Functional MRI in Perspective

Peter A. Bandettini, Ph.D.

Section on Functional Imaging Methods

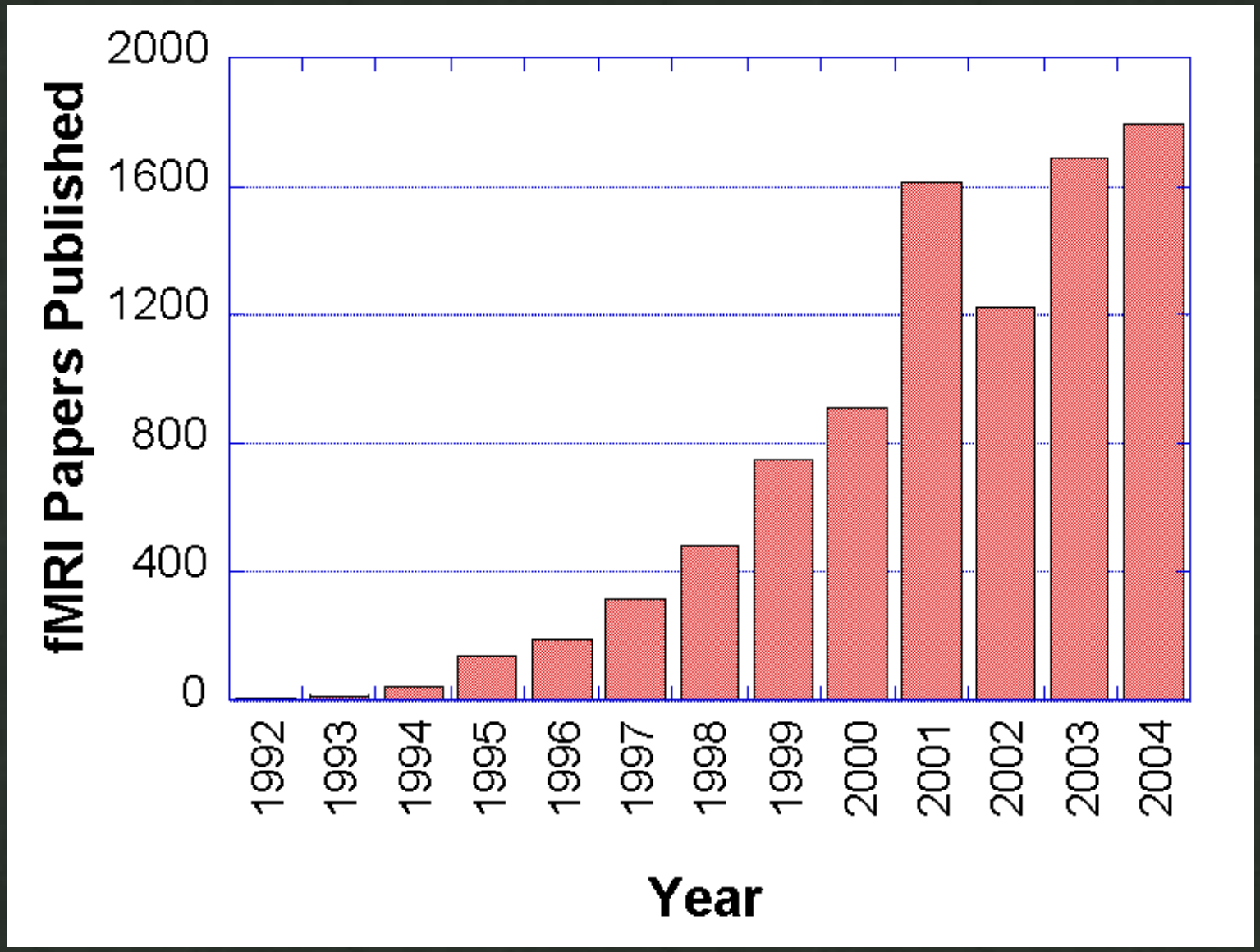
http://fim.nimh.nih.gov

Laboratory of Brain and Cognition

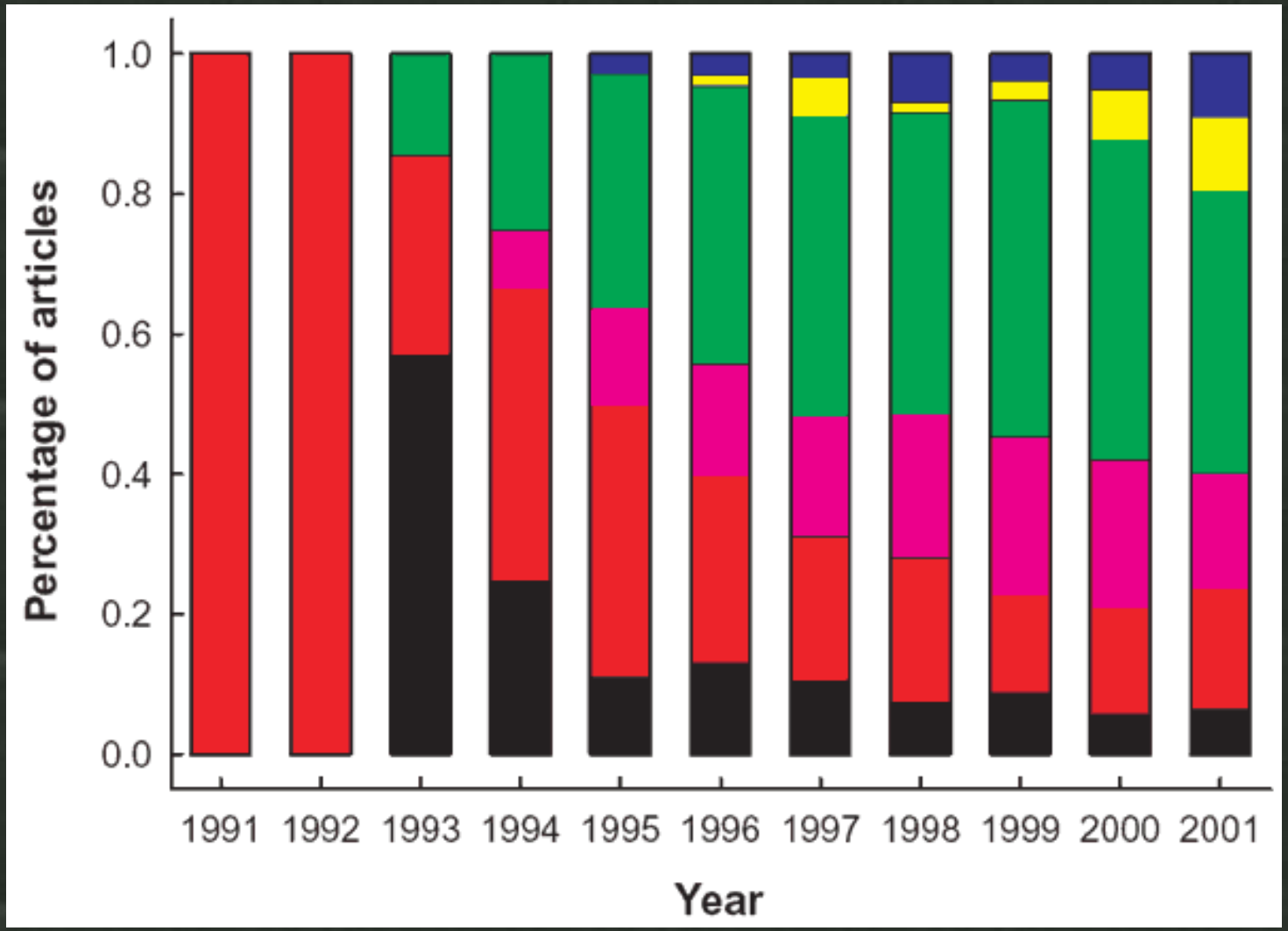
&

Functional MRI Facility

http://fmrif.nimh.nih.gov

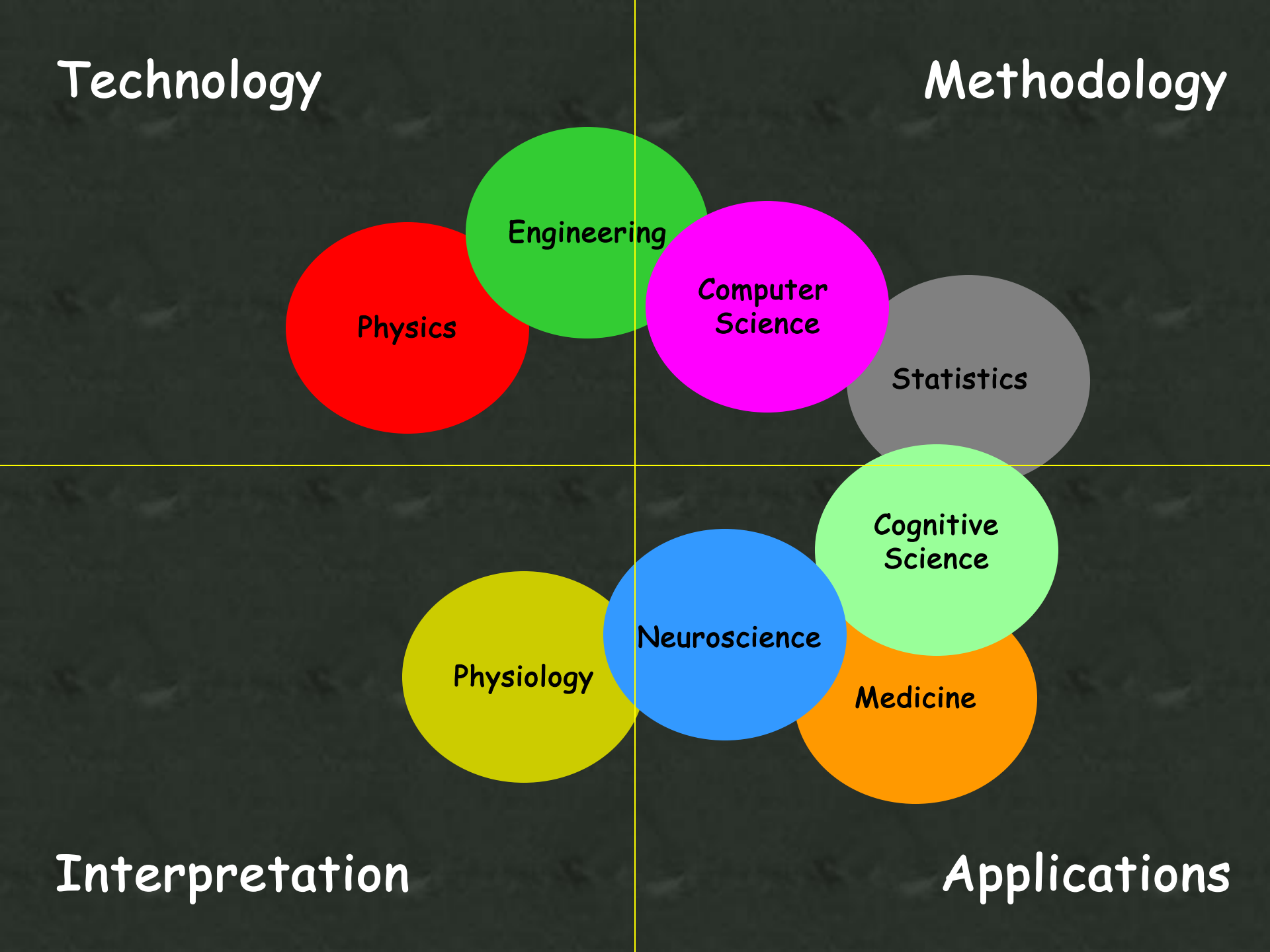


"fMRI" or "functional MRI"



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


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

Trends

(that I find interesting)

Technology

more coils
higher field strength
parallel excitation/acquisition
higher resolution
perfusion imaging

Methodology

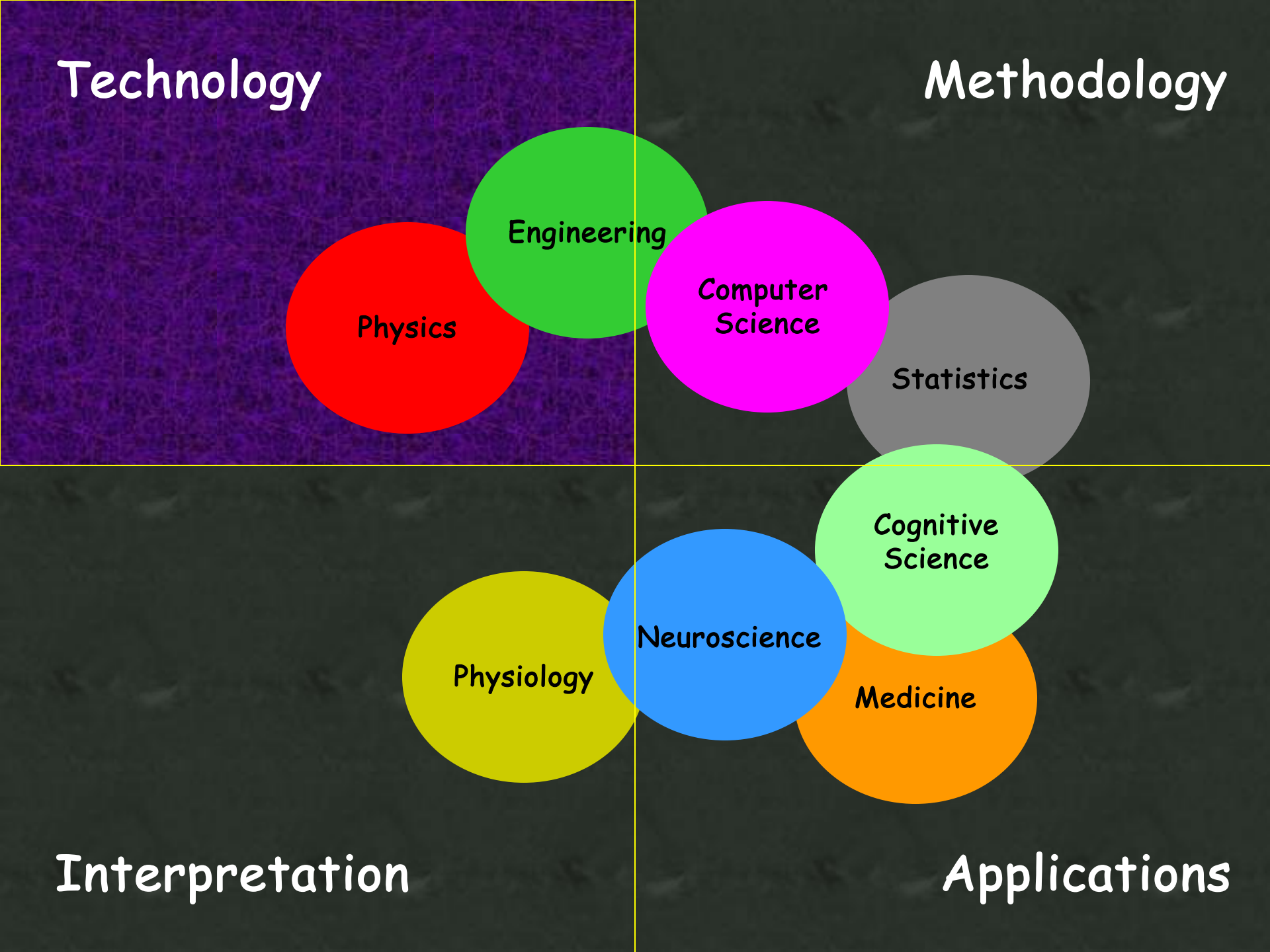
connectivity
free behavior
"resting state"
multi-modal integration
pattern classification
voxel based morphometry

Interpretation

fluctuations
dynamics
cross - modal comparison

Applications

decision making
genetics
social cognition
clinical
"brain-reading"


Technology
Methodology
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Interpretation
Applications

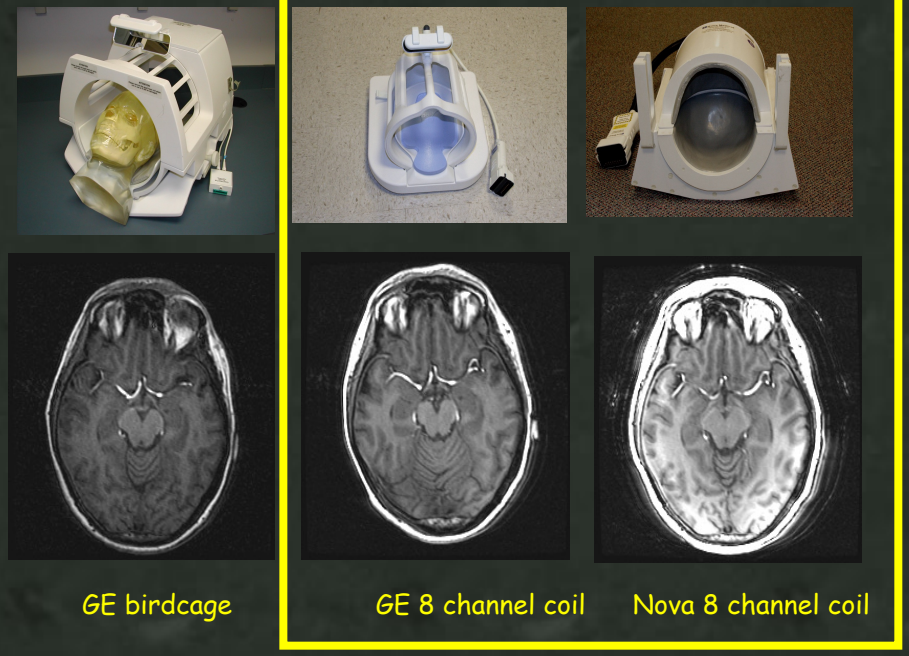
Technology

- Parallel Acquisition
- SENSE Imaging
- High Fields

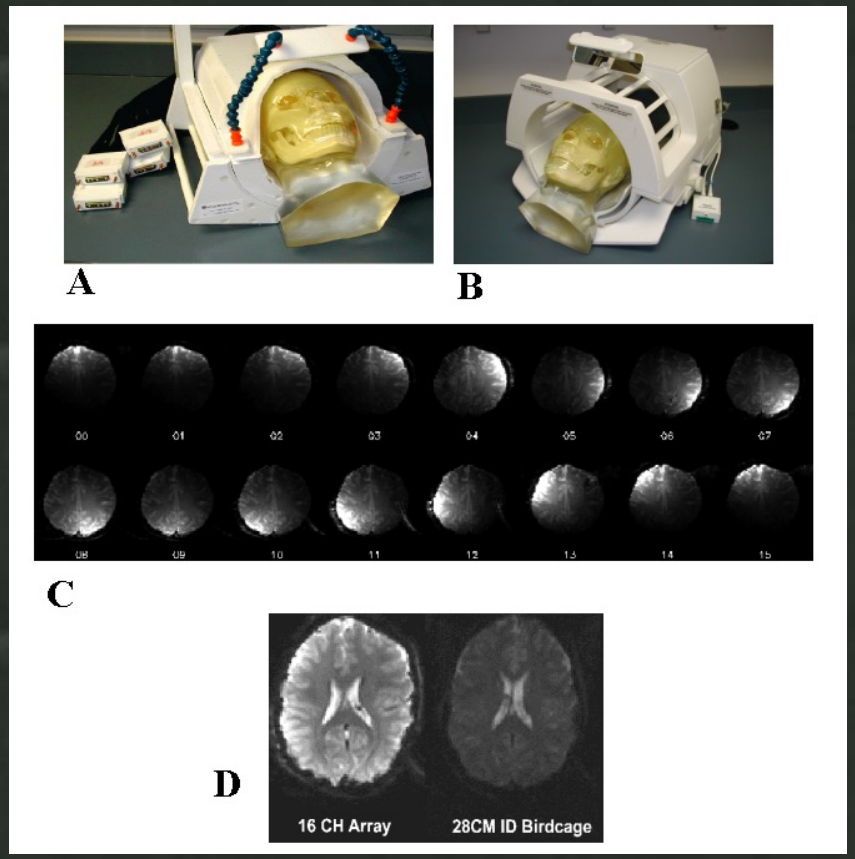
Technology

Parallel Acquisition

8 channel parallel receiver coil

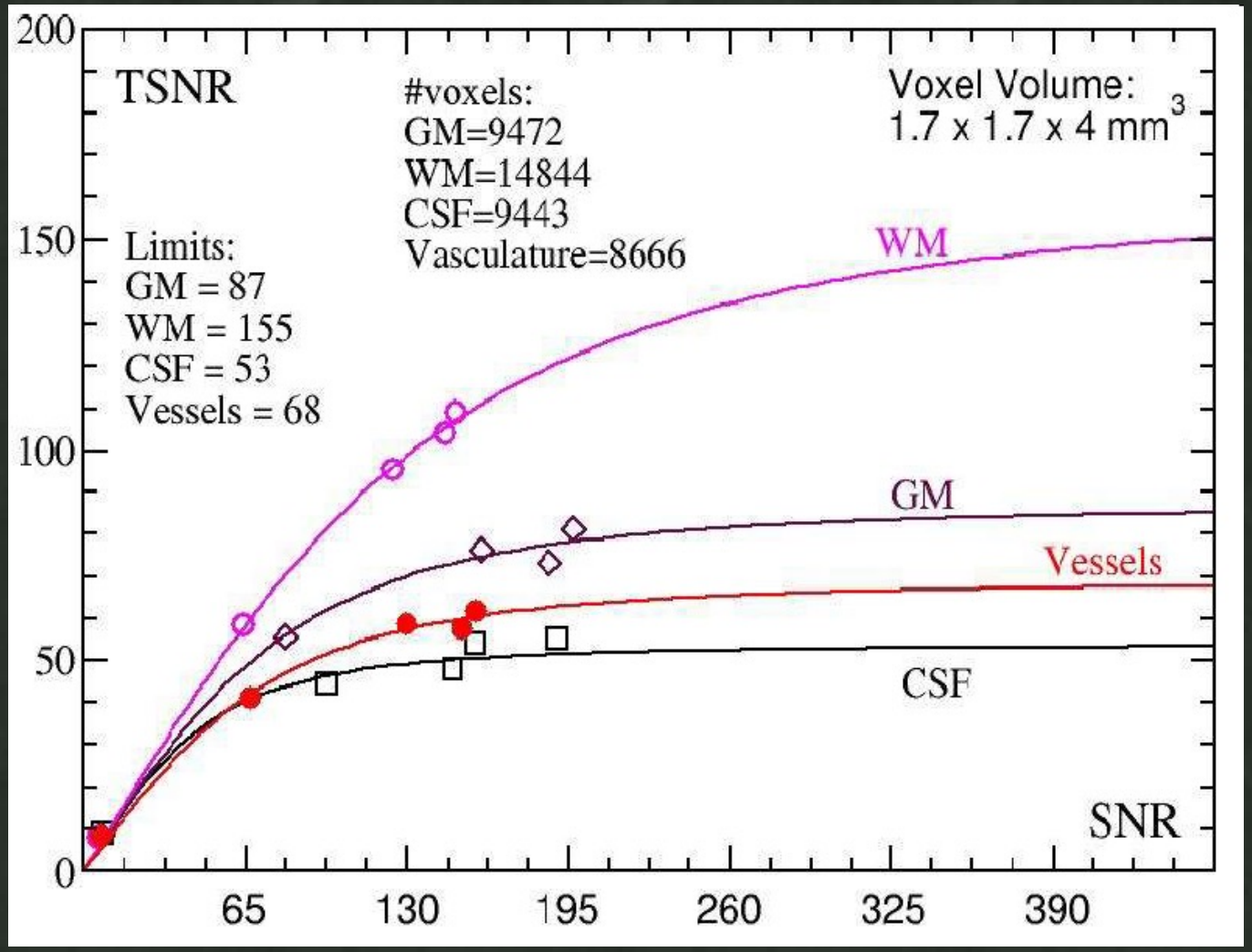


16 channel parallel receiver coil



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

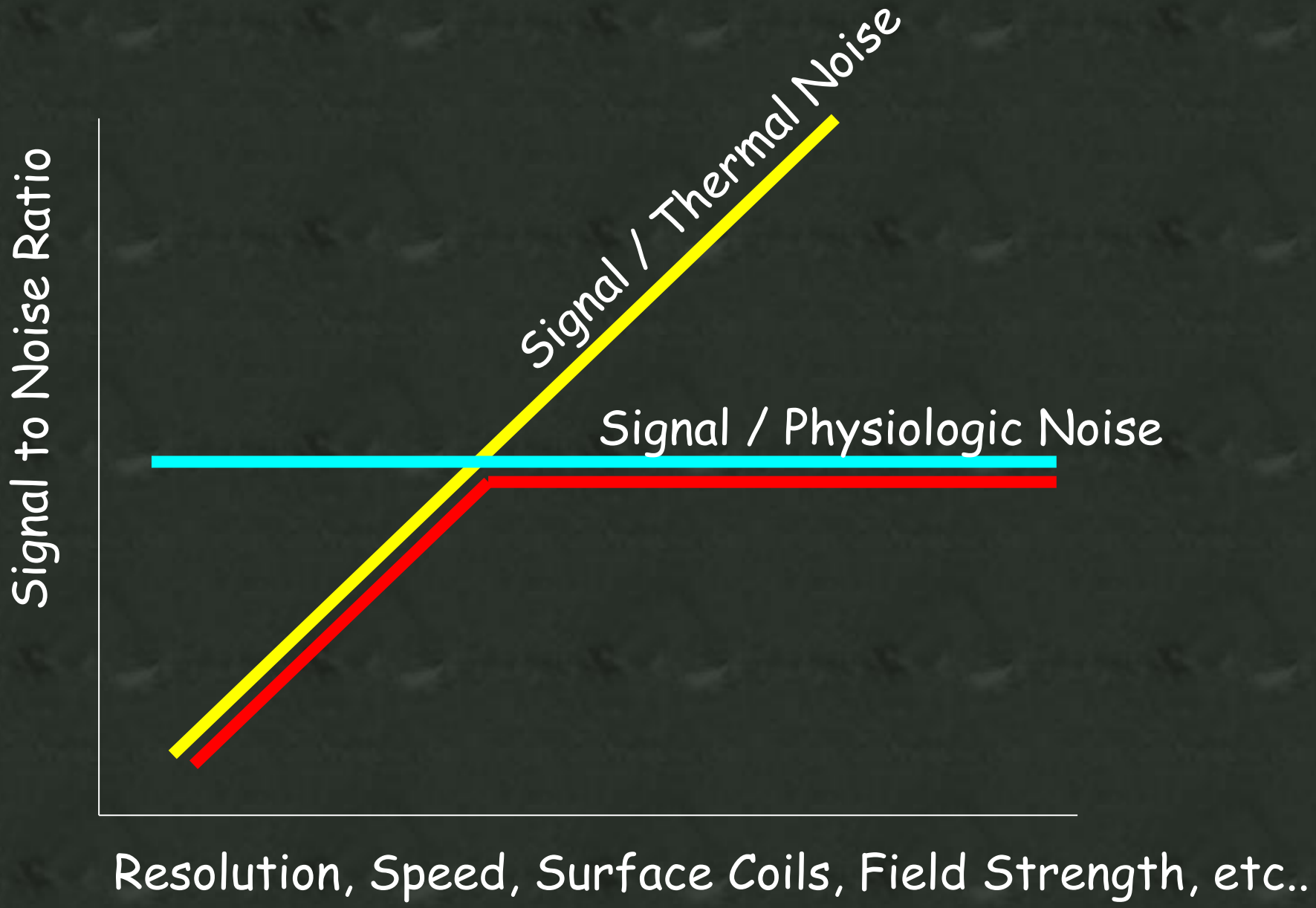
Parallel Acquisition



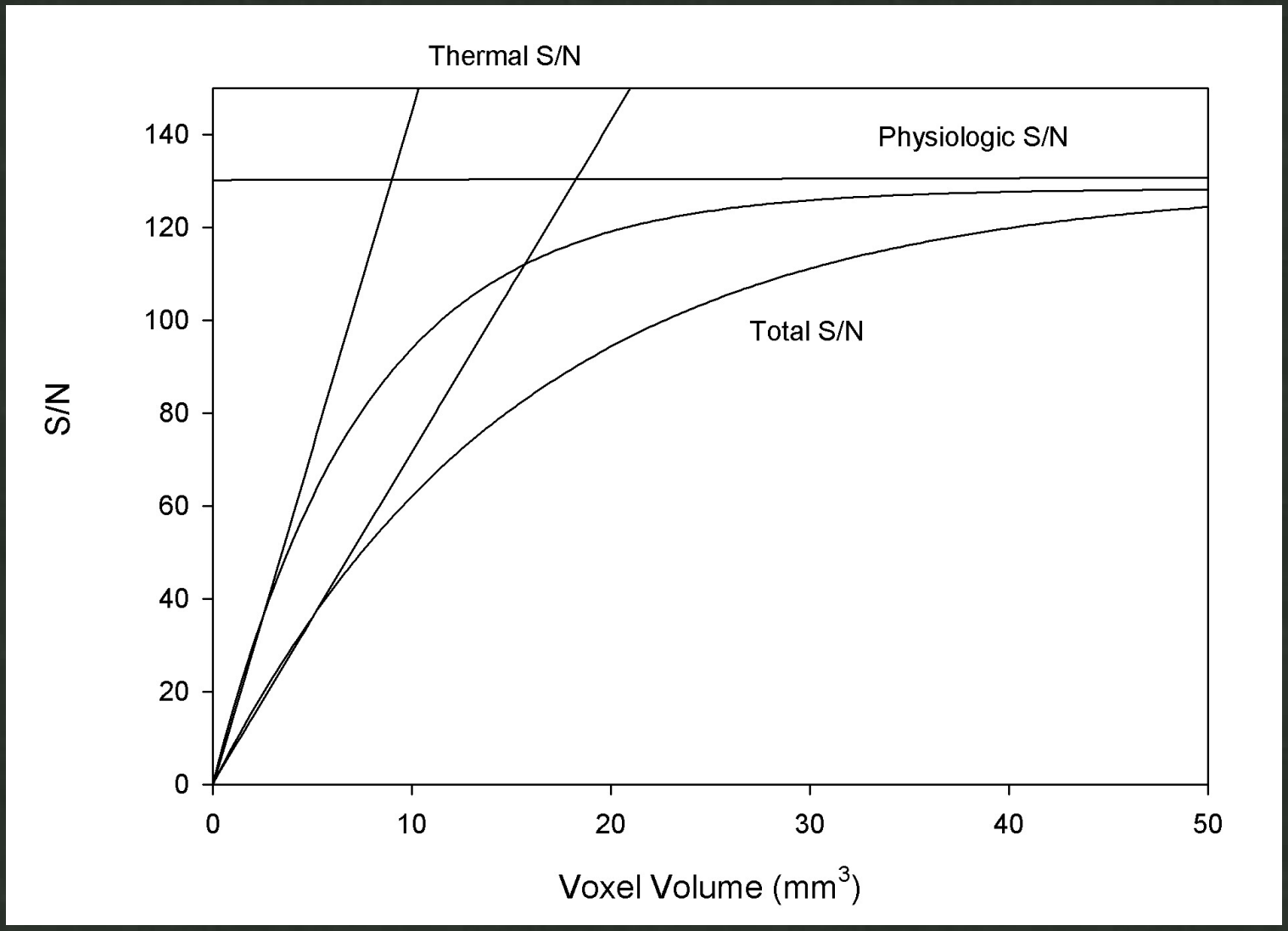
J. Bodurka

Technology

Parallel Acquisition

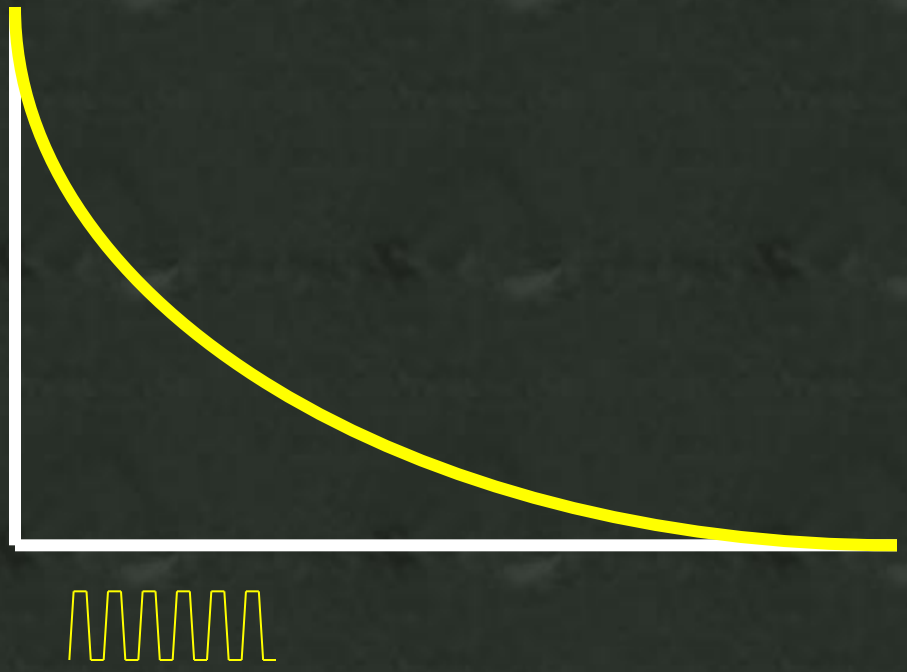


Simulated gains in TNSR with doubling sensitivity

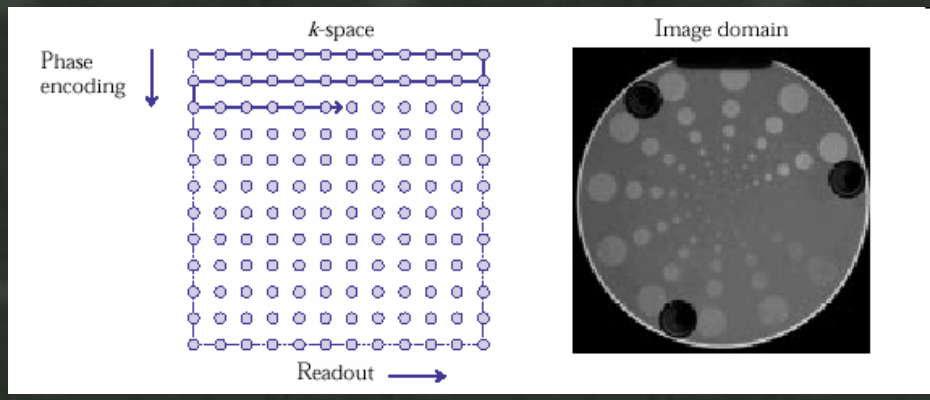


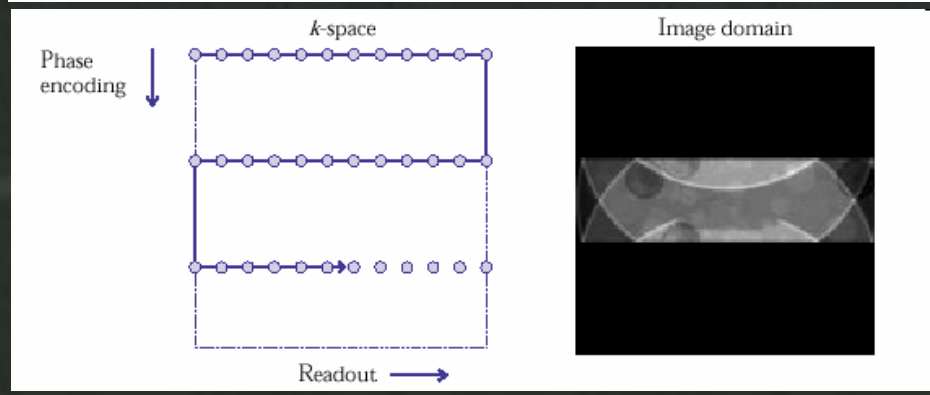
Technology

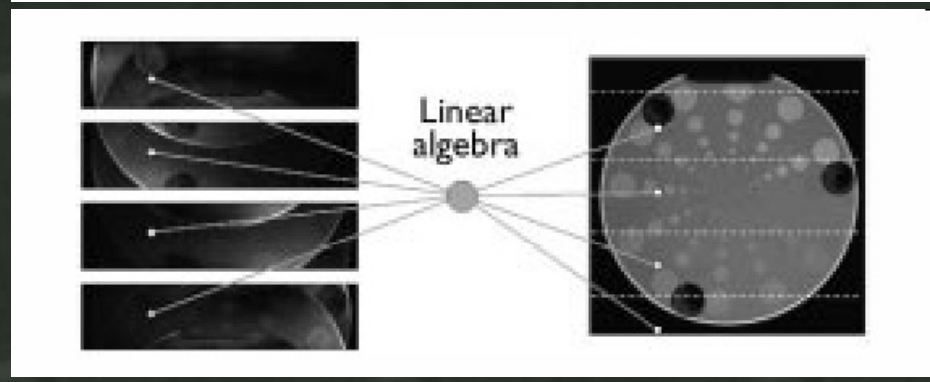
SENSE Imaging



≈ 5 to 30 ms







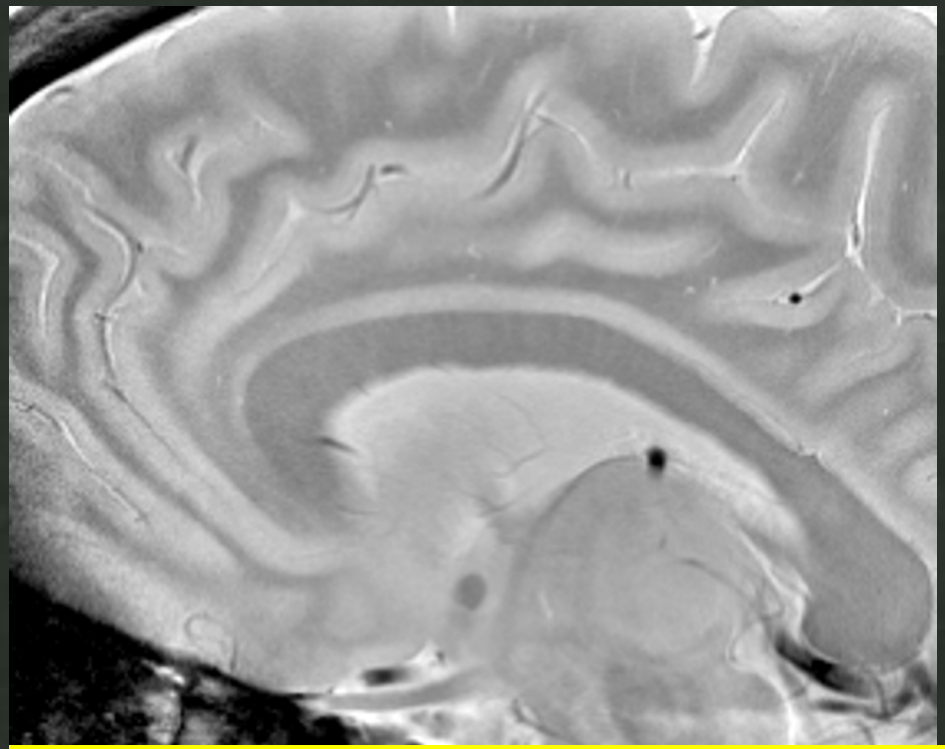
Pruessmann, et al.

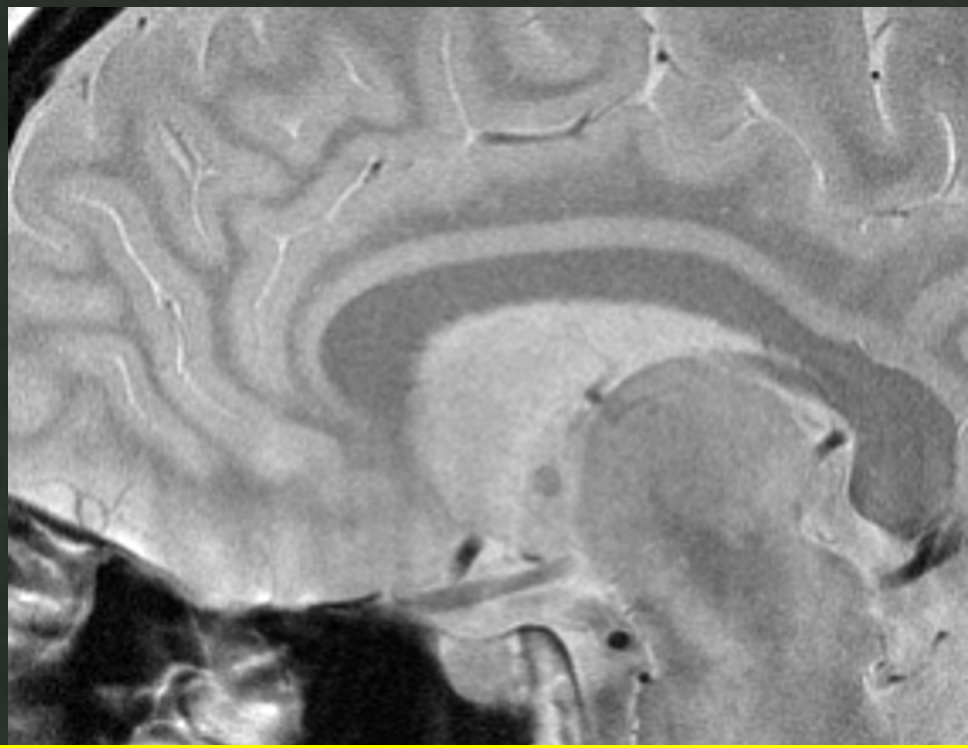
SENSE Imaging

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

7T head coil

3T head coil



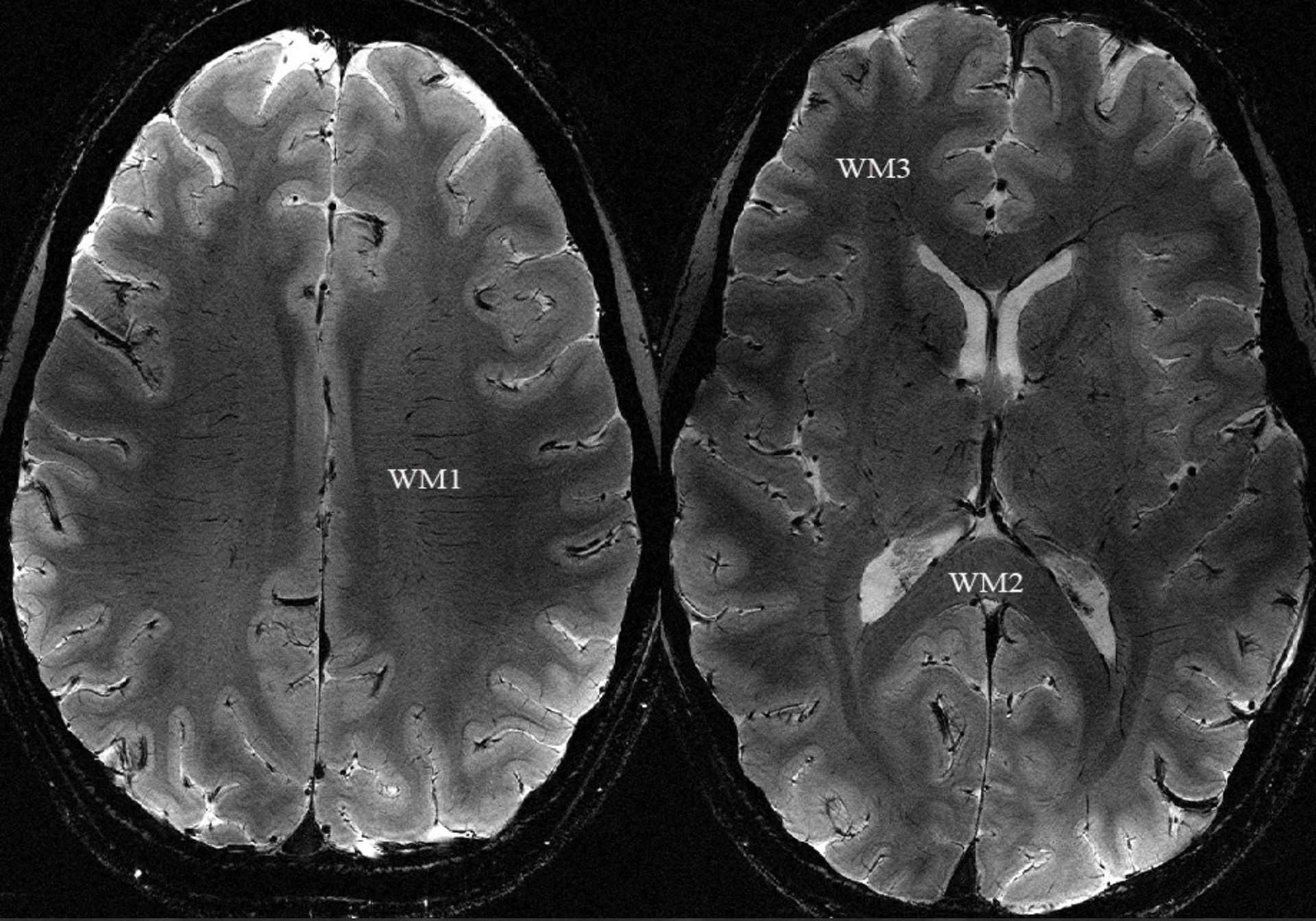


TSE, 11 echoes, 7 min exam, 20cm FOV, 512x512 (0.4mm x 0.4mm), 3mm thick slices.

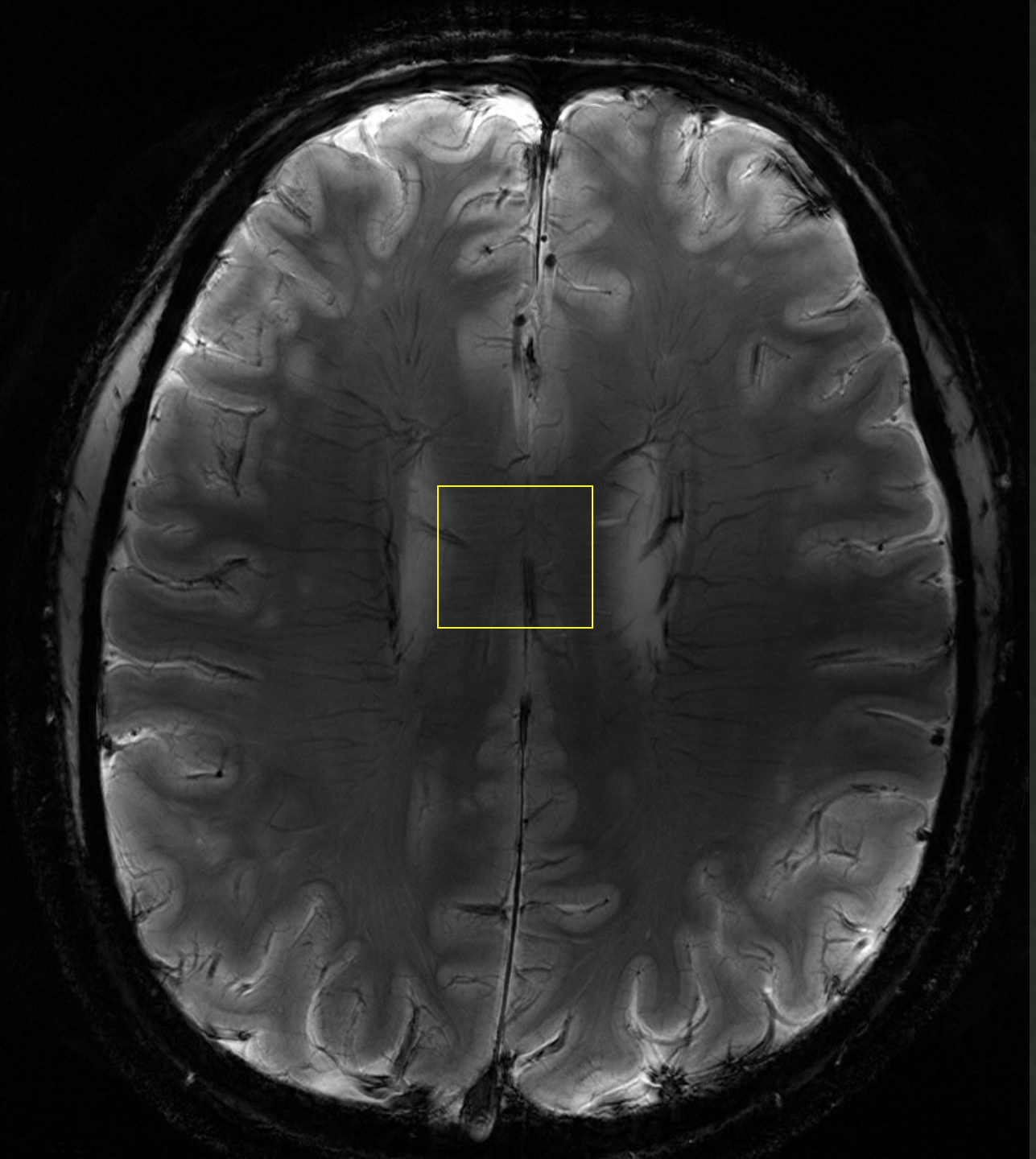
7T
white matter SNR =65
Gray matter SNR = 76

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

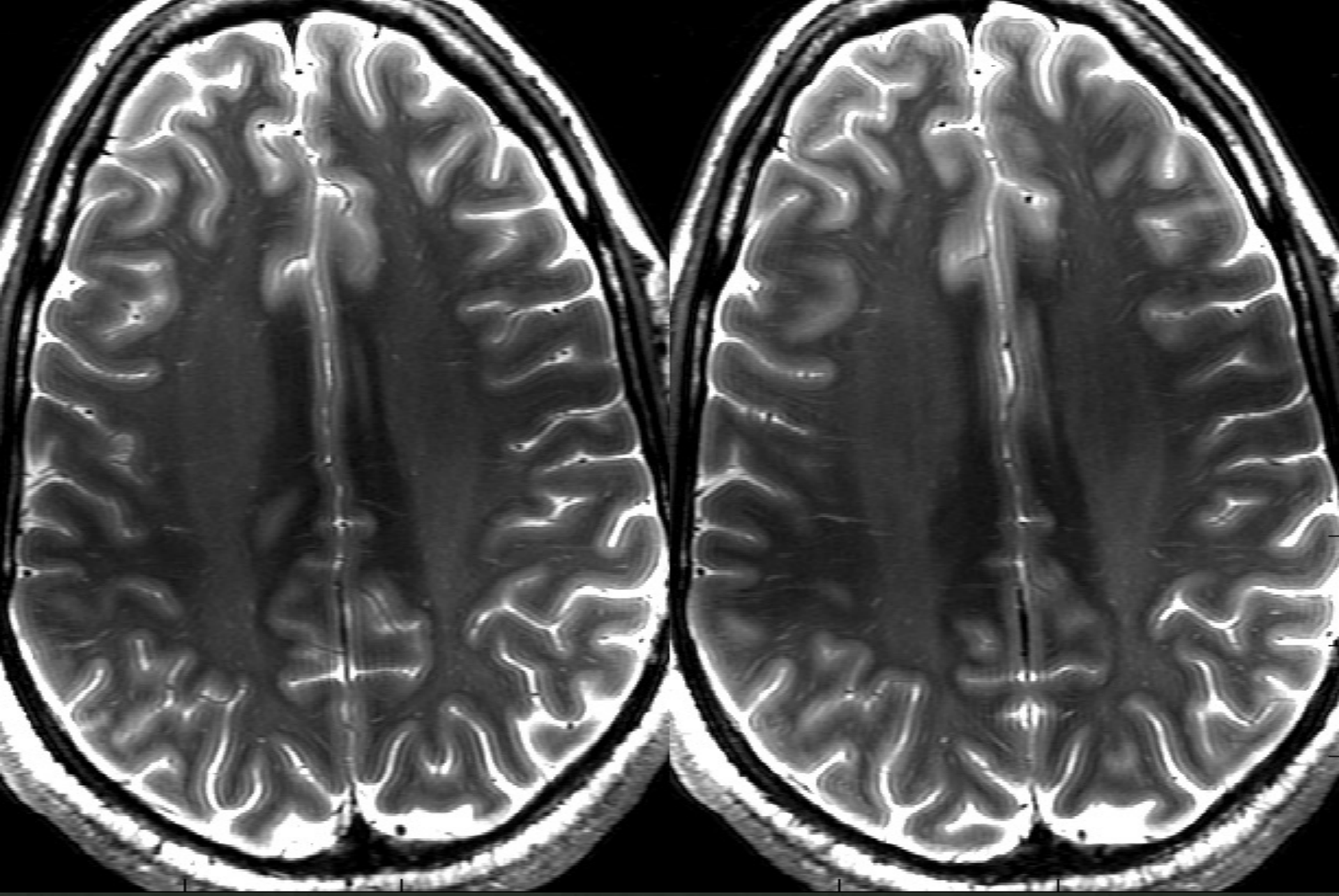
Courtesy Larry Wald



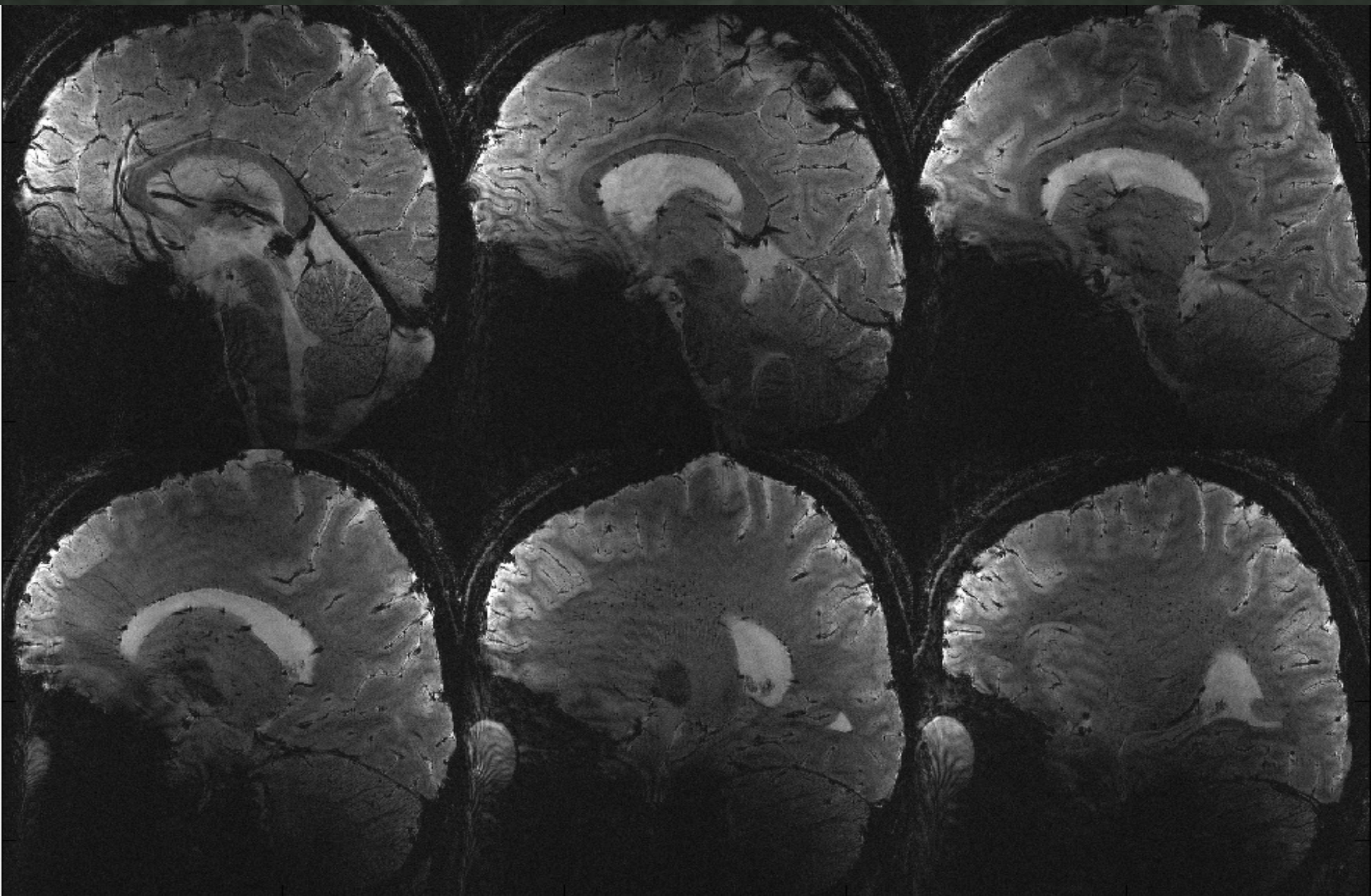
Different fiber bundles depict different intensities

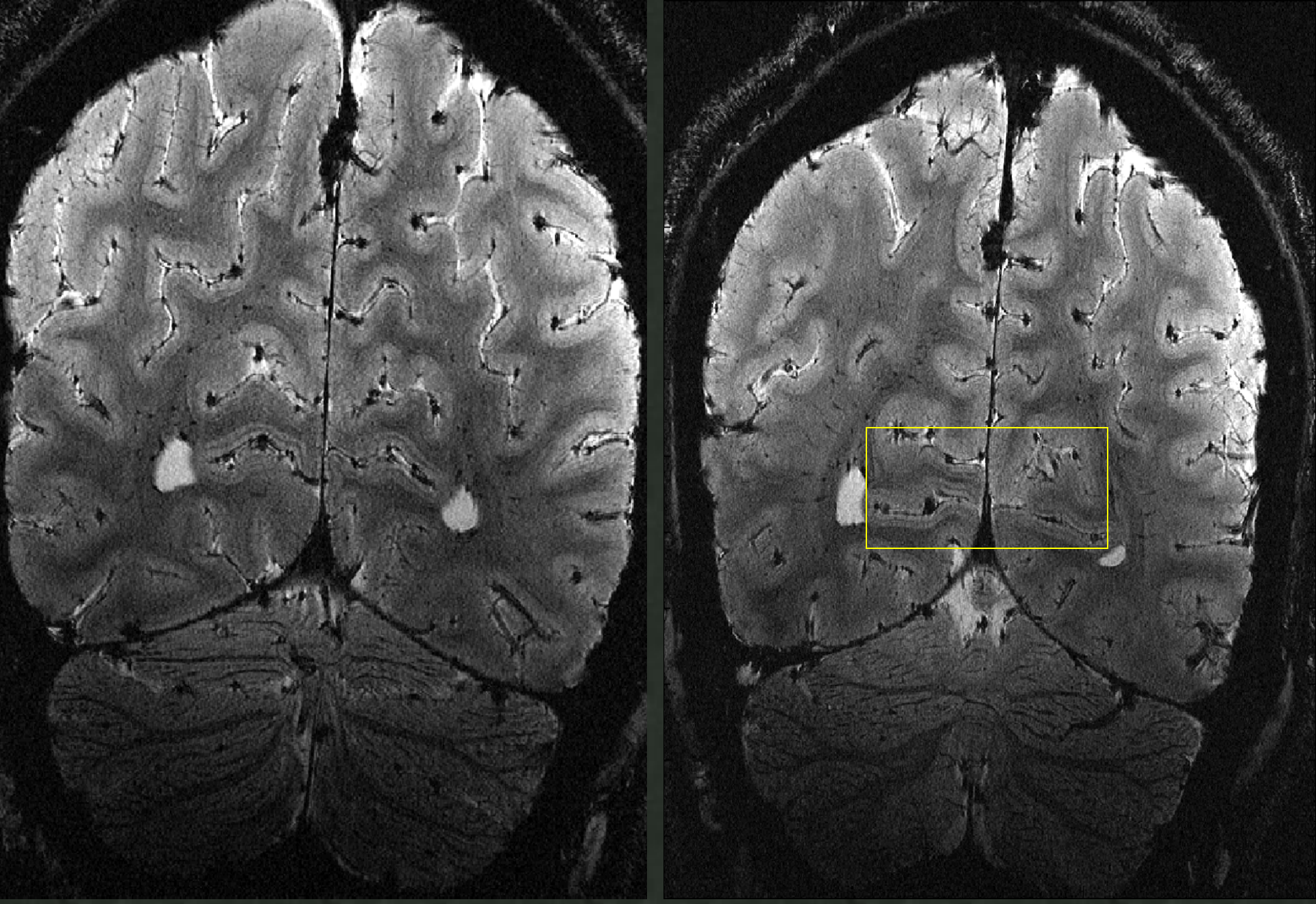


fiber bundles?



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

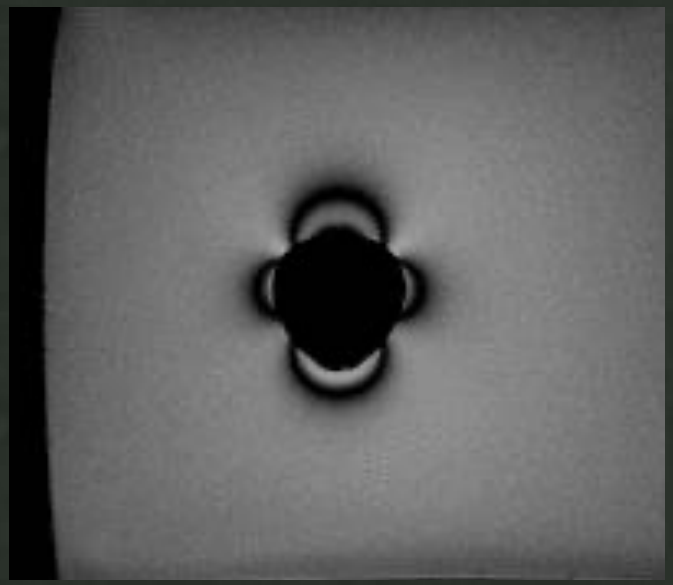




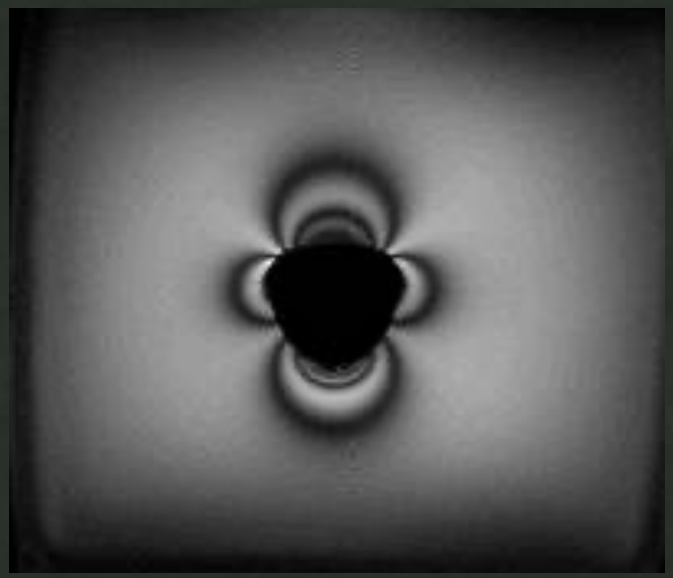
Layered structure i
n the visual cortex

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

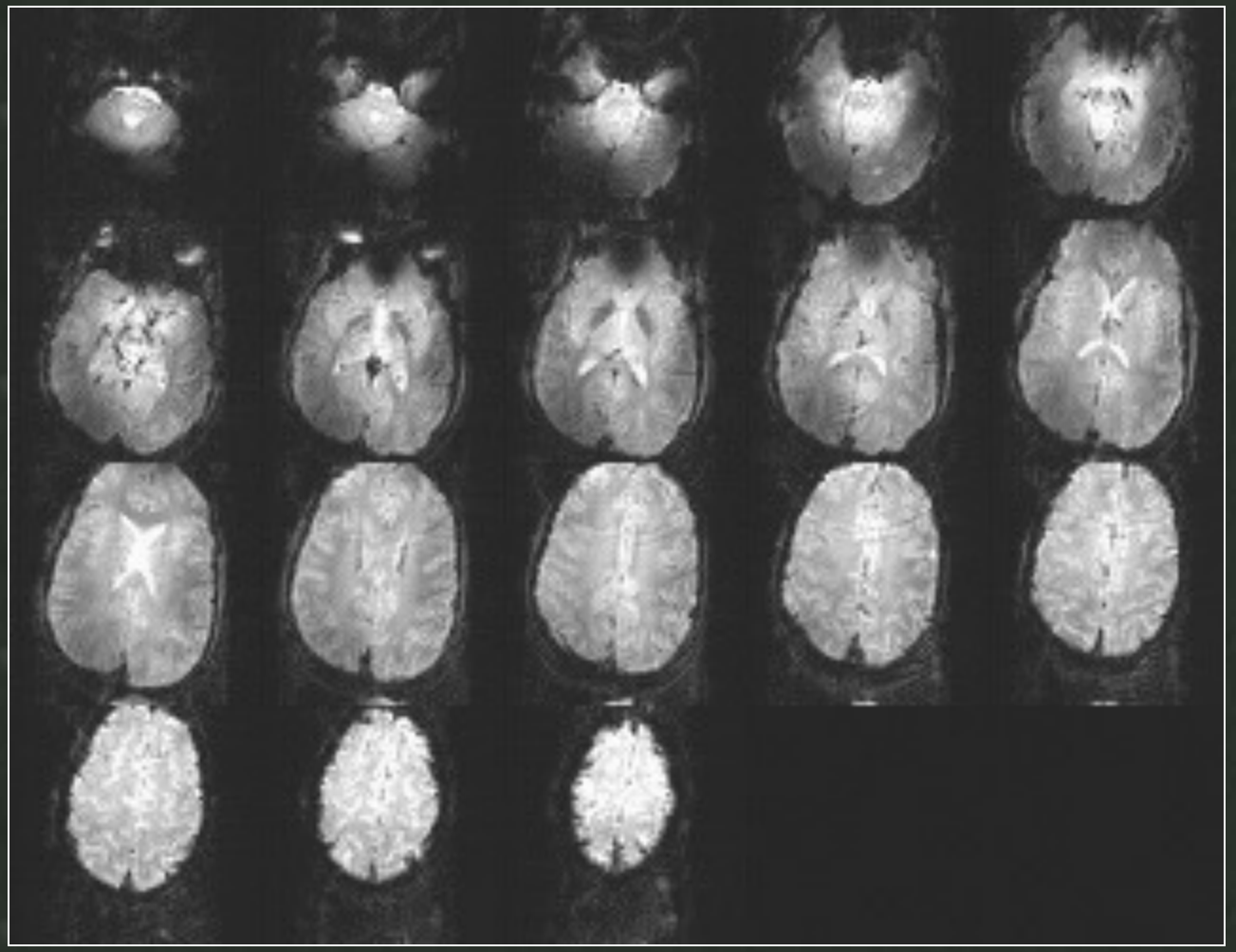


3T

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

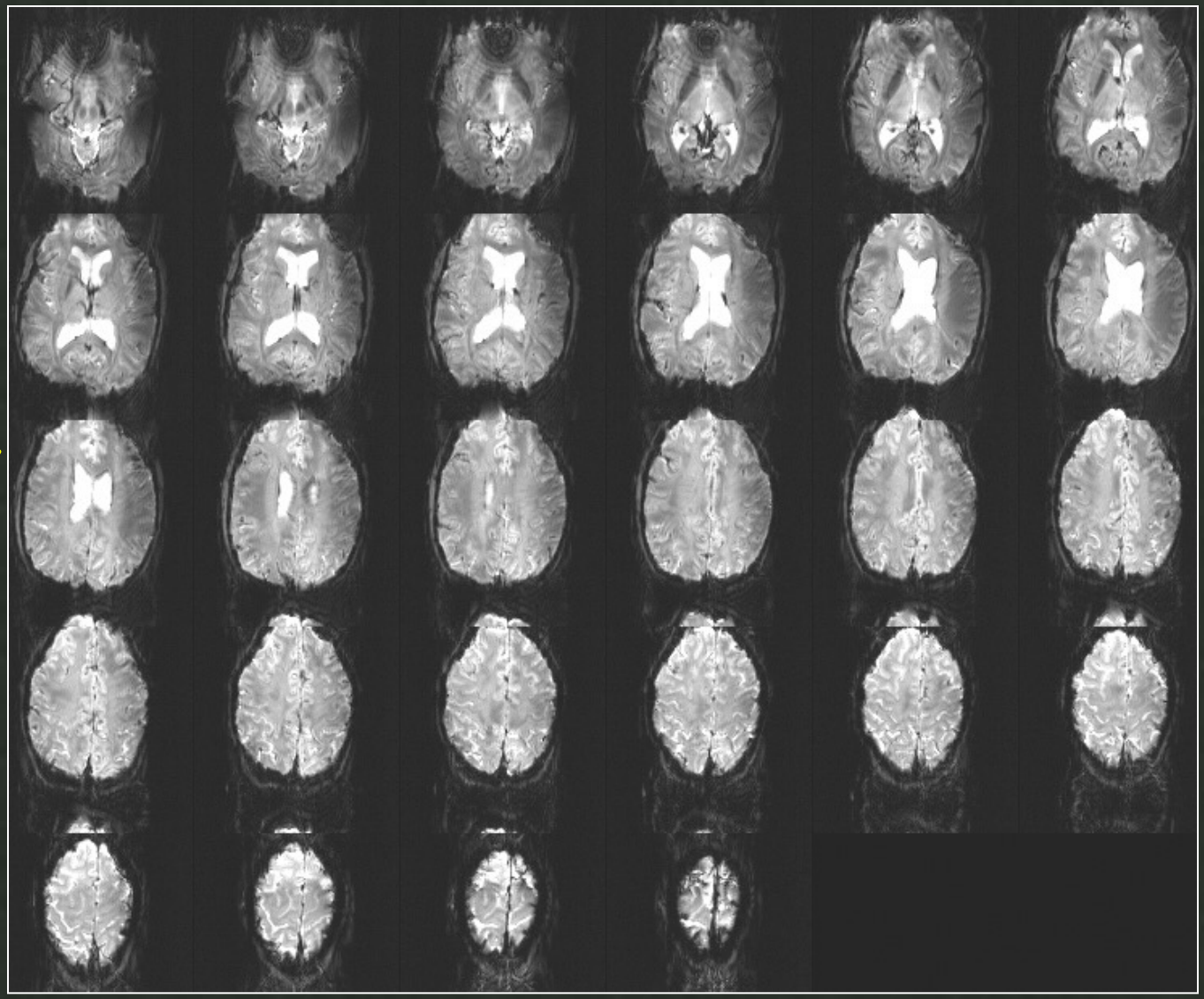
7T: Single Shot whole head EPI

1.5mm inplane

single shot EPI, 7T.

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

TE = 20ms



Courtesy Larry Wald

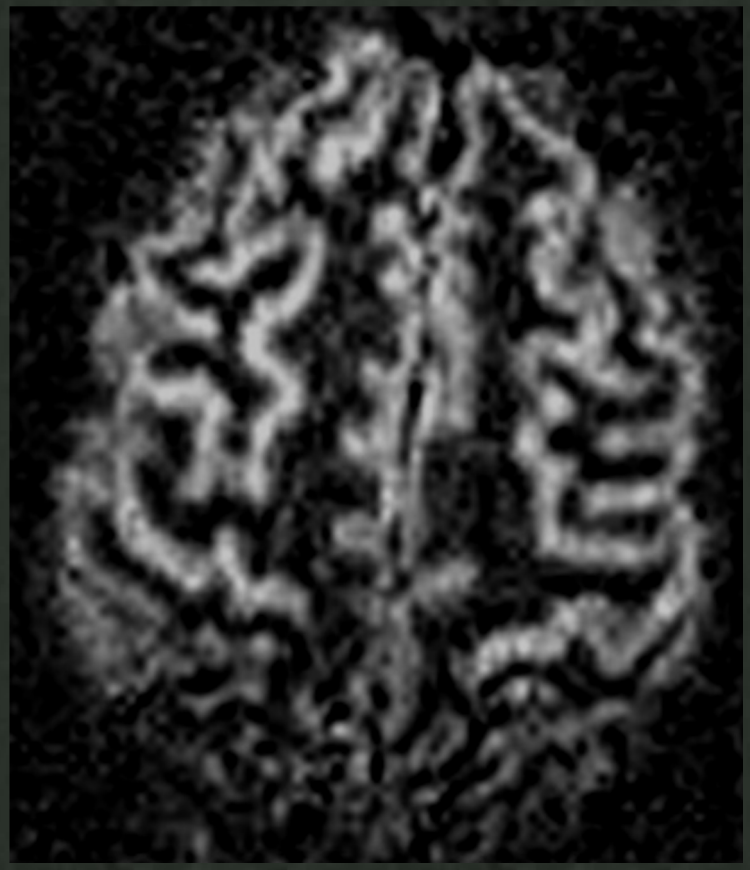
7T Blood flow and BOLD based fMRI

Longer T1 means better ASL…

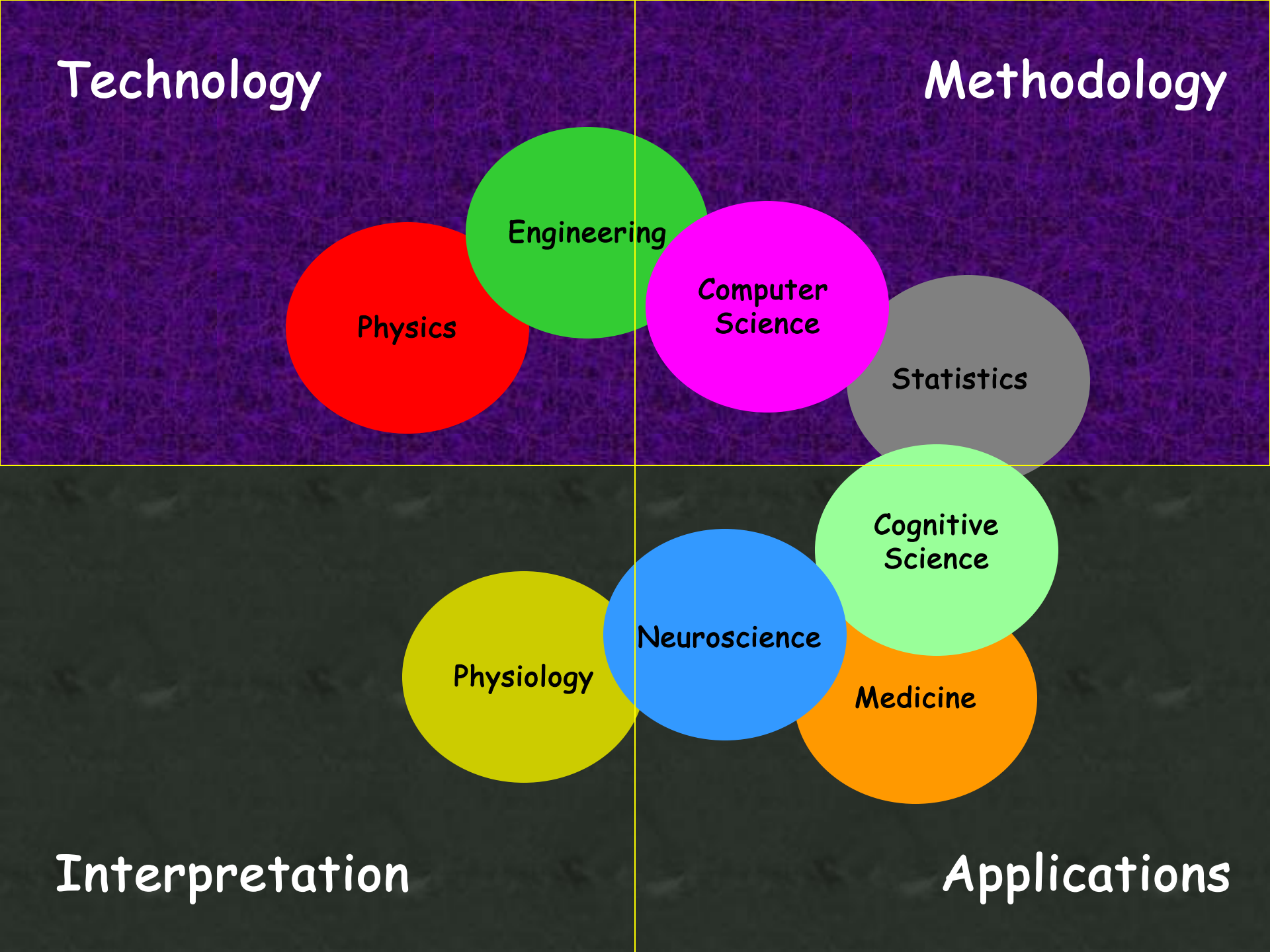
6 minute pulse Arterial Spin Labeling blood flow image

1.56mm x 1.56mm x 4mm

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



Courtesy Larry Wald


Technology
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Methodology

- New Contrasts
- Paradigm Designs
- Temporal Resolution
- Spatial Resolution
- Processing Methods

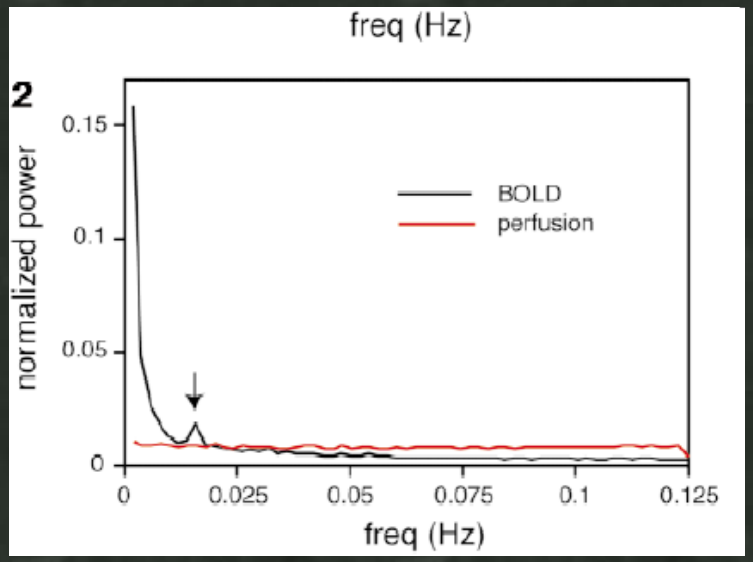
fMRI Contrast

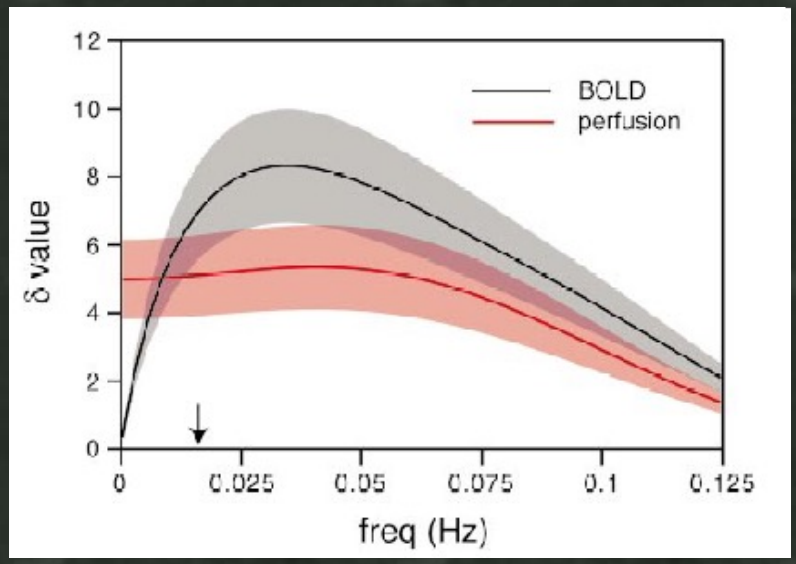
- Volume (gadolinium)
- BOLD
- Perfusion (ASL)
- $\Delta CMRO_2$
- ΔVolume (VASO)
- Neuronal Currents
- Diffusion coefficient
- Temperature

fMRI Contrast

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

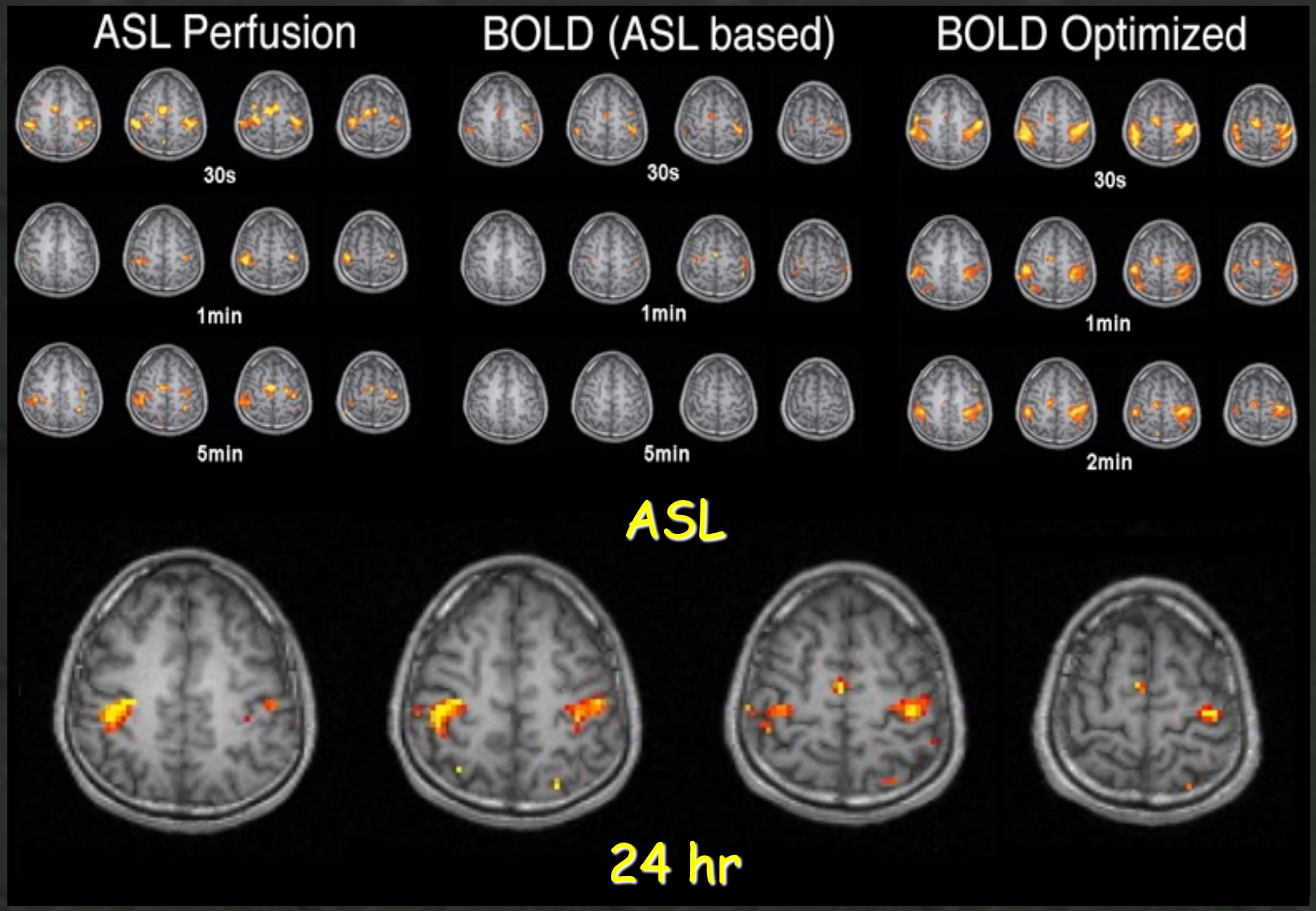
Better than BOLD for long duration activation…





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

Perfusion vs. BOLD: Low Task Frequency



Wang et al., 2002

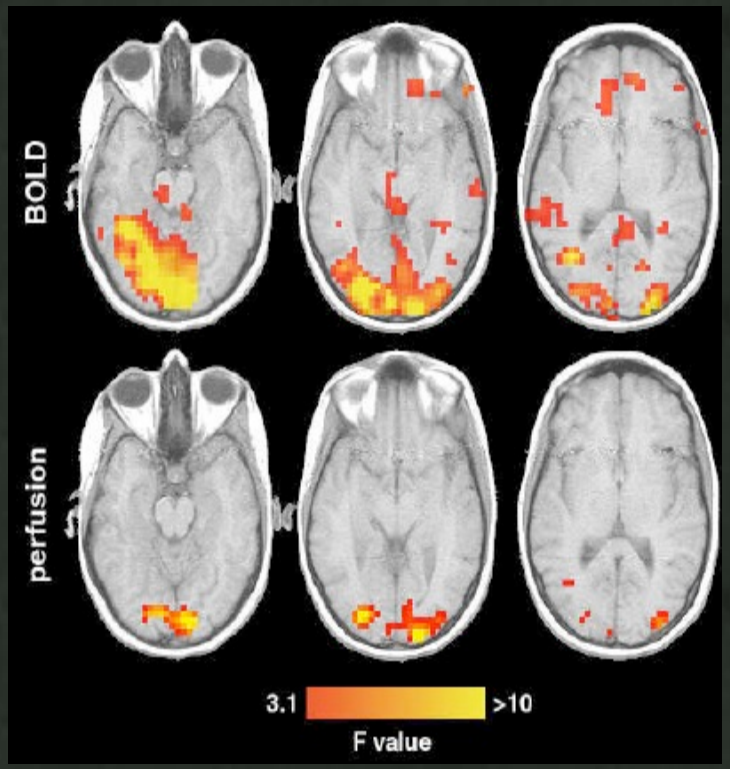
Methodology

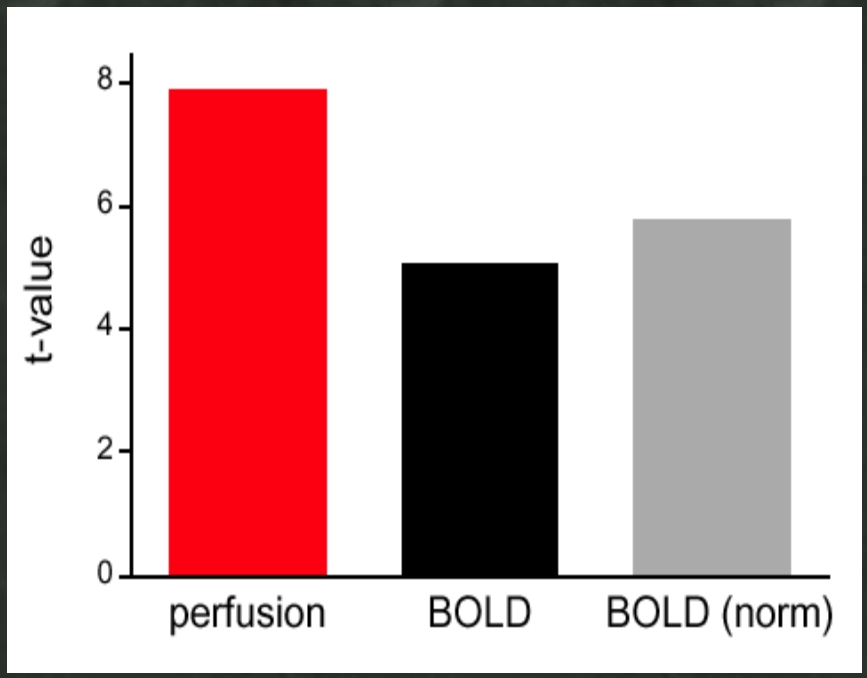
New Contrasts

Perfusion (ASL)

ASL Perfusion fMRI vs. BOLD

Improved Intersubject Variability vs. BOLD





Single Subject

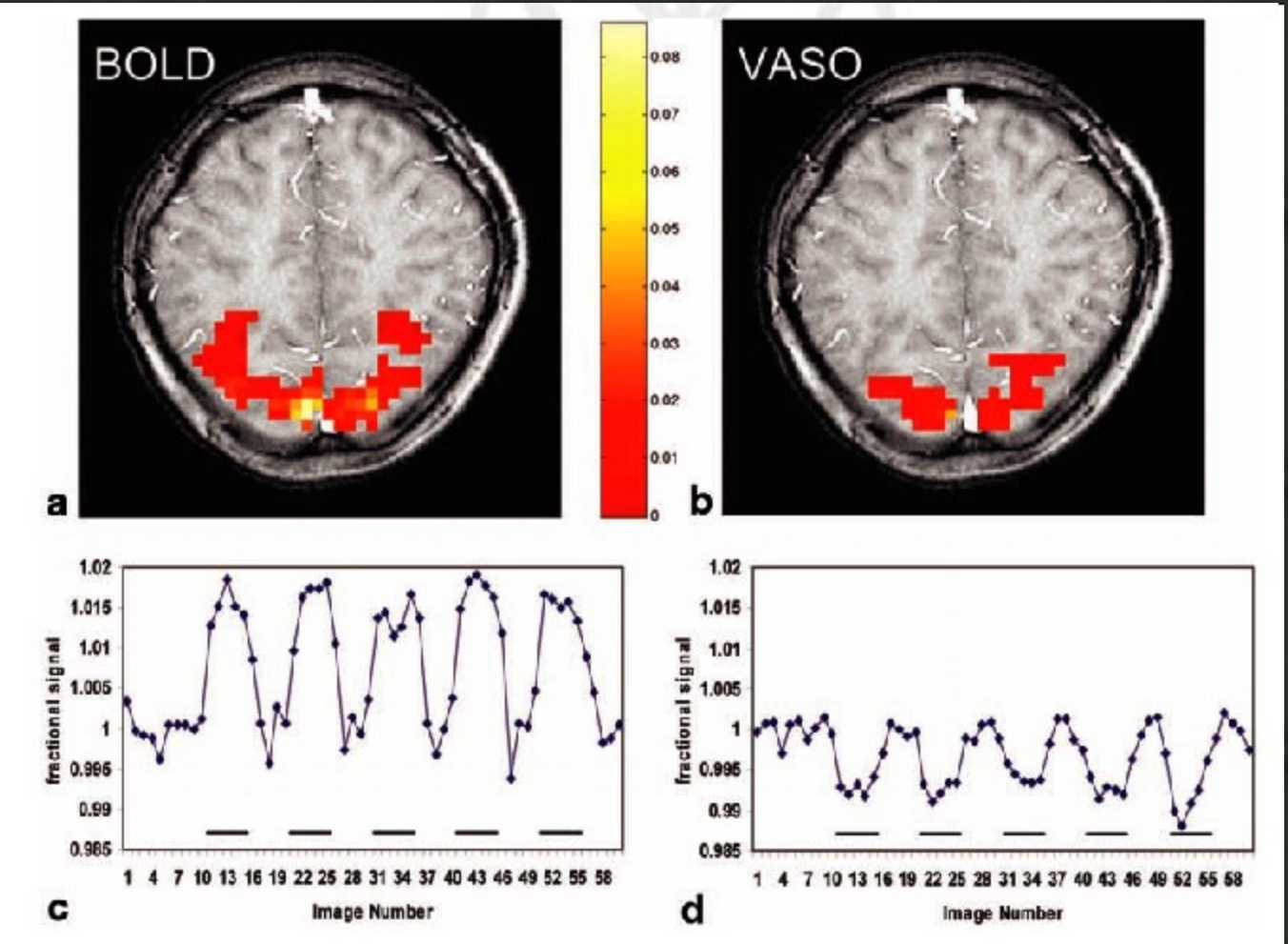
Group (Random Effects)

Aguirre et al., NeuroImage, in press

Methodology

New Contrasts

VASO

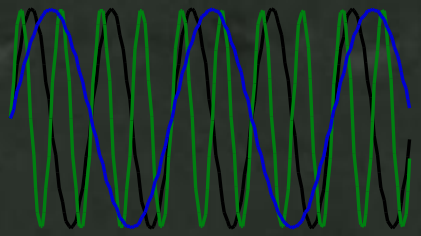


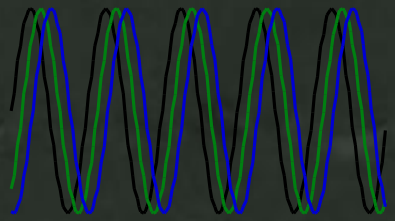
Lu et al, MRM 50 (2): 263-274 (2003)

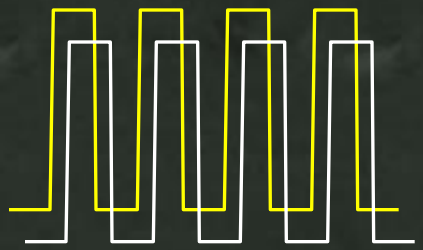
Methodology

Neuronal Activation Input Strategies

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



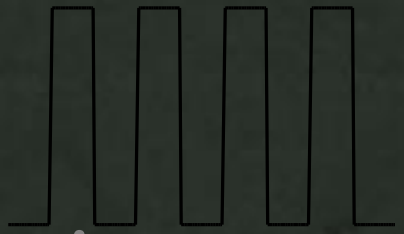




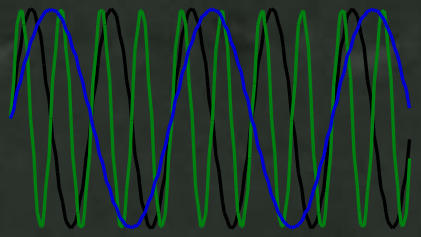
Methodology

Neuronal Activation Input Strategies

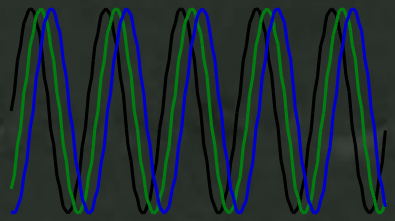
1. Block Design



2. Frequency Encoding

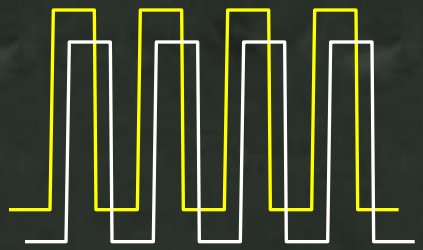


3. Phase Encoding



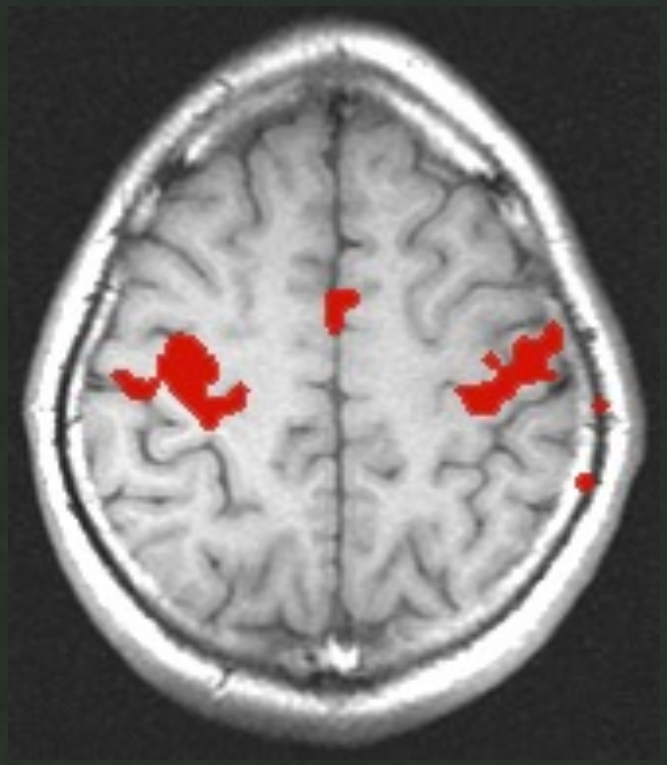
4. Event-Related

5. Orthogonal Block Design

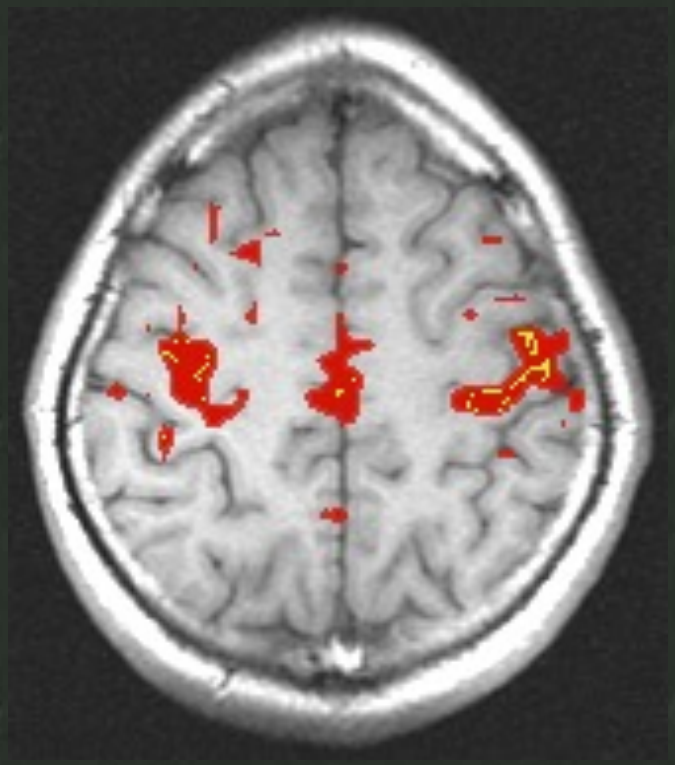


6. Free Behavior Design.

Resting State Correlations



Activation:
correlation with reference function



Rest:
seed voxel in motor cortex

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

Methodology

NAIS

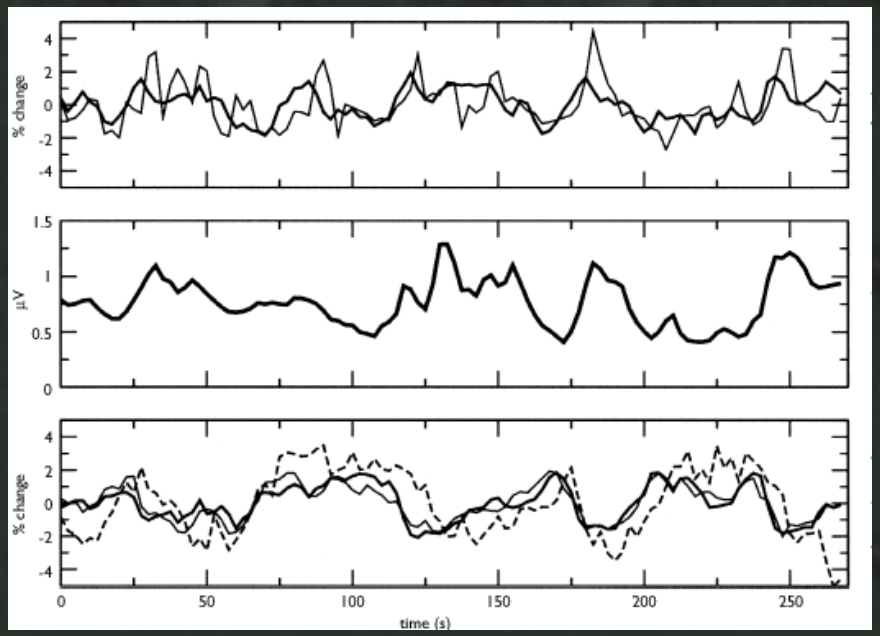
Free Behavior

BOLD correlated with 10 Hz power during "Rest"

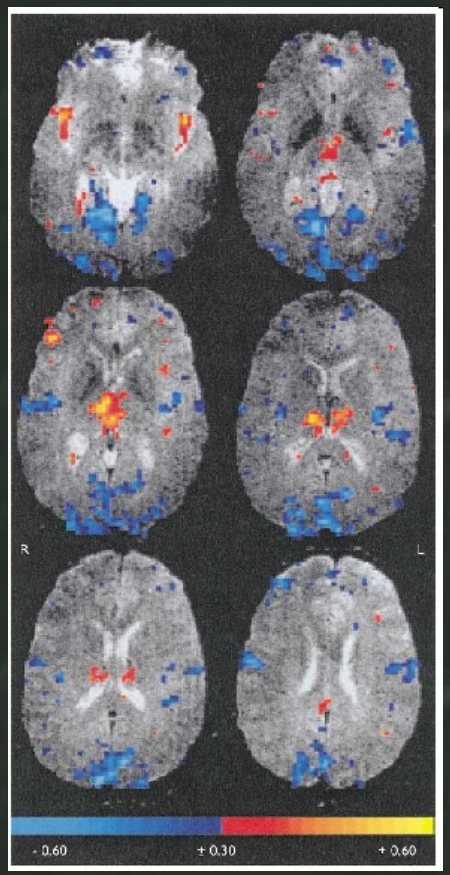
Positive

10 Hz power

Negative



Goldman, et al (2002), Neuroreport

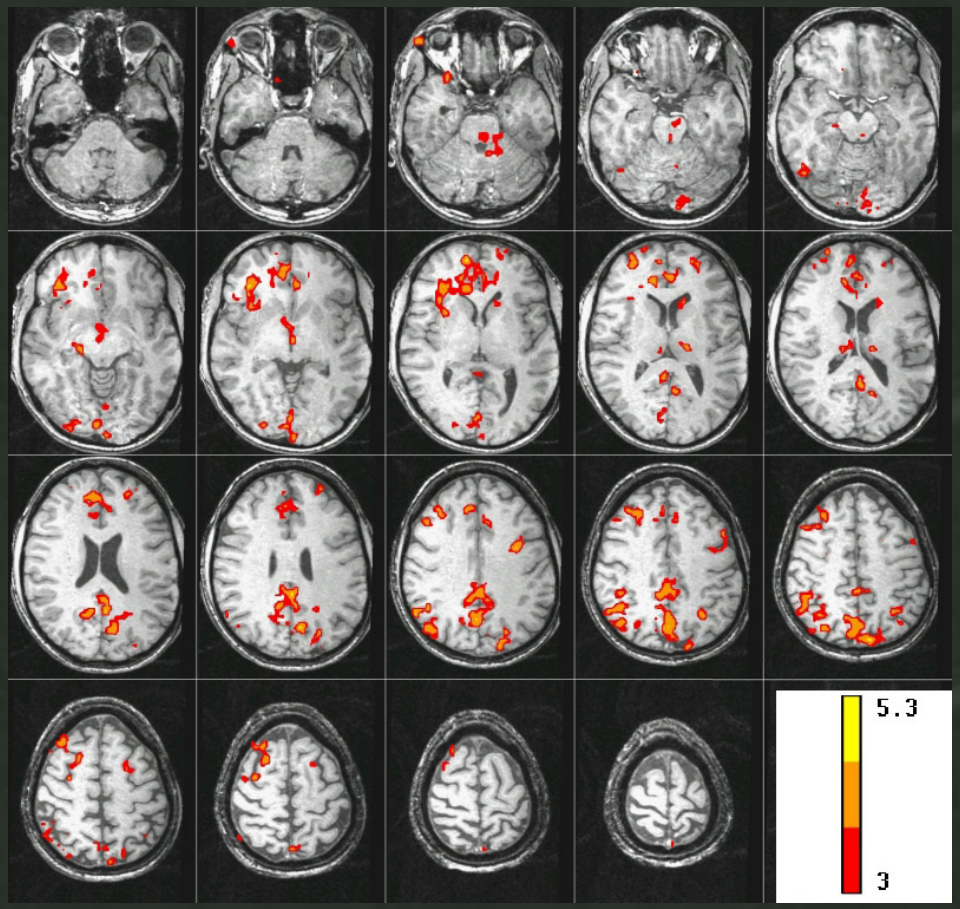


Methodology

NAIS

Free Behavior

BOLD correlated with SCR during "Rest"



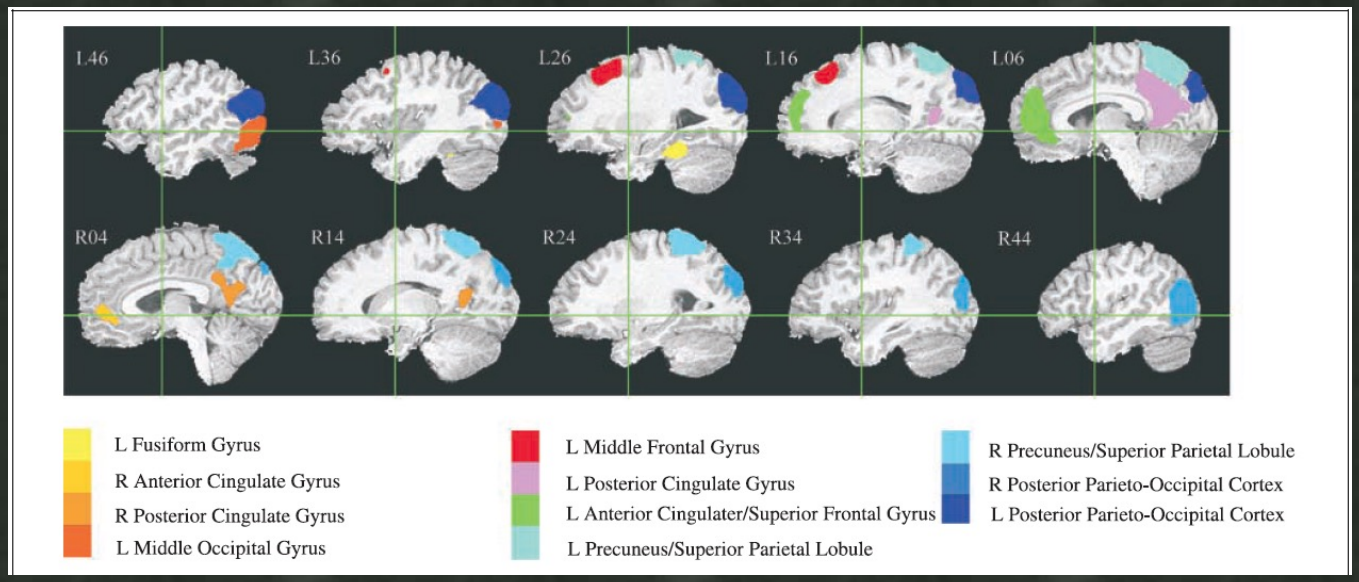
J. C. Patterson II, L. G. Ungerleider, and P. A Bandettini, *NeuroImage* **17**: *1787-1806, (2002).*

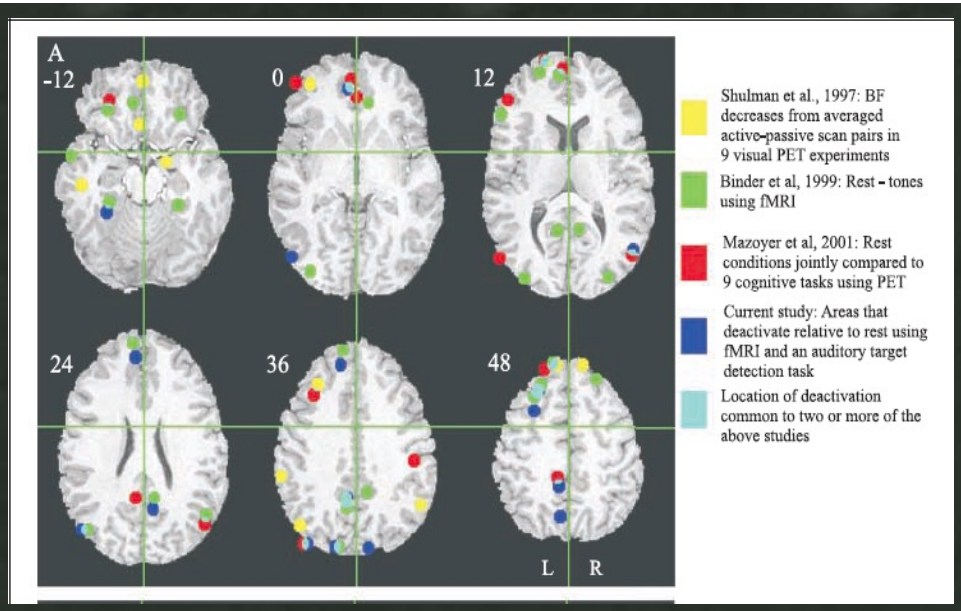
Methodology

NAIS

Free Behavior

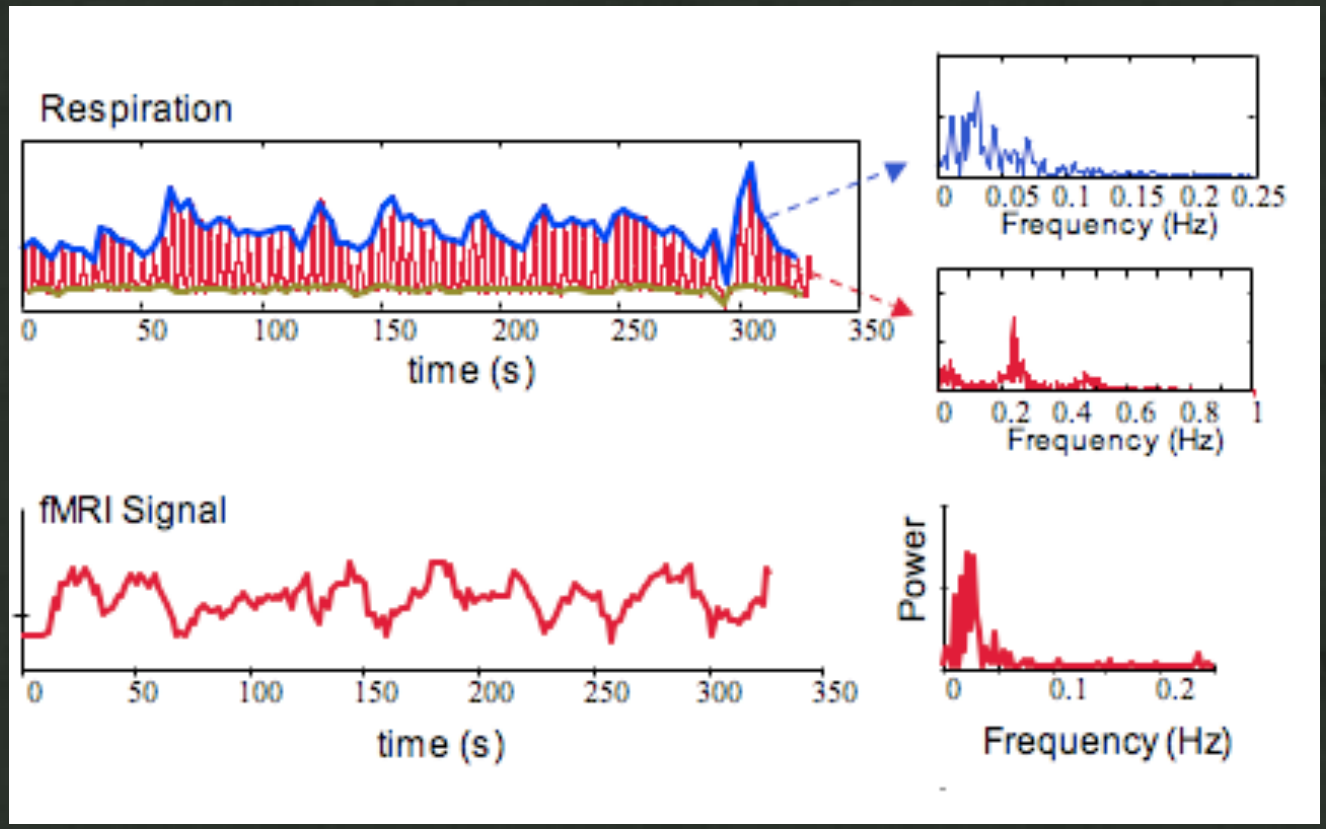
Regions showing decreases during cognitive tasks





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

Effects of Respiration on Signal



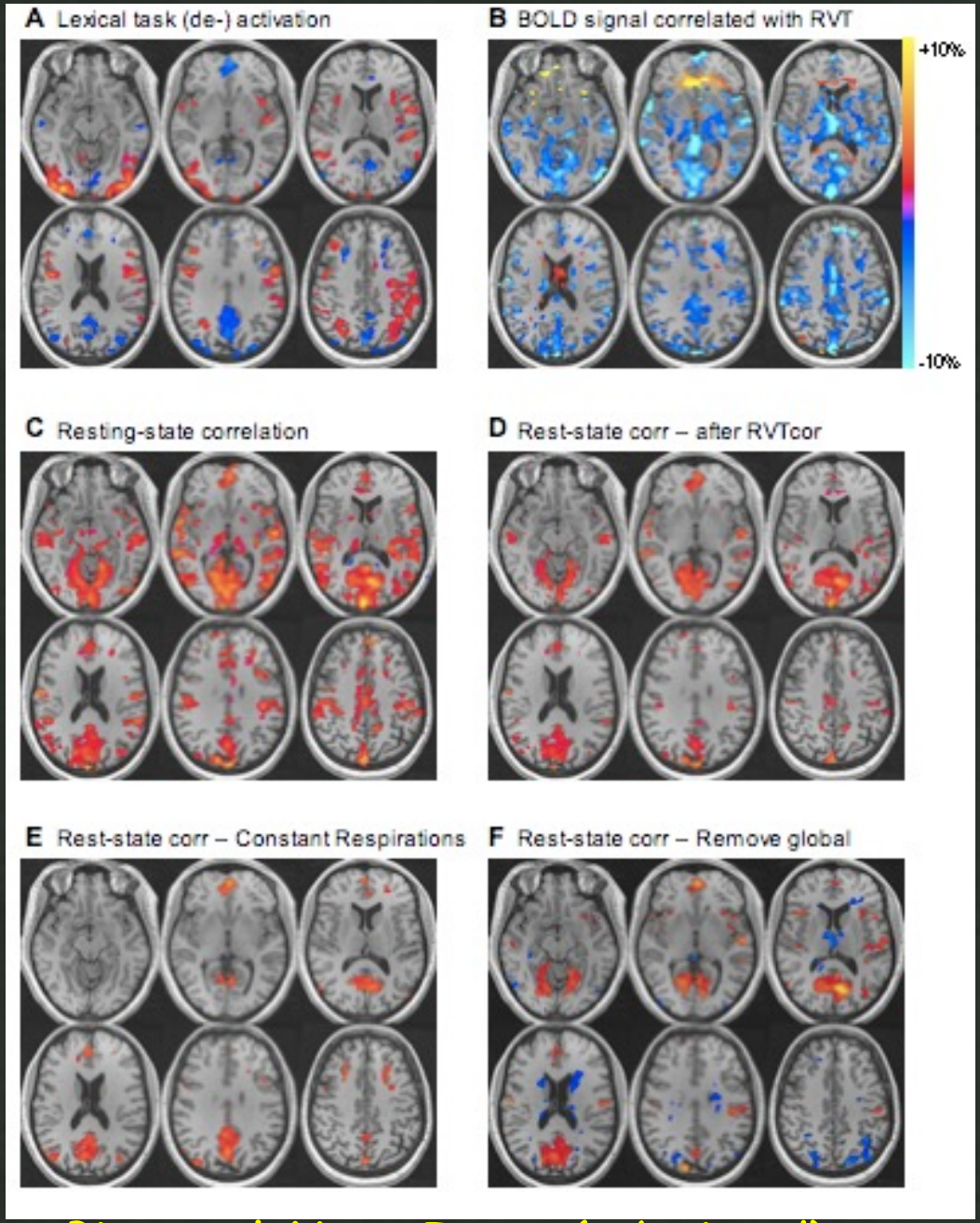
Birn et al. NeuroImage (submitted)

Methodology

NAIS

Free Behavior

Individual Maps



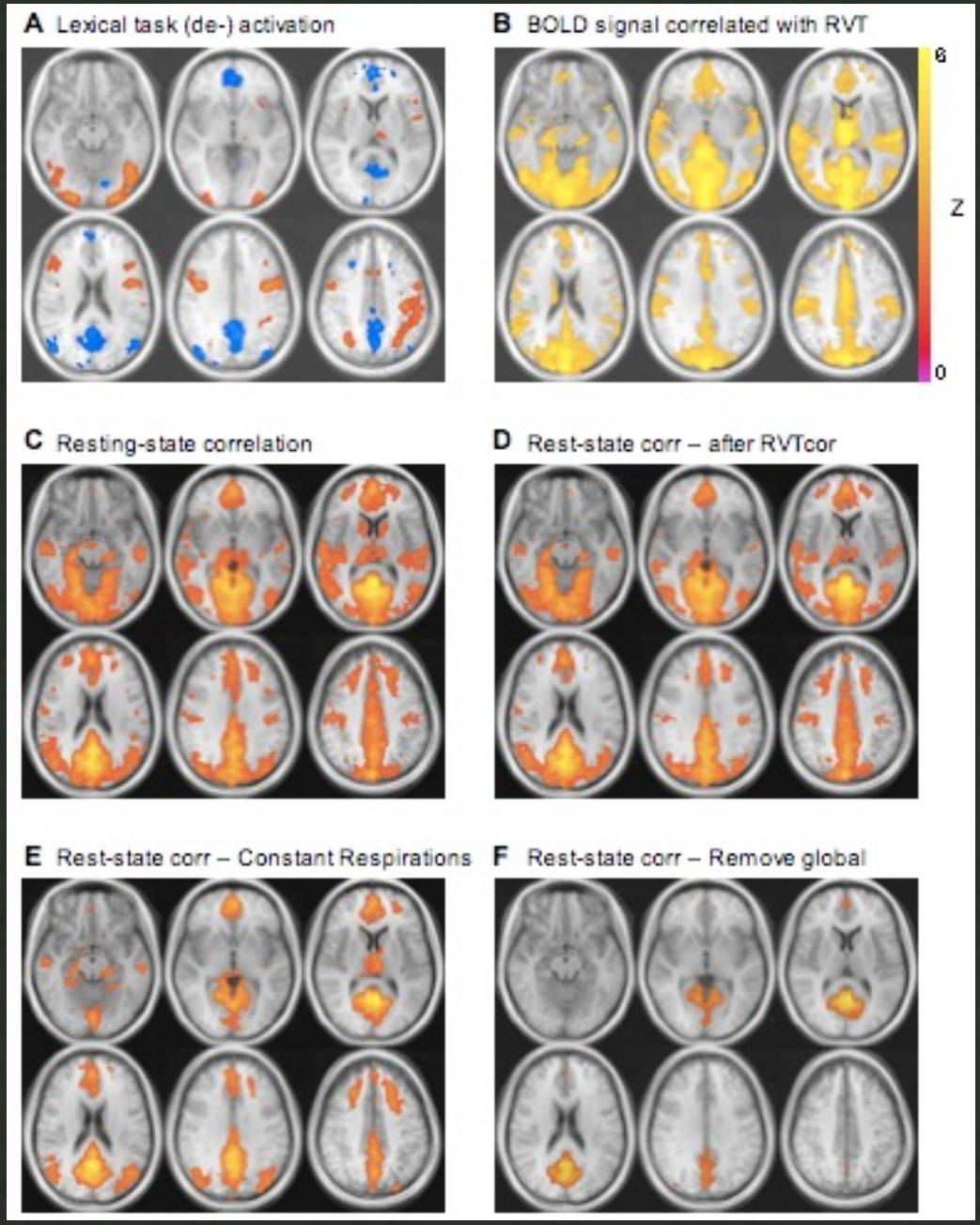
Birn et al. NeuroImage (submitted)

Methodology

NAIS

Free Behavior

Group Maps

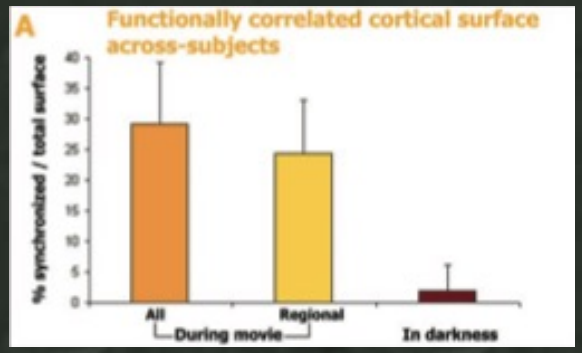


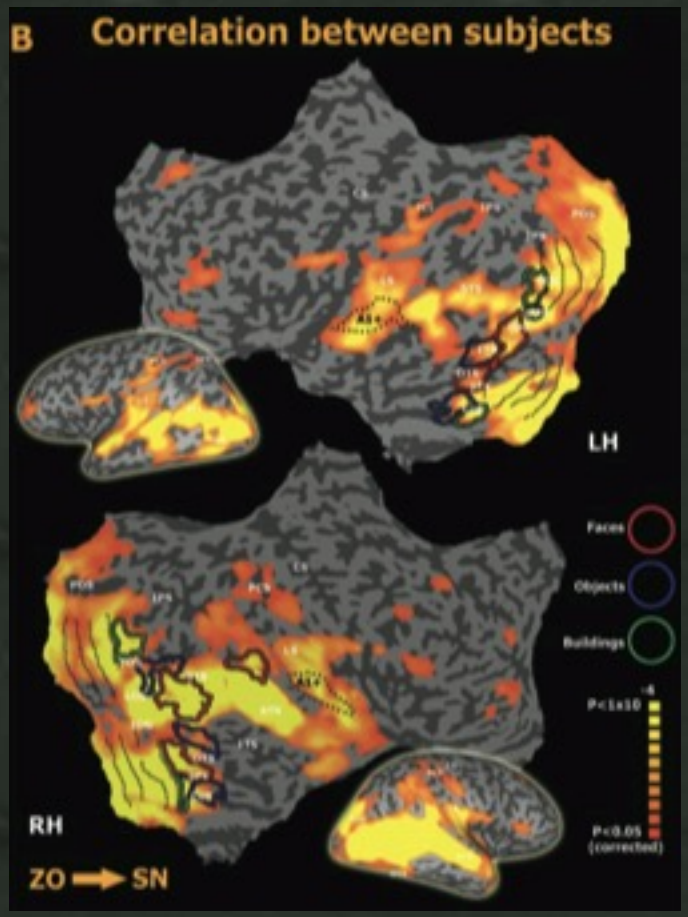
Birn et al. NeuroImage (submitted)

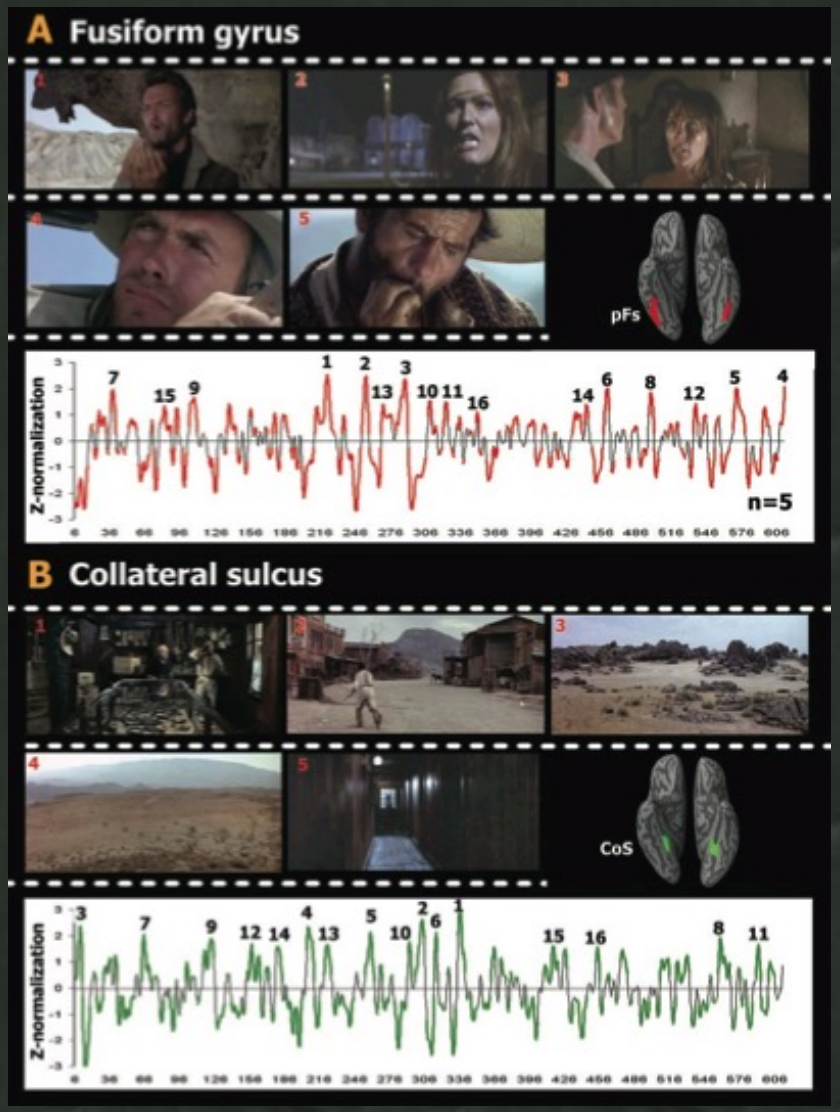
Methodology

NAIS

*Free Behavior







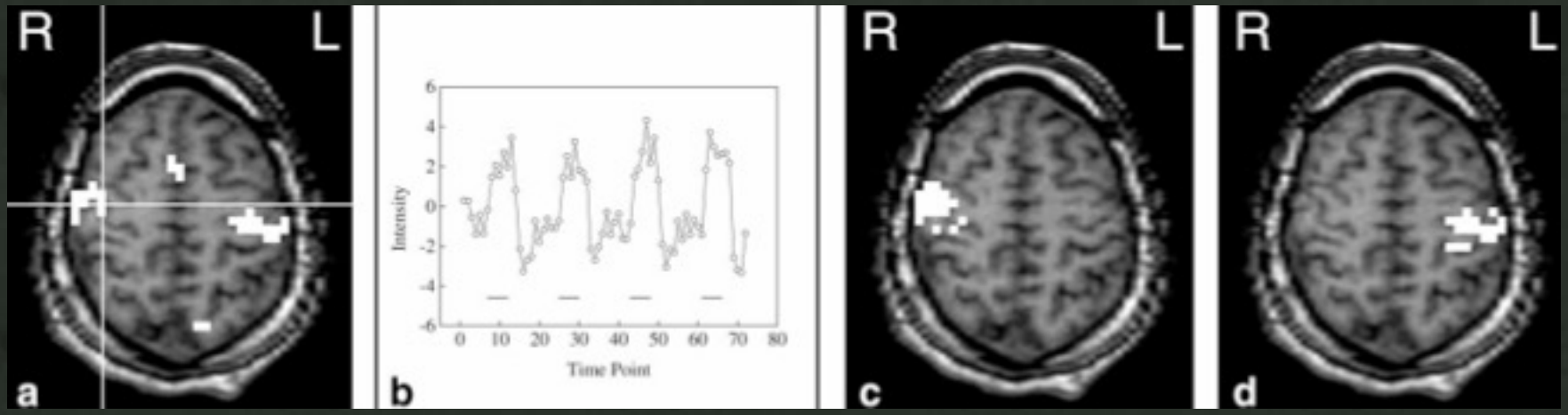
Hasson, et al (2004), Science, 303, 1634-1640

Methodology

NAIS

*Free Behavior

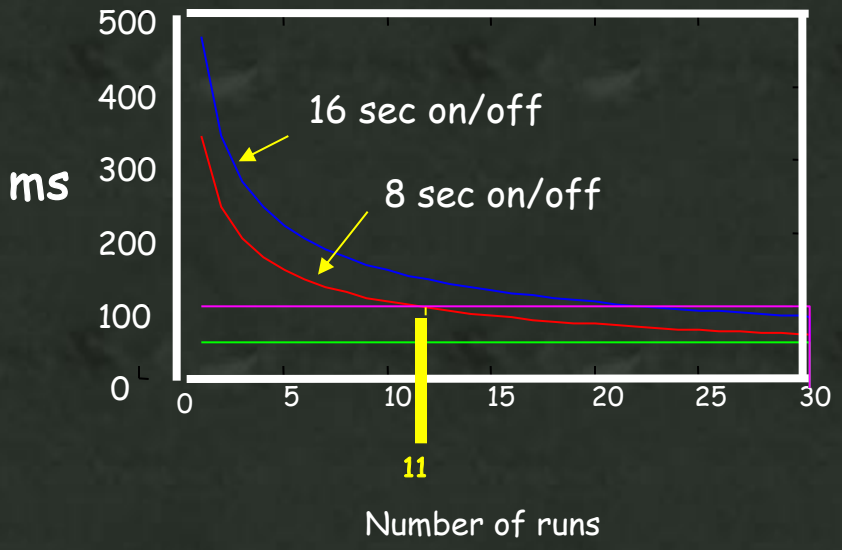
One doesn't need prior knowledge as long as the task is repeatable



Levin, et al (2001), NeuroImage, 13, 153-160

Methodology

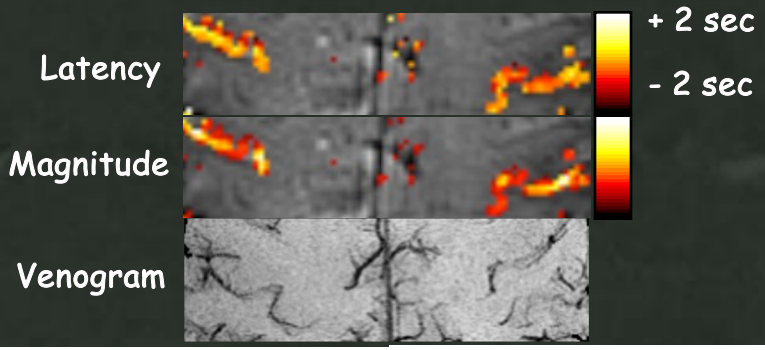
In an ideal world… no latency variation

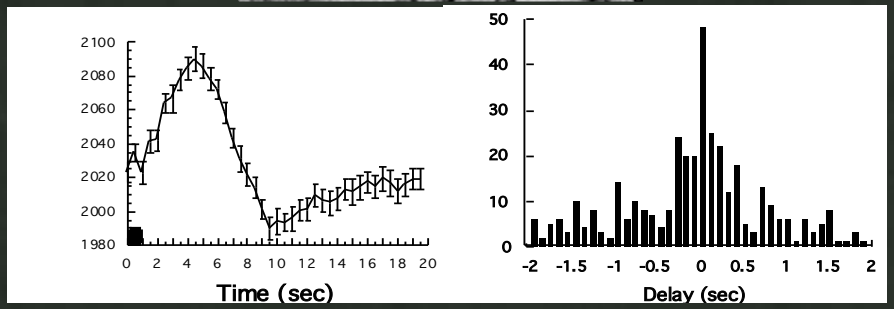


R. Birn

Temporal Resolution

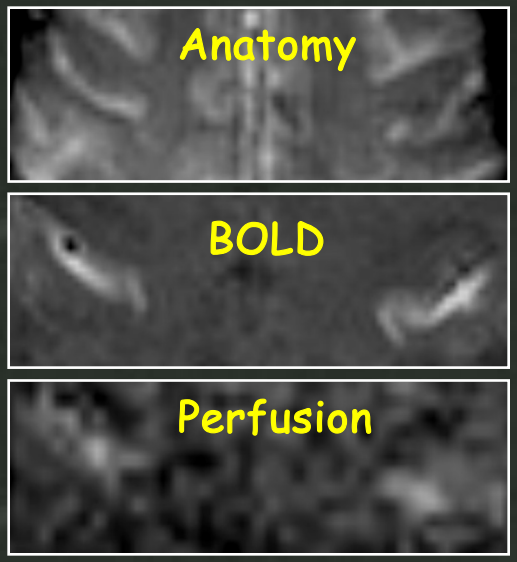
Latency Variation…





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

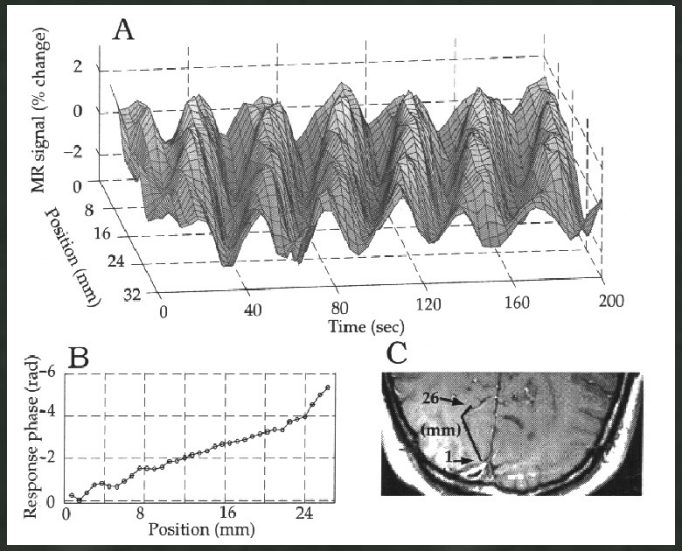
Methodology



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

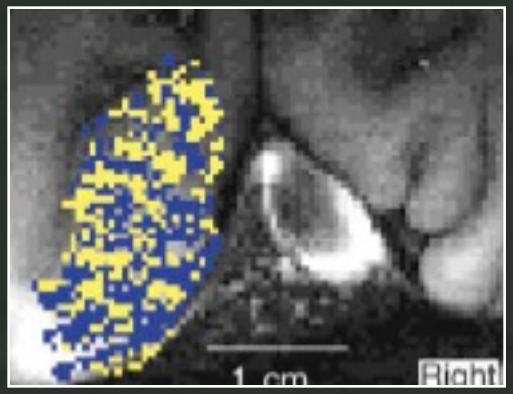
Spatial Resolution

PSF FWHM = 3.5mm



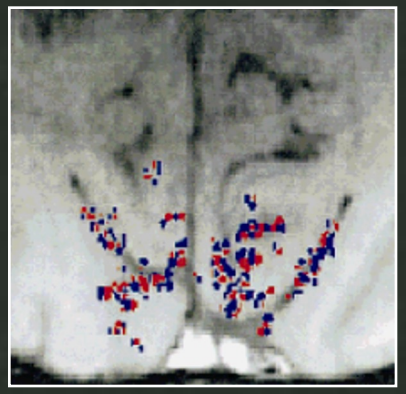
S.A. Engel, et al. Investigative Ophthalmology & Visual Science 35 (1994) 1977-1977.

0.47 x 0.47 in plane resolution



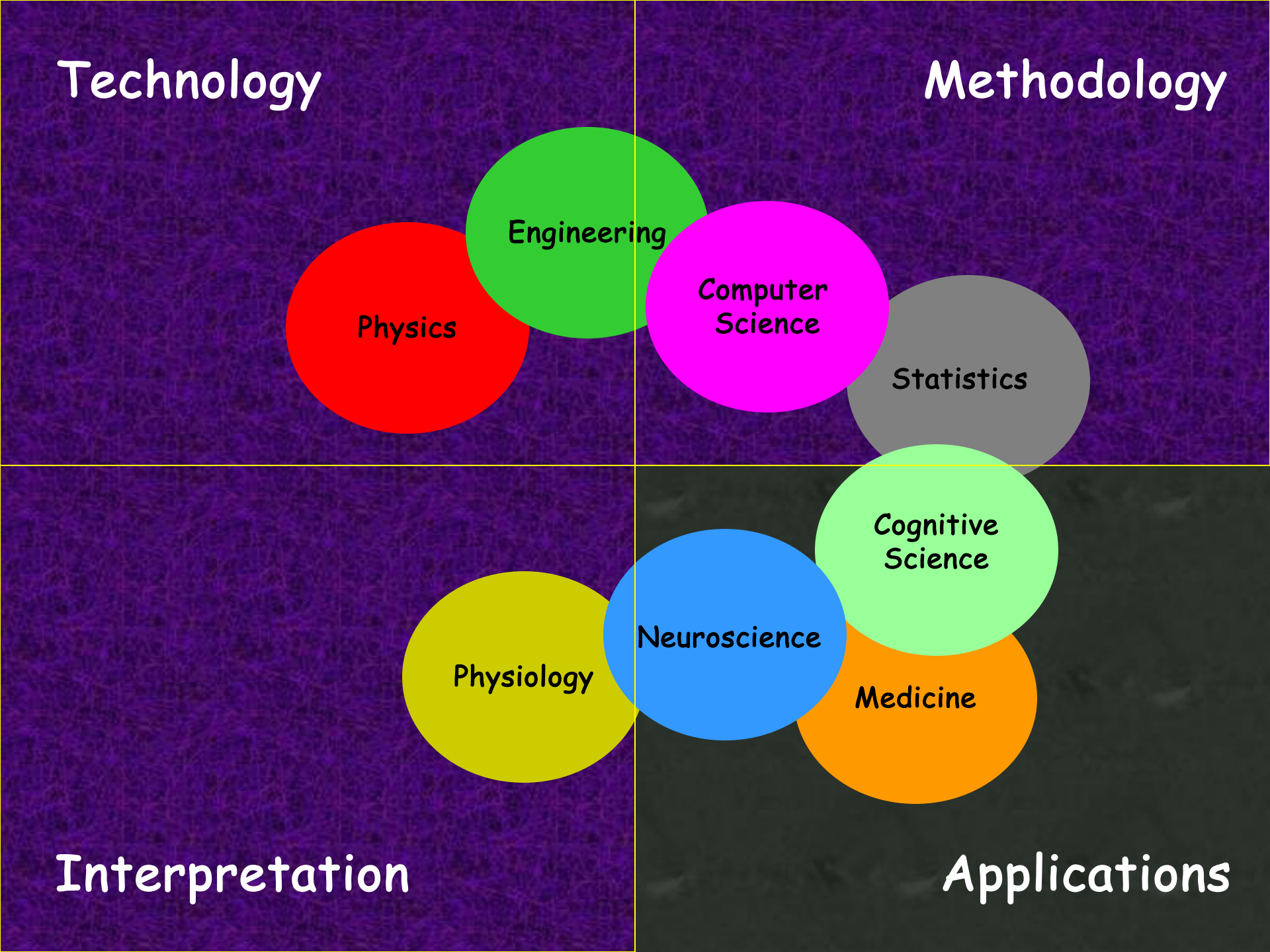
Cheng, et al. (2001) Neuron,32:359-374

0.54 x 0.54 in plane resolution



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

Multi-shot with navigator pulse


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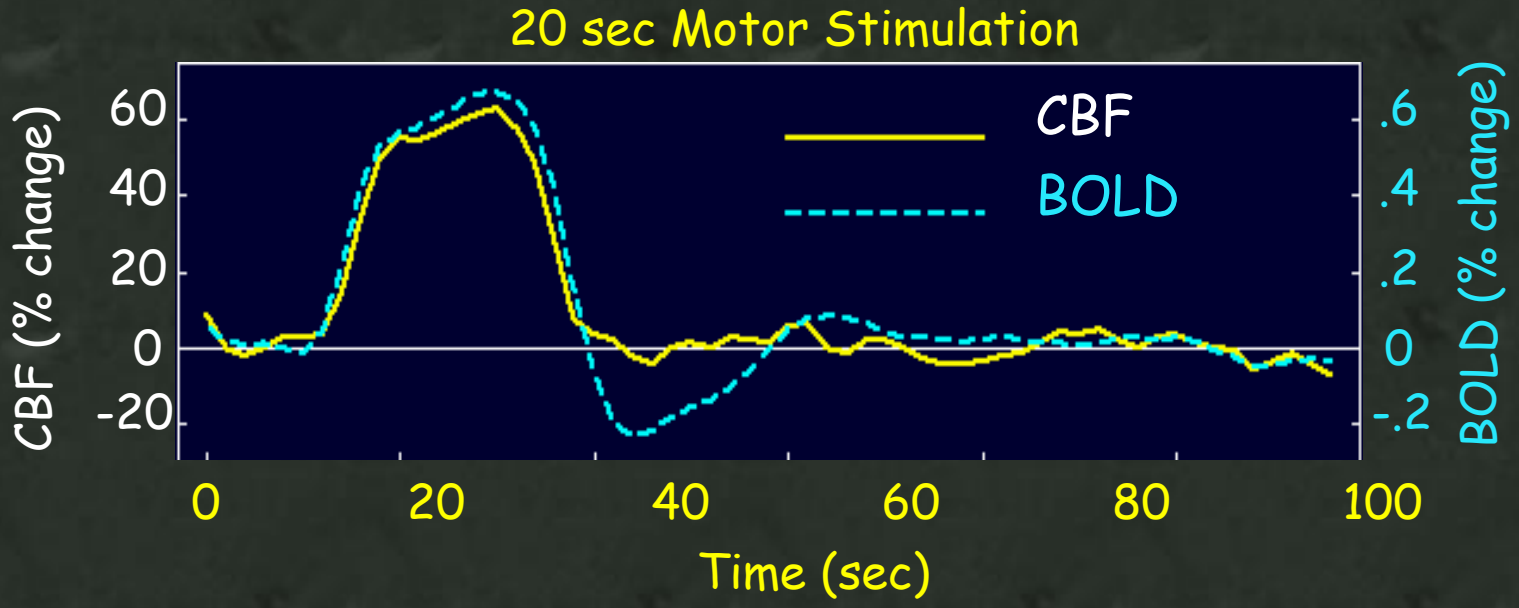
Cognitive Science
Neuroscience
Physiology
Medicine
Interpretation
Applications

Interpretation

- Post Undershoot
- Linearity (effect of task duty cycle)

BOLD post-stimulus undershoot



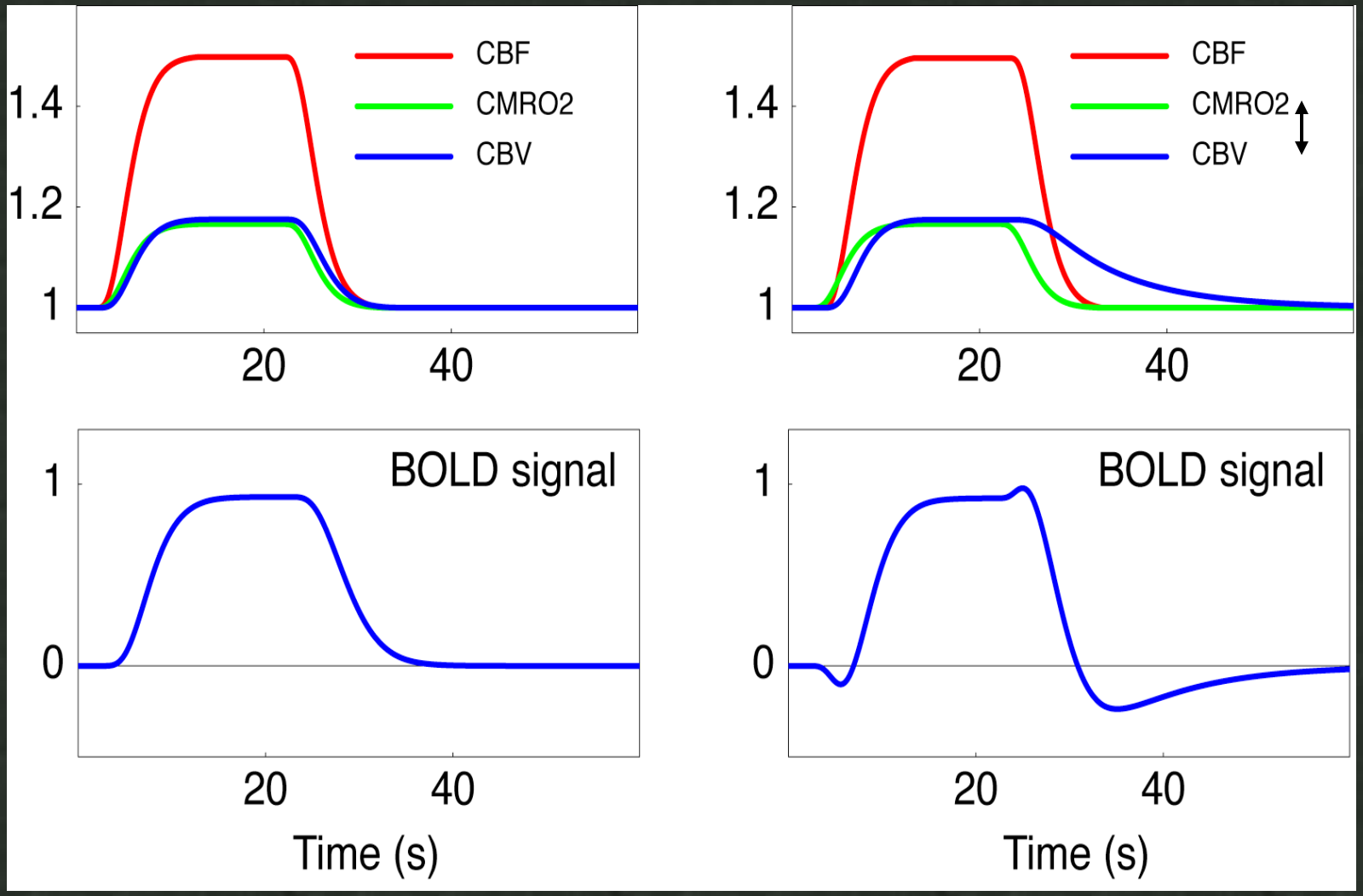
A BOLD undershoot without a CBF undershoot could be due to a slow return to baseline of either CBV or $CMRO_2$

Courtesy Rick Buxton

Interpretation

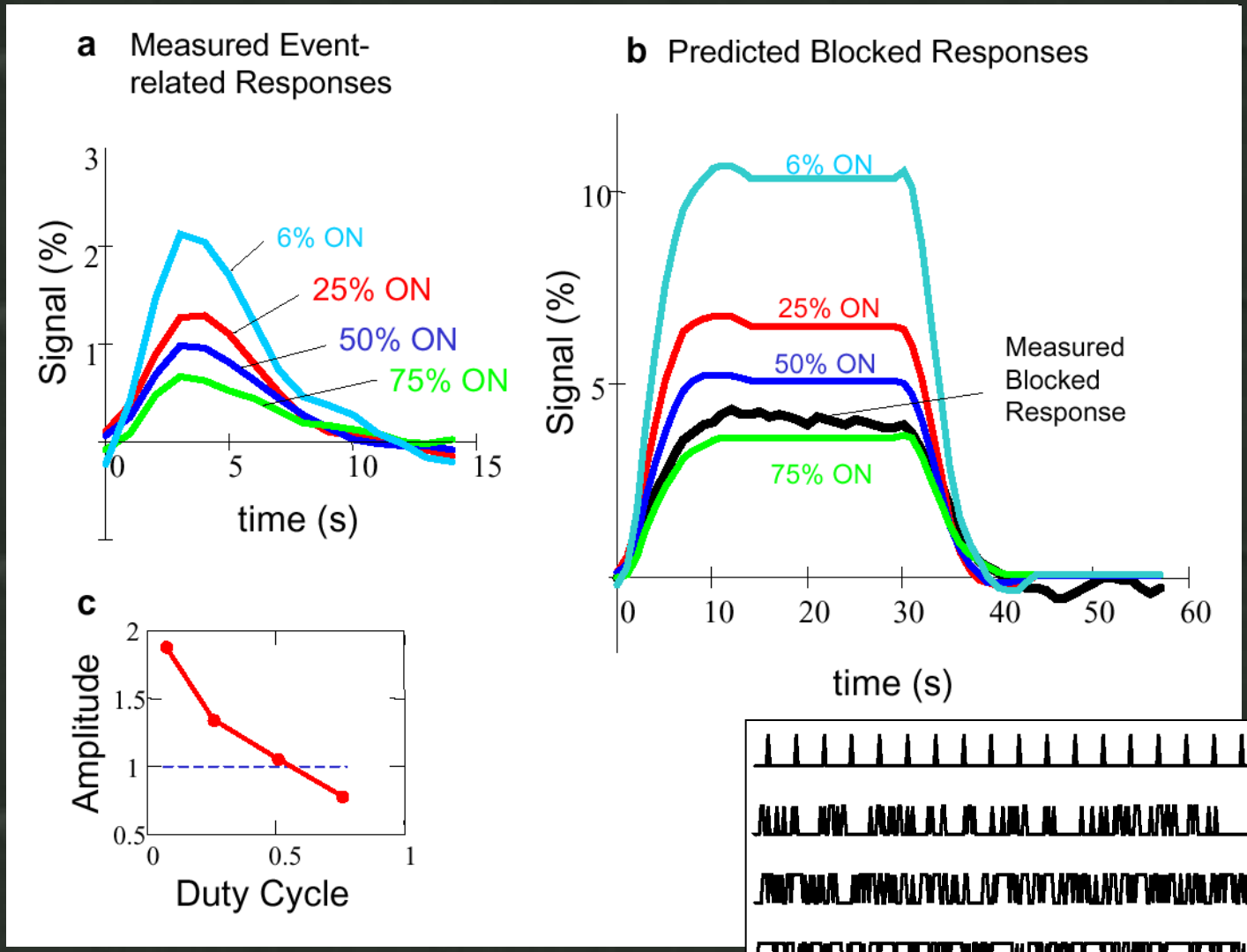
Post Undershoot

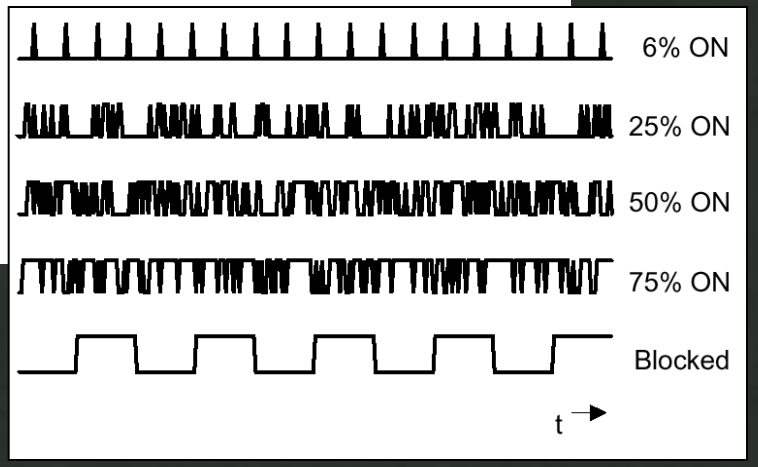
BOLD Signal Dynamics



Courtesy Rick Buxton

Interpretation duty cycle effects Linearity



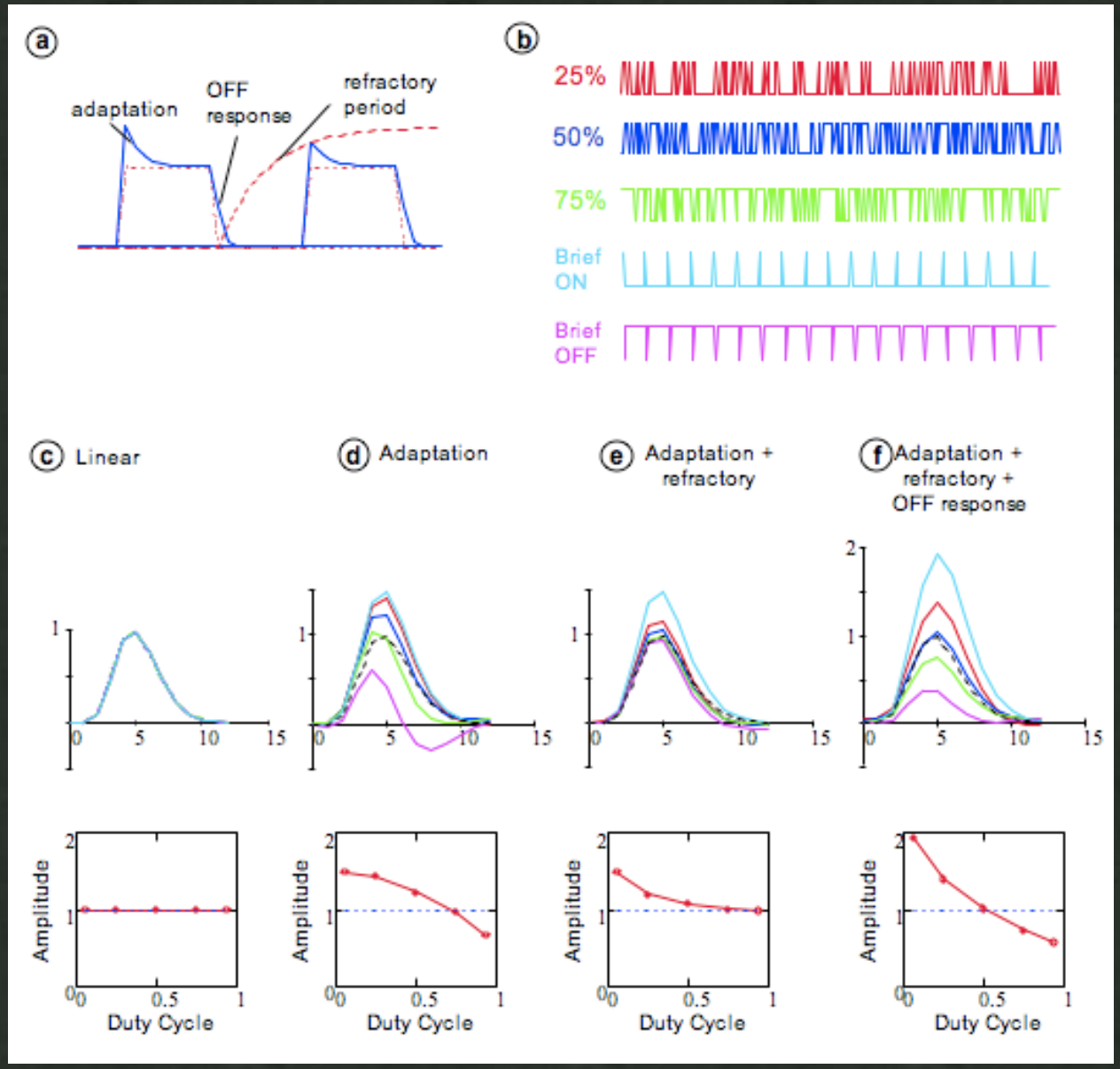


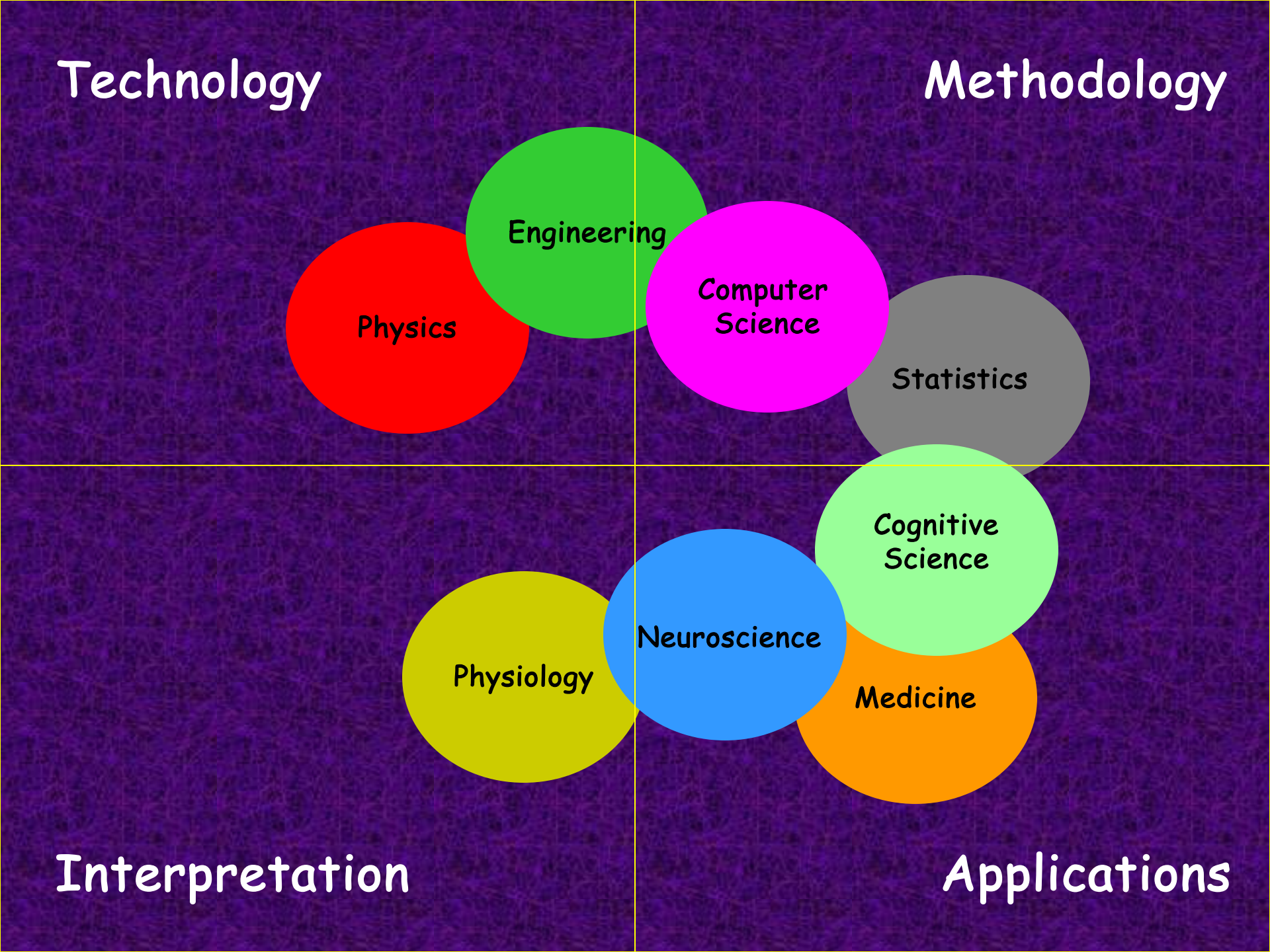
R.M. Birn, P. A. Bandettini. *NeuroImage*, 27, 70-82 (2005)

Interpretation

Linearity

duty cycle effects




Technology
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Neuroscience
Physiology
Medicine
Interpretation
Applications

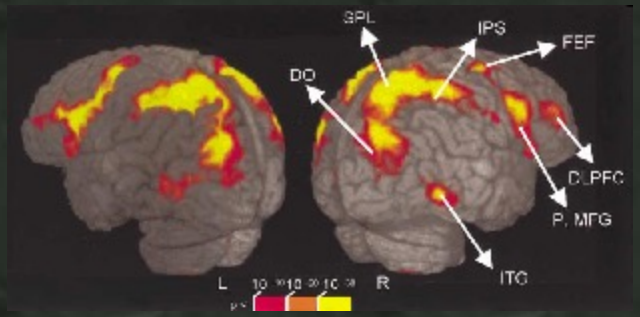
"Brain Reading"

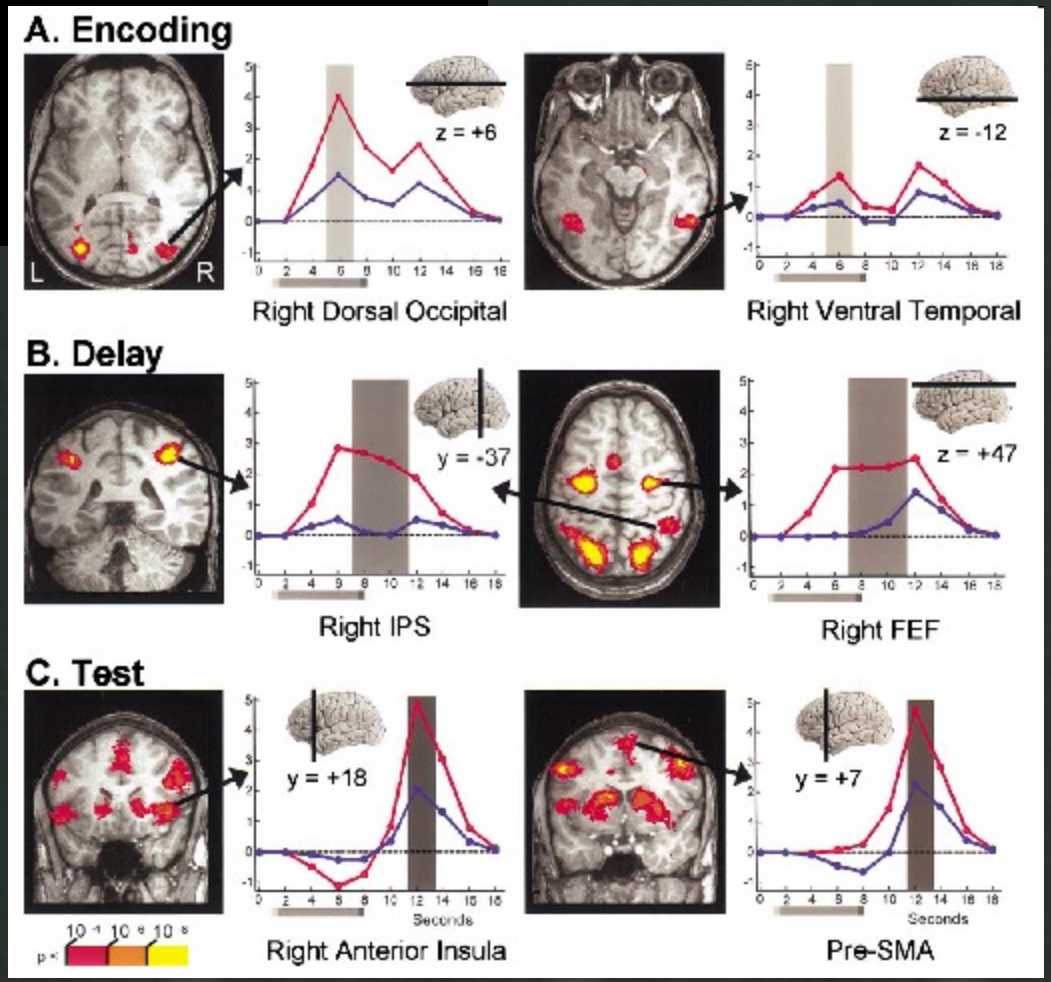
Rather than mapping what is correlated with a task, "brain reading" involves predicting what the brain is doing based on the pattern of activation.

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

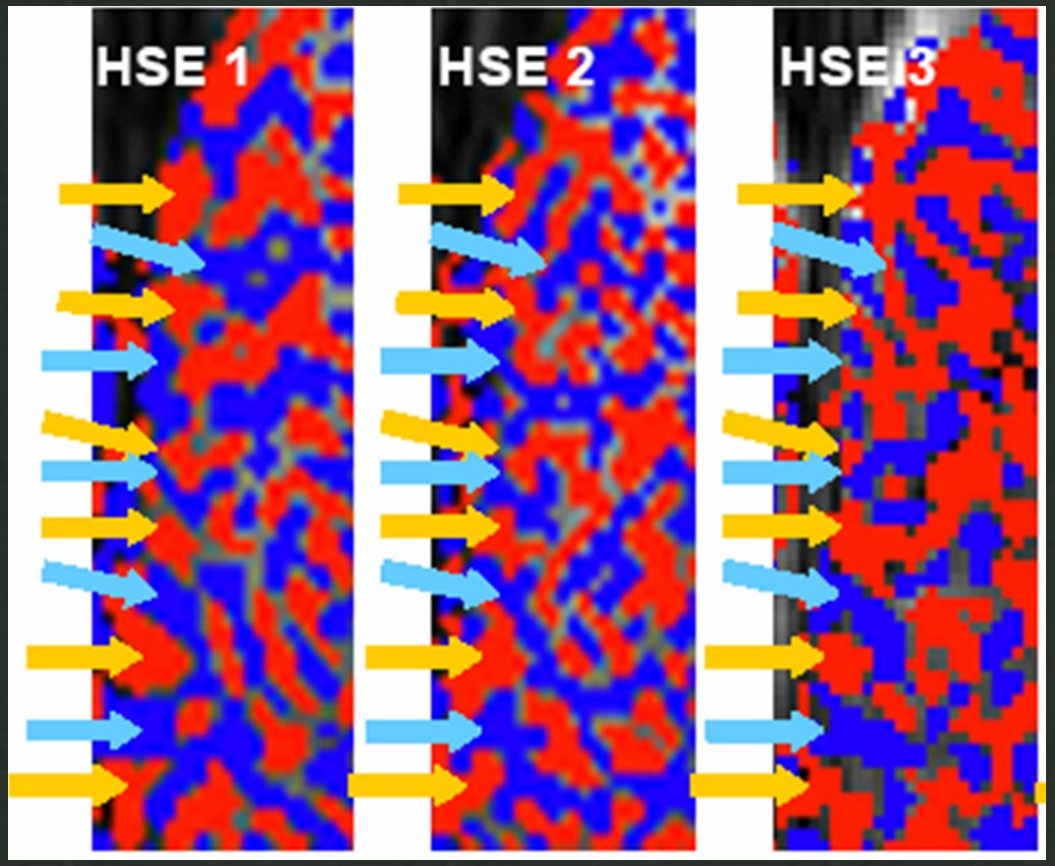
Neural Correlates of Visual Working Memory: fMRI Amplitude Predicts Task Performance

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





Differential mapping of human ocular dominance columns



Yacoub et al., 7T, $(0.5mm)^2 \times 3mm$ voxels, Hahn-spin-echo BOLD

Differential mapping was needed

- **Hi-res neuronal-pattern information**: BOLD activity patterns *distinguish* the neuronal activity pattern evoked by left- and right-eye stimulation.

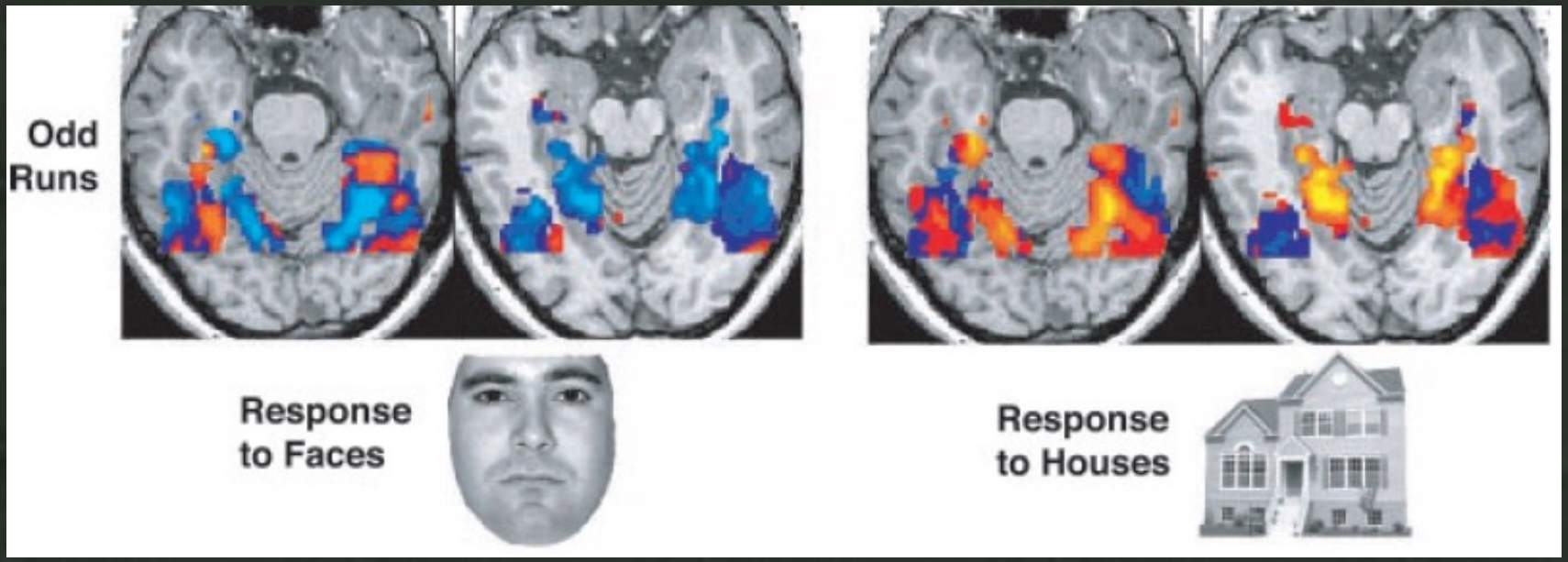
- **Limited specificity**: Voxels do not respond exclusively to neuronal activity within their boundaries.

What data analysis is best suited to reveal fMRI pattern information?

Pattern-recognition analysis of fMRI activity patterns

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

Visual object categories distinguished by widely distributed inferotemporal activity pattern



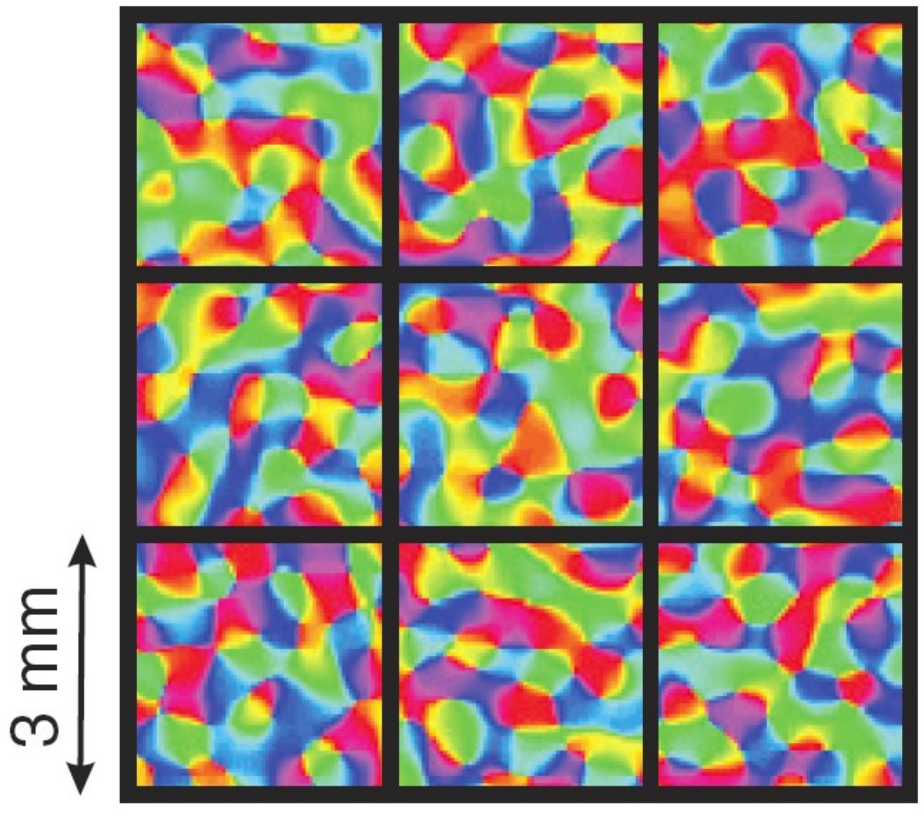
Haxby et al. (2001)

Orientation information in early visual areas

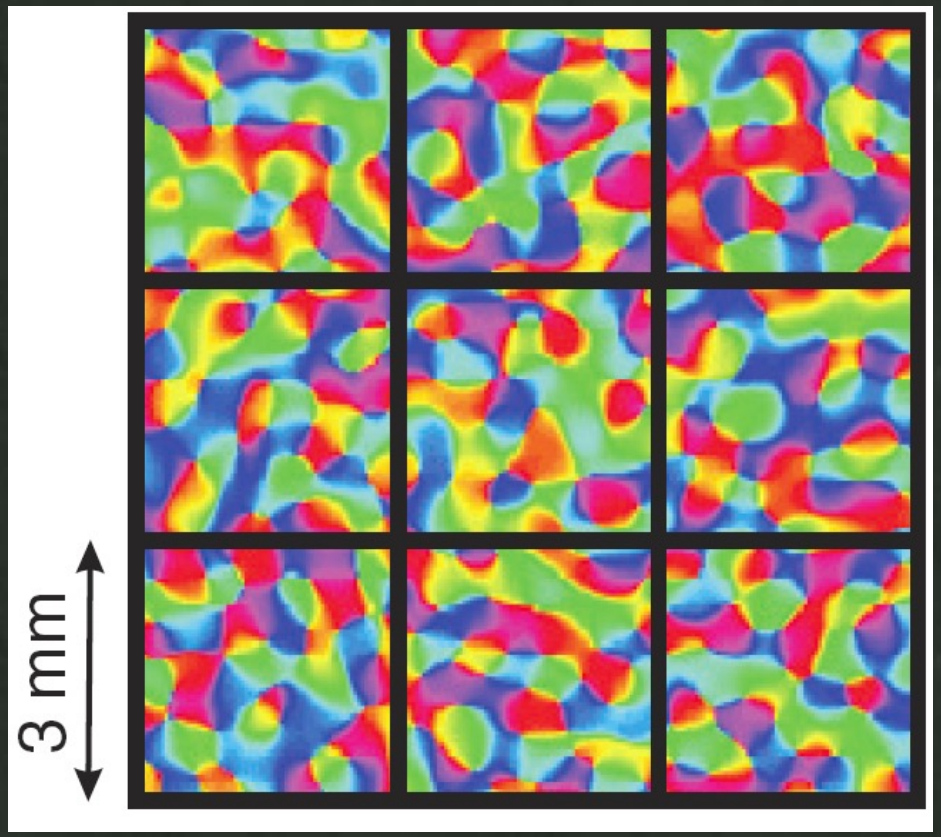
Kamitani & Tong (2005), Haynes & Rees (2005)

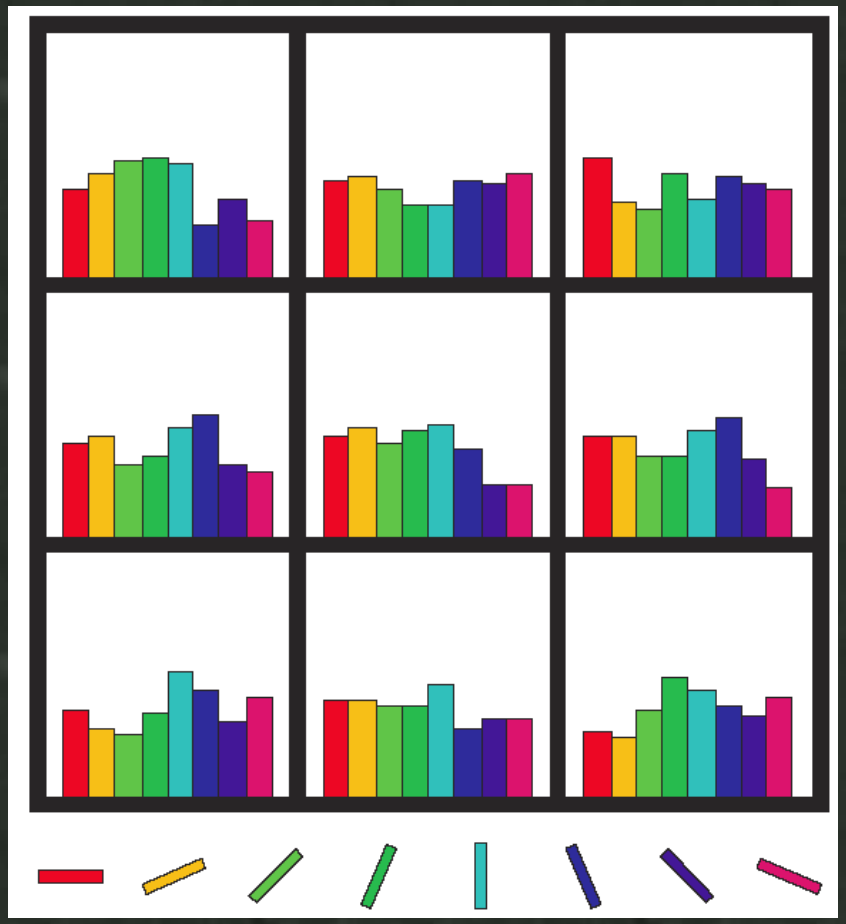
Let's image the fine-scale orientation map

with 3-mm voxels...

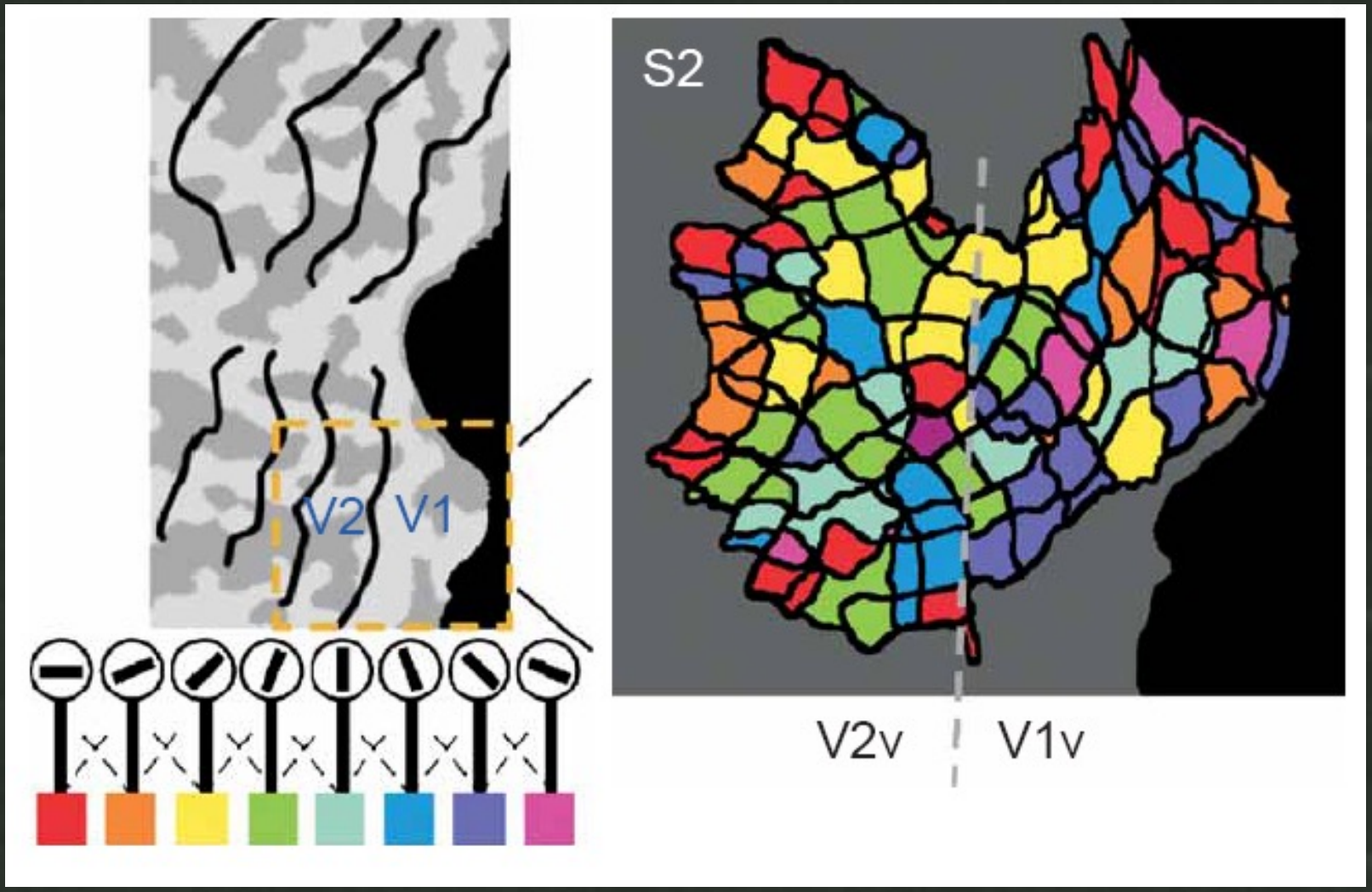


Boynton (2005), News & Views on Kamitani & Tong (2005) and Haynes & Rees (2005)

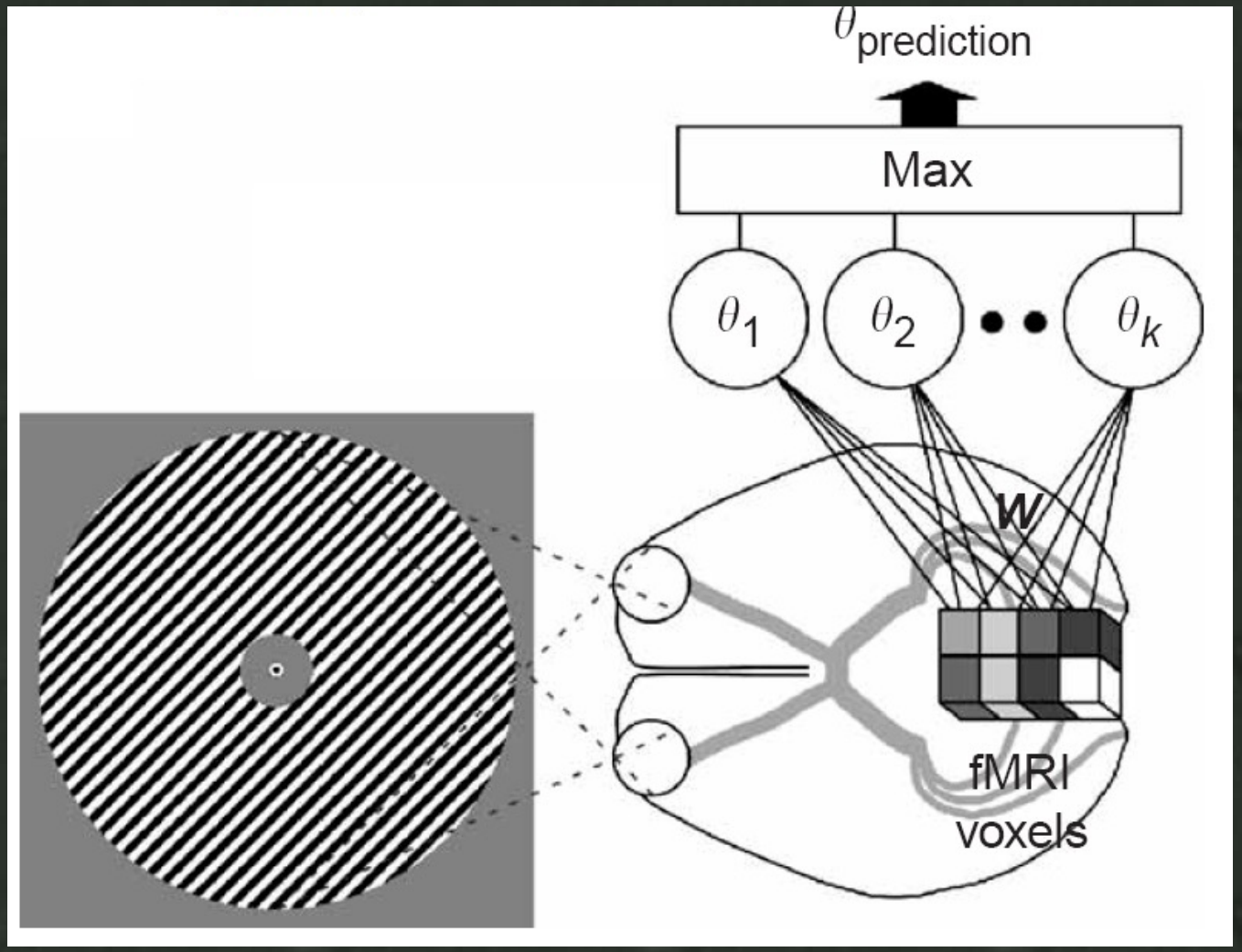




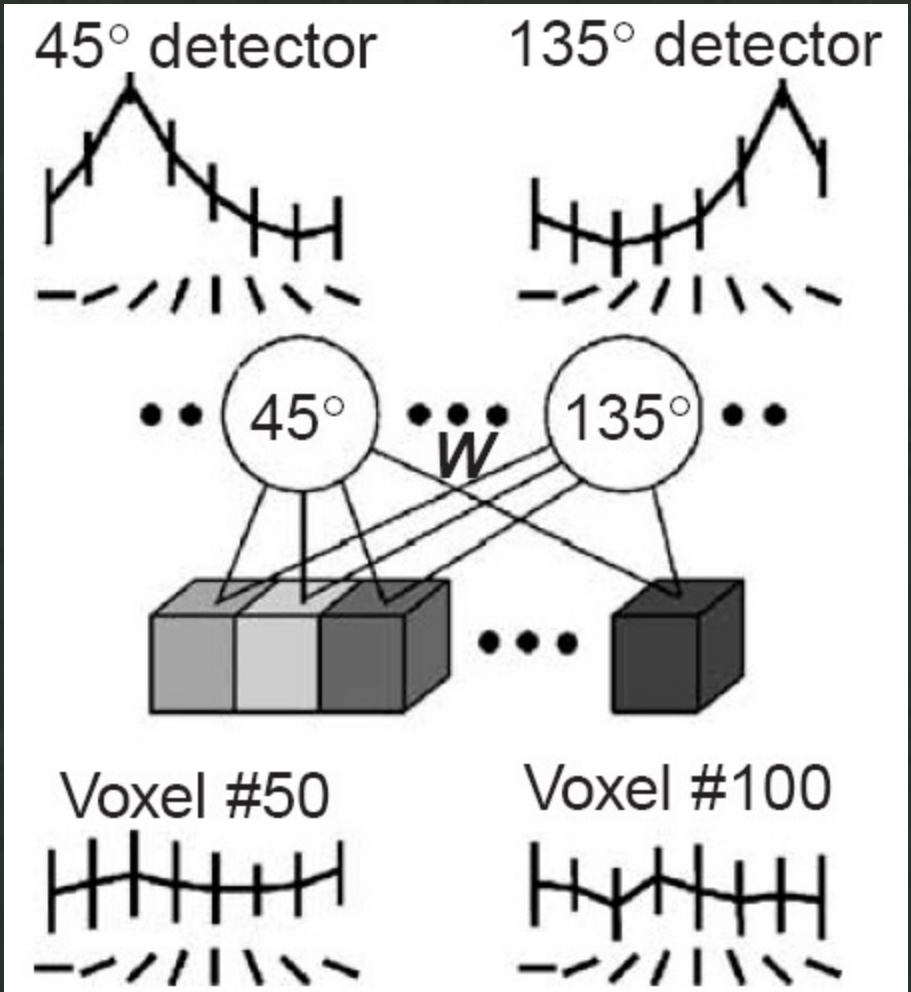
Boynton (2005), News & Views on Kamitani & Tong (2005) and Haynes & Rees (2005)


S2
V2
V1
V2v
V1v

Iso-orientation domains are not resolved,
but the viewed orientation can be predicted



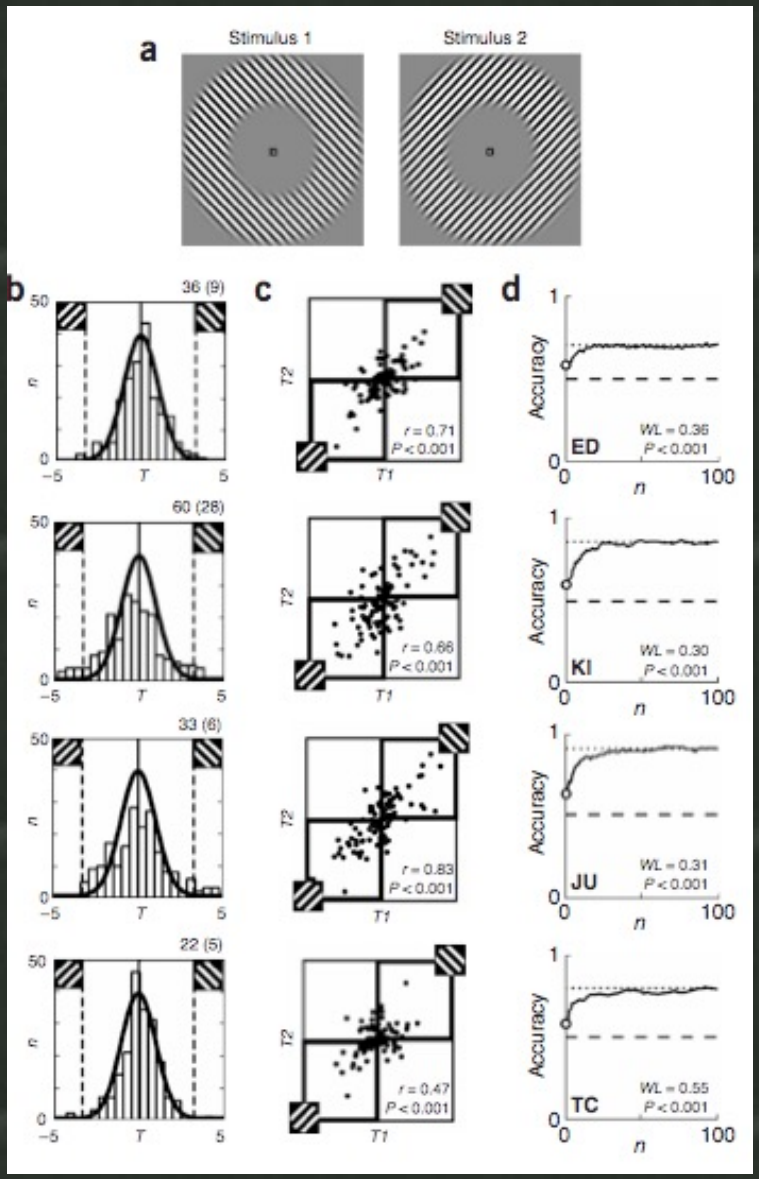
Iso-orientation domains are not resolved, but the viewed orientation can be predicted



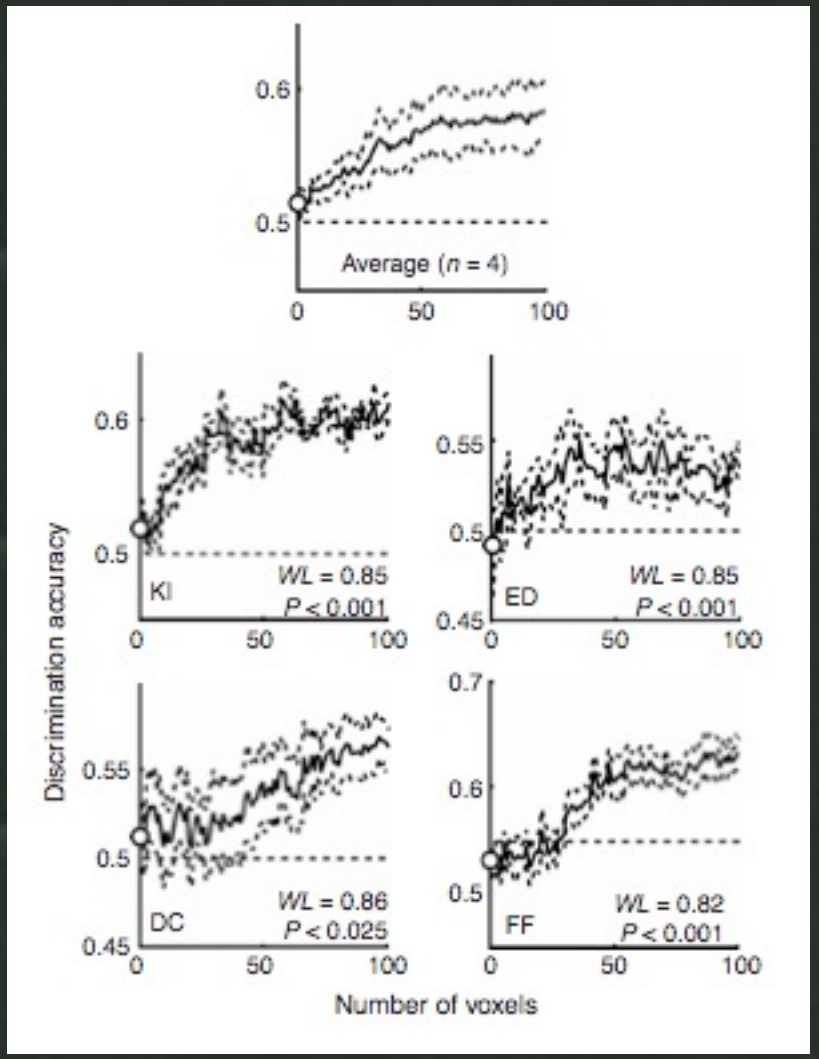
subject 1, V1 & V2, 400 voxels

Local combination of signals used for statistical power without data smoothing.

Visible



Invisible



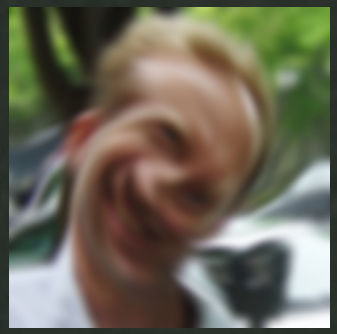
J.-D. Haynes and G. Rees, Nature Neuroscience, 8, 686-691 (2005).

fMRI information

neuronal
activity pattern

fMRI
activity pattern

condition 1



condition 2

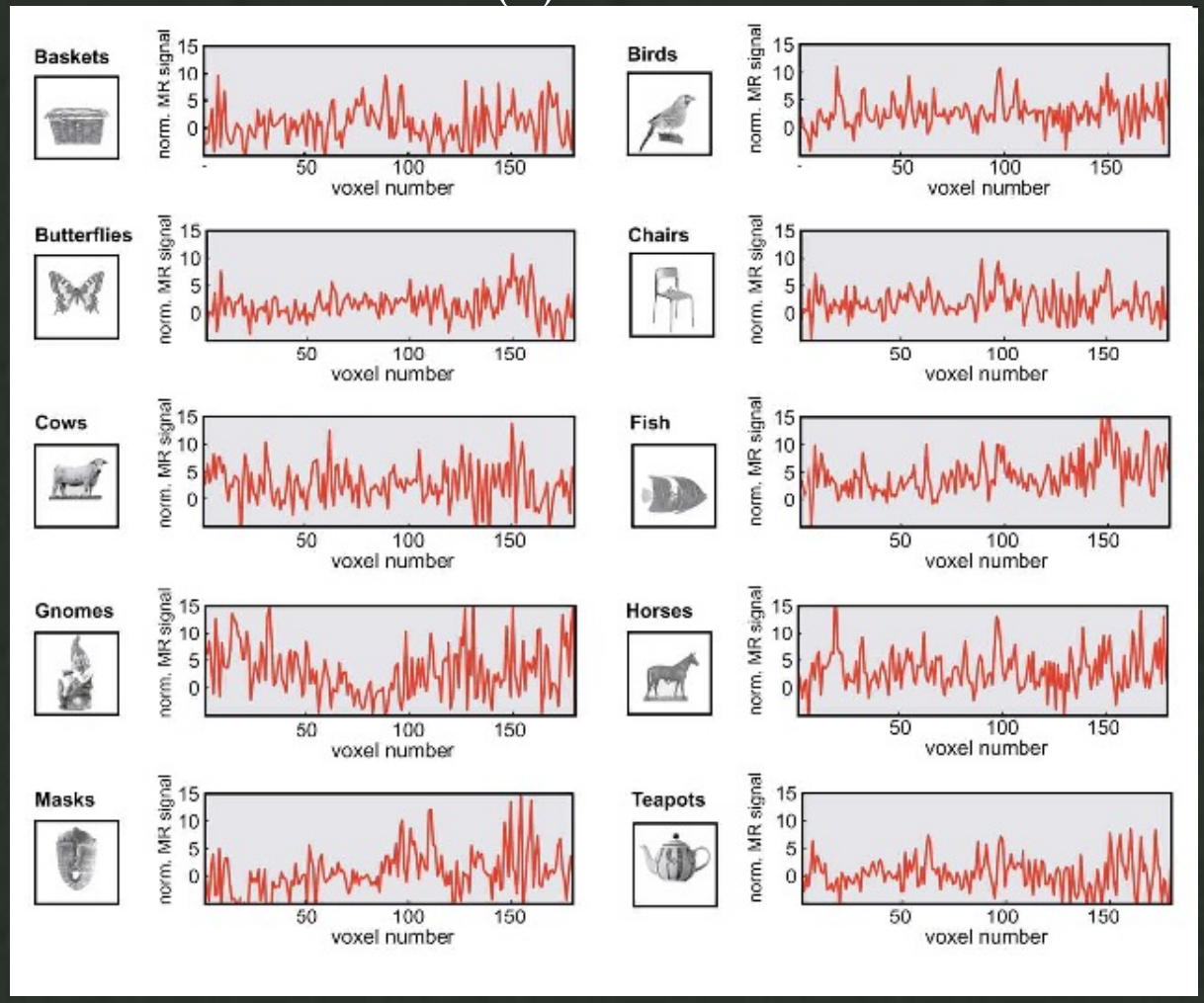
Functional magnetic resonance imaging (fMRI) "brain reading": detecting and classifying distributed patterns of fMRI activity in human visual cortex

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

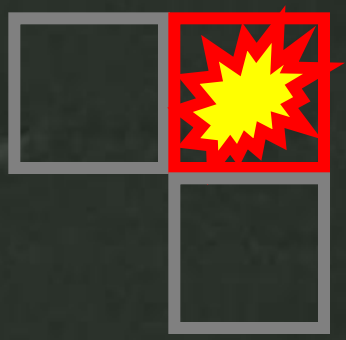
[a] Rowland Institute for Science, Cambridge, MA 02142, USA
[b] Athinoula A. Martinos Center for Structural and Functional Biomedical Imaging, Charlestown, MA 02129, USA
[c] HyperVision, Inc., P.O. Box 158, Lexington, MA 02420, USA

Received 15 July 2002; accepted 10 December 2002

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



Ways to think of a voxel..



Spatial specificity

\+ accurate depiction of neuronal pattern
up to the voxel Nyquist limit

Fine-scale neuronal-pattern information

\+ sensitive detection of changes
even beyond the voxel Nyquist limit

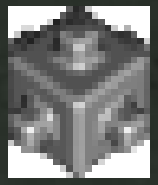
*irregular multipronged sensor

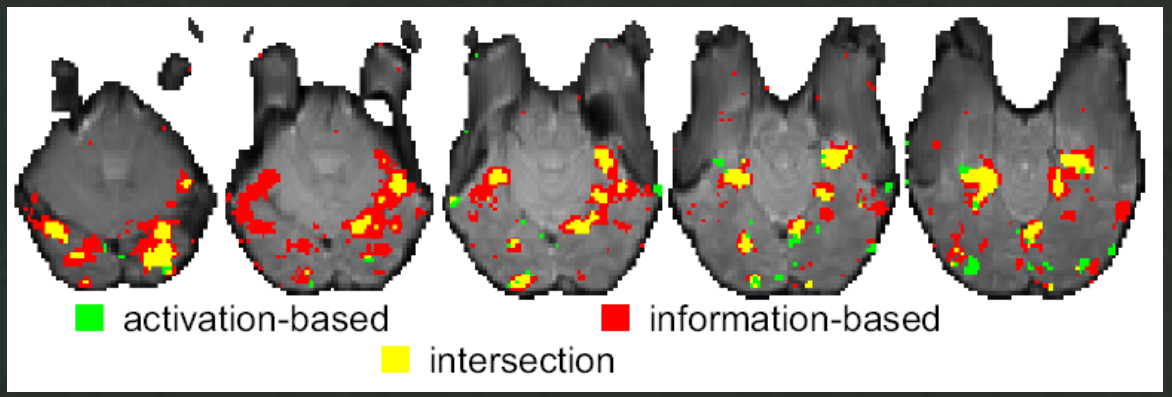
*(Niko Kriegeskorte)

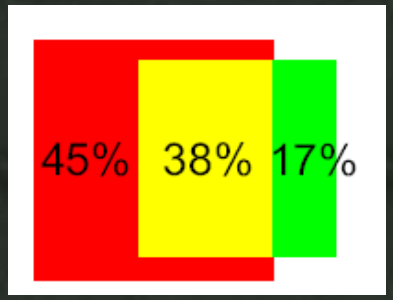
Activation-based mapping: data smoothing
(classical approach)

Information-based mapping: local multivariate analysis

volume scanned with MANCOVA searchlight

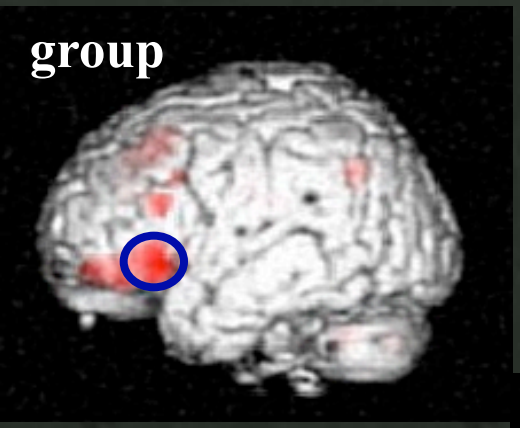






voxel sets

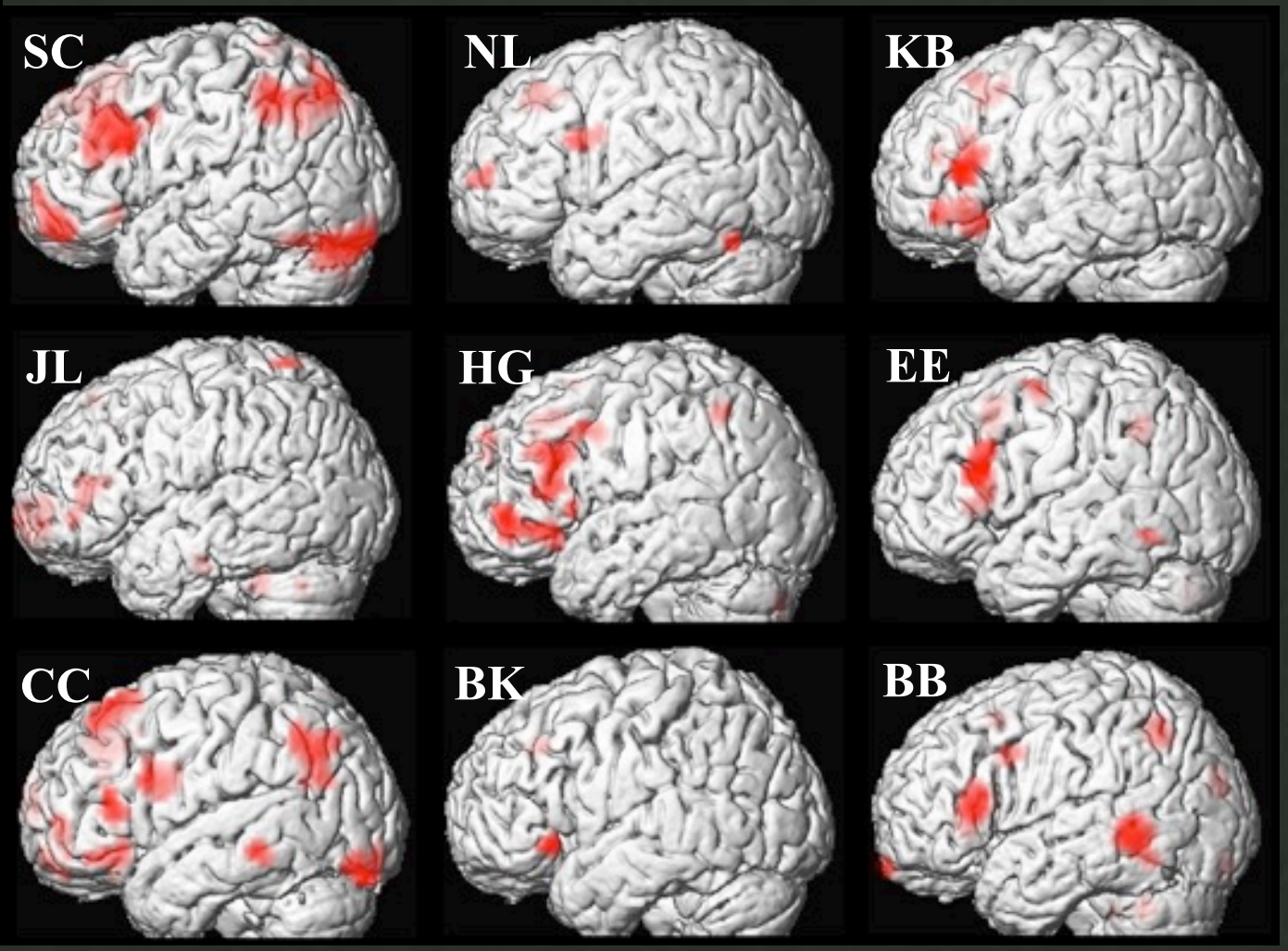
N. Kriegeskorte, et al. (submitted)



Extensive Individual Differences in Brain Activations During Episodic Retrieval

Miller et al., 2002

Individual activations from the left hemisphere of the 9 subjects



Courtesy, Mike Miler, UC Santa Barbara and Jack Van Horn, fMRI Data Center, Dartmouth University

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