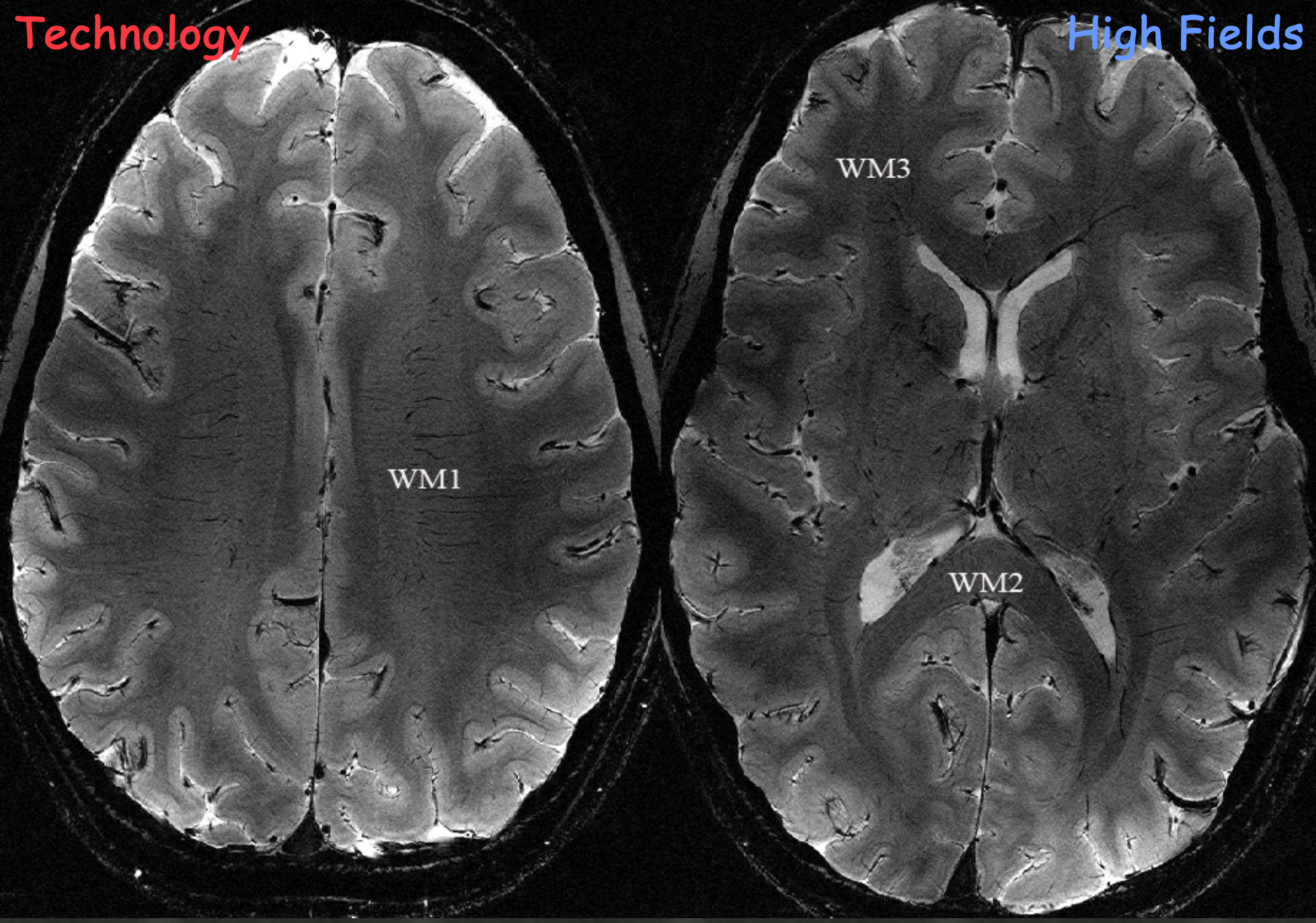
7T
white matter SNR =65
Gray matter SNR = 76

3T
white matter SNR =26
Gray matter SNR = 34

Courtesy Larry Wald



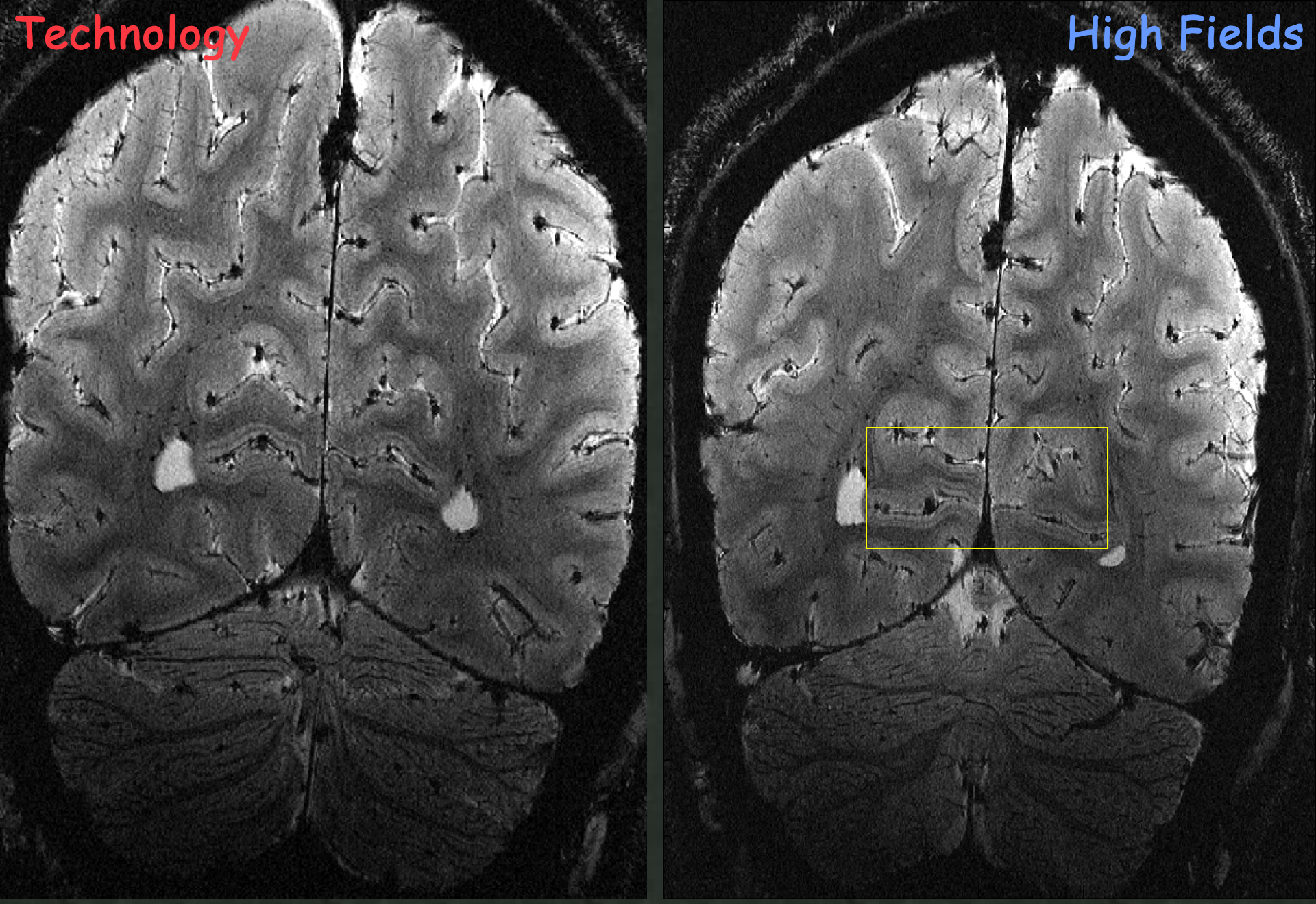
FSE **images** at 0.2x.2x1mm^3


Technology
High Fields
WM1
WM3
WM2

Technology

High Fields

fiber bundles?


Technology
High Fields

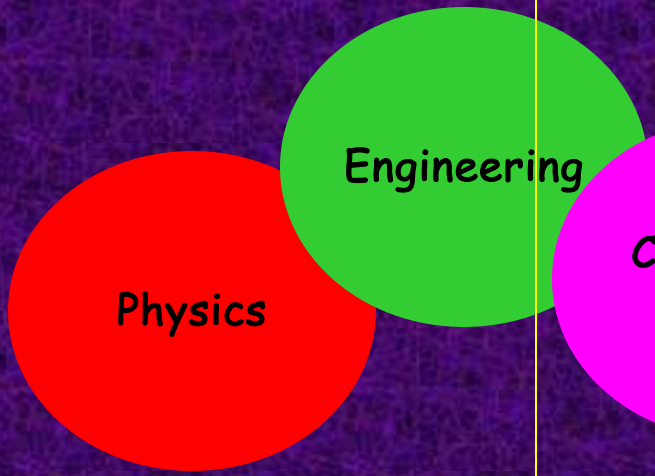
Technology

High Fields

Layered structure in the visual cortex

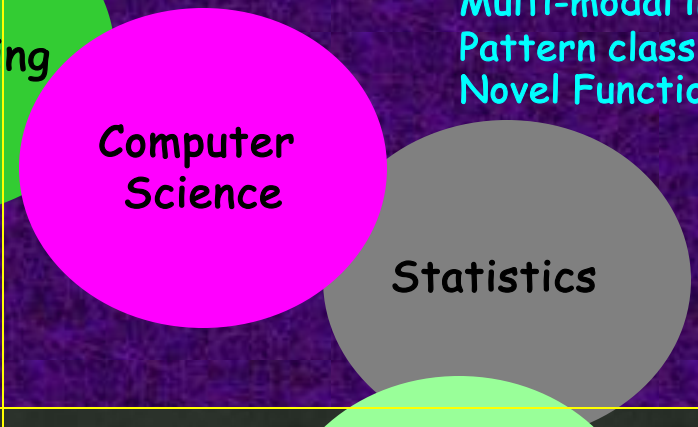
Technology

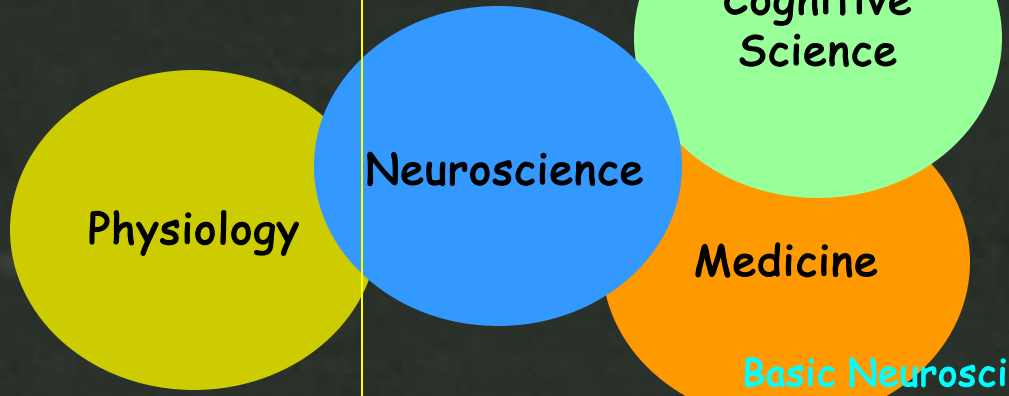
Coil arrays
Higher field strength
Higher resolution



Methodology

"Resting state"
Fluctuation assessment
Multi-modal integration
Pattern classification
Novel Functional Contrasts





Fluctuations
Dynamics
Cross - modal comparison

Interpretation

Basic Neuroscience
Behavior correlation/prediction
Pathology correlation

Applications

fMRI Contrast

- Volume (gadolinium)
- BOLD
- Perfusion (ASL)
- $\Delta CMRO_2$
- ΔVolume (VASO)
- Neuronal Currents
- Diffusion coefficient
- Temperature

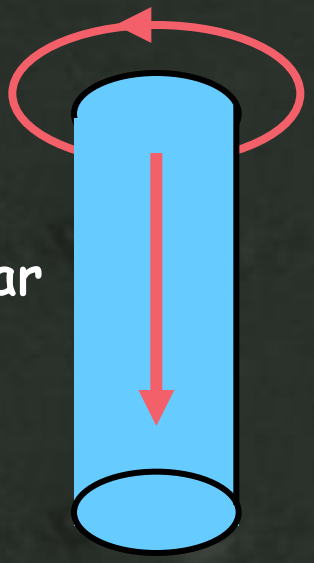
Methodology

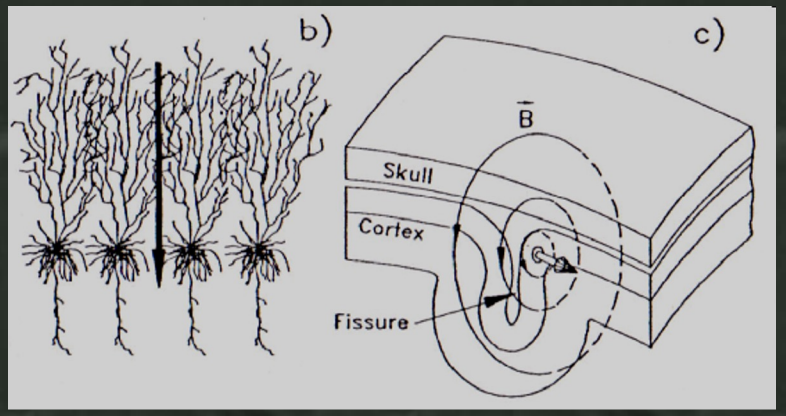
New Contrasts

Neuronal Currents

Magnetic Field

Intracellular Current





Surface Fields

100 fT at on surface of skull

And 0.2 nT near source

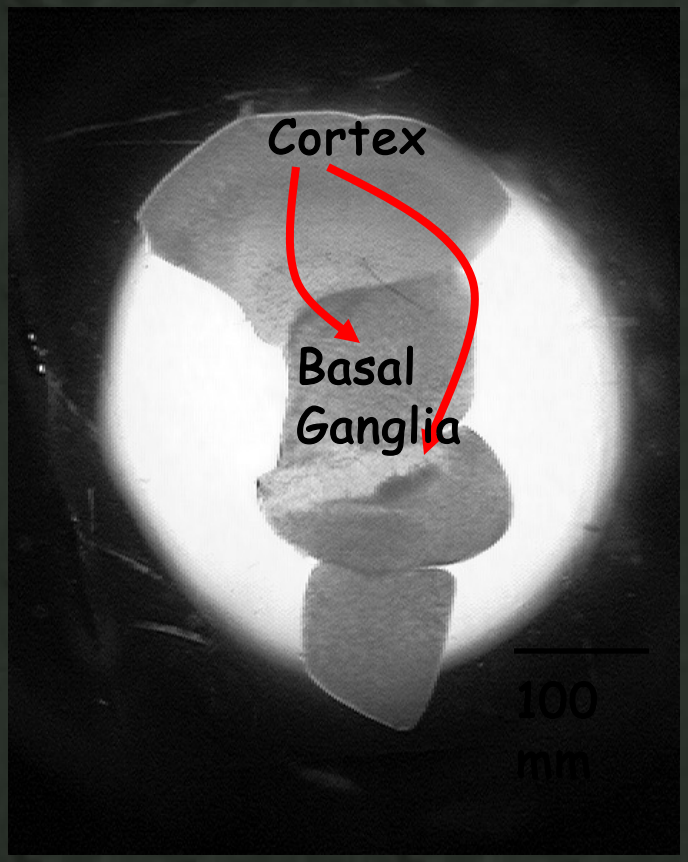
Methodology

New Contrasts

Neuronal Currents

In Vitro Results

Organotypic (*no blood supply or hemoglobin traces*) sections of newborn-rat somato-sensory Cortex, or somato-sensory Cortex & Basal Ganglia



- Size: in-plane:~1-2mm^2, thickness: 60-100μm
- Neuronal Population: 10,000-100,000

- Spontaneous synchronized activity < 2Hz
- Epileptiform activity
- Spontaneous beta freq. activity (20-30Hz)
- Network Activity Range: ~ 0.5-15μV

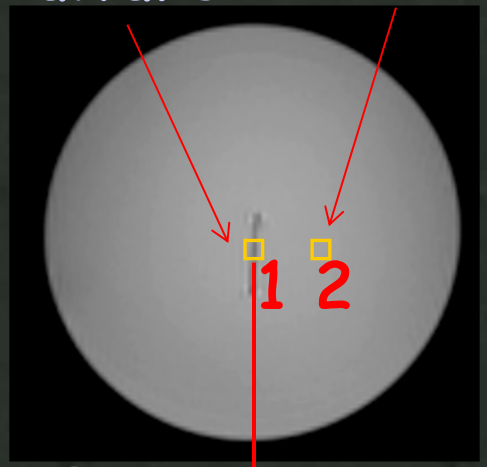
Plenz, D. et al. *Neurosci* 70(4): 861-924, 1996

Methodology

New Contrasts

Neuronal Currents

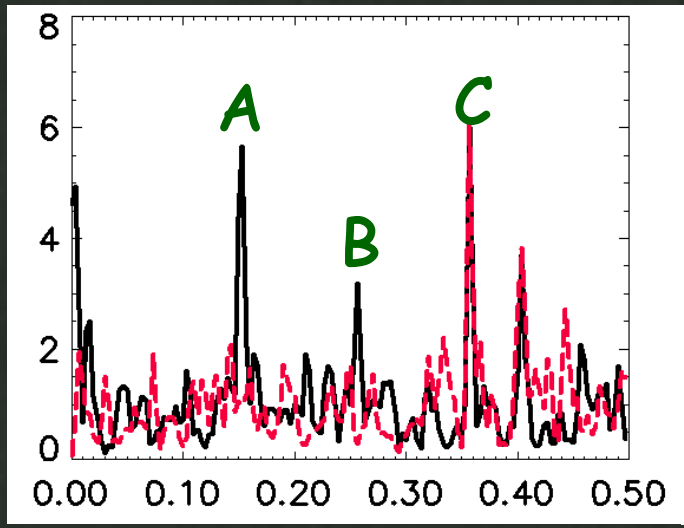
Culture ACSF



FSE image

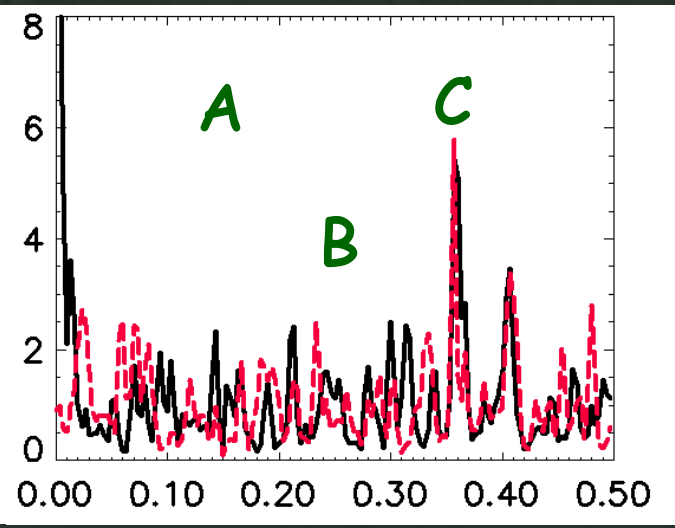
0.15Hz map

1: culture



Hz

2: ACSF



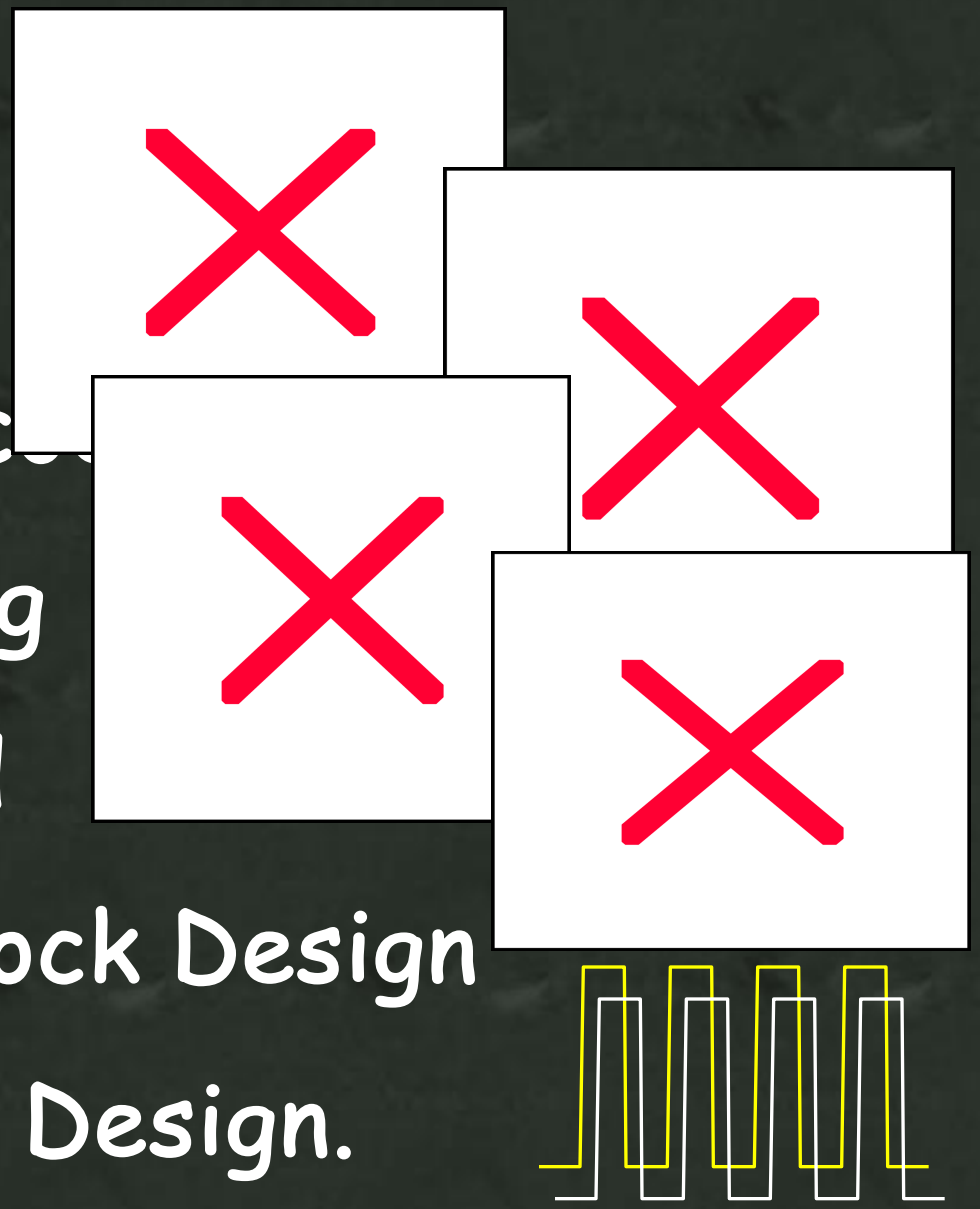
Hz

Active condition: black line
Inactive condition: red line

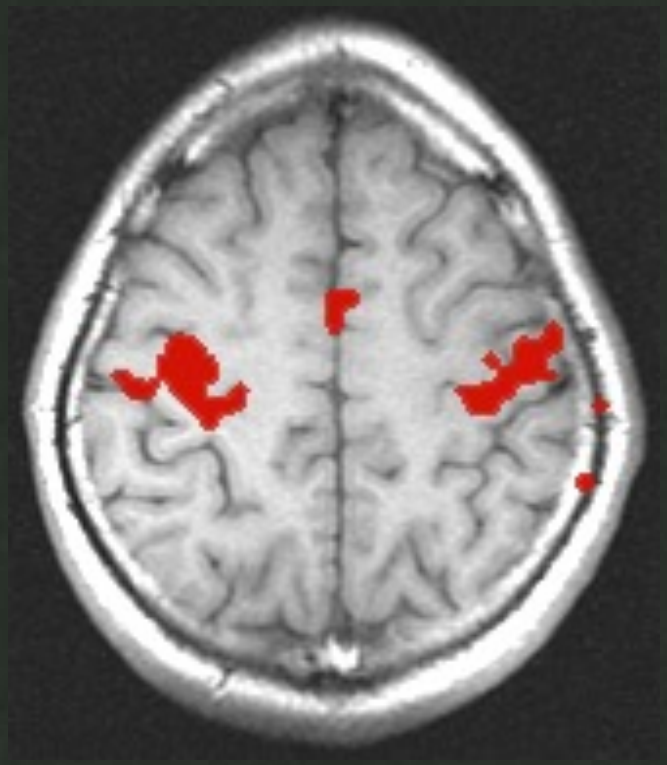
A: 0.15 Hz activity, on/off frequency
B: activity
C: scanner noise (cooling-pump)

Methodology

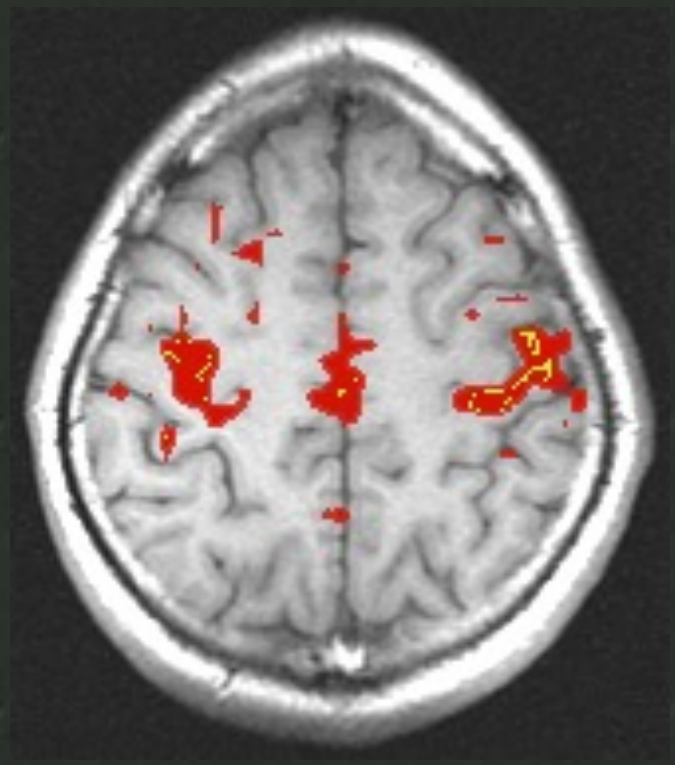
1. Block Design
2. Frequency Enc
3. Phase Encoding
4. Event-Related
5. Orthogonal Block Design
6. Free Behavior Design.



Resting State Correlations



Activation:
correlation with reference function



Rest:
seed voxel in motor cortex

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

Methodology

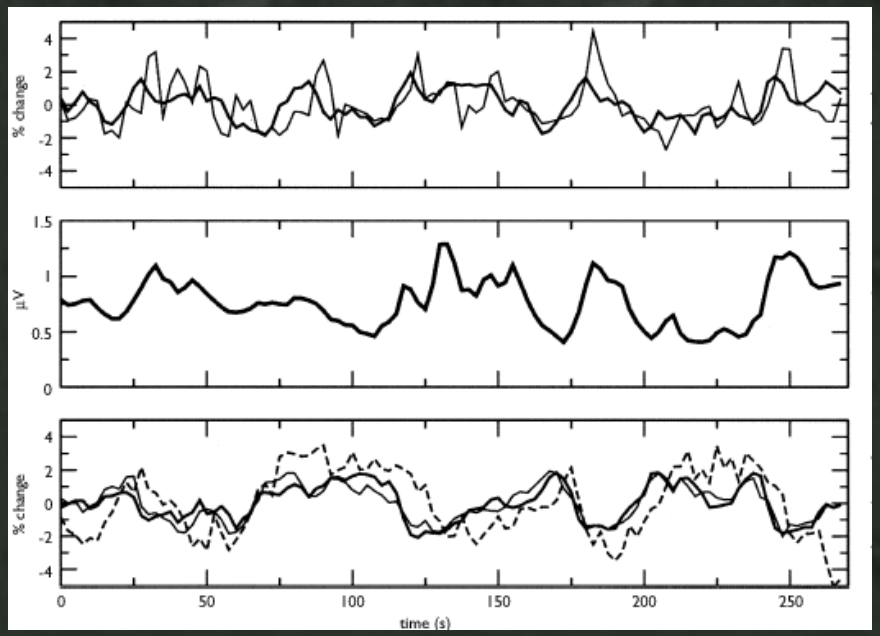
Fluctuations and "Resting" State

BOLD correlated with 10 Hz power during "Rest"

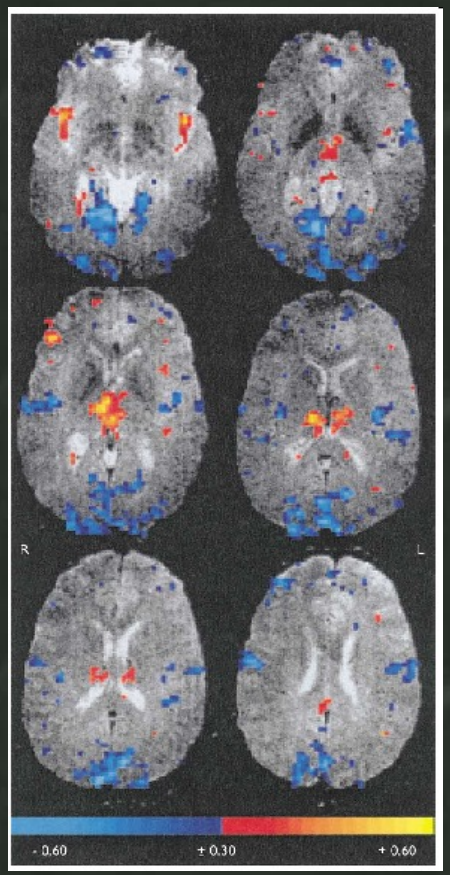
Positive

10 Hz power

Negative



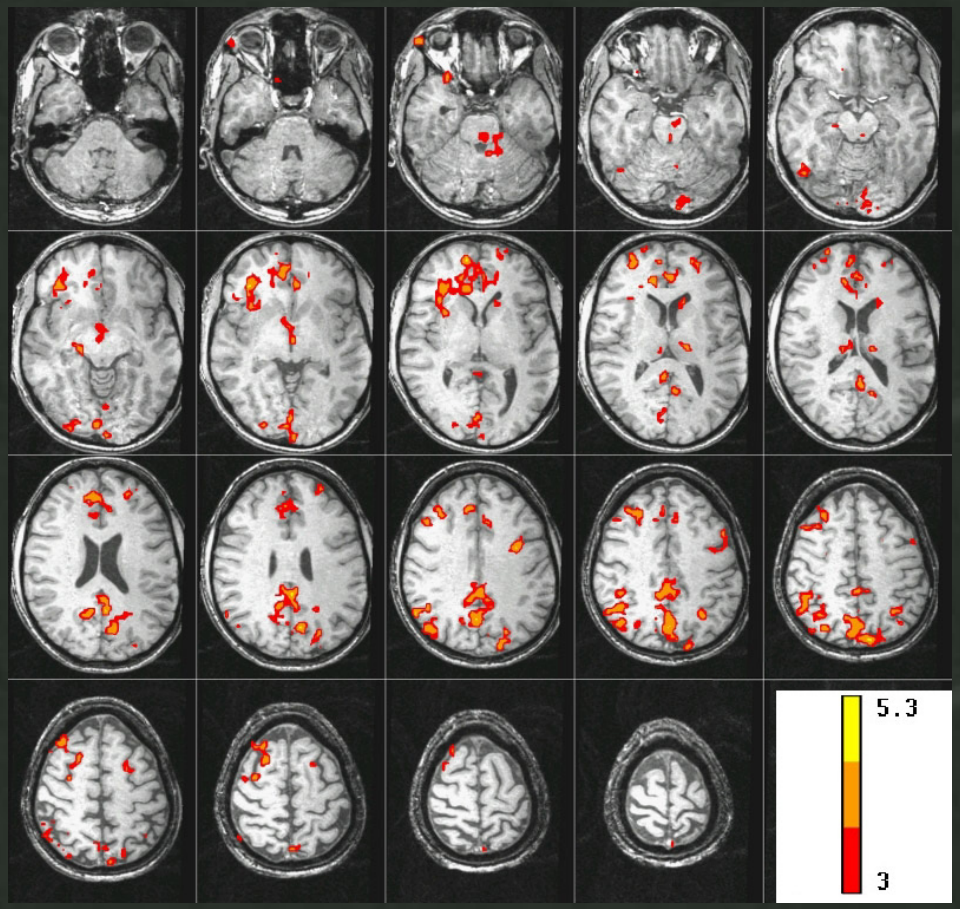
Goldman, et al (2002), Neuroreport



Methodology

Fluctuations and "Resting" State

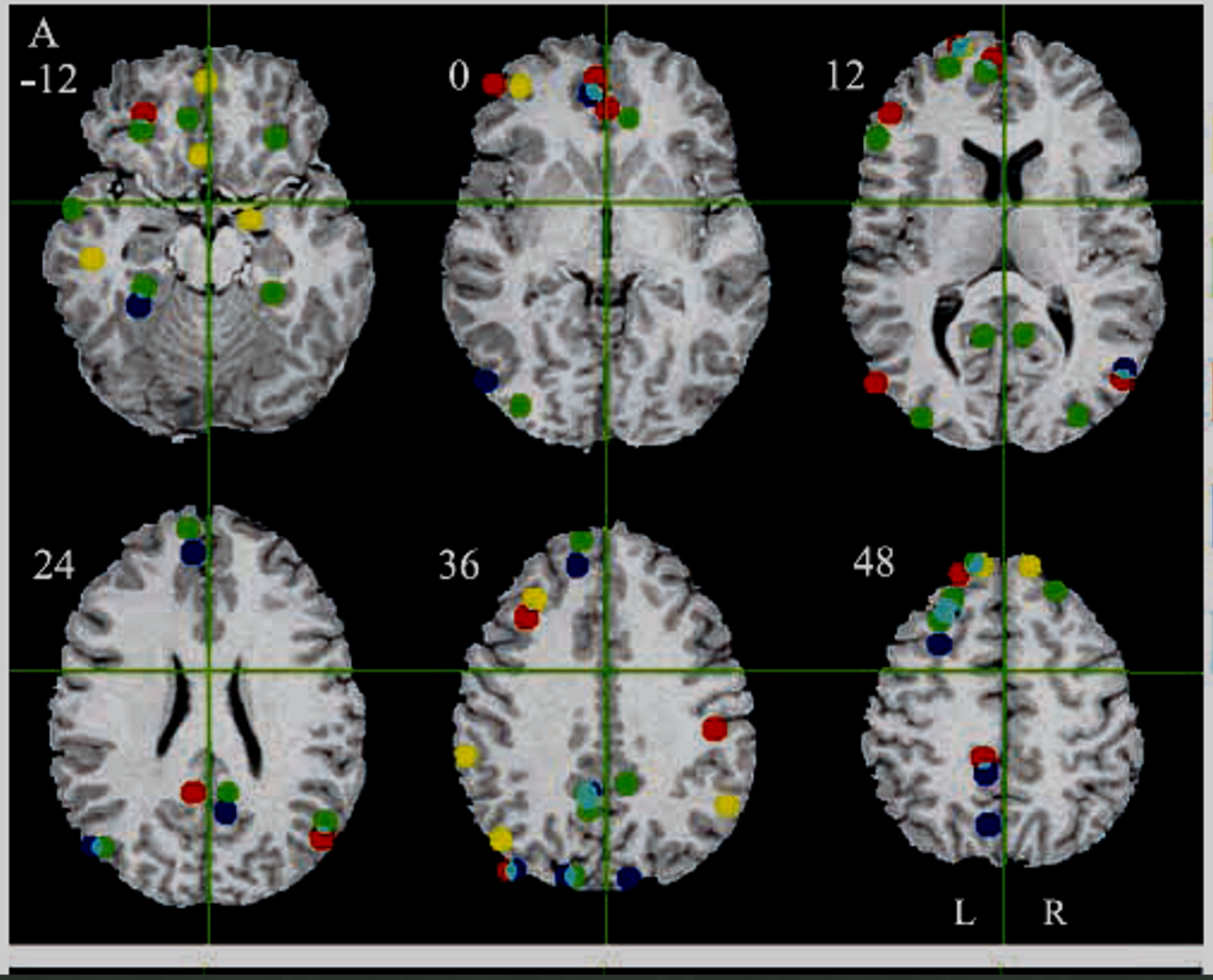
BOLD correlated with SCR during "Rest"



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

Methodology

Regions showing decreases during cognitive tasks



Shulman et al., 1997: BF decreases from averaged active-passive scan pairs in 9 visual PET experiments

Binder et al, 1999: Rest - tones using fMRI

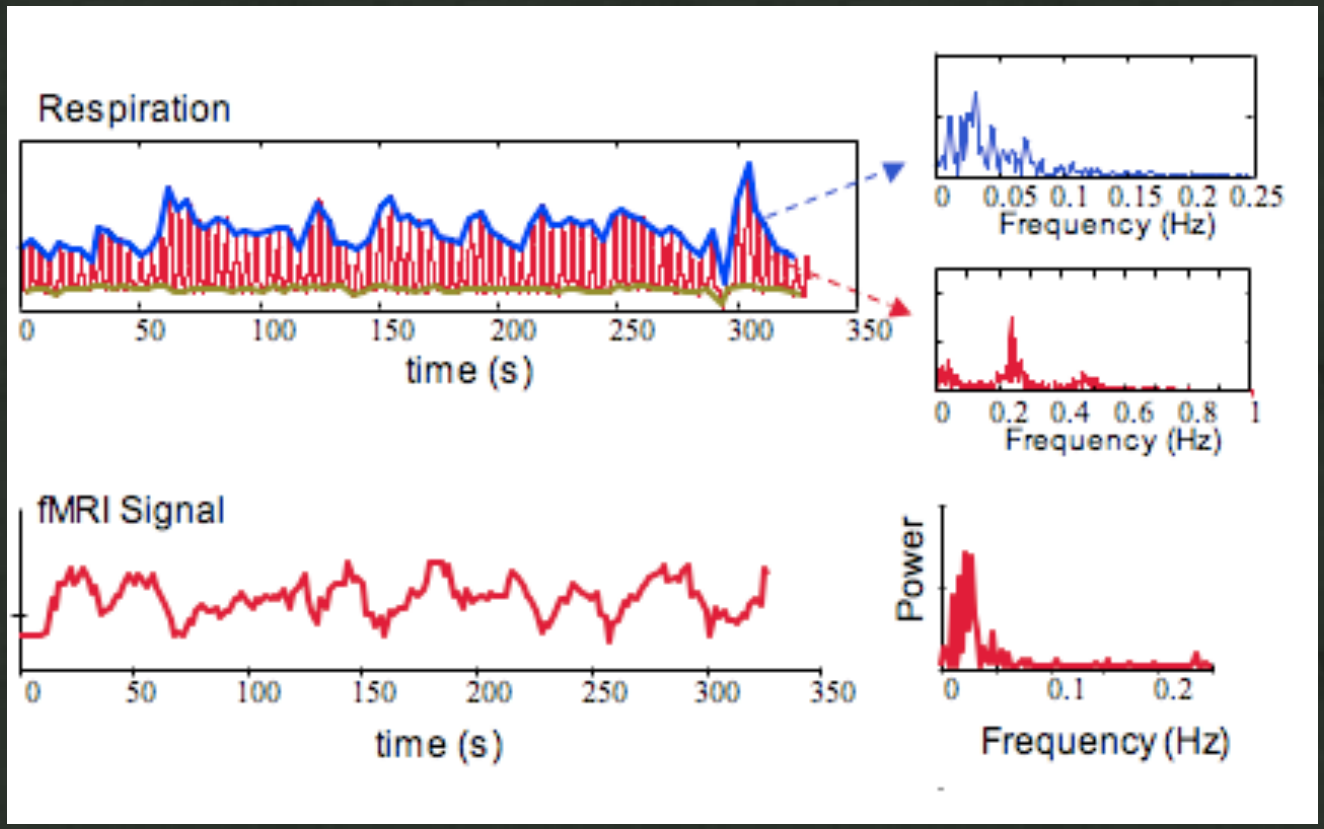
Mazoyer et al, 2001: Rest conditions jointly compared to 9 cognitive tasks using PET

Current study: Areas that deactivate relative to rest using fMRI and an auditory target detection task

Location of deactivation common to two or more of the above studies

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

Effects of Respiration on Signal

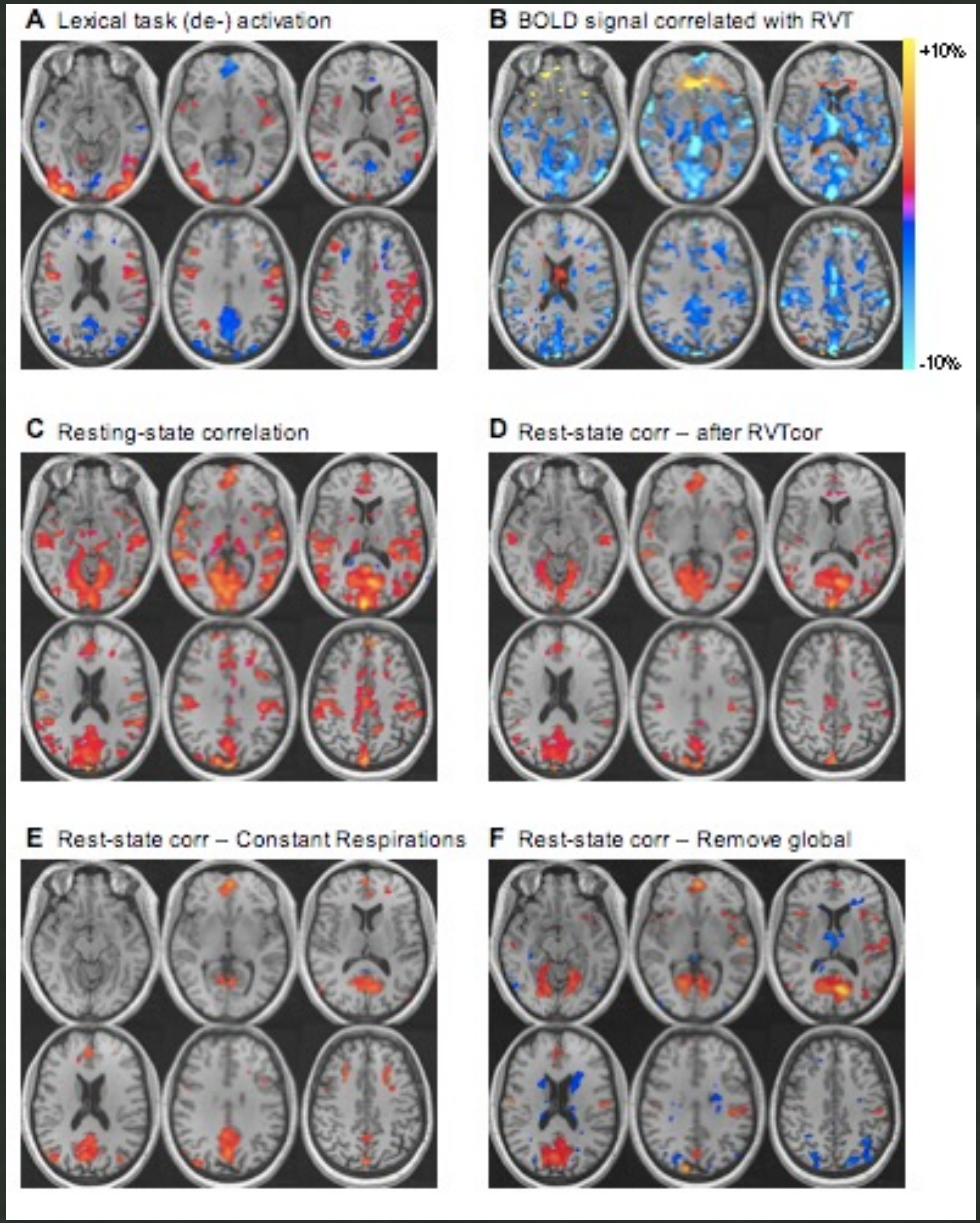


R. M. Birn, J. B. Diamond, M. A. Smith, P. A. Bandettini, Separating respiratory variation-related fluctuations from neuronal activity-related fluctuations in fMRI, NeuroImage (in press)

Methodology

Fluctuations and "Resting" State

Individual Maps

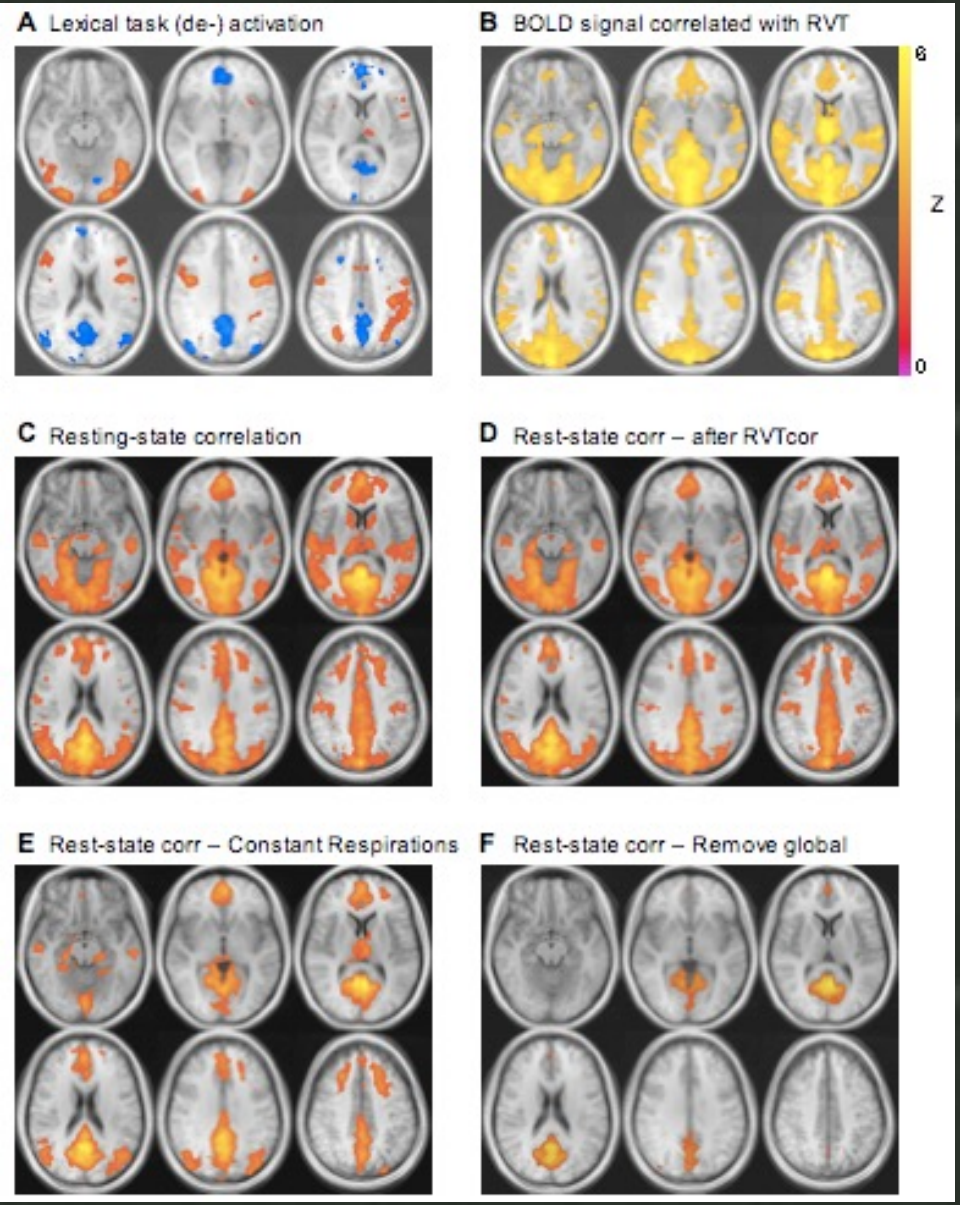


R. M. Birn, J. B. Diamond, M. A. Smith, P. A. Bandettini, Separating respiratory variation-related fluctuations from neuronal activity-related fluctuations in fMRI, NeuroImage (in press)

Methodology

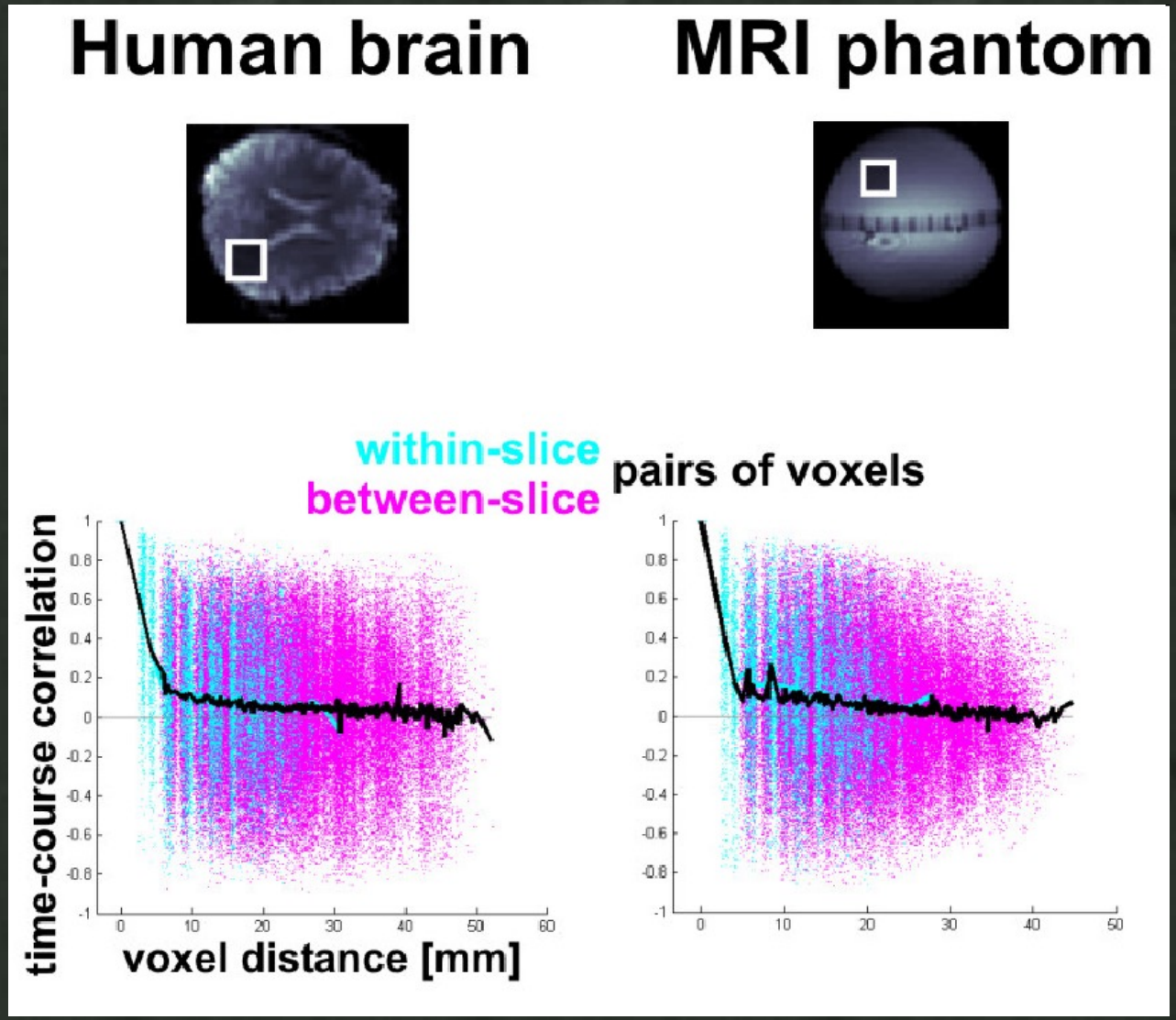
Fluctuations and "Resting" State

Group Maps



R. M. Birn, J. B. Diamond, M. A. Smith, P. A. Bandettini, Separating respiratory variation-related fluctuations from neuronal activity-related fluctuations in fMRI, NeuroImage (in press)

Local Correlations…



N. Kriegeskorte, J. Bodurka

Methodology

Pattern Classification

Mapping ⟷ "Reading"

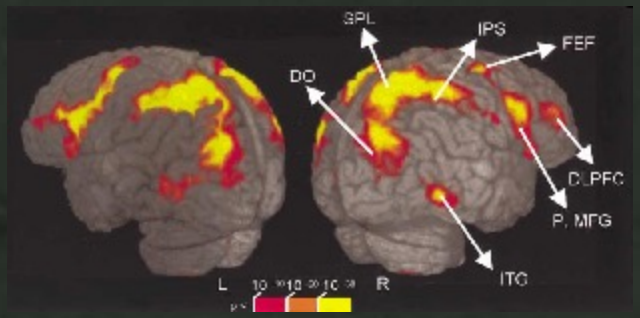
Methodology

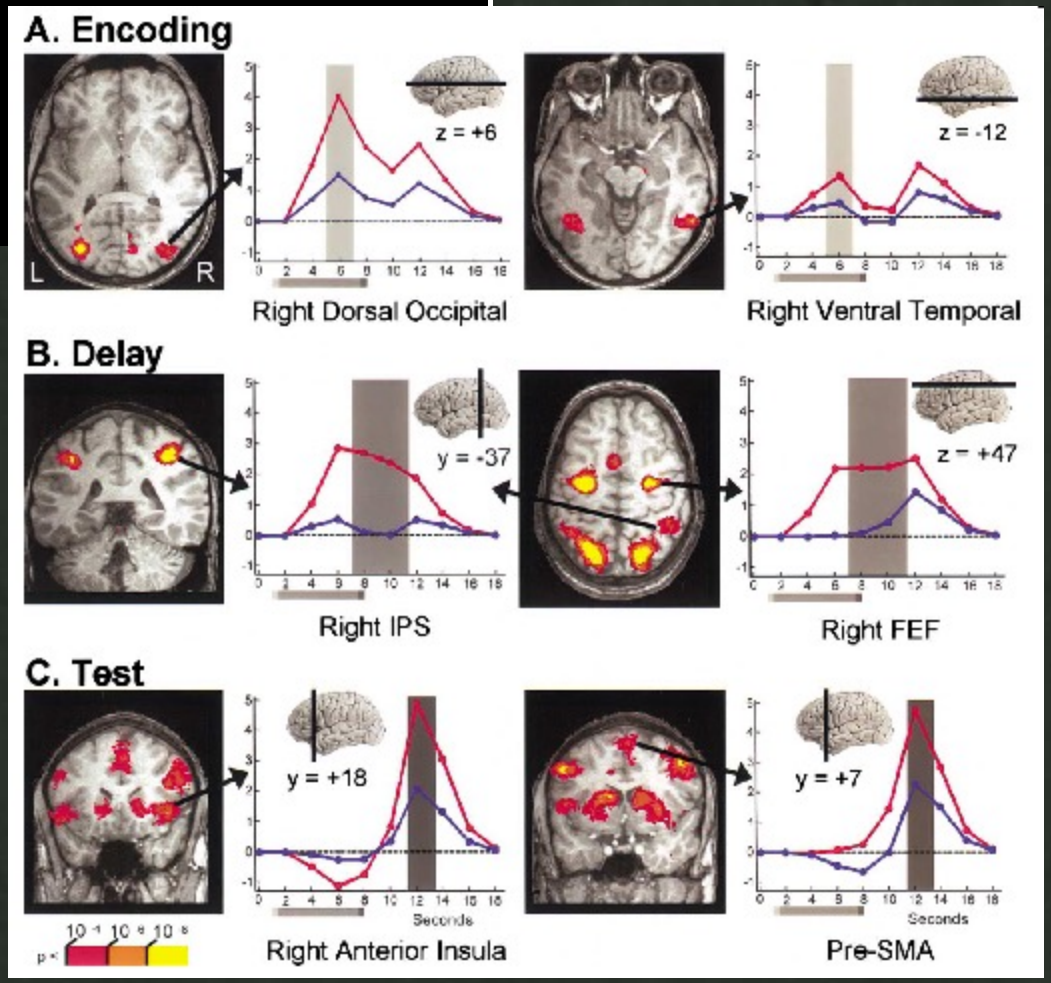
Pattern Classification

Neuron, Vol. 35, 975–987, August 29, 2002, Copyright ©2002 by Cell Press

Neural Correlates of Visual Working Memory: fMRI Amplitude Predicts Task Performance

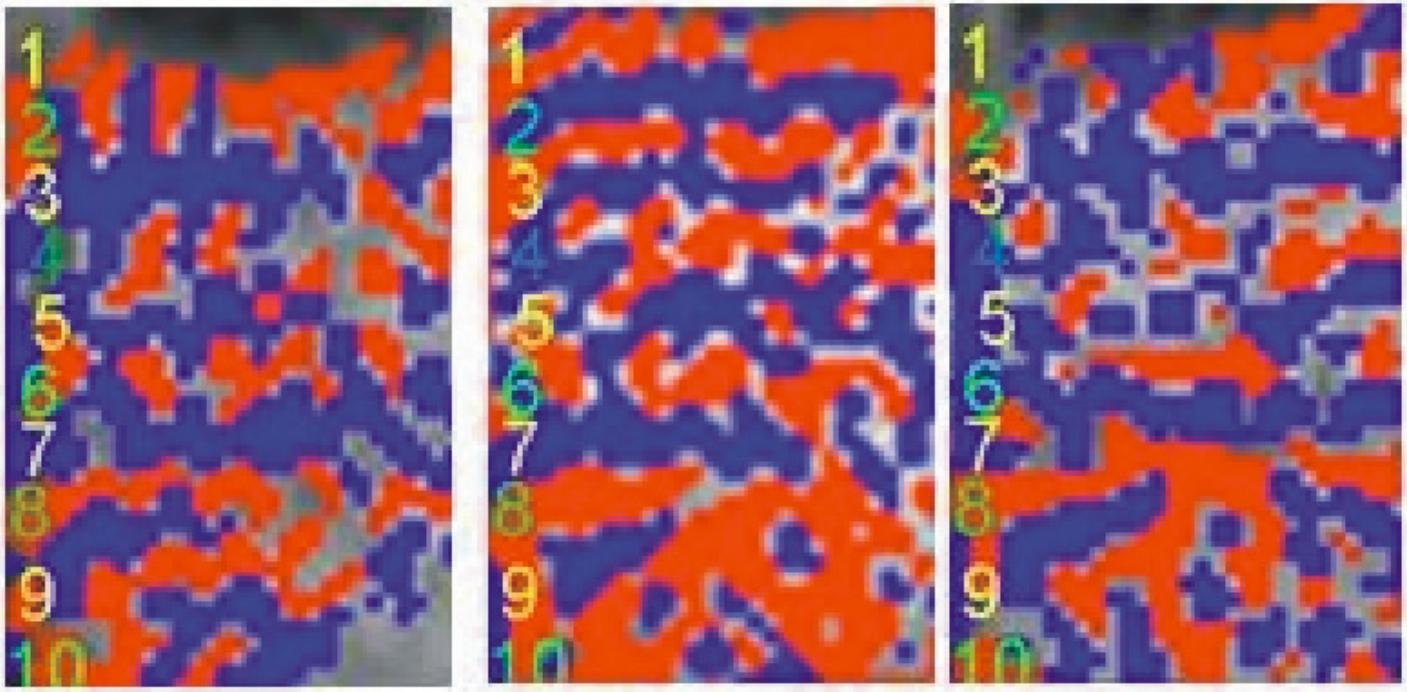
Luiz Pessoa,[1] Eva Gutierrez, Peter A. Bandettini, and Leslie G. Ungerleider
Laboratory of Brain and Cognition
National Institute of Mental Health
National Institutes of Health
Bethesda, Maryland 20892





HSE-BOLD demonstration of ocular dominance columns

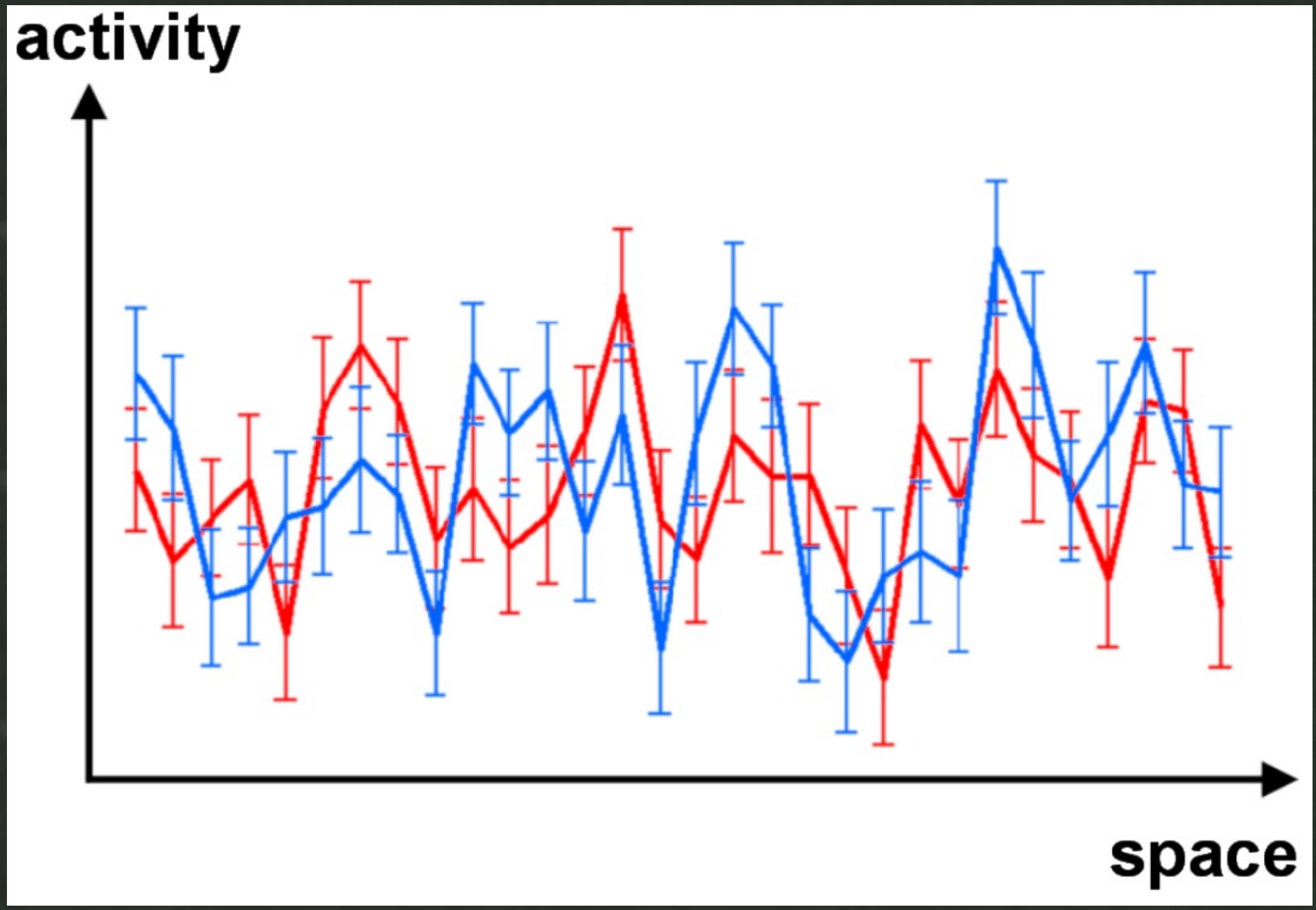
human, 7T, 0.5×0.5×3 mm^3



day 1 day 2 day 3

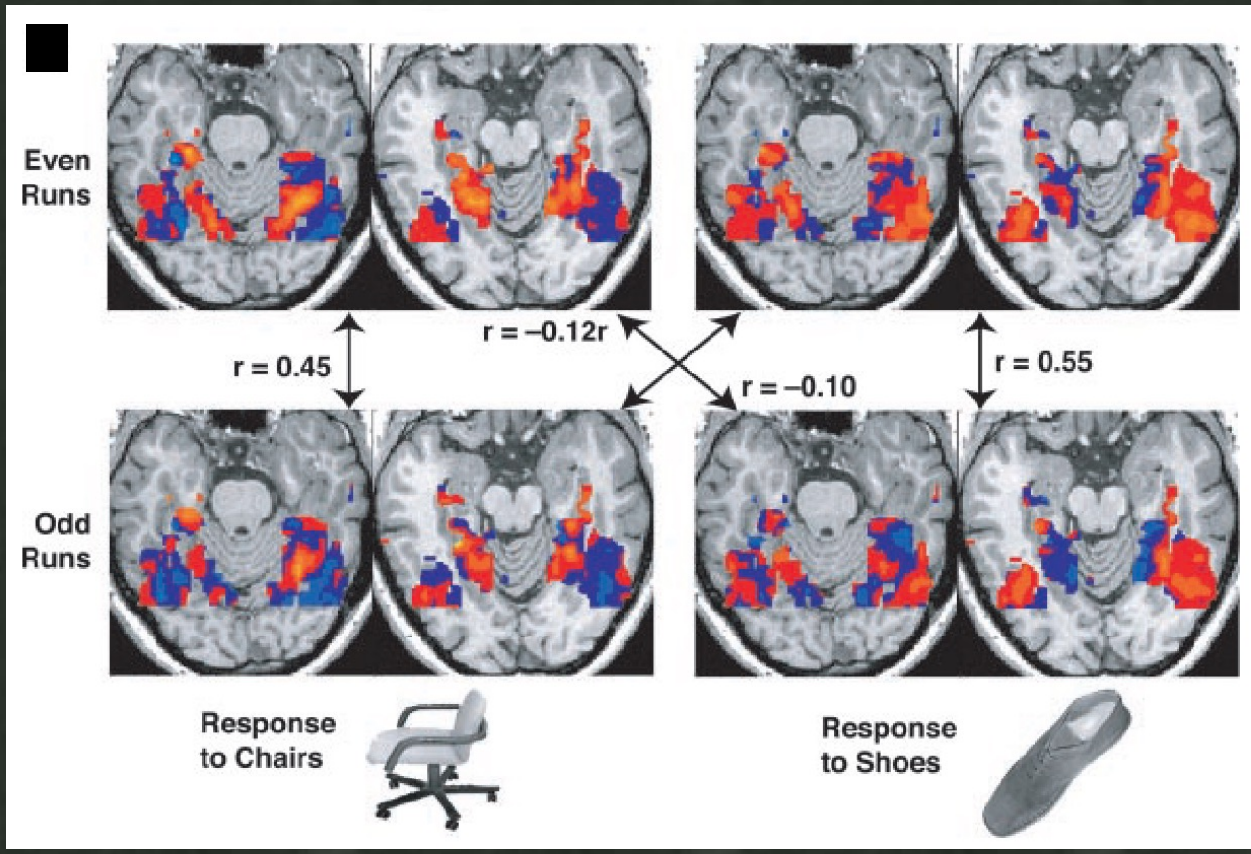
Yacoub et al: differential maps contrasting stimulation of the left and right eye

Pattern Classification



Ventral temporal category representations

- Object categories are associated with distributed representations in ventral temporal cortex
  - Present photos of common objects **blocked by category**.
  - Use fMRI to measure the pattern of high and low responses across large areas of ventral temporal cortex.
  - Observe **stable**, distributed "category representations"

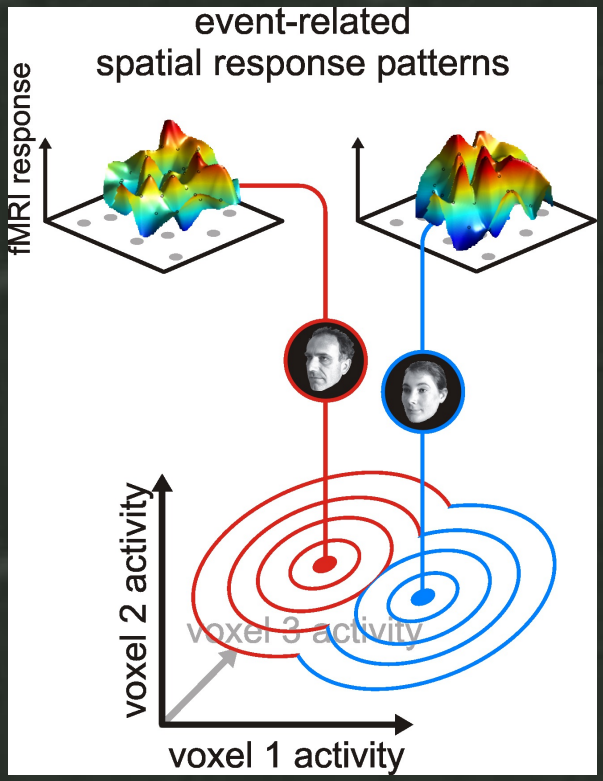


Pattern-recognition analysis of fMRI activity

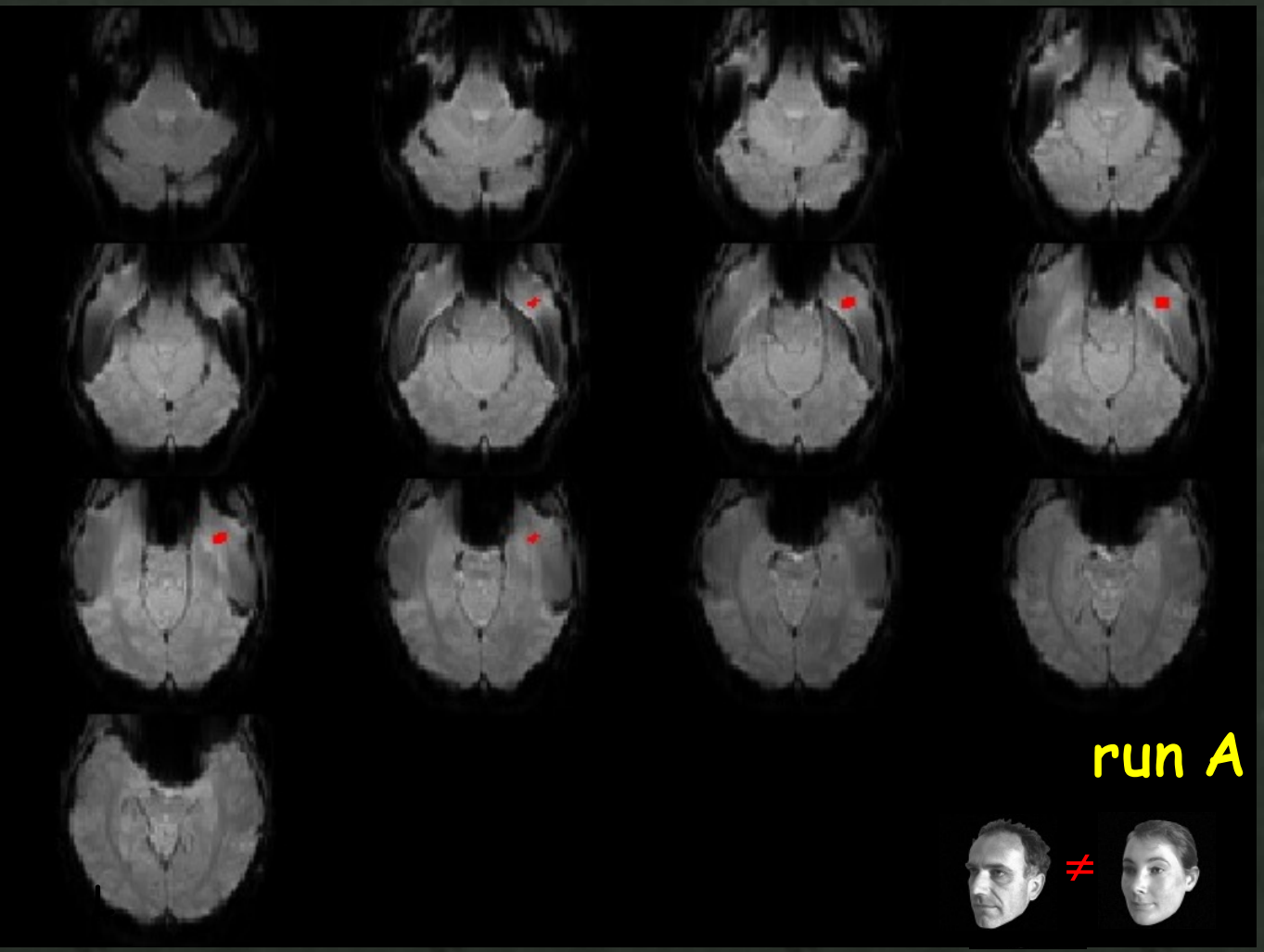
- Haxby et al. (2001)
- Cox & Savoy (2003)
- Carlson et al. (2003)
- Kamitani & Tong (2005)
- Haynes & Rees (2005)

Multivariate Searchlight Approach

Kriegeskorte et al.



Anterior inferotemporal face-exemplar region

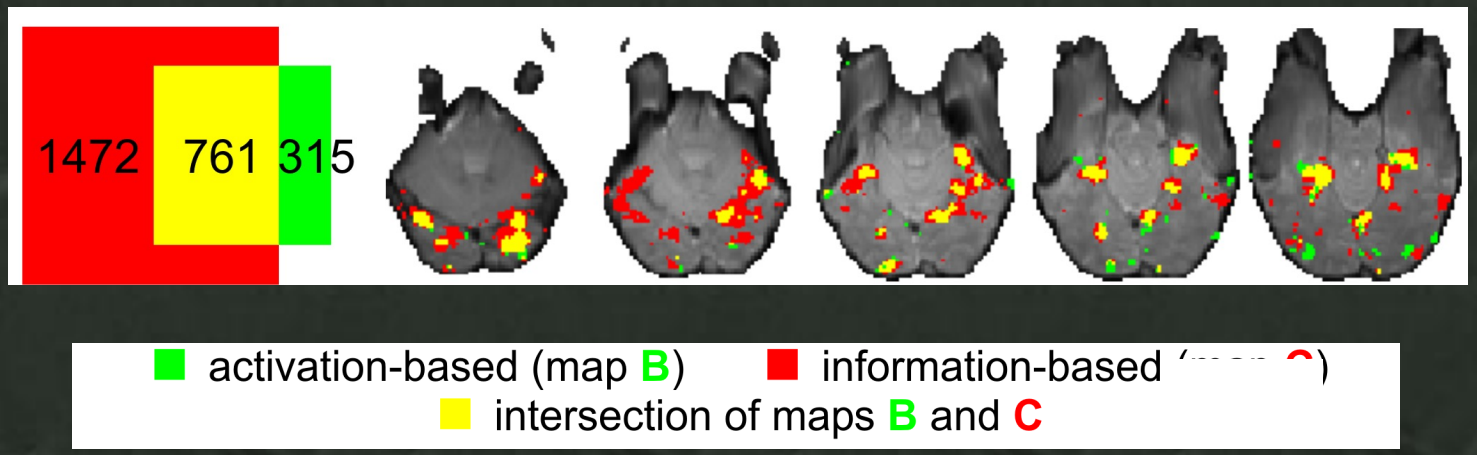


run B

Talairach: 33, -8, -33

spatial mean removed, fisherAtestB: single-sided test and info estimate

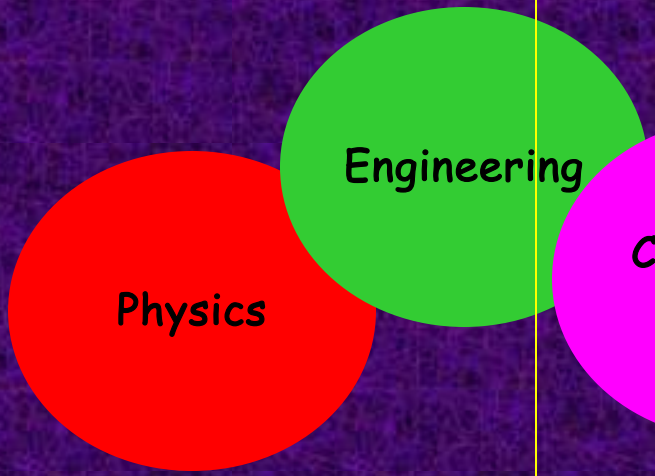
Application to Typical fMRI data to increase sensitivity



N. Kriegeskorte, R. Goebel, P. Bandettini, Information-based functional brain mapping. *Proc. Nat'l. Acad. Sci. USA*, (*in press*).

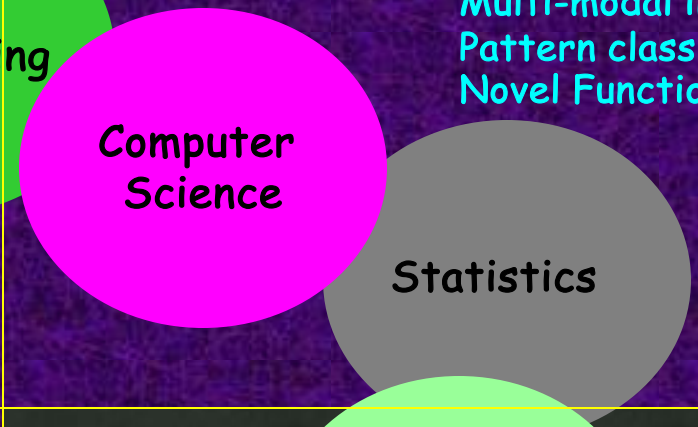
Technology

Coil arrays
Higher field strength
Higher resolution

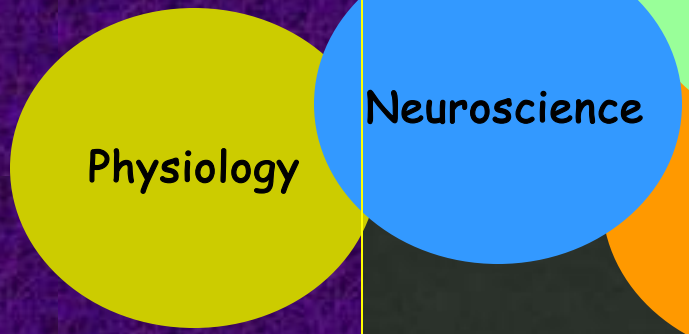


Methodology

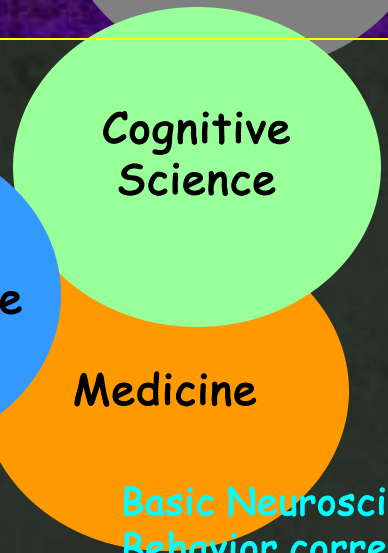
"Resting state"
Fluctuation assessment
Multi-modal integration
Pattern classification
Novel Functional Contrasts



Fluctuations
Dynamics
Cross - modal comparison



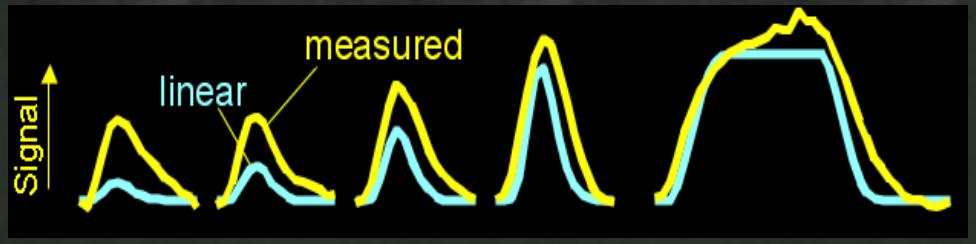
Interpretation



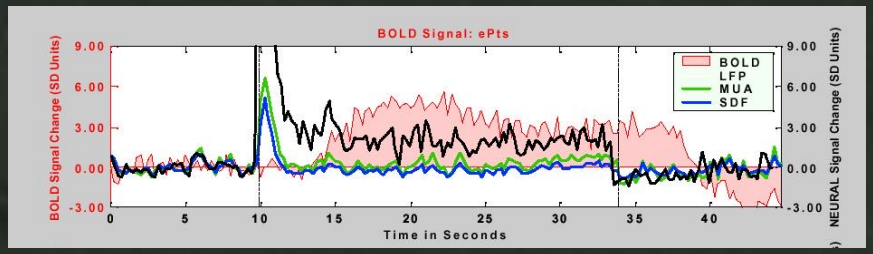
Basic Neuroscience
Behavior correlation/prediction
Pathology correlation

Applications

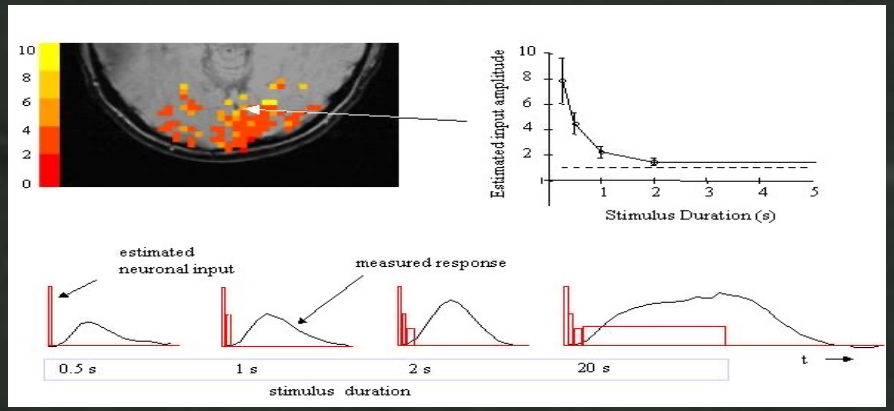
Increases: linearity



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



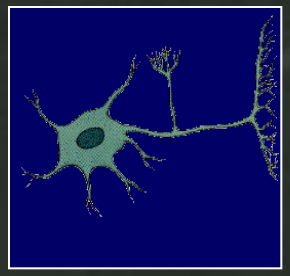
Logothetis et al. (2001) Nature, 412, 150-157.

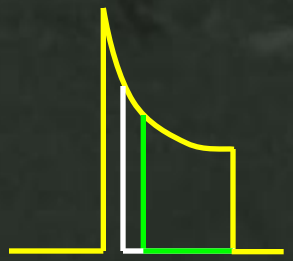


P. A. Bandettini et al, (2001) Nature Neuroscience, 4: 864-866.

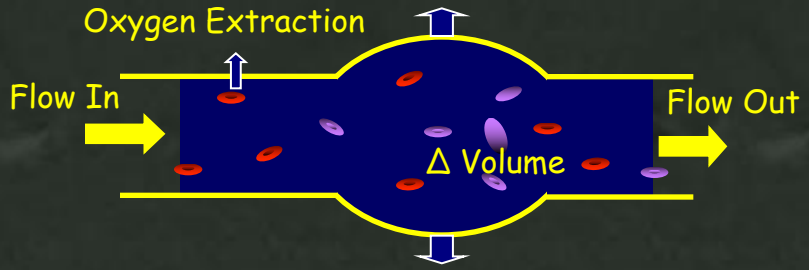
Sources of this Nonlinearity

- Neuronal





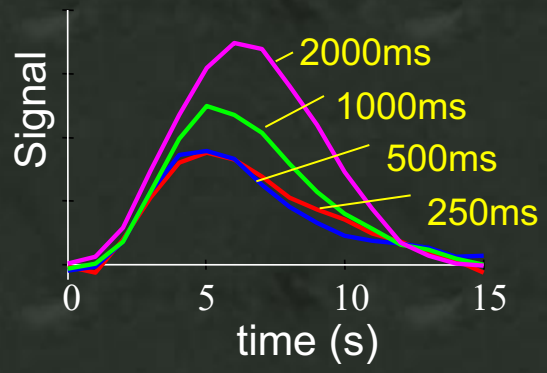
- Hemodynamic
  - -Oxygen extraction
  - -Blood volume dynamics

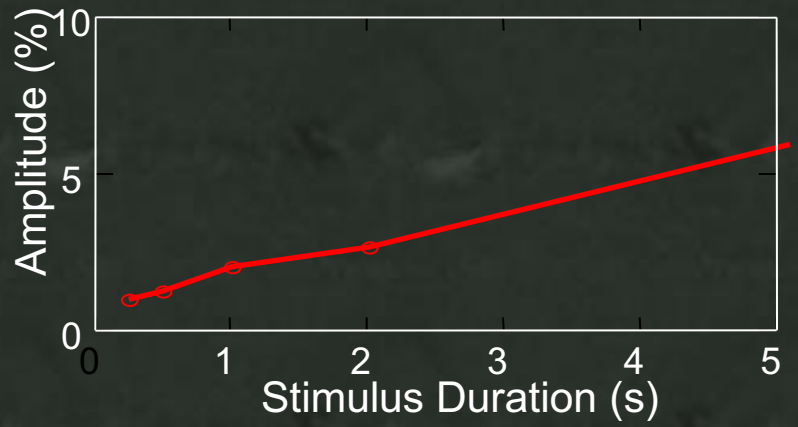


Interpretation

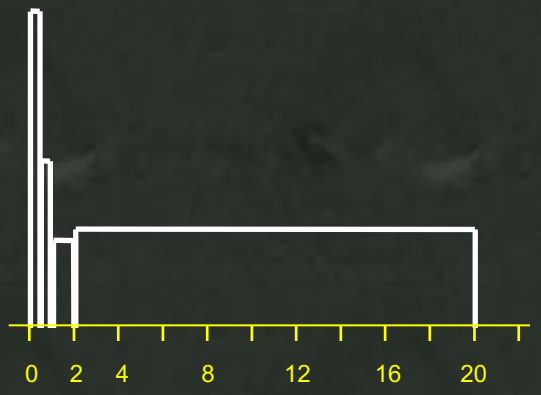
Linearity

Contrast Reversing Checkerboard





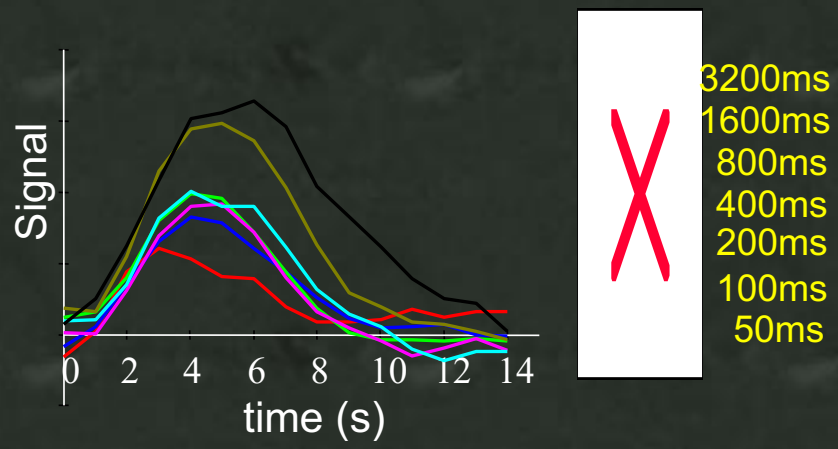
Estimated Neuronal Activity

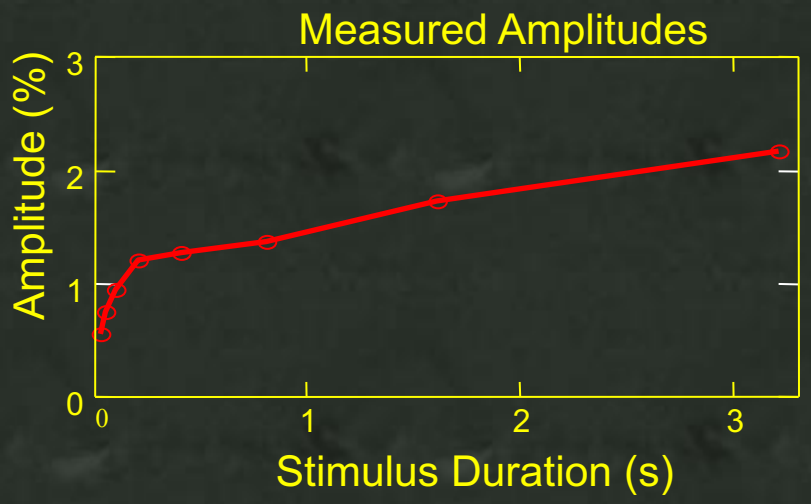


Interpretation

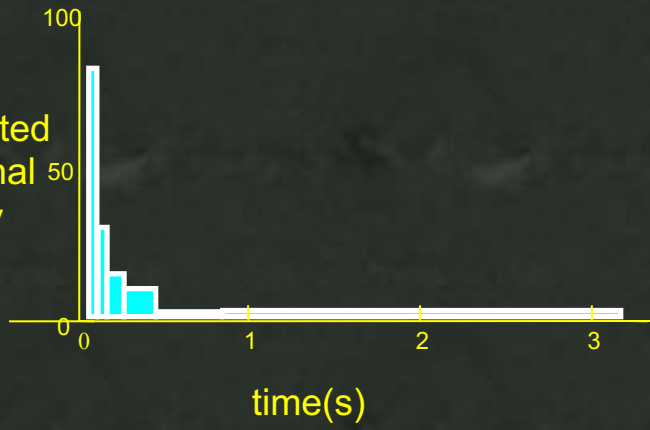
Linearity

Static Grating

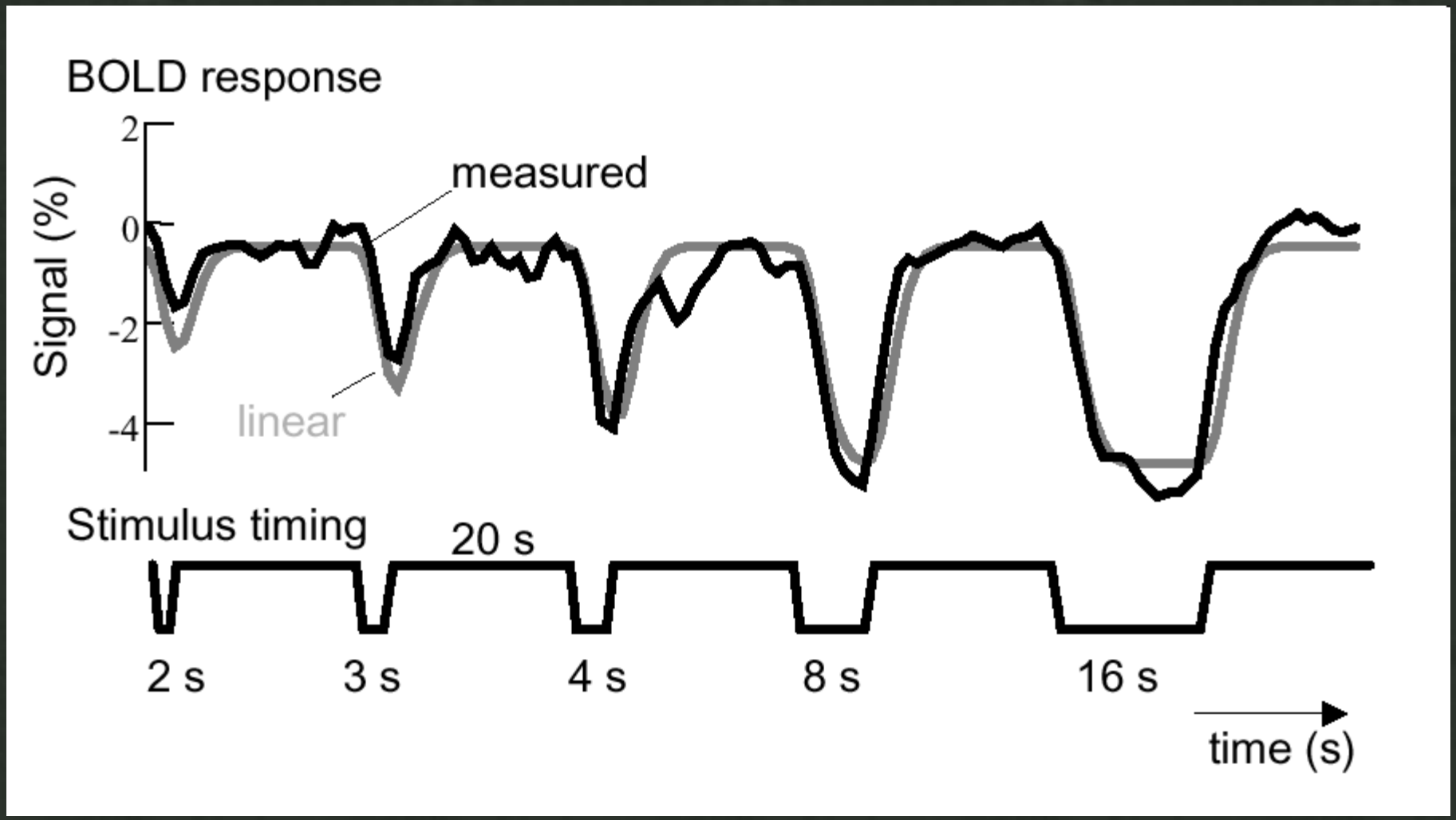




Estimated Neuronal Activity

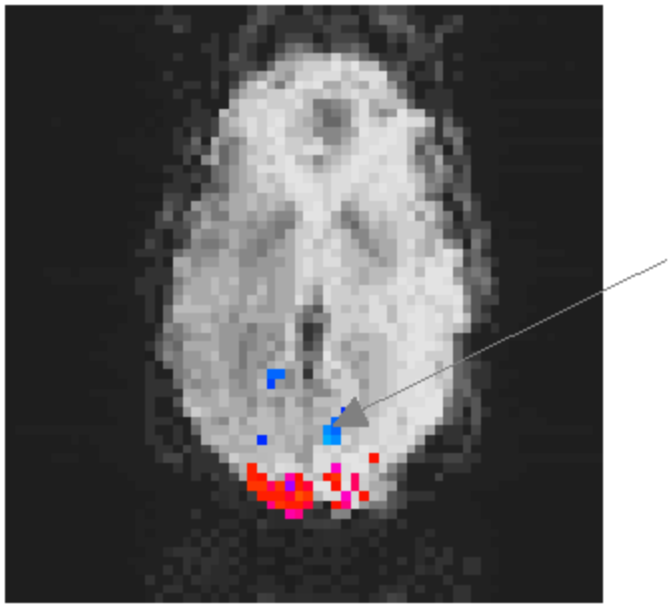


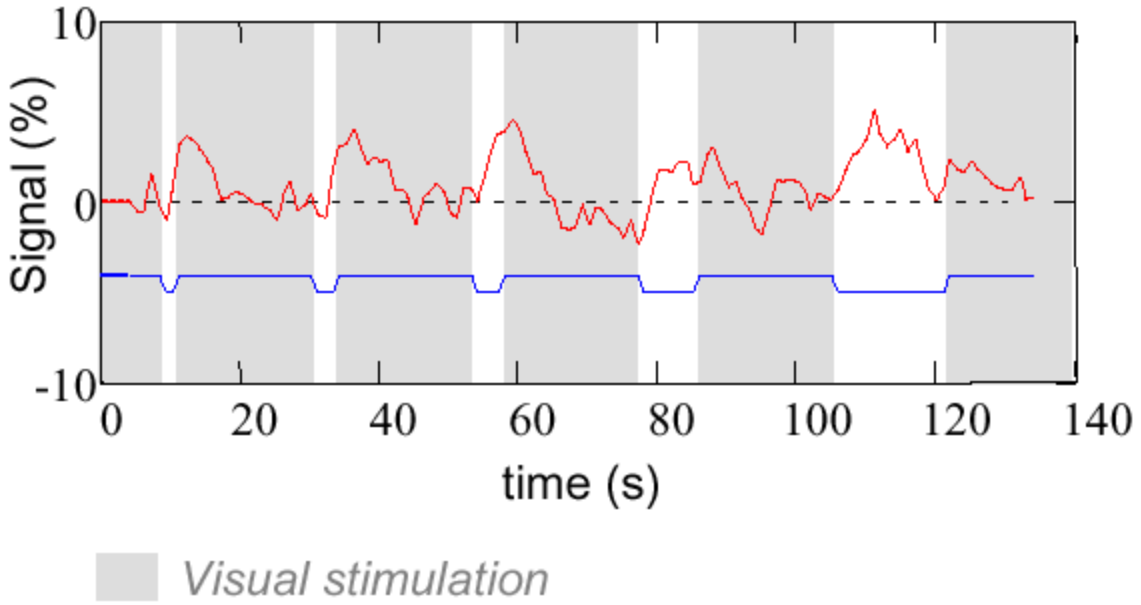
Decreases: linearity



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

We also see increases during stimulus cessation...

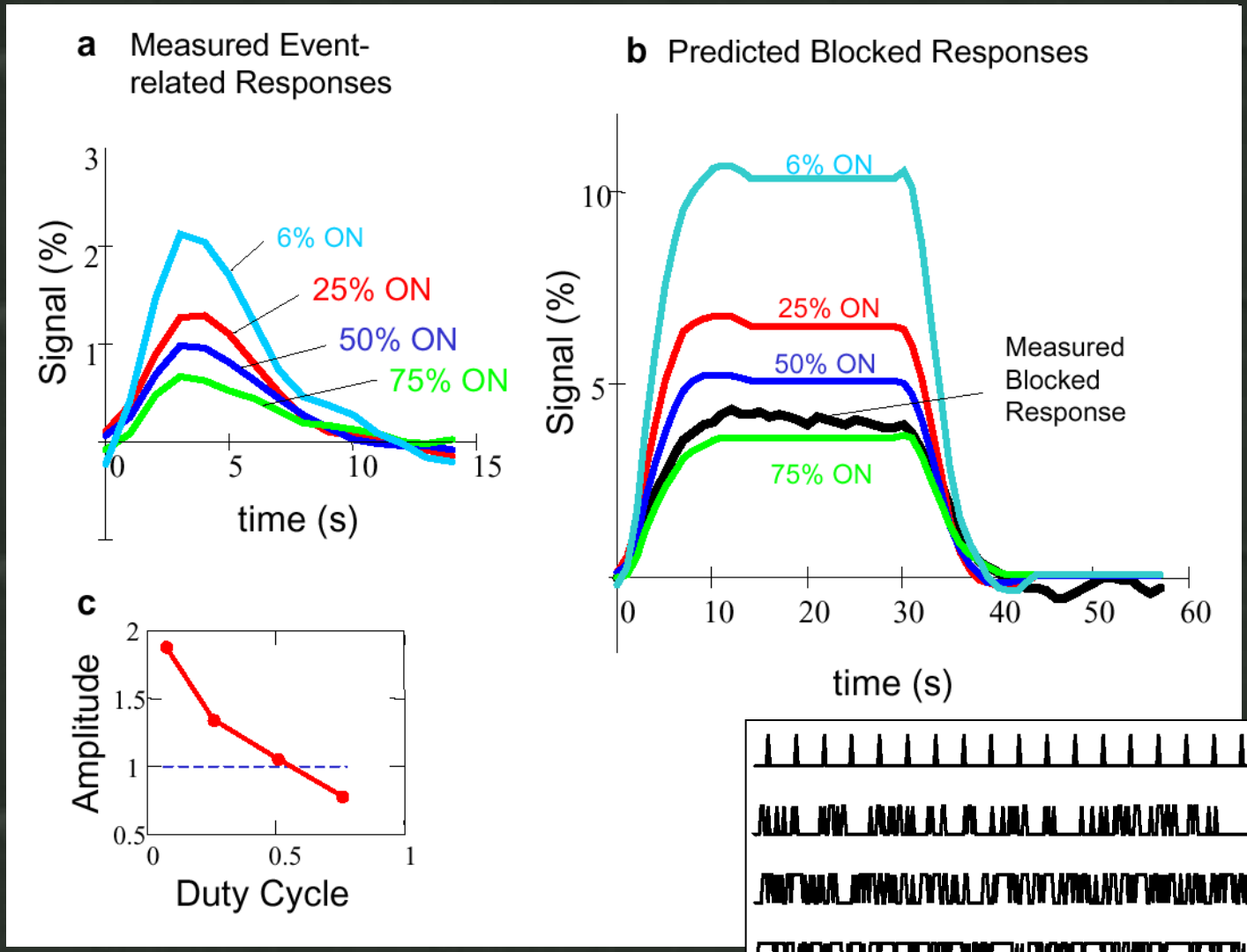


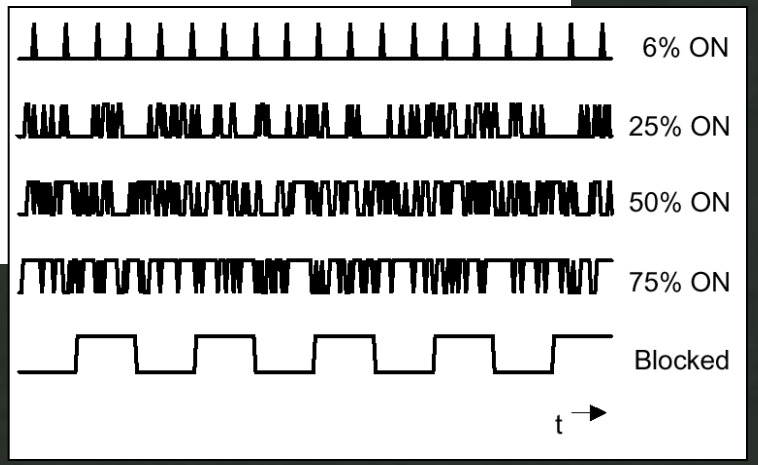


Interpretation

Increases: duty cycle

Linearity



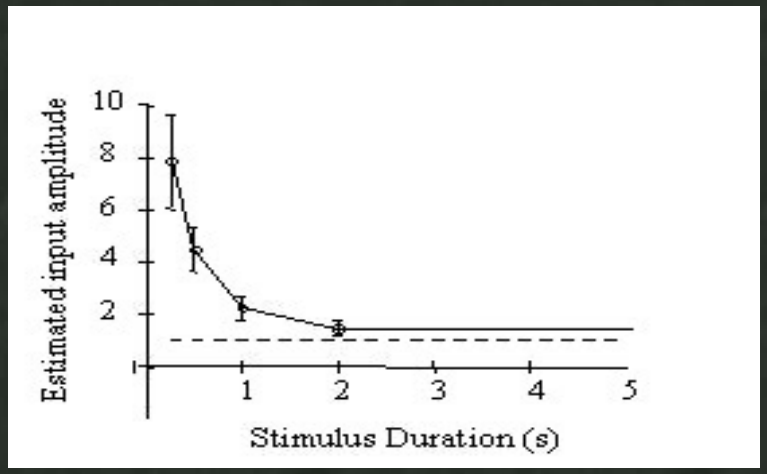


R.M. Birn, P. A. Bandettini, The effect of stimulus duty cycle and "off" duration on BOLD response linearity. *NeuroImage*, 27, 70-82 (2005)

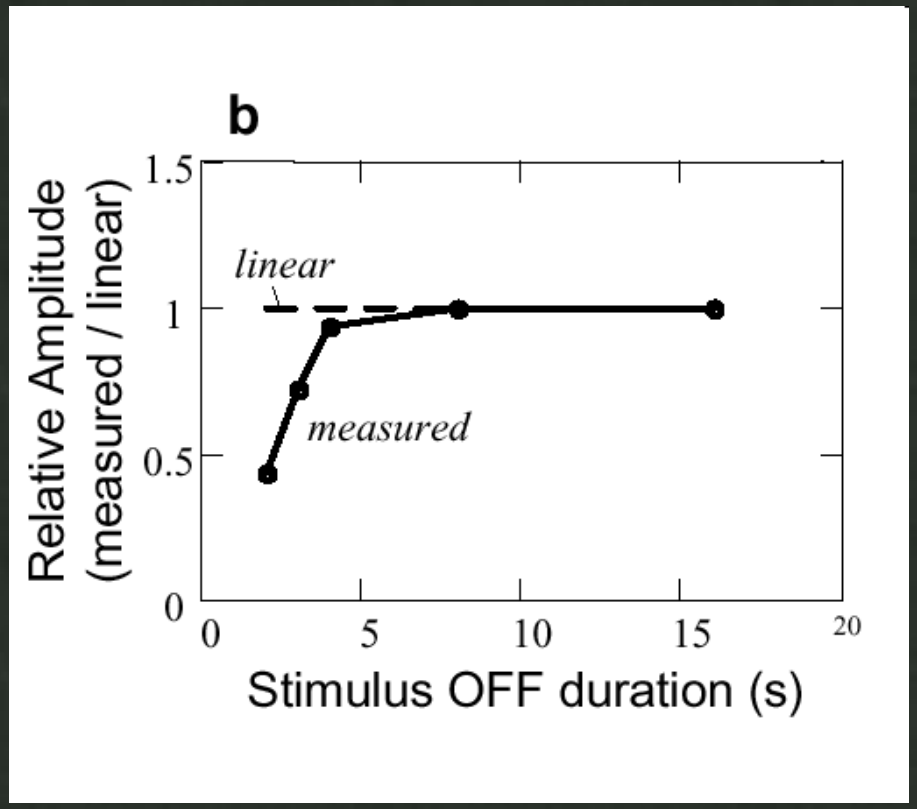
Interpretation

Linearity

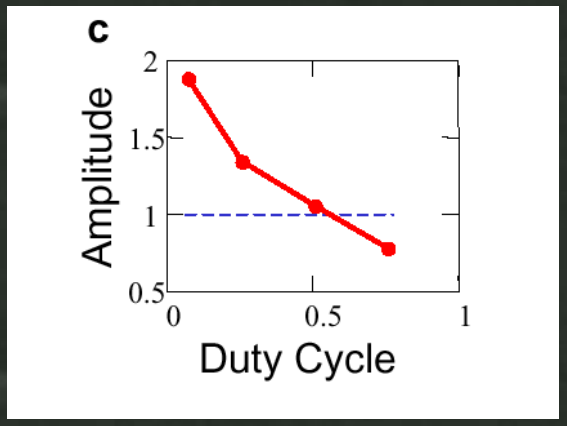
Increase: duration on



Decrease: duration off



Increase: duty cycle

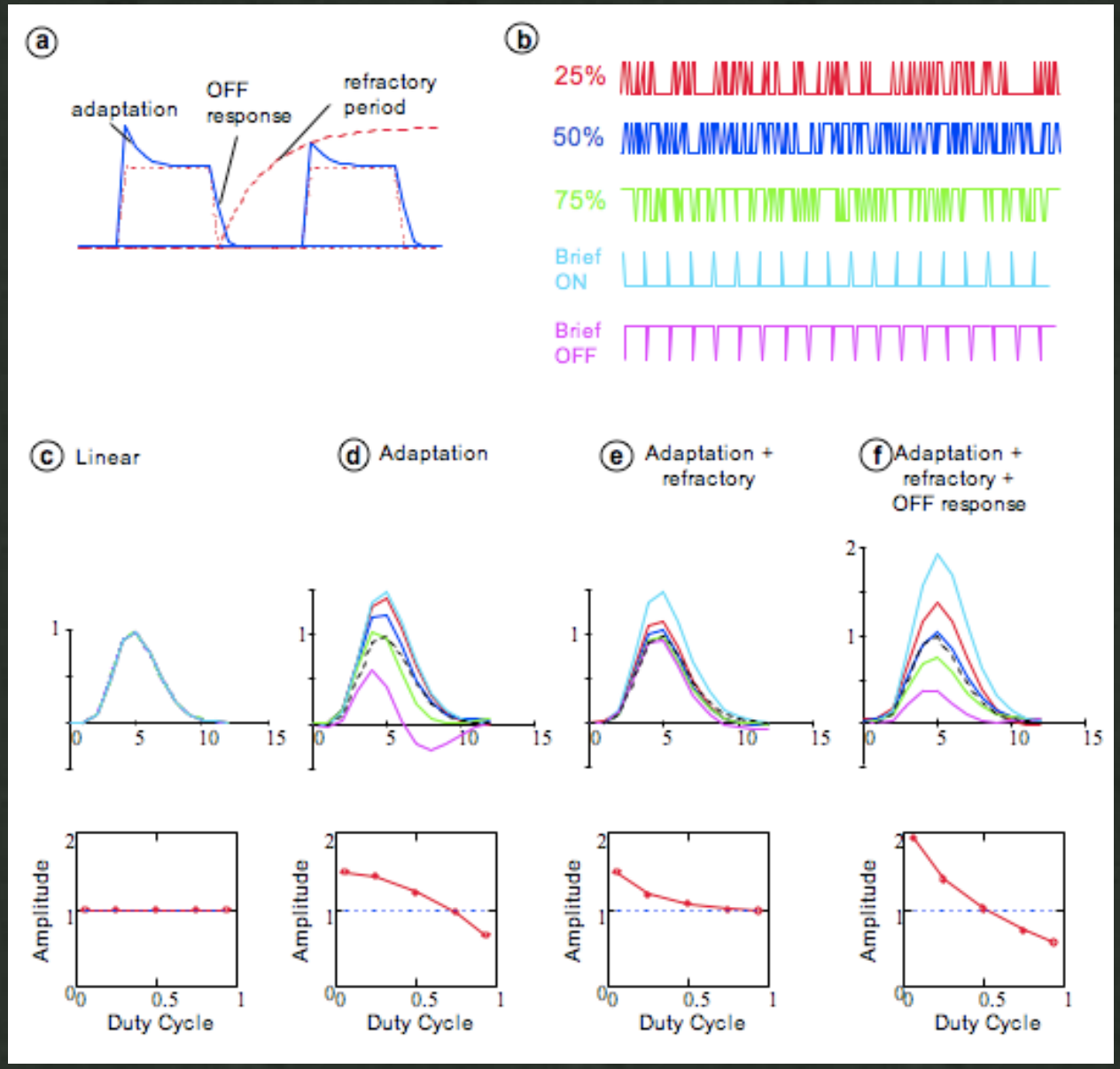


R.M. Birn, P. A. Bandettini. *NeuroImage, (in press)*

Interpretation

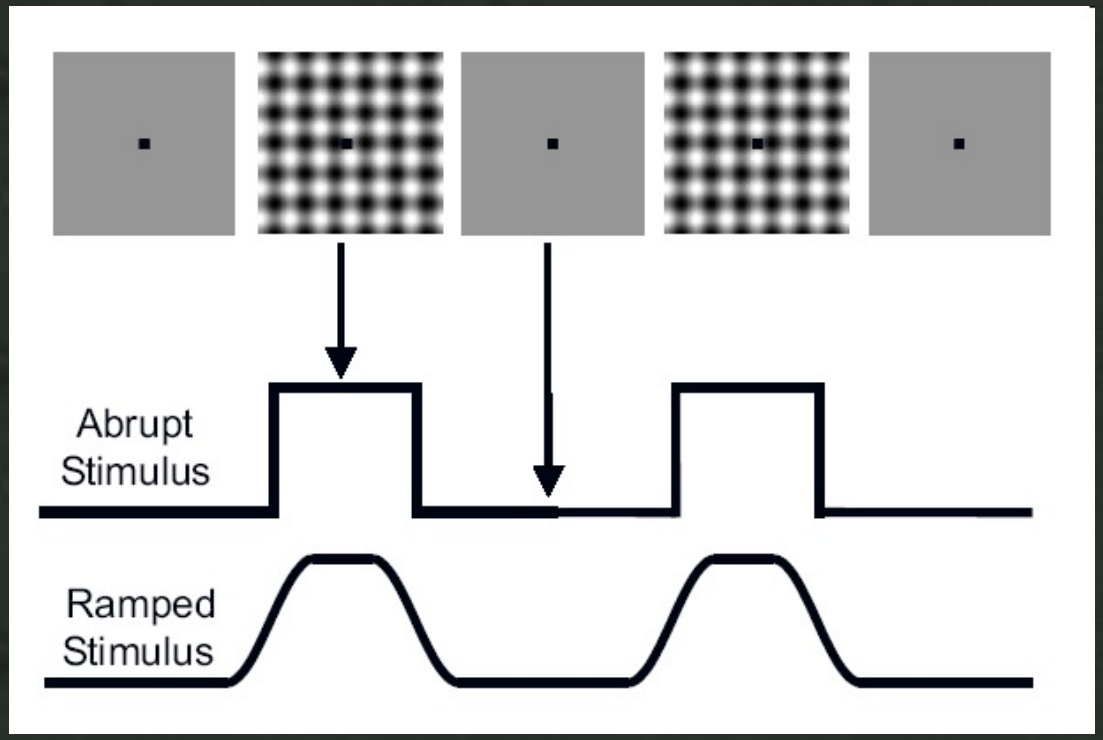
Linearity

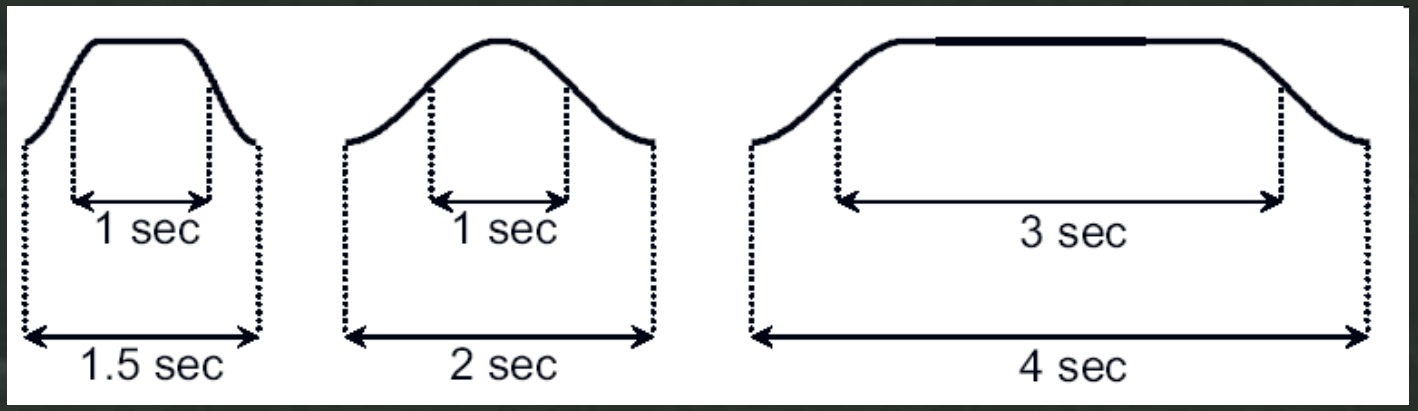
duty cycle effects



Interpretation

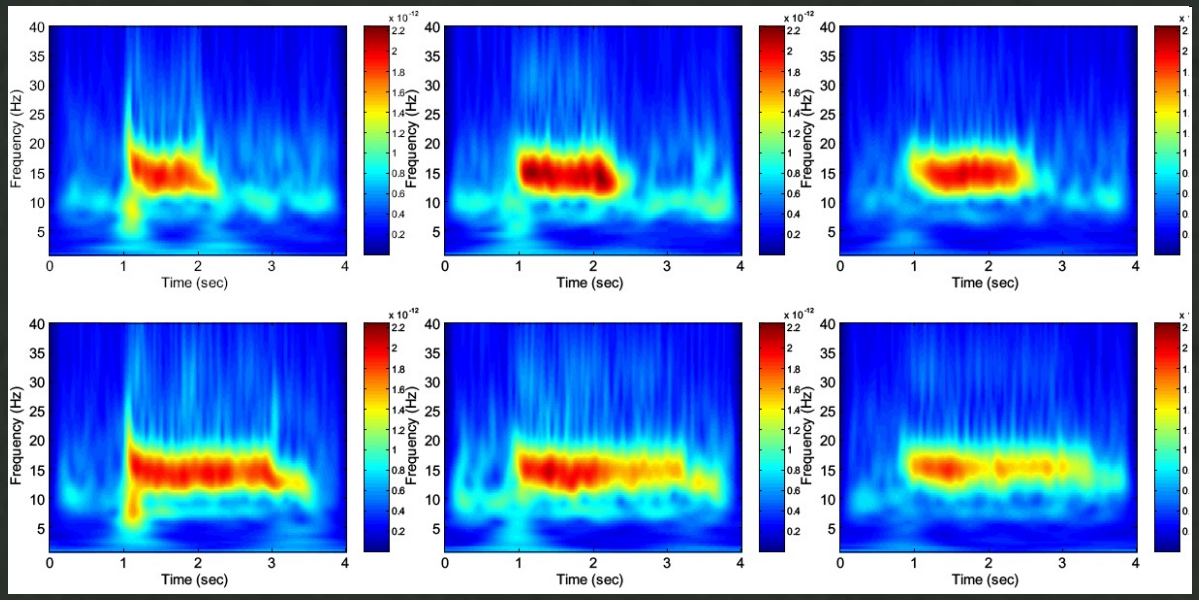
Linearity

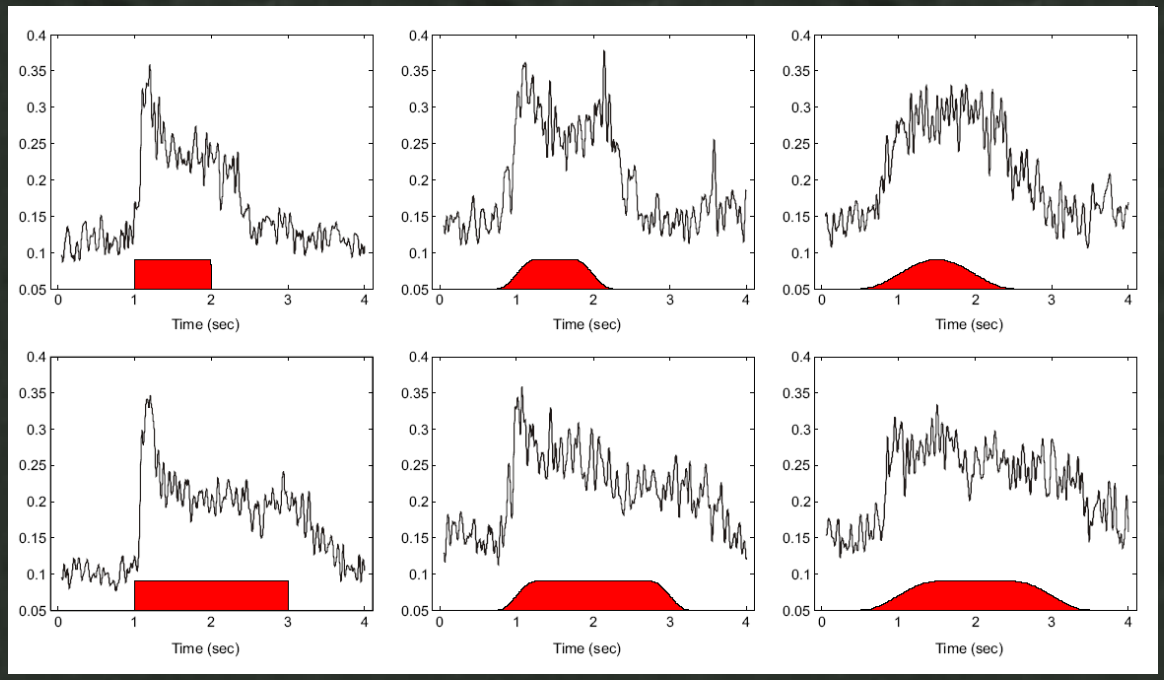




Interpretation

Linearity

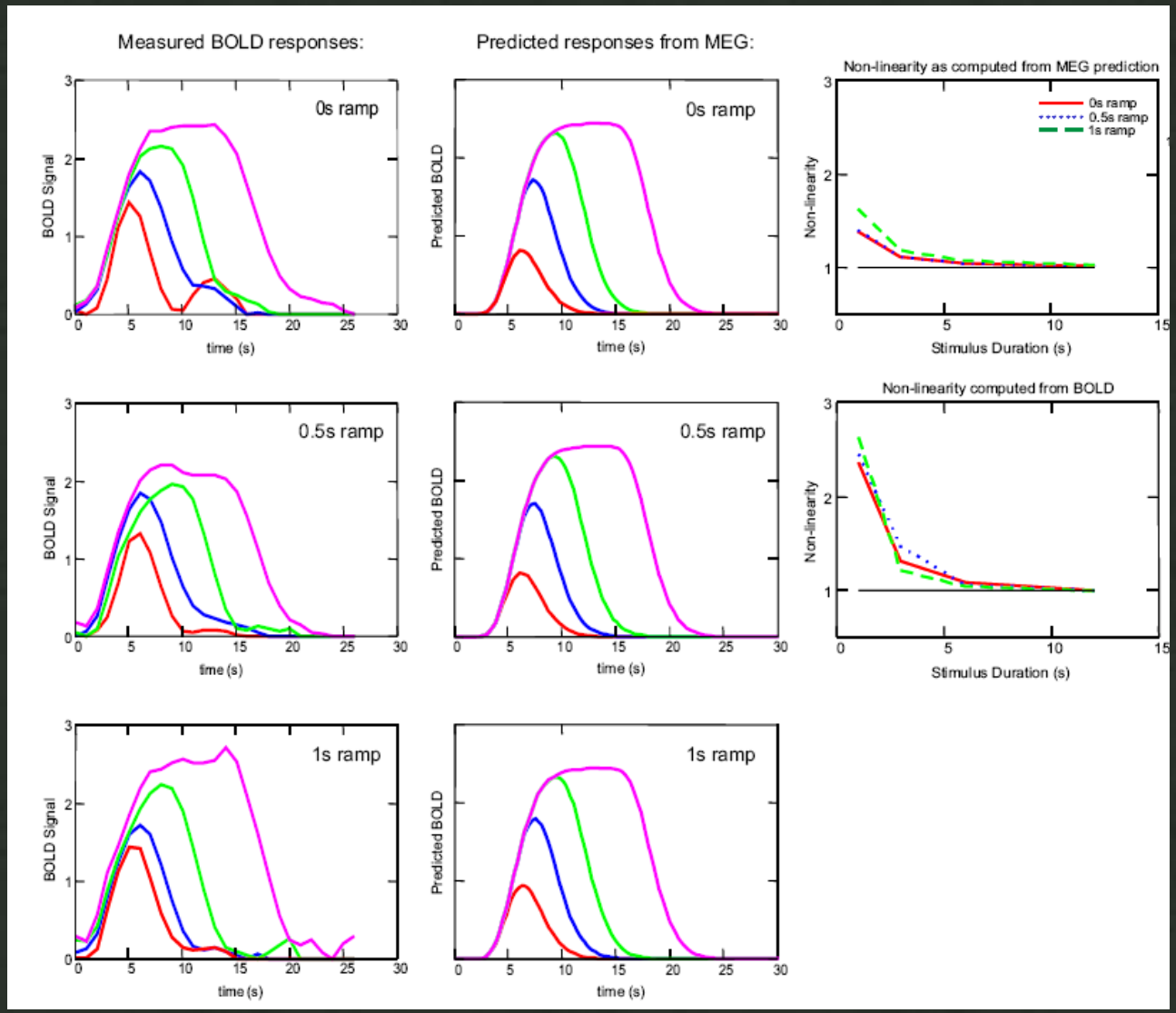




Tuan, Birn et al.

Interpretation

Linearity



Tuan, Birn et al.

Technology

Coil arrays
Higher field strength
Higher resolution

Methodology

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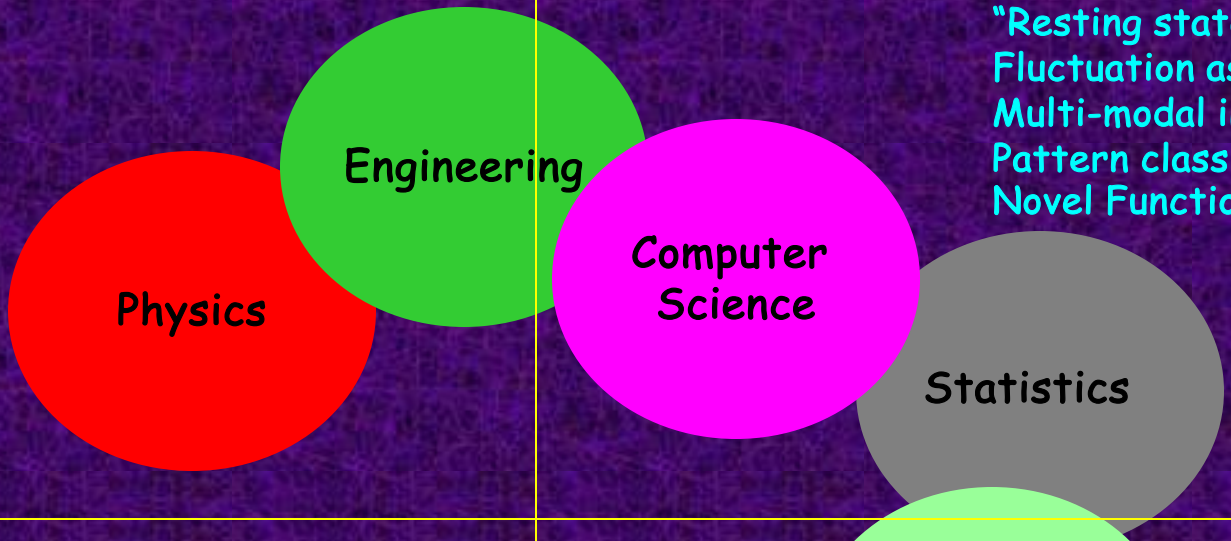
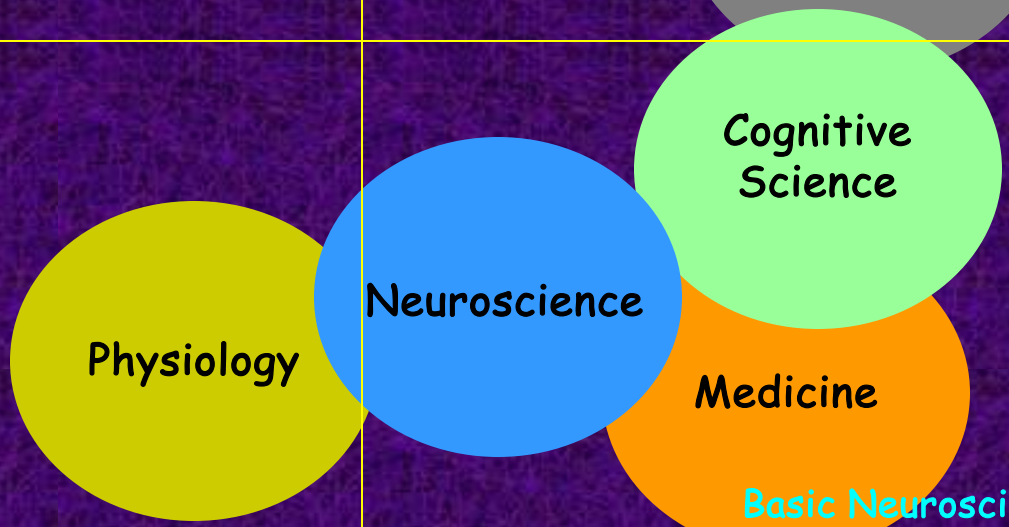
Fluctuation assessment
Multi-modal integration
Pattern classification
Novel Functional Contrasts





Fluctuations
Dynamics
Cross - modal comparison

Basic Neuroscience
Behavior correlation/prediction
Pathology correlation

Interpretation

Applications

Section on Functional Imaging Methods

Rasmus Birn
David Knight
Anthony Boemio
Nikolaus Kriegeskorte
Kevin Murphy
Monica Smith
Douglass Ruff
Joey Dunsmoor
Scott Phelps
Jon West

Functional MRI Fa

Kay Kuhns
Sean Marrett
Wen-Ming Luh
Jerzy Bodurka
Adam Thomas
James Hoskie

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