Recent Advances in Functional MRI

Peter A. Bandettini, Ph.D.

Section on Functional Imaging Methods

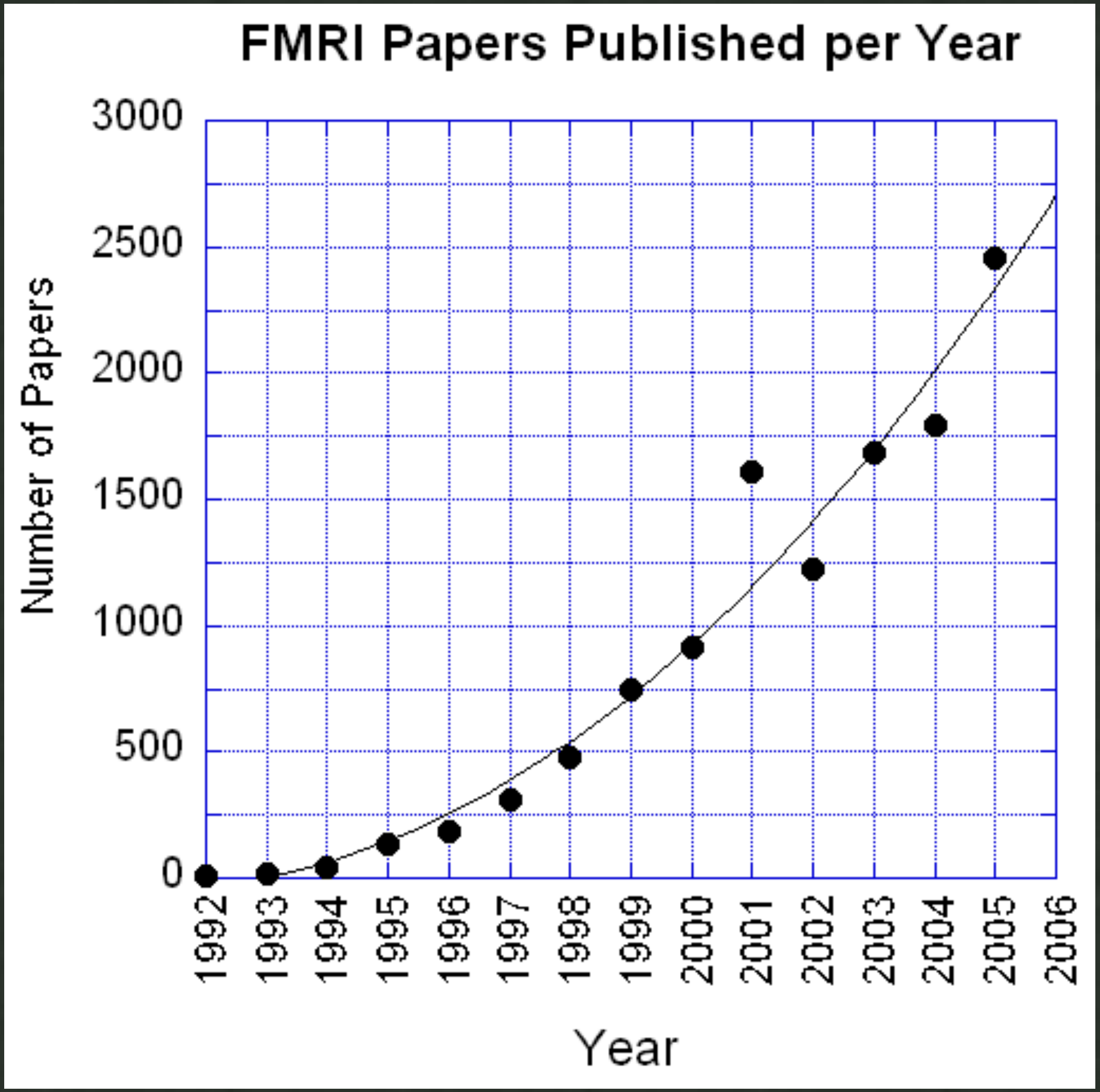
http://fim.nimh.nih.gov

Laboratory of Brain and Cognition

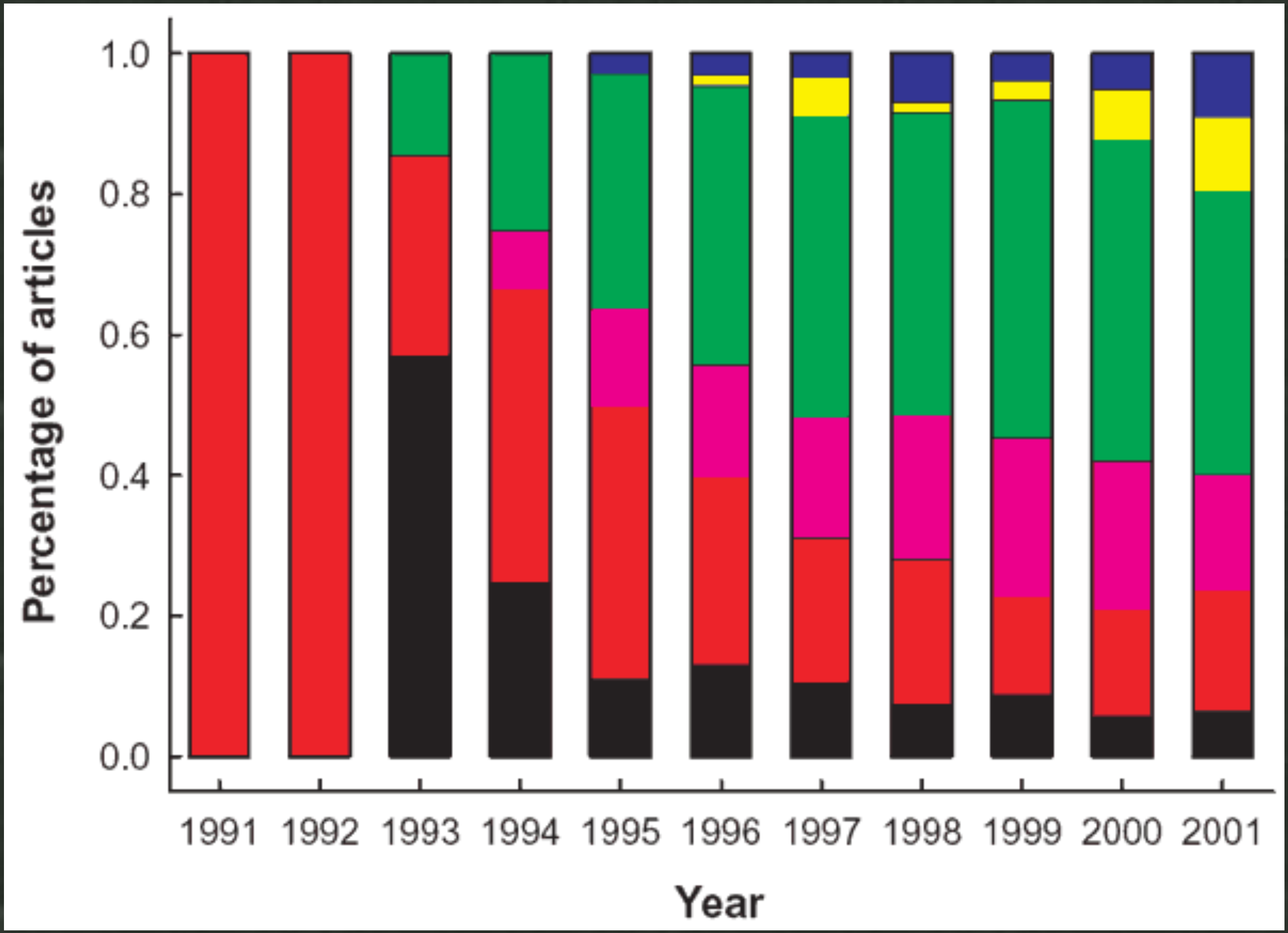
&

Functional MRI Facility

http://fmrif.nimh.nih.gov



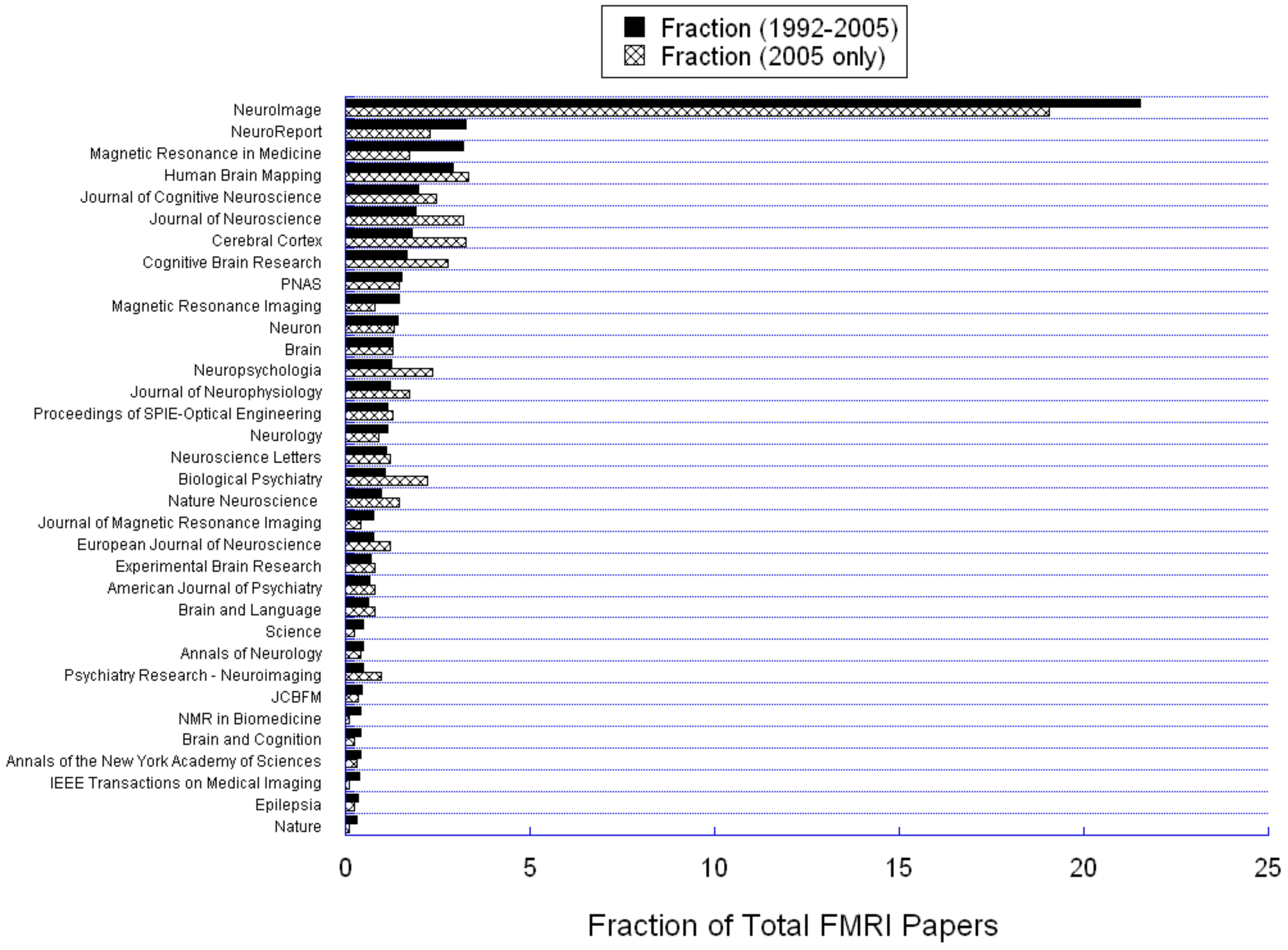
"fMRI" or "functional MRI"

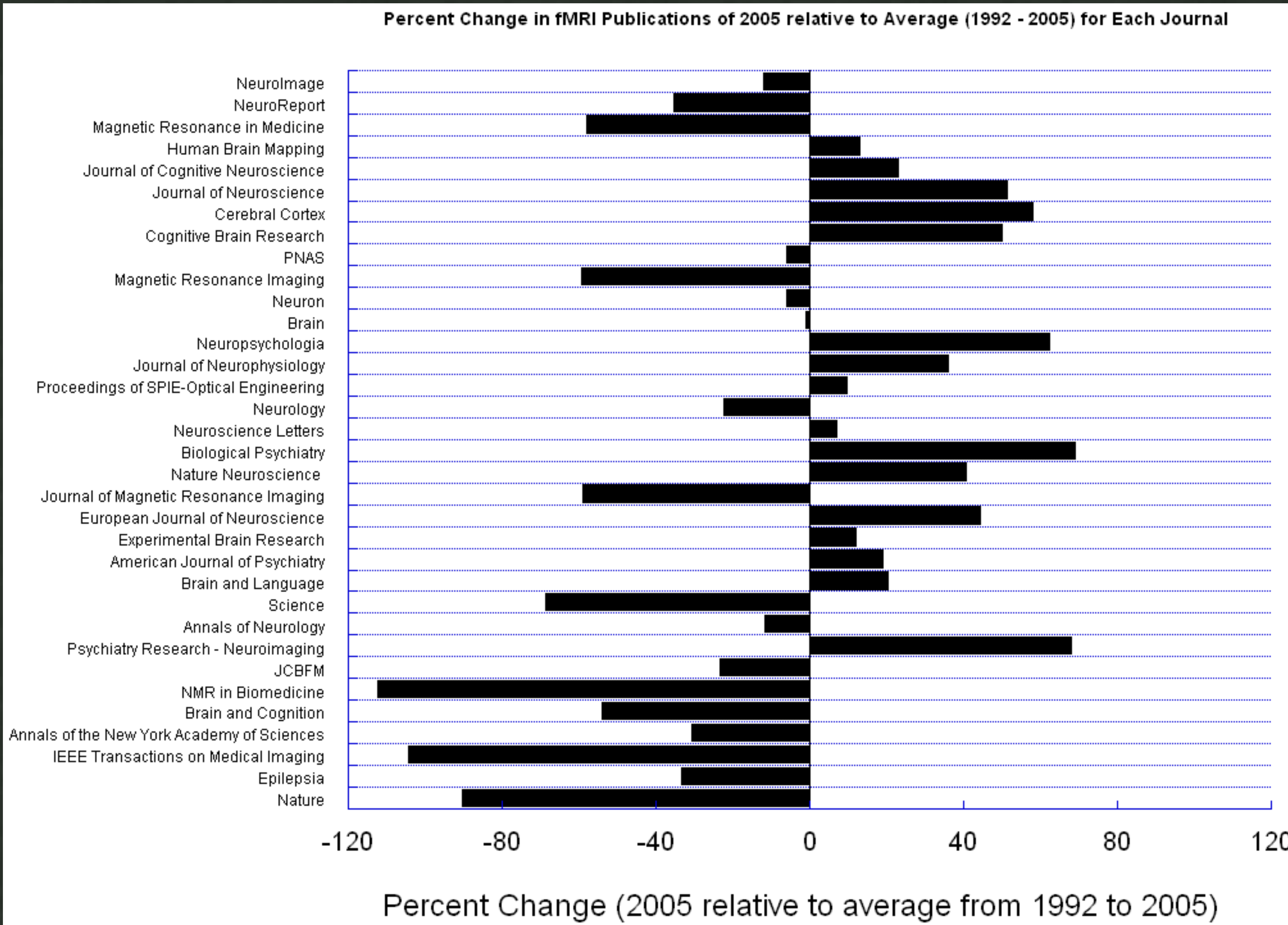


Motor (black)
Primary Sensory (red)
Integrative Sensory (violet)
Basic Cognition (green)
High-Order Cognition (yellow)
Emotion (blue)

J. Illes, M. P. Kirschen, J. D. E. Gabrielli, Nature Neuroscience, 6 (3)m p.205

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)

Technology

Coil arrays
Higher field strength
Higher resolution

Methodology

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

Post undershoot
Pre undershoot
Linearity
Local Field Potentials vs Spiking
Inhibition and Decreases
Neuronal vs. Hemodynamic Refraction

Interpretation

Basic Neuroscience
Behavior correlation/prediction
Pathology correlation / therapy

Applications

Technology

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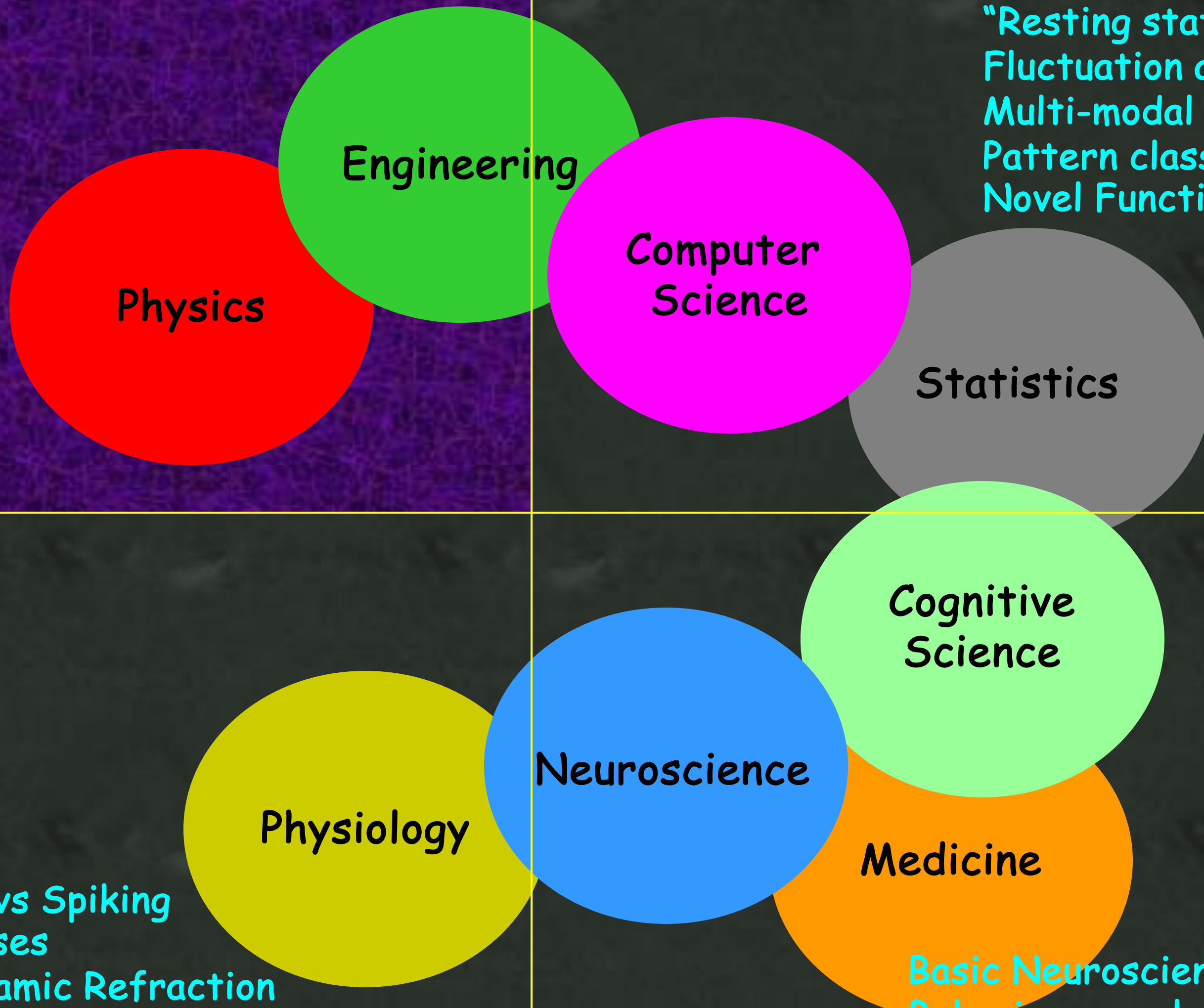

Post undershoot
Pre undershoot
Linearity
Local Field Potentials vs Spiking
Inhibition and Decreases
Neuronal vs. Hemodynamic Refraction

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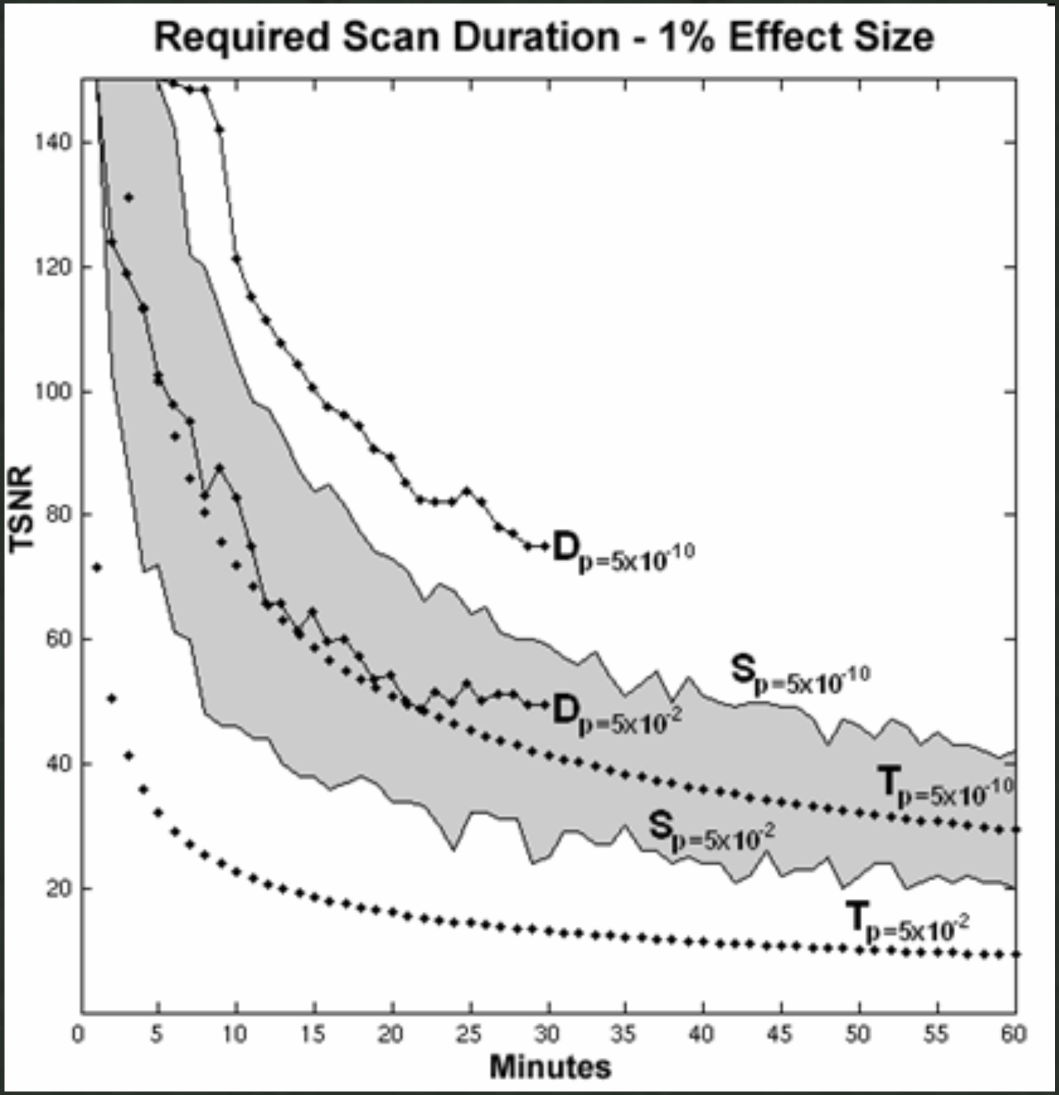
Applications

Parallel Acquisition



Reasons for higher SNR

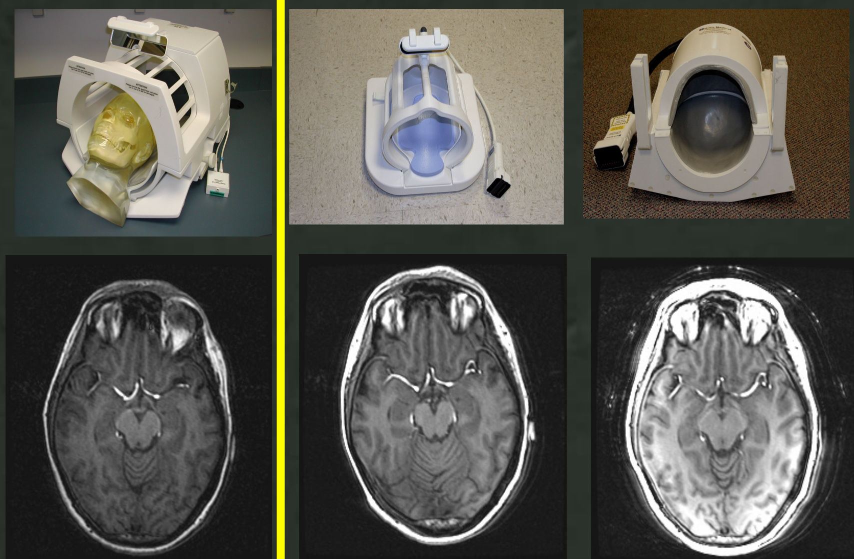
- -Shorter scan duration
- -Higher Resolution
- -More subtle comparisons

Murphy et al.

Technology

Parallel Acquisition

8 channel parallel receiver coil

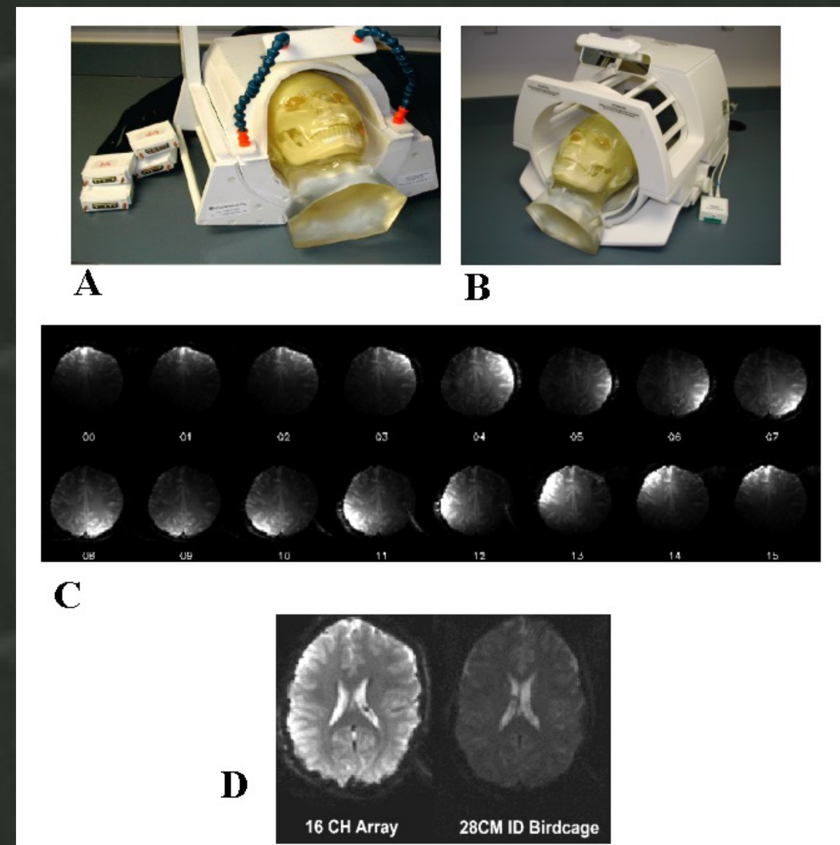


GE birdcage

GE 8 channel coil

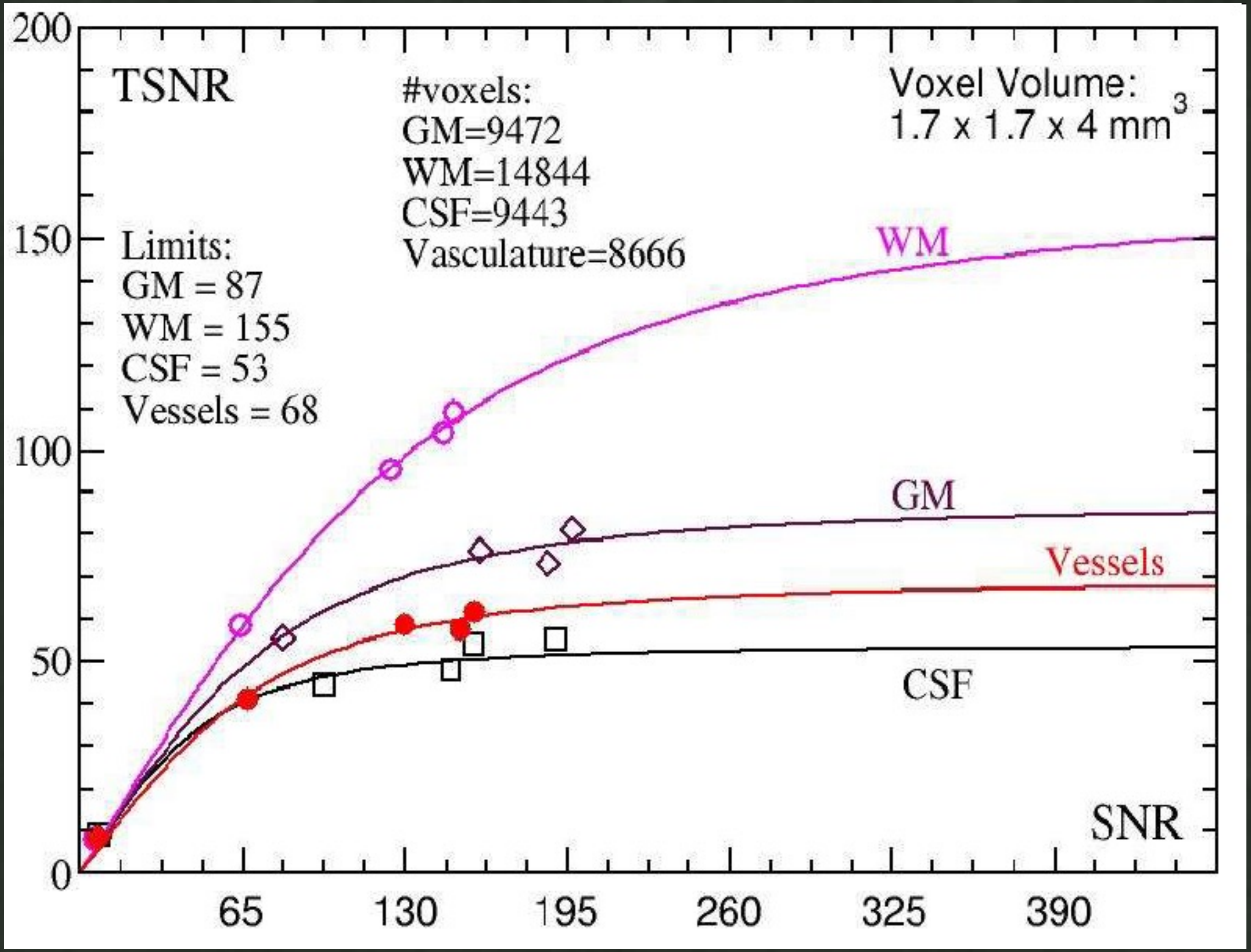
Nova 8 channel coil

16 channel parallel receiver coil



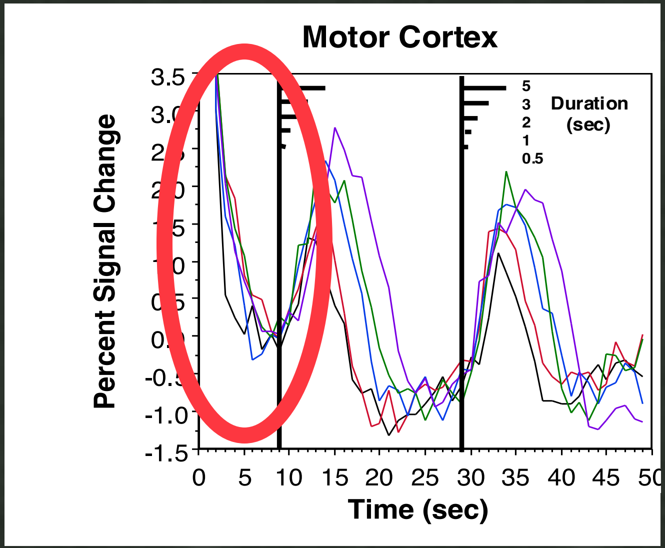
J. Bodurka, et al, Magnetic Resonance in Medicine 51 (2004) 165-171.

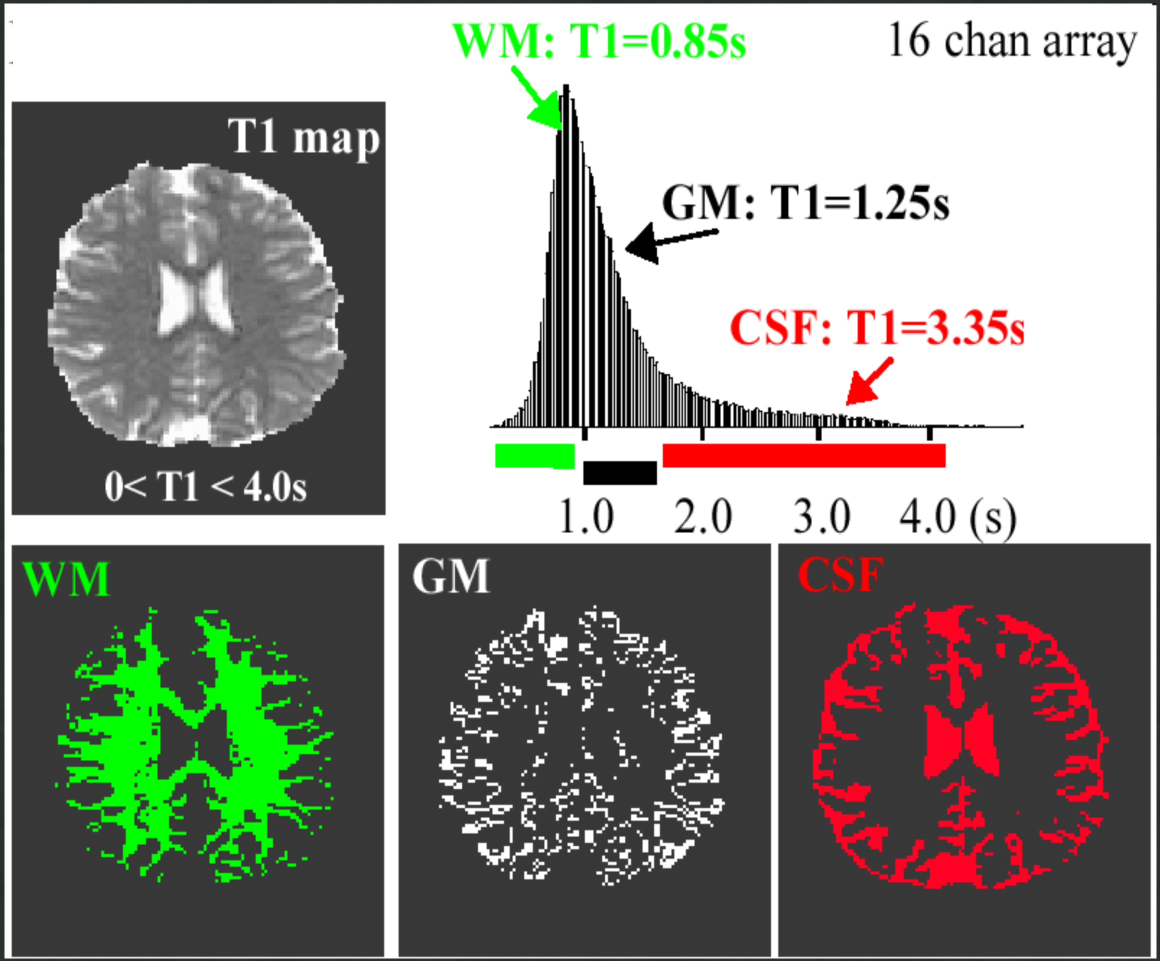
Parallel Acquisition



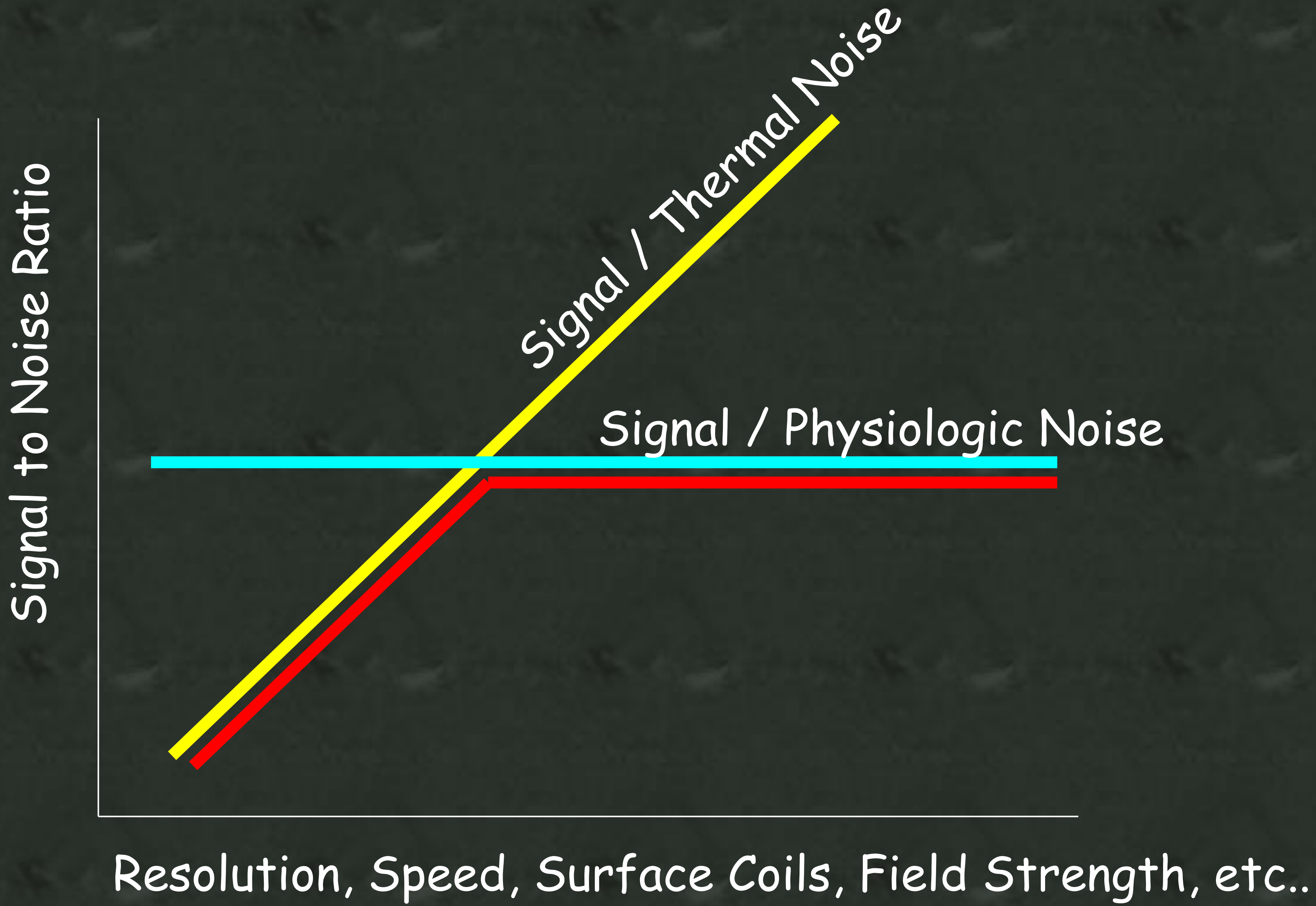
J. Bodurka

Segmentation using EPI Transient

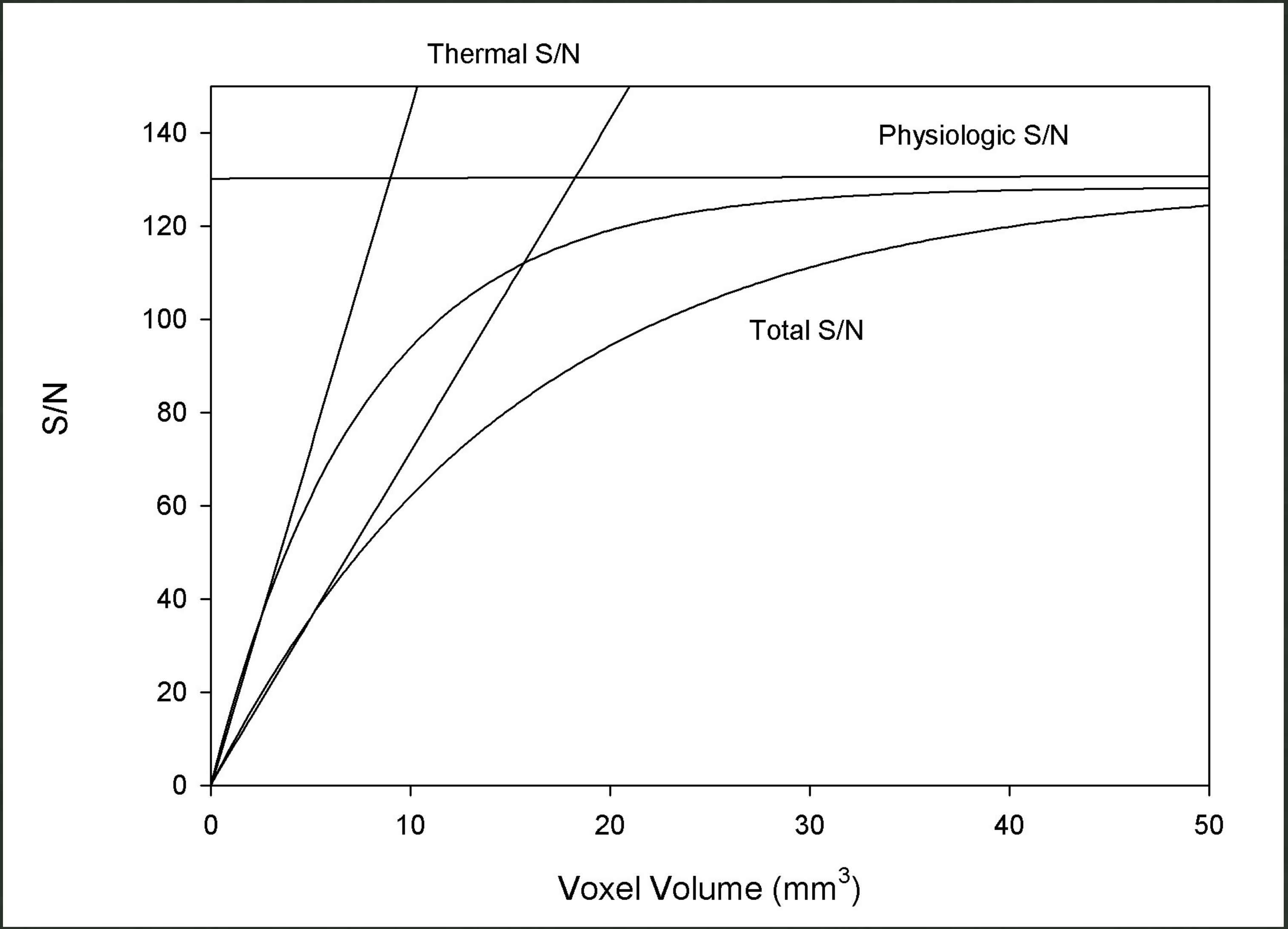




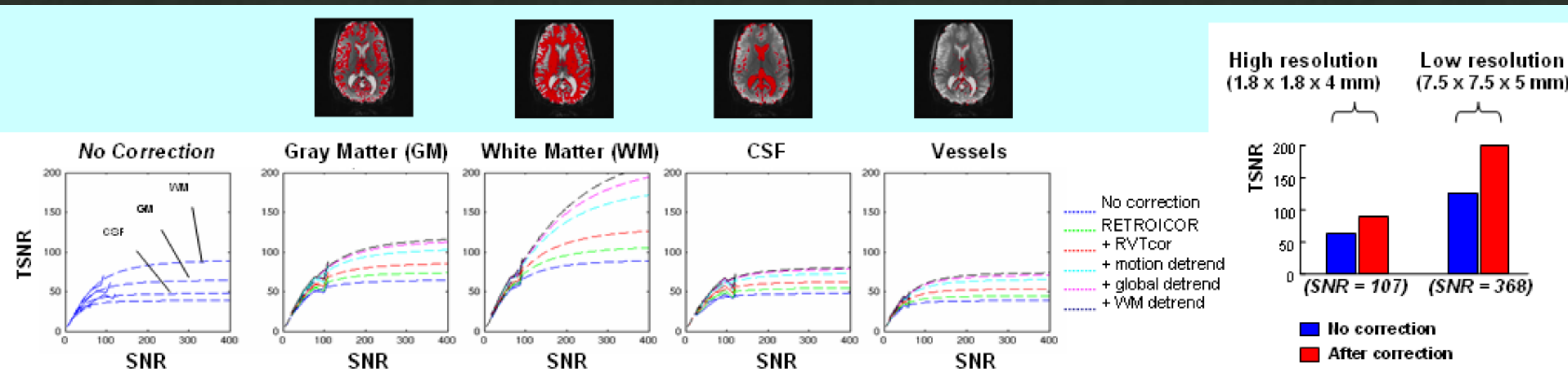
J. Bodurka

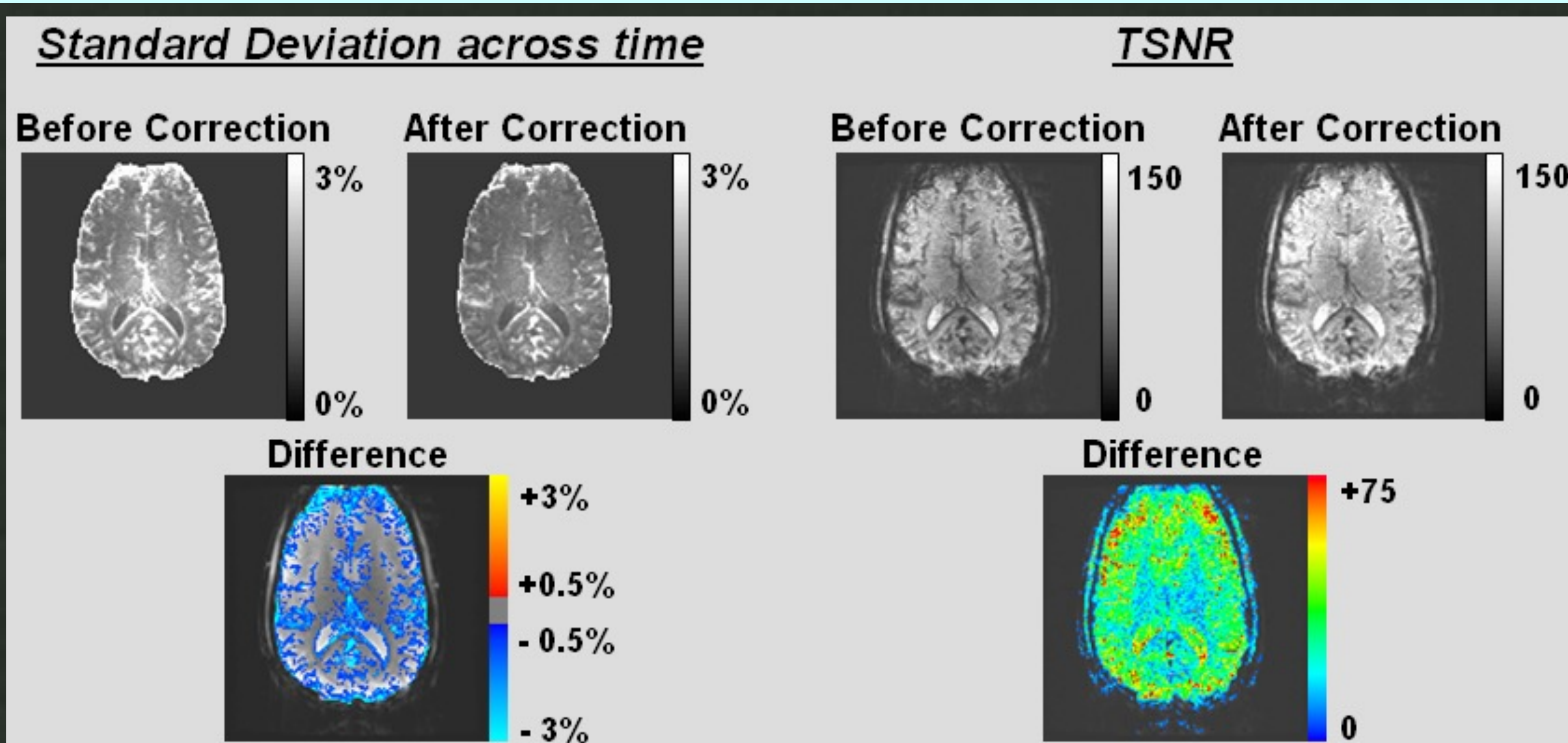

Signal / Thermal Noise
Signal / Physiologic Noise
Signal to Noise Ratio
Resolution, Speed, Surface Coils, Field Strength, etc..

Simulated gains in TNSR with doubling sensitivity



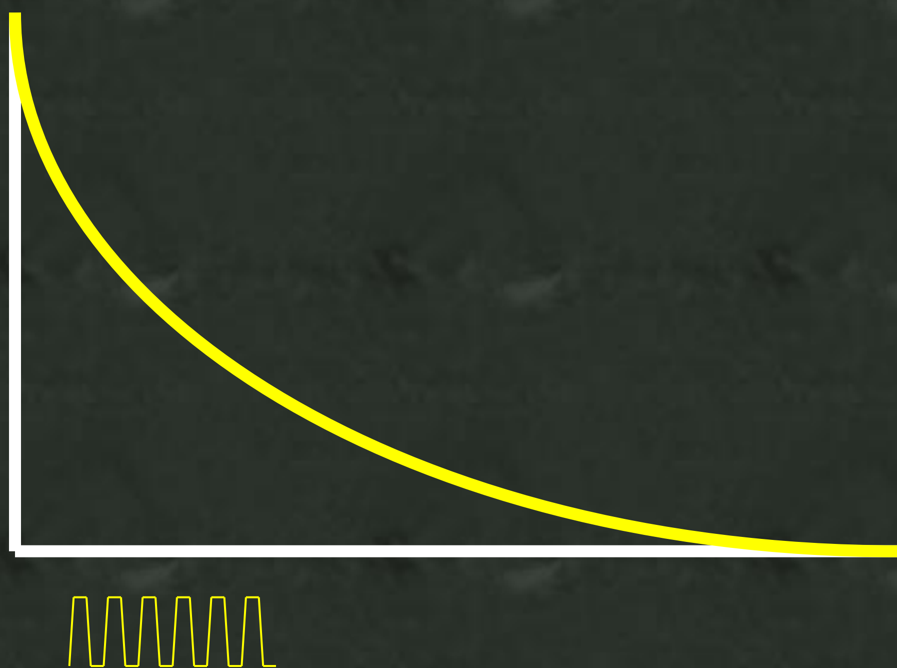
Parallel Acquisition



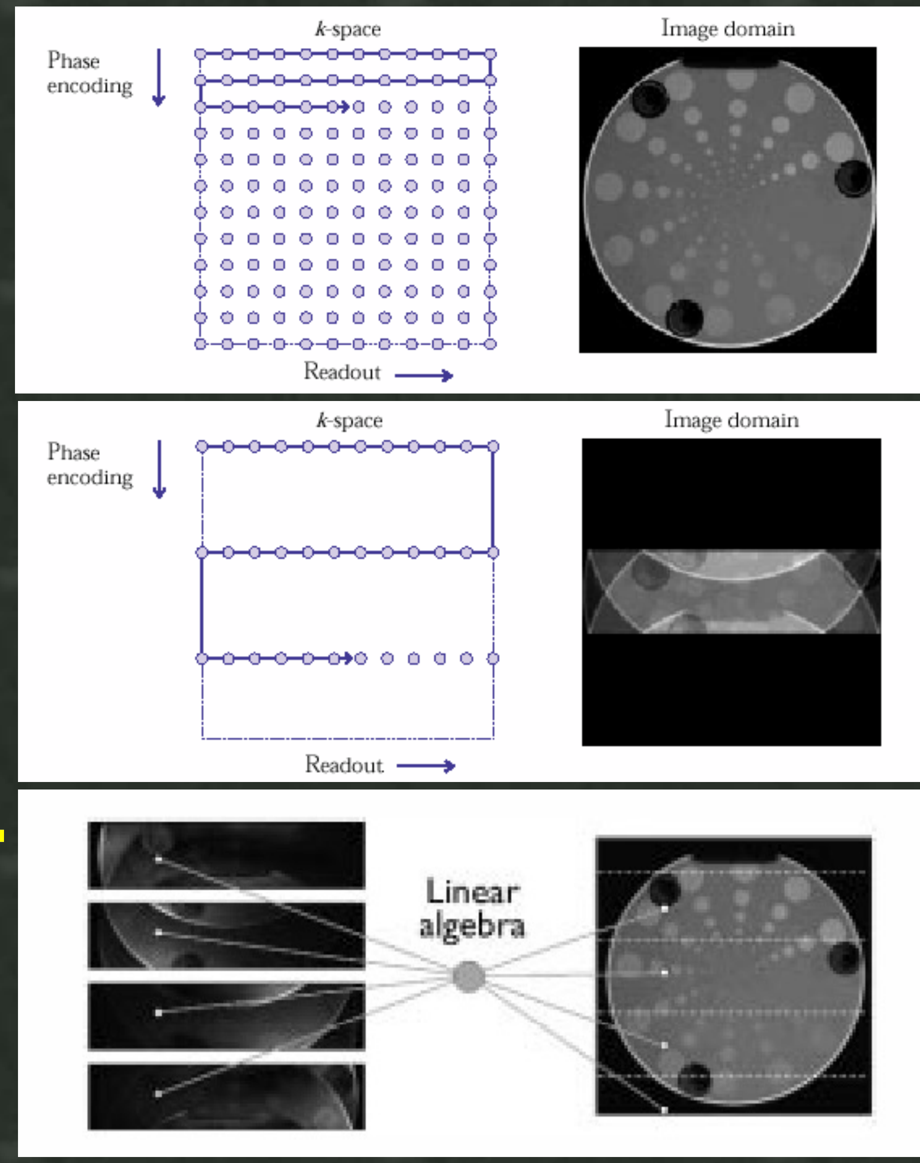


R. Birn, et al. ISMRM 2006

SENSE Imaging



≈ 5 to 30 ms



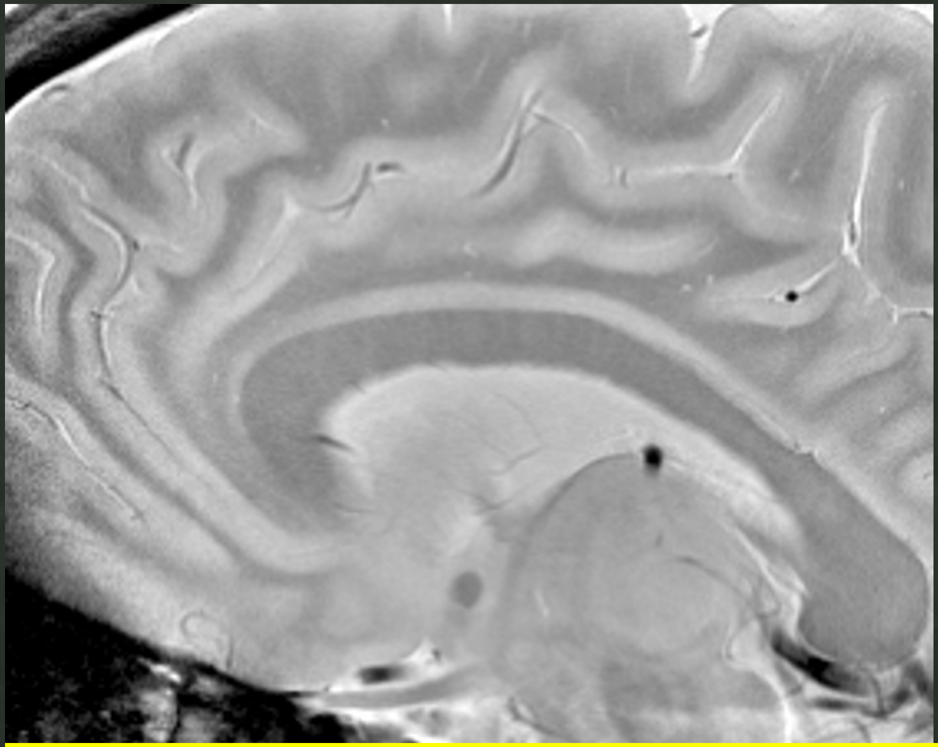
Pruessmann, et al.

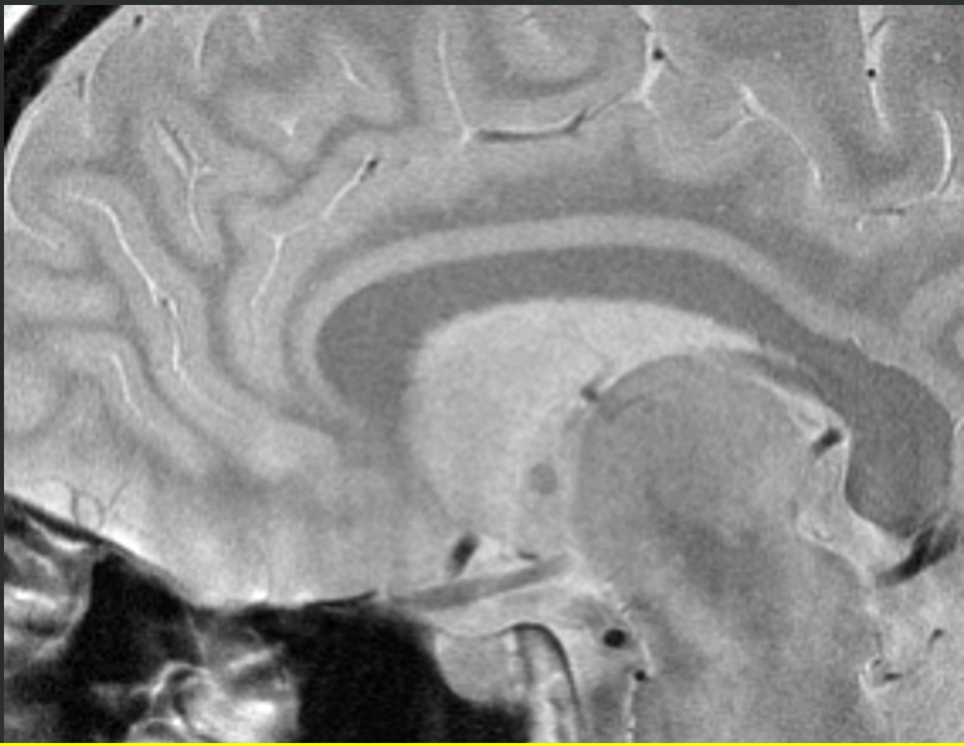
SENSE Imaging

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.

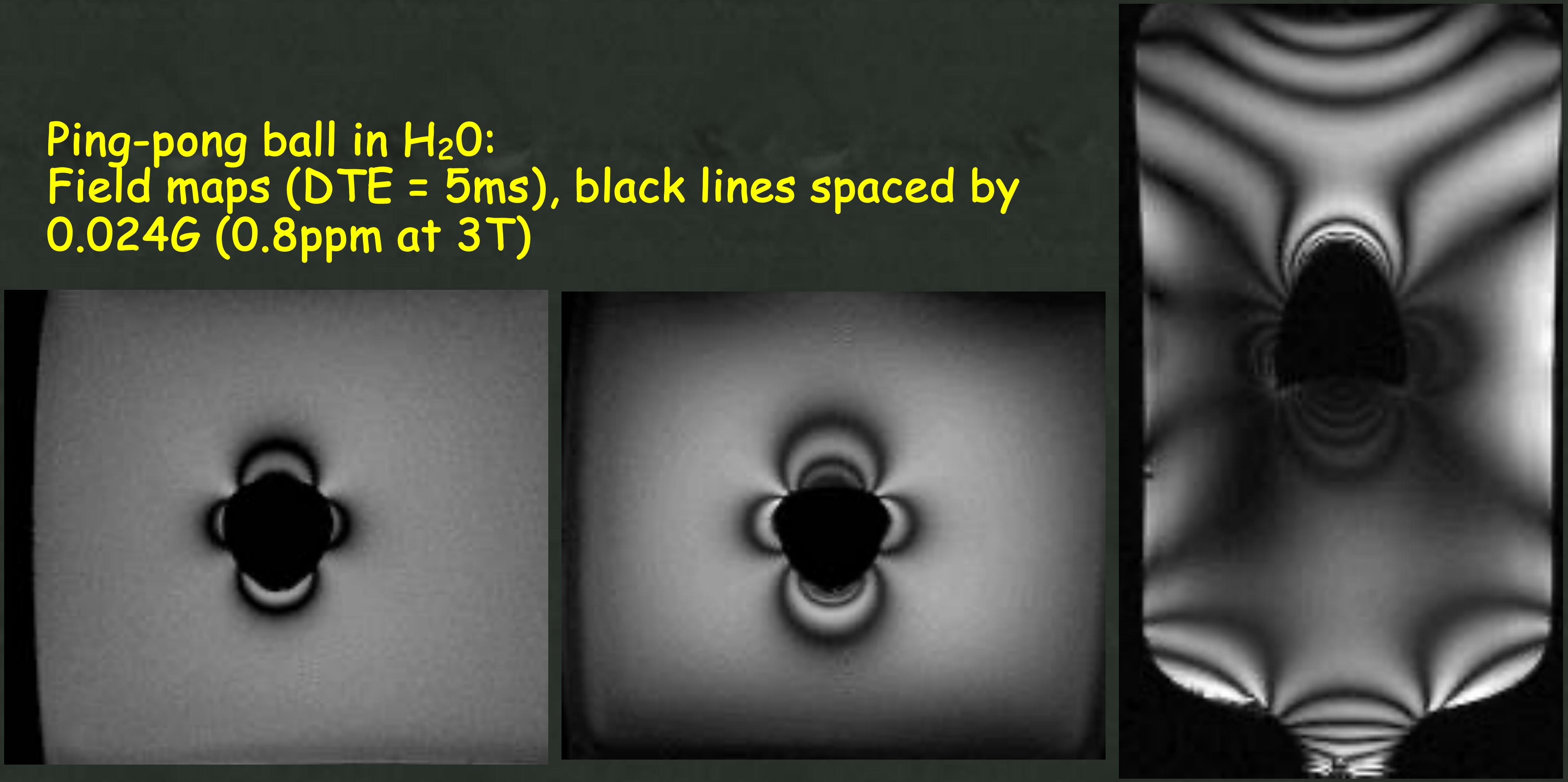
7T
white matter SNR =65
Gray matter SNR = 76

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

Courtesy Larry Wald

Susceptibility field (in Gauss) increases w/ B_o

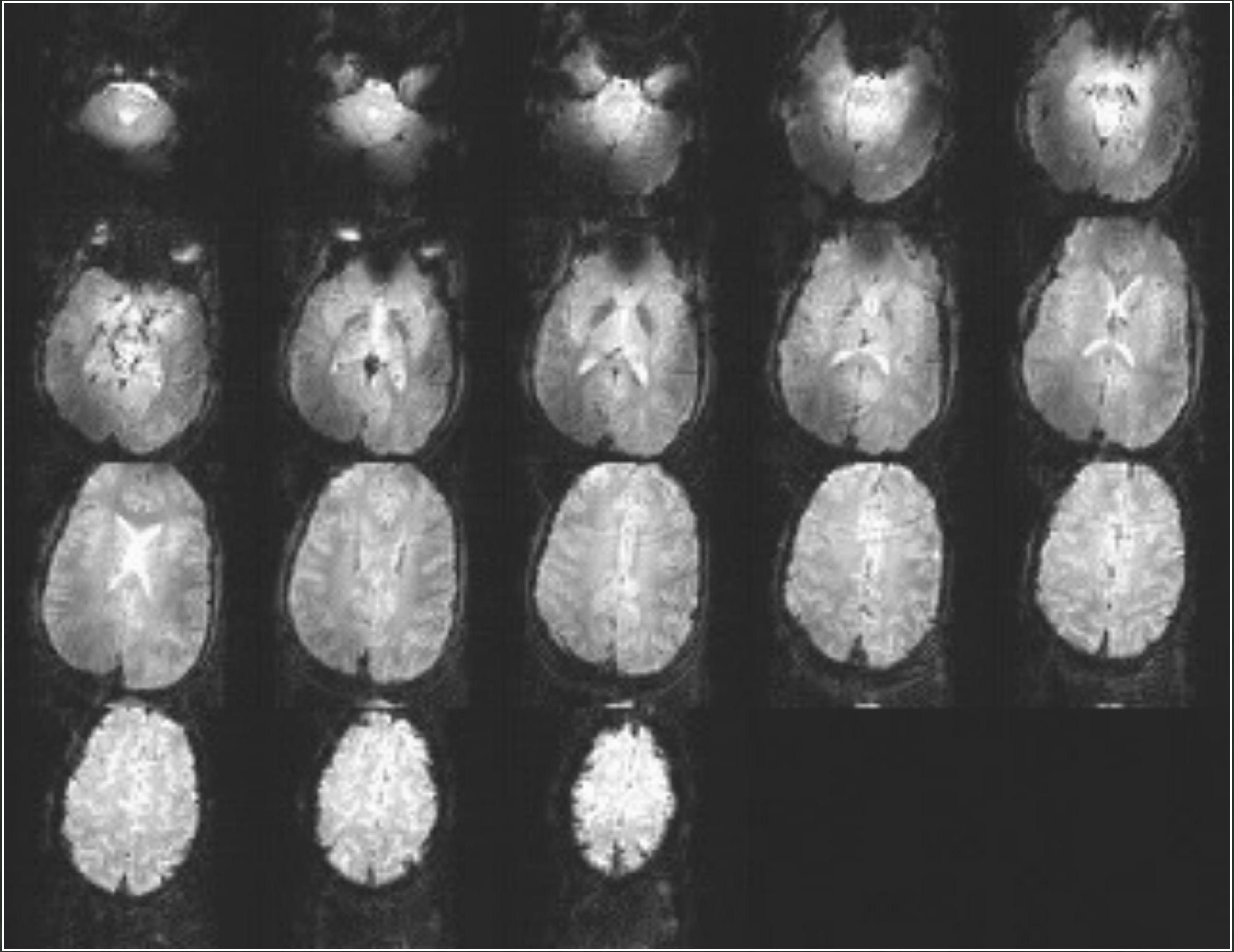
Ping-pong ball in H_2O:
Field maps (DTE = 5ms), black lines spaced by 0.024G (0.8ppm at 3T)



1.5T 3T 7T

Courtesy Larry Wald

7T: Single Shot whole head EPI



3mm isotropic

single shot EPI, 7T.

64x64, 19cm FOV(3mm resolution), 3mm slice.

TE=20ms

Courtesy Larry Wald

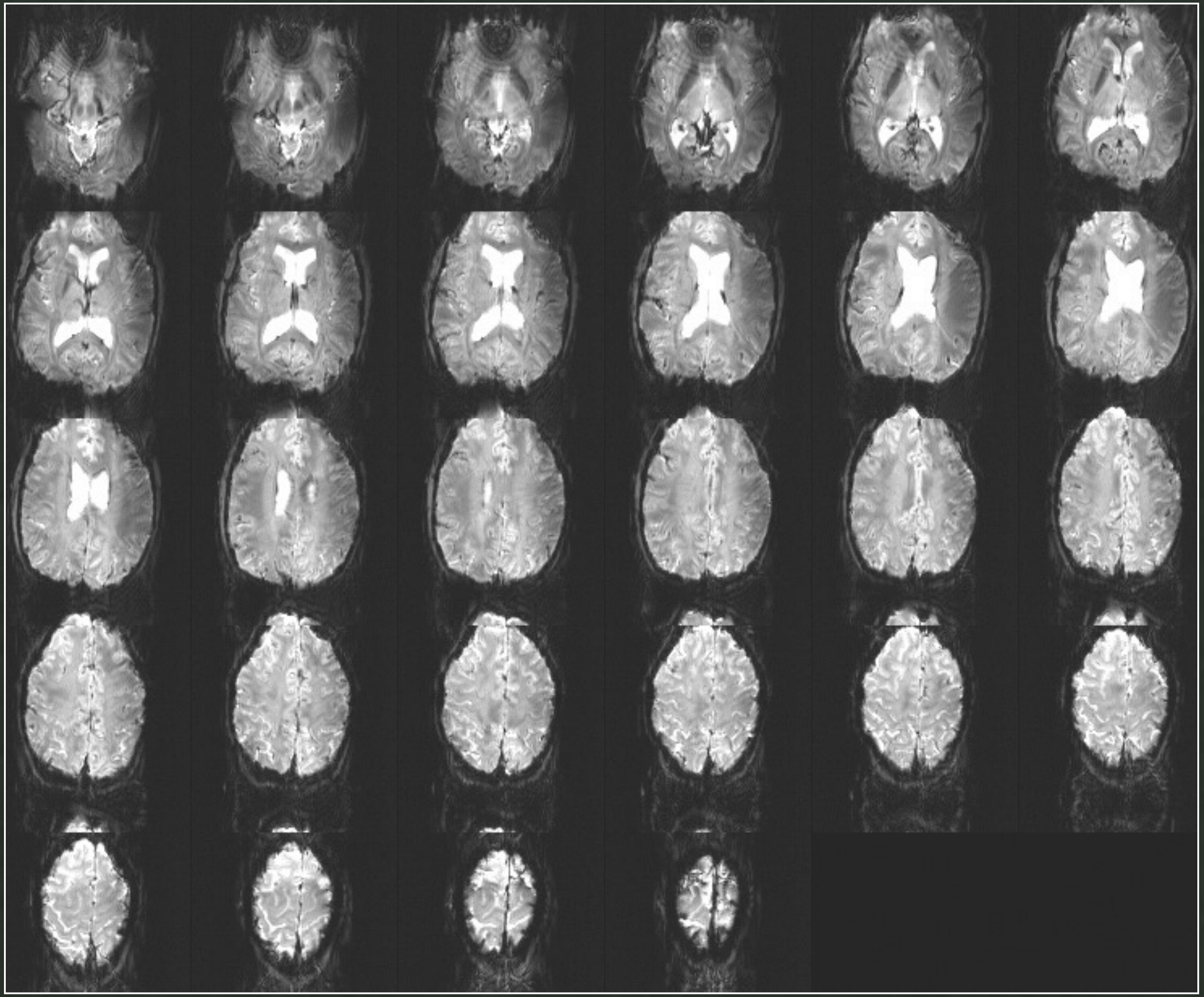
7T: Single Shot whole head EPI

1.5mm inplane

single shot EPI, 7T.

128x128, 20cm FOV (1.5mm resolution), 2mm slice,

TE = 20ms



Courtesy Larry Wald

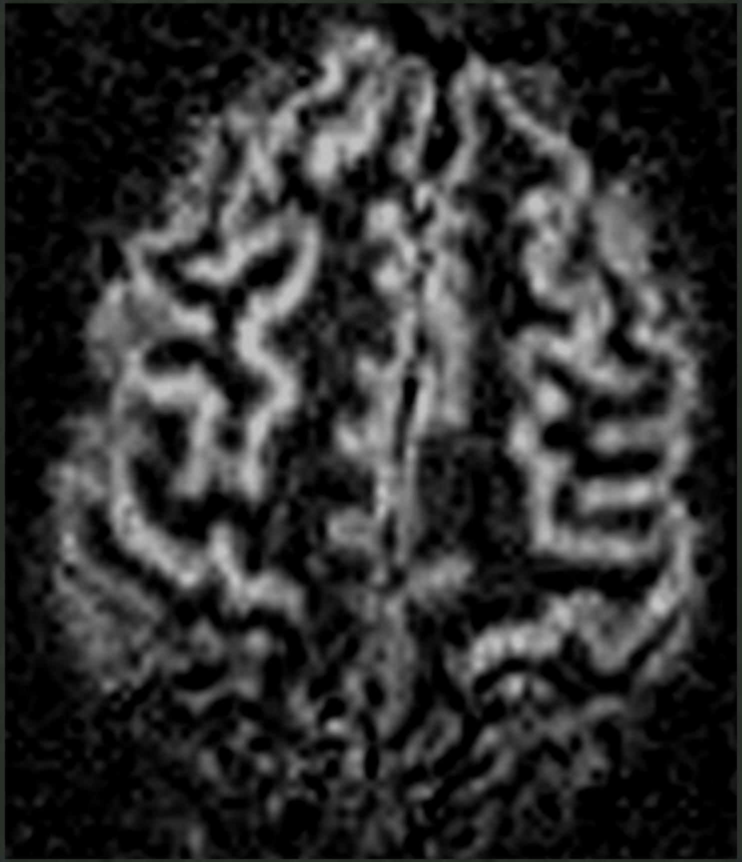
7T Blood flow and BOLD based fMRI

Longer T1 means better ASL…

6 minute pulse Arterial Spin Labeling blood flow image

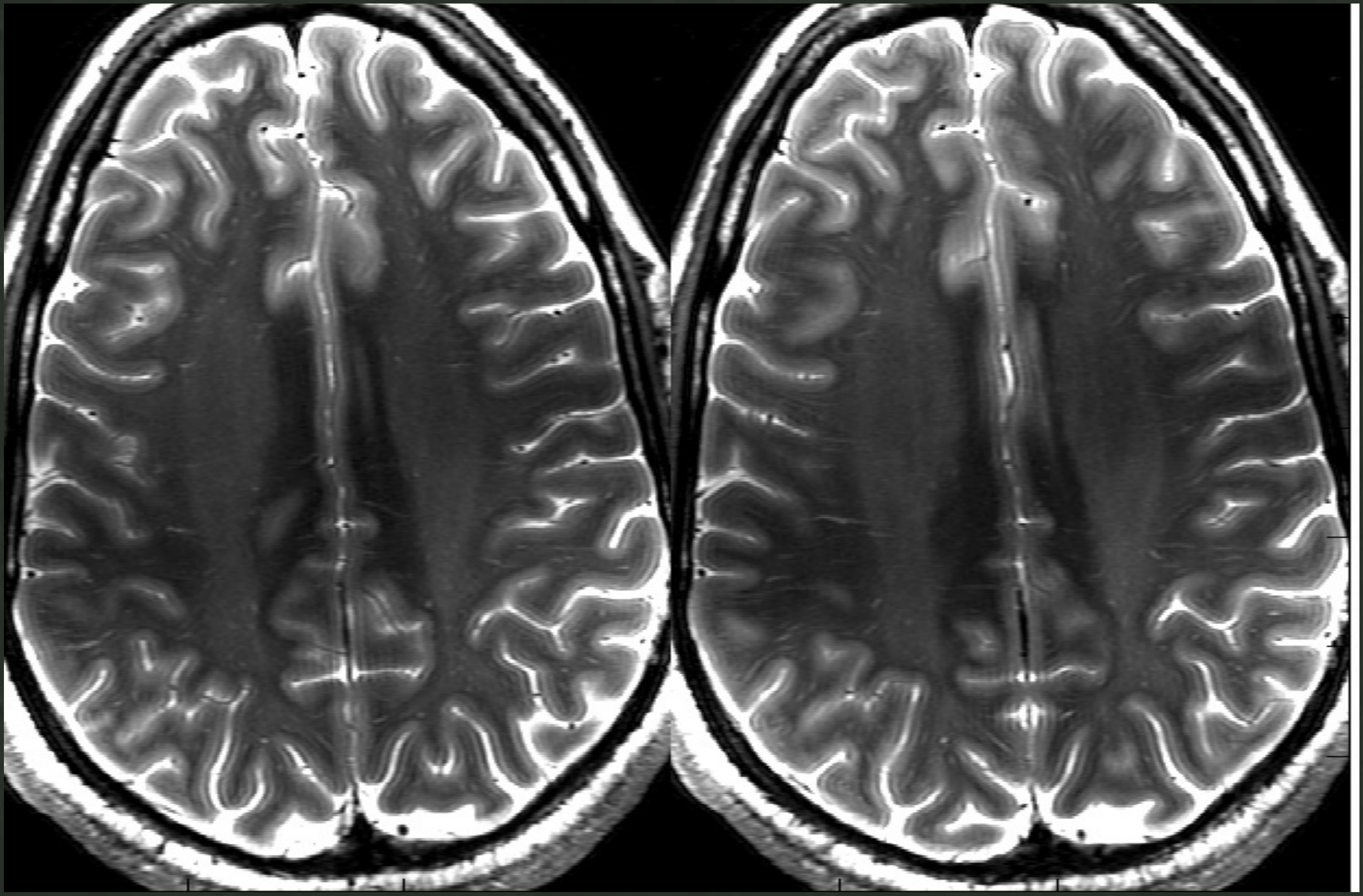
1.56mm x 1.56mm x 4mm

(3T typical resolution: 3mmx 3mm x 5mm)

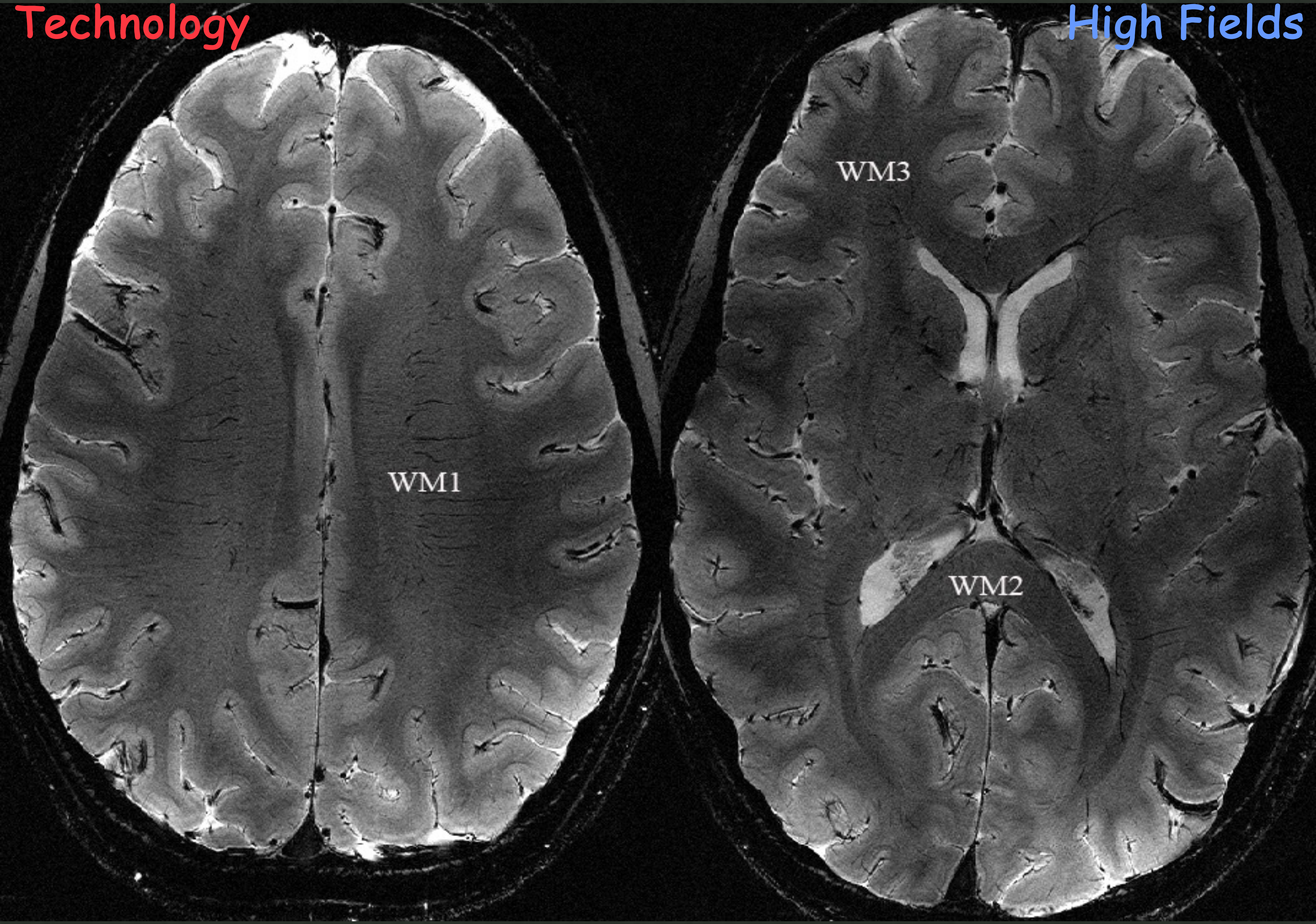


Courtesy Larry Wald

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



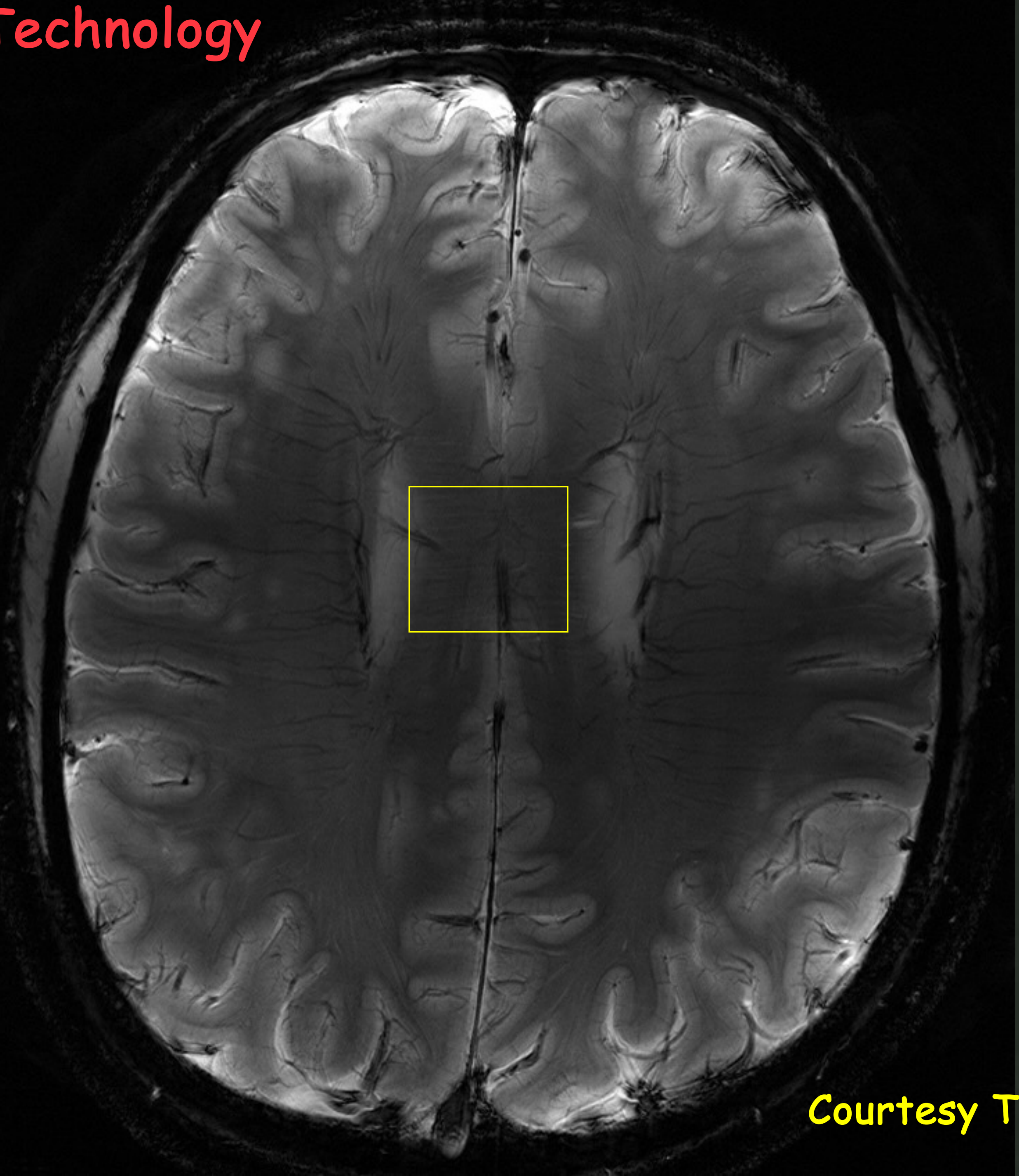
Courtesy Tie-Qiang Li, NINDS



Courtesy Tie-Qiang Li, NINDS

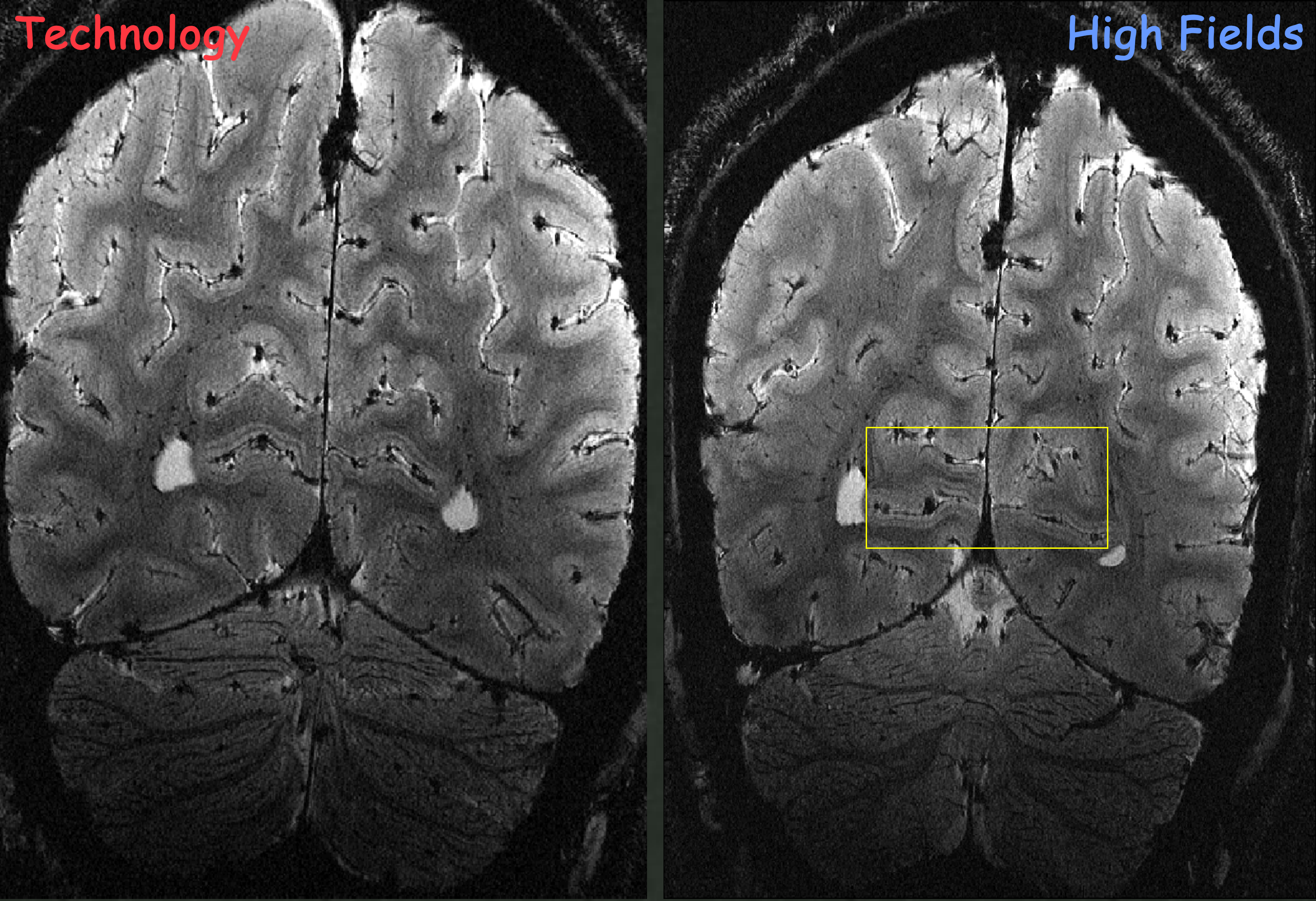
Technology

High Fields



fiber bundles?

Courtesy Tie-Qiang Li, NINDS



Courtesy Tie-Qiang Li, NINDS

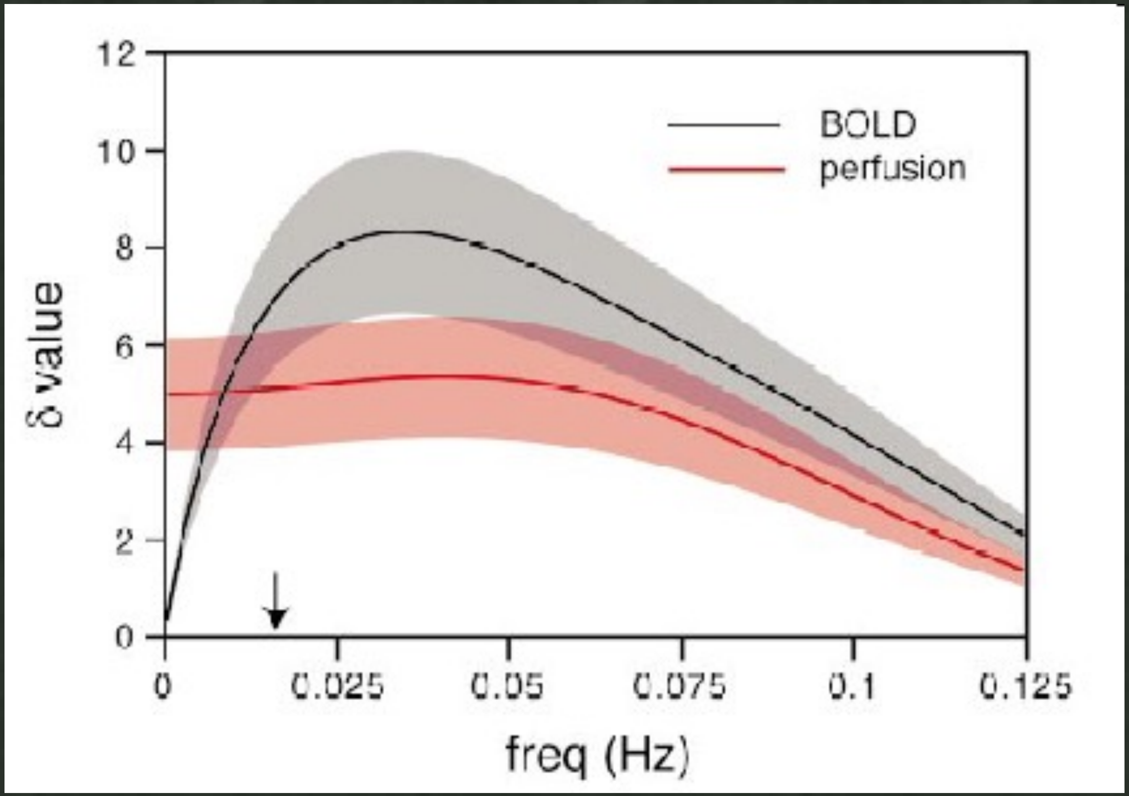
Layered structure in the visual cortex

fMRI Contrast

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

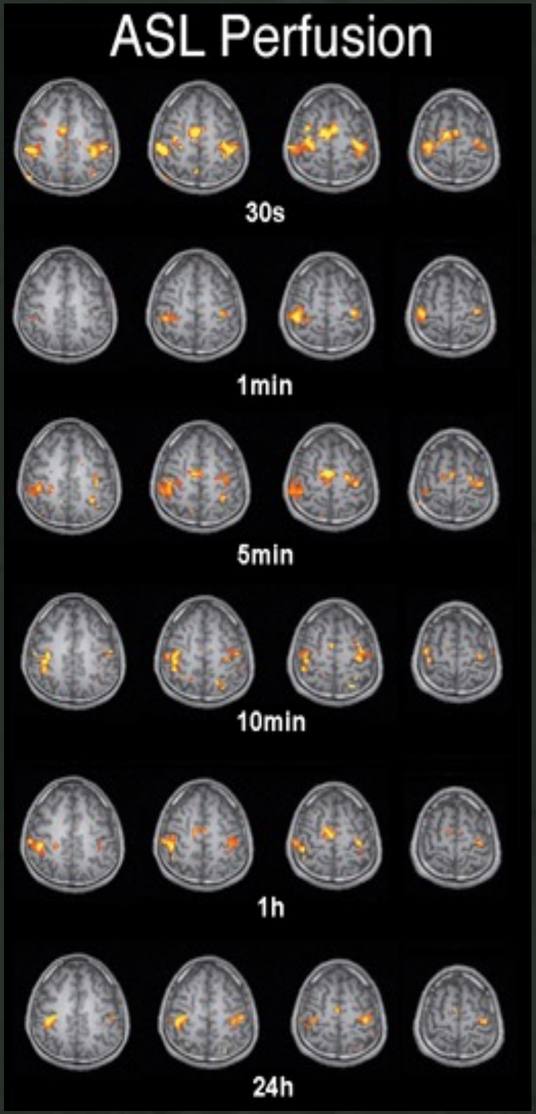
Perfusion (ASL)

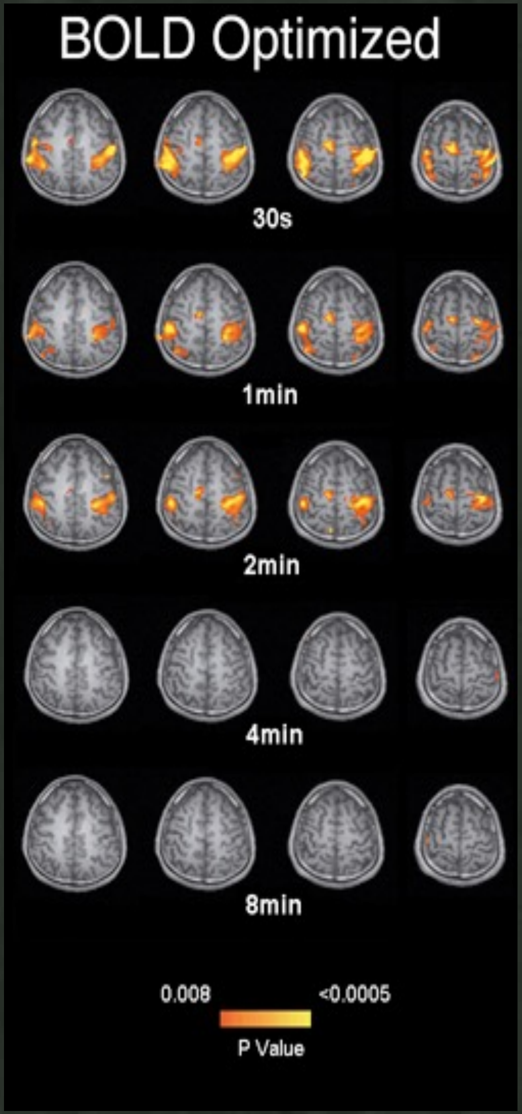
Better than BOLD for long duration activation...



GK Aguirre et al, (2002) NeuroImage 15 (3): 488-500

Perfusion vs. BOLD: Low Task Frequency

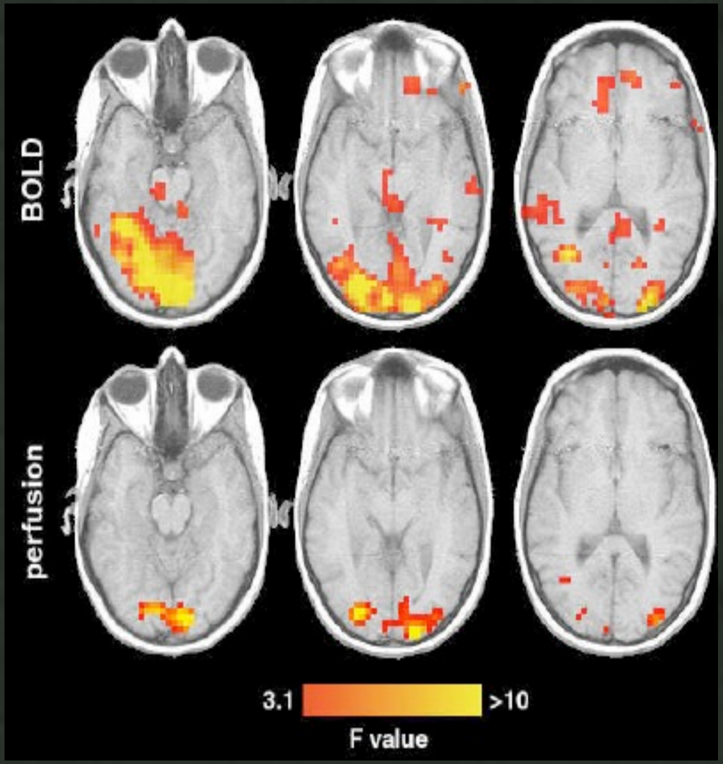


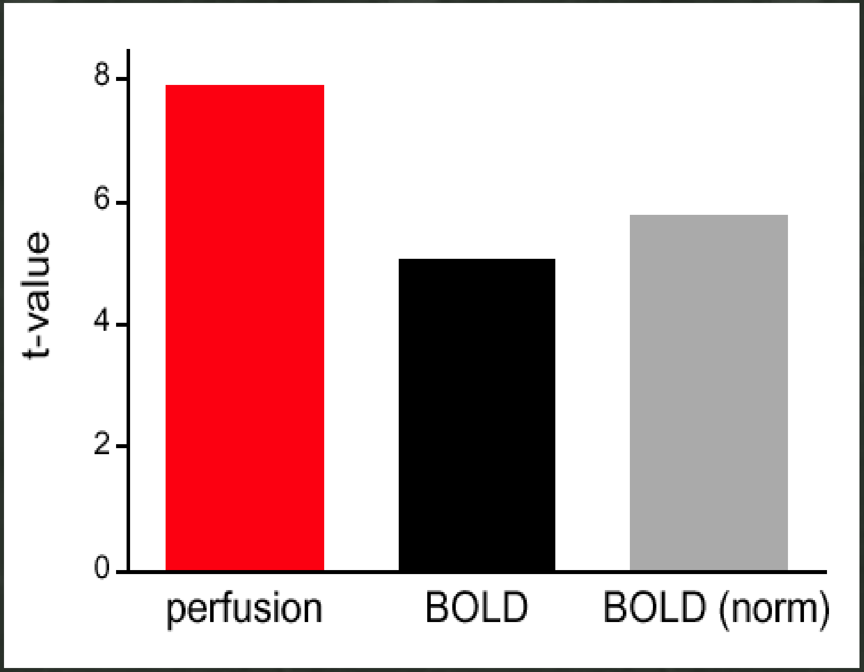


Wang et al., 2002

ASL Perfusion fMRI vs. BOLD

Improved Intersubject Variability vs. BOLD





Single Subject

Group (Random Effects)

Aguirre et al., NeuroImage

BOLD effect to highlight veins: 3 Tesla

Bove-Bettis, et al (2004), SMRT

NeuroImage

www.elsevier.com/locate/ynimg
NeuroImage 29 (2006) 1013 – 1022

Rapid Communication

Enhancing BOLD response in the auditory system by neurophysiologically tuned fMRI sequence

Erich Seifritz,[a,b,*] Francesco Di Salle,[c] Fabrizio Esposito,[d] Marcus Herdener,[a,b] John G. Neuhoff,[e] and Klaus Scheffler[f]

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[b]*Department of Psychiatry, University of Basel, 4025 Basel, Switzerland*
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[d]*Department of Neurological Sciences, University of Naples Federico II, 80127 Naples, Italy*
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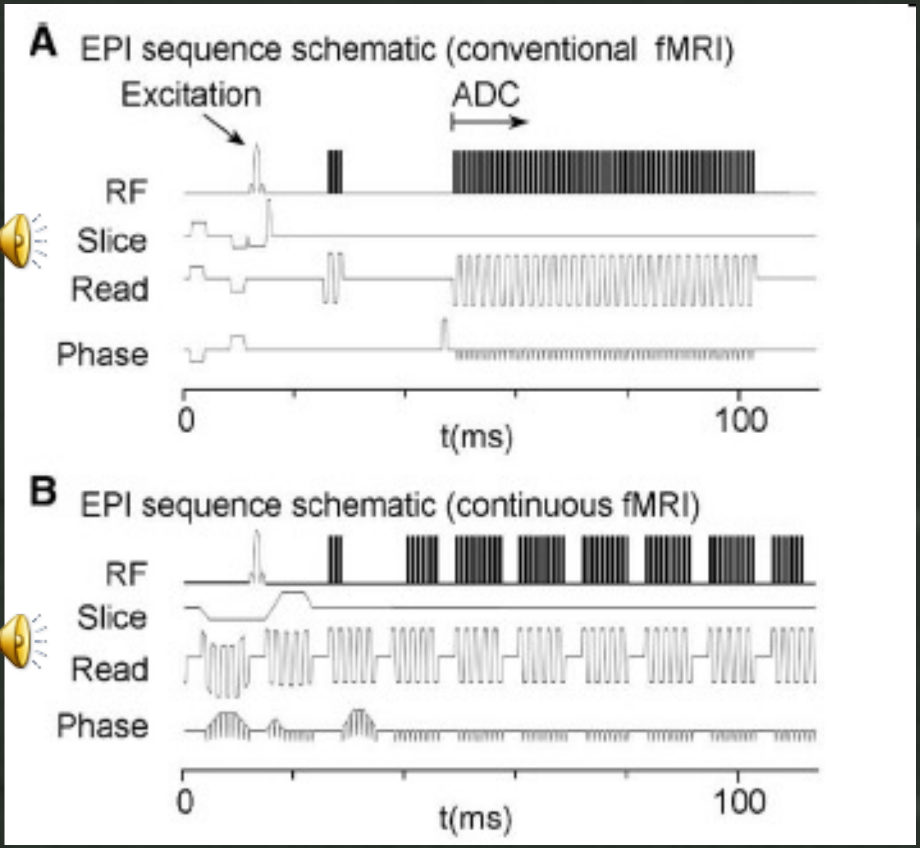
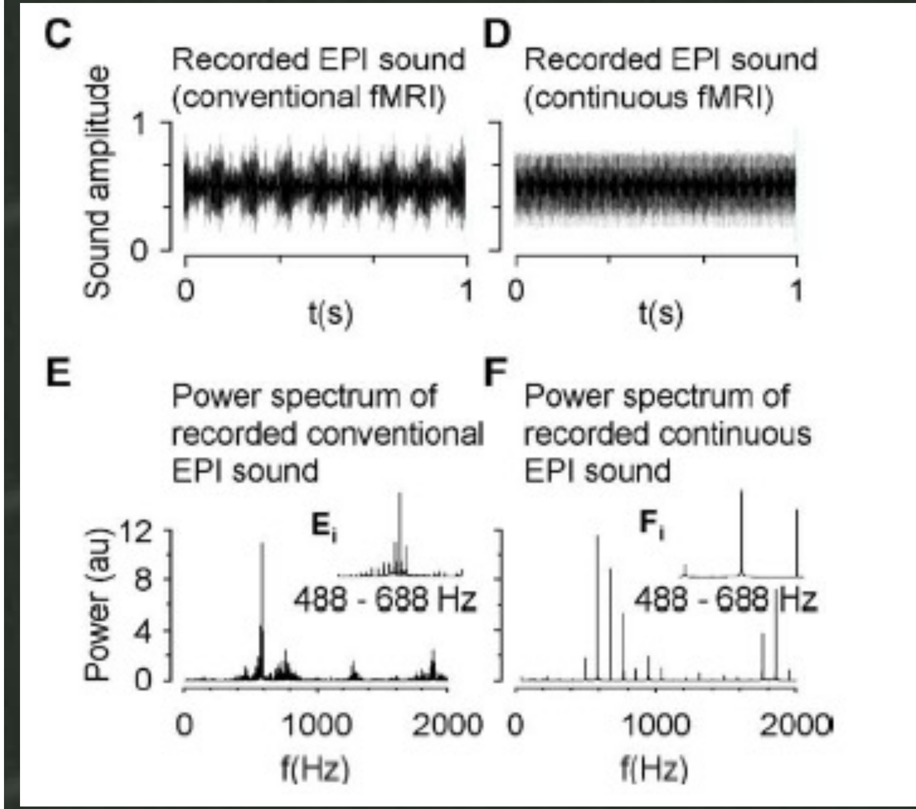
Available online 25 October 2005



A EPI sequence schematic (conventional fMRI)
Excitation
ADC
RF
Slice
Read
Phase
0
t(ms)
100
B EPI sequence schematic (continuous fMRI)
RF
Slice
Read
Phase
0
t(ms)
100



C
Recorded EPI sound (conventional fMRI)
D
Recorded EPI sound (continuous fMRI)
Sound amplitude
1
0
0
t(s)
1
0
t(s)
1
E
Power spectrum of recorded conventional EPI sound
F
Power spectrum of recorded continuous EPI sound
Power (au)
12
8
4
0
Ei
488 - 688 Hz
Fi
488 - 688 Hz
0
1000
2000
f(Hz)
0
1000
2000
f(Hz)

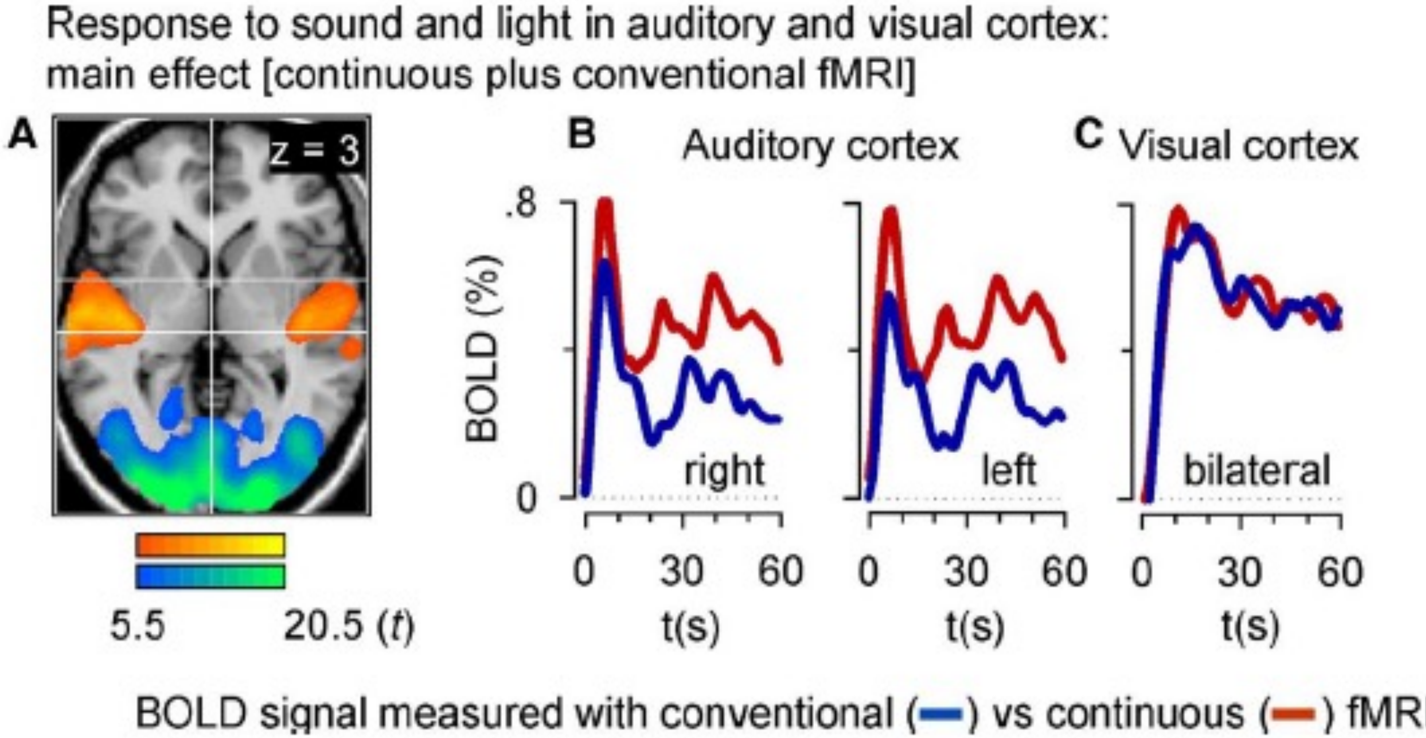
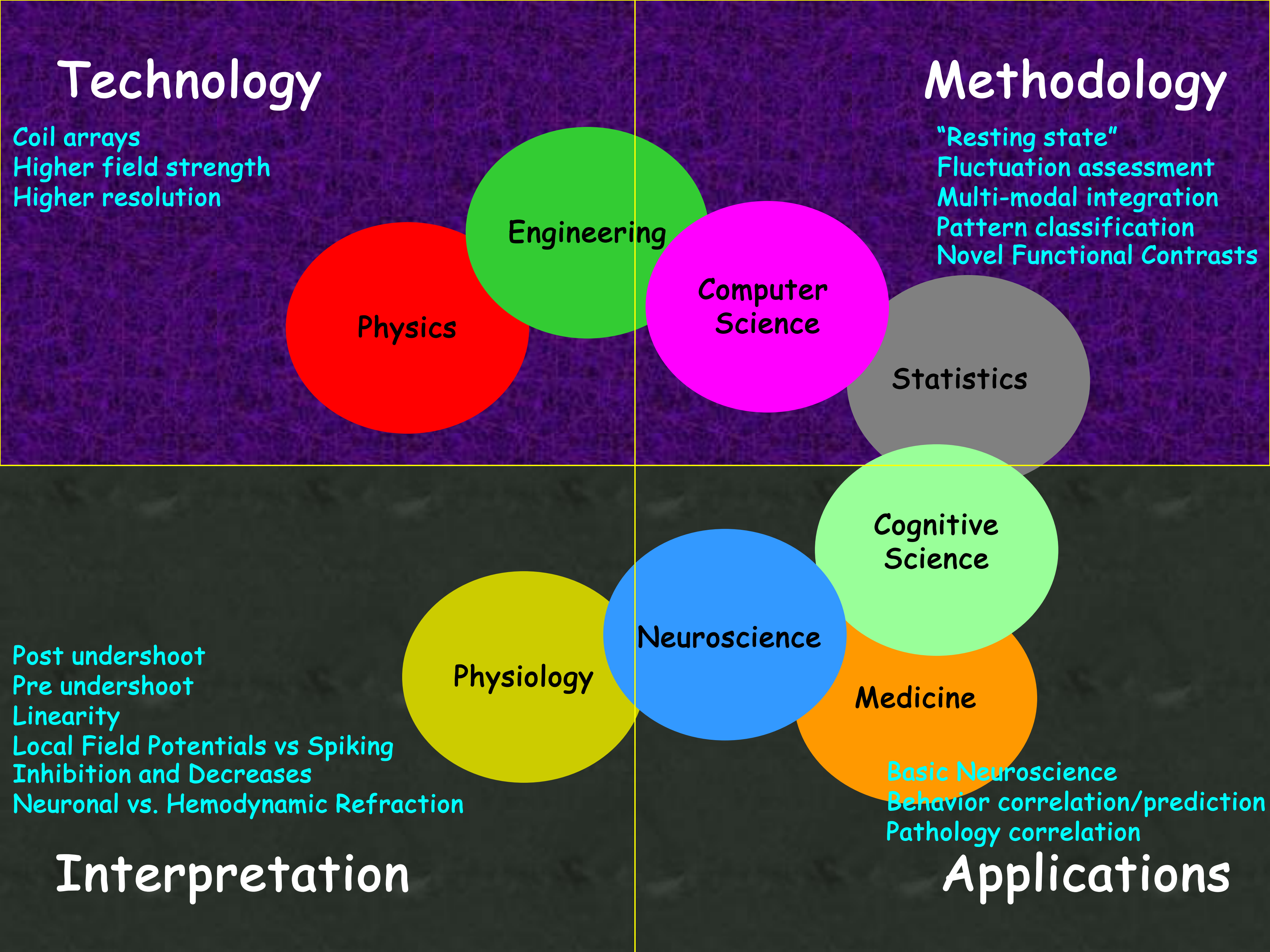


Fig. 4. (A) Main effects of response to pulsed sound and light measured with continuous-sound and conventional fMRI ($P_{corrected} \leq 0.001$). Corresponding BOLD signal time-course in auditory (B) and visual (C) cortex (red, measured with continuous-sound fMRI; blue, measured with conventional fMRI). Note, continuous-sound fMRI produced an enhanced BOLD signal only in the auditory but not in the visual system, demonstrating a domain-specific physiological effect.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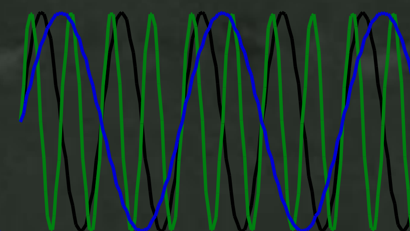
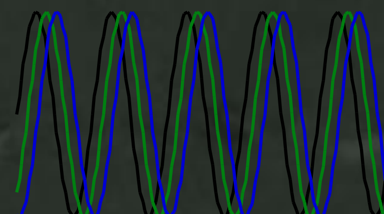
Neuronal Activation Input Strategies

1. Block Design

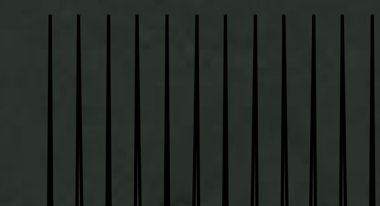
2. Frequency Encoding



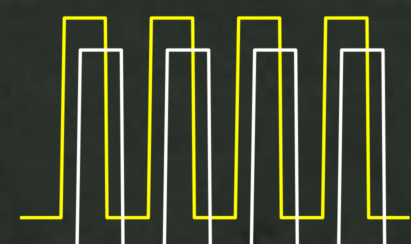
3. Phase Encoding



4. Event-Related

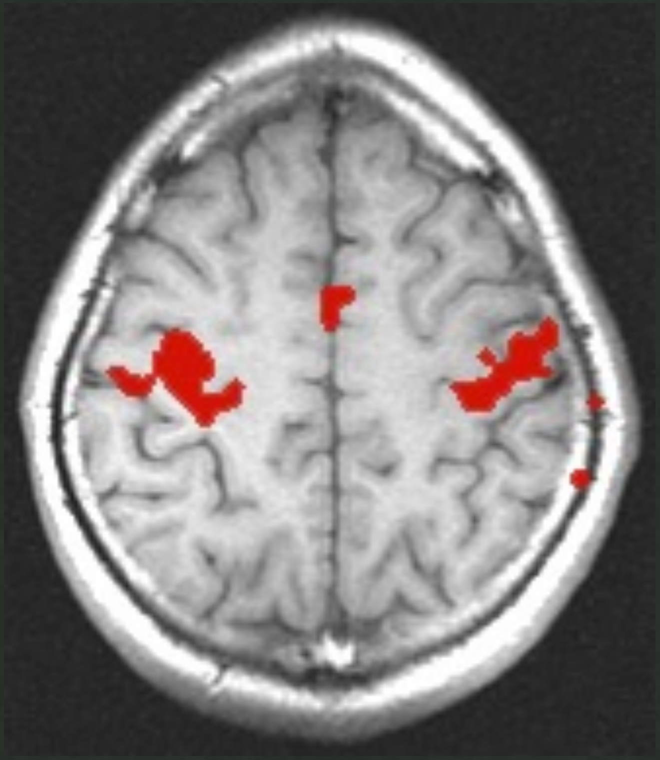


5. Orthogonal Block Design

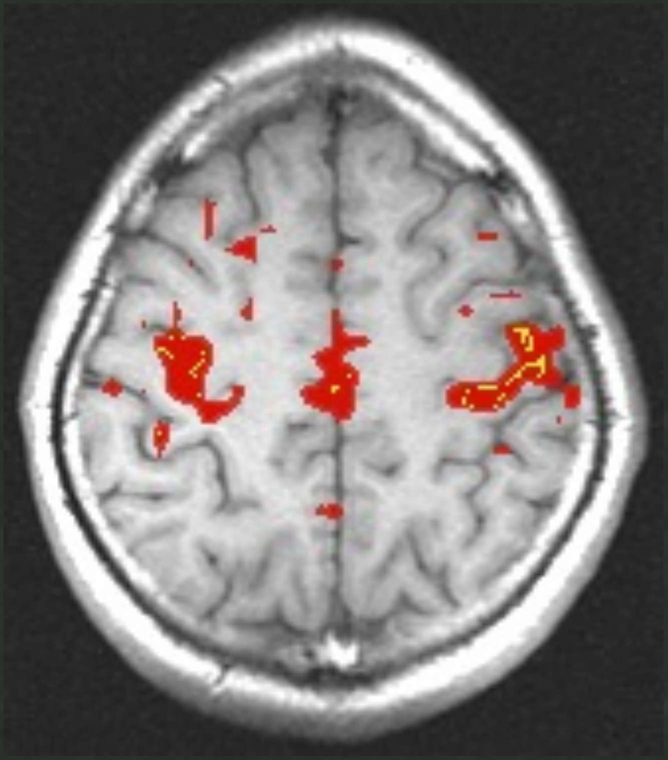


6. Free Behavior Design.

Resting State Correlations



Activation:
correlation with reference function



Rest:
seed voxel in motor cortex

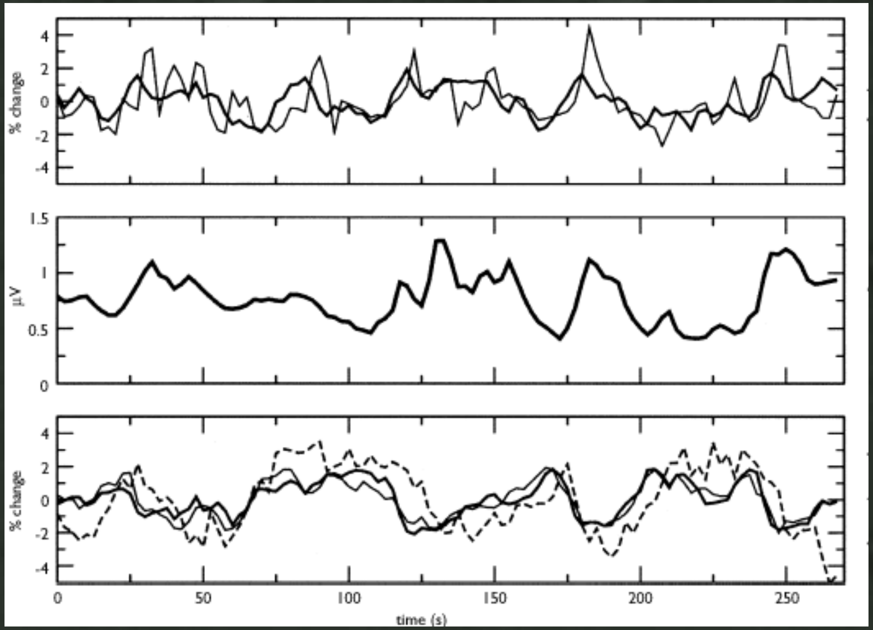
B. Biswal *et al.*, MRM, 34:537 (1995)

BOLD correlated with 10 Hz power during "Rest"

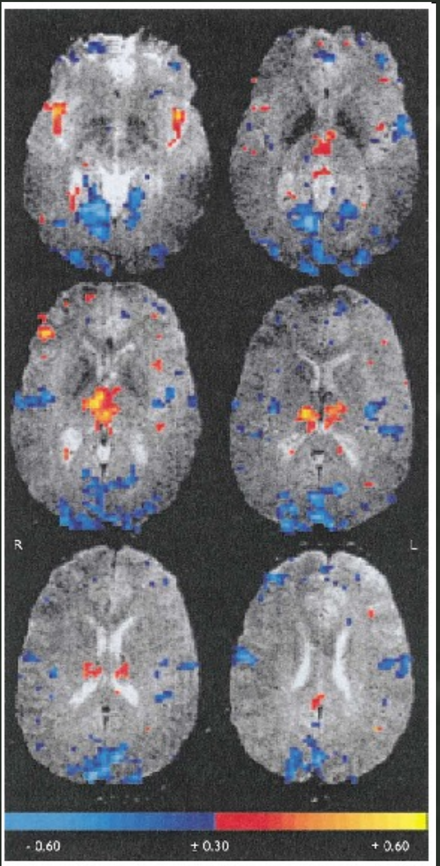
Positive

10 Hz power

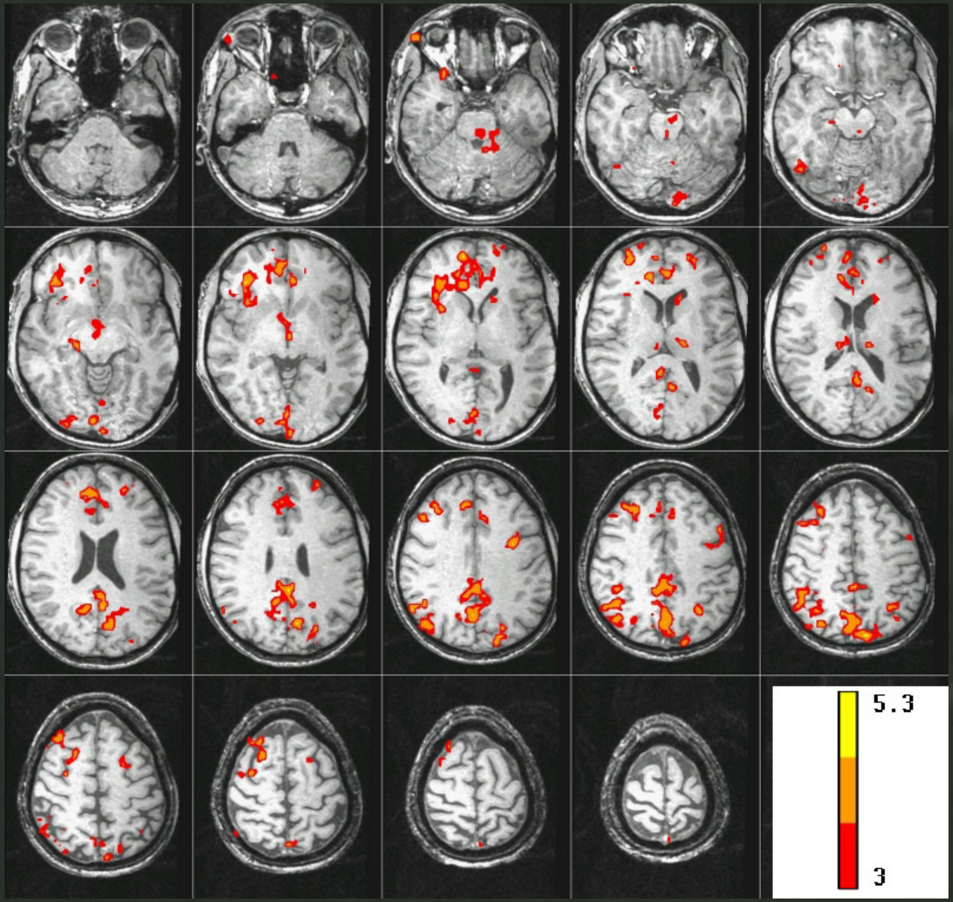
Negative



Goldman, et al (2002), Neuroreport



BOLD correlated with SCR during "Rest"



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

Approaches to assessing spatial connectivity:

ICA, PCA, seed voxel...

Why not correlate every voxel with every other voxel?

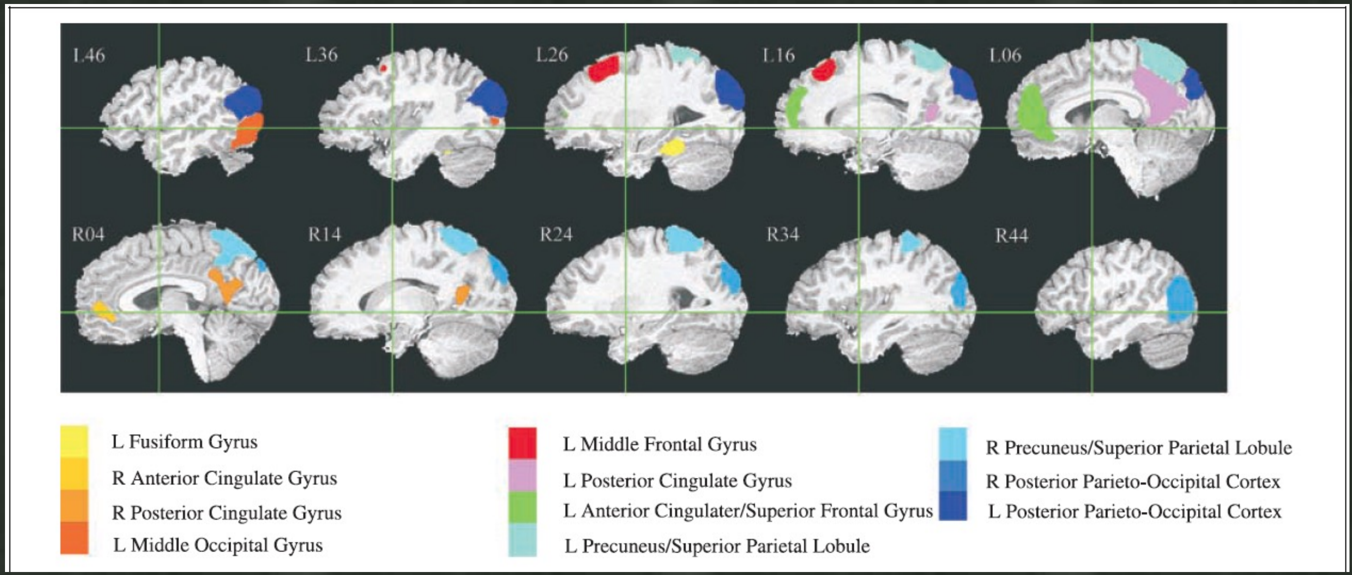
For 64 x 64 resolution, 27 slices, 165 time points:
-160 voxel ROI = 5 min and 63 MB memory....

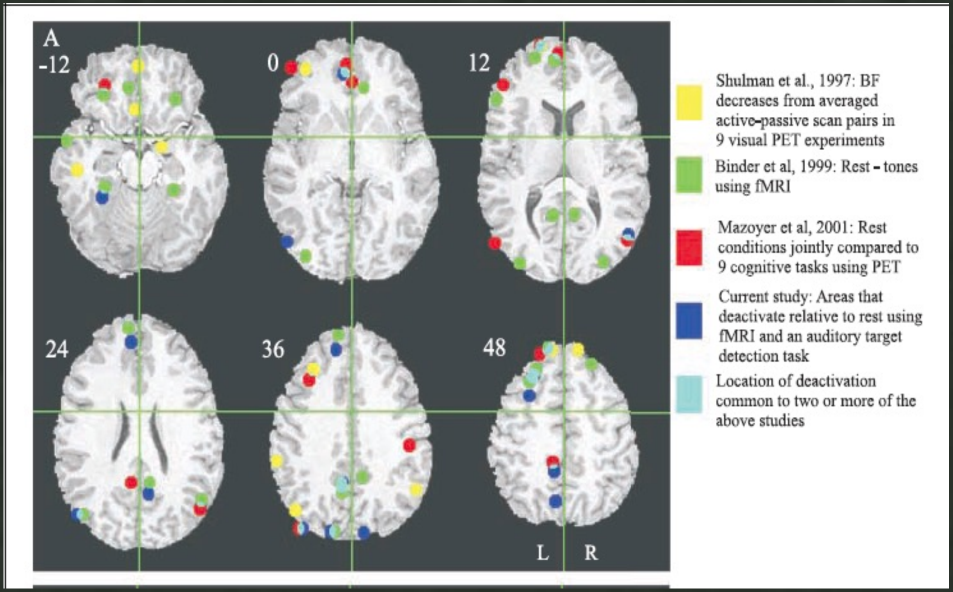
-Gray matter (10,000 voxels) = 5.32 hrs and 4.3 GB memory
-Entire volume (110,000 voxels) = 59 hrs and 47.5 GB memory

Resting state connectivity

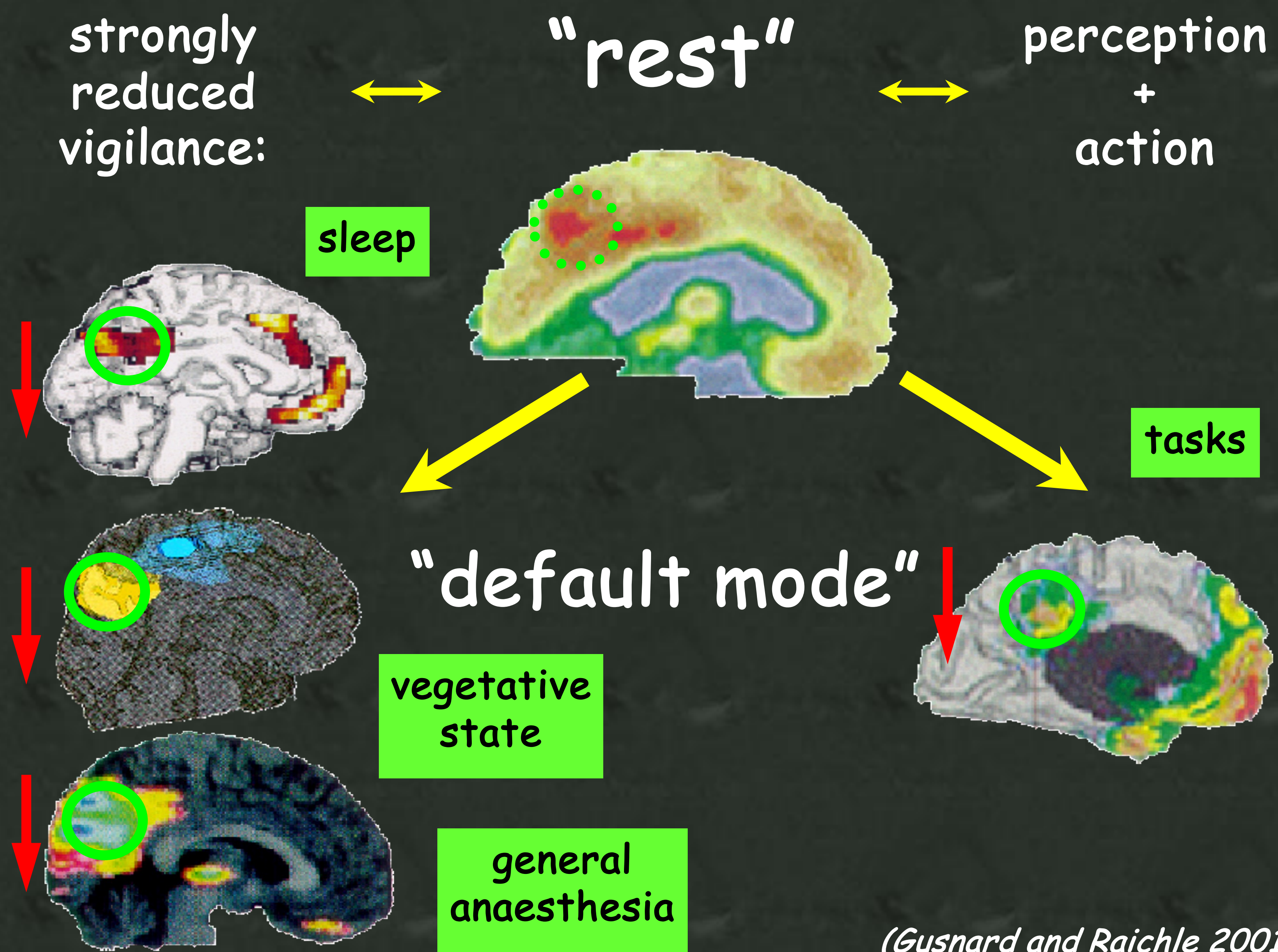
Decreases during cognitive tasks

Regions showing decreases during cognitive tasks





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

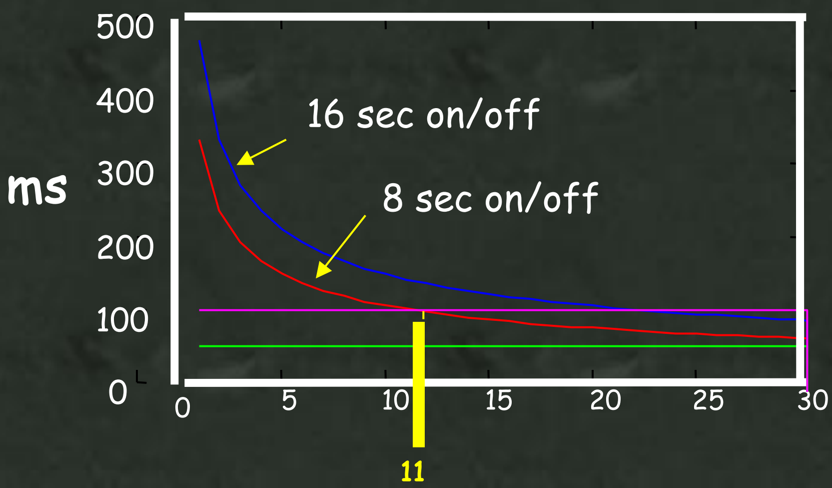


(Gusnard and Raichle 2001)

Methodology

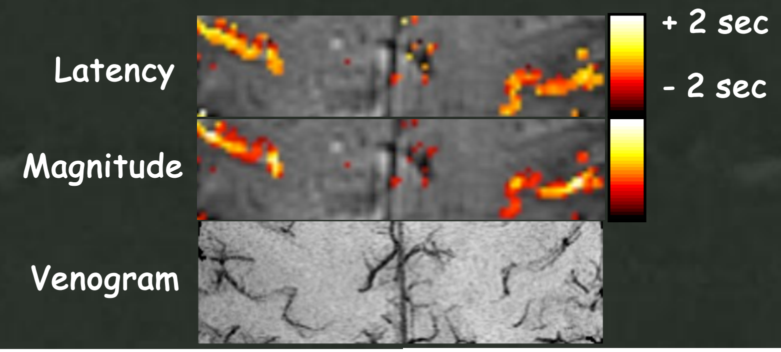
Temporal Resolution

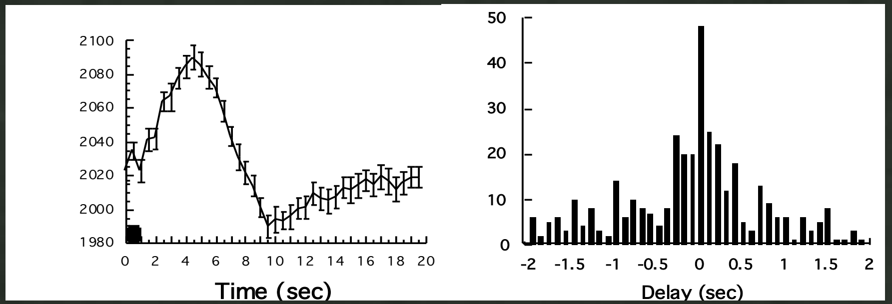
In an ideal world… no latency variation



R. Birn

Latency Variation…





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

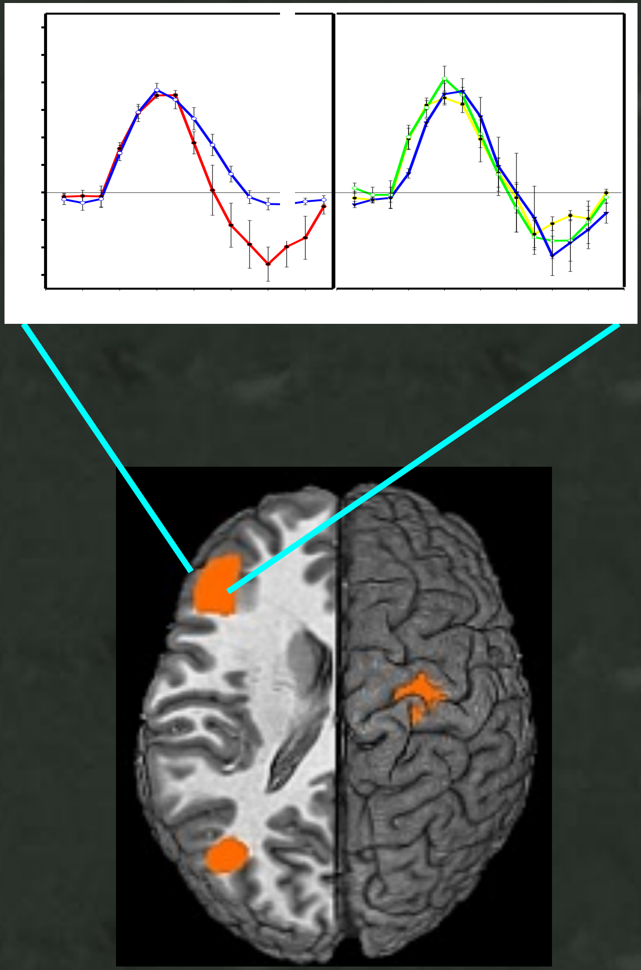
Methodology

Temporal Resolution

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

Word vs. Non-word

0°, 60°, 120° Rotation

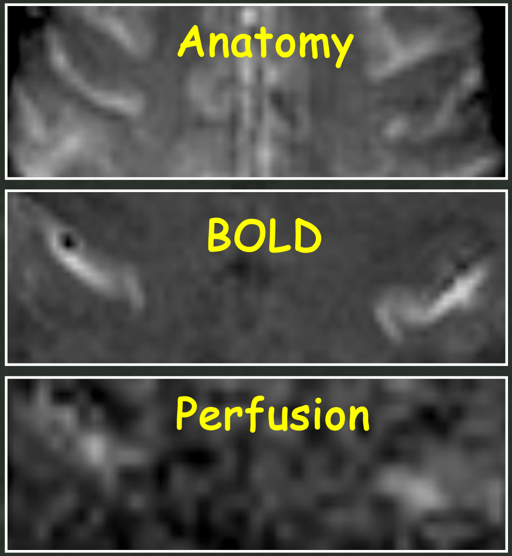


Bellgowan, et al (2003), PNAS 100, 15820-15283

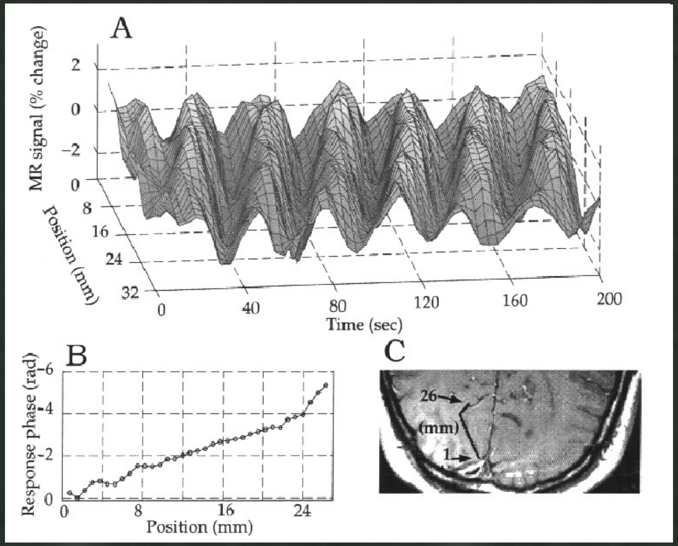
Methodology

Spatial Resolution

PSF FWHM = 3.5mm

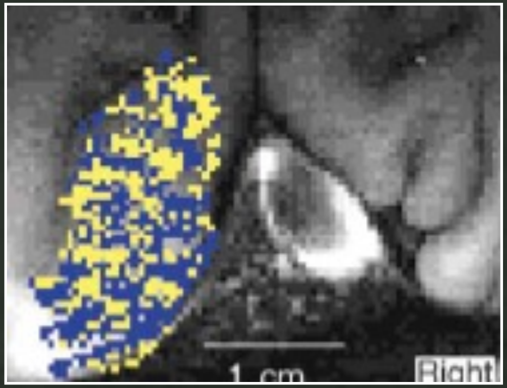


P. A. Bandettini, (1999) "Functional MRI" 205-220.



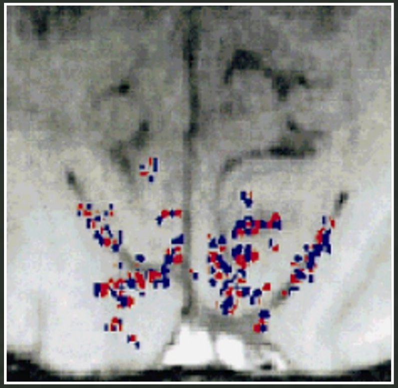
S.A. Engel, et al. Investigative Ophthalmology & Visual Science 35 (1994) 1977-1977.

0.47 x 0.47 in plane resolution



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

0.54 x 0.54 in plane resolution



Multi-shot with navigator pulse

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

Mapping ⟷ "Reading"

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
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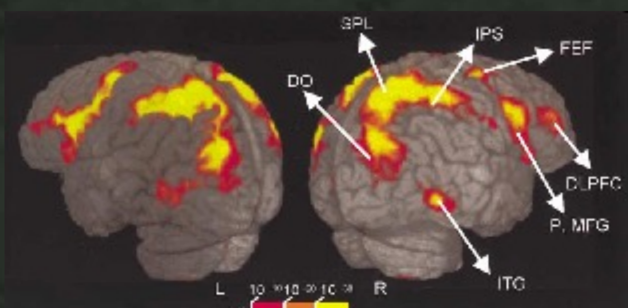
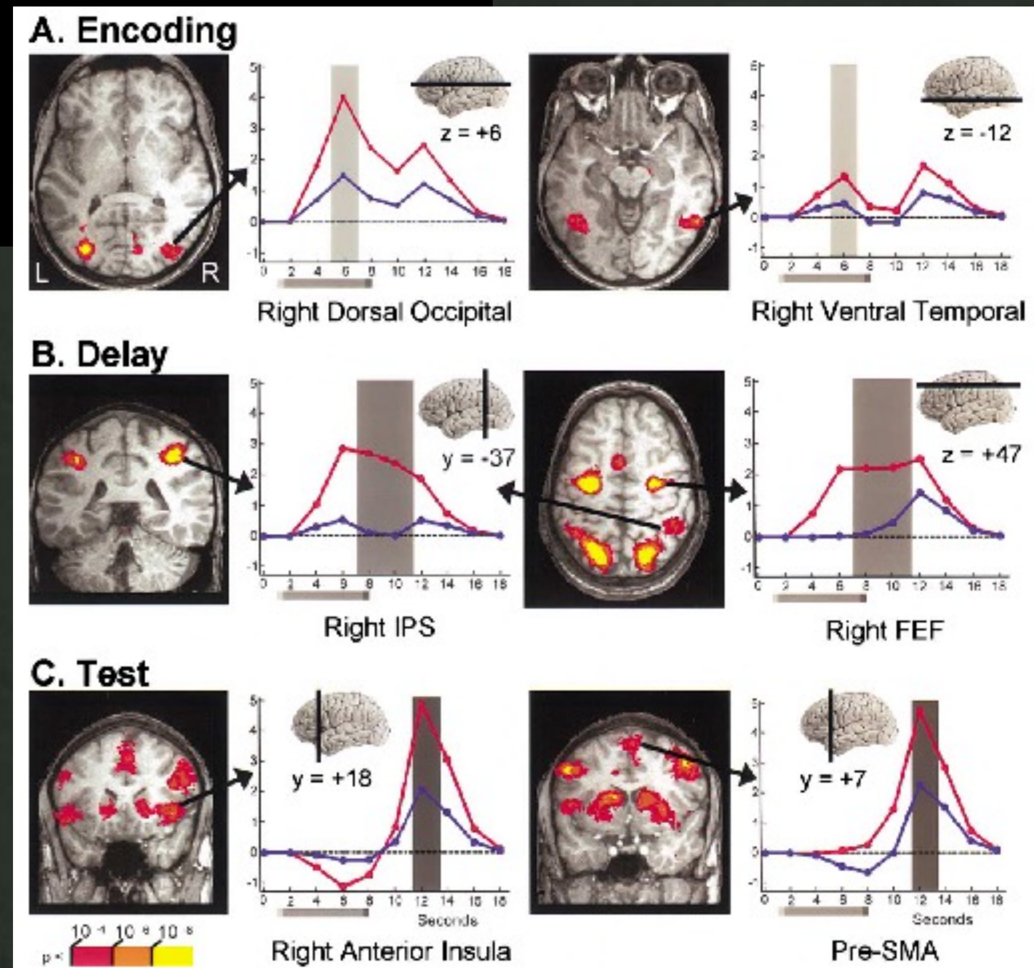
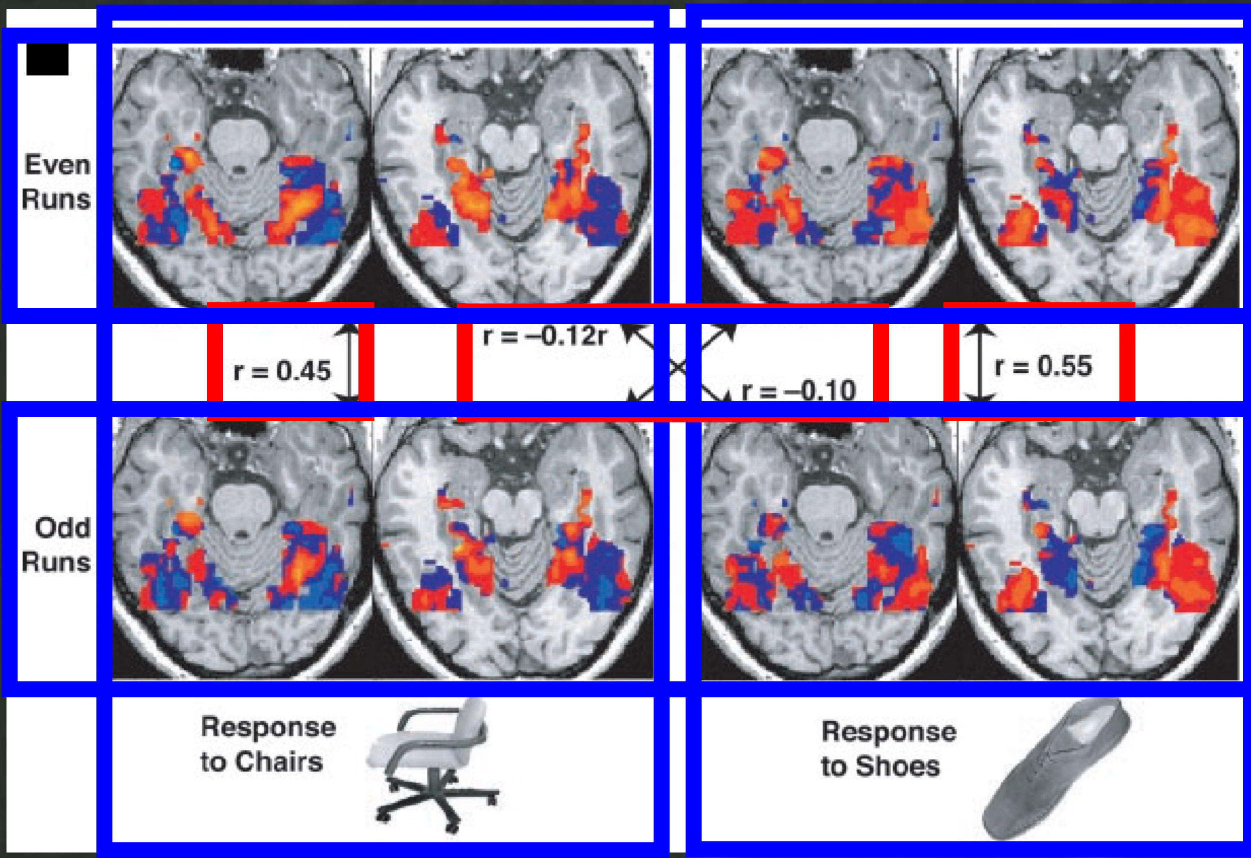
National Institute of Mental Health
National Institutes of Health
Bethesda, Maryland 20892

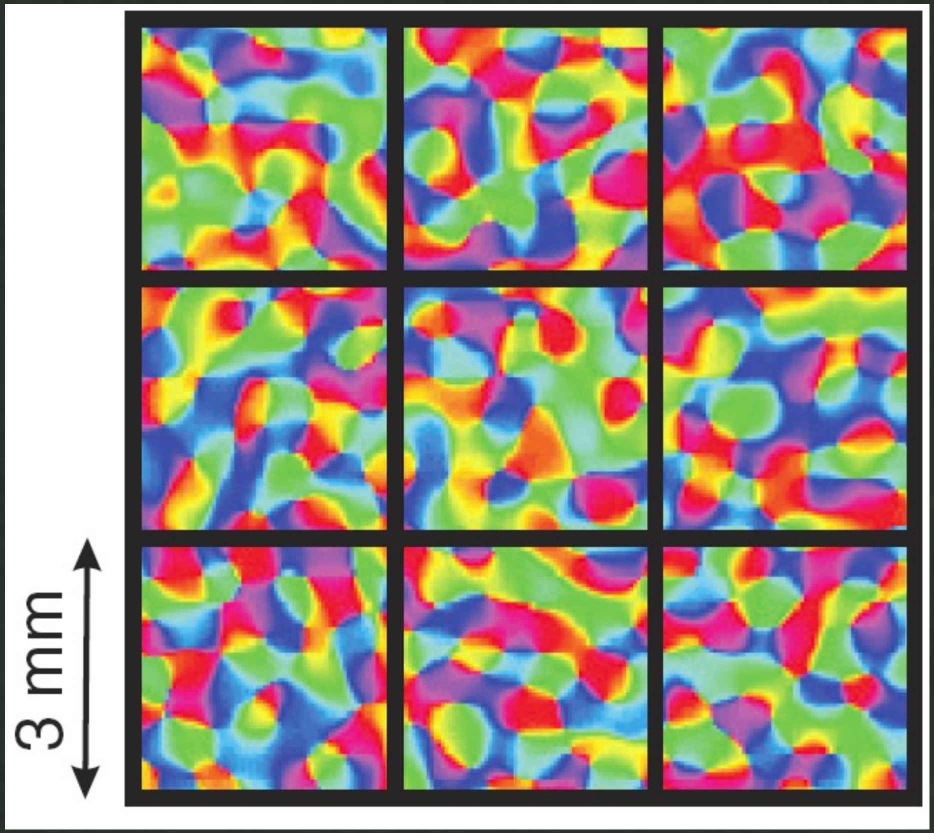


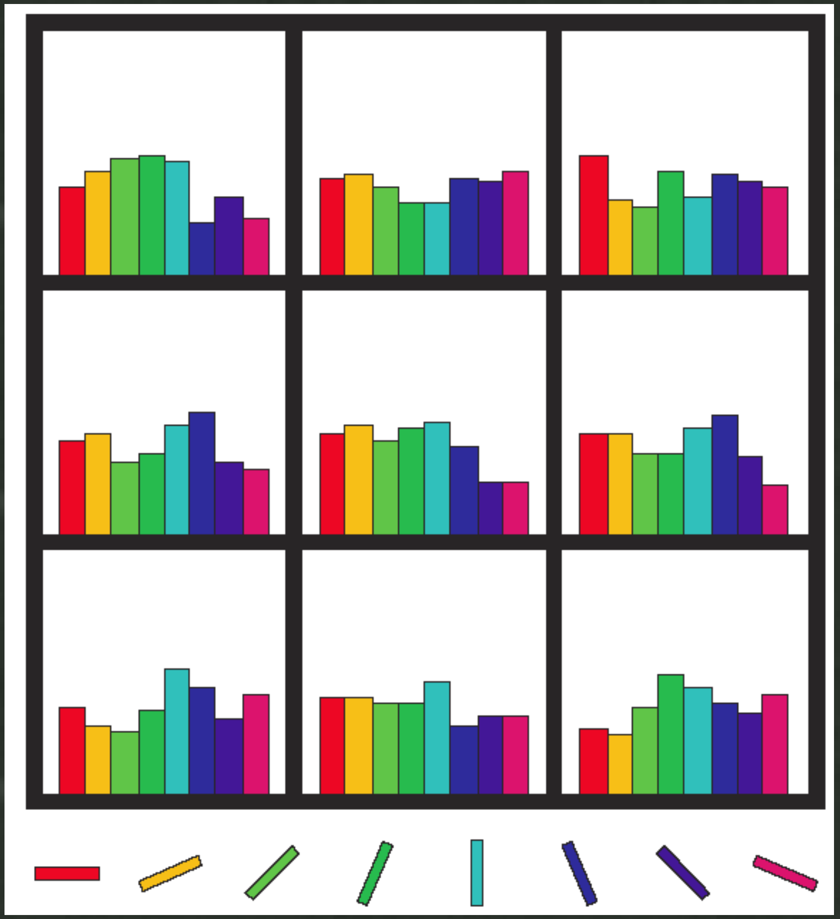


Ventral temporal category representations

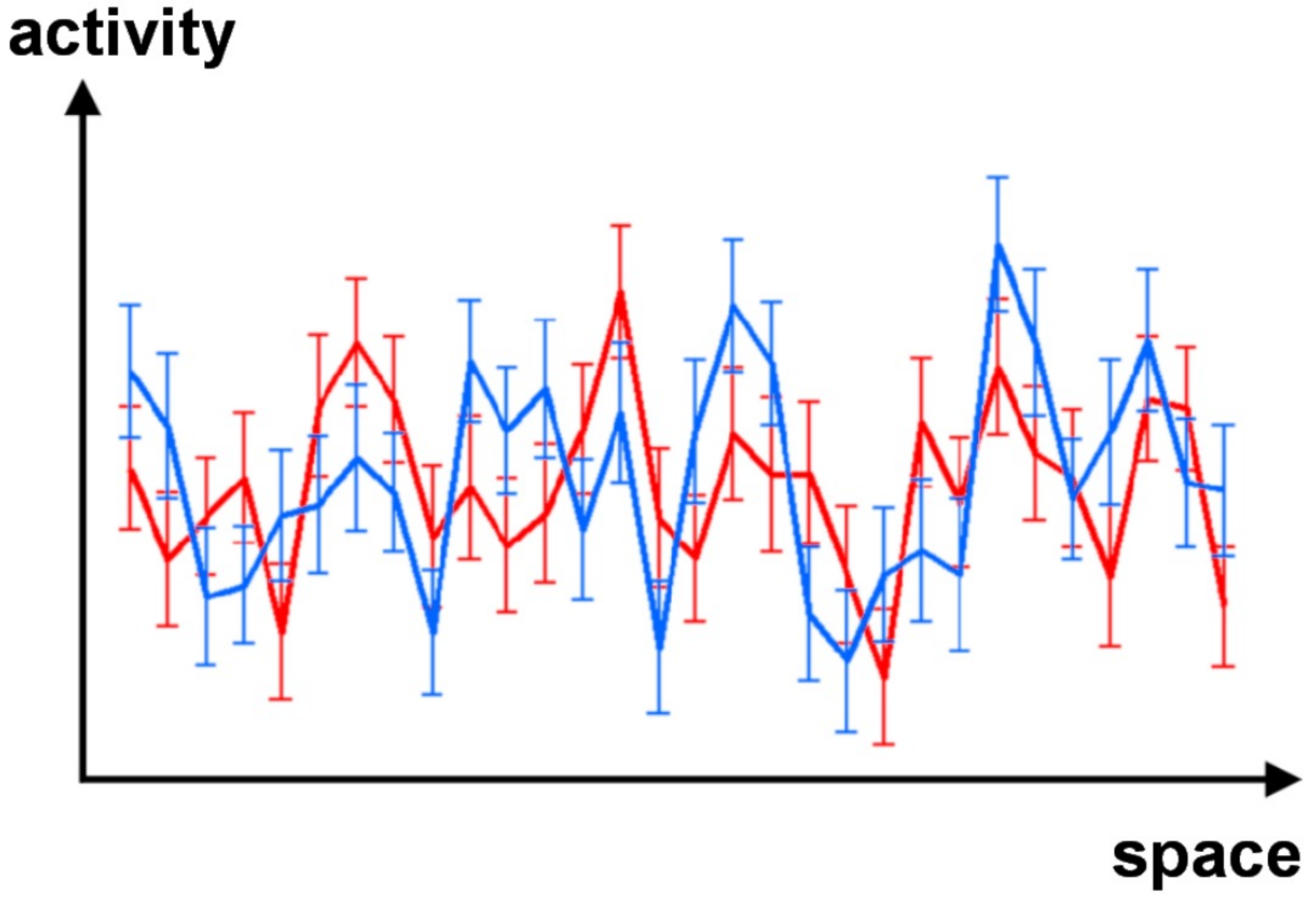
- Object categories are associated with distributed representations in ventral temporal cortex
  - Present photos of common objects **blocked by category**.
  - Use fMRI to measure the pattern of high and low responses across large areas of ventral temporal cortex.
  - Observe **stable**, distributed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







Boynton (2005), News & Views on Kamitani & Tong (2005) and Haynes & Rees (2005)


activity
space

Functional magnetic resonance imaging (fMRI) "brain reading": detecting and classifying distributed patterns of fMRI activity in human visual cortex

David D. Cox[a,b,*] and Robert L. Savoy[a,b,c]

[a] Rowland Institute for Science, Cambridge, MA 02142, USA
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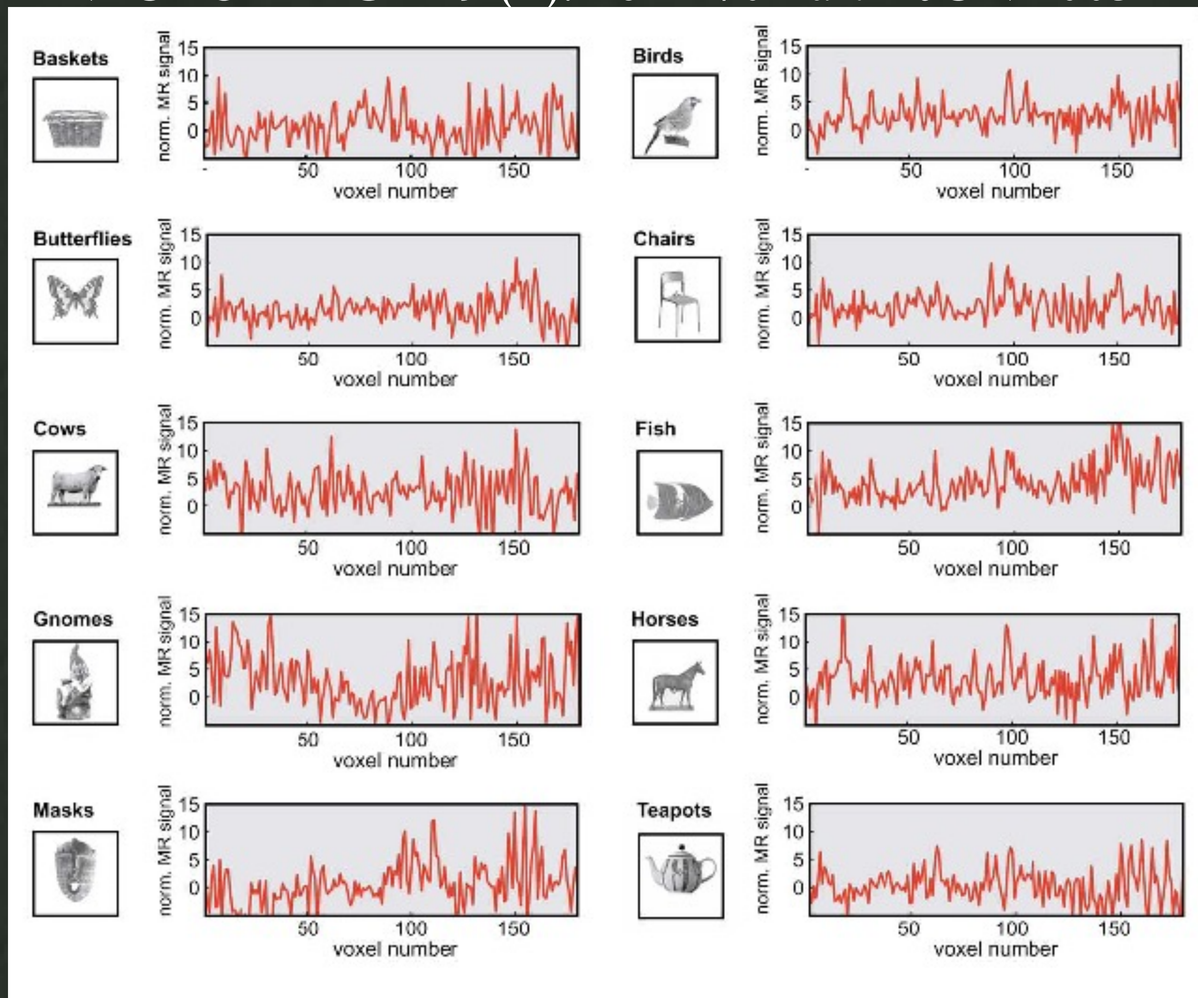
[c] HyperVision, Inc., P.O. Box 158, Lexington, MA 02420, USA

Received 15 July 2002; accepted 10 December 2002

NEUROIMAGE 19 (2): 261-270 Part 1 JUN 2003

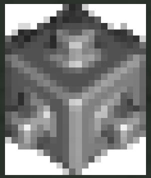


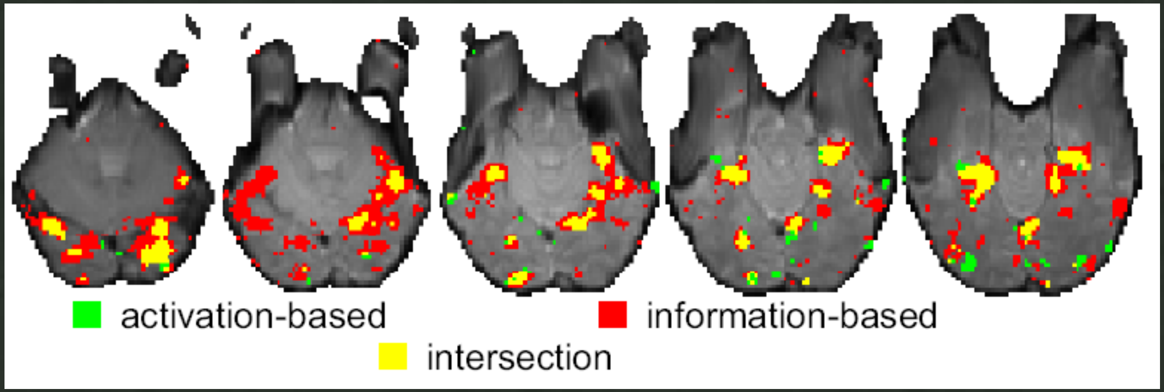
Processing Methods

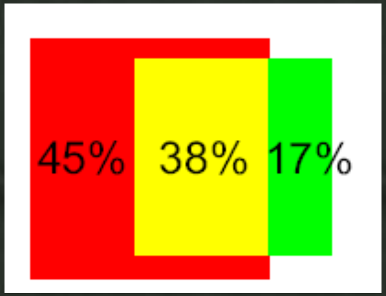
Activation-based mapping: data smoothing
(classical approach)

Information-based mapping: local multivariate analysis

volume scanned with MANCOVA searchlight→







voxel sets

N. Kriegeskorte

Pattern-recognition analysis of fMRI activity patterns

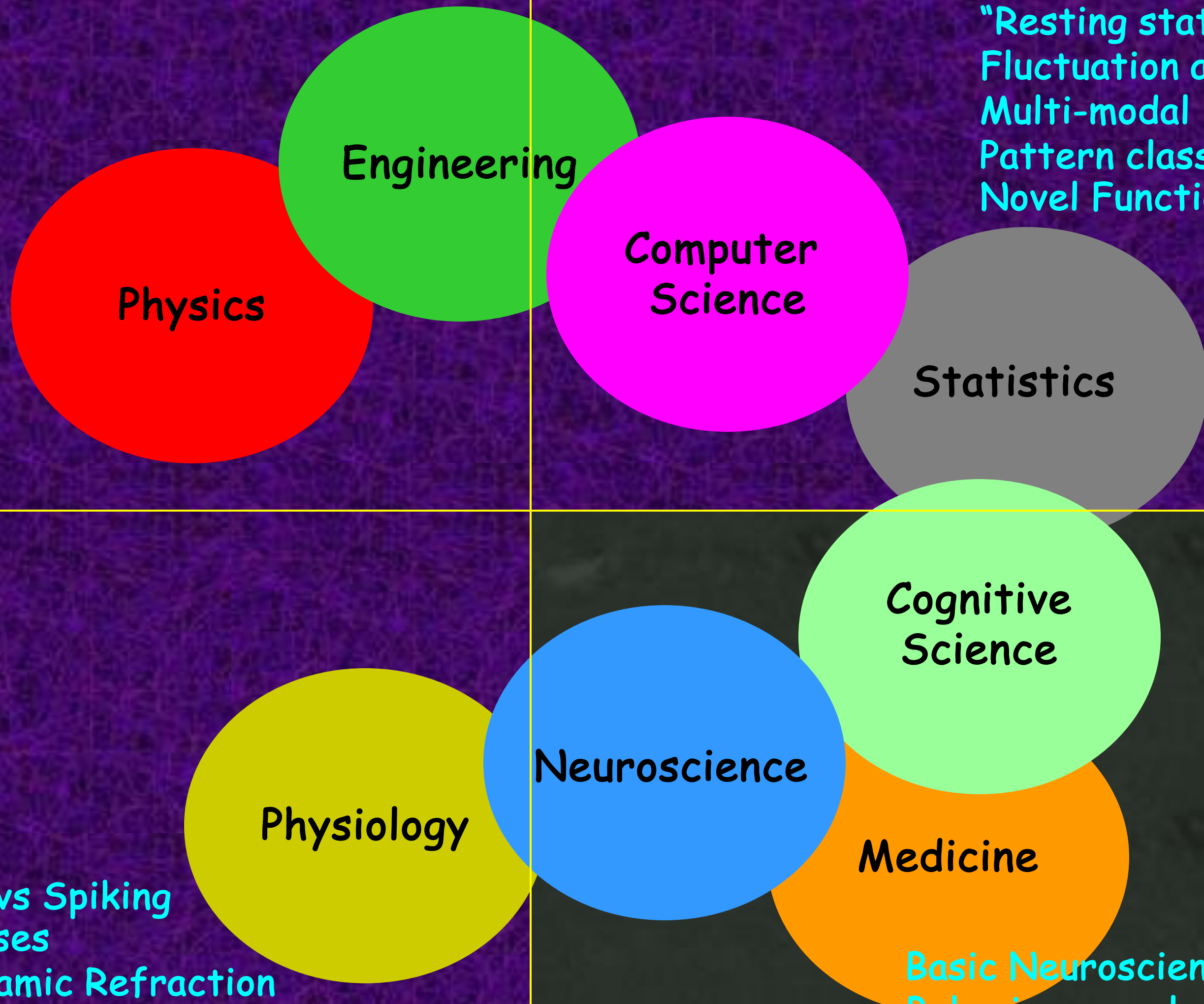
- Haxby et al. (2001)
- Cox & Savoy (2003)
- Carlson et al. (2003)
- Kamitani & Tong (2005)
- Haynes & Rees (2005)
- Kriegeskorte et al (2006)

Technology

Coil arrays
Higher field strength
Higher resolution

Methodology

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



Post undershoot
Pre undershoot
Linearity
Local Field Potentials vs Spiking
Inhibition and Decreases
Neuronal vs. Hemodynamic Refraction

Interpretation

Basic Neuroscience
Behavior correlation/prediction
Pathology correlation

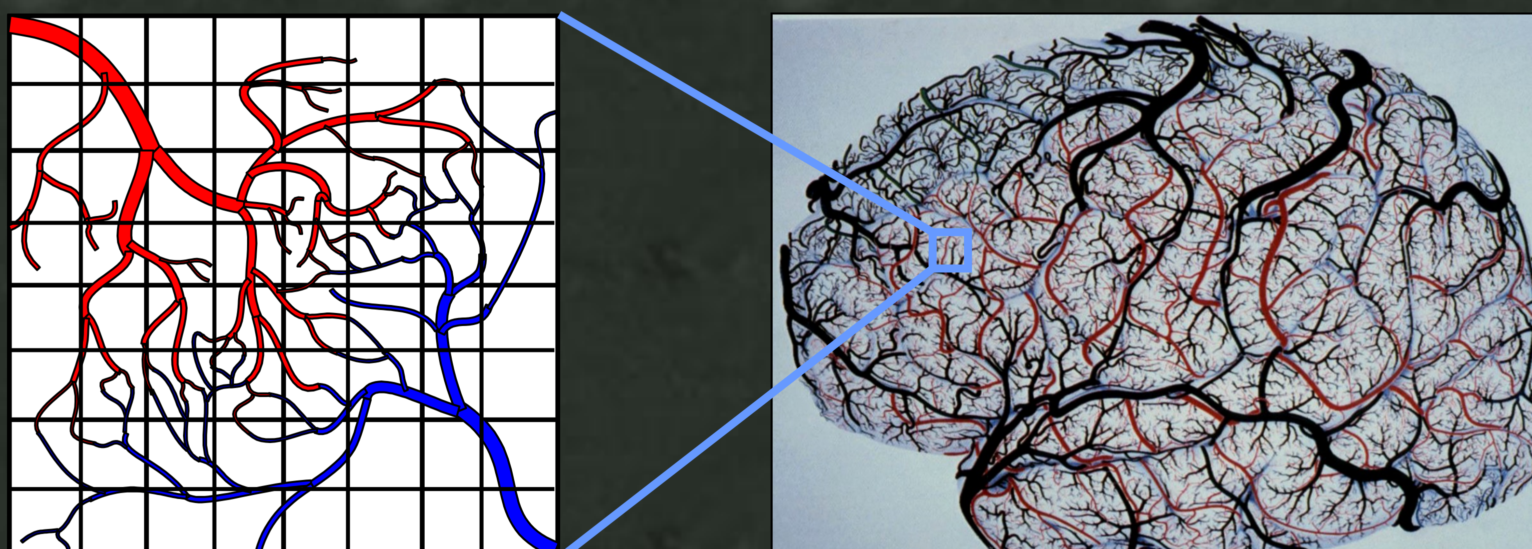
Applications

Neuronal Activation → Measured Signal ?

Neuronal Activation → Hemodynamics ?

Hemodynamics → Measured Signal ?

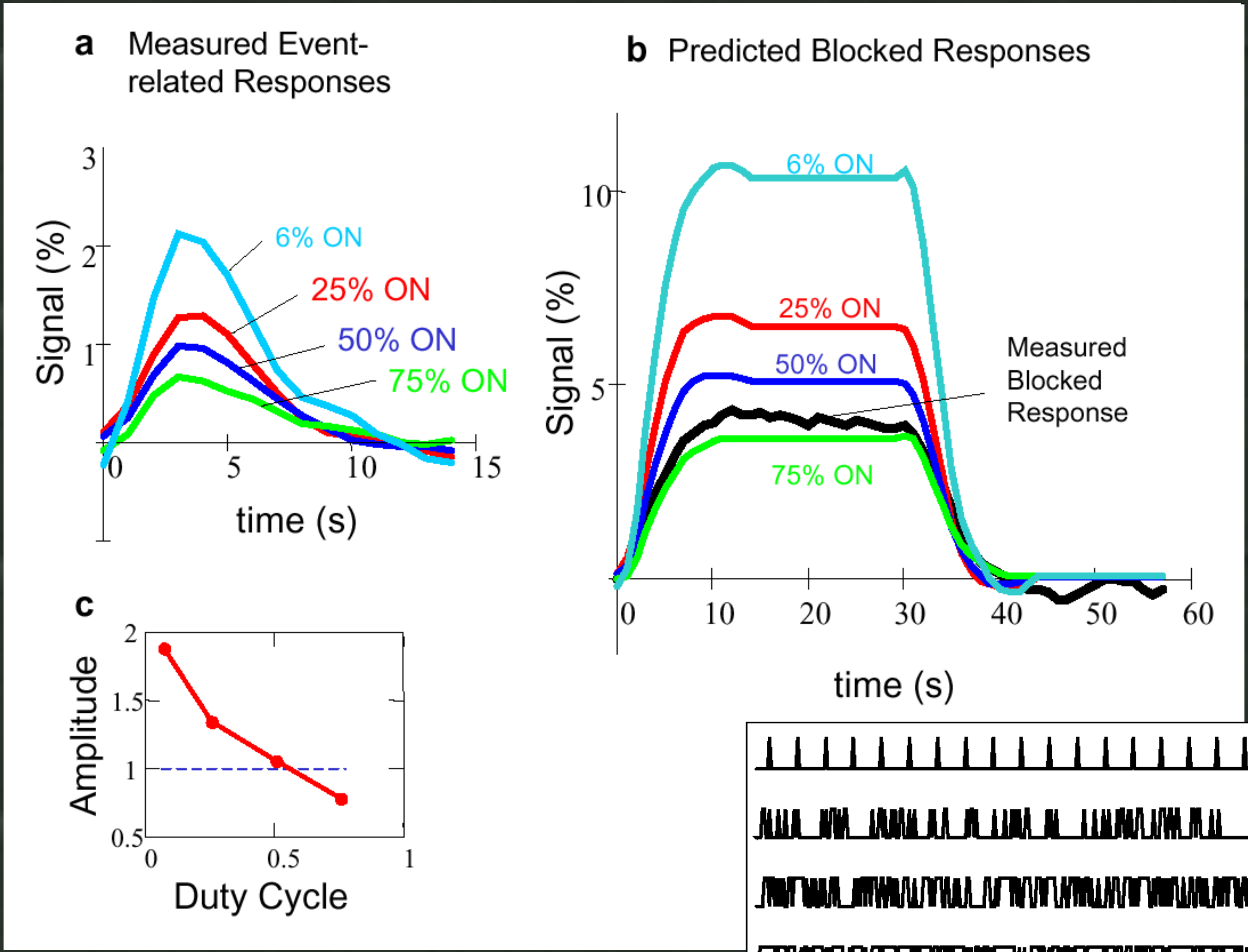
Noise → Measured Signal ?

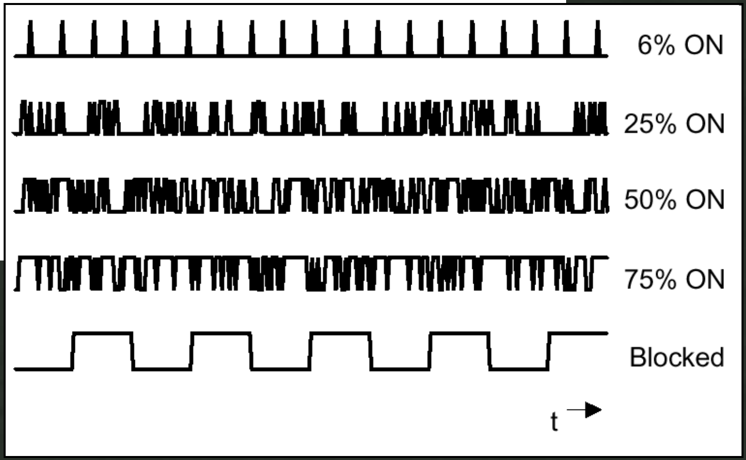


Interpretation

Increases: duty cycle

Linearity





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

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Higher resolution

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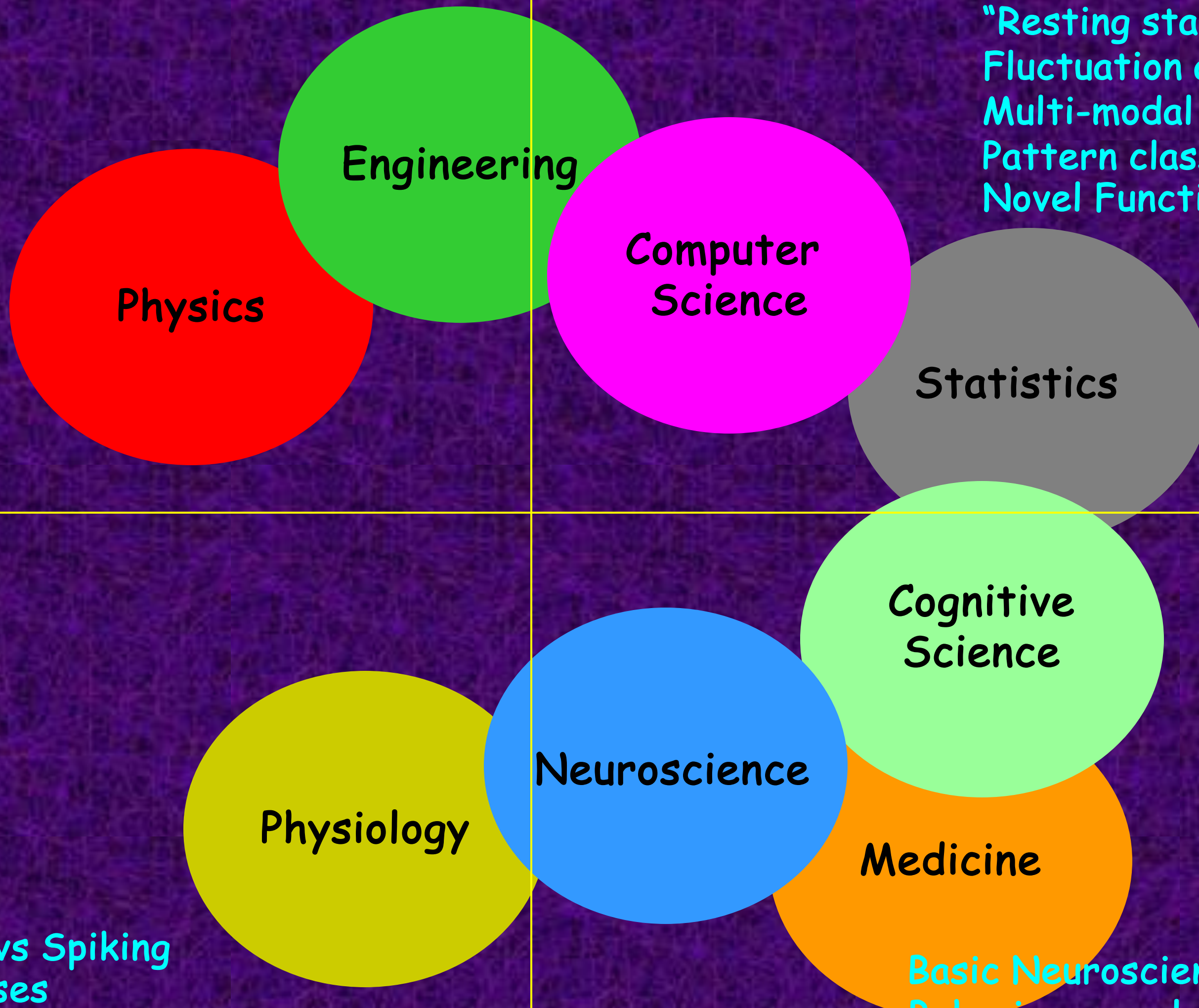

Post undershoot
Pre undershoot
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Applications

Current Uses of fMRI

Understanding normal brain organization and changes

-networks involved with specific tasks (low to high level processing)
-changes over time (seconds to years)
-correlates of behavior (response accuracy, performance changes...)

Clinical research

-correlates of specifically activated networks to clinical populations
-presurgical mapping
-epileptic foci mapping
-drug effects

Potential uses of fMRI

Complementary use for clinical diagnosis

-utilization of clinical research results

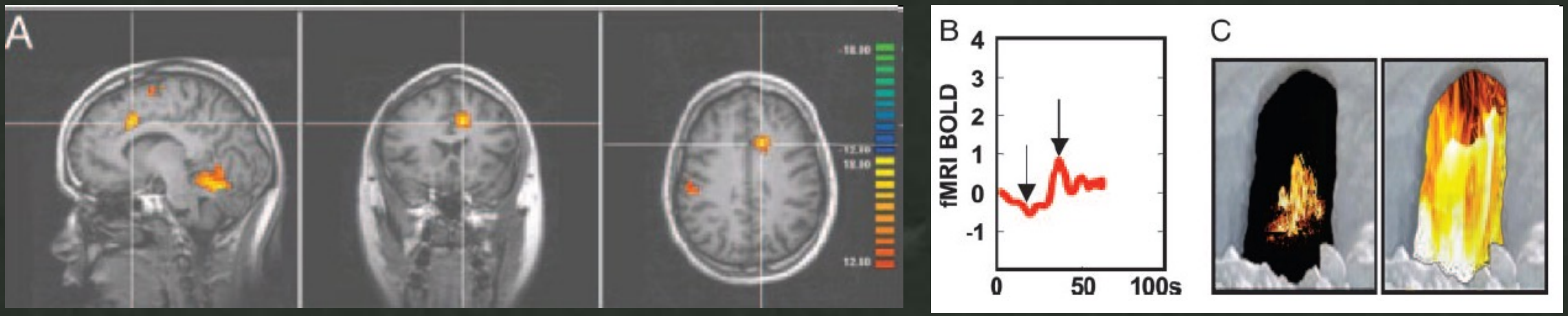
Clinical treatment and assessment

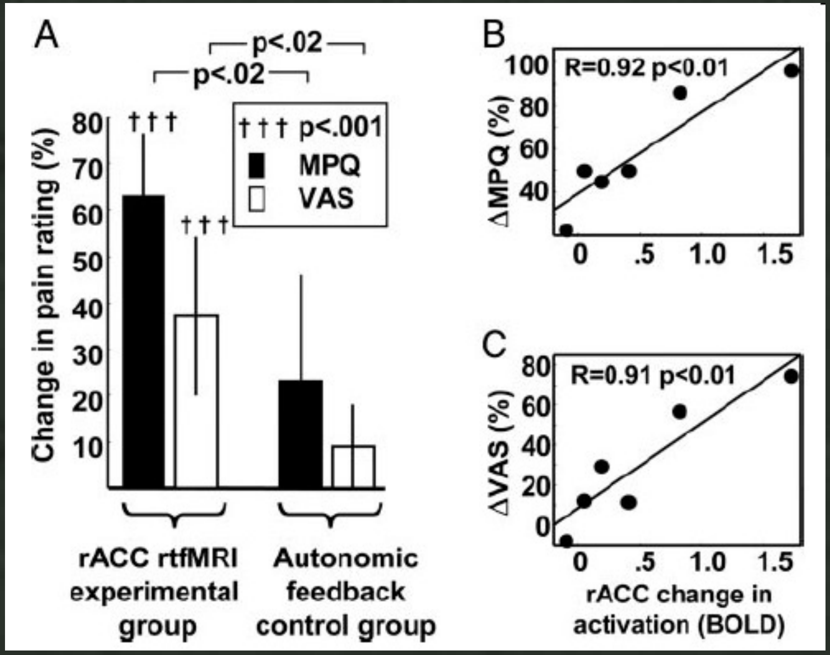
-drug effects, therapy, rehabilitation, biofeedback

Non clinical uses

-complementary use with behavioral results
-lie detection
-prediction of behavior tendencies (many contexts)
-brain/computer interface

Real time fMRI feedback to reduce chronic pain





Control over brain activation and pain learned by using real-time functional MRI, R. C. deCharms, et al. PNAS, 102; 18626-18631 (2005)

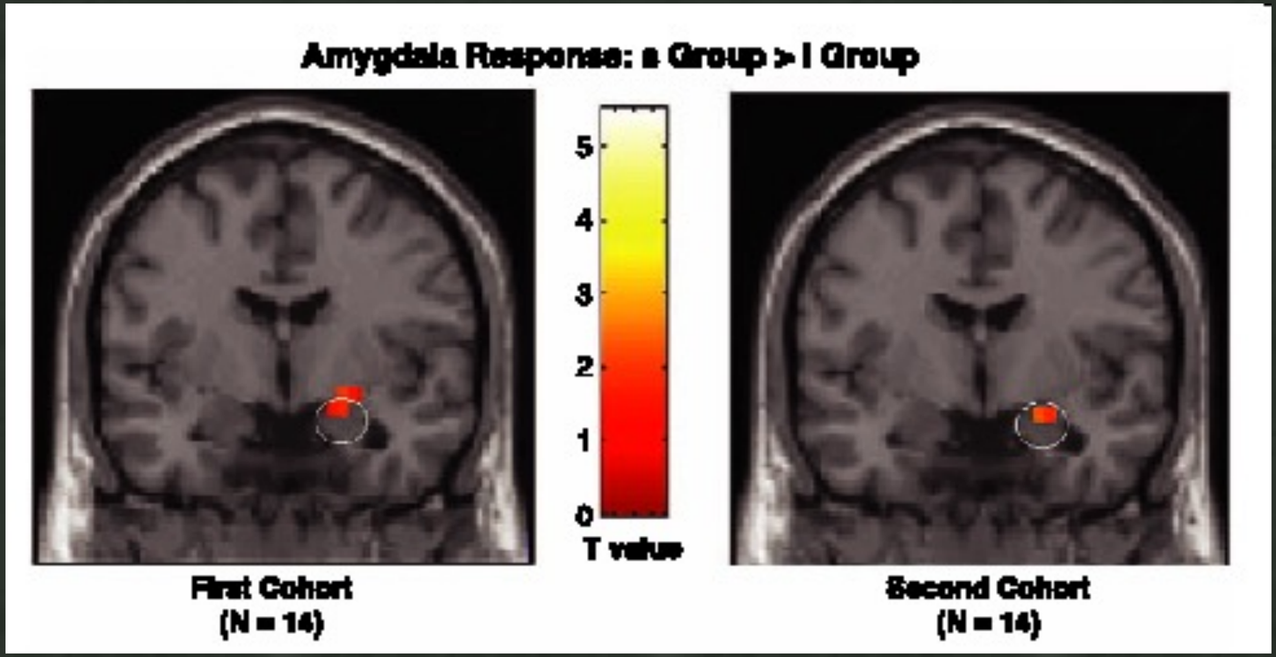
Applications

Clinical Applications

Comparison of two groups of *normal* individuals with differences in the Serotonin Transporter Gene

Serotonin Transporter Genetic Variation and the Response of the Human Amygdala

Ahmad R. Hariri,[1] Venkata S. Mattay,[1] Alessandro Tessitore,[1] Bhaskar Kolachana,[1] Francesco Fera,[1] David Goldman,[2] Michael F. Egan,[1] Daniel R. Weinberger[1*]



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