Latest Developments of fMRI

Peter A. Bandettini, Ph.D.

Section on Functional Imaging Methods

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Laboratory of Brain and Cognition

&

Functional MRI Facility

http://fmrif.nimh.nih.gov

Section on Functional Imaging Methods & Functional MRI Facility Jan 19, 2007

Back row: Wenming Luh, Niko Kriegeskorte, Rasmus Birn, Tyler Jones, Sean Marrett
Middle row: Jon West, Kay Kuhns, Anthony Boemio, Peter Bandettini, Joey Dunsmoor, Doug Ruff, Kevin Murphy
Front row: Dorian Van Tassel, Jerzy Bodurka, Adam Thomas, Marieke Mur, David Knight

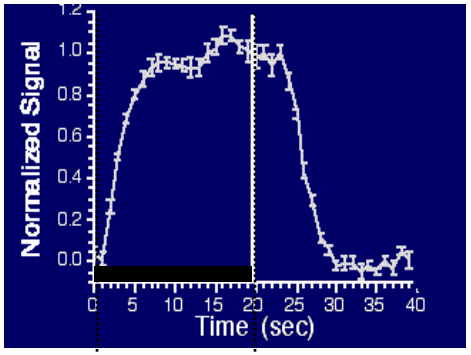
Overview of fMRI

Functional Contrast:
- Blood volume
- Blood flow/perfusion
- Blood oxygenation

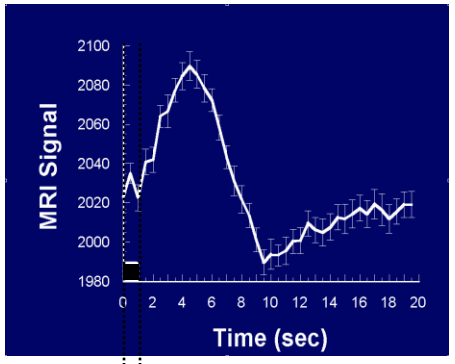
Spatial resolution:
- Typical: 3 mm^3
- Upper: 0.5 mm^3

Temporal resolution:
- Minimum duration: < 16 ms
- Minimum onset diff: 100 ms to 2 sec

Interpretability:
- Neurovascular coupling, vascular sampling, blood, physiologic noise, motion and other artifacts, etc..

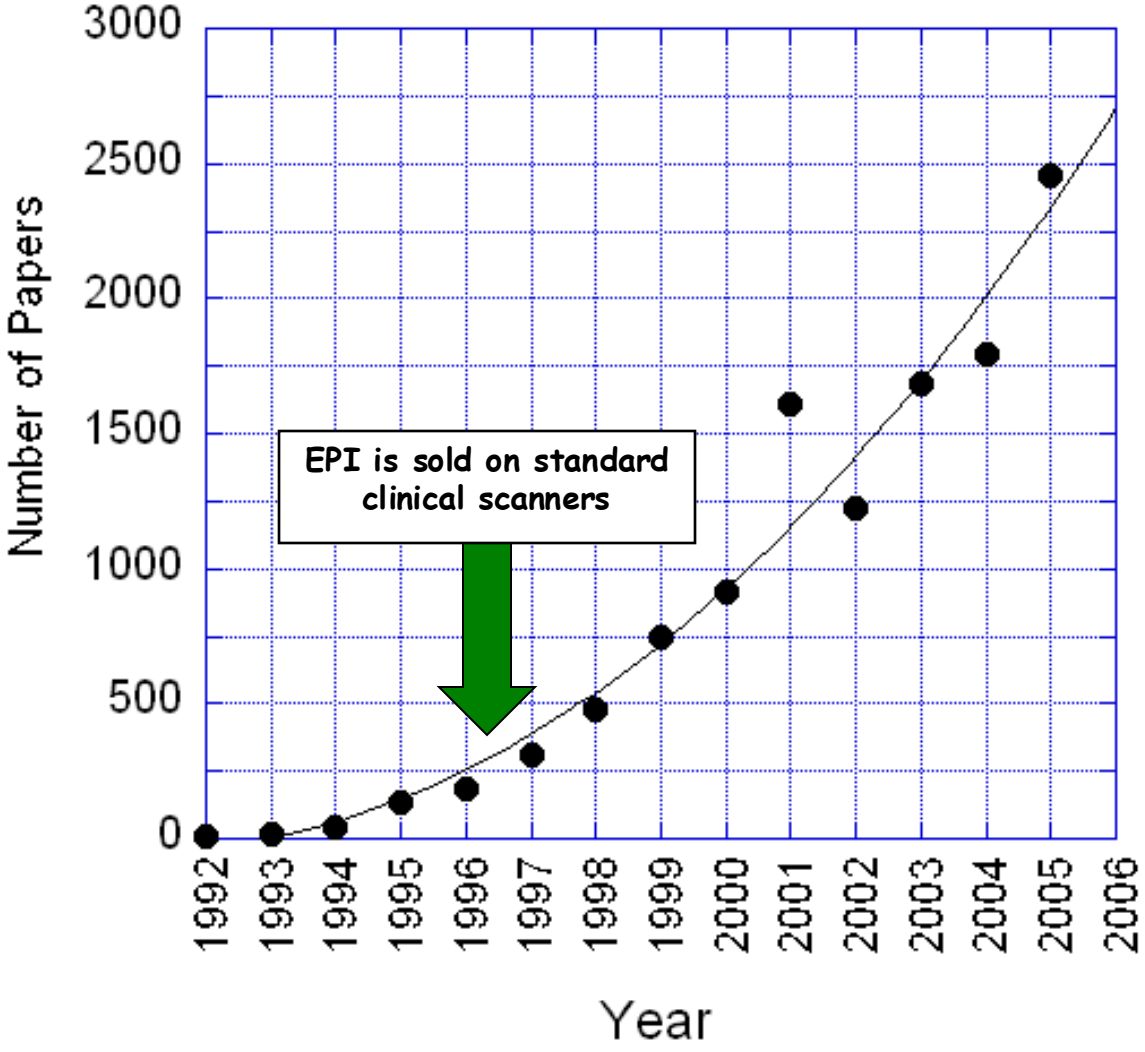


task



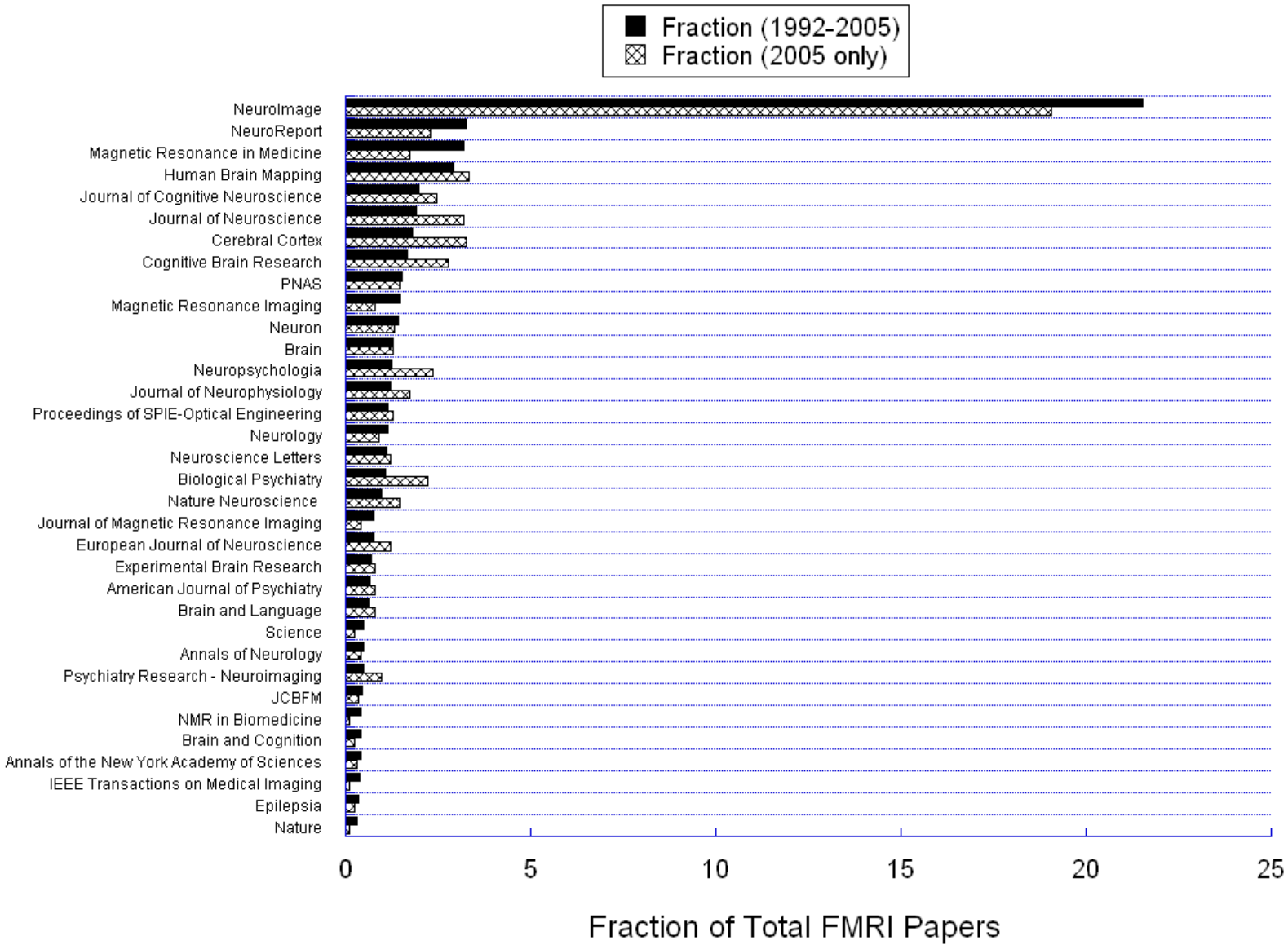
task

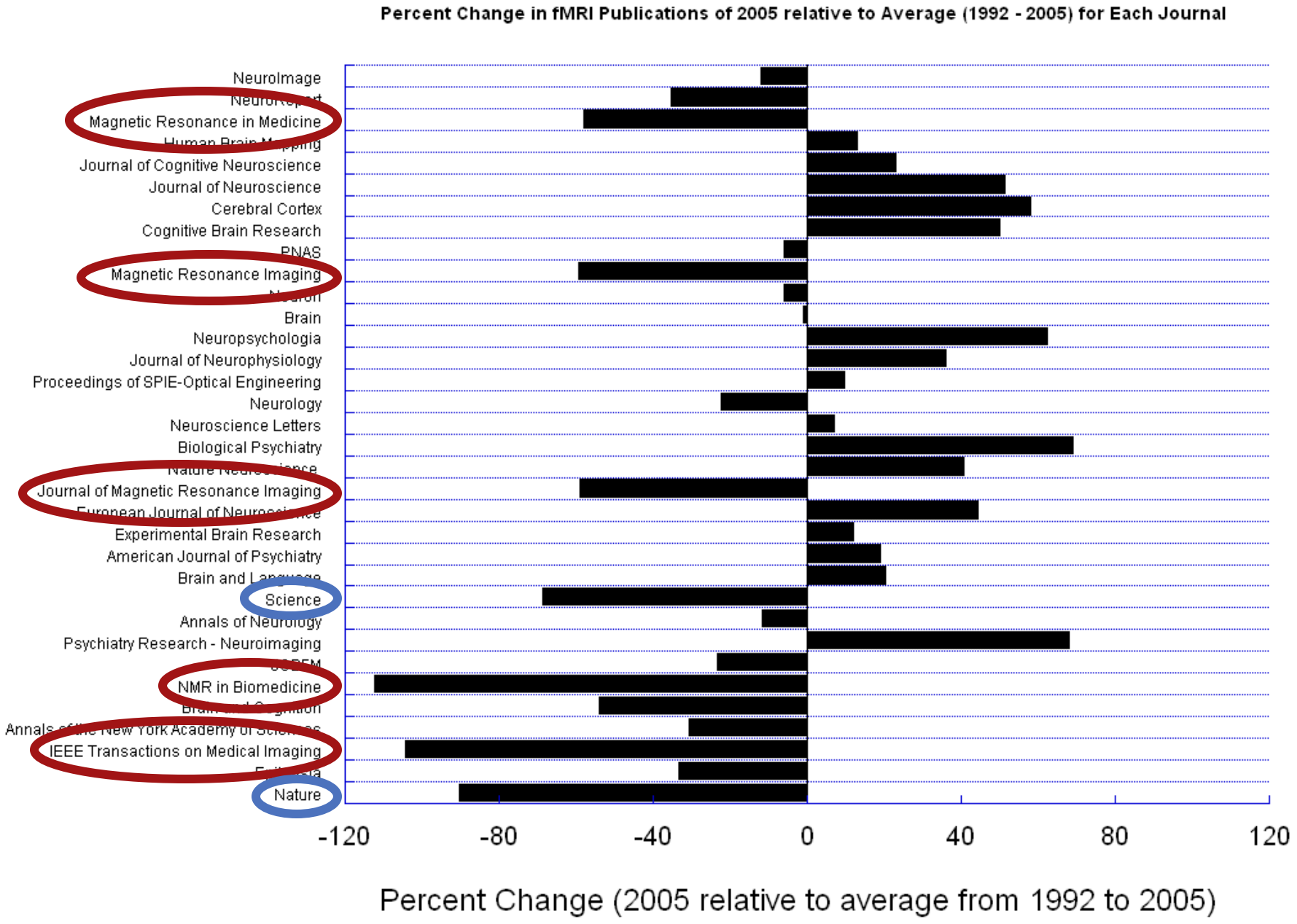
fMRI Papers Published per Year

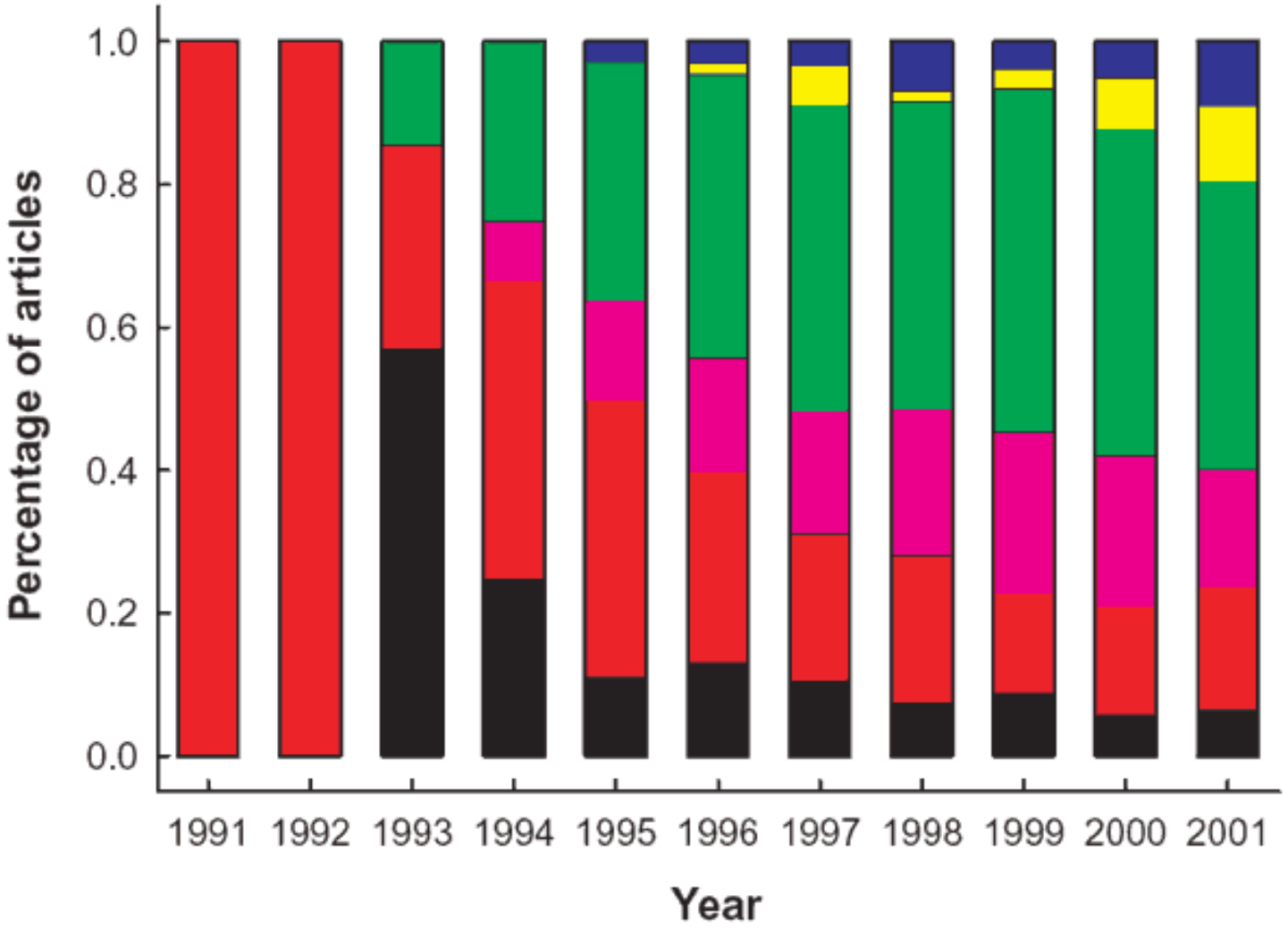


"fMRI" or "functional MRI"

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)



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

What fMRI Can Do (routine fMRI)

Help in understanding healthy brain organization

- -map networks involved with specific behavior, stimulus, or performance
- -characterize changes over time (seconds to years)
- -determine correlates of behavior (response accuracy, etc…)

Current Clinical Applications

- -presurgical mapping (CPT code in place as of Jan, 2007)

Current Clinical Research

- -assessment of recovery and plasticity
- -clinical population characterization with probe task or resting state

What fMRI Can't Do (what are the problems with fMRI?)

- Too low SNR for routine clinical use (takes too long)
- Requires patient cooperation (too sensitive to motion)
- Too low spatial resolution (each voxel has several million neurons)
- Too low temporal resolution (hemodynamics are variable and sluggish)
- Too indirectly related to neuronal activity
- Too many physiologic variables influence signal
- Requires a task (BOLD cannot look at baseline maps)
- Too confined space and high acoustic noise.

Technology

Coil arrays
High field strength
High resolution
Novel functional contrast

Methodology

Functional Connectivity Assessment
Multi-modal integration
Pattern classification
Real time feedback
Task design

Interpretation

Fluctuations
Dynamics
Cross - modal comparison

Applications

Basic Neuroscience
Behavior correlation/prediction
Pathology assessment

Technology

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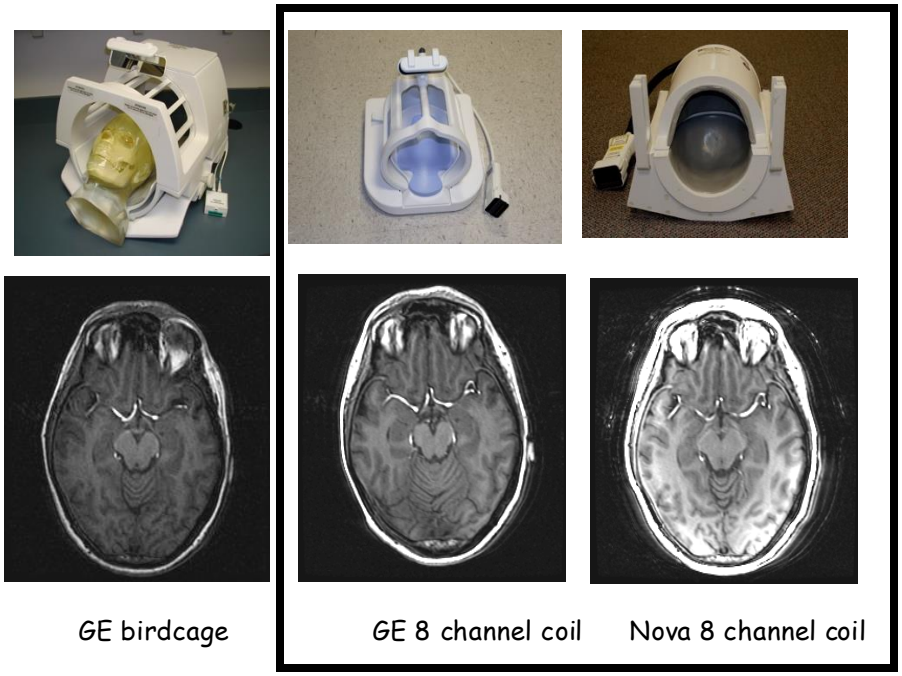
Applications

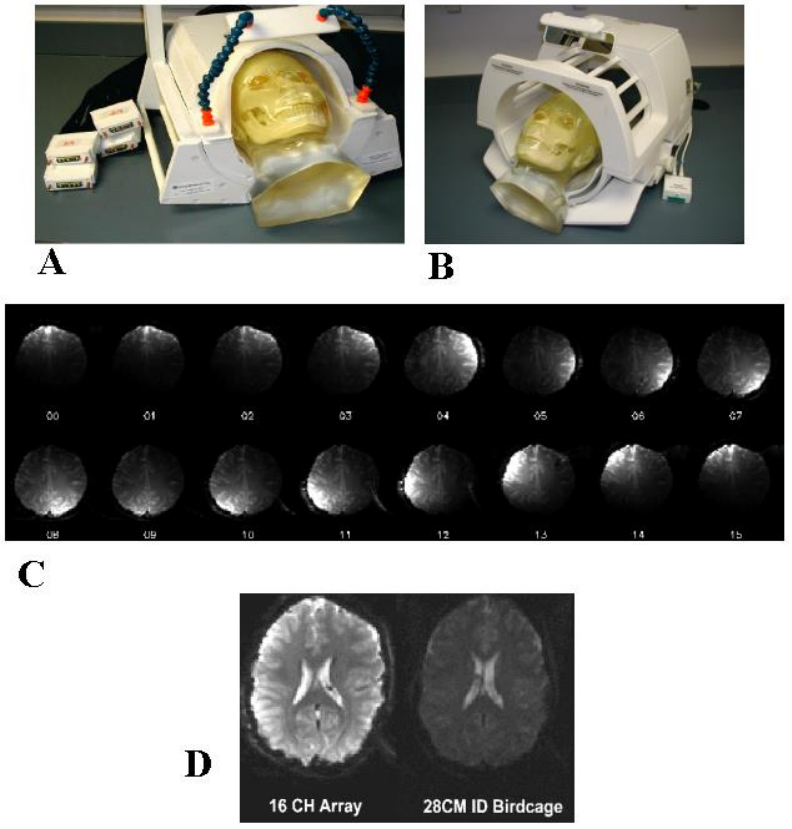
Technology

8 channel parallel receiver coil



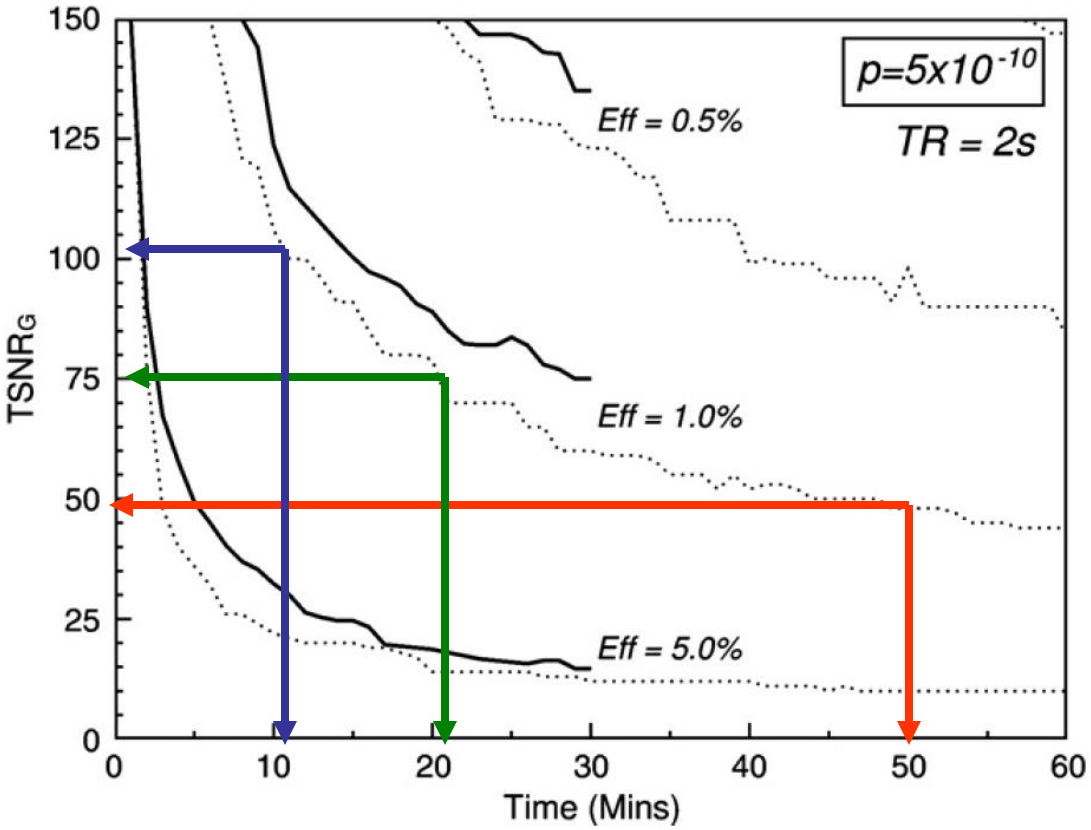
GE birdcage | GE 8 channel coil | Nova 8 channel coil

16 channel parallel receiver coil



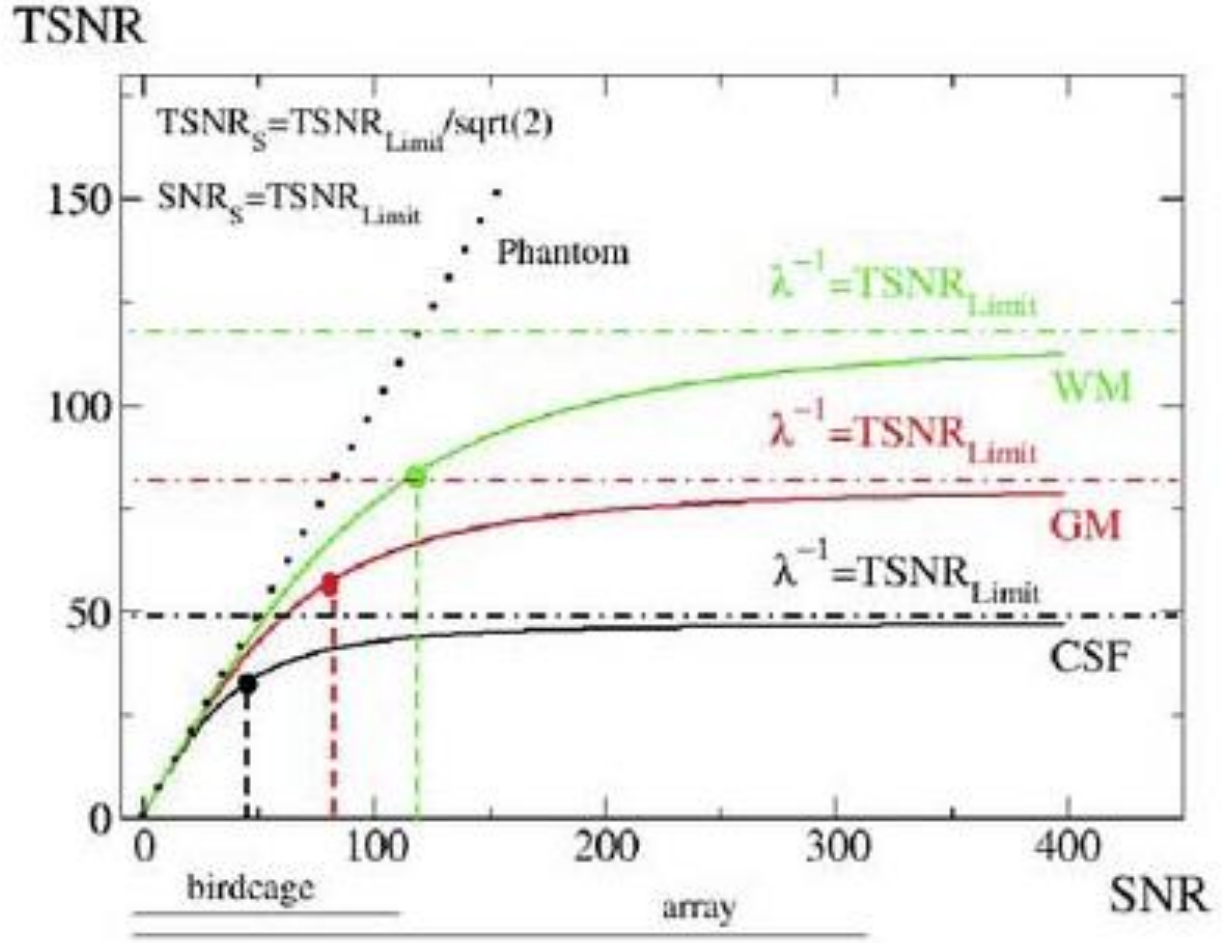
J. Bodurka, et al, Magnetic Resonance in Medicine 51 (2004) 165-171.

Technology



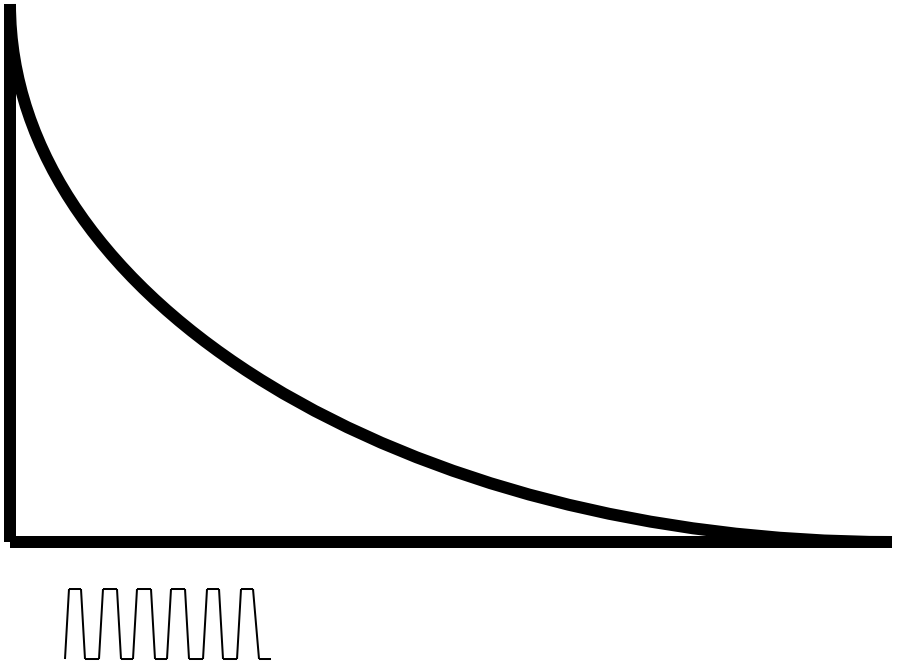
K. Murphy, J. Bodurka, P. A. Bandettini, How long to scan? The relationship between fMRI temporal signal to noise and the necessary scan duration. *NeuroImage*, 34, 565-574 (2007)

SNR vs TSNR

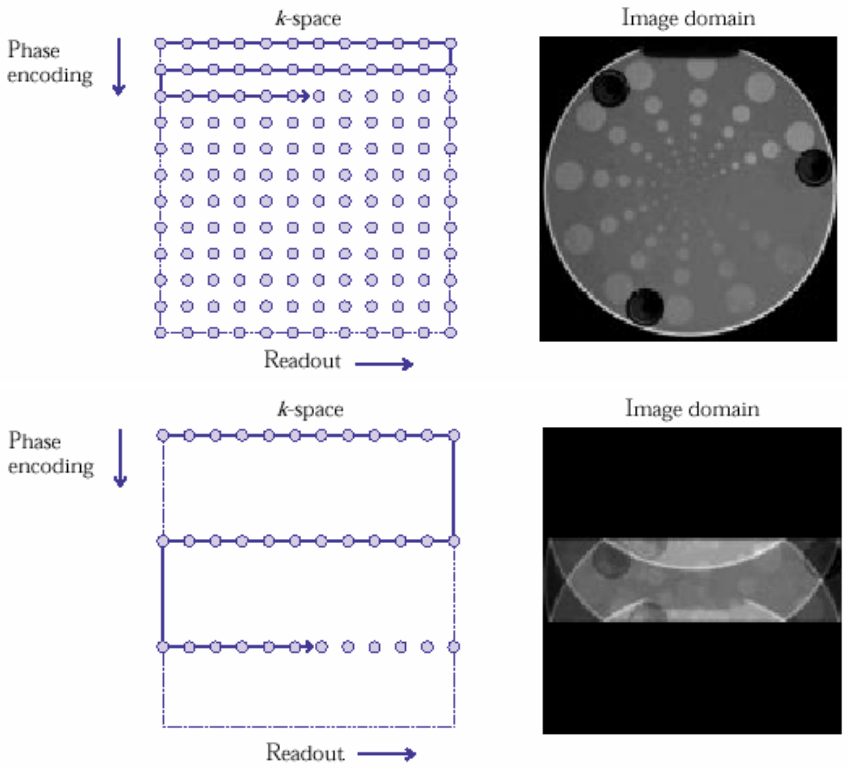


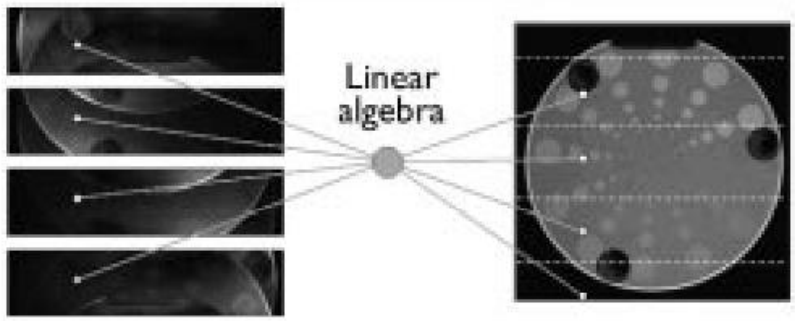
J. Bodurka, F. Ye, N Petridou, P. A. Bandettini, Mapping the MRI voxel volume in which thermal noise matches physiological noise – implications for fMRI. *NeuroImage*, 34, 542-549 (2007)

Technology



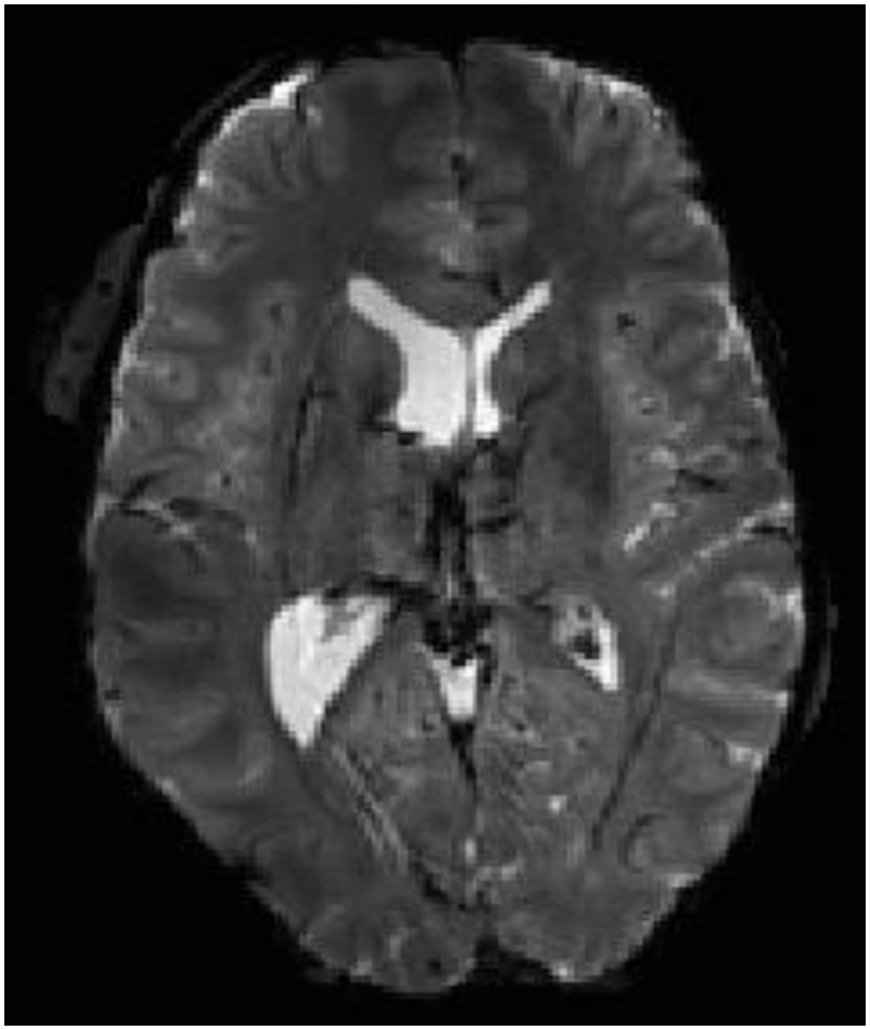
≈ 5 to 30 ms





Pruessmann, et al.

Technology



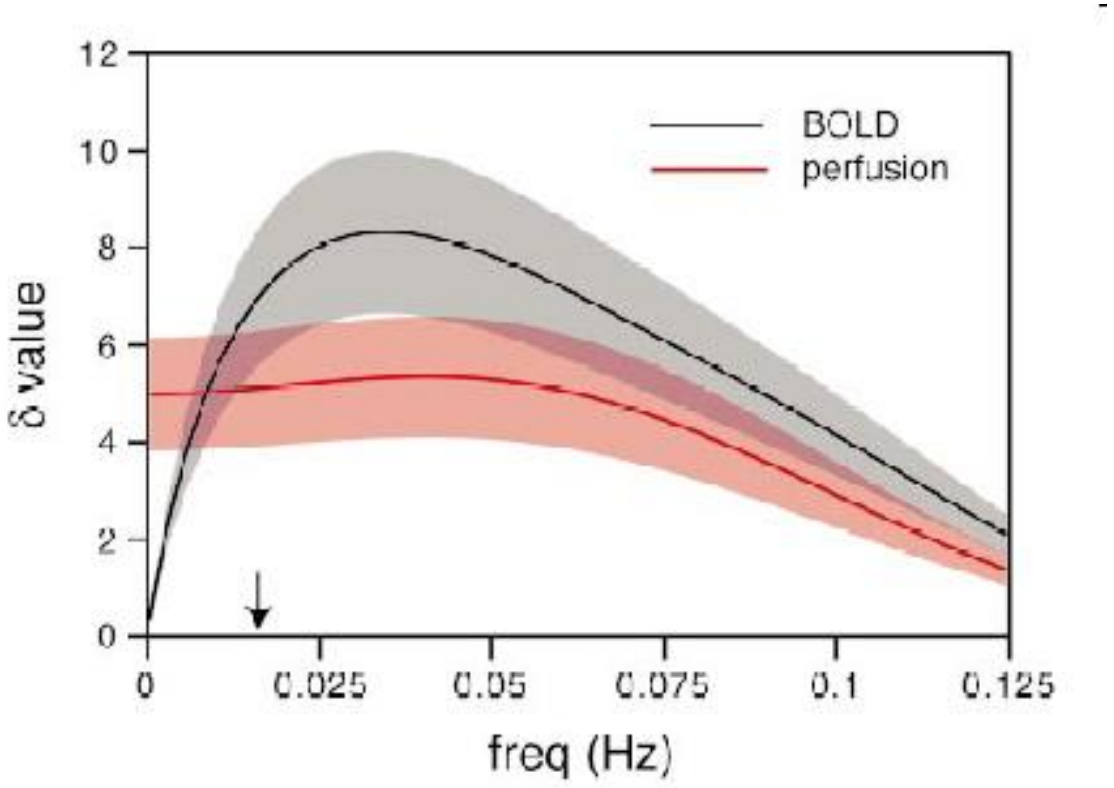
3T single-shot SENSE EPI using 16 channels: 1.25x1.25x2mm

fMRI Contrast

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

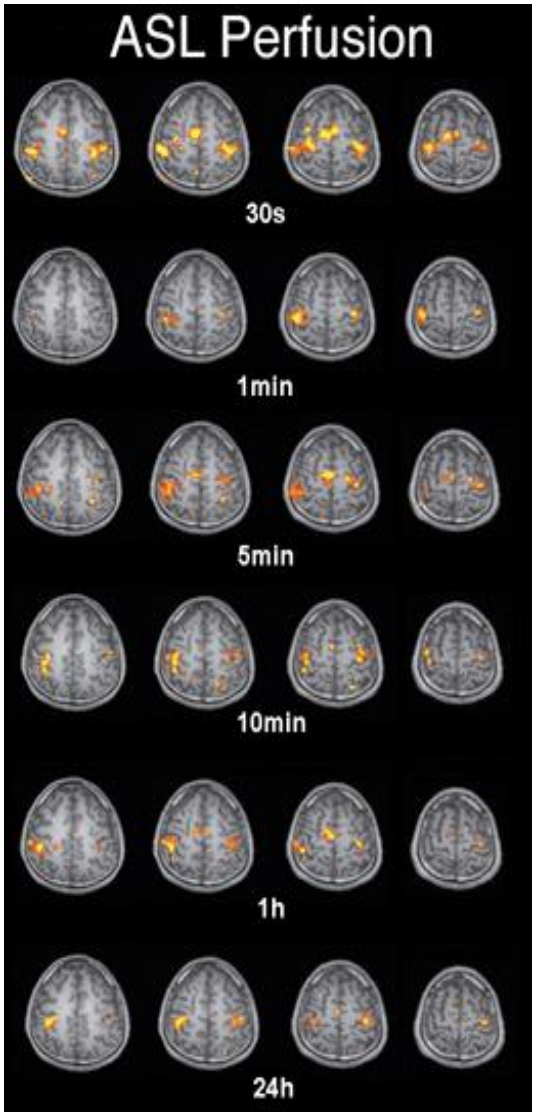
Perfusion (ASL)

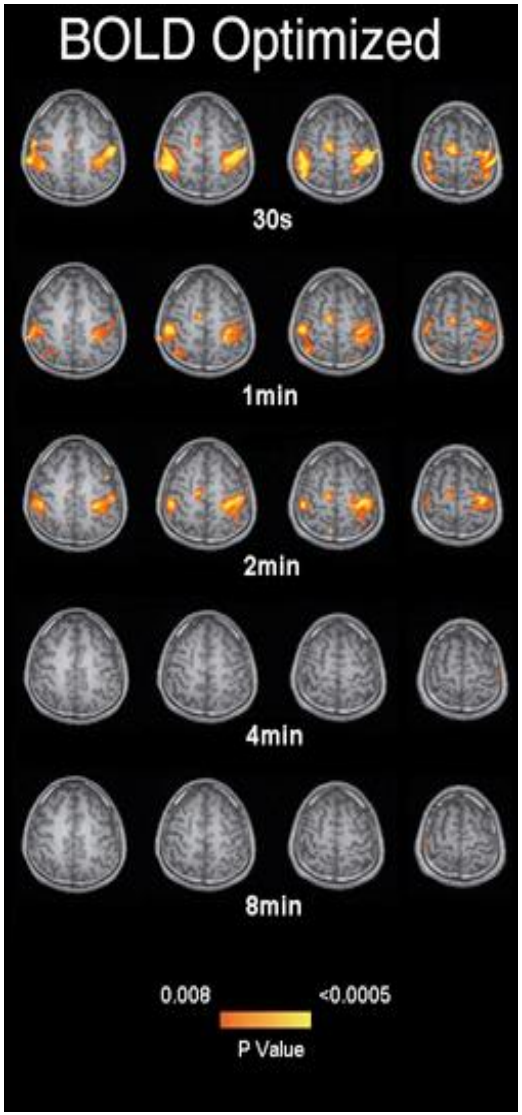
Better than BOLD for long duration activation…



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

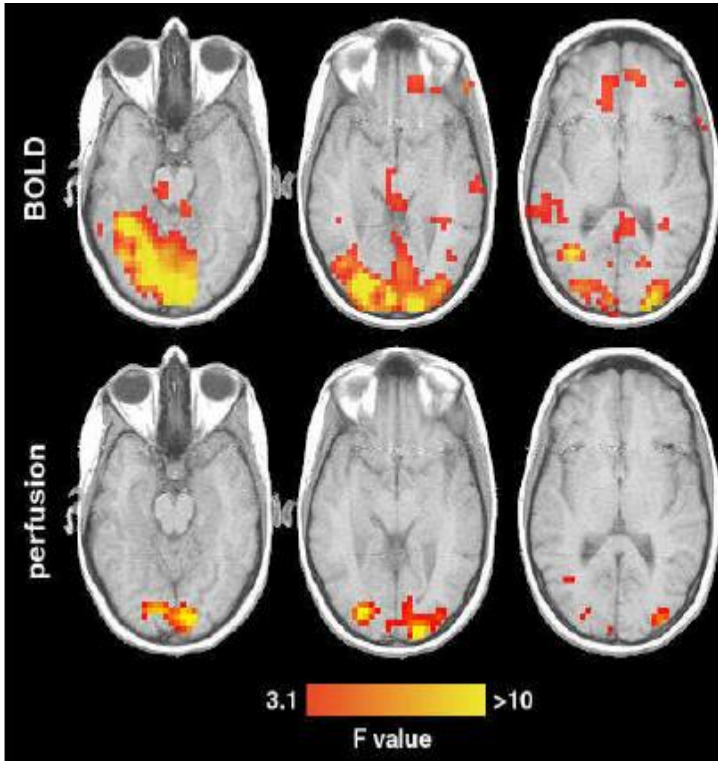
Perfusion vs. BOLD: Low Task Frequency



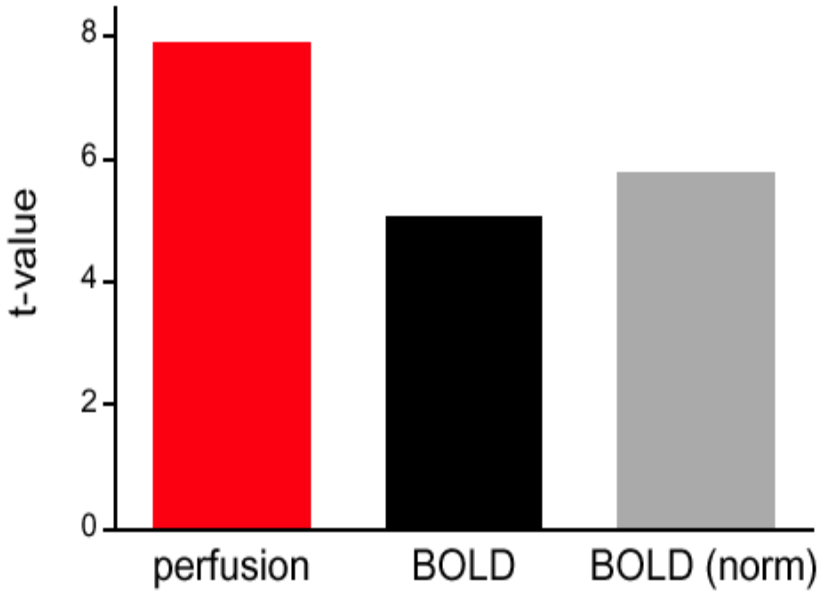


Perfusion (ASL)

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

Technology

Coil arrays
High field strength
High resolution
Novel functional contrast

Methodology

Functional Connectivity Assessment
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Task design

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Dynamics
Cross - modal comparison

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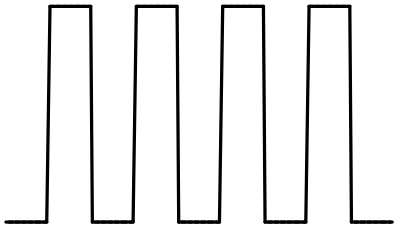
Basic Neuroscience
Behavior correlation/prediction
Pathology assessment

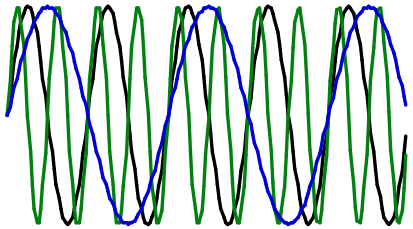
Applications

Neuronal Activation Input Strategies

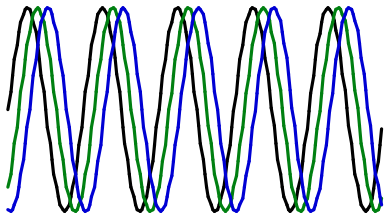
1. Block Design



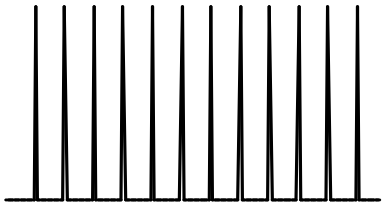
2. Frequency Encoding



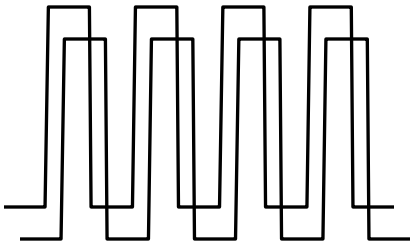
3. Phase Encoding



4. Event-Related



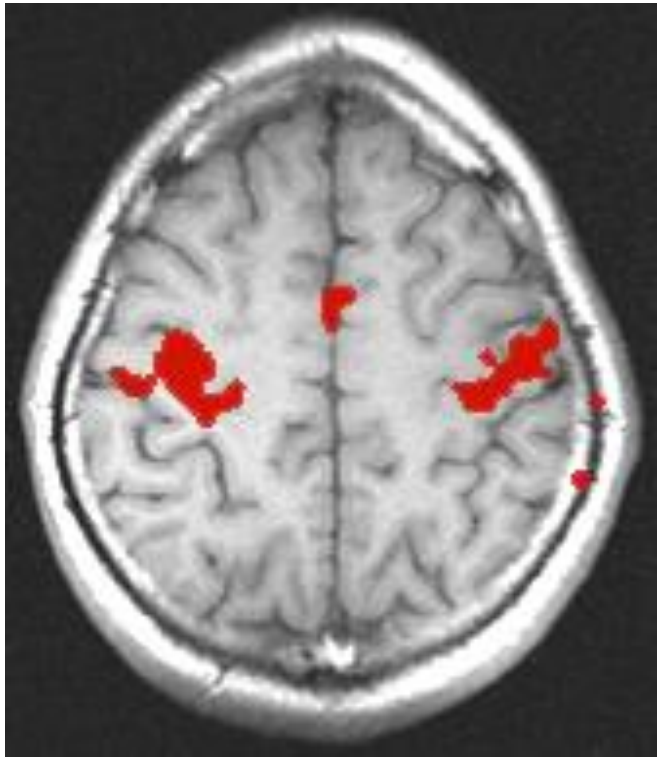
5. Orthogonal Block Design



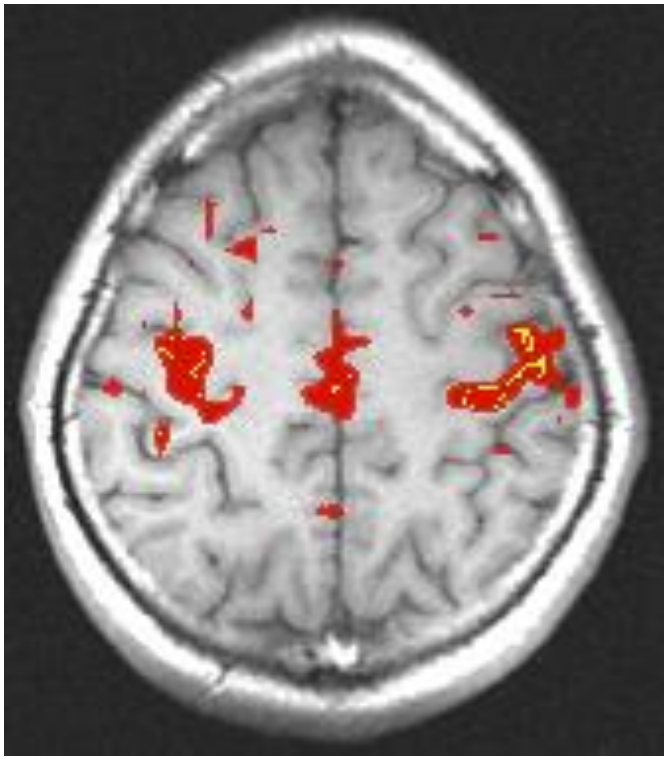
6. Free Behavior Design.

Methodology

Resting State Correlations



Activation:
correlation with reference function

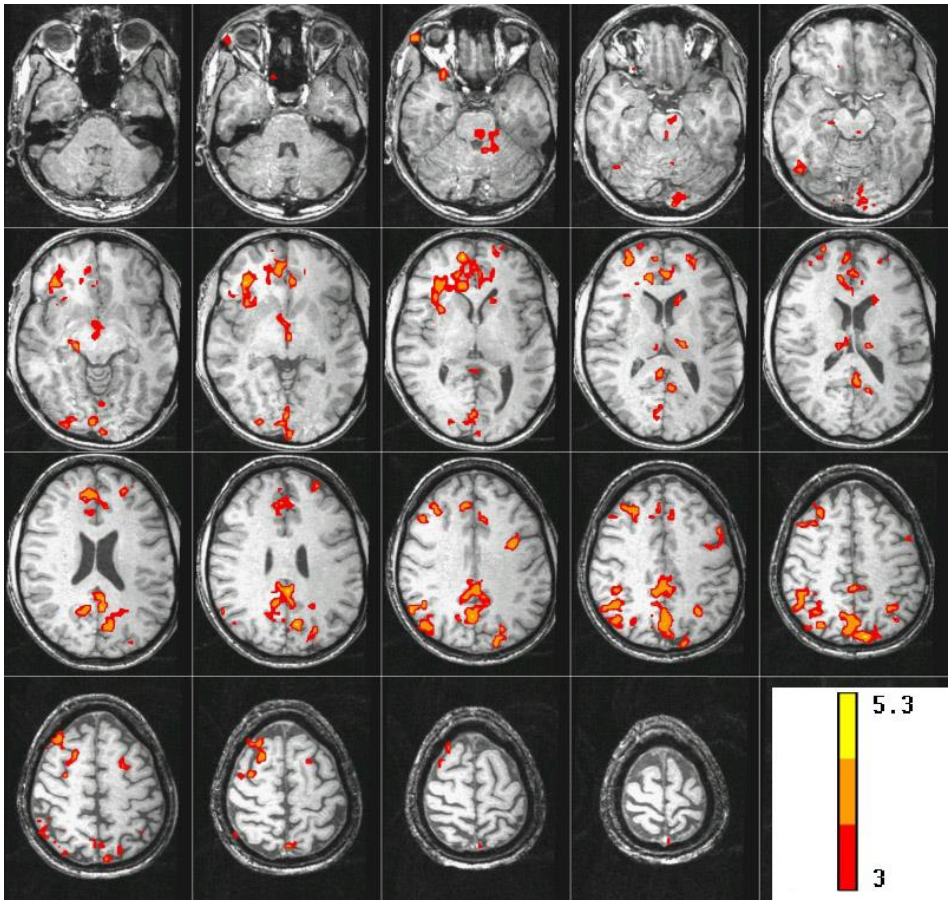


Rest:
seed voxel in motor cortex

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

Methodology

BOLD correlated with SCR during "Rest"



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

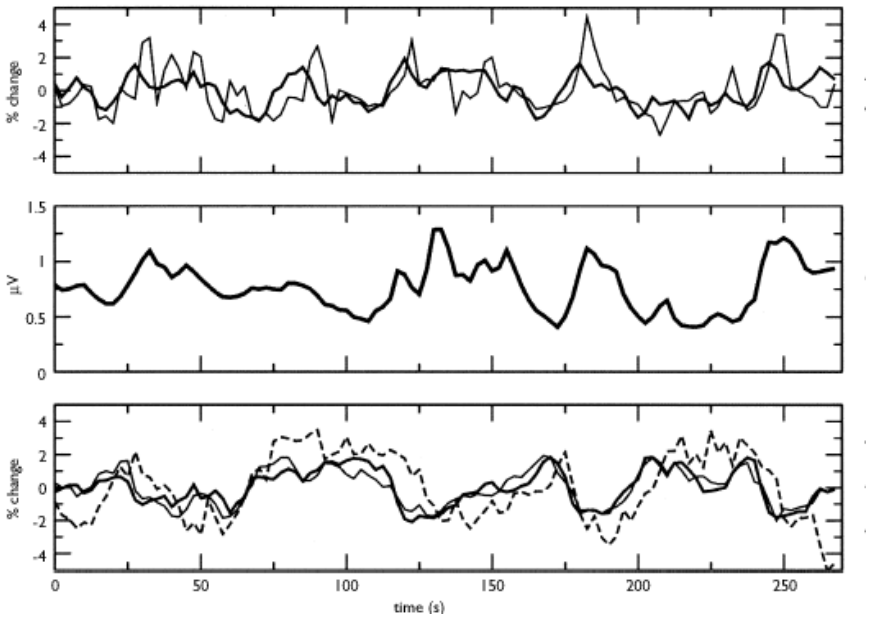
Methodology

BOLD correlated with 10 Hz power during "Rest"

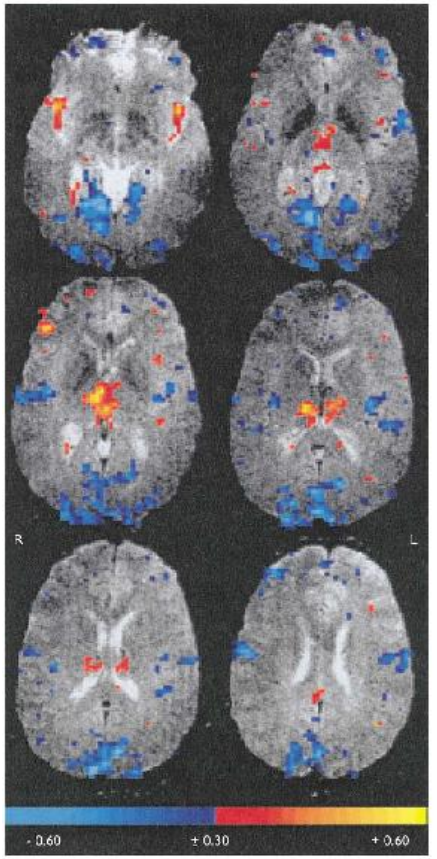
Positive

10 Hz power

Negative



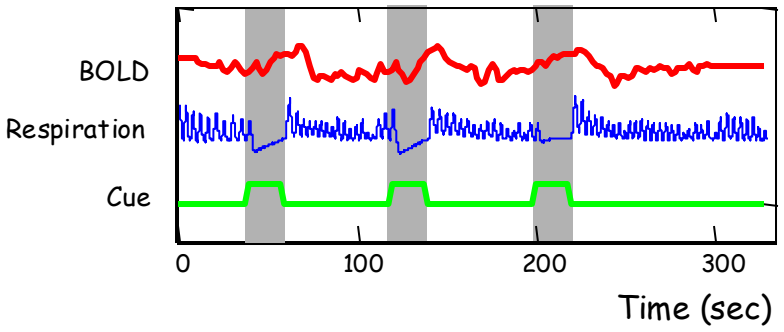
Goldman, et al (2002), Neuroreport



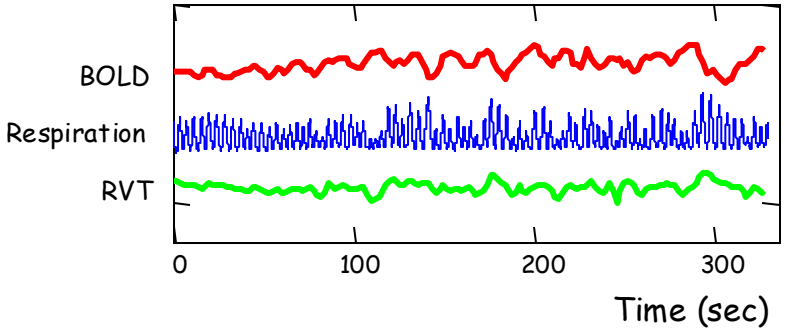
Methodology

Respiration induced signal changes

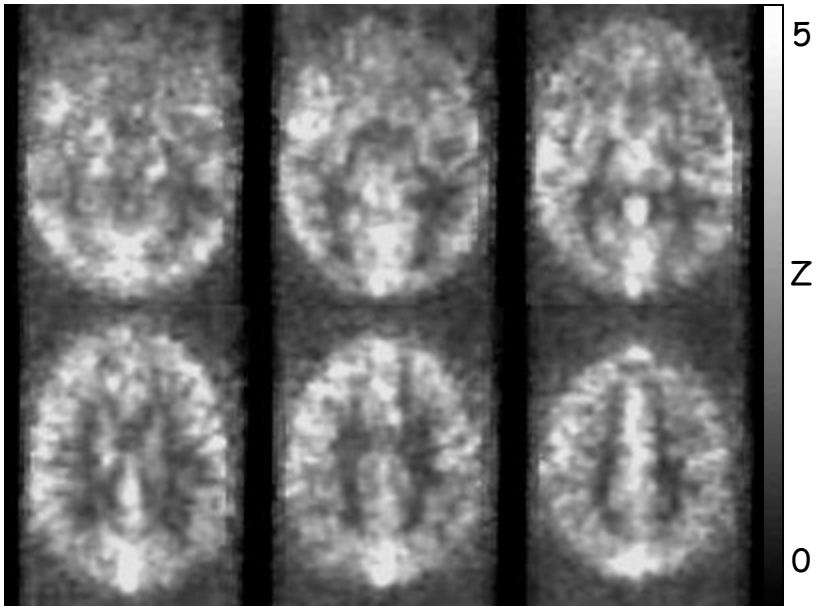
Breath-holding

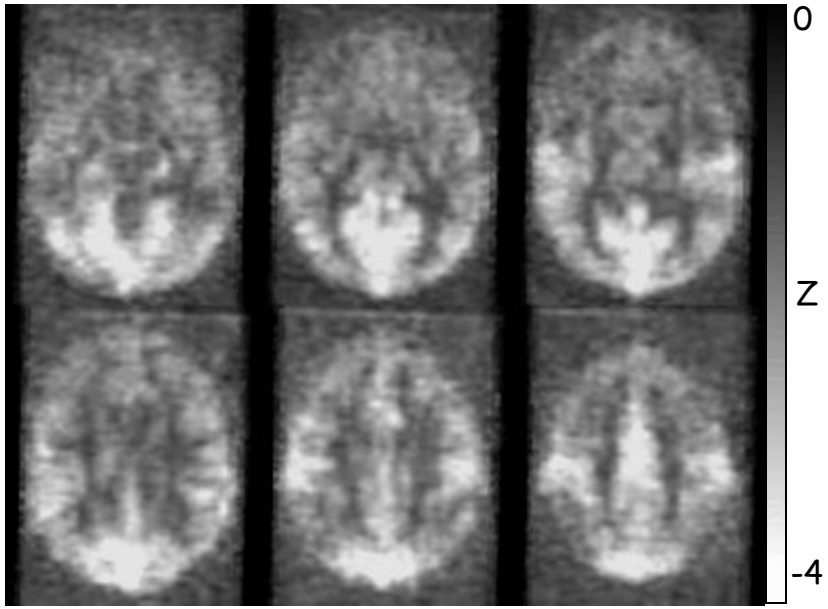


Rest



(N=7)





R. M. Birn, J. B. Diamond, M. A. Smith, P. A. Bandettini, Separating respiratory variation-related fluctuations from neuronal activity-related fluctuations in fMRI, NeuroImage 31, 1536-1548 (2006)

Methodology

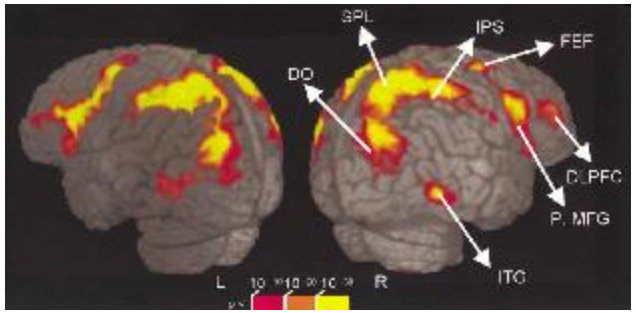
Mapping ⟷ "Reading"

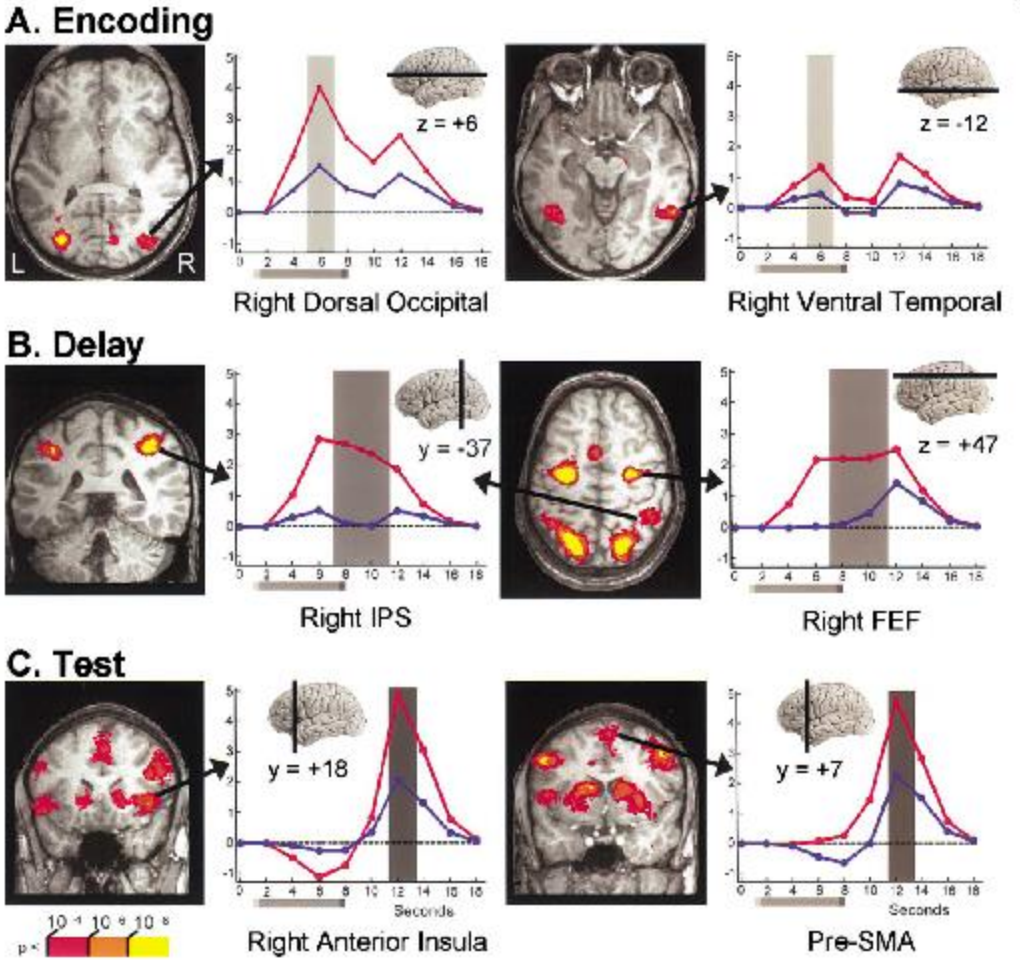
Methodology

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

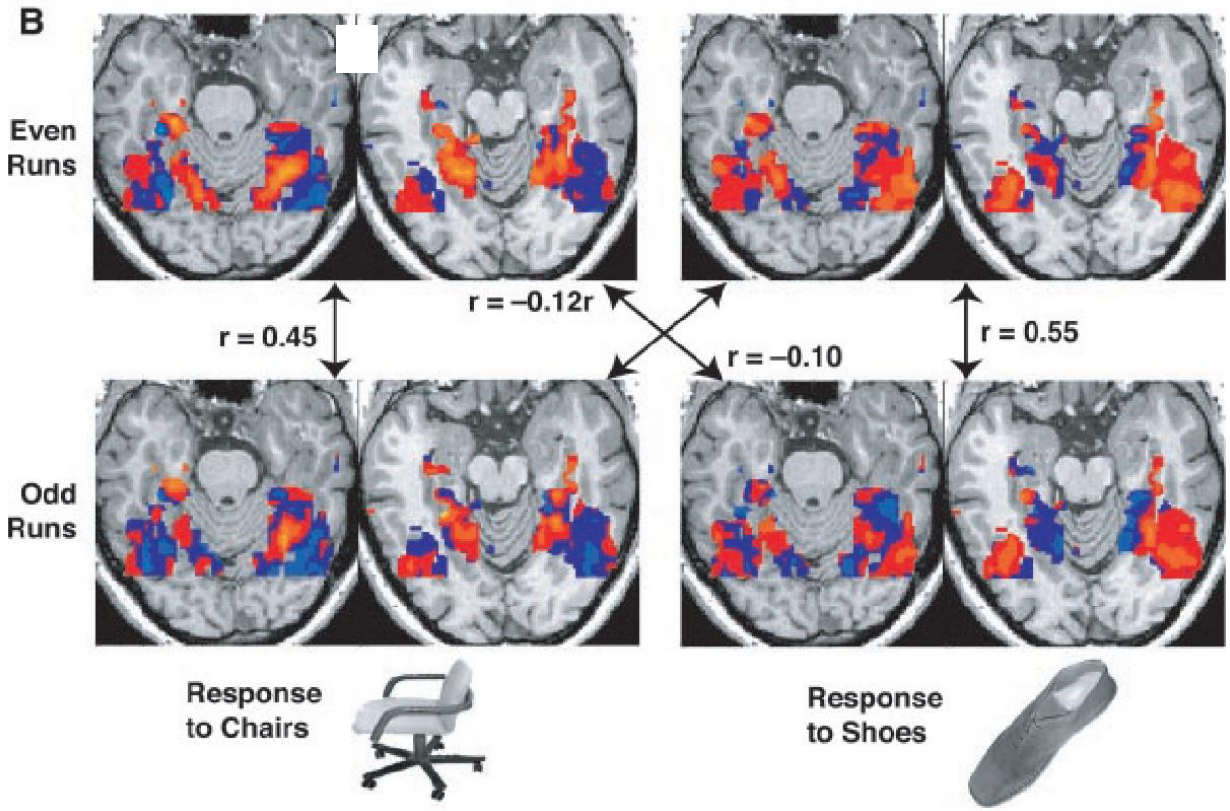




Methodology

Ventral temporal category representations

Object categories are associated with distributed representations in ventral temporal cortex



Haxby et al. 2001

Methodology

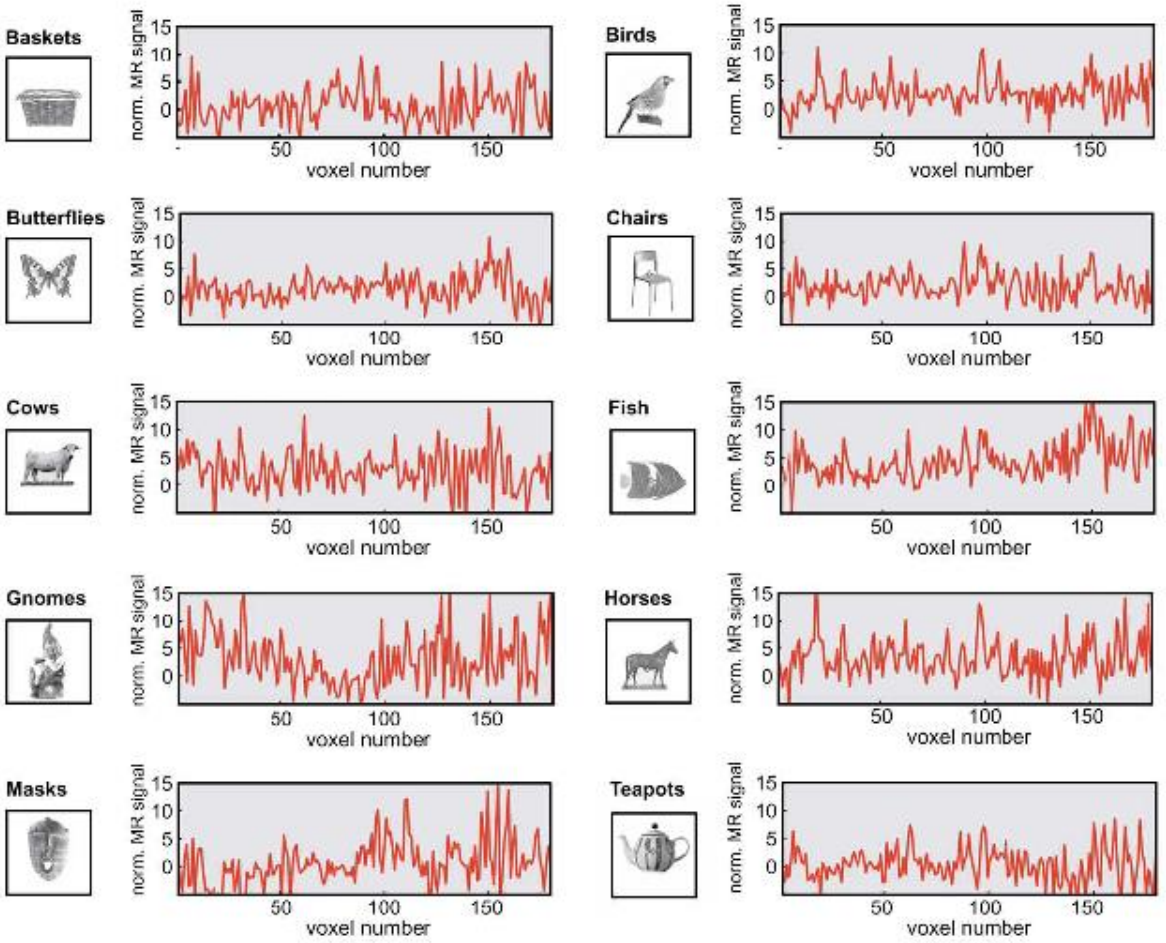
Functional magnetic resonance imaging (fMRI) "brain reading": detecting and classifying distributed patterns of fMRI activity in human visual cortex

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

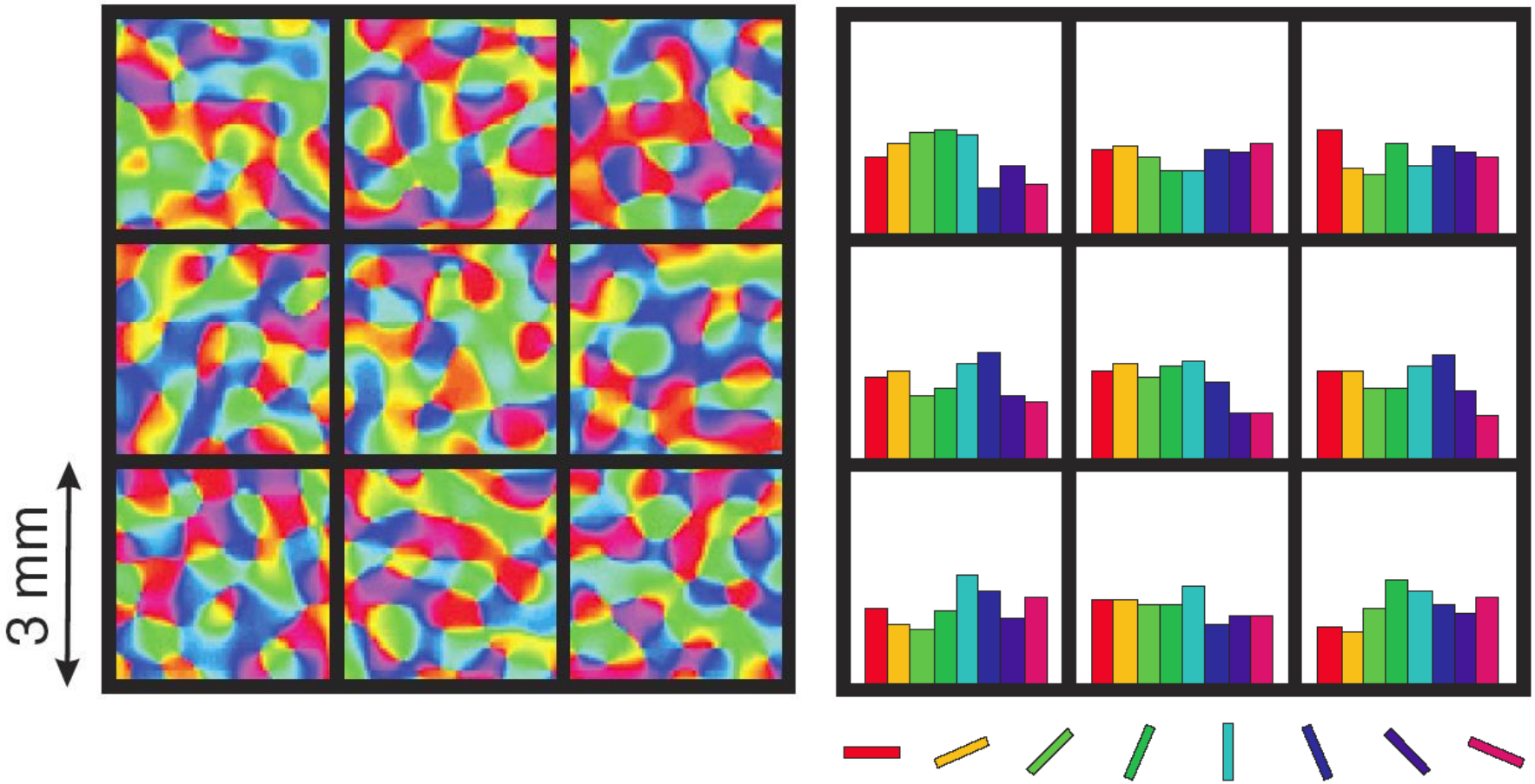
[a] Rowland Institute for Science, Cambridge, MA 02142, USA
[b] Athinoula A. Martinos Center for Structural and Functional Biomedical Imaging, Charlestown, MA 02129, USA
[c] HyperVision, Inc., P.O. Box 158, Lexington, MA 02420, USA

Received 15 July 2002; accepted 10 December 2002

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



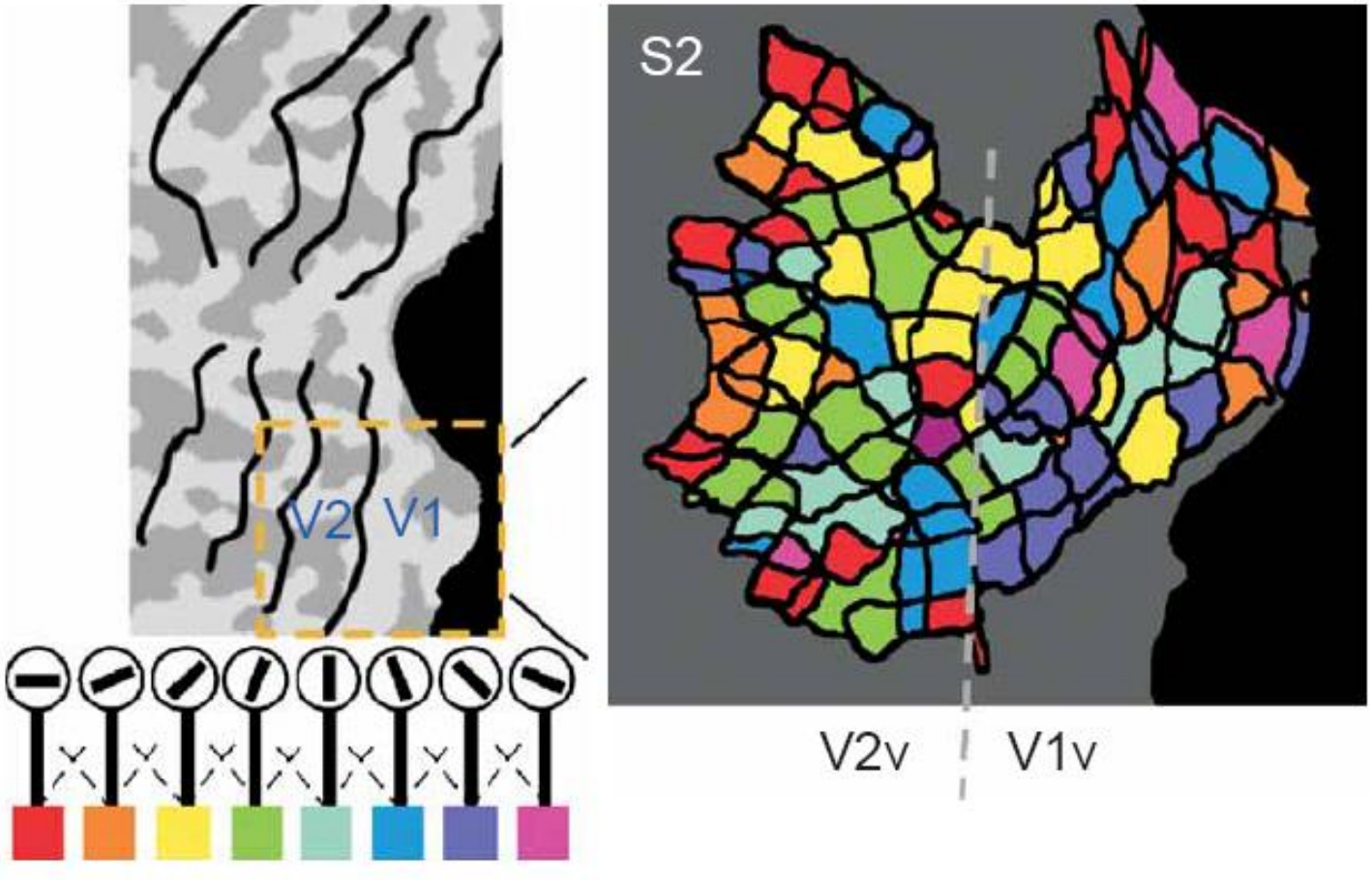
Methodology



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

Methodology

Lower spatial frequency clumping

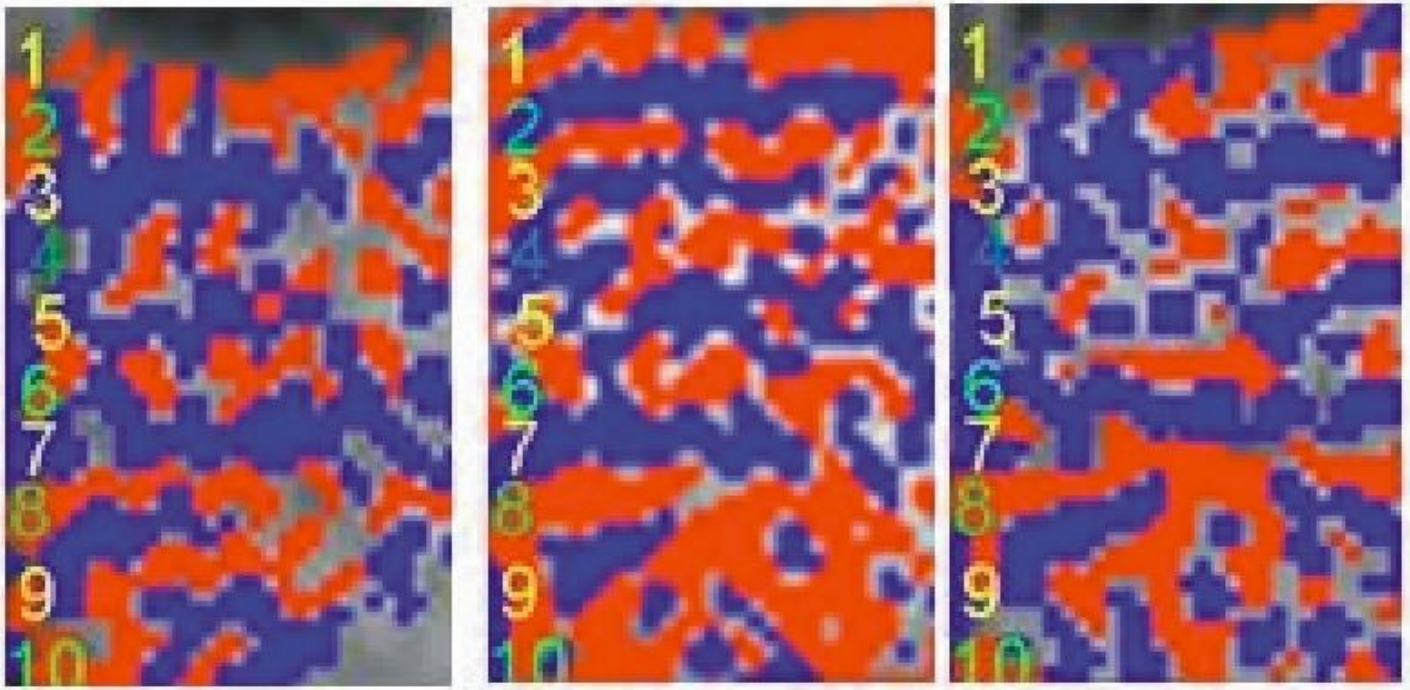


Kamitani & Tong (2005)

What to do with high resolution data?

HSE-BOLD demonstration of ocular dominance columns

human, 7T, 0.5×0.5×3 mm^3

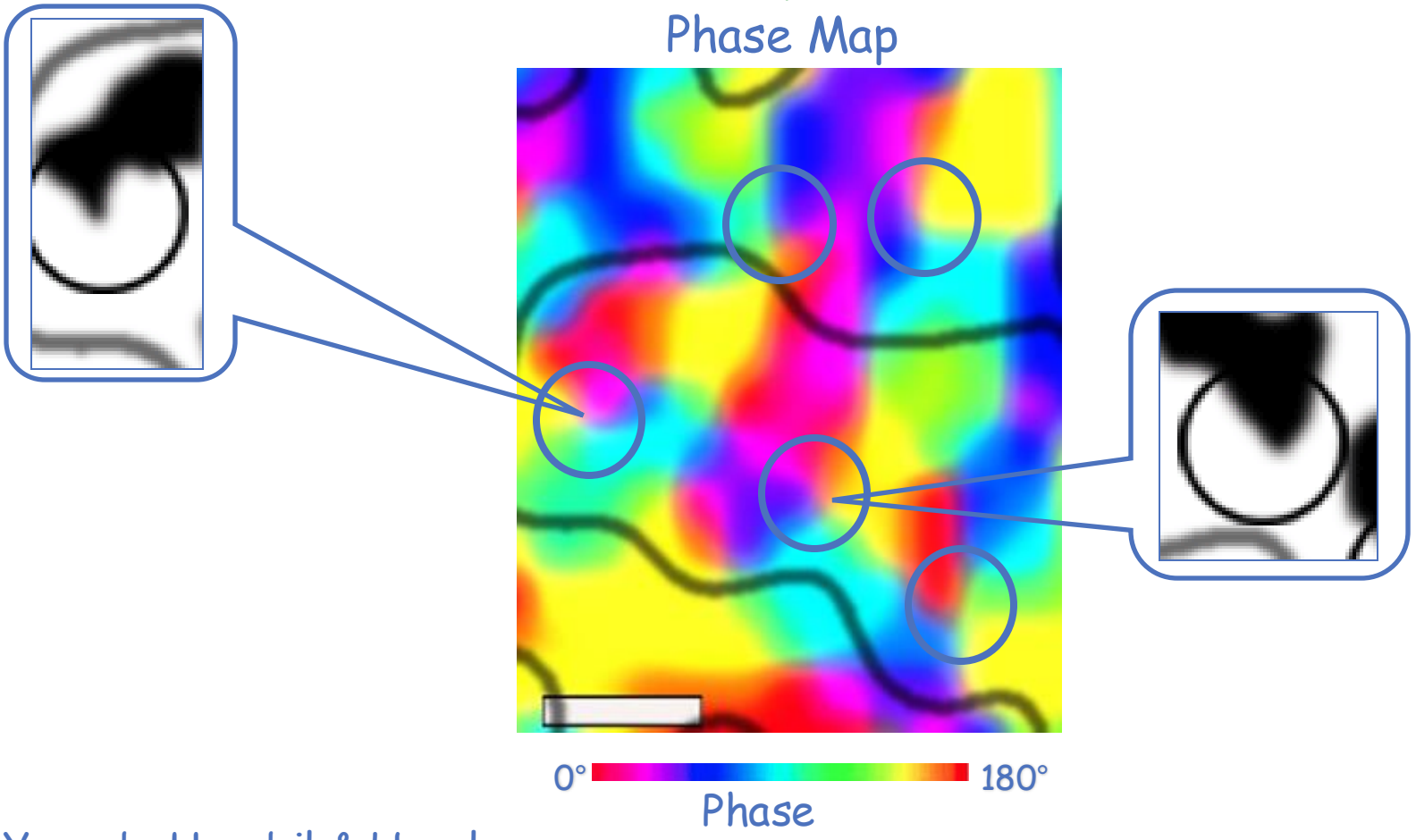


day 1 day 2 day 3

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

Methodology

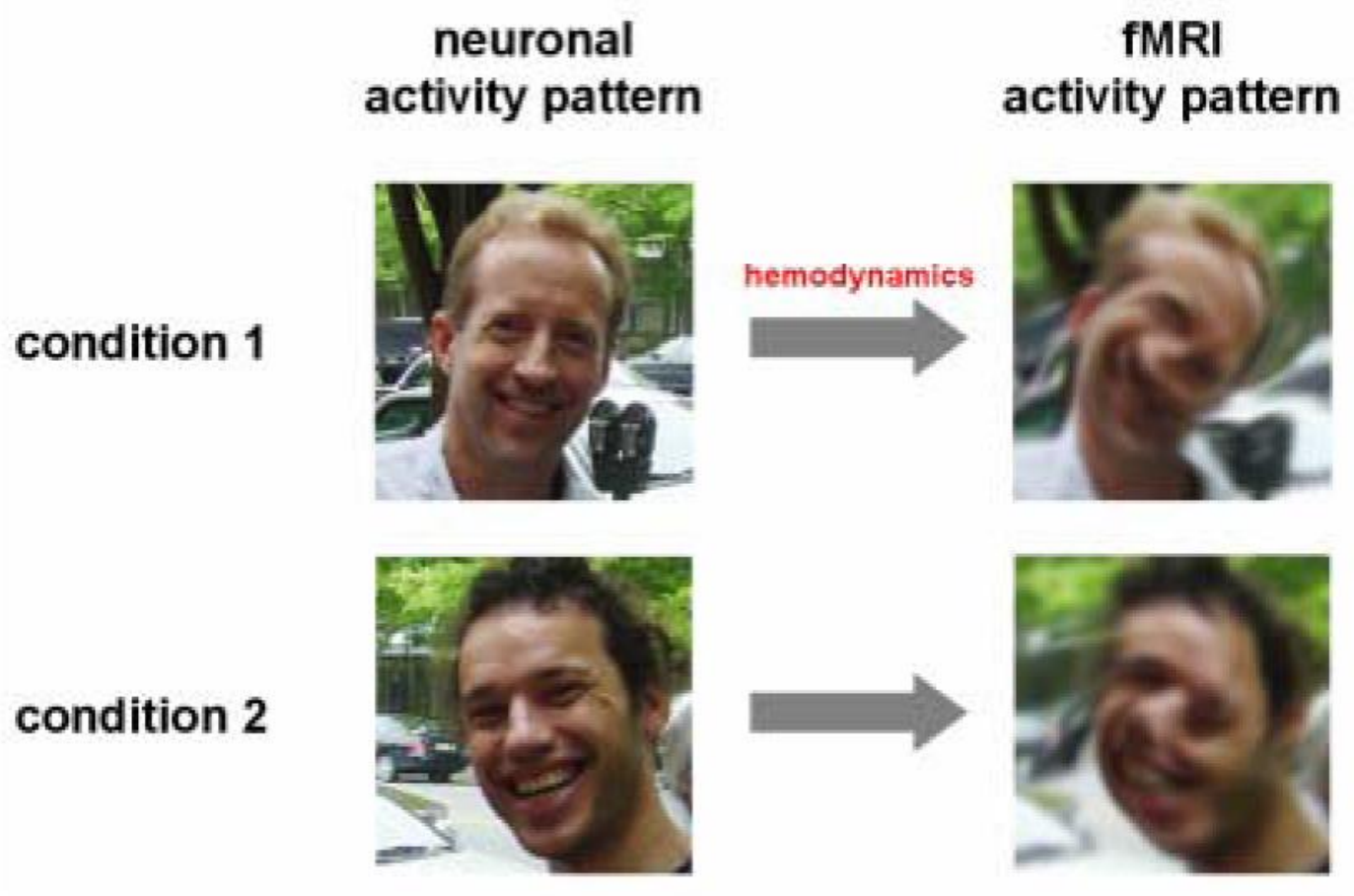
Orientation Columns in Human V1 as Revealed by fMRI at 7T



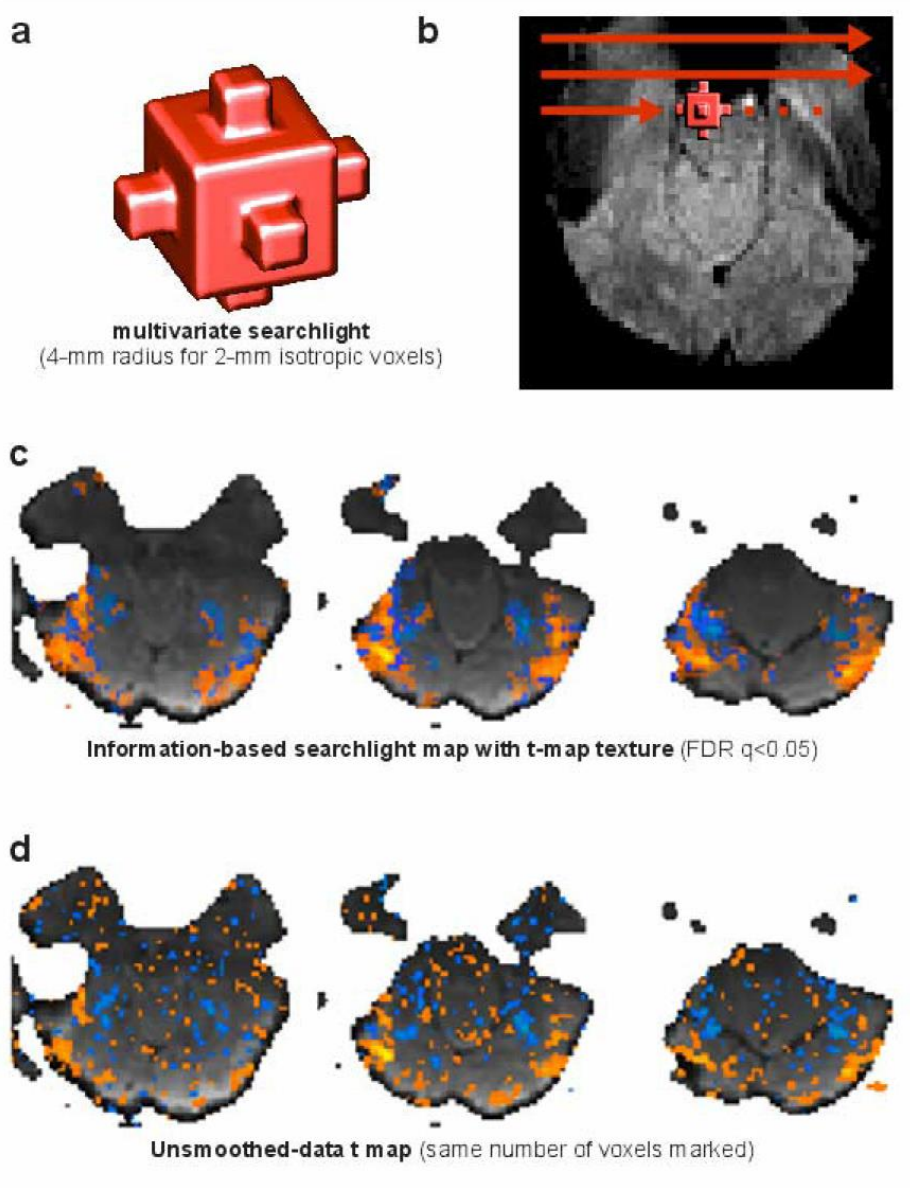
Yacoub, Ugurbil & Harel
University of Minnesota / CMRR
HBM 2006: Thursday, June 15, 2006 at 9:30

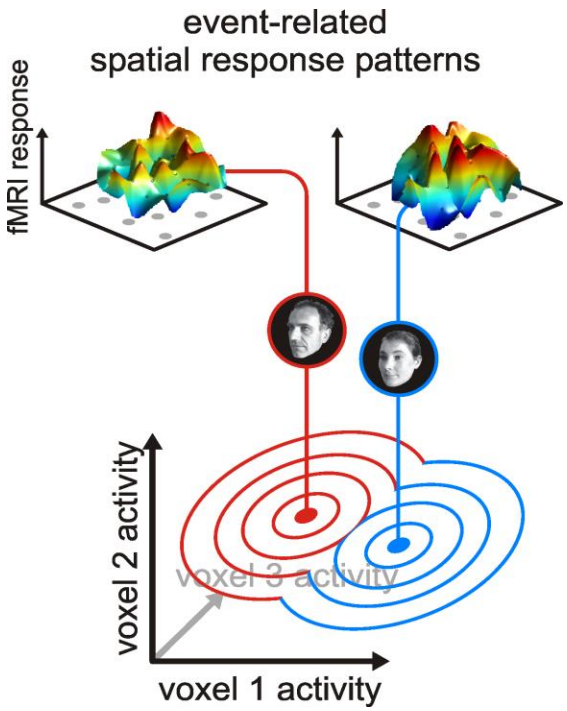
Scalebar = 0.5 mm

Methodology



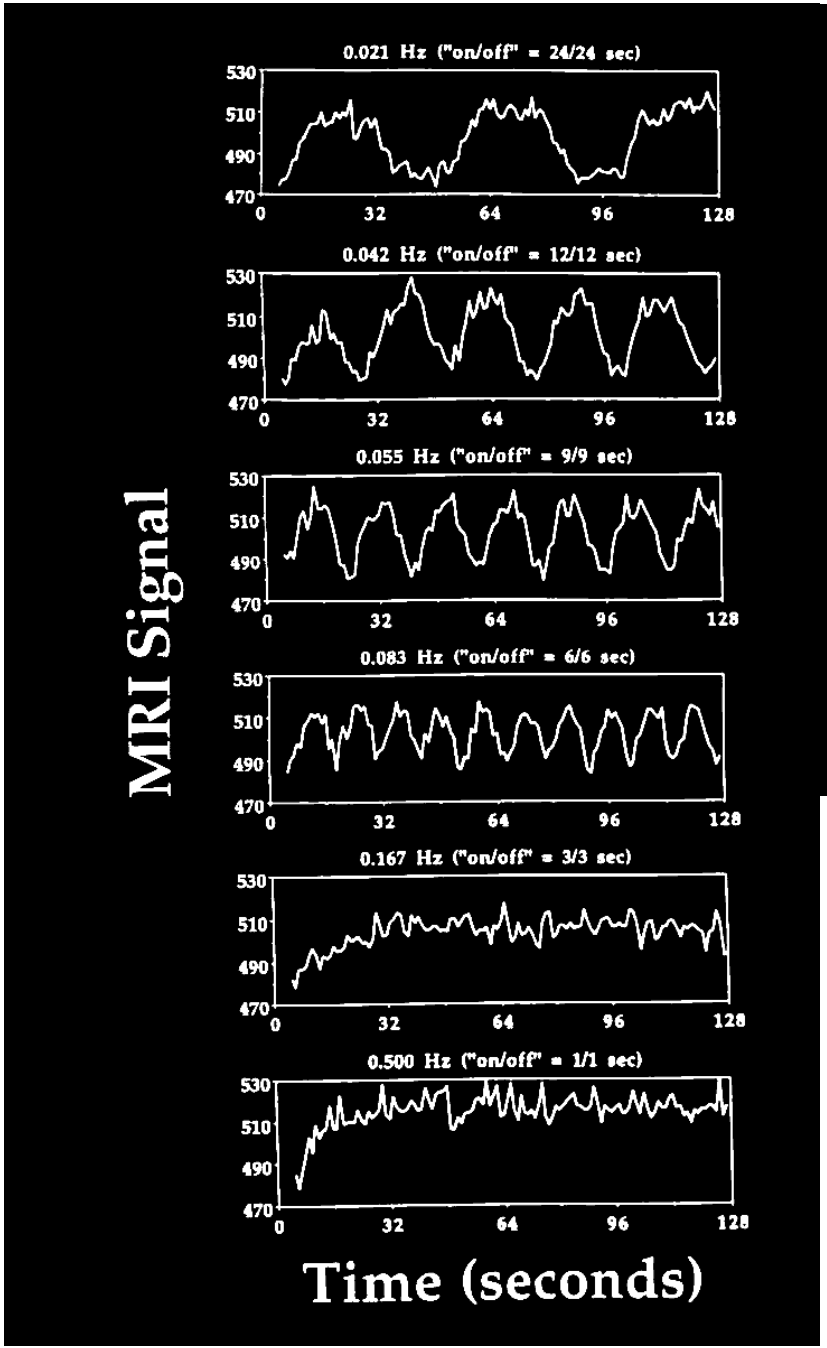
Methodology



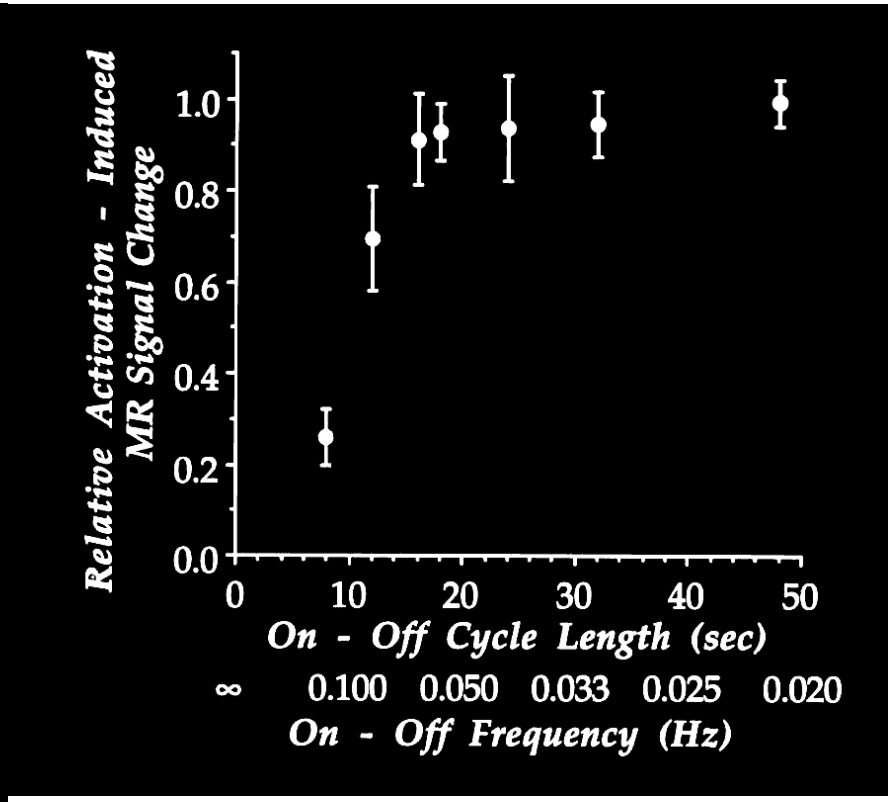


N. Kriegeskorte, R. Goebel, P. Bandettini, Information-based functional brain mapping. *Proc. Nat'l. Acad. Sci. USA*, 103, 3863-3868 (2006).

Methodology



Temporal Resolution

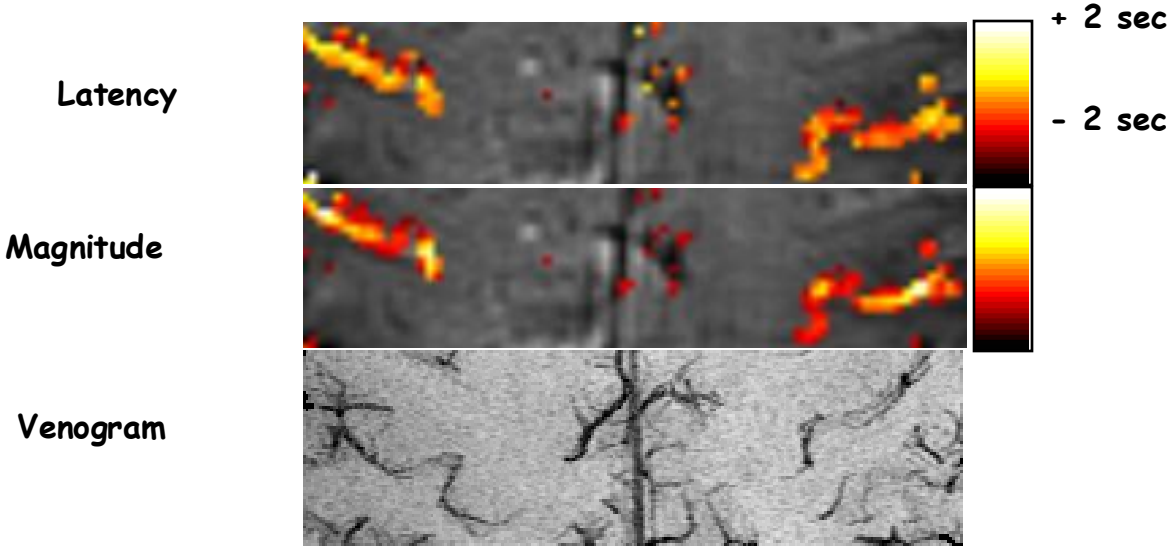


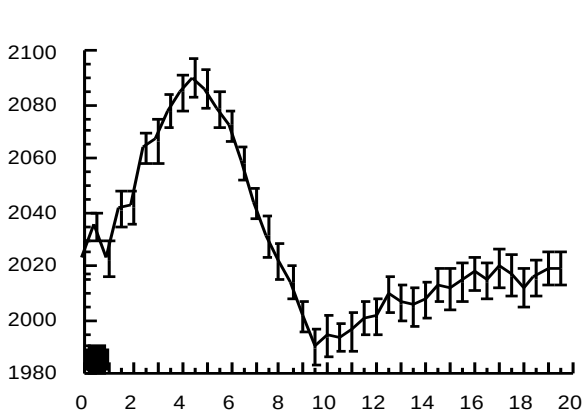
P. A. Bandettini, Functional MRI temporal resolution *in* "Functional MRI" (C. Moonen, and P. Bandettini., Eds.), p. 205-220, Springer - Verlag,. 1999.

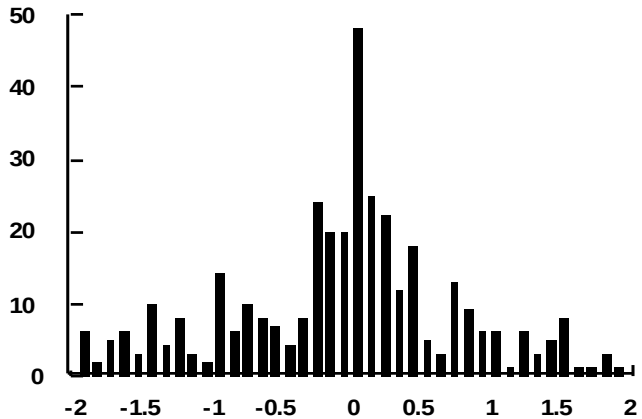
Methodology

Temporal Resolution

Latency Variation…



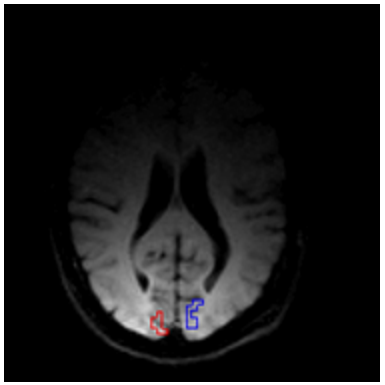




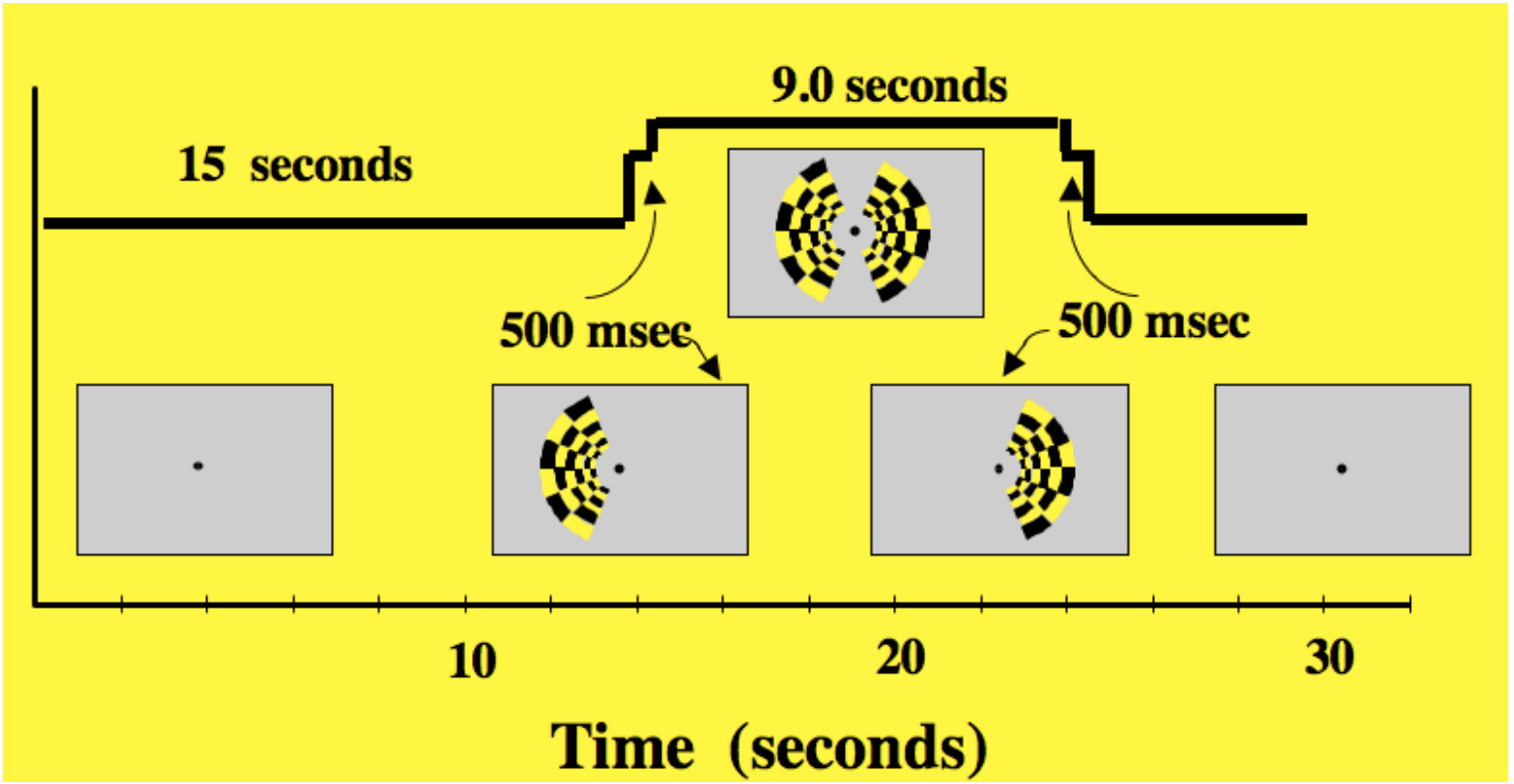
P. A. Bandettini, (1999) "Functional MRI" 205-220.

Hemi-Field Experiment

Right Hemisphere

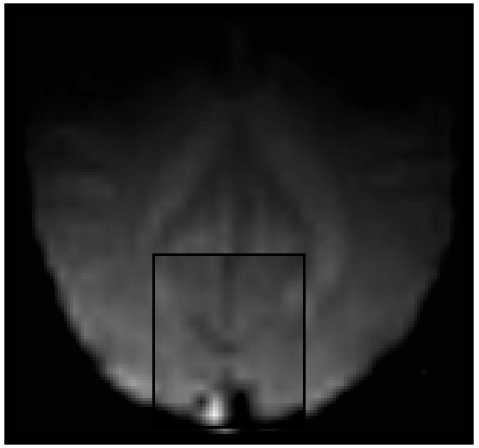


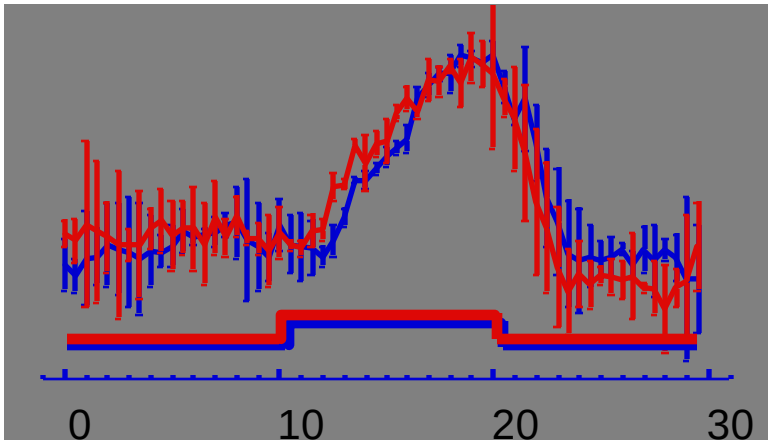
Left Hemisphere



Methodology

Temporal Resolution



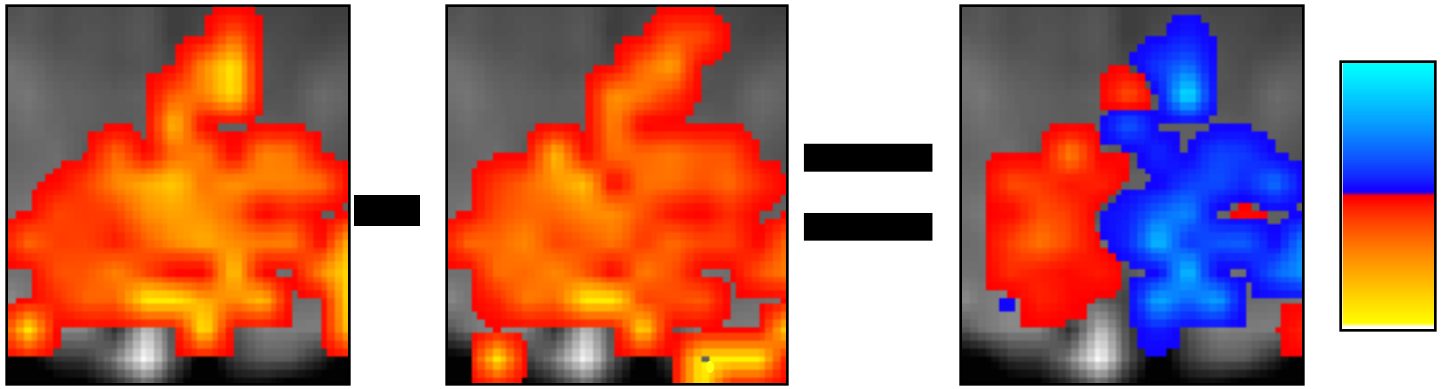


500 ms
||

500 ms
||

Right Hemifield

Left Hemifield



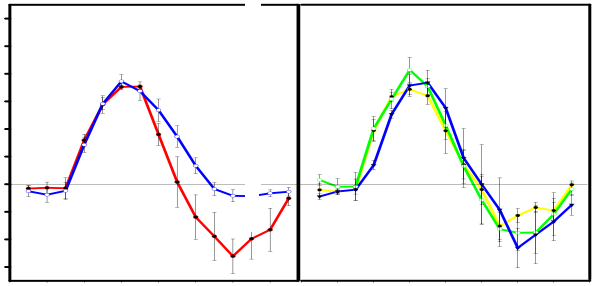
Methodology

Temporal Resolution

Word vs. Non-word

0°, 60°, 120° Rotation

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



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

Technology

Coil arrays
High field strength
High resolution
Novel functional contrast

Methodology

Functional Connectivity Assessment
Multi-modal integration
Pattern classification
Real time feedback
Task design

Fluctuations
Dynamics
Cross - modal comparison

Interpretation

Basic Neuroscience
Behavior correlation/prediction
Pathology assessment

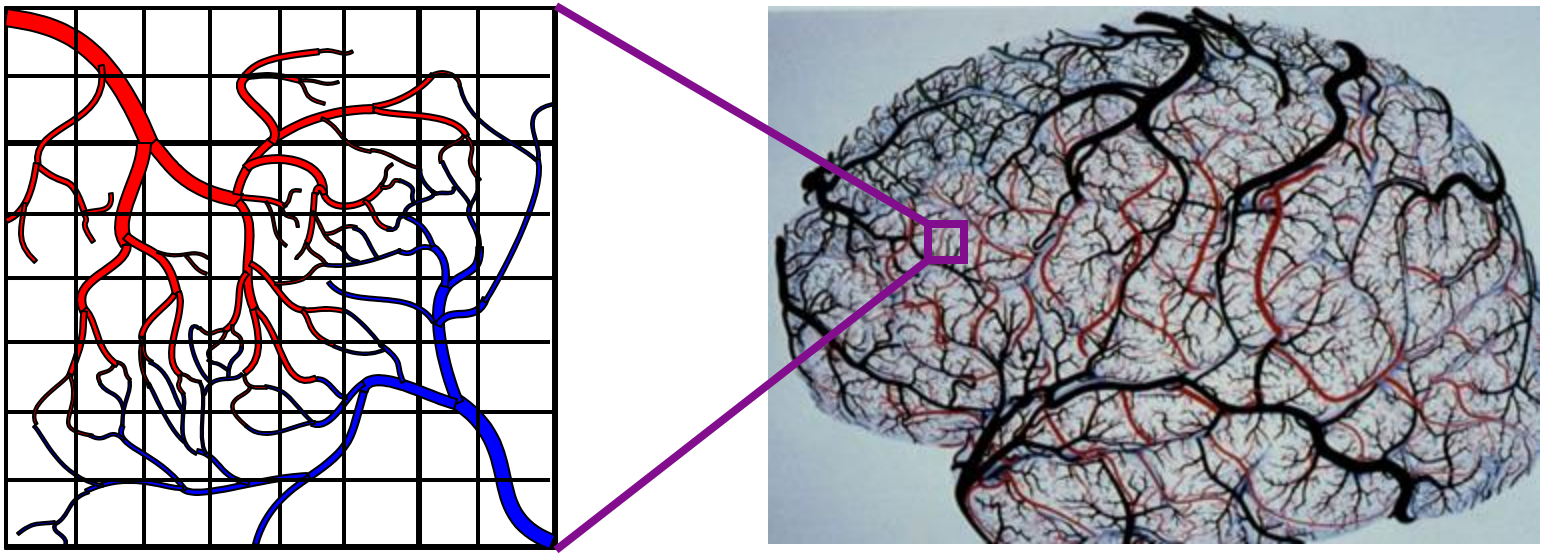
Applications

Interpretation

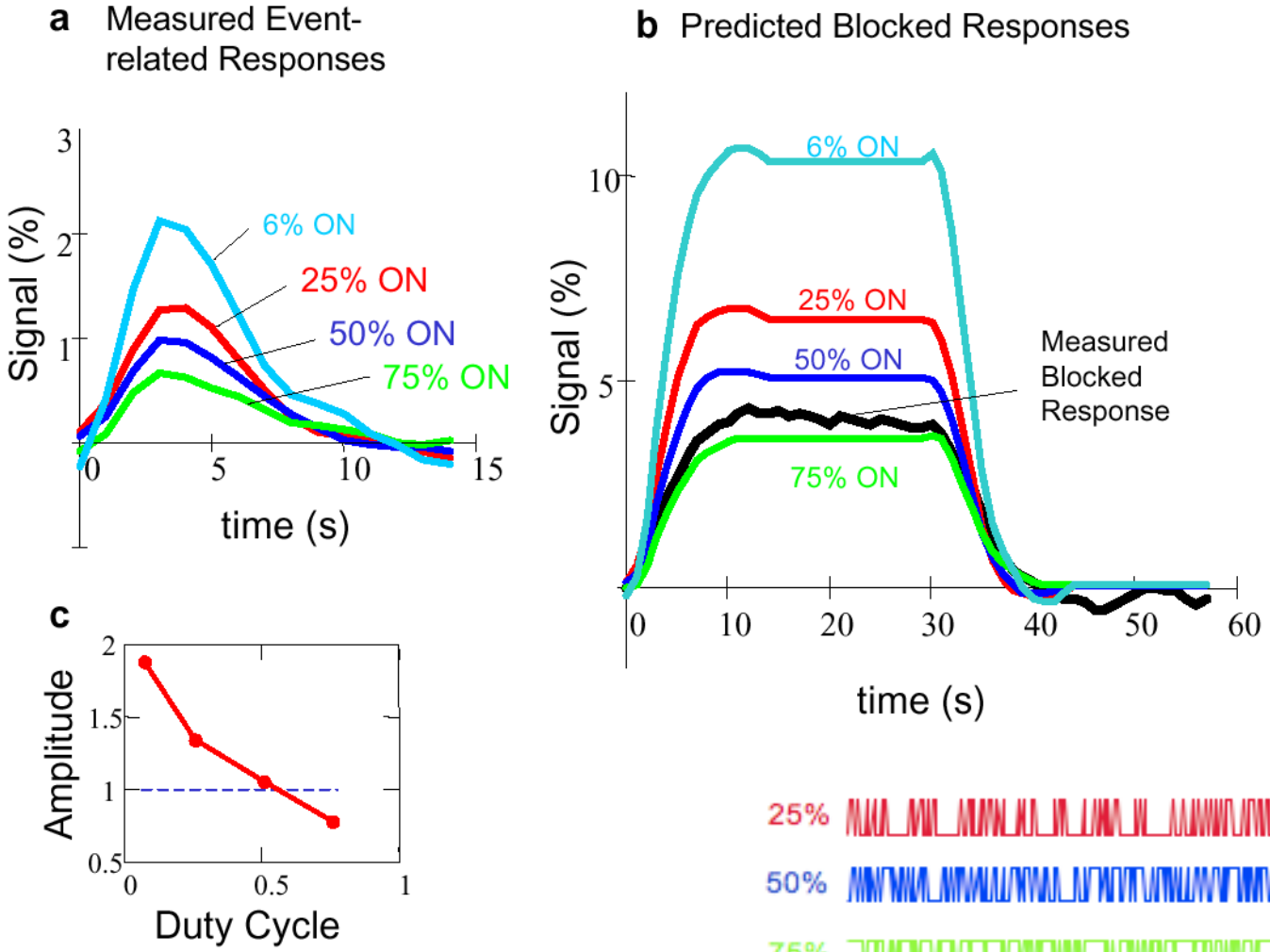
Neuronal Activation ? Measured Signal

? Hemodynamics ?

Noise ?



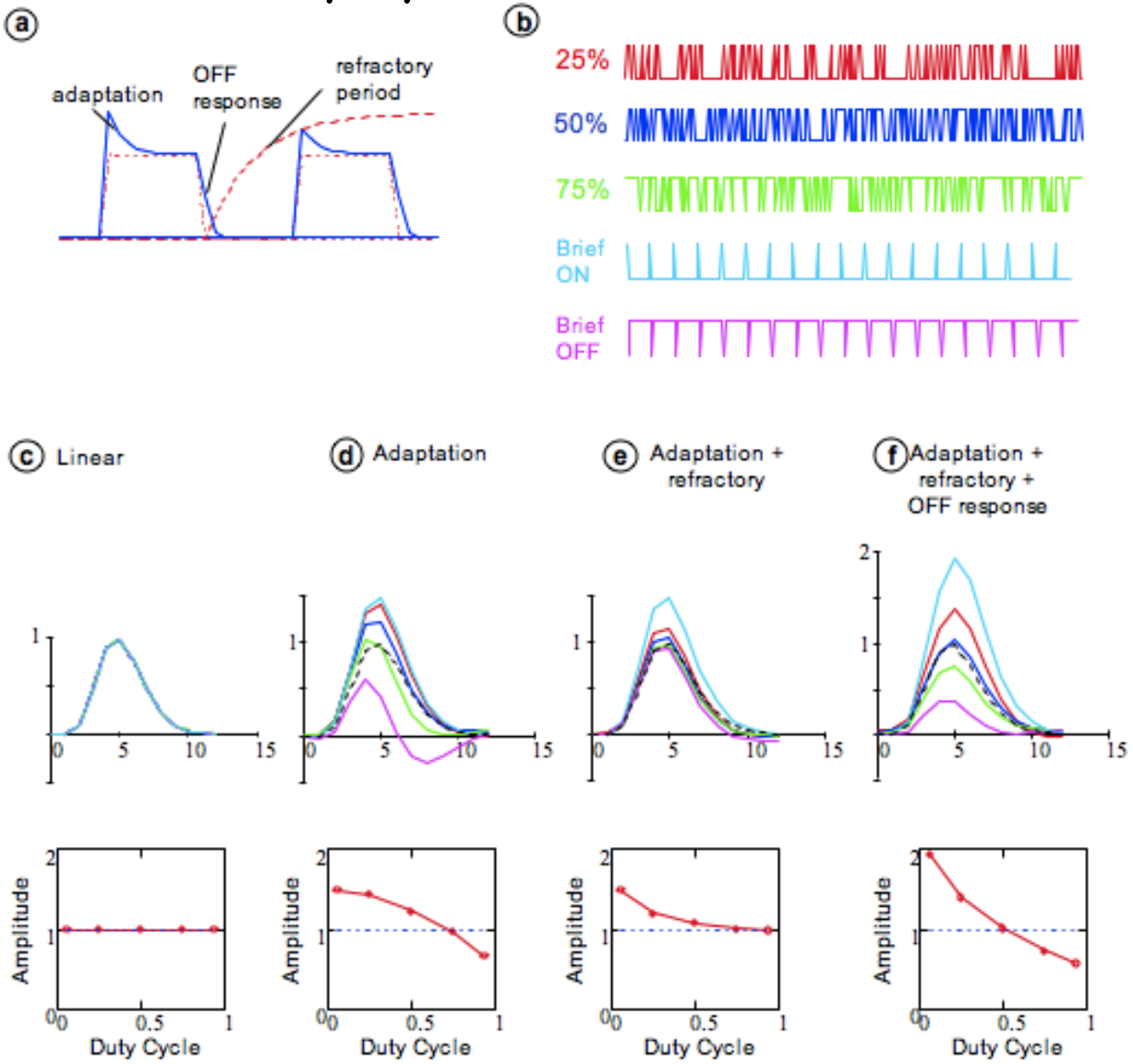
Interpretation Duty Cycle Effects



R.M. Birn, et al, NeuroImage, 27, 70-82 (2005)

Interpretation

duty cycle effects



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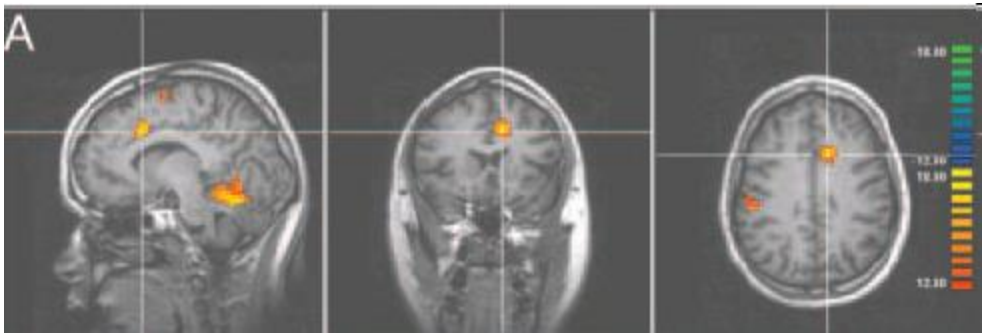
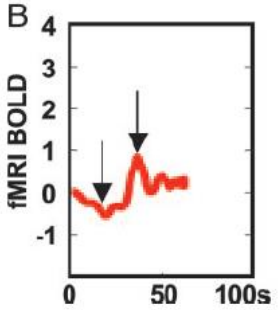
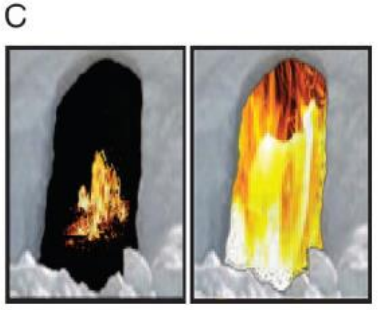
Applications

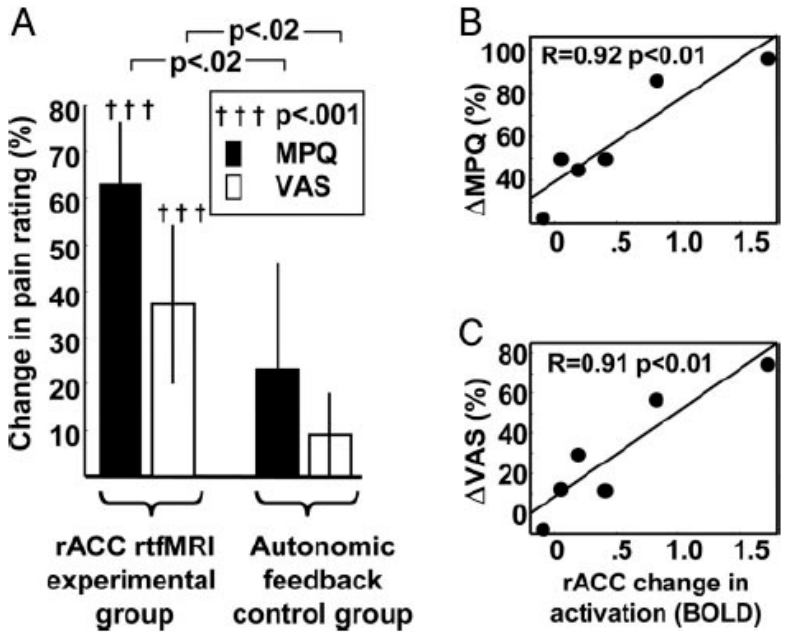
Applications

Real time fMRI feedback from Anterior Cingulate Cortex 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)

What fMRI Might Do

Complementary use for clinical diagnoses
- -utilization of clinical research results for diagnoses
- -prediction of pathology

Clinical treatment and assessment of therapy
- -better understanding mechanism of pathology for focused therapy
- -drug effect assessment
- -assessment of therapy progress, biofeedback
- -epileptic foci mapping
- -neurovascular physiology assessment

Non clinical uses
- -lie detection
- -prediction of behavior tendencies
- -brain/computer interface