What fMRI Can, Can't, and Might Do

Peter A. Bandettini, Ph.D.

Section on Functional Imaging Methods

http://fim.nimh.nih.gov

Laboratory of Brain and Cognition

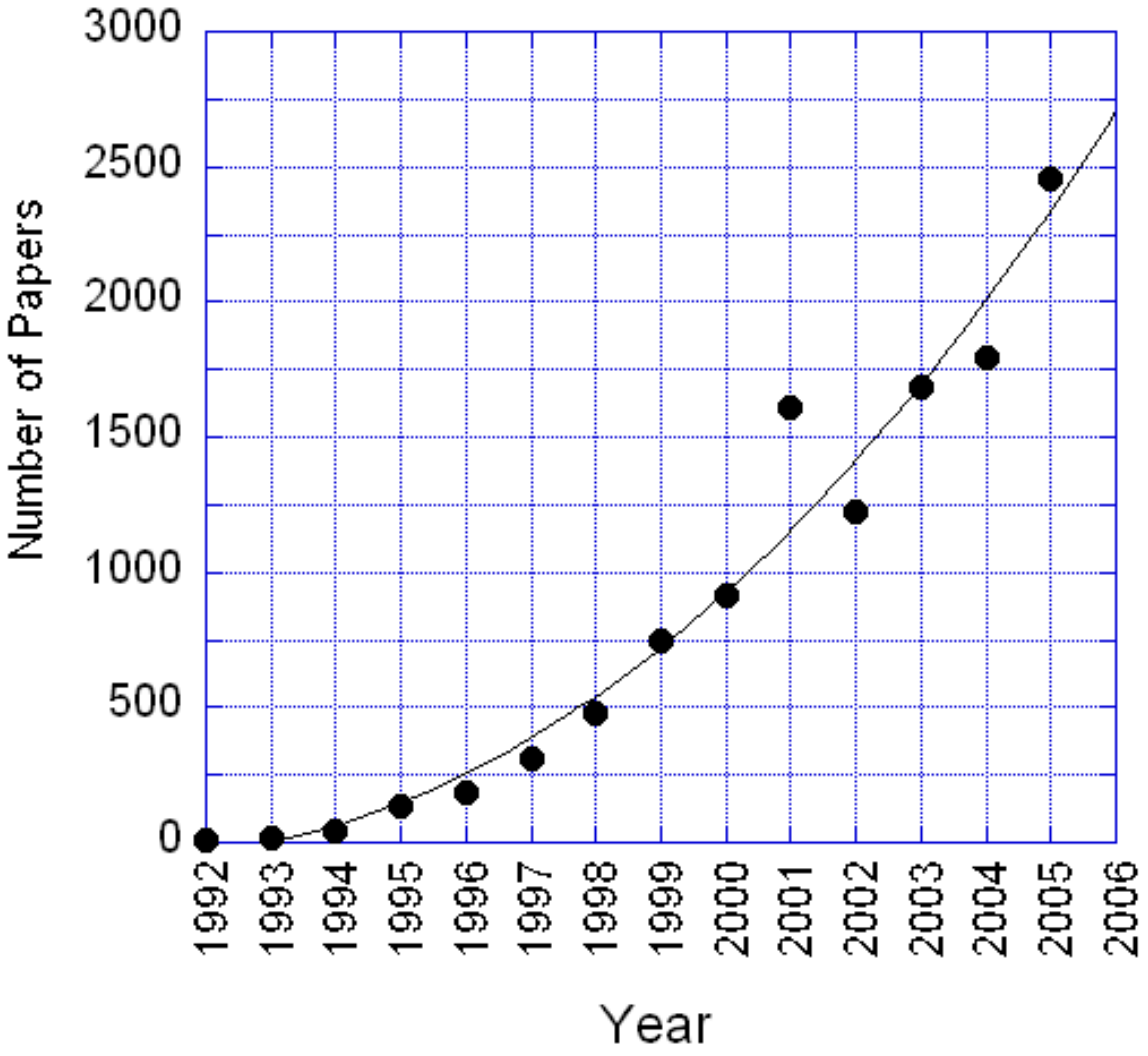
&

Functional MRI Facility

http://fmrif.nimh.nih.gov

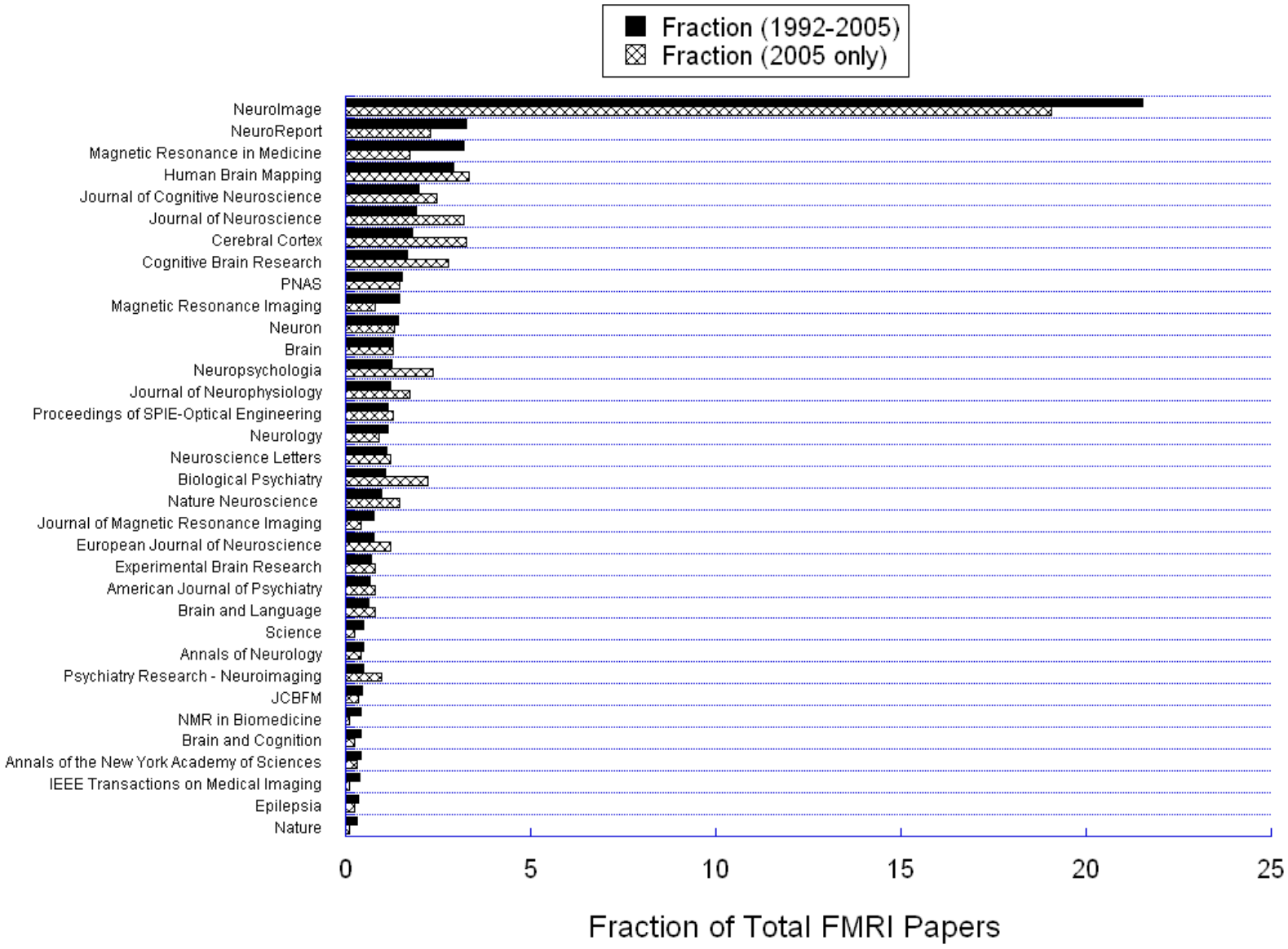
1991

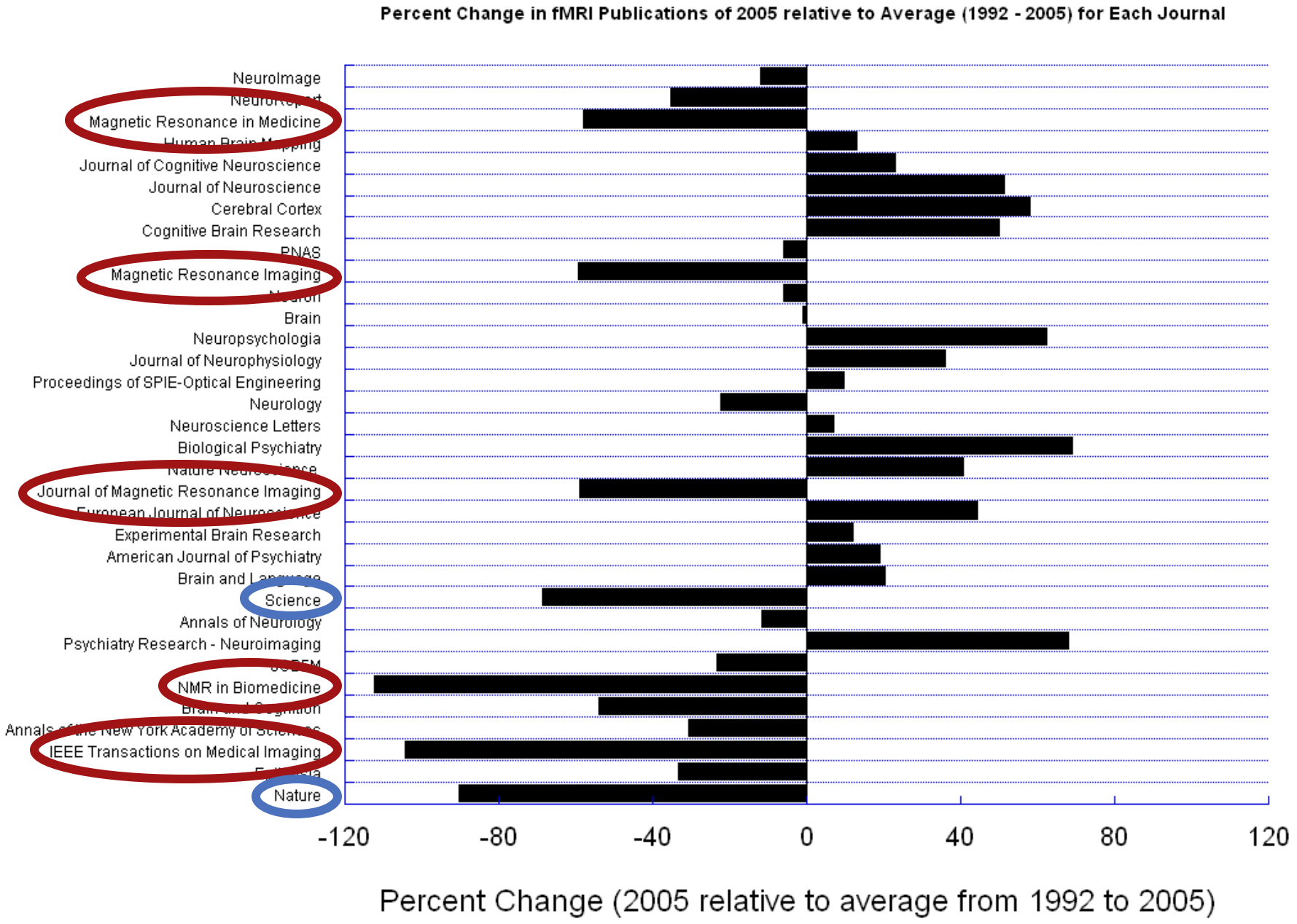
fMRI Papers Published per Year



"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
Magnetic Resonance in Medicine
Journal of Cognitive Neuroscience
Journal of Neuroscience
Cerebral Cortex
Cognitive Brain Research
PNAS
Magnetic Resonance Imaging
Brain
Neuropsychologia
Journal of Neurophysiology
Proceedings of SPIE-Optical Engineering
Neurology
Neuroscience Letters
Biological Psychiatry
Journal of Magnetic Resonance Imaging
Experimental Brain Research
American Journal of Psychiatry
Science
Psychiatry Research - Neuroimaging
NMR in Biomedicine
IEEE Transactions on Medical Imaging
Nature
-120
-80
-40
0
40
80
120
Percent Change (2005 relative to average from 1992 to 2005)

How most fMRI studies are performed

MRI parameters:
1.5T - 3T, 64 x 64 matrix, 3mm x 3mm x 5mm voxel size, whole brain, TR = 2 sec.

Paradigm:
Block design or event-related, single or multiple conditions.

Analysis:
Motion correct, multi-regression, spatial smoothing and spatial normalization, standard classical statistical tests, multi-subject averaging.

Hypothesis:
A region or network of regions show modulation with a task. This modulation is unique to the task and/or population.

How fMRI might be be performed

MRI parameters:

3T - 11.7T, 256 x 256 matrix, 0.5 x 0.5 x 0.5 voxel size, whole brain TR = 1sec or select slab TR = 100 ms.

Paradigm:

Natural, continuous, or no stimuli/task. Simultaneous multi-modal, or multiple contrast measurements.

Analysis:

Motion correct, dynamic Bo-field correction, no spatial or temporal smoothing, machine learning algorithms, pattern classification, hemodynamic parameter assessment, correlation with behavior.

Hypothesis:

Similar to previous but using the high resolution patterns, fluctuations, dynamics, and contrast mechanisms that we are still figuring out how to interpret and extract.

Technology

Coil arrays
High field strength
High resolution
Novel functional contrast

Methodology

Connectivity assessment
Multi-modal integration
Pattern classification
Task design

Interpretation

Fluctuations
Dynamics
Cross - modal comparison

Applications

Basic Neuroscience
Behavior correlation/prediction
Pathology correlation

Technology

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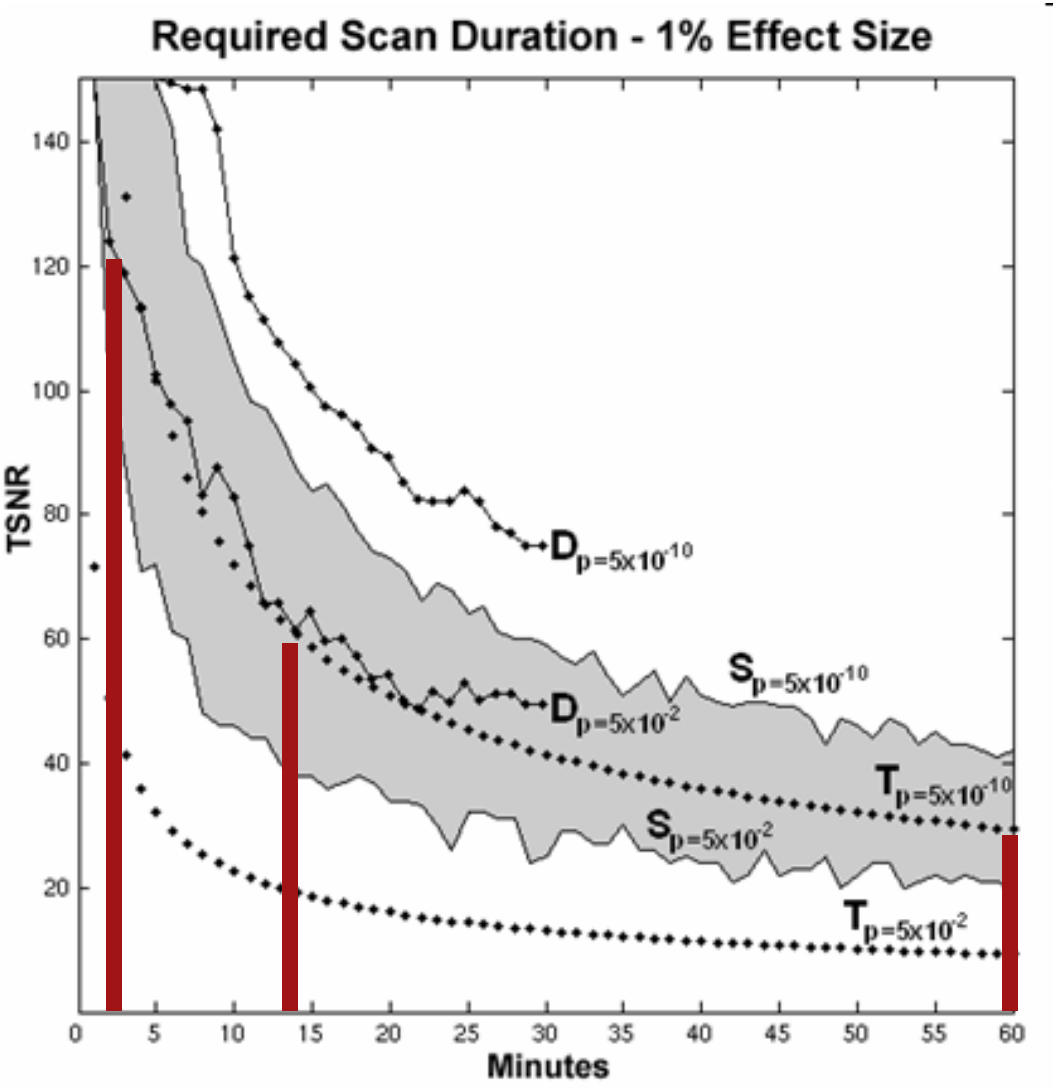
Technology

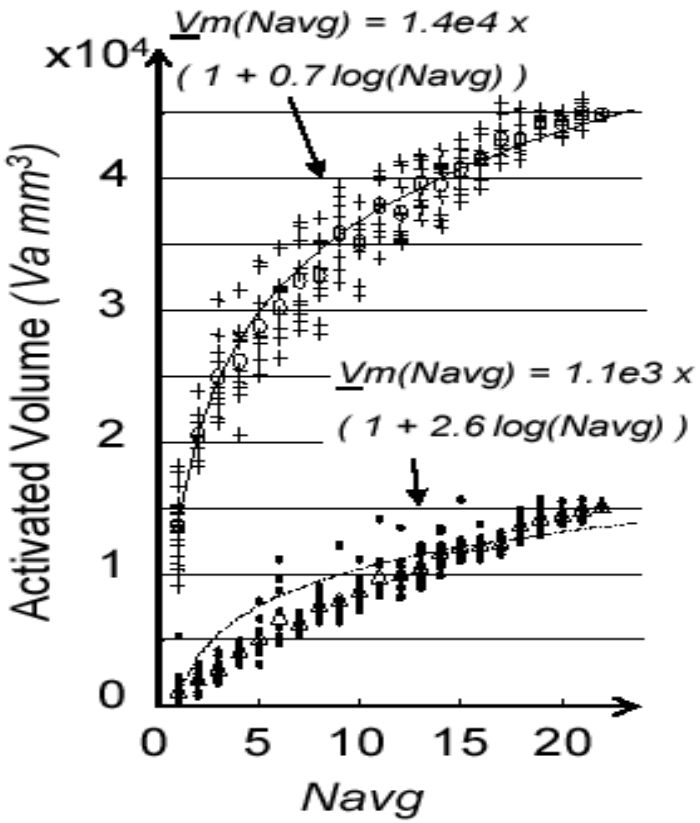


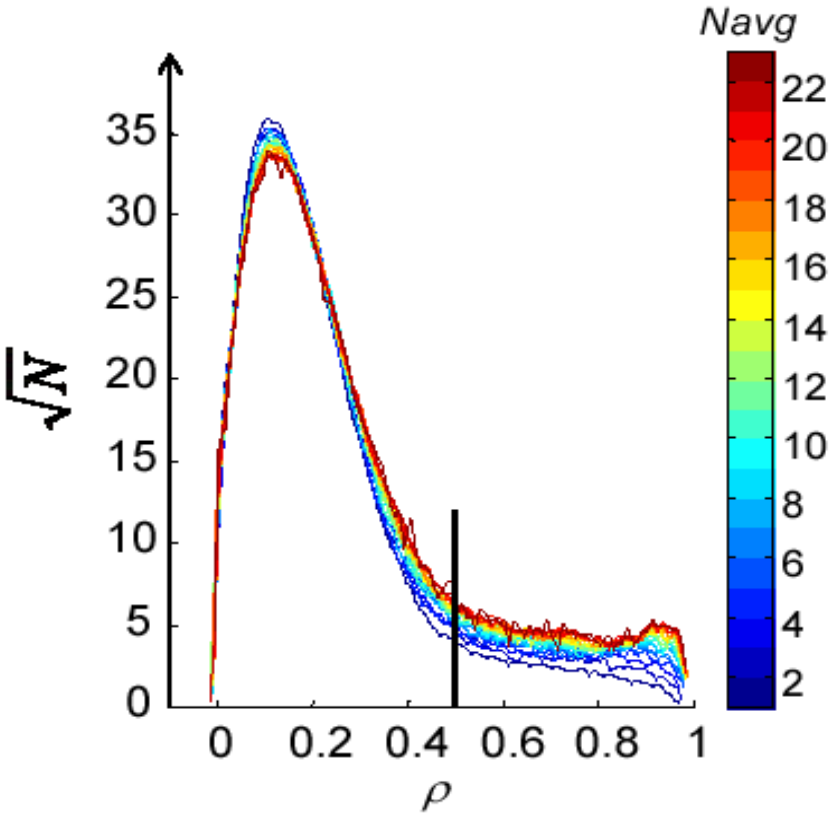
Reasons for higher SNR

-Shorter scan duration
-Higher Resolution
-More subtle comparisons

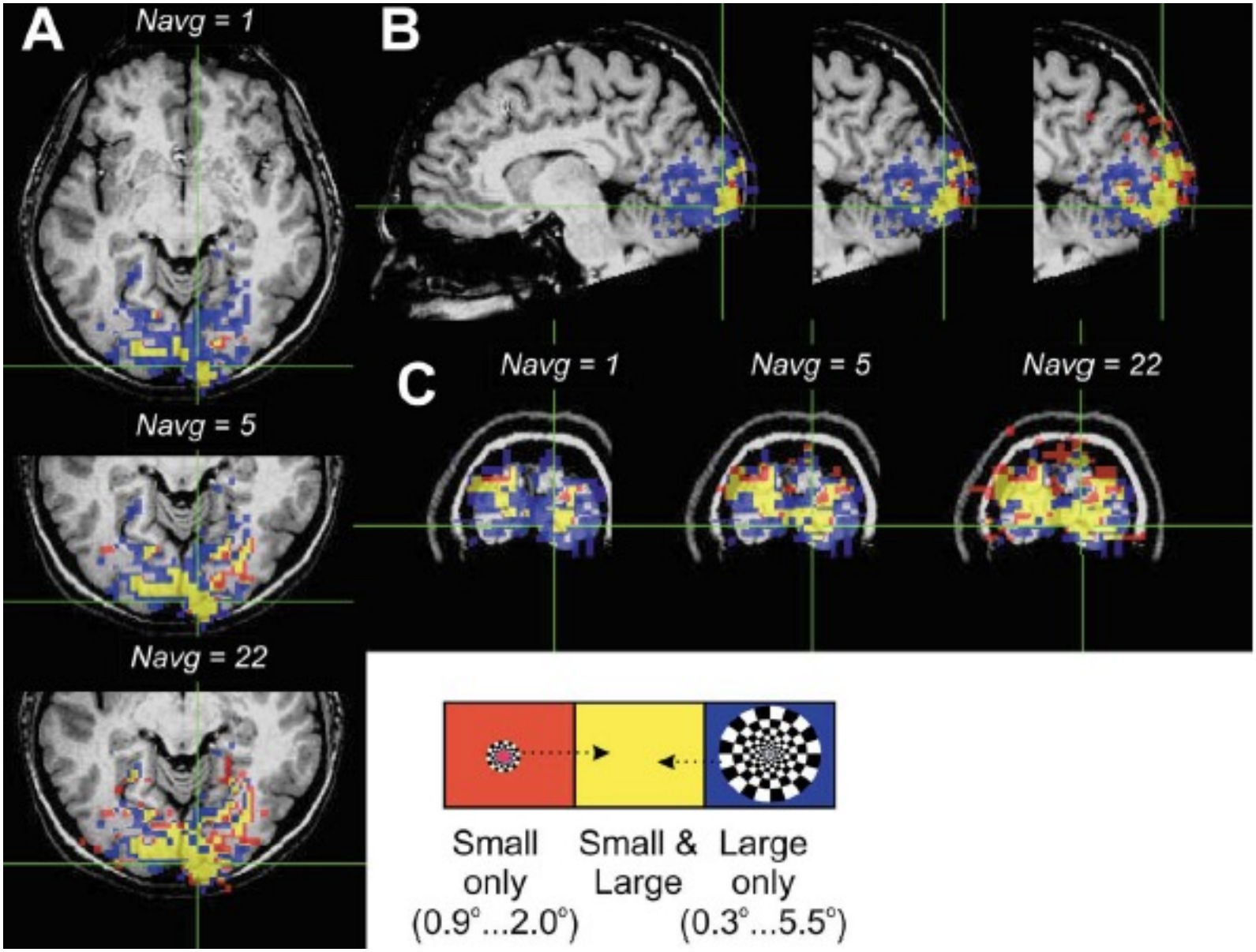
Murphy et al.

Technology





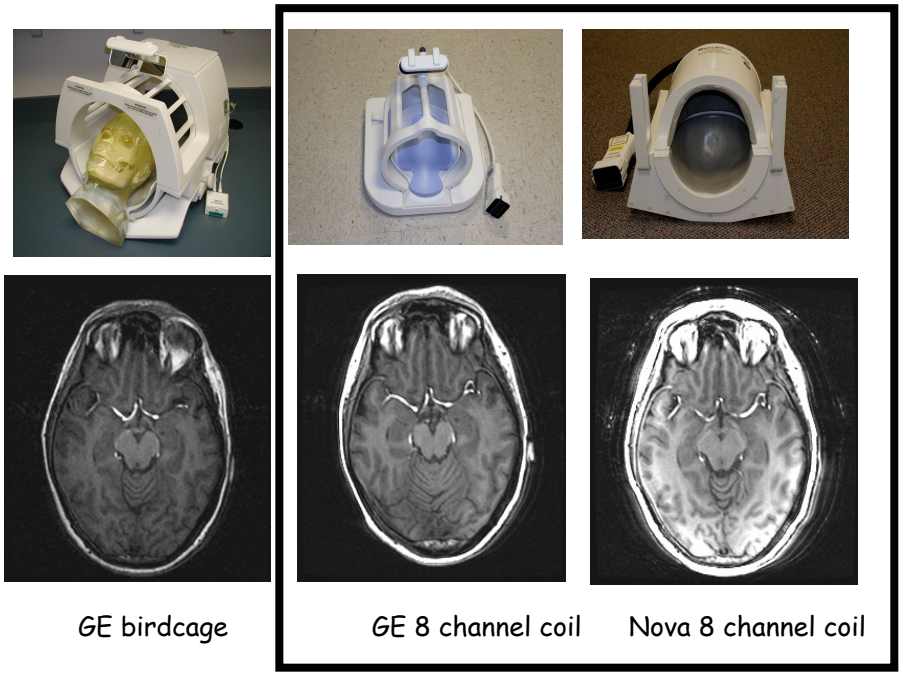
Z. S. Saad, K. M. Ropella, E. A. DeYoe, P. A. Bandettini, The spatial extent of the BOLD response. NeuroImage, 19: 132-144, (2003)



Z. S. Saad, K. M. Ropella, E. A. DeYoe, P. A. Bandettini, The spatial extent of the BOLD response. NeuroImage, 19: 132-144, (2003)

Technology

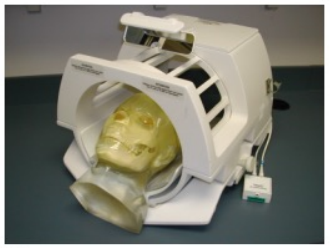
8 channel parallel receiver coil



GE birdcage | GE 8 channel coil | Nova 8 channel coil

16 channel parallel receiver coil

A



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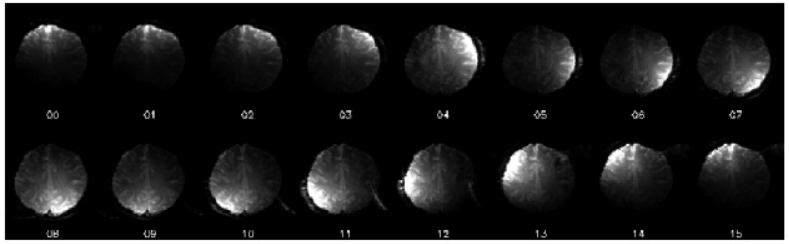
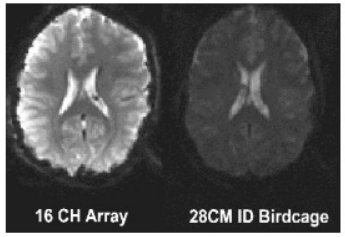


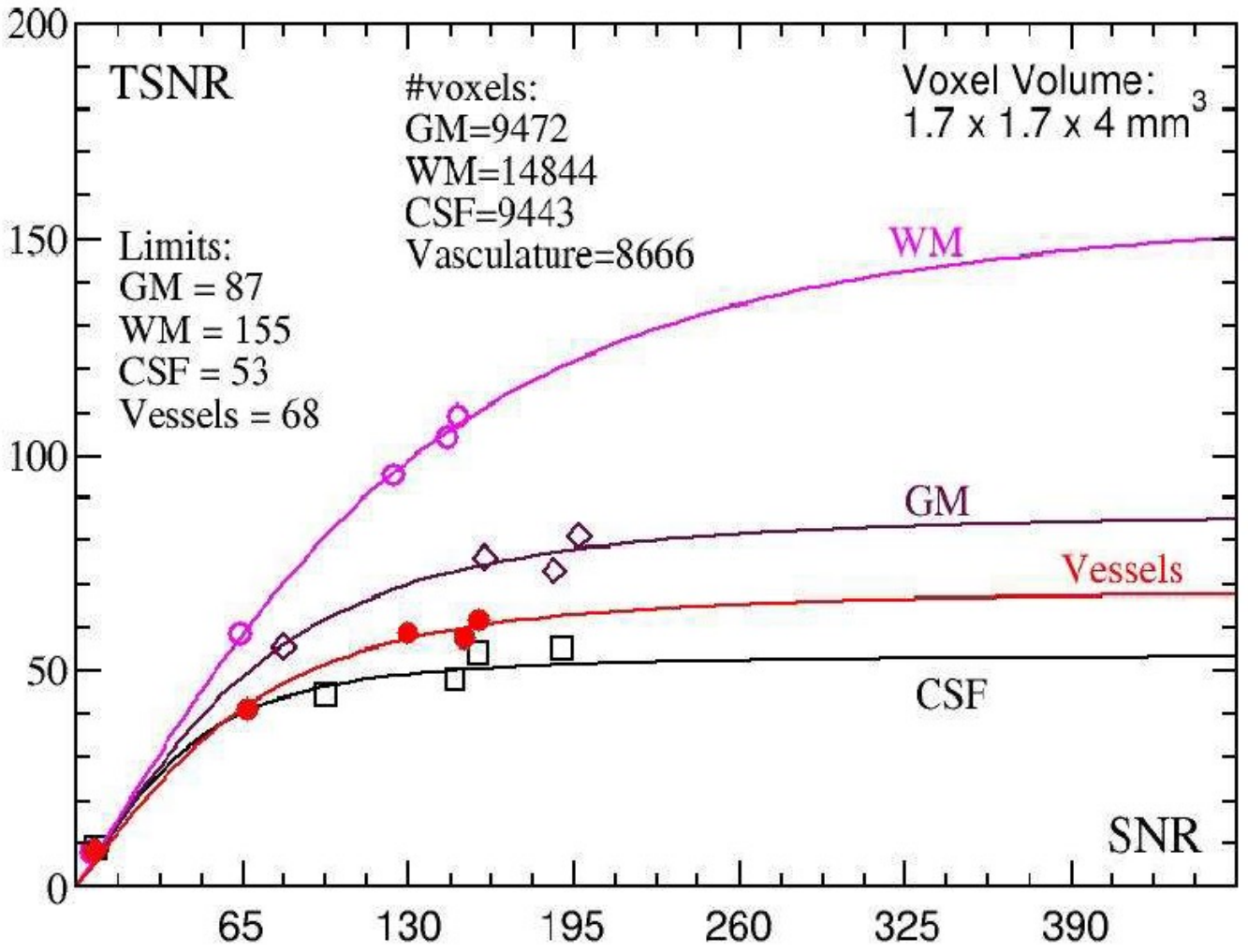
C



D

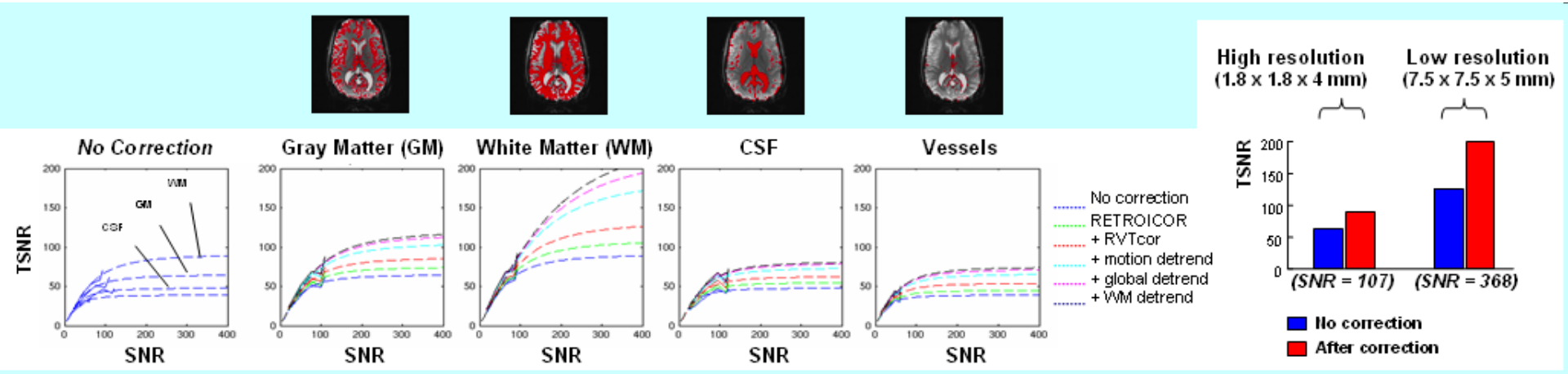
J. Bodurka, et al, Magnetic Resonance in Medicine 51 (2004) 165-171.

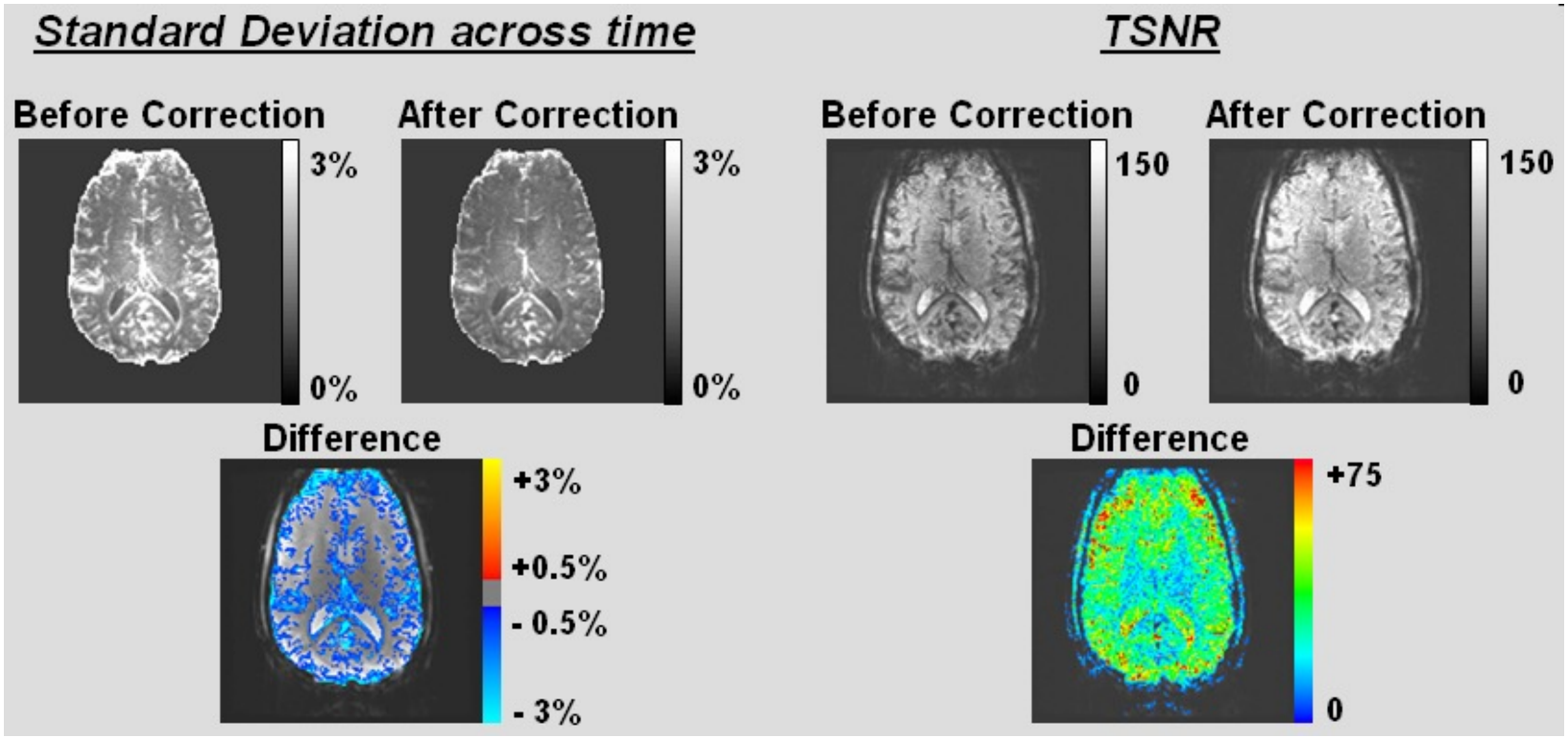
Technology



J. Bodurka

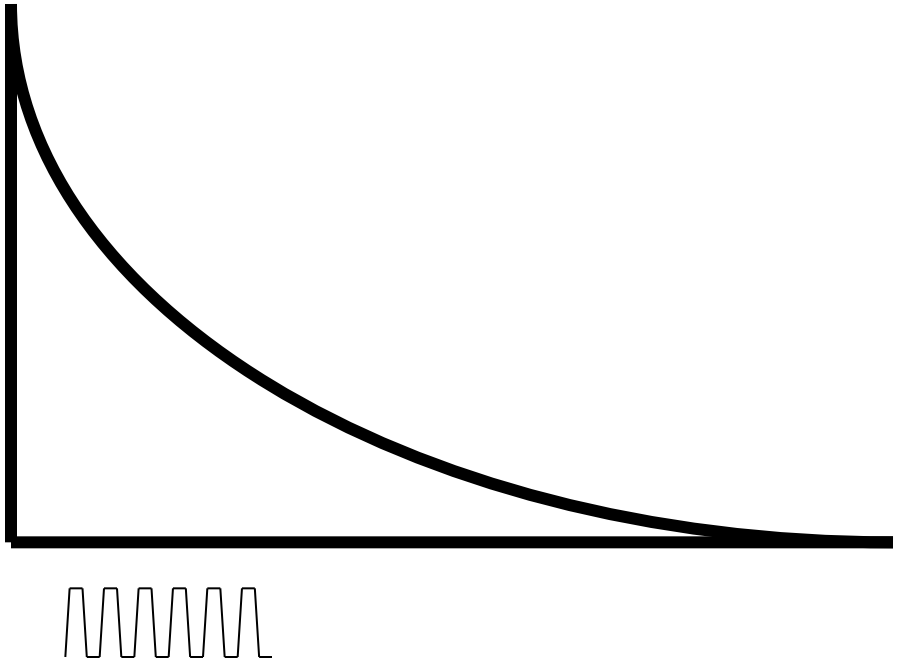
Technology



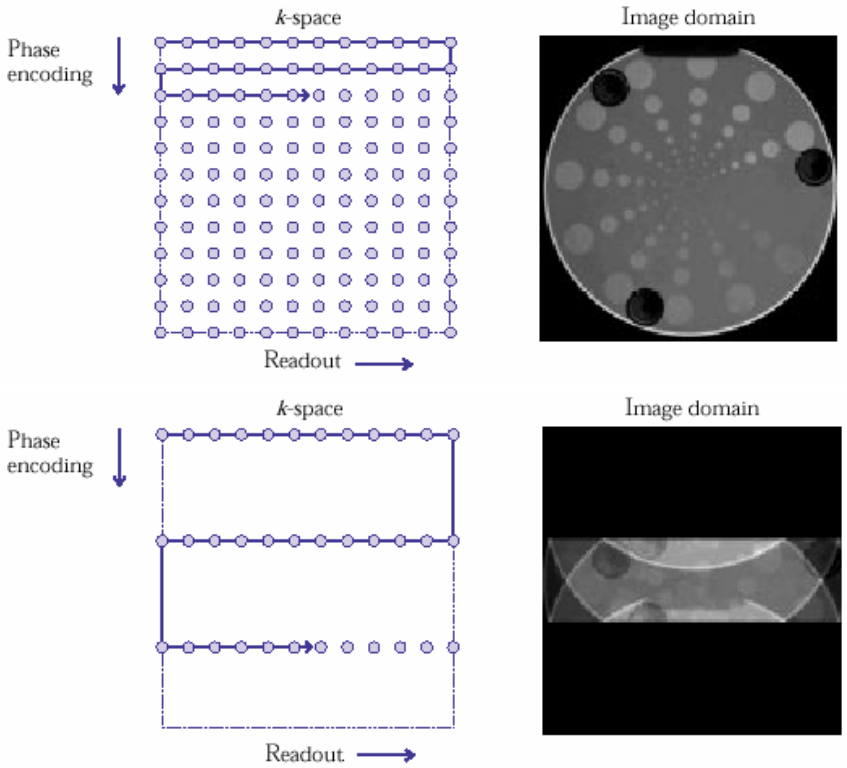


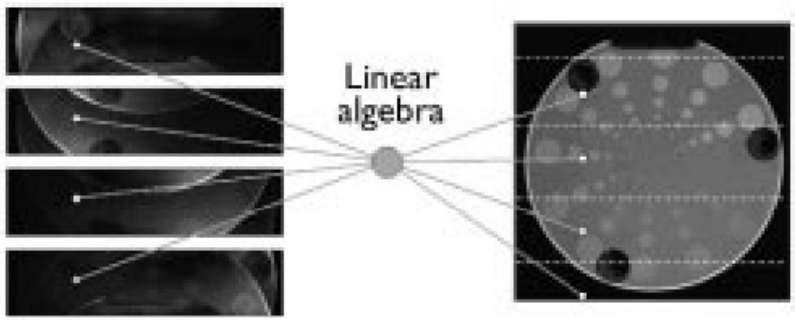
R. Birn, et al. ISMRM 2006

Technology



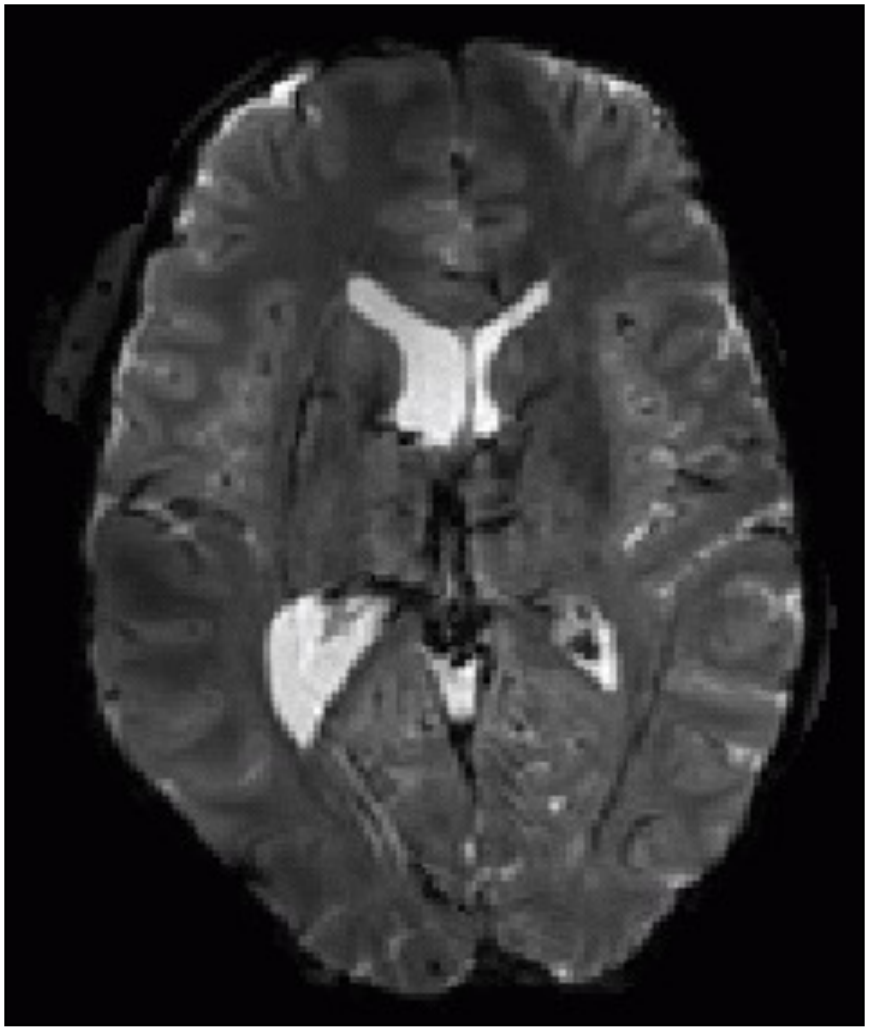
≈ 5 to 30 ms





Pruessmann, et al.

Technology



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

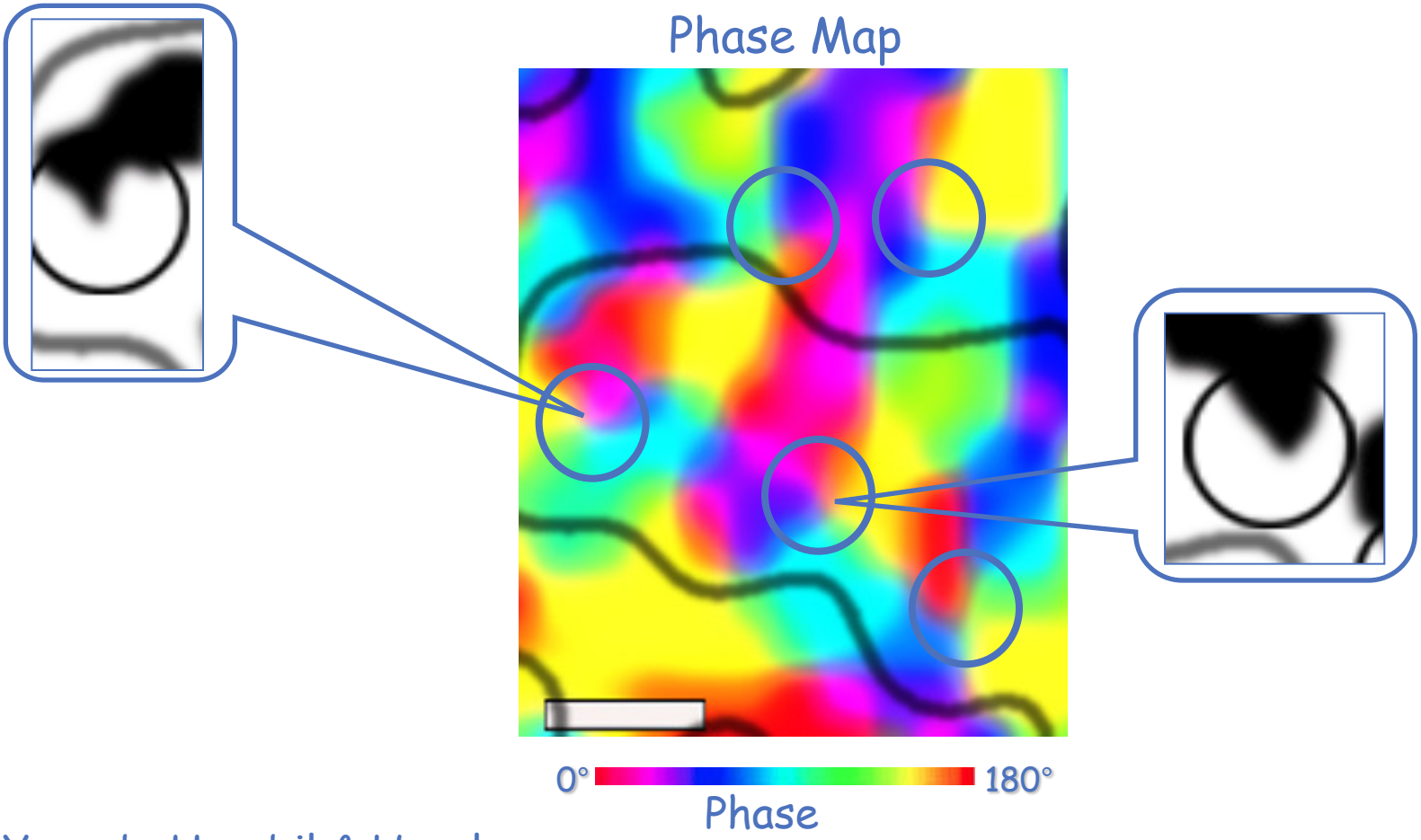
Technology

fiber bundles?

Courtesy Tie-Qiang Li, NINDS

Technology

Orientation Columns in Human V1 as Revealed by fMRI at 7T



Yacoub, Ugurbil & Harel
University of Minnesota / CMRR
HBM 2006

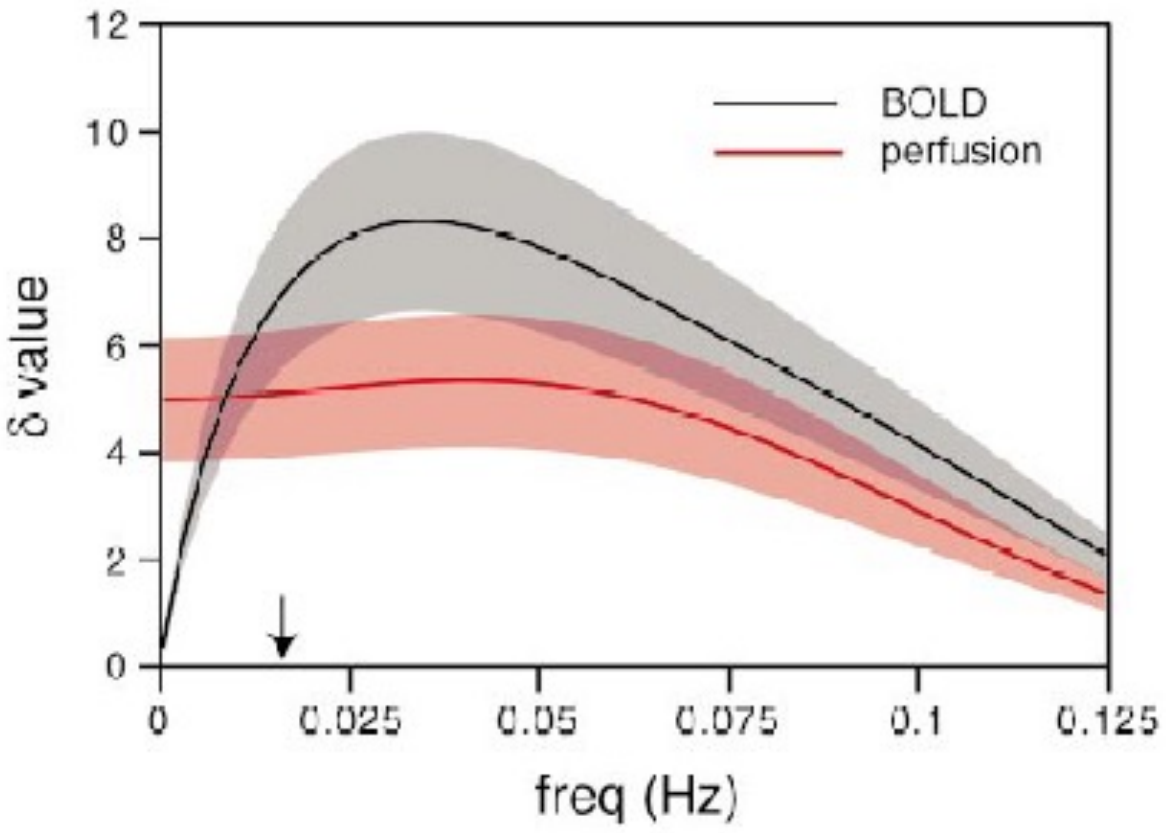
Scalebar = 0.5 mm

fMRI Contrast

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

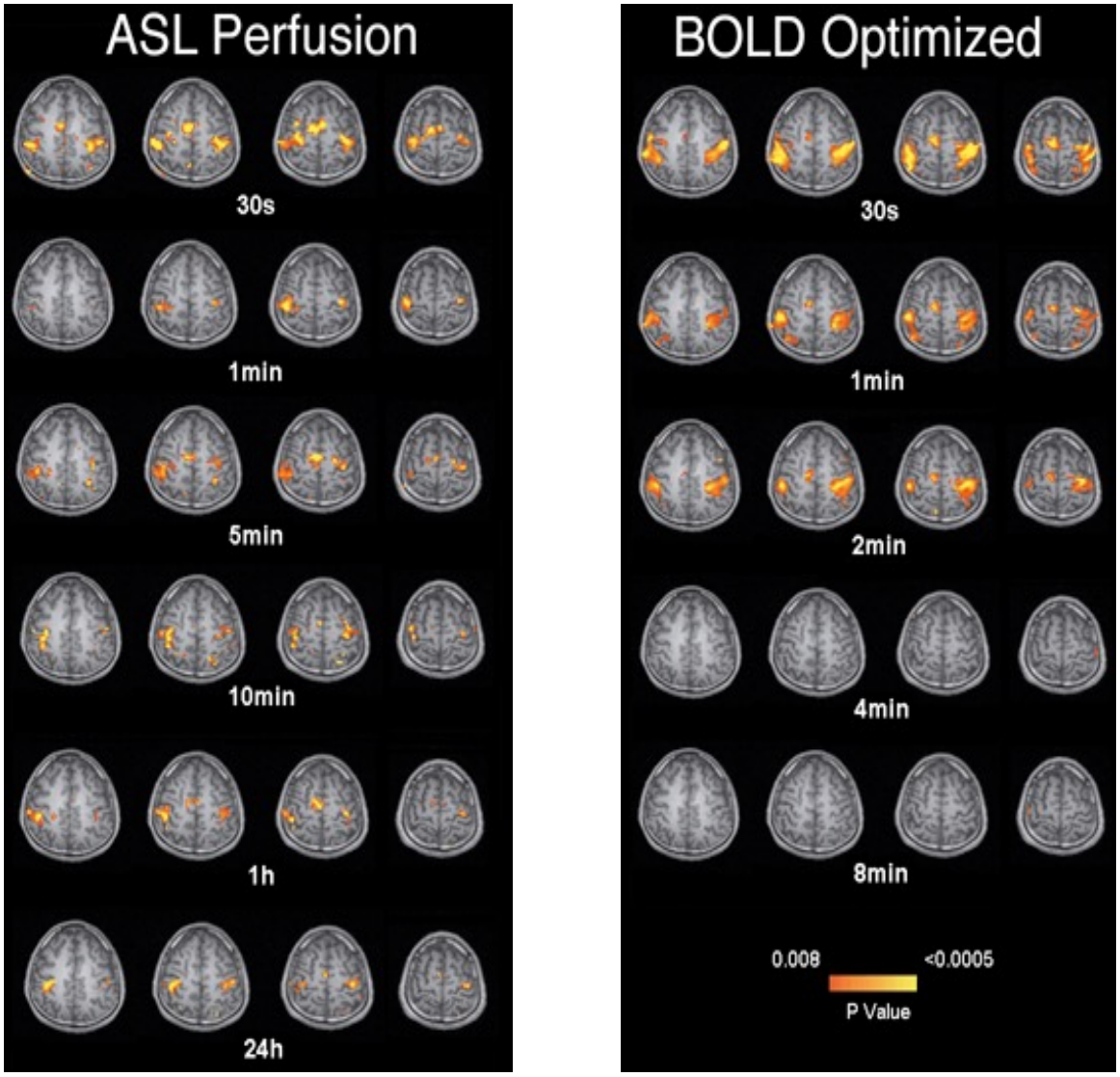
Technology

Better than BOLD for long duration activation…



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

Perfusion vs. BOLD: Low Task Frequency



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

Technology

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High field strength
High resolution
Novel functional contrast

Methodology

Connectivity assessment
Multi-modal integration
Pattern classification
Task design

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Cross - modal comparison

Interpretation

Basic Neuroscience
Behavior correlation/prediction
Pathology correlation

Applications

Methodology

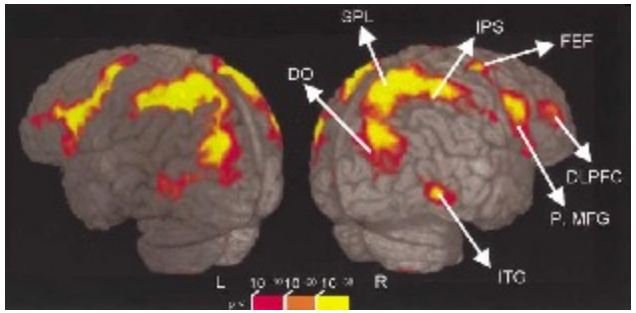
Mapping ⟷ "Reading"

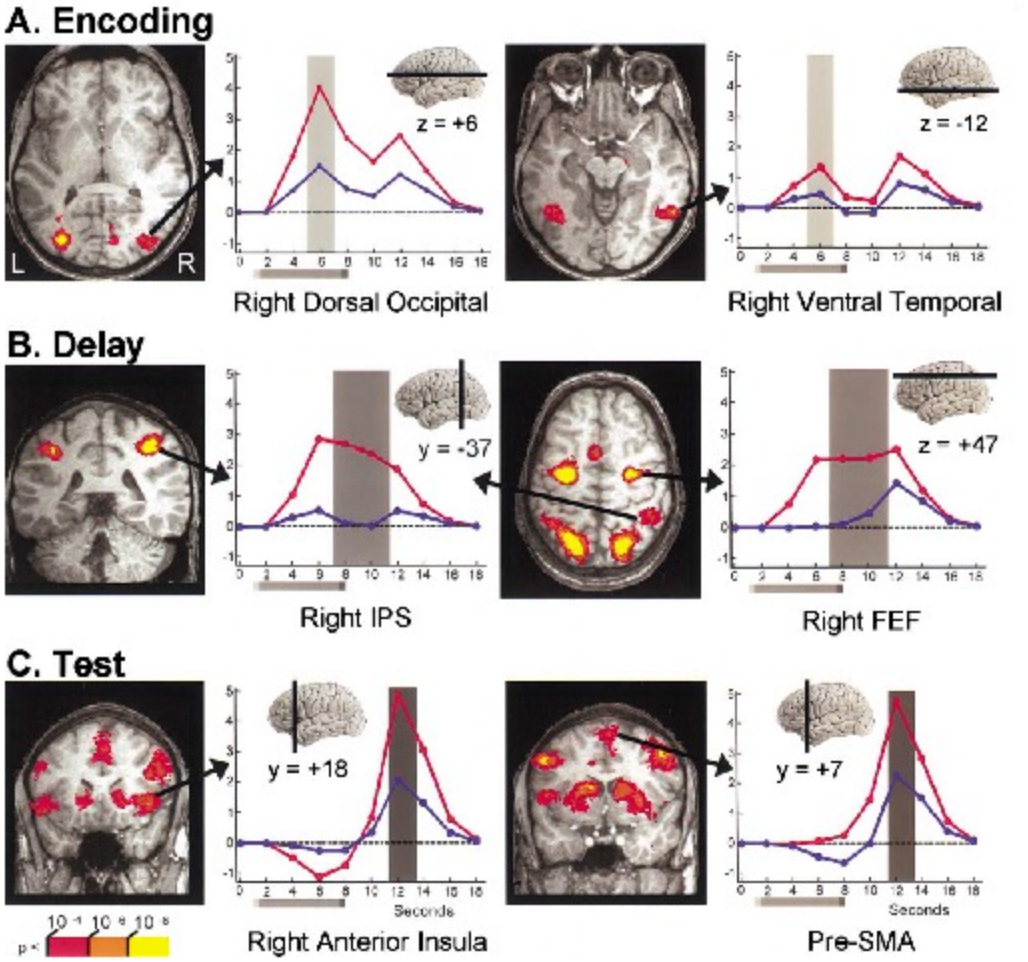
Methodology

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

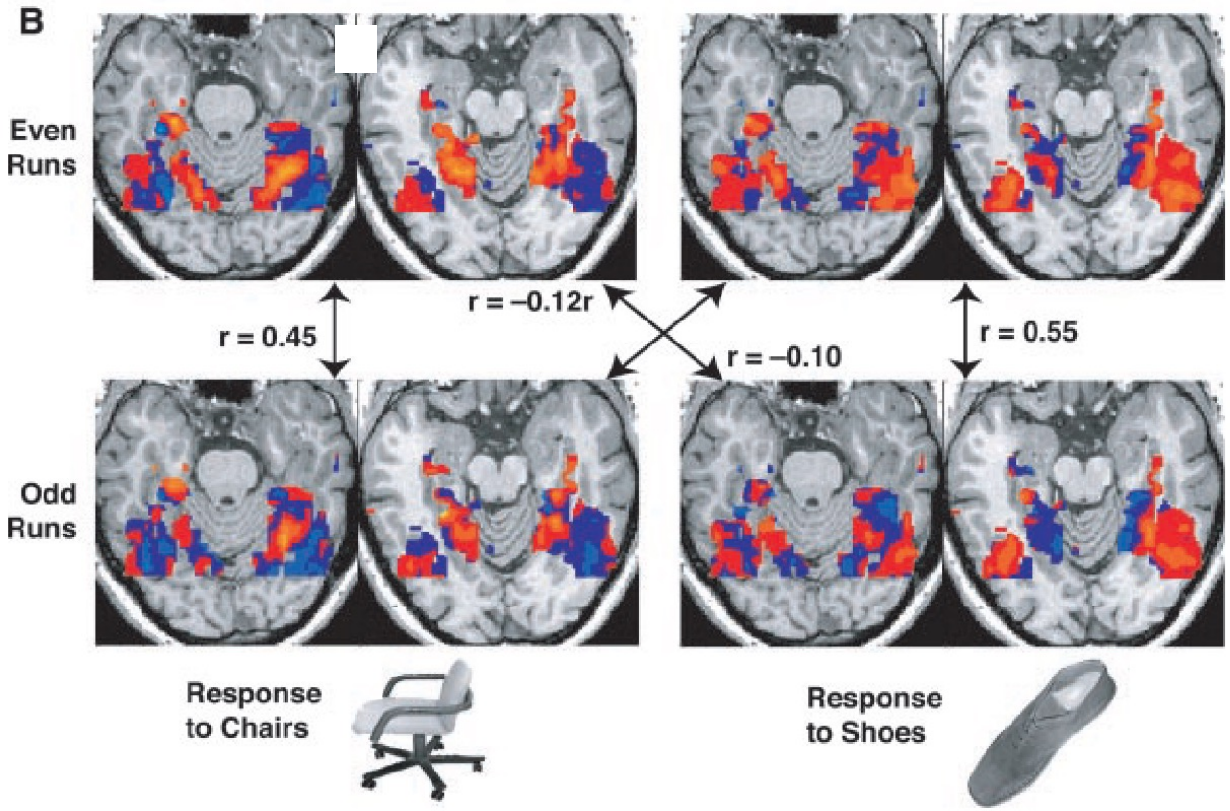




Methodology

Ventral temporal category representations

Object categories are associated with distributed representations in ventral temporal cortex



Haxby et al. 2001

Methodology

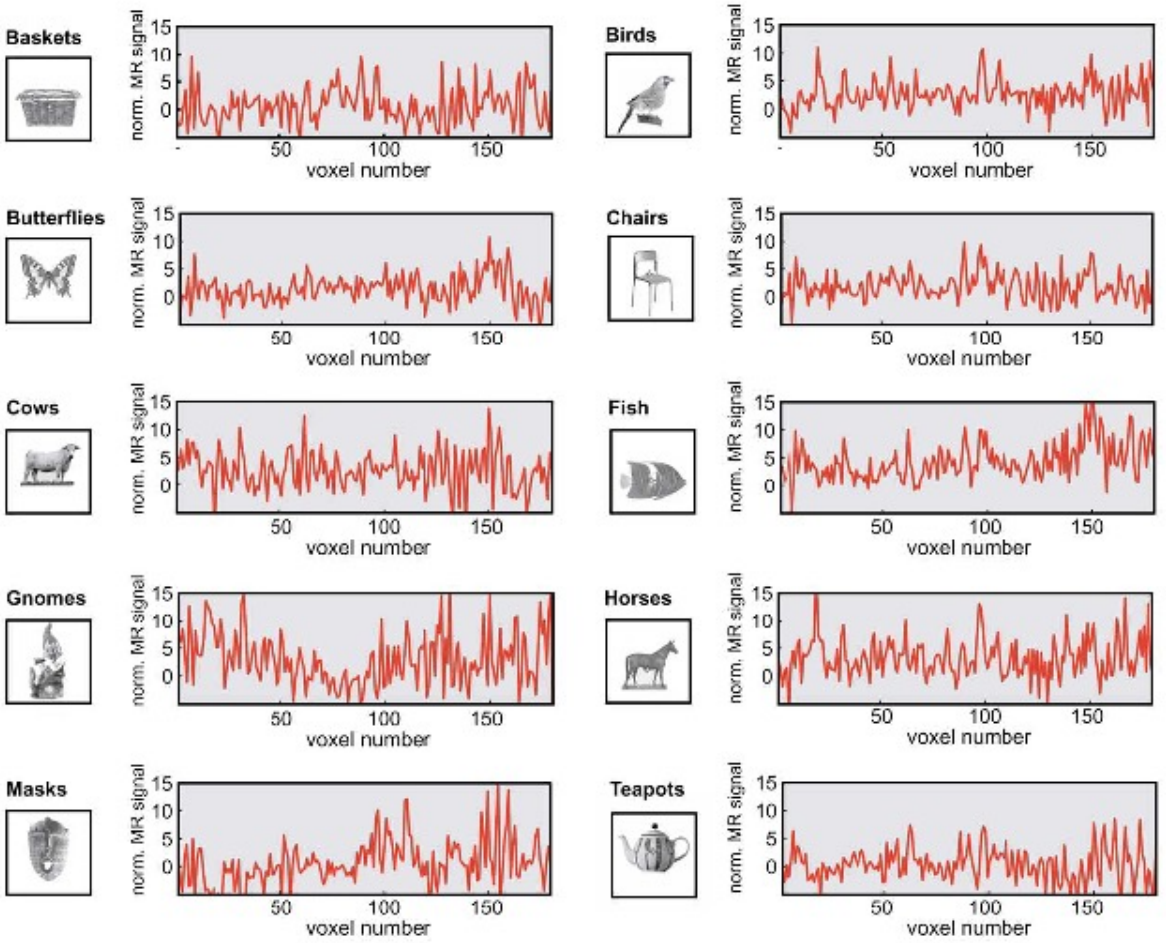
Functional magnetic resonance imaging (fMRI) "brain reading": detecting and classifying distributed patterns of fMRI activity in human visual cortex

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

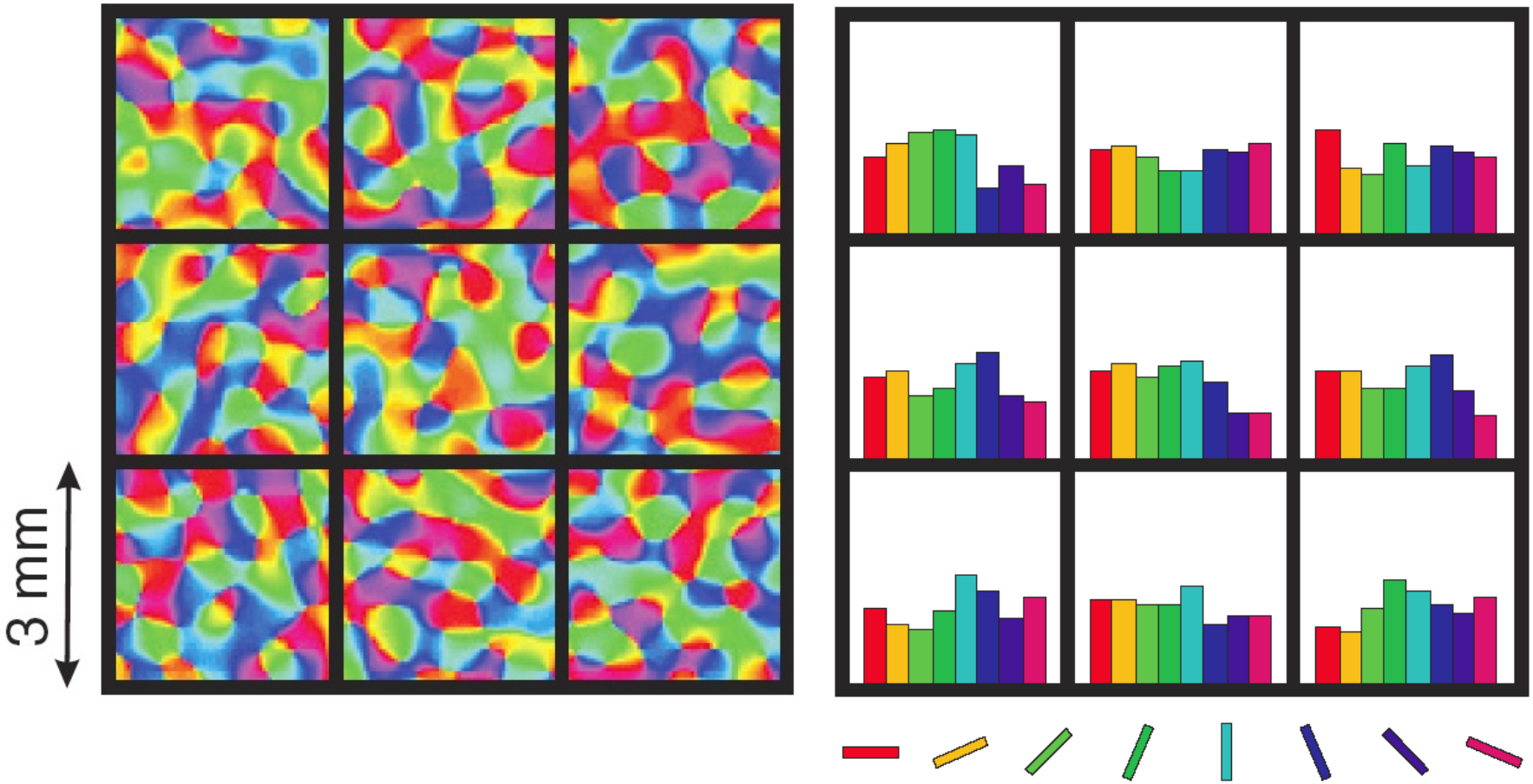
[a] Rowland Institute for Science, Cambridge, MA 02142, USA
[b] Athinoula A. Martinos Center for Structural and Functional Biomedical Imaging, Charlestown, MA 02129, USA
[c] HyperVision, Inc., P.O. Box 158, Lexington, MA 02420, USA

Received 15 July 2002; accepted 10 December 2002

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



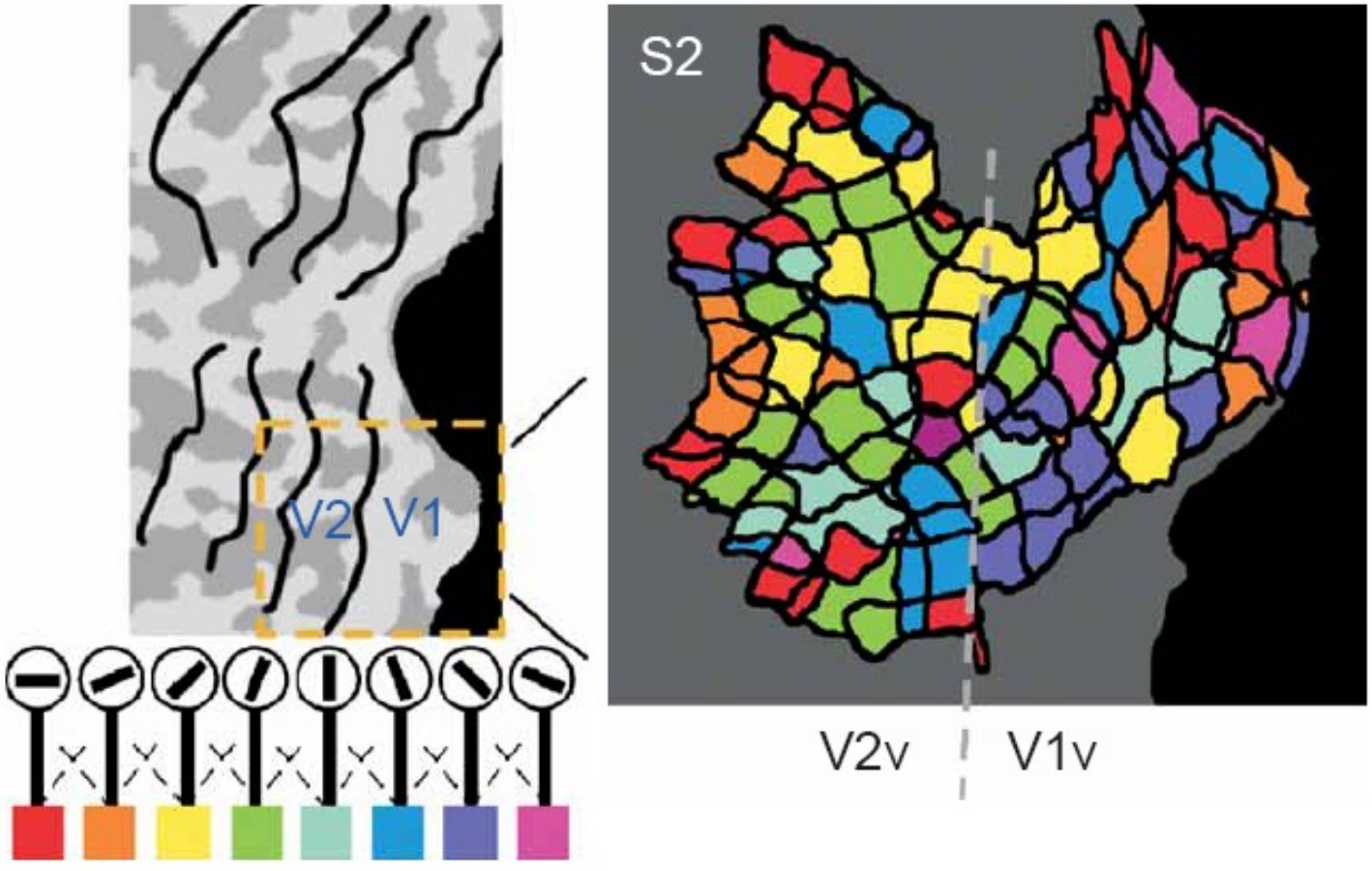
Methodology



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

Methodology

Lower spatial frequency clumping



Kamitani & Tong (2005)

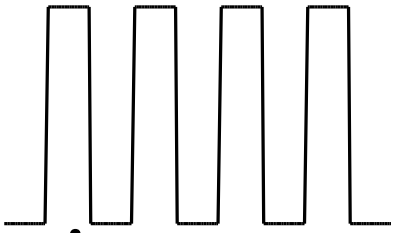
Pattern-recognition analysis of fMRI activity patterns

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

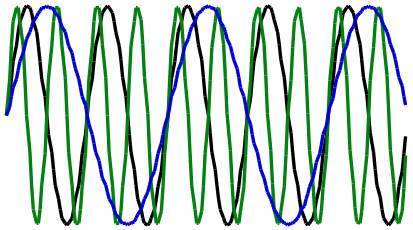
Methodology

Neuronal Activation Input Strategies

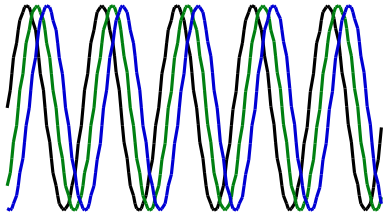
1. Block Design



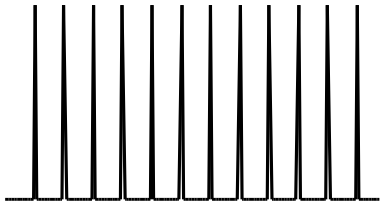
2. Frequency Encoding



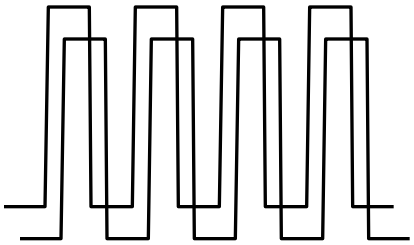
3. Phase Encoding



4. Event-Related



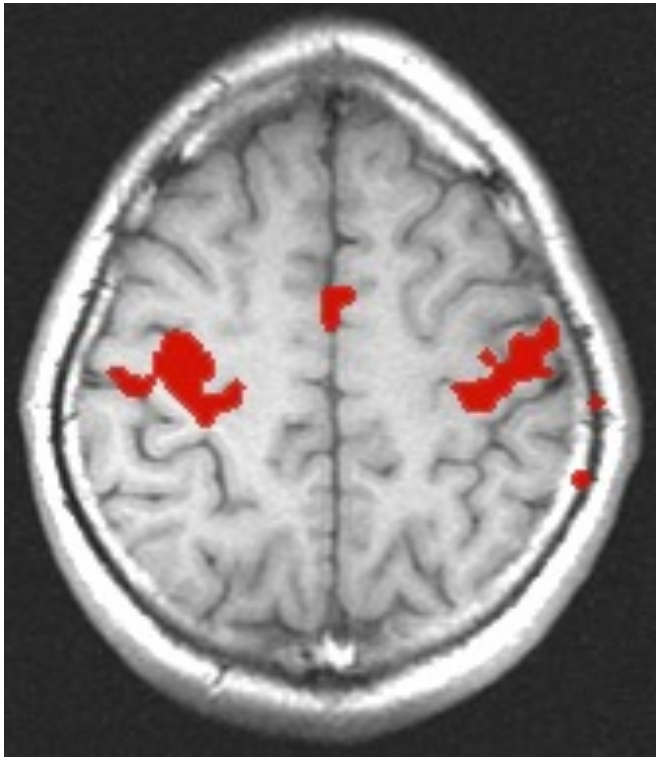
5. Orthogonal Block Design



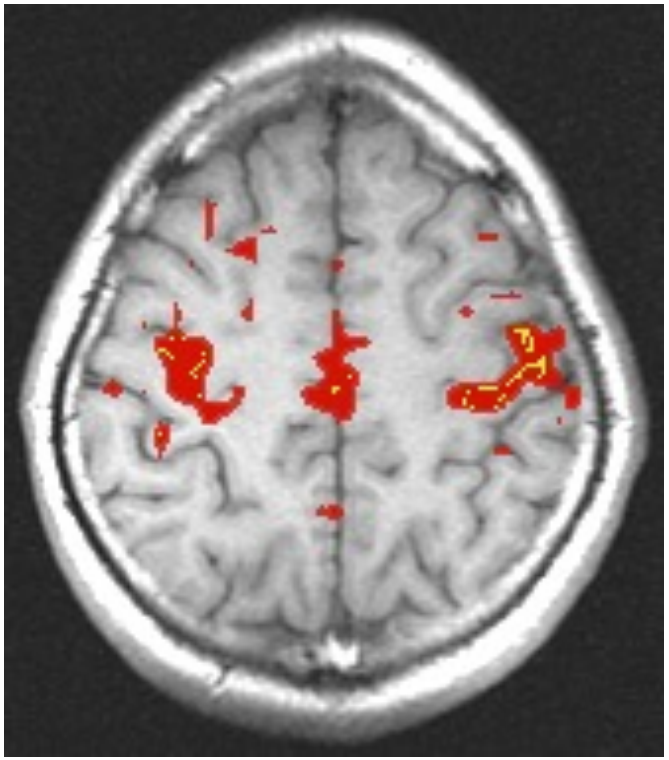
6. Free Behavior Design.

Methodology

Resting State Correlations



Activation:
correlation with reference function



Rest:
seed voxel in motor cortex

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

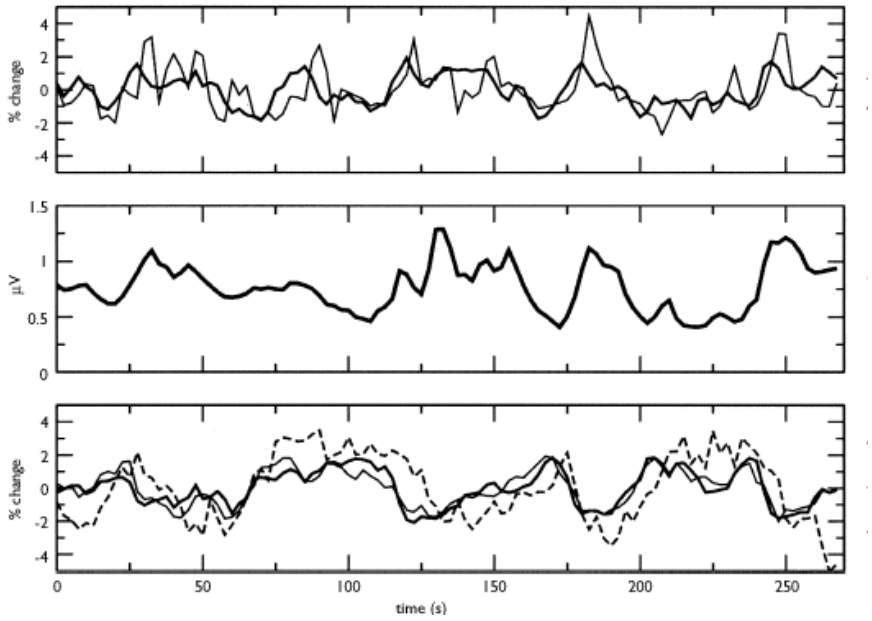
Methodology

BOLD correlated with 10 Hz power during "Rest"

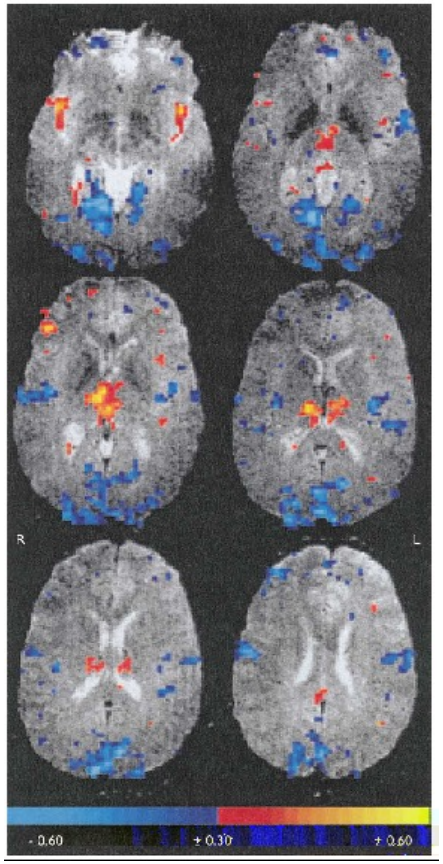
Positive

10 Hz power

Negative

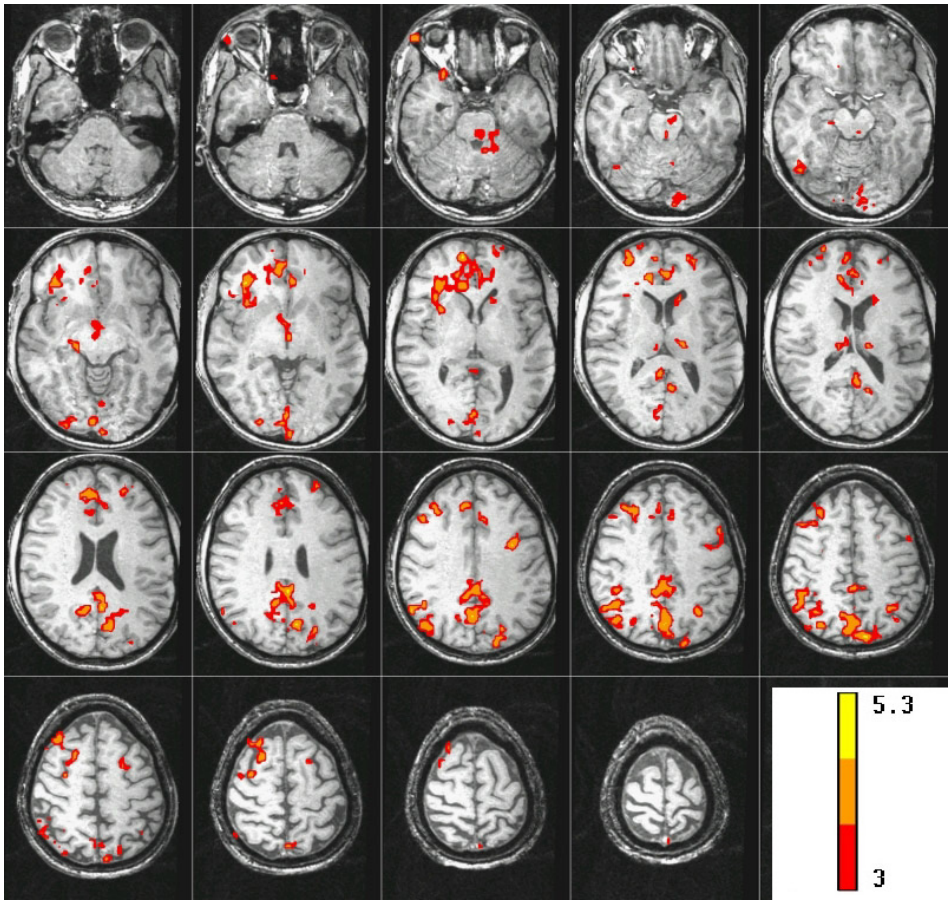


Goldman, et al (2002), Neuroreport



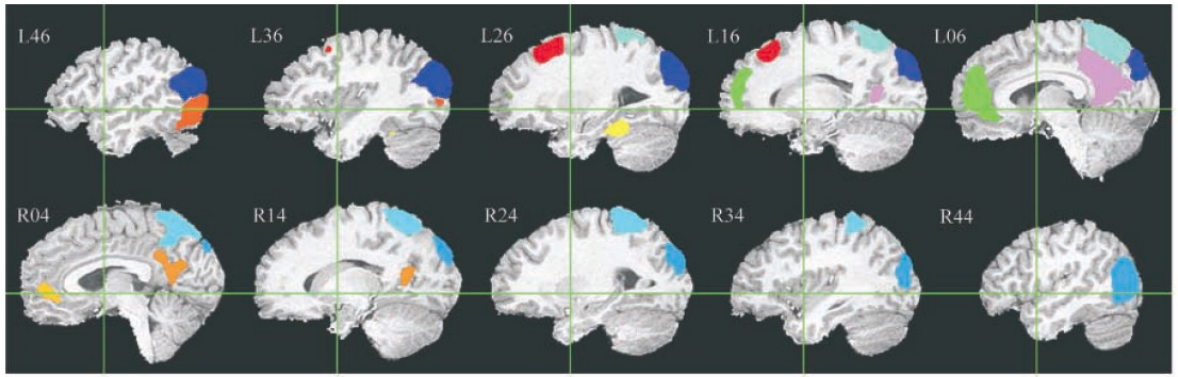
Methodology

BOLD correlated with SCR during "Rest"



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

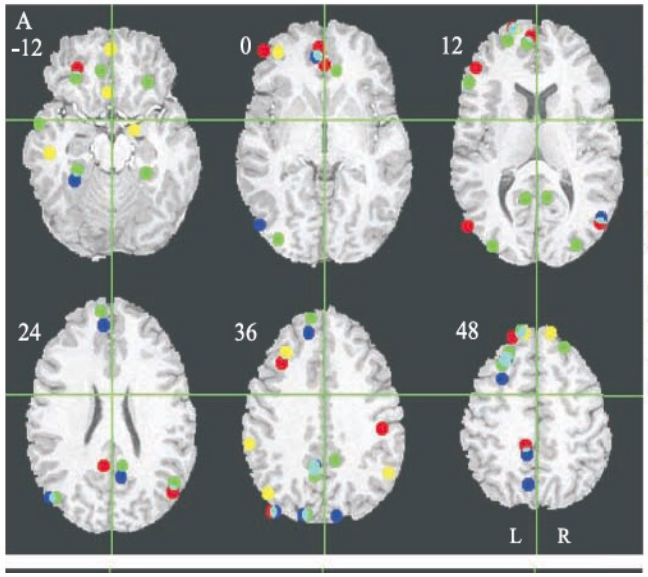
Regions showing decreases during cognitive tasks



L Fusiform Gyrus
R Anterior Cingulate Gyrus
R Posterior Cingulate Gyrus
L Middle Occipital Gyrus

L Middle Frontal Gyrus
L Posterior Cingulate Gyrus
L Anterior Cingulater/Superior Frontal Gyrus
L Precuneus/Superior Parietal Lobule

R Precuneus/Superior Parietal Lobule
R Posterior Parieto-Occipital Cortex
L Posterior Parieto-Occipital Cortex



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

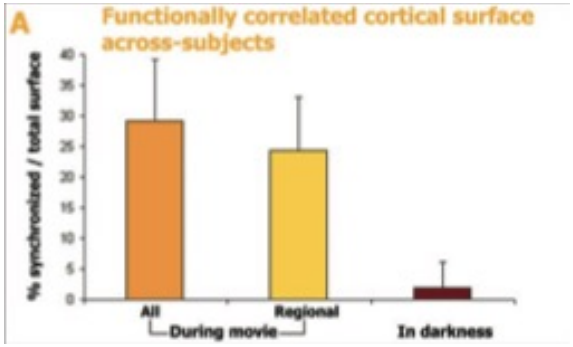
Location of deactivation common to two or more of the above studies

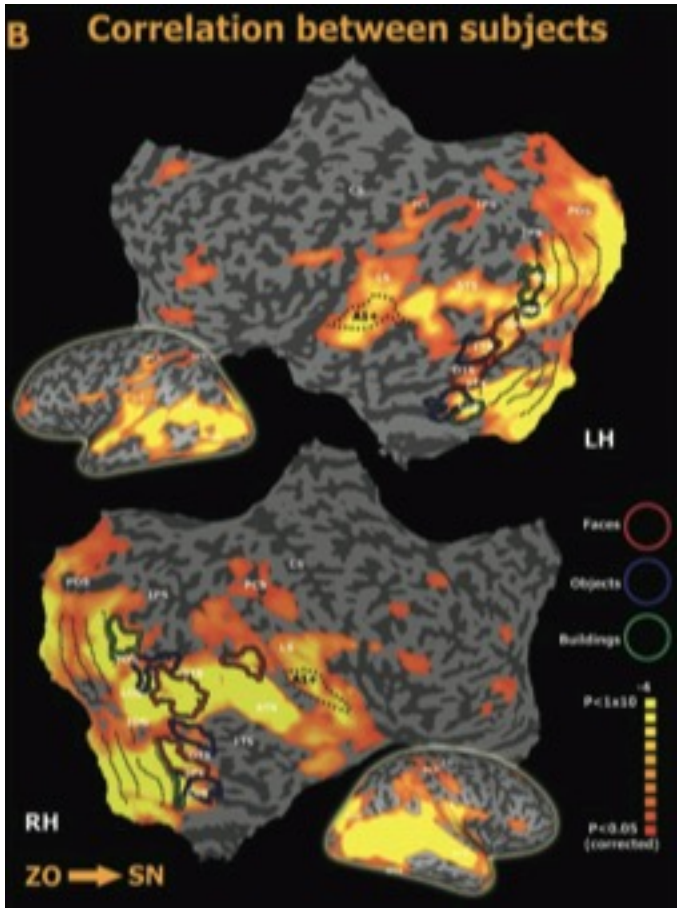
McKiernan, et al (2003), Journ. of Cog. Neurosci. 15 (3), 394-408

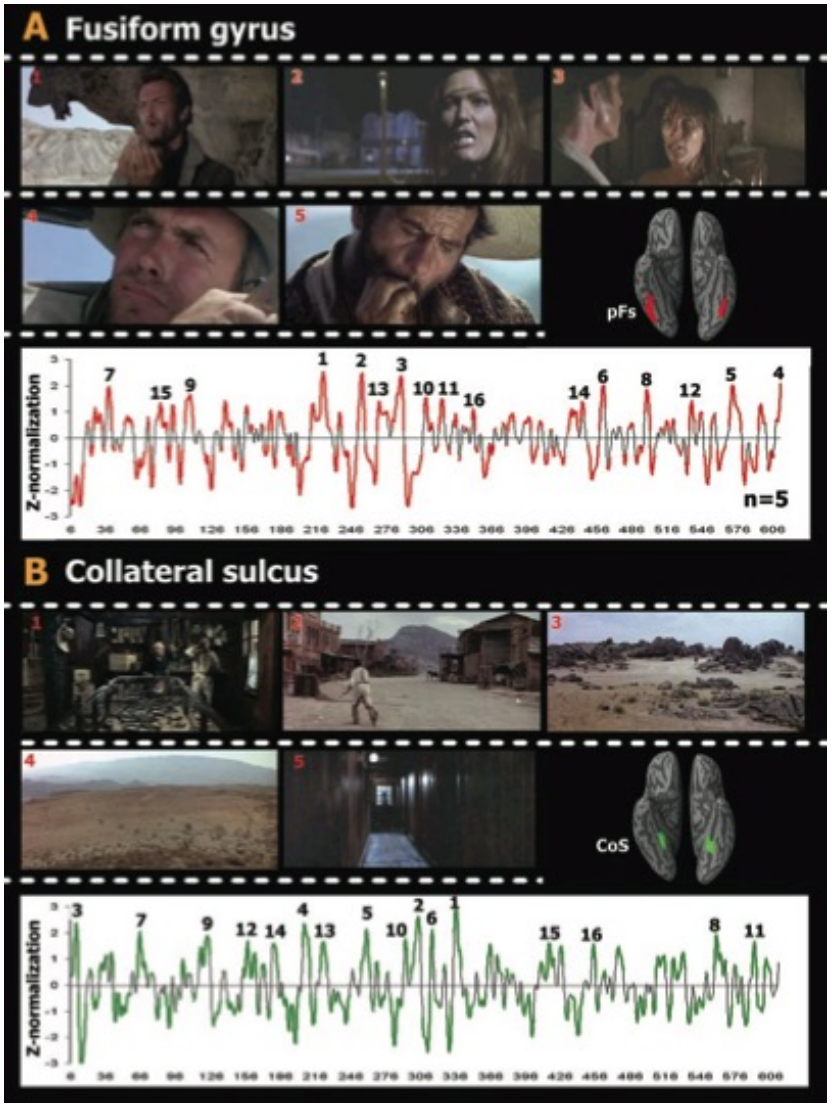
Resting state connectivity

Decreases during
cognitive tasks

Methodology



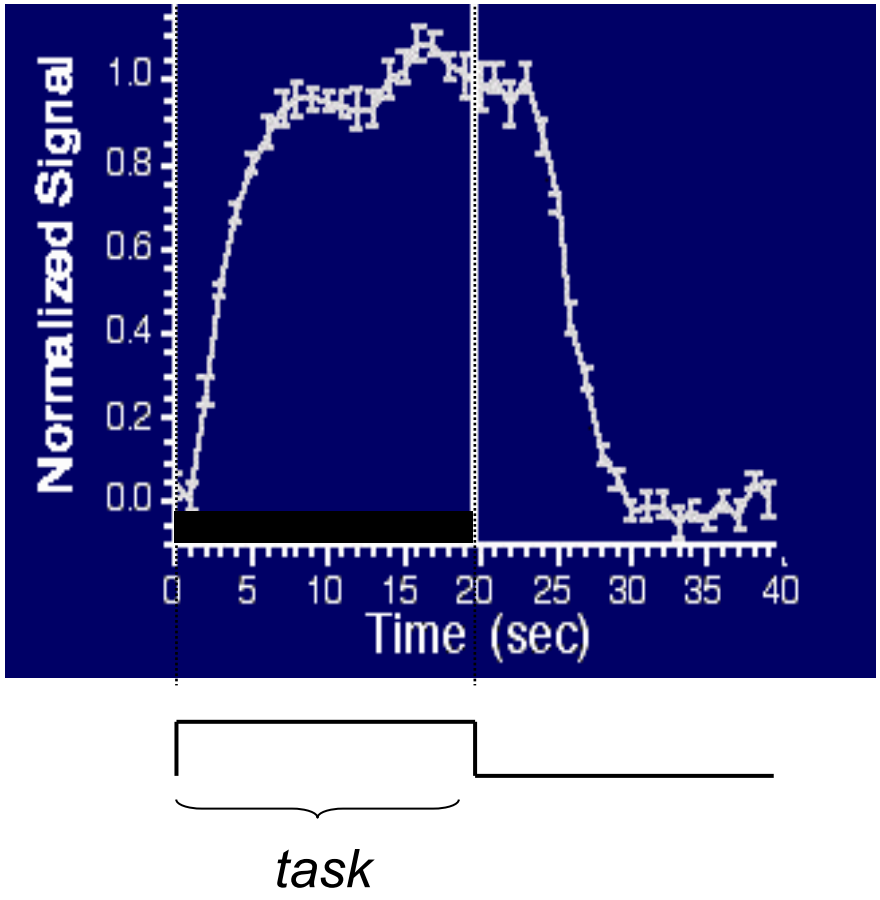


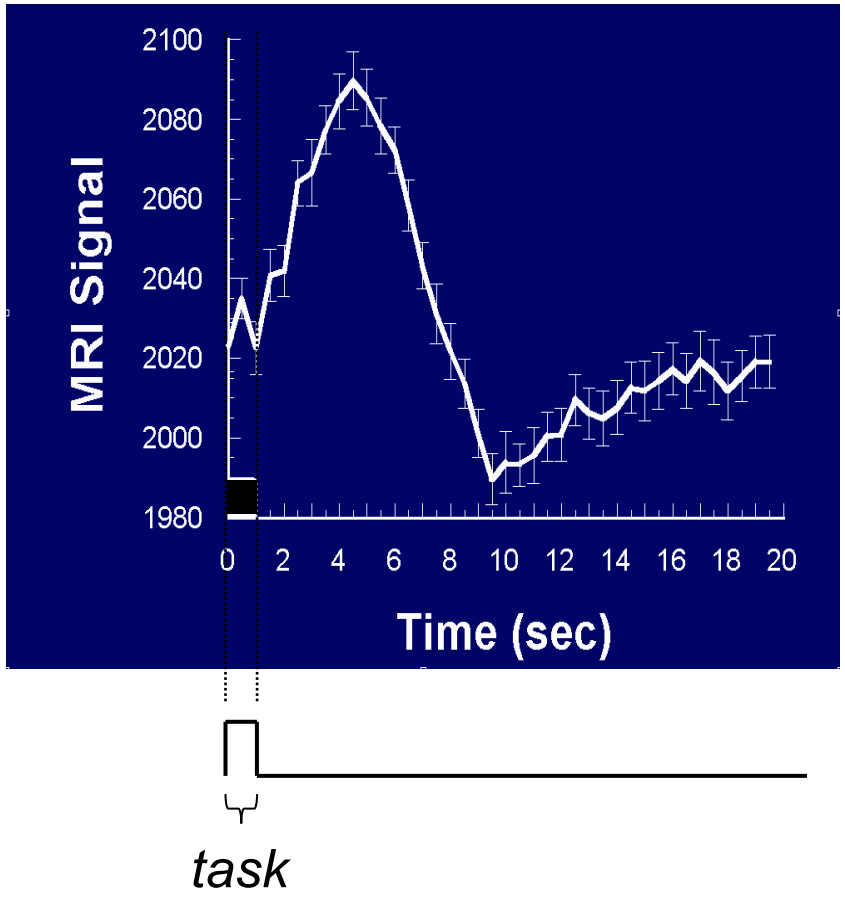


Hasson, et al (2004), Science, 303, 1634-1640

Methodology

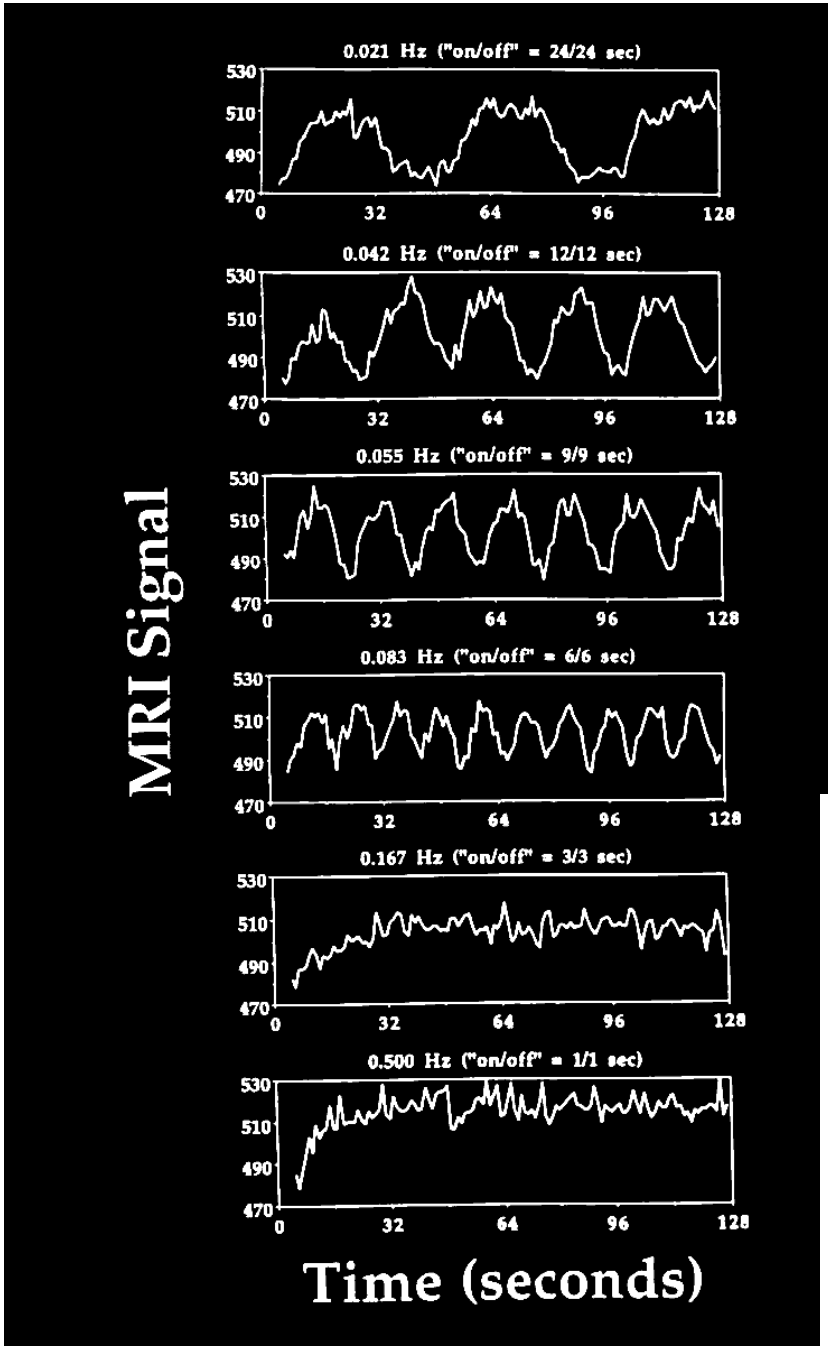
Temporal Resolution

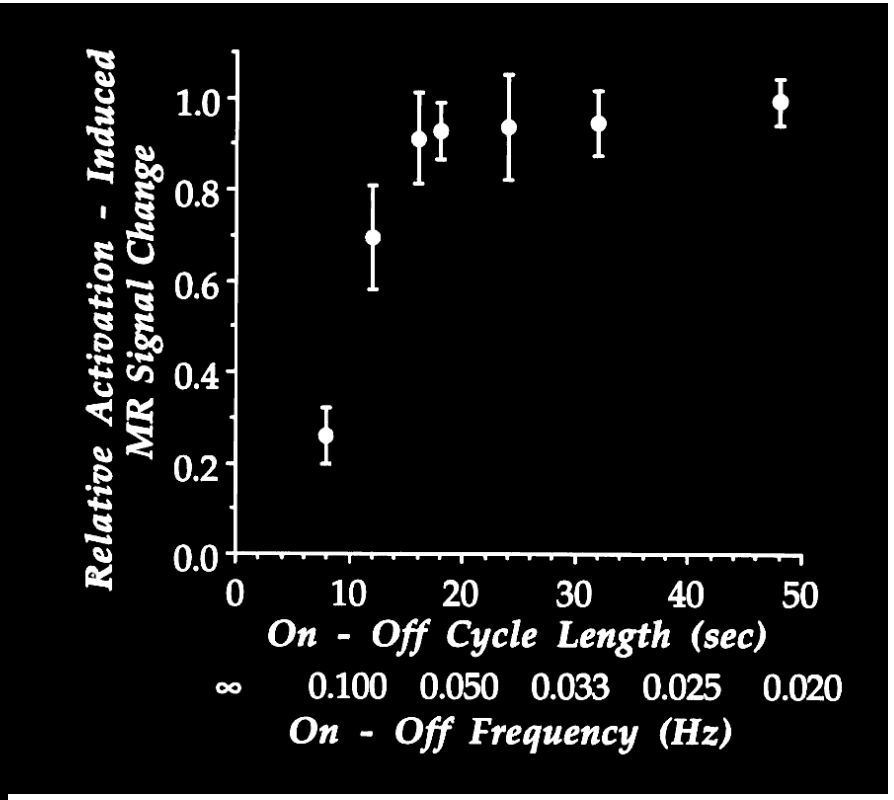




Methodology

Temporal Resolution



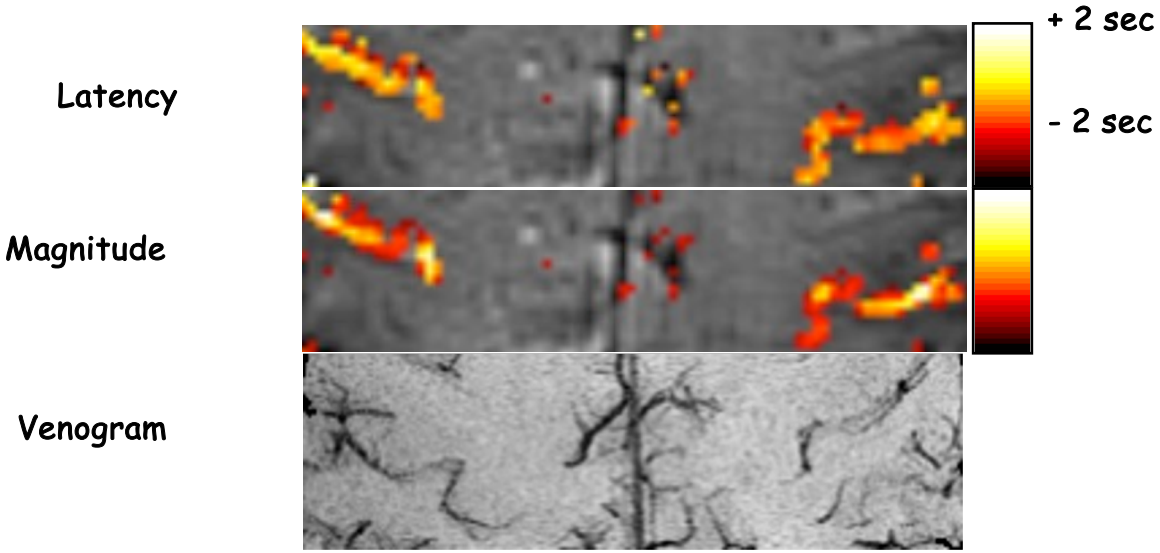


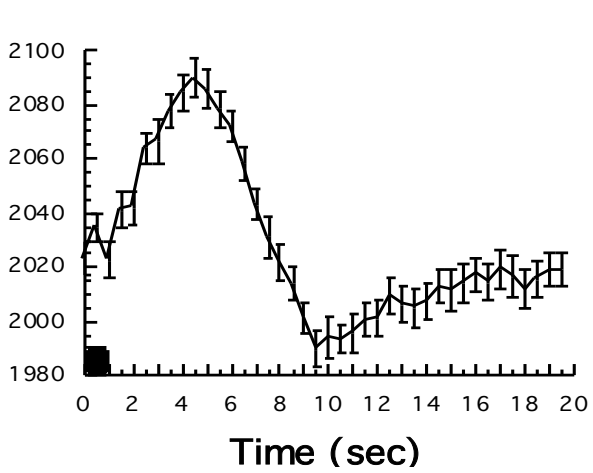
P. A. Bandettini, Functional MRI temporal resolution *in* "Functional MRI" (C. Moonen, and P. Bandettini., Eds.), p. 205-220, Springer - Verlag,. 1999.

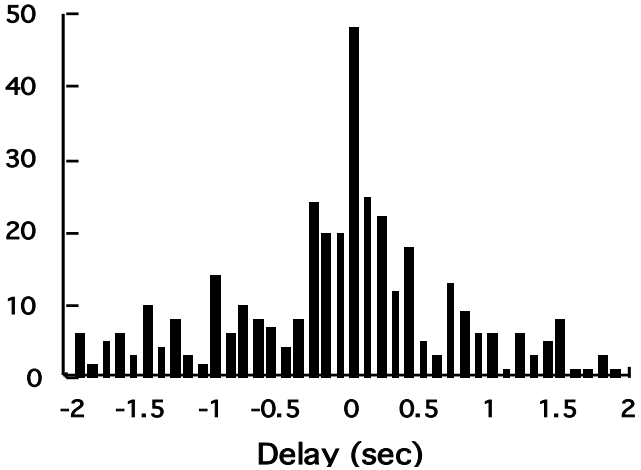
Methodology

Temporal Resolution

Latency Variation…



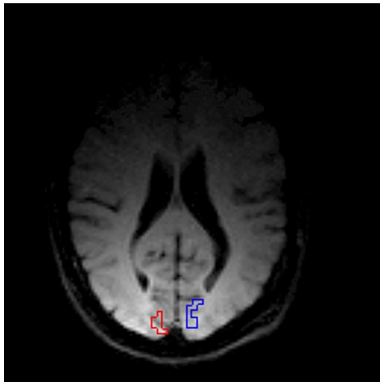




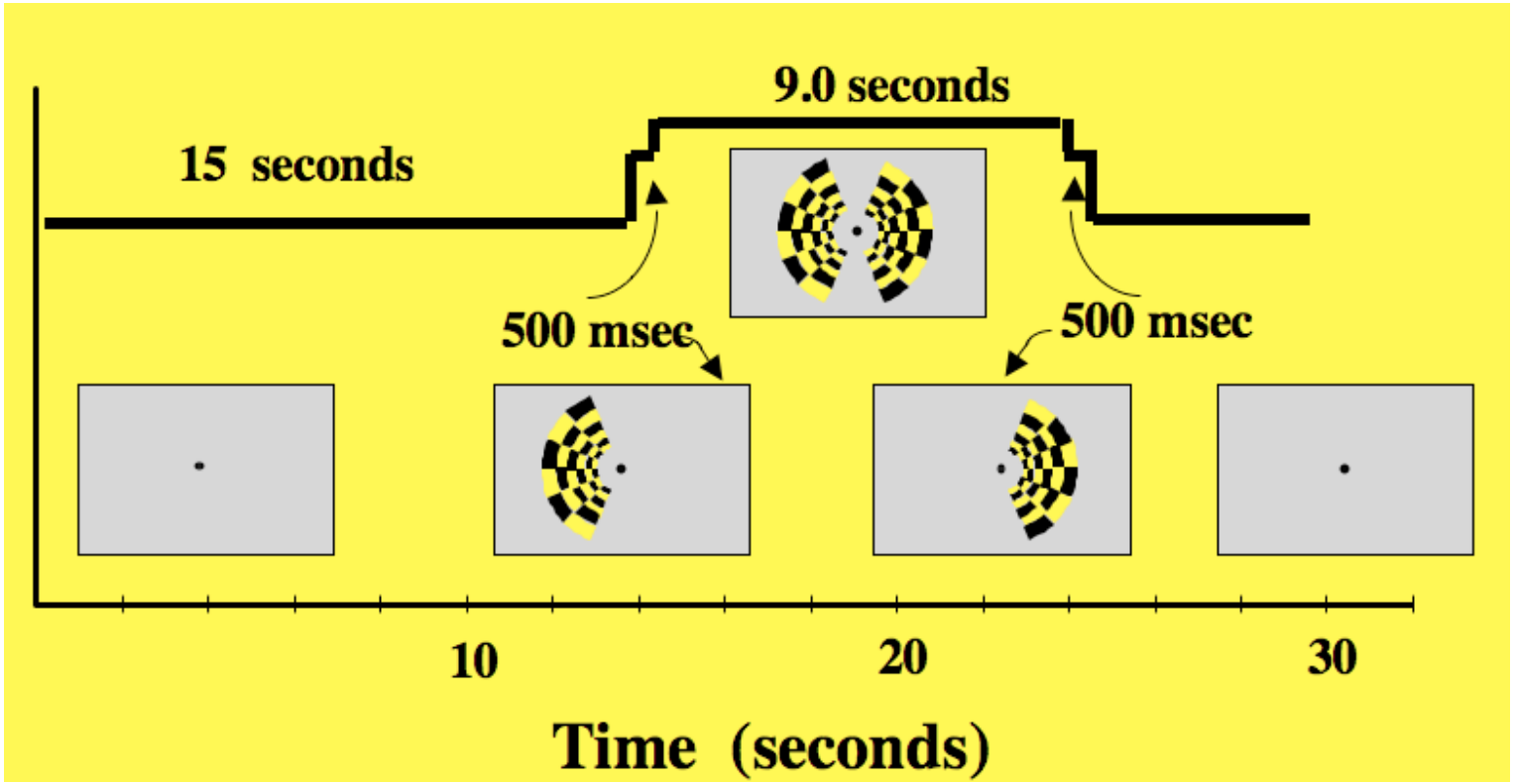
P. A. Bandettini, (1999) "Functional MRI" 205-220.

Hemi-Field Experiment

Right Hemisphere

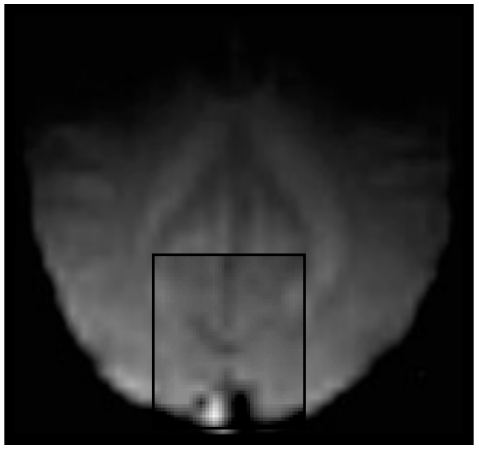


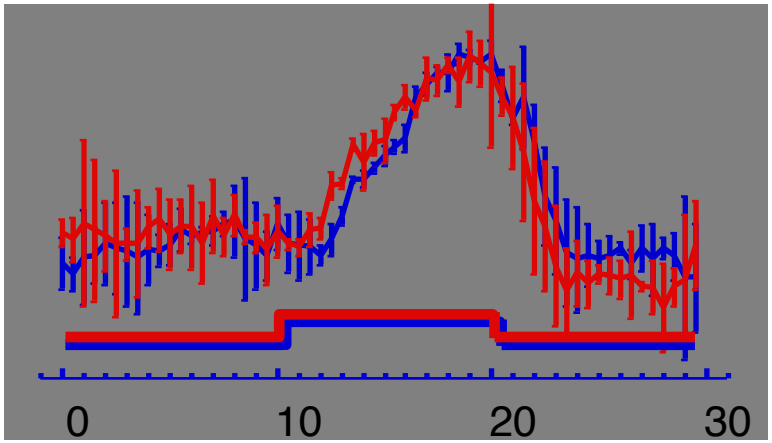
Left Hemisphere



Methodology

Temporal Resolution



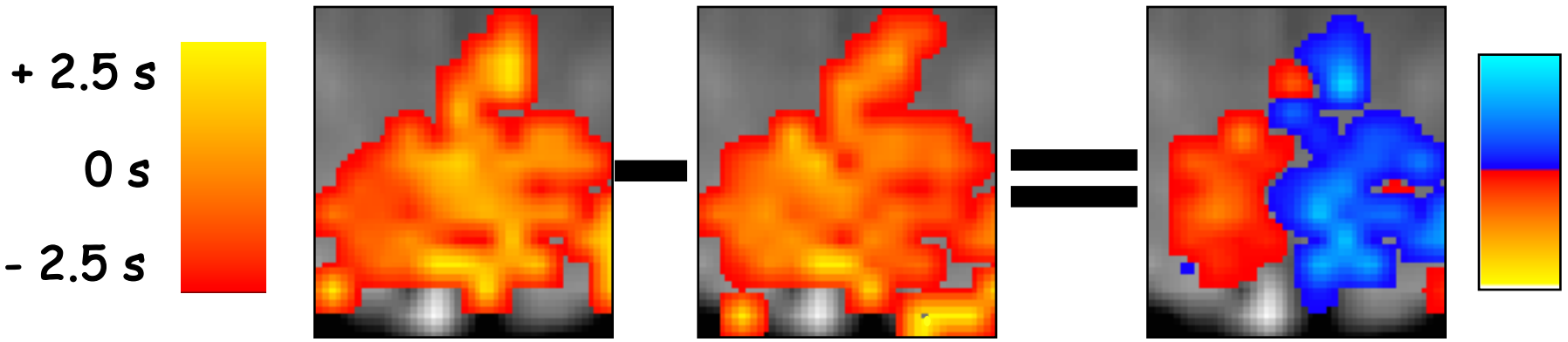


500 ms

500 ms

Right Hemifield

Left Hemifield



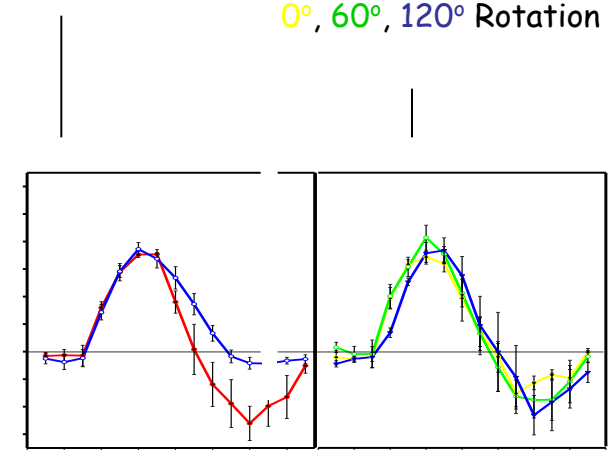
Methodology

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

Temporal Resolution

Word vs. Non-word

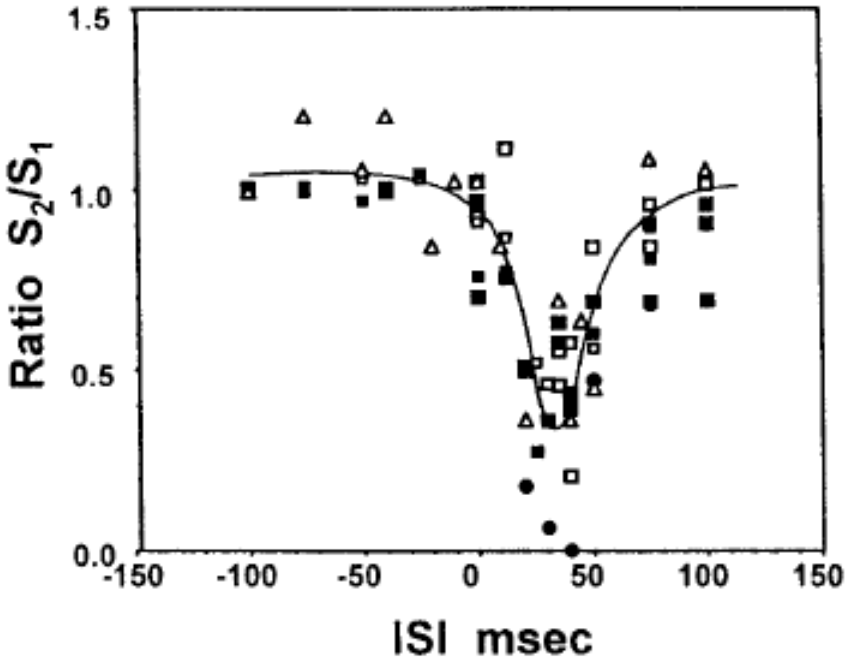
0°, 60°, 120° Rotation



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

An approach to probe some neural systems interaction by functional MRI at neural time scale down to milliseconds

Seiji Ogawa[†‡], Tso-Ming Lee[†], Ray Stepnoski[†], Wei Chen[§], Xiao-Hong Zhu[§], and Kamil Ugurbil[§]



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

Technology

Coil arrays
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Cross - modal comparison

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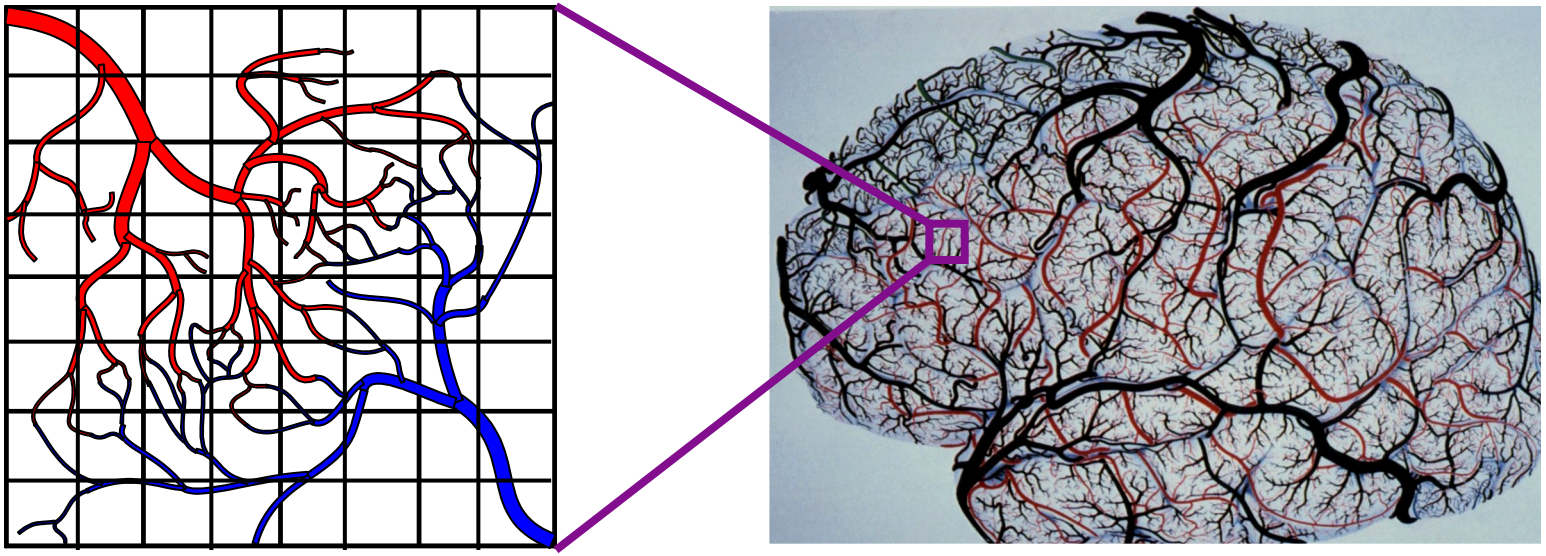
Pathology correlation

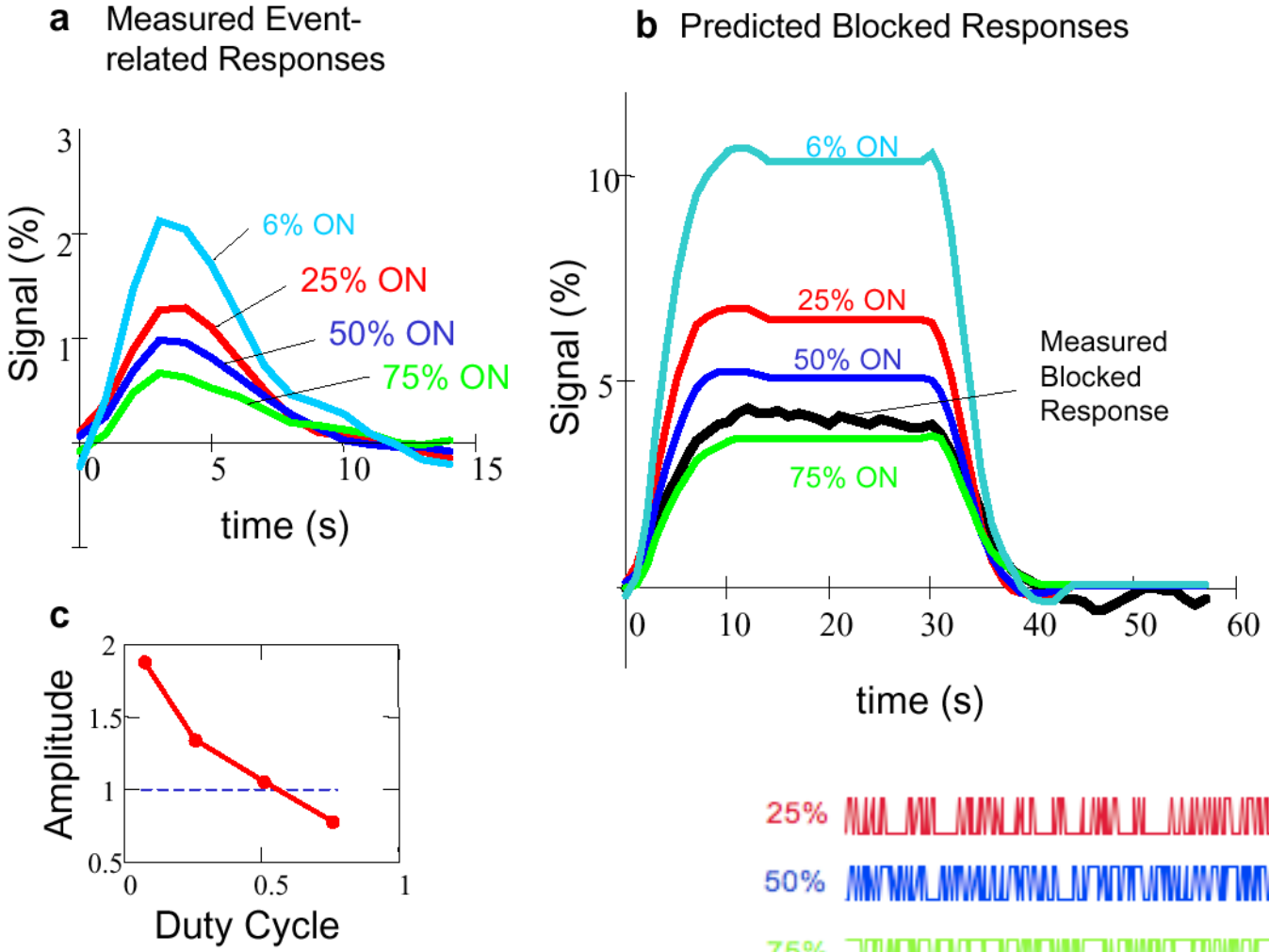
Interpretation

Neuronal Activation ? Measured Signal

? Hemodynamics ? Noise ?

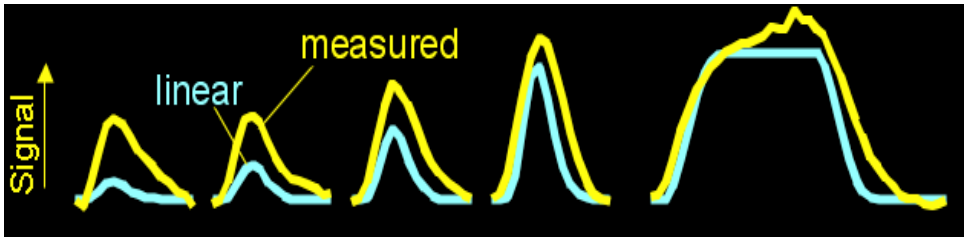


Interpretation Duty Cycle Effects

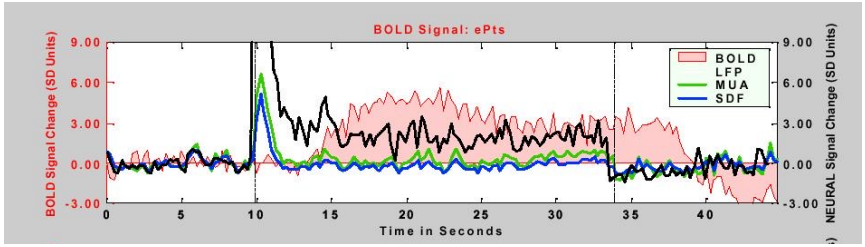


R.M. Birn, P. A. Bandettini, The effect of stimulus duty cycle and "off" duration on BOLD response linearity. *NeuroImage*, **27**, 70-82 (2005)

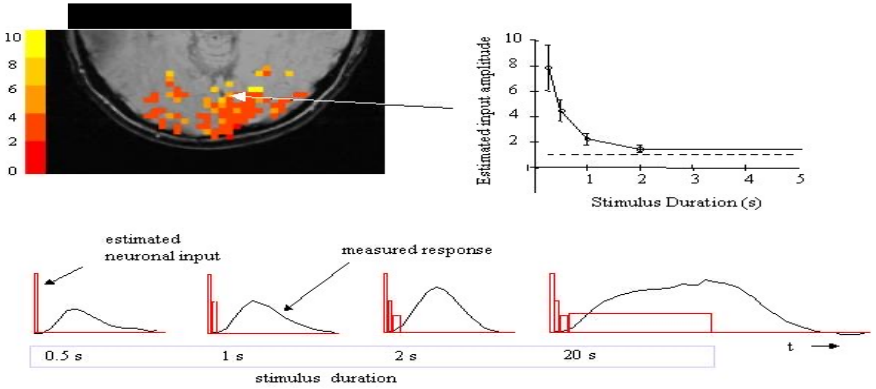
Interpretation



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



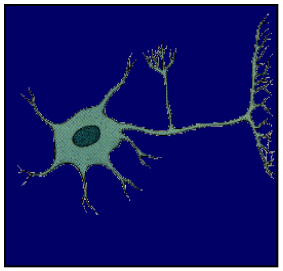
Logothetis et al. (2001) Nature, 412, 150-157.

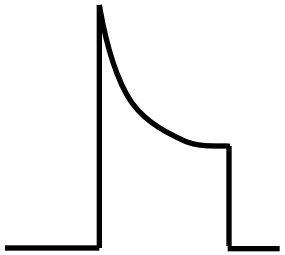


P. A. Bandettini et al, (2001) Nature Neuroscience, 4: 864-866.

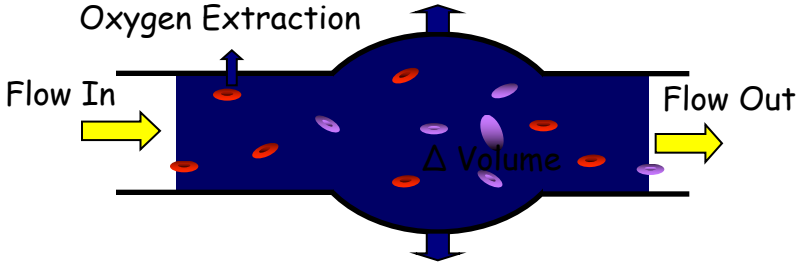
Sources of this Nonlinearity

- Neuronal

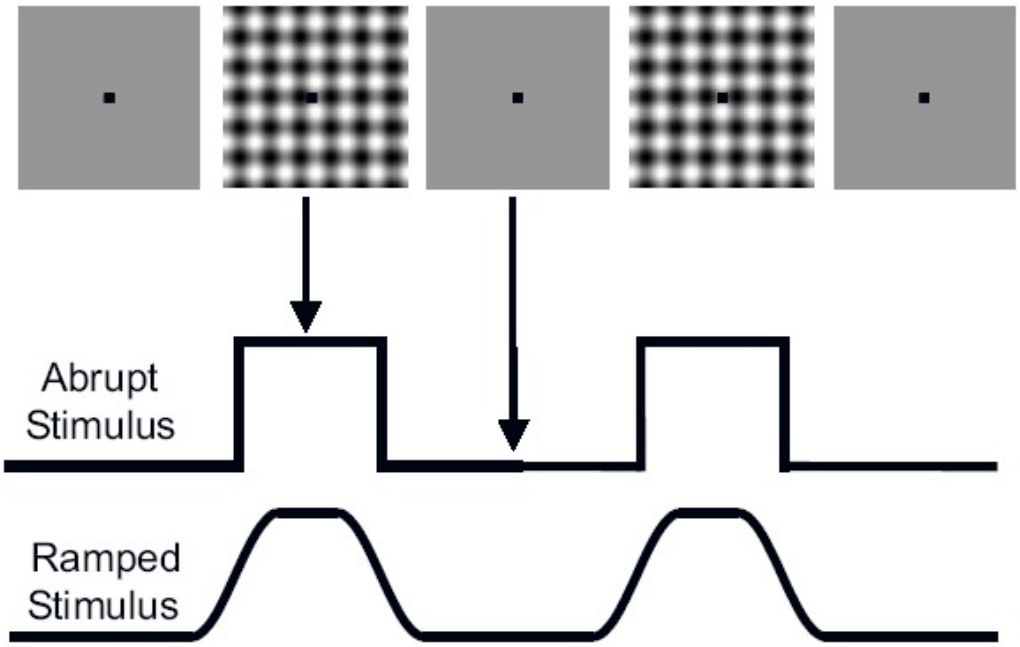


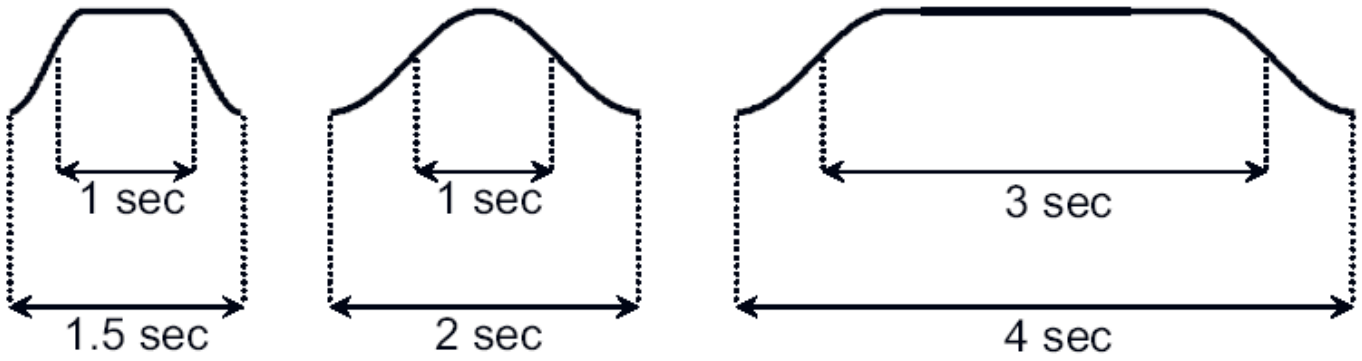


- Hemodynamic
  - -Oxygen extraction
  - -Blood volume dynamics



Interpretation





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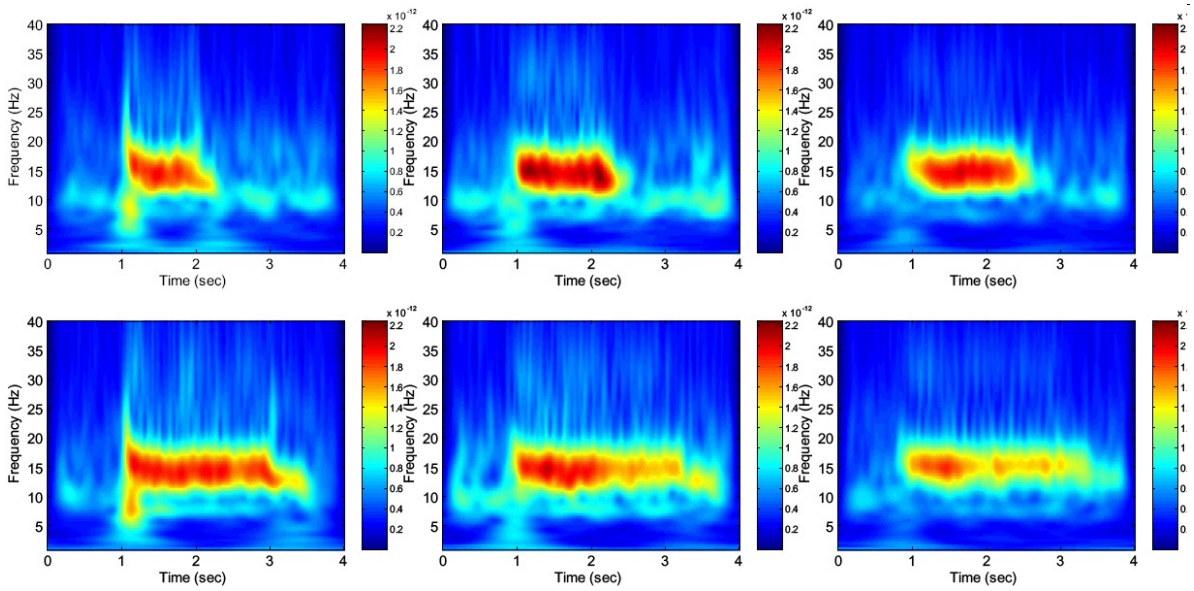
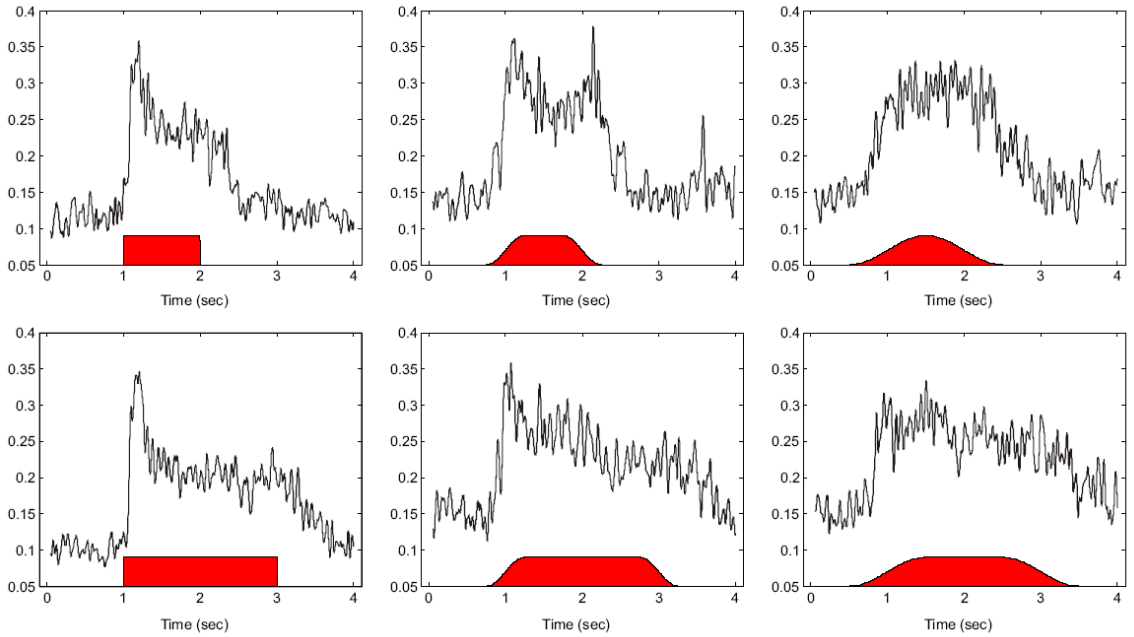
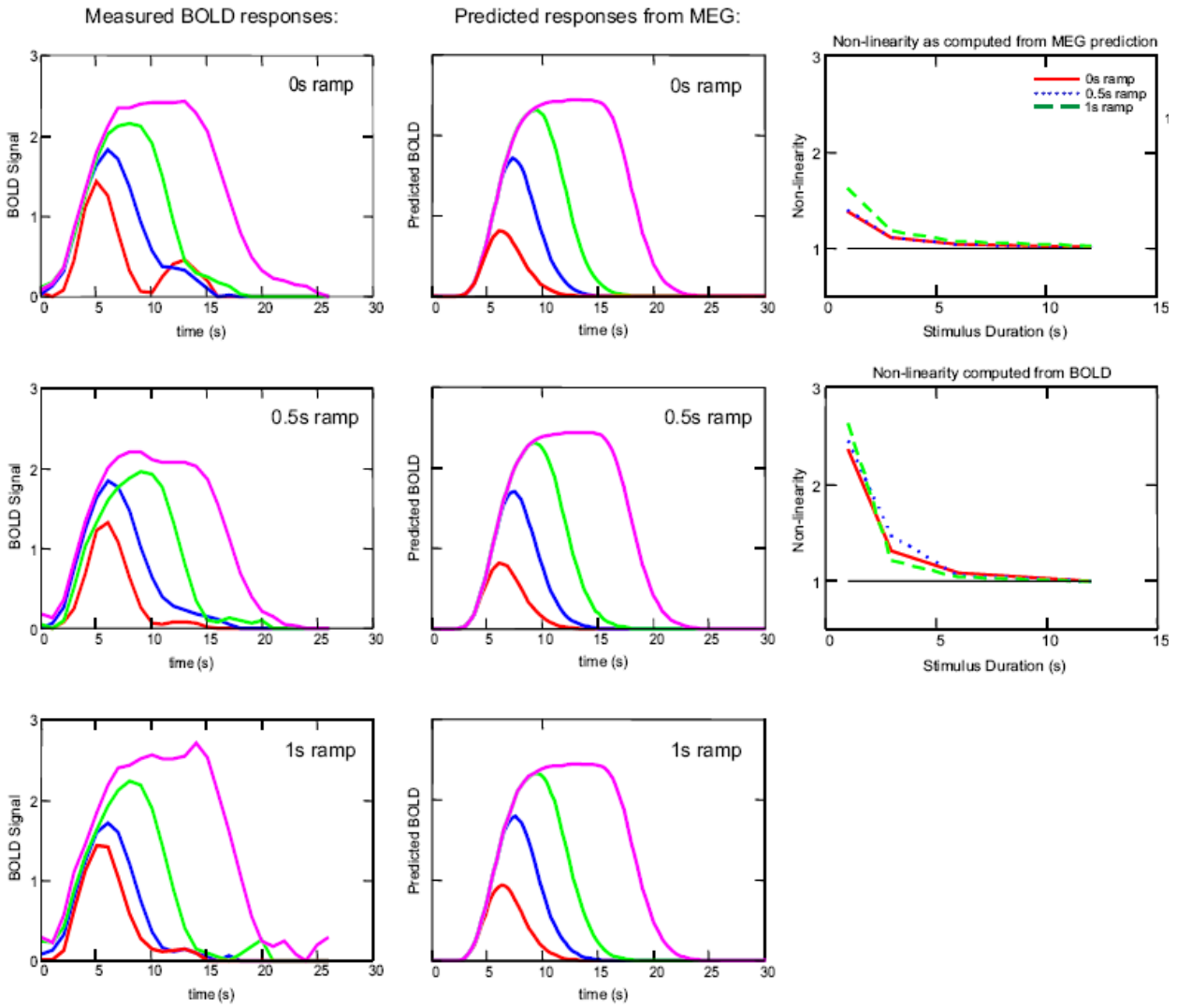




Tuan, Birn et al.

Interpretation



Tuan, Birn et al.

NeuroImage **16,** 103–114 (2002)
doi:10.1006/nimg.2001.1050, available online at http://www.idealibrary.com on IDEAL®

Task-Related Changes in Cortical Synchronization Are Spatially Coincident with the Hemodynamic Response

Krish D. Singh,*,†,‡ Gareth R. Barnes,* Arjan Hillebrand,* Emer M. E. Forde,* and Adrian L. Williams§

*The Wellcome Trust Laboratory for MEG Studies, Neurosciences Research Institute, Aston University, Birmingham, United Kingdom; †MARIARC, Liverpool University, Liverpool, United Kingdom; ‡Walton Centre for Neurology and Neurosurgery, Liverpool, United Kingdom; and §Department of Psychology, Royal Holloway, University of London, Egham, United Kingdom

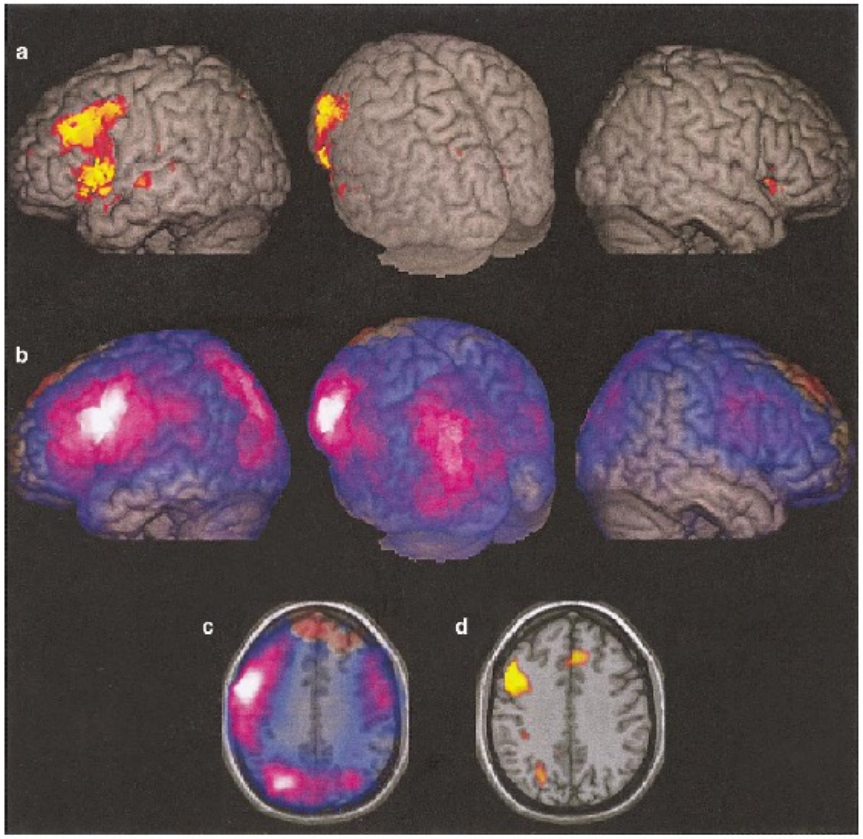


FIG. 2. The results of the group fMRI experiment and the group MEG experiment for the letter fluency task, superimposed on a template brain. The color scales are as described in the legend of Fig. 1. (a) Group fMRI data. Only those clusters significant at $P < 0.05$ (corrected) are shown. (b) The peak group SAM image. This shows the peak power increase or decrease at each voxel in the brain, irrespective of which frequency band the power change occurred in. This image can be thought of as an amalgam of Figs. 1b to 1f. (c) The peak group SAM data superimposed on a slice through the template brain at an MNI Z coordinate of +36. The image shows bilateral, but strongly left biased, activation within the dorsolateral prefrontal cortex (DLPFC) and posterior parietal cortex. (d) The group fMRI data superimposed on the $Z = +36$ slice. Note the left DLPFC and left posterior parietal activation which match the group SAM results. However, there is also a small cluster in a more anterior portion of the parietal lobe, and another in the medial frontal gyri, which are visible in the group fMRI data but not in the group MEG data.

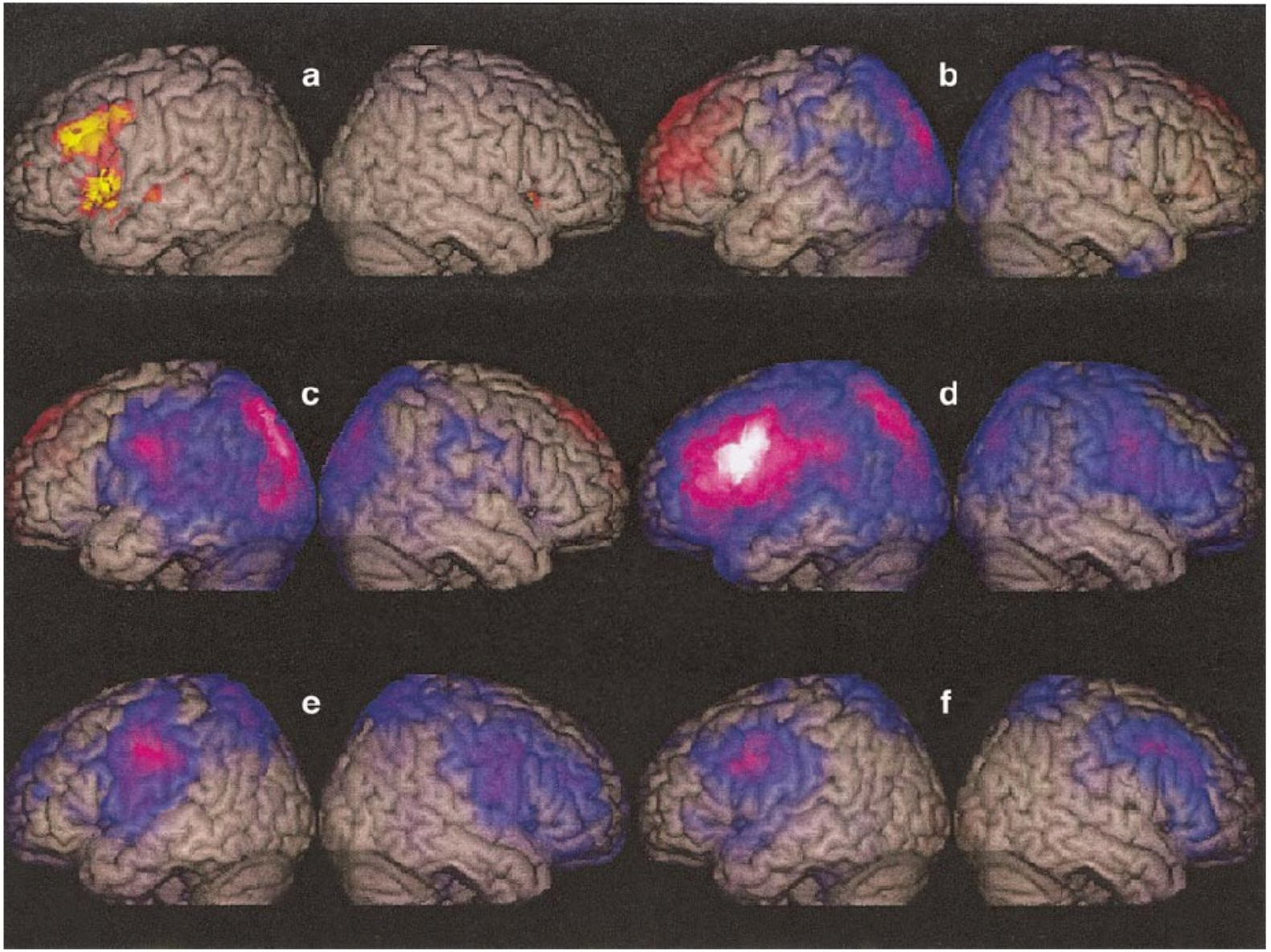


FIG. 1. The results of the group fMRI experiment and the group MEG experiment for the covert letter fluency task, superimposed on a template brain. (a) Group fMRI data. Only those clusters significant at $P < 0.05$ (corrected) are shown. The red–orange–yellow color scale depicts increasing BOLD amplitude. (b–f) The results of the group SAM analysis of the MEG data. Increases in signal power in the Active phase, compared to the Passive baseline are shown using a red–orange–yellow color scale. Decreases in signal power in the Active phase are shown using a blue–purple–white color scale. The power changes are in the following frequency bands (b) 1–10 Hz; (c) 5–15 Hz; (d) 15–25 Hz; (e) 25–35 Hz; and (f) 35–45 Hz.

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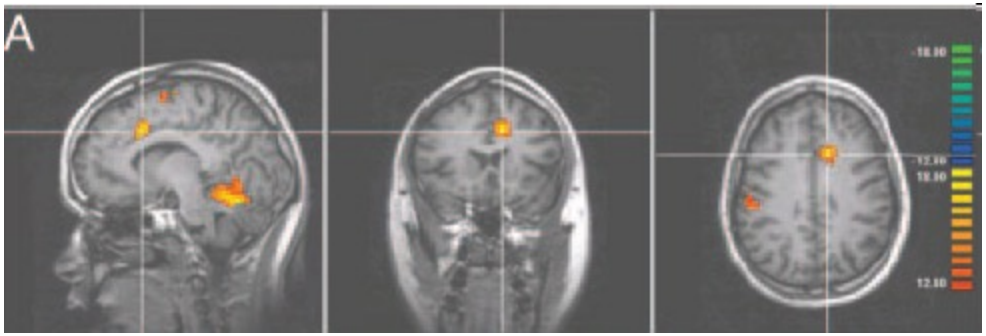
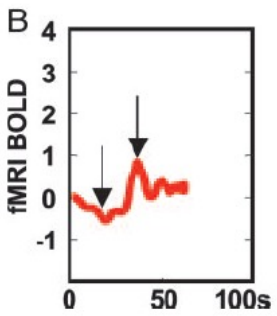
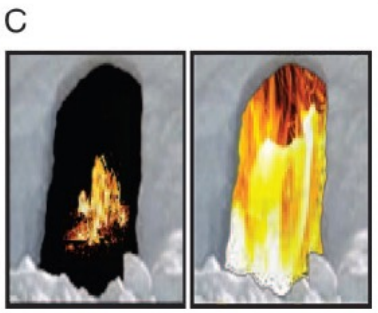
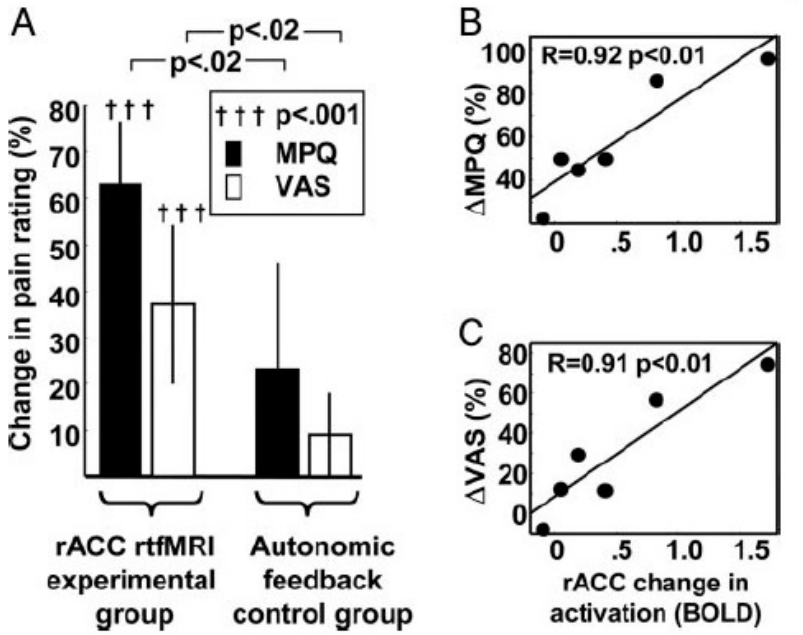
Applications

Real time fMRI feedback to reduce chronic pain



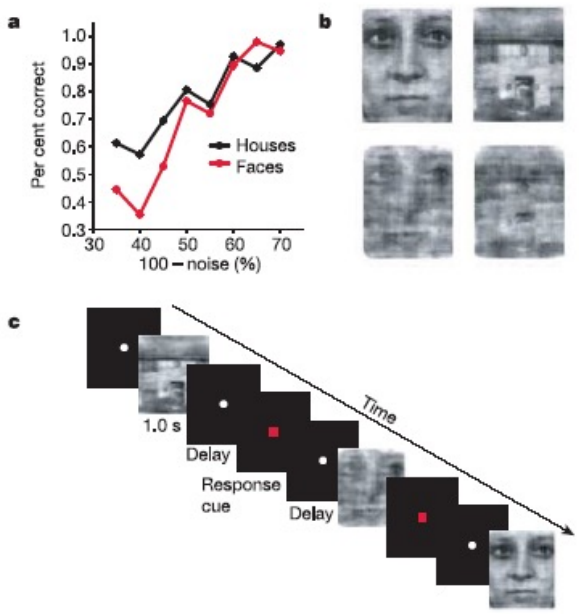


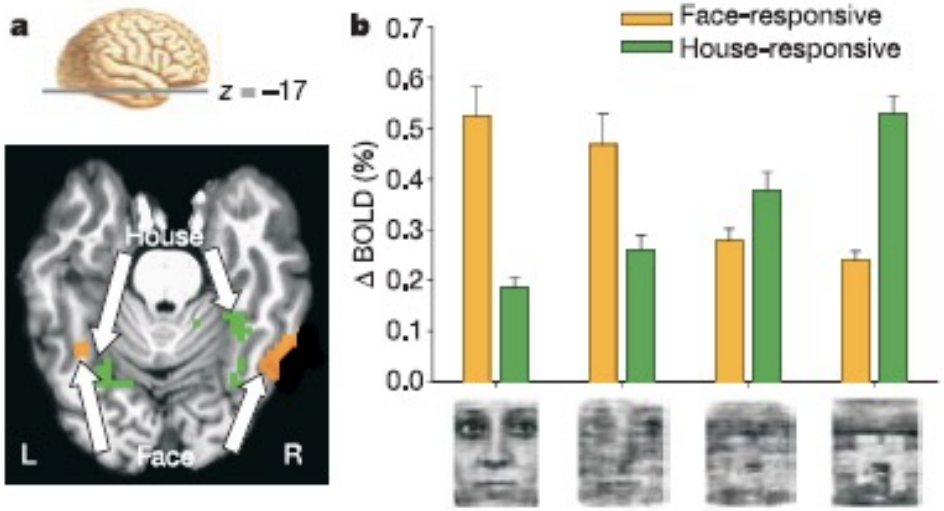


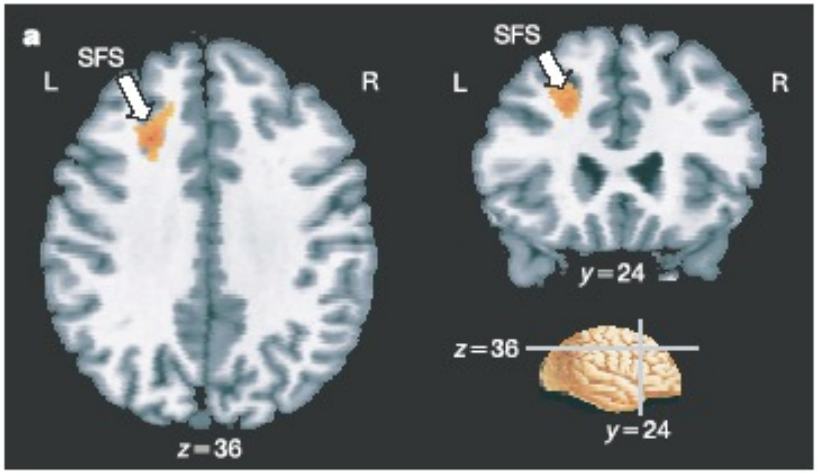


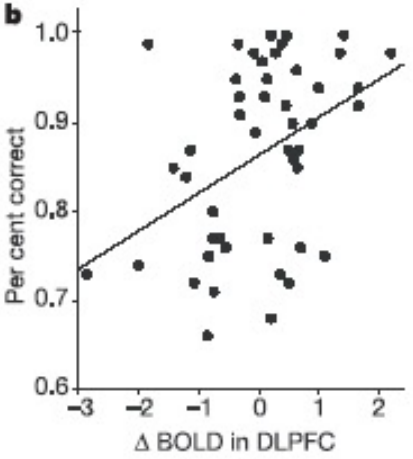
Control over brain activation and pain learned by using real-time functional MRI, R. C. deCharms, et al. PNAS, 102; 18626-18631 (2005)

Applications









H. Heekeren, S. Marrett, P. A. Bandettini, L. G. Ungerleider, A general mechanism for perceptual decision-making in the human brain, Nature, 431, 859-862

What fMRI Can Do

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

What fMRI Might Do

Complementary use for clinical diagnosis

- -utilization of clinical research results
- -prediction of pathology

Clinical treatment and assessment

- -drug, therapy, rehabilitation, biofeedback
- -epileptic foci mapping
- -drug effects

Non clinical uses

- -complementary use with behavioral, anatomical, other modality results
- -lie detection
- -prediction of behavior tendencies
- -brain/computer interface

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 Facility

Kay Kuhns
Sean Marrett
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Jerzy Bodurka
Adam Thomas
James Hoskie

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