Latest Developments of fMRI

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Section on Functional Imaging Methods

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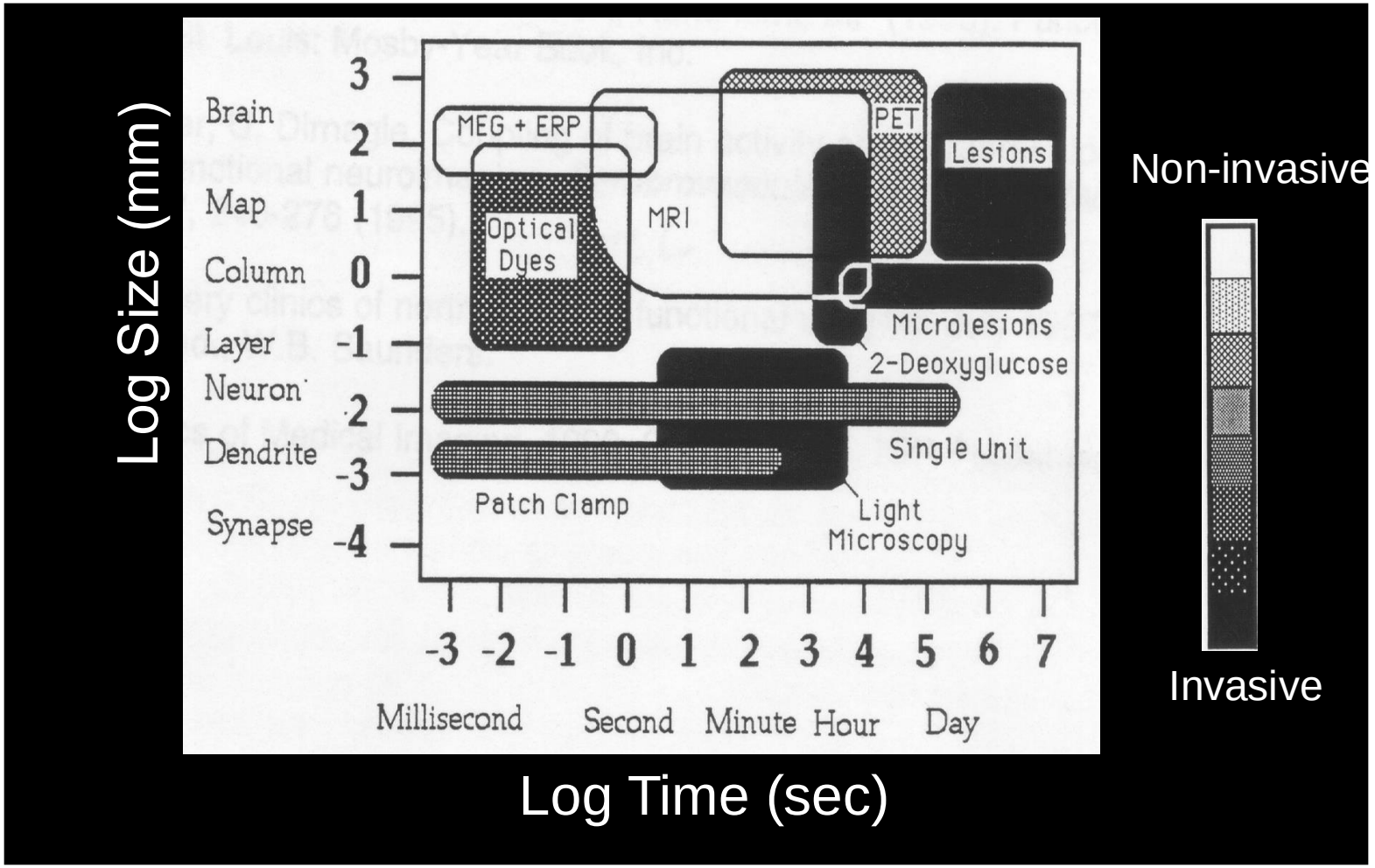
Laboratory of Brain and Cognition

&

Functional MRI Facility

http://fmrif.nimh.nih.gov

Functional Neuroimaging Techniques



A brief overview of the three main types of fMRI contrast

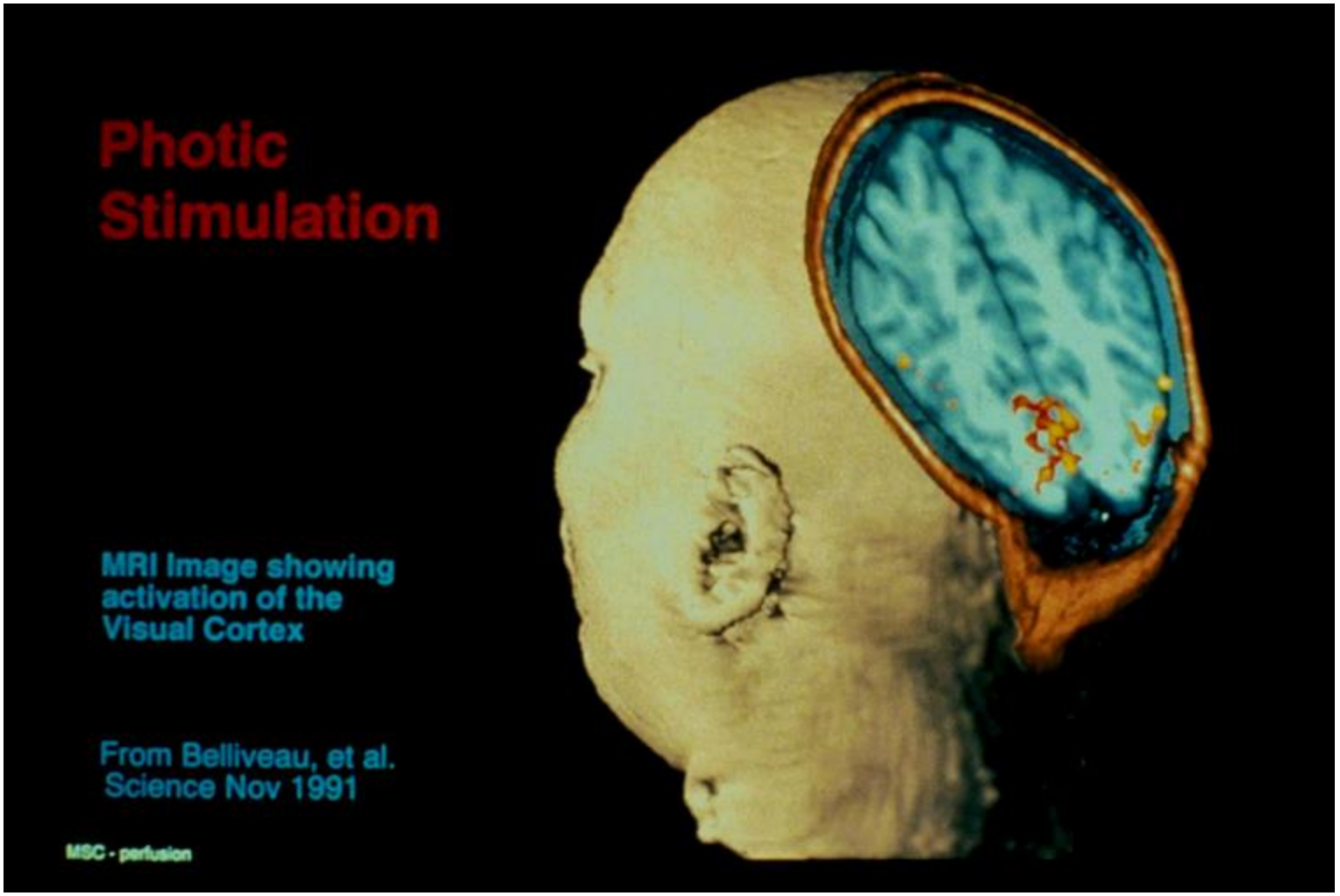
Volume

Flow or Perfusion

Oxygenation

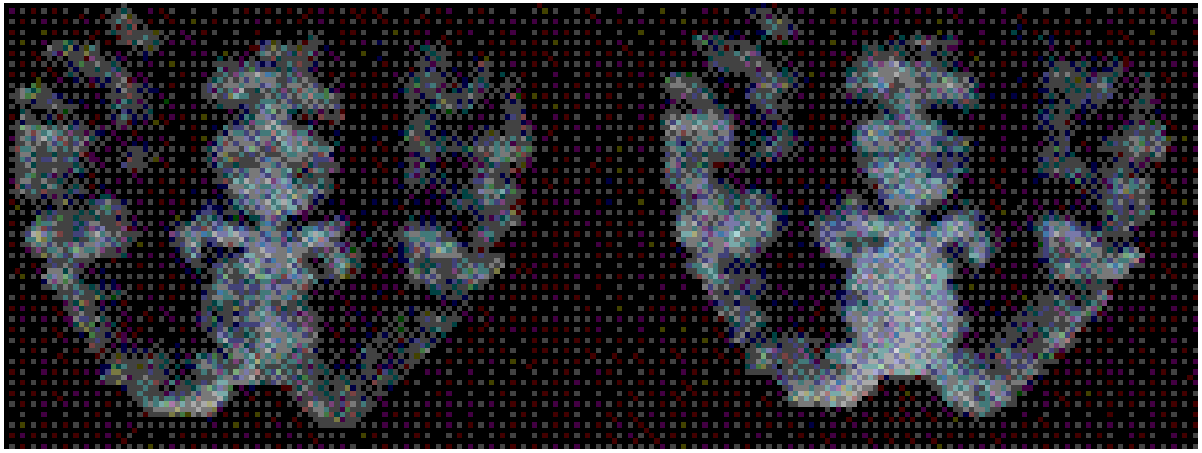
Blood Volume

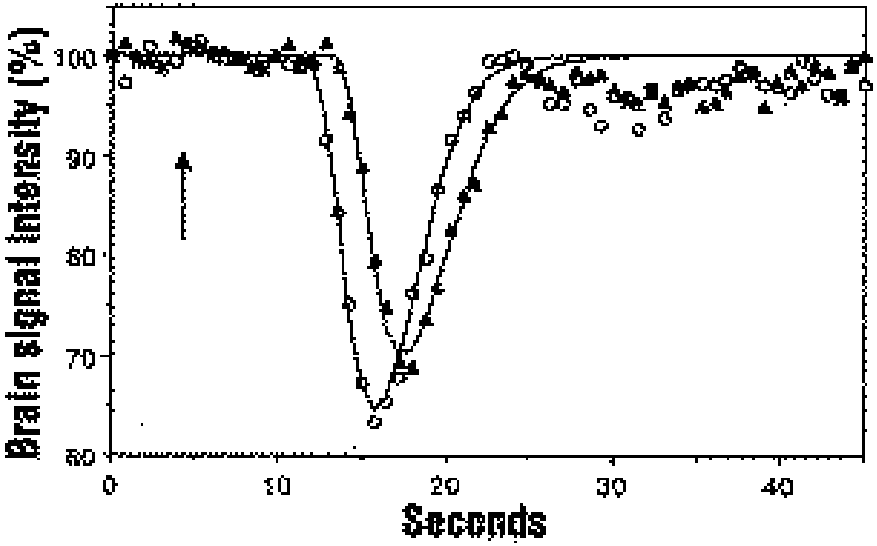
What started it all…

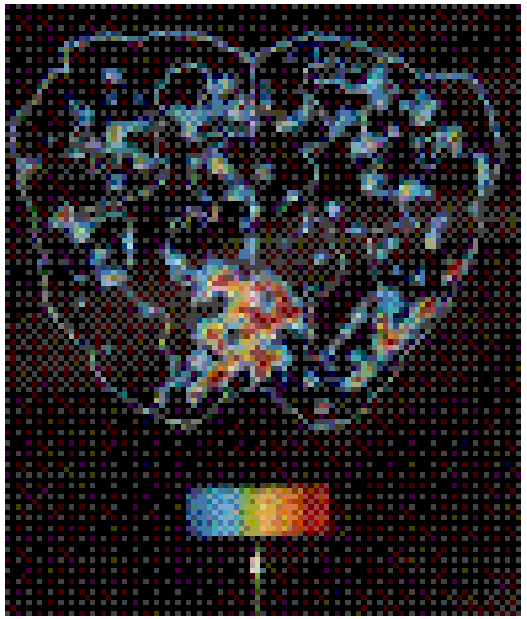


Blood Volume

Resting Active

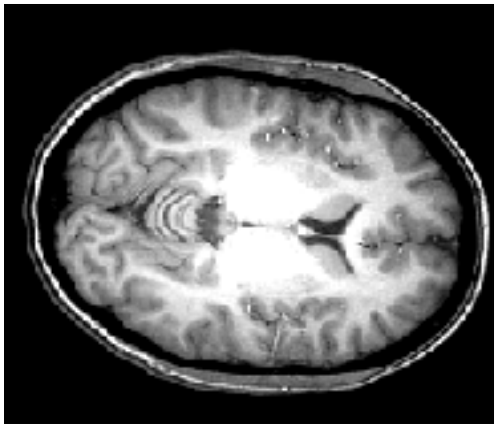






MRI vs. fMRI

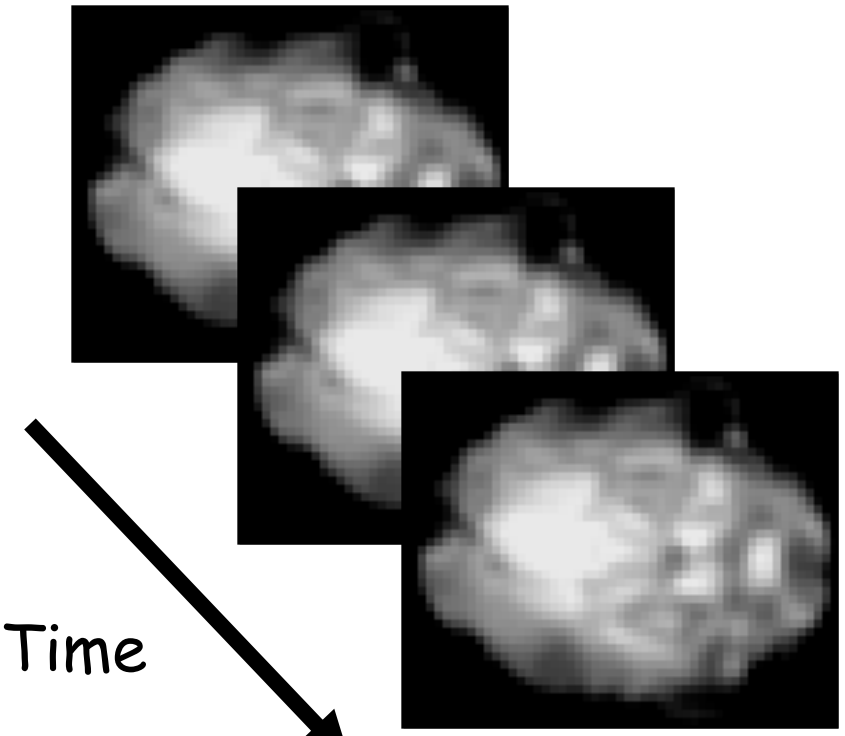
MRI



one image

high resolution
(1 mm or less)

fMRI

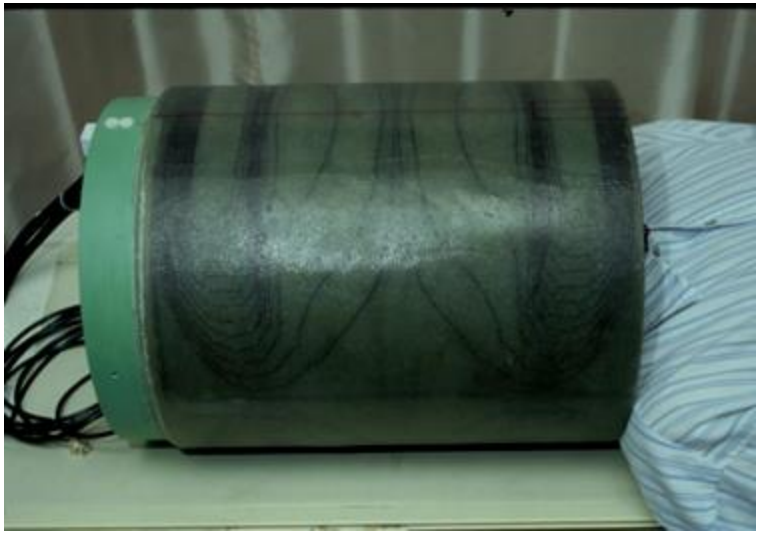


many images
(e.g., every 2 sec for 5 mins)

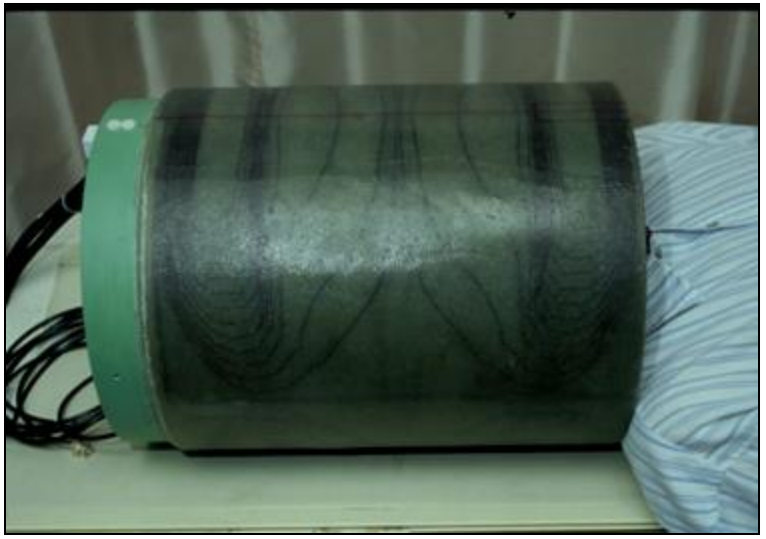
low resolution
(1.5 to 4 mm)

1991-1992

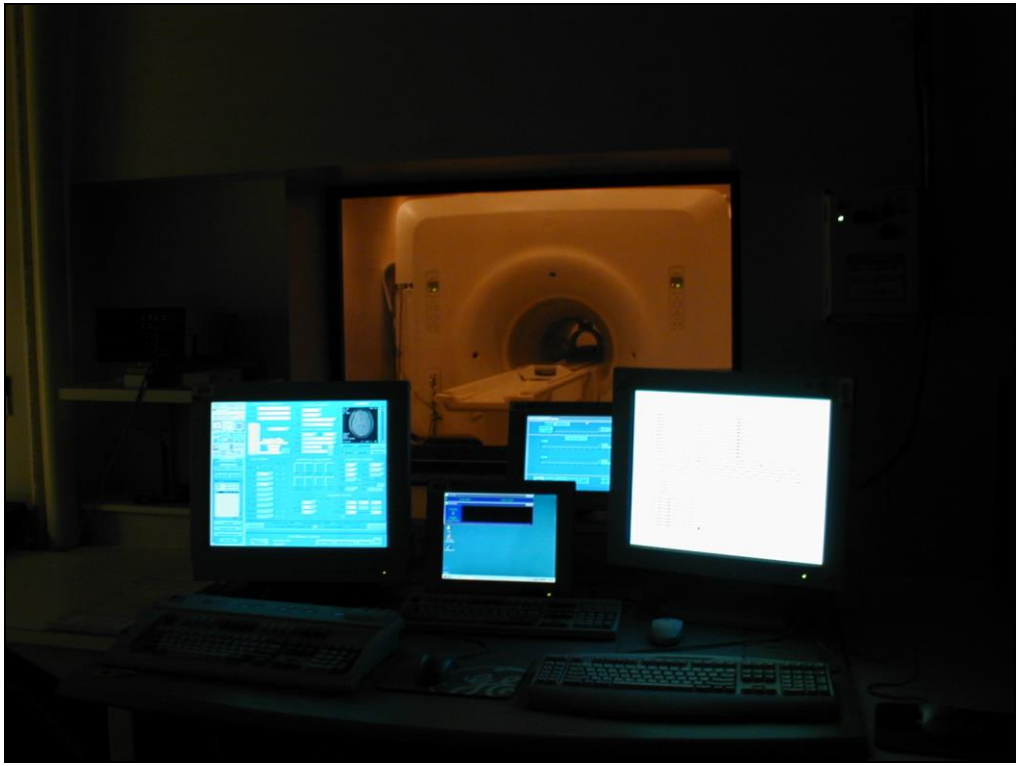
1992-1999



Local Gradient Coil
(low inductance)

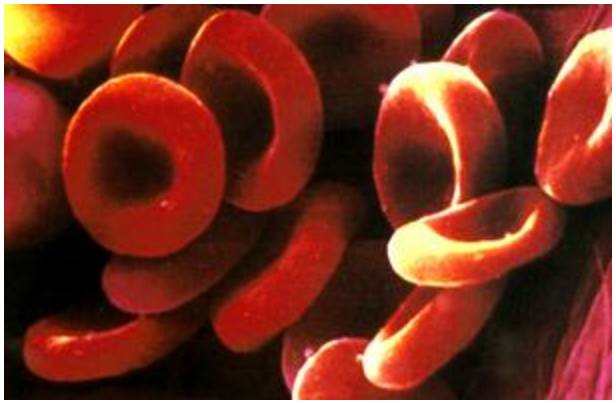


Whole body gradients
(more powerful amplifiers)



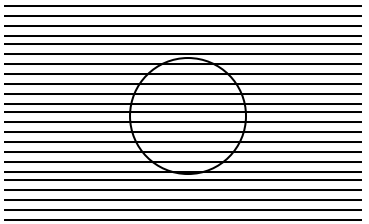
Blood Oxygenation

Oxygenated and deoxygenated red blood cells have different magnetic properties

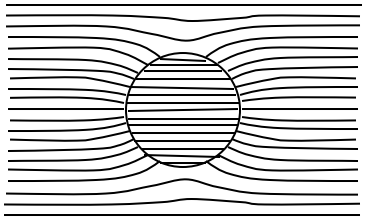


red blood cells

oxygenated



deoxygenated



L. Pauling, C. D. Coryell, *Proc.Natl. Acad. Sci. USA 22, 210-216*, **1936**.

K.R. Thulborn, J. C. Waterton, et al., *Biochim. Biophys. Acta. 714: 265-270*, **1982**.

S. Ogawa, T. M. Lee, A. R. Kay, D. W. Tank, *Proc. Natl. Acad. Sci. USA 87, 9868-9872*, **1990**.

Blood Oxygenation

Cerebral Tissue Activation

↓

Local Vasodilatation

↓

Increase in Cerebral Blood Flow and Volume → Oxygen Delivery Exceeds Metabolic Need

↓

Increase in Capillary and Venous Blood Oxygenation

↓

Decrease in Deoxy-hemoglobin

Deoxy-hemoglobin: paramagnetic
Oxy-hemoglobin: diamagnetic

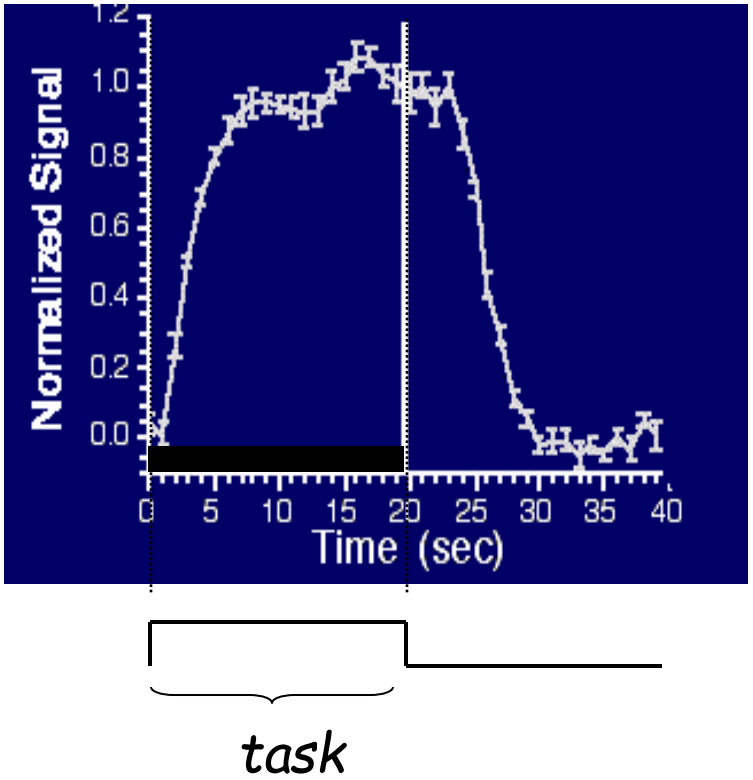
↓

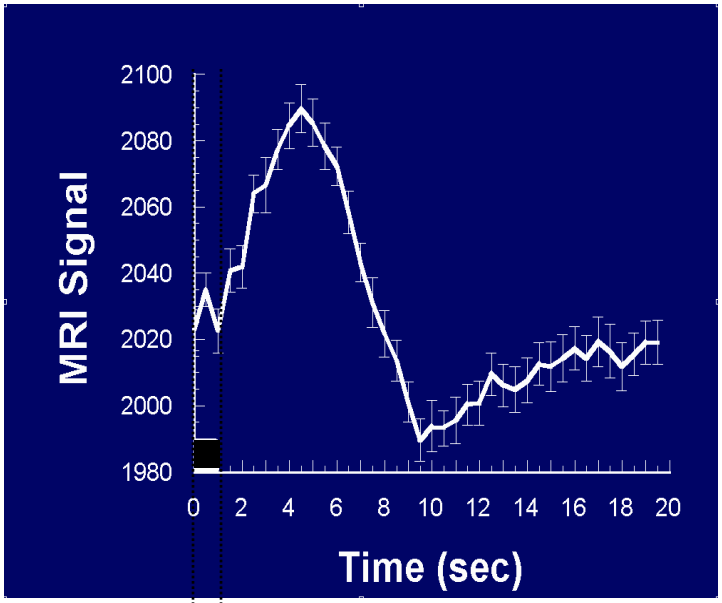
Decrease in susceptibility-related intravoxel dephasing → Increase in T2 and T2*

↓

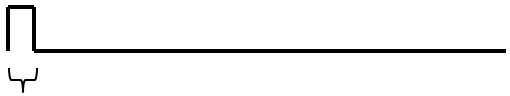
Local Signal Increase in T2 and T2* - weighted sequences

Blood Oxygenation





task

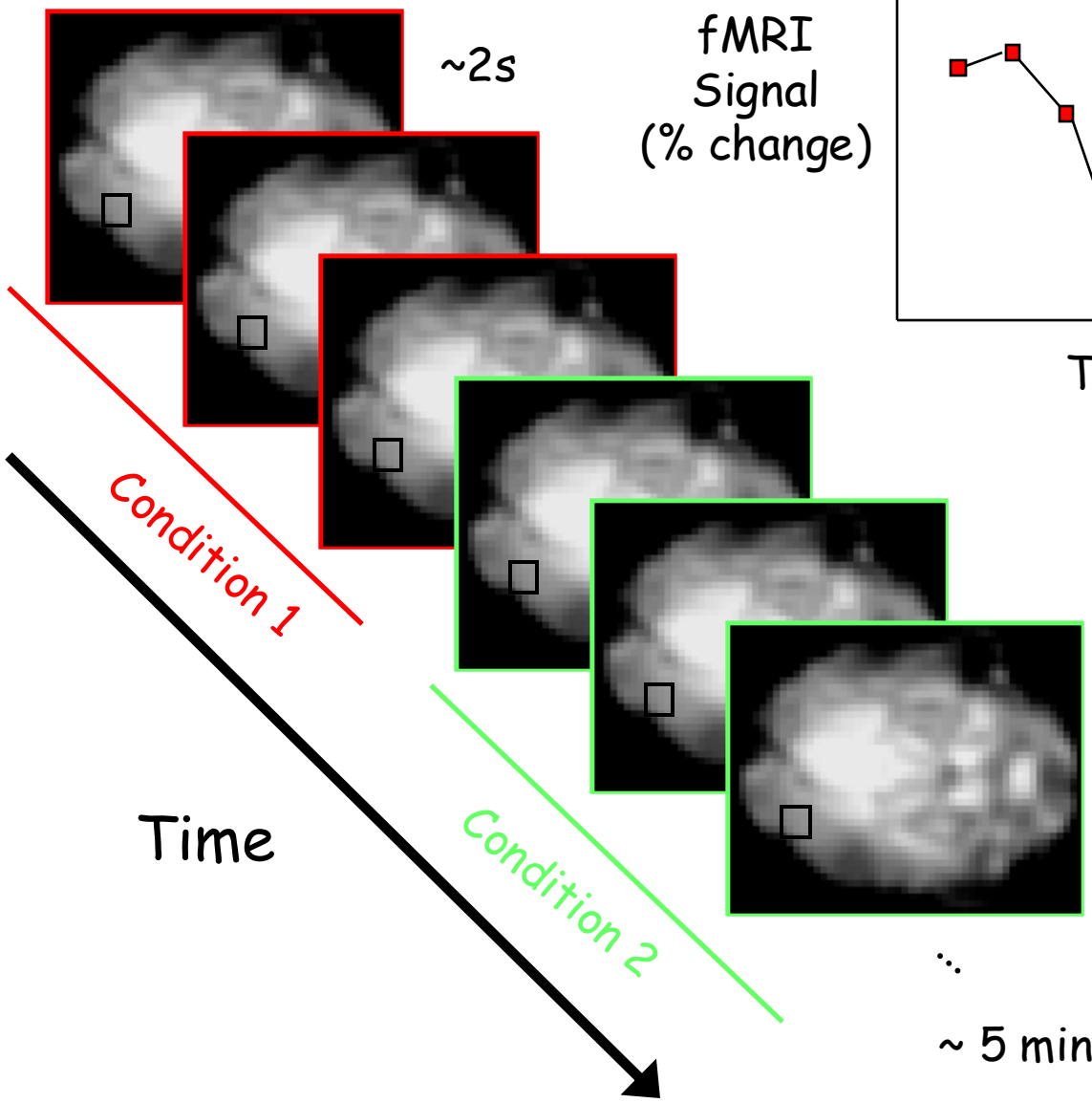


task

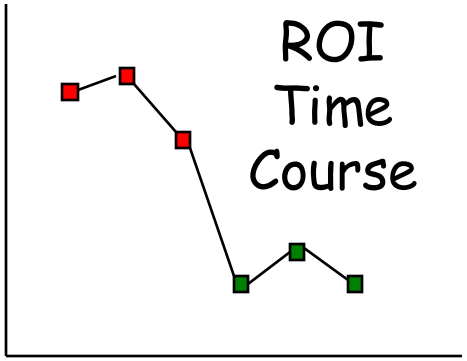
1991

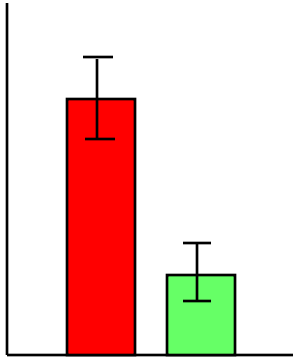
Activation Statistics

Functional images

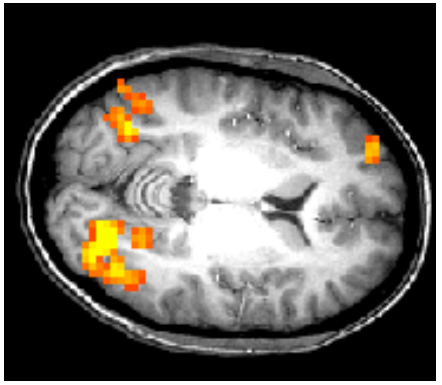


fMRI Signal (% change)



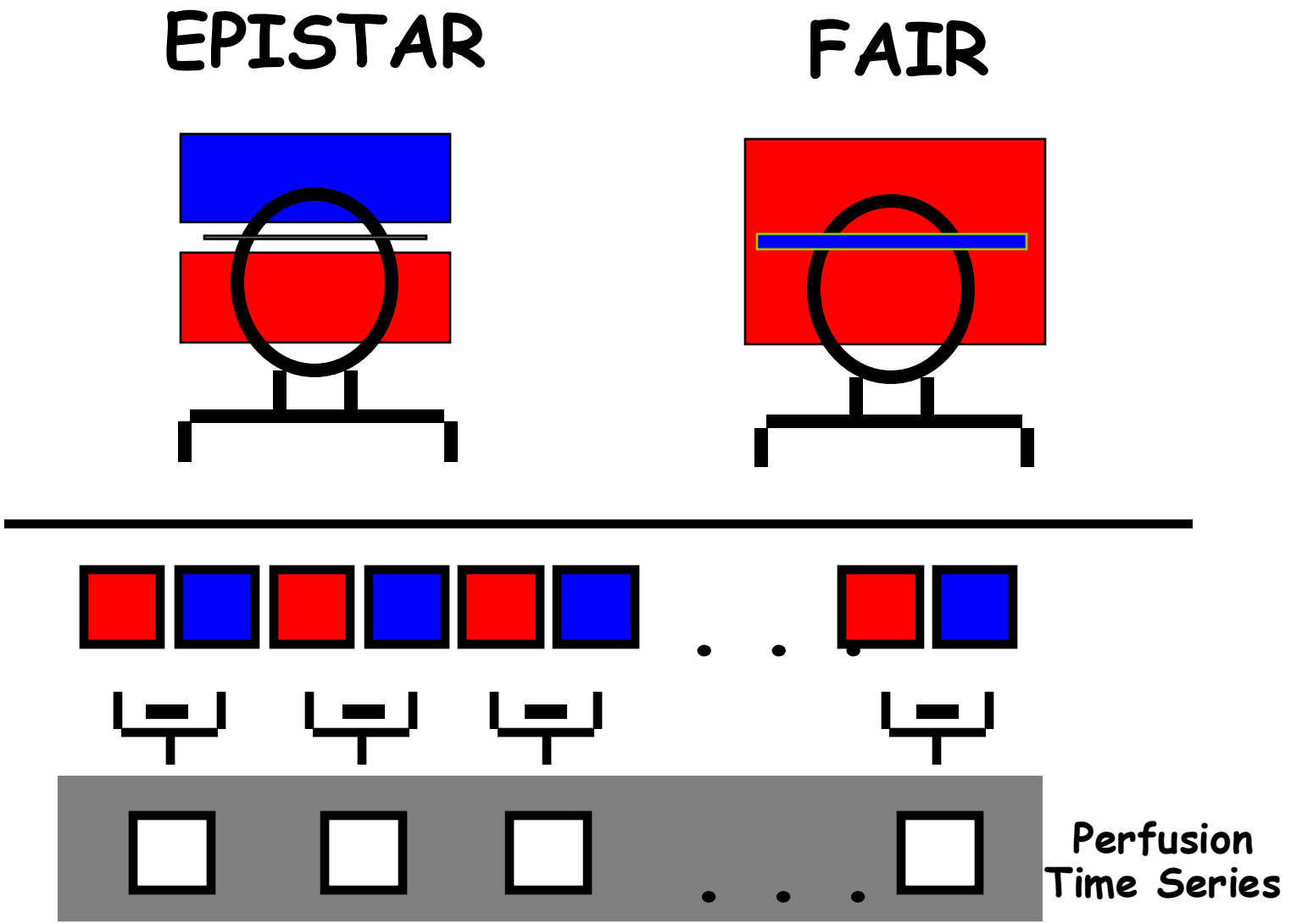


Statistical Map
superimposed on anatomical MRI image

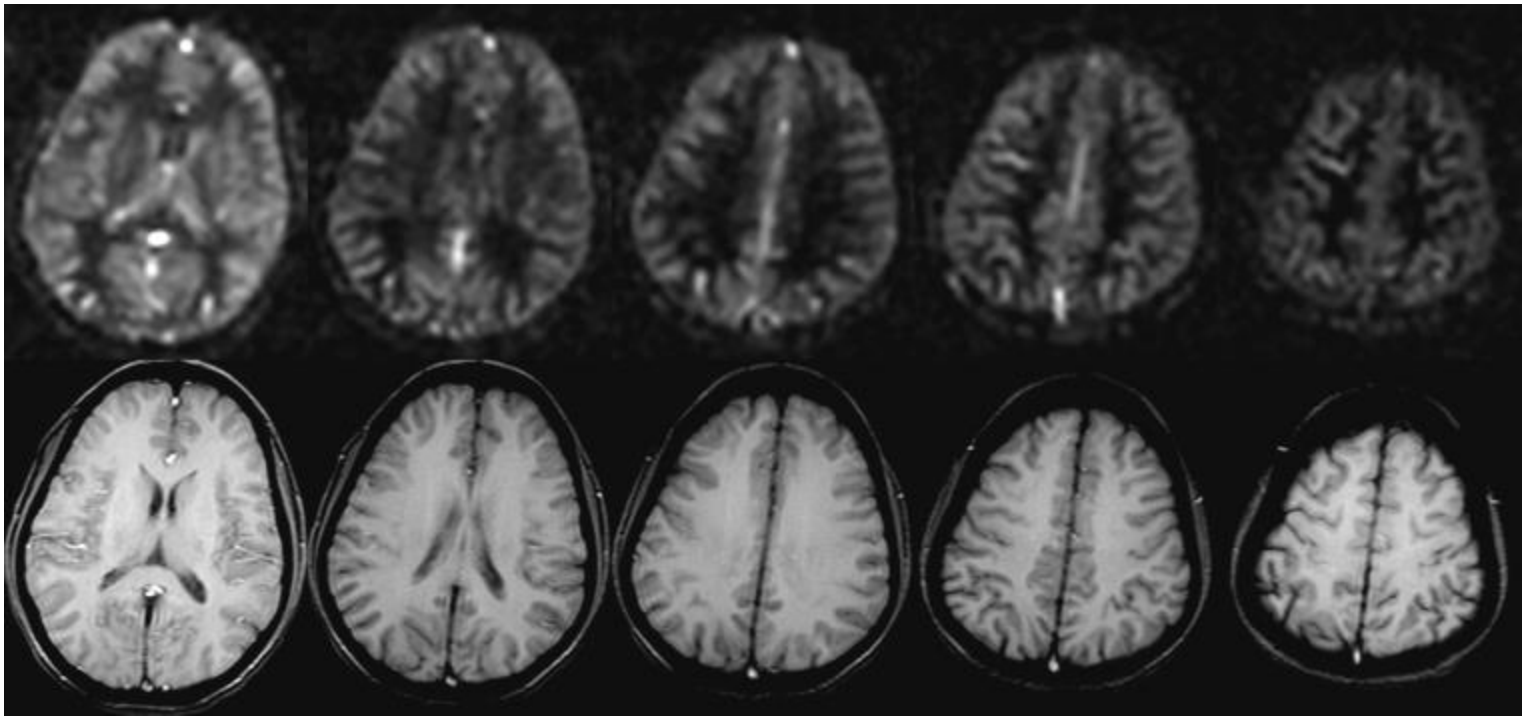


Courtesy, Robert Cox

Perfusion



Perfusion



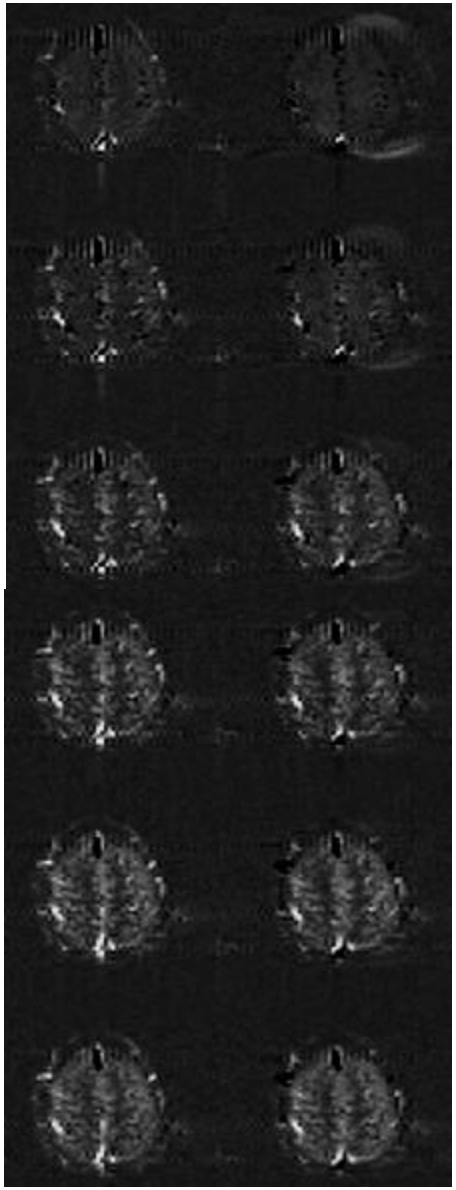
Williams, D. S., Detre, J. A., Leigh, J. S. & Koretsky, A. S. (1992) "Magnetic resonance imaging of perfusion using spin-inversion of arterial water." Proc. Natl. Acad. Sci. USA 89, 212-216.

Edelman, R., Siewert, B. & Darby, D. (1994) "Qualitative mapping of cerebral blood flow and functional localization with echo planar MR imaging ans signal targeting with alternating radiofrequency (EPISTAR)." Radiology **192**, 1-8.

Kim, S.-G. (1995) "Quantification of relative cerebral blood flow change by flow-sensitive alternating inversion recovery (FAIR) technique: application to functional mapping." Magn. Reson. Med. **34**, 293-301.

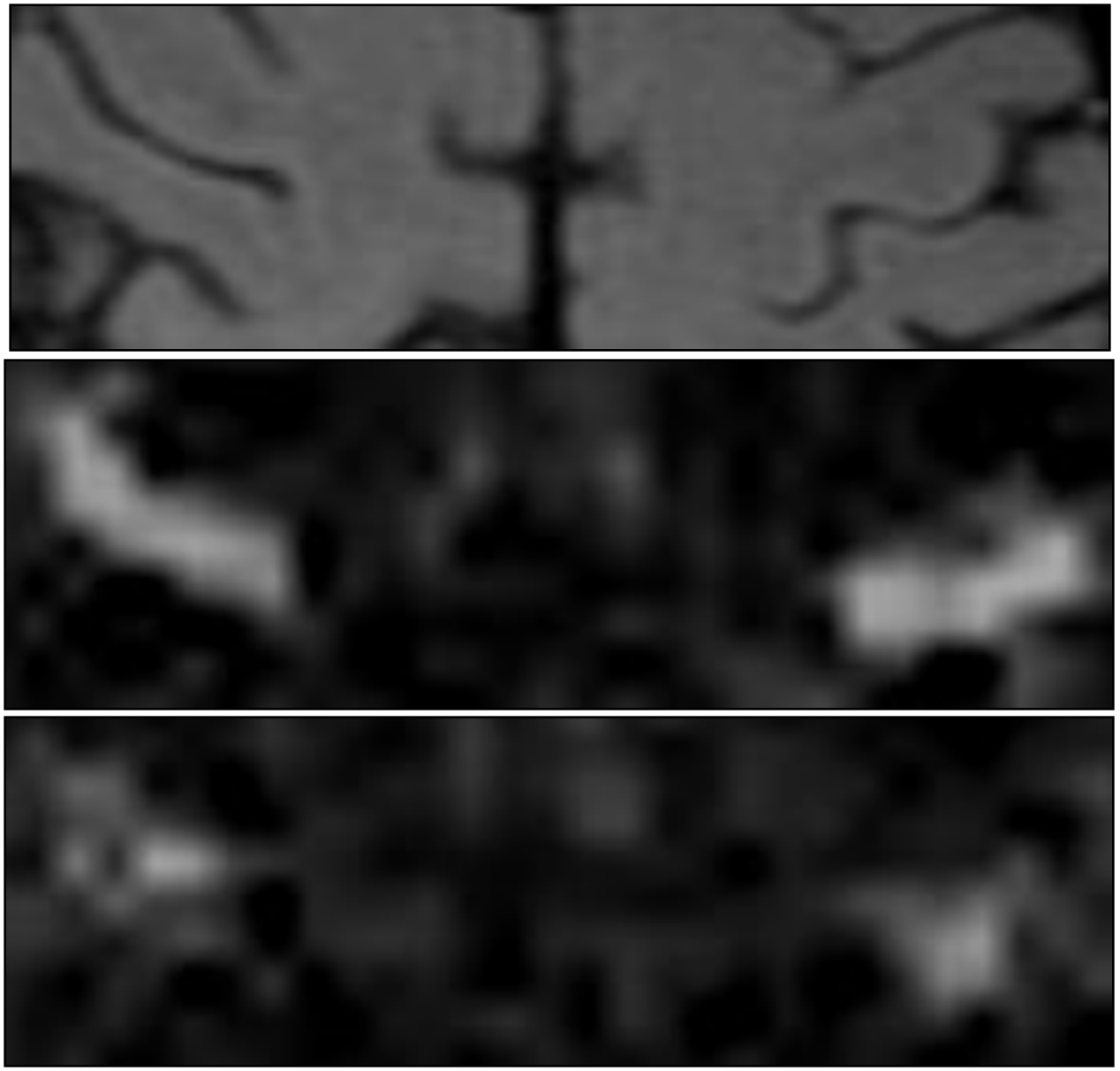
Kwong, K. K. et al. (1995) "MR perfusion studies with T1-weighted echo planar imaging."Magn. Reson. Med. **34**, 878-887.

Perfusion

TI (ms)	FAIR	EPISTAR
200		
400		
600		
800		
1000		
1200		

Perfusion

Simultaneous BOLD and Perfusion



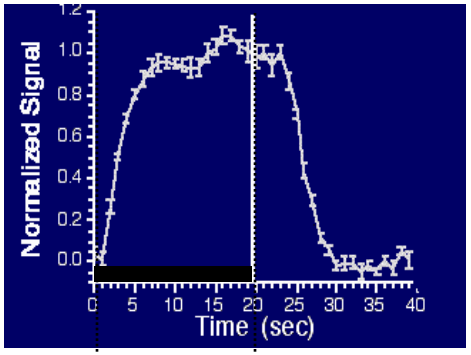
Overview of fMRI

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

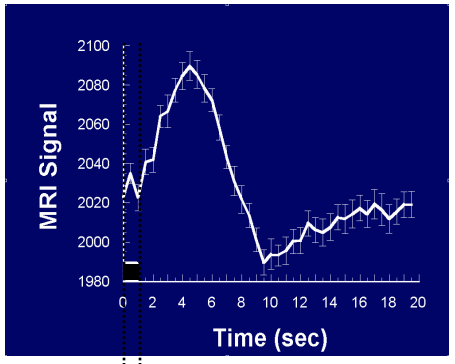
Spatial resolution:
- Typical: 3 mm^3
- Upper: 0.5 mm^3

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..

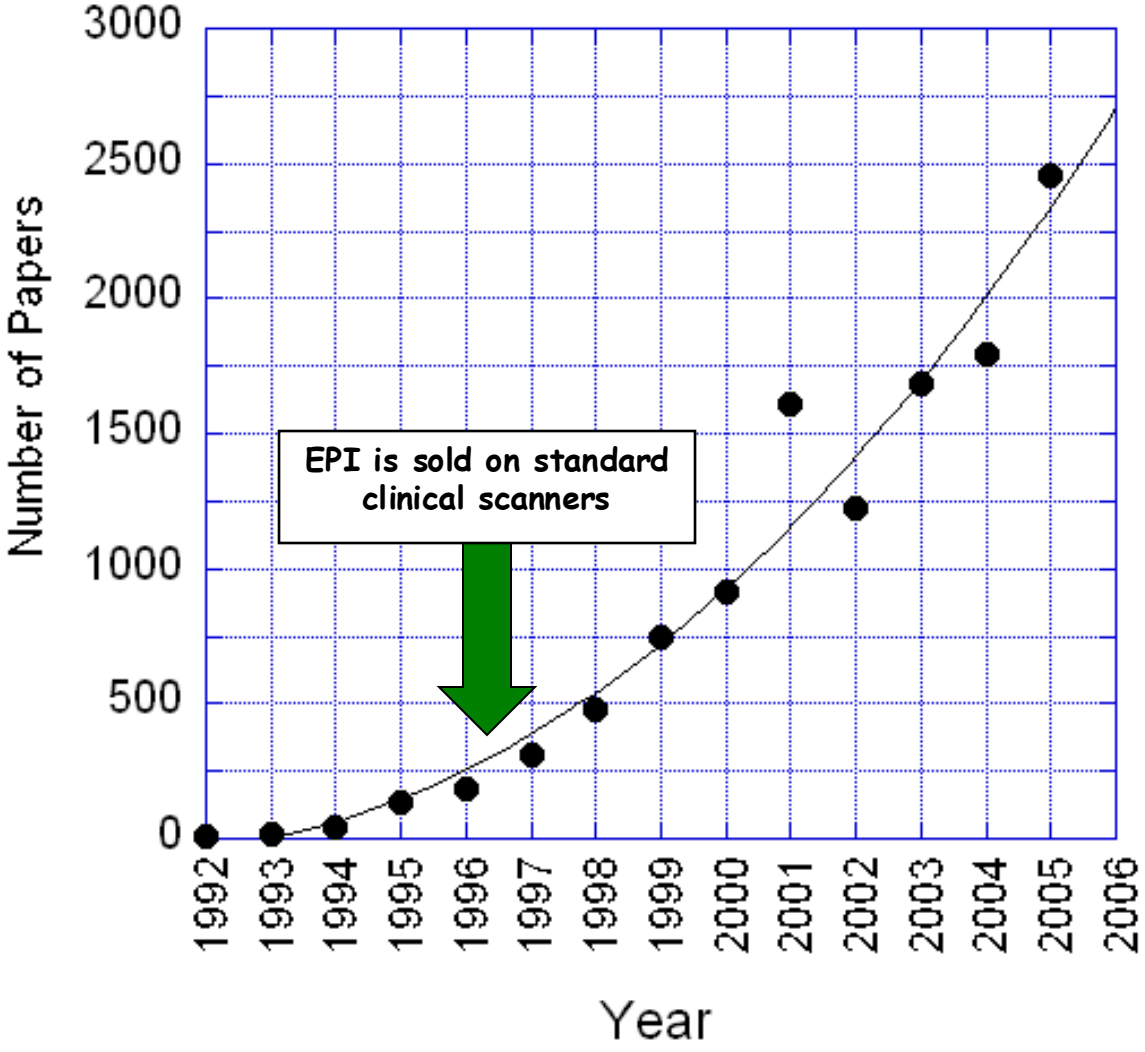


task



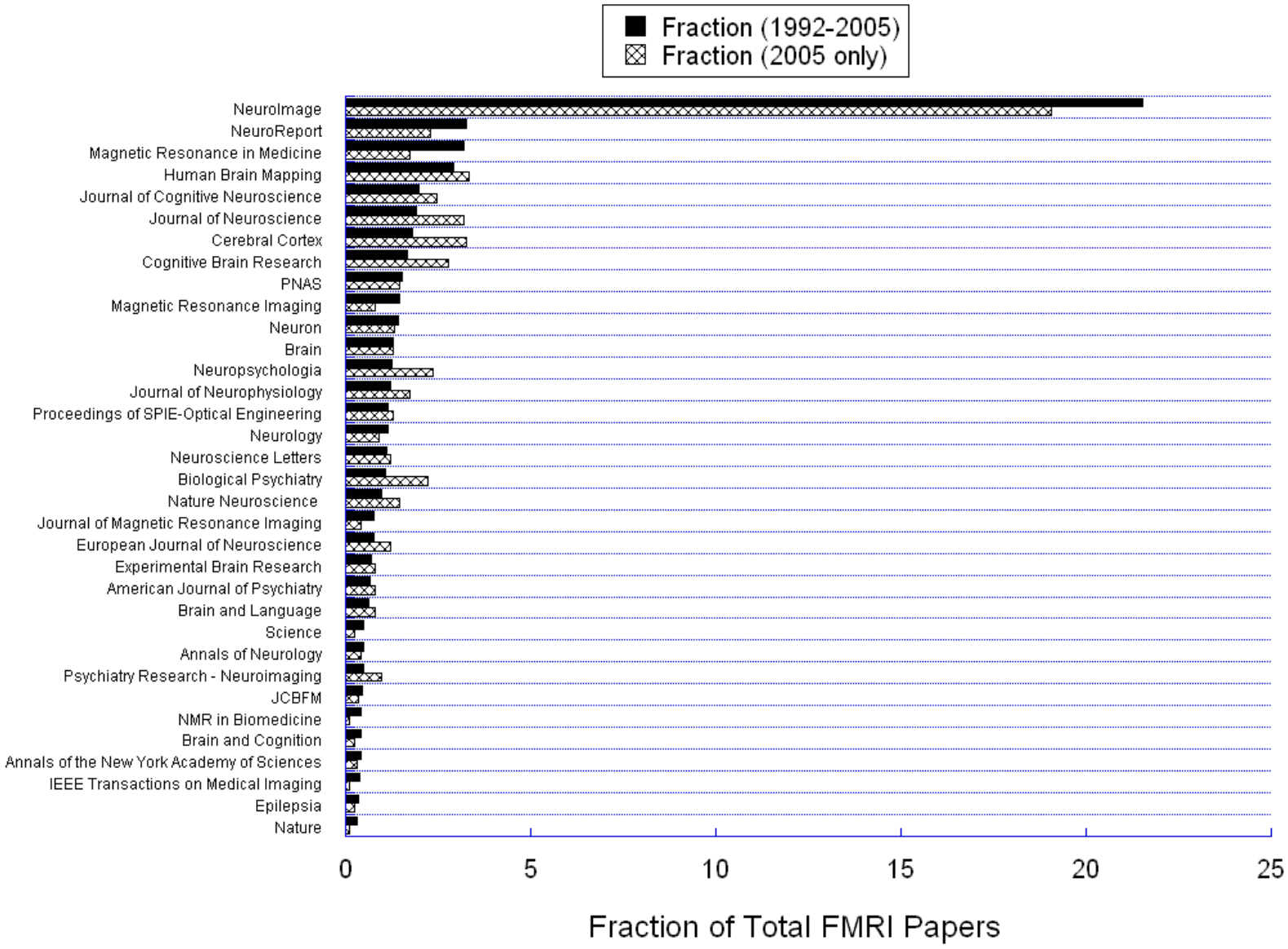
task

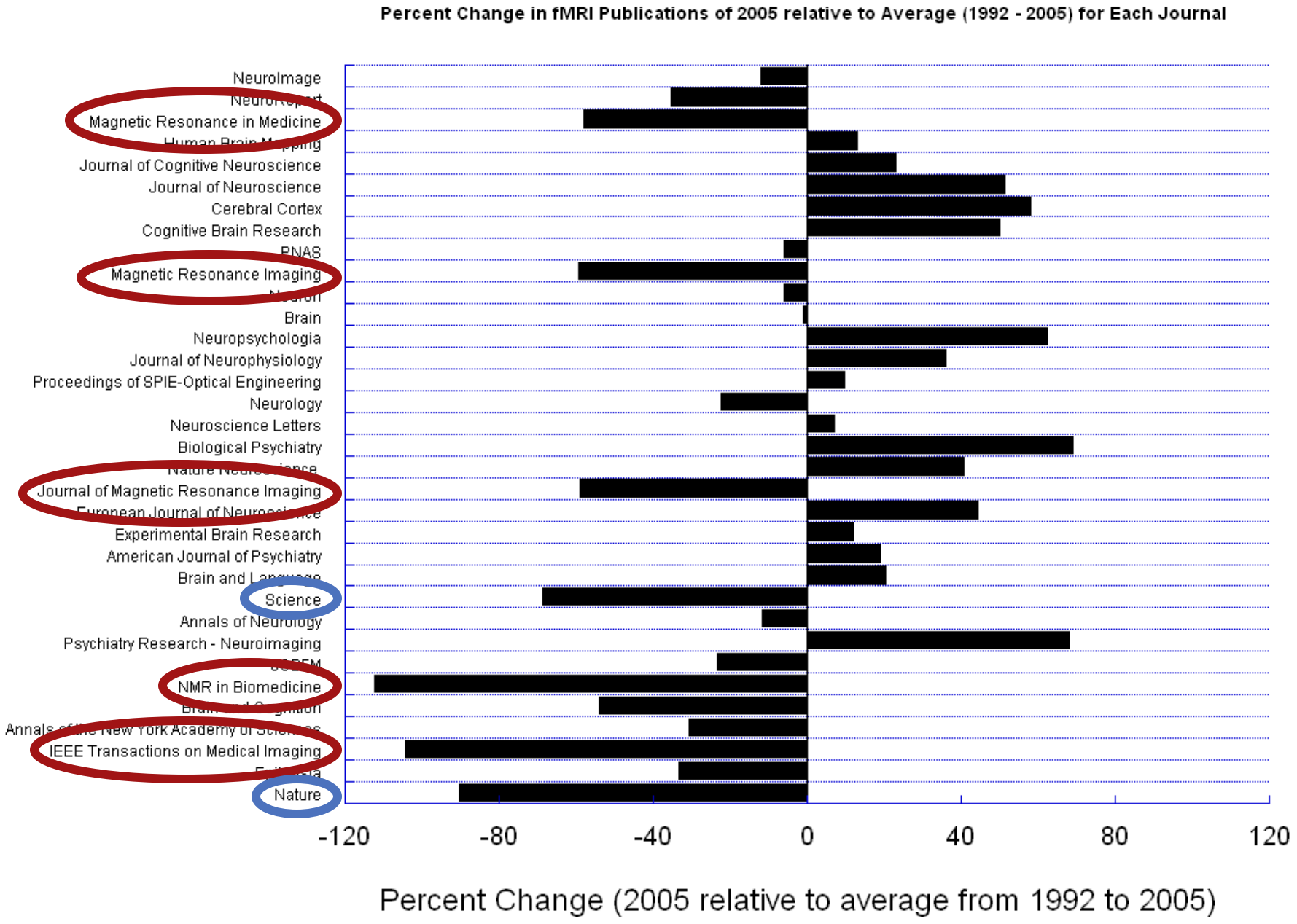
fMRI Papers Published per Year

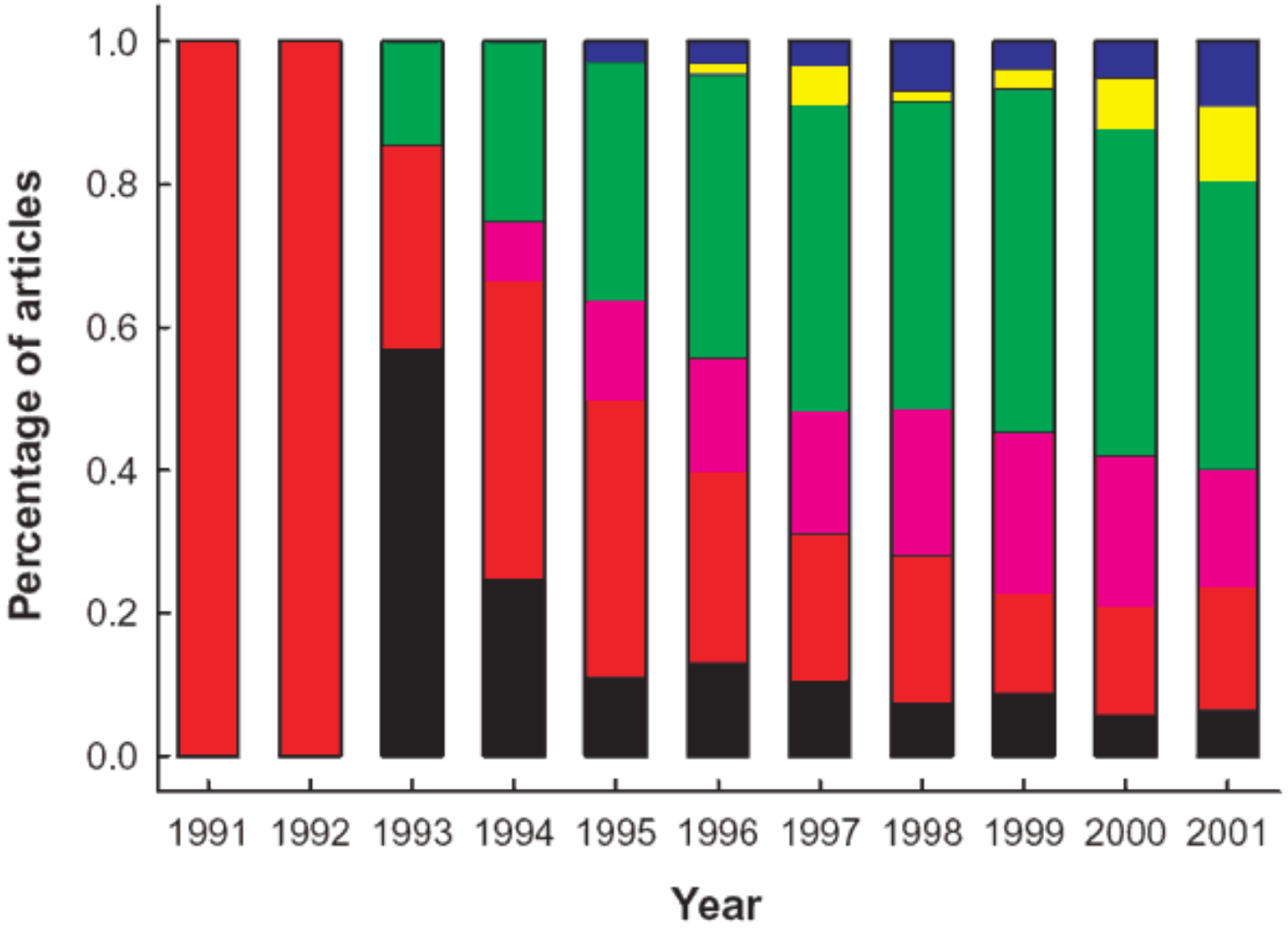


"fMRI" or "functional MRI"

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

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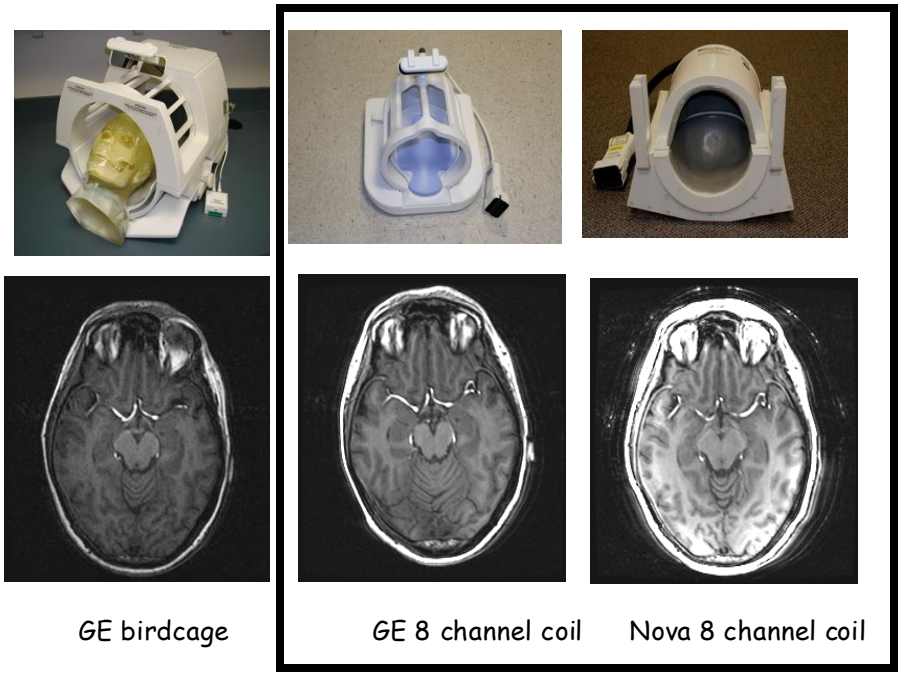
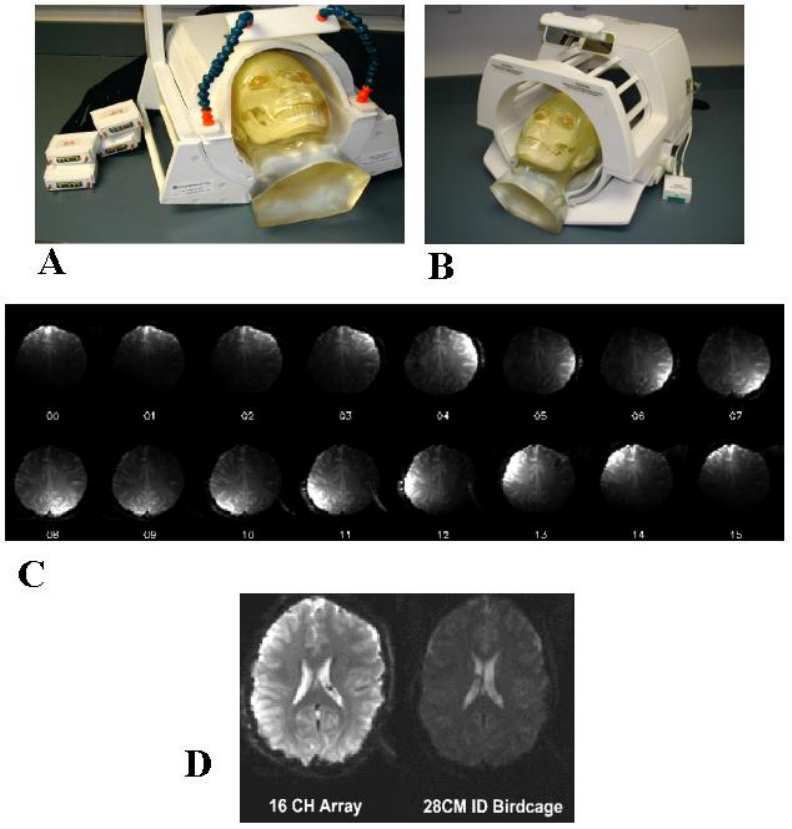
Technology

8 channel parallel receiver coil



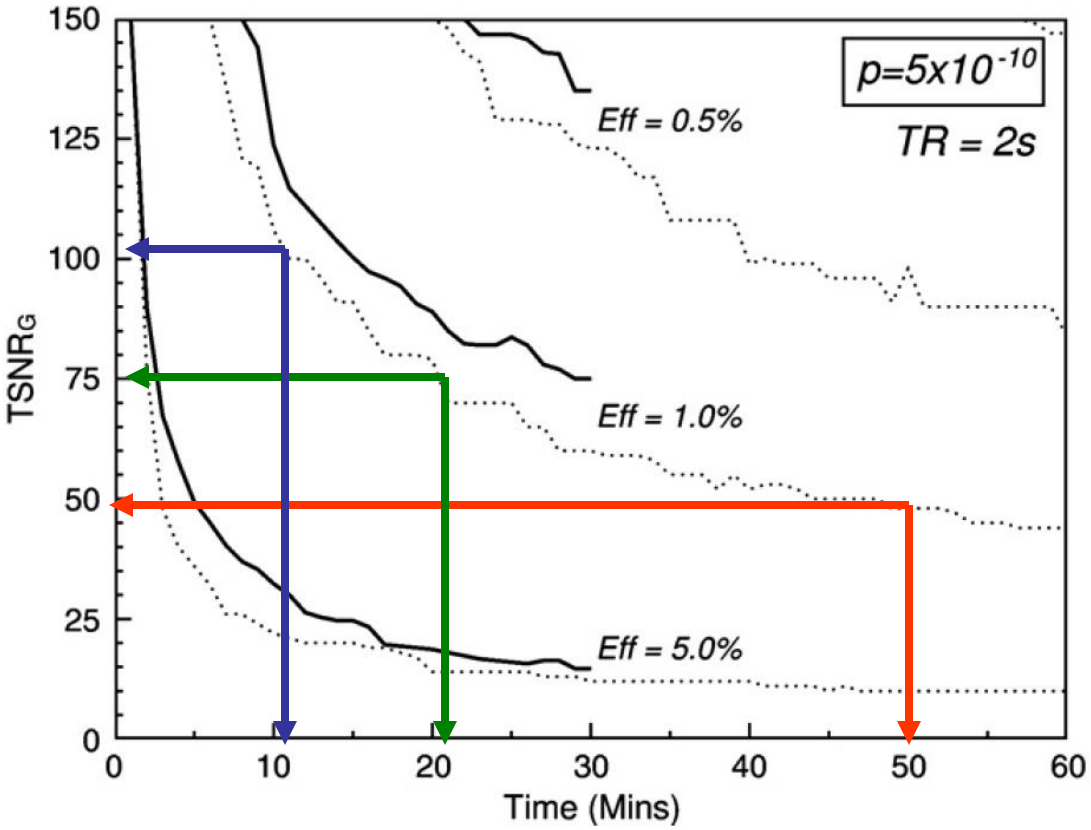
GE birdcage | GE 8 channel coil | Nova 8 channel coil

16 channel parallel receiver coil



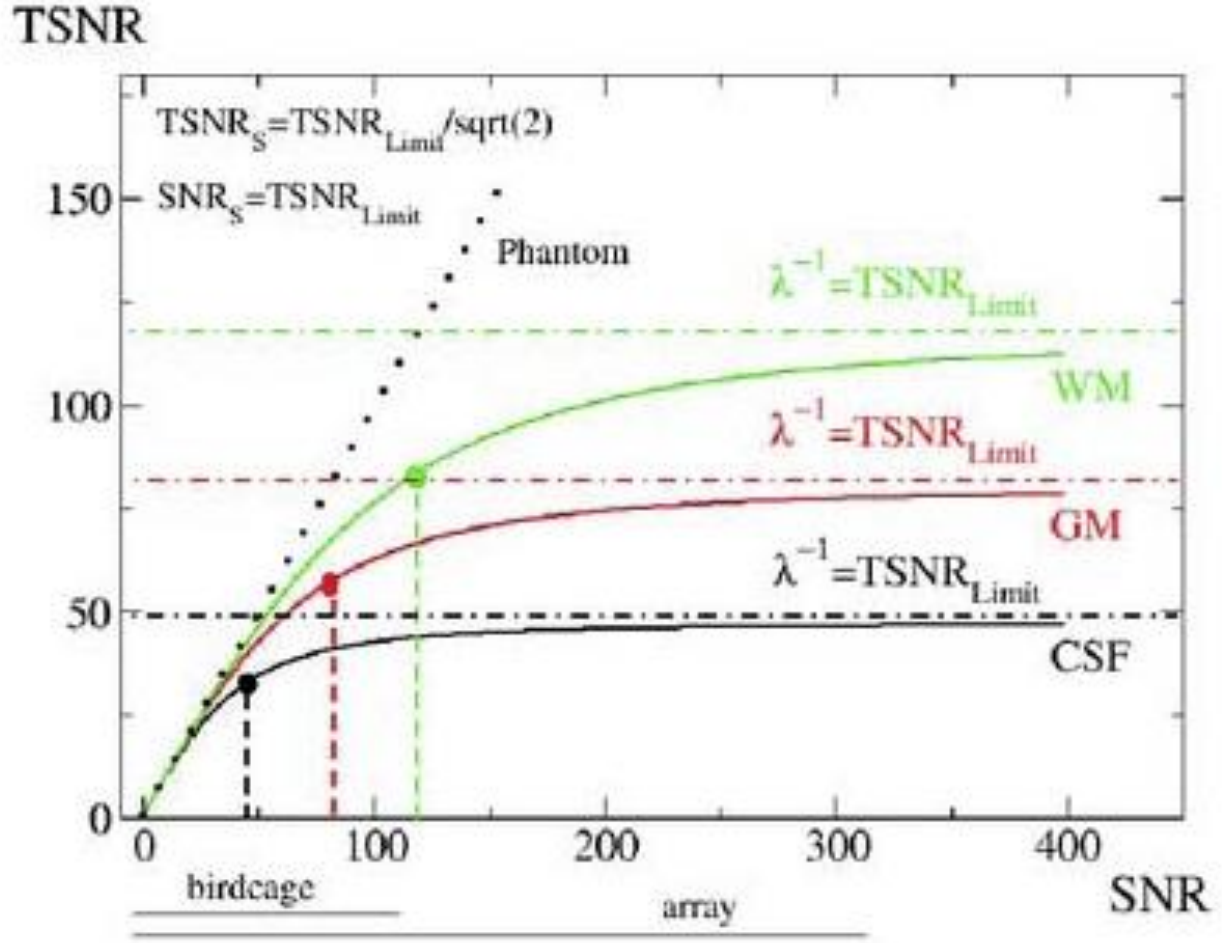
J. Bodurka, et al, Magnetic Resonance in Medicine 51 (2004) 165-171.

Technology



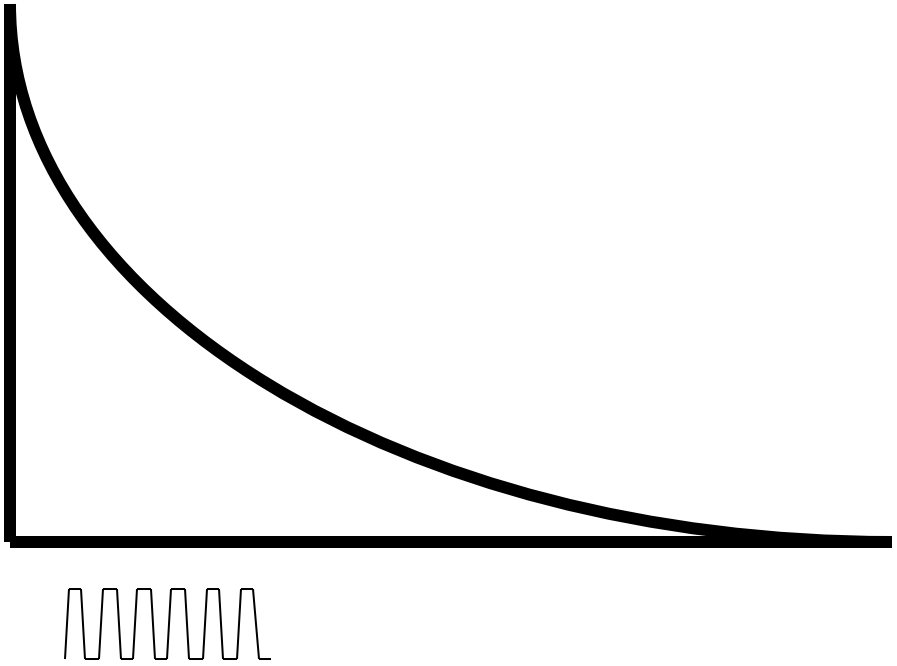
K. Murphy, J. Bodurka, P. A. Bandettini, How long to scan? The relationship between fMRI temporal signal to noise and the necessary scan duration. *NeuroImage*, 34, 565-574 (2007)

SNR vs TSNR

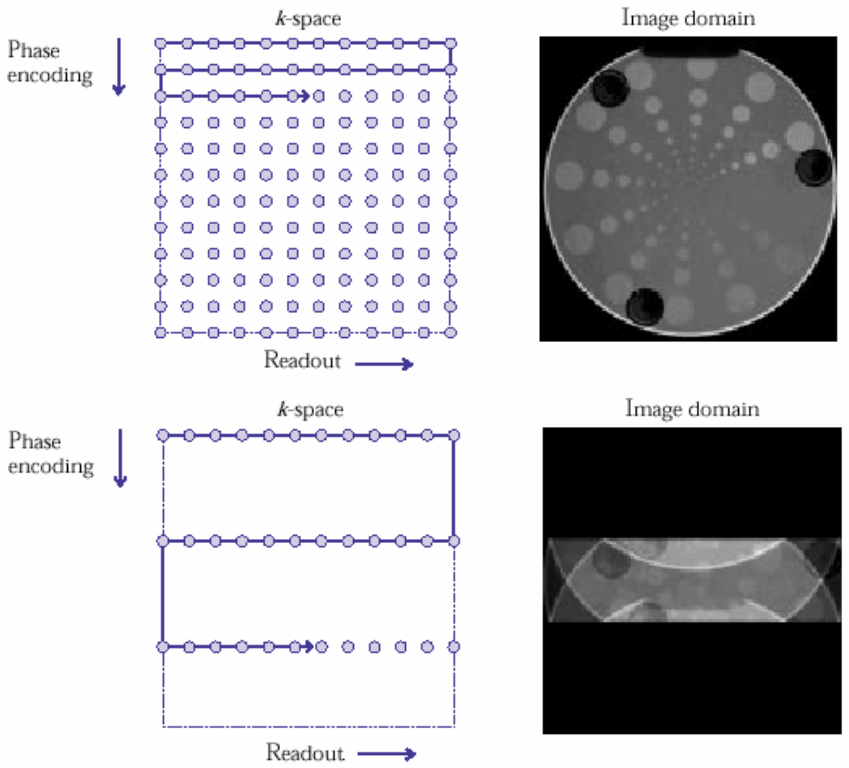


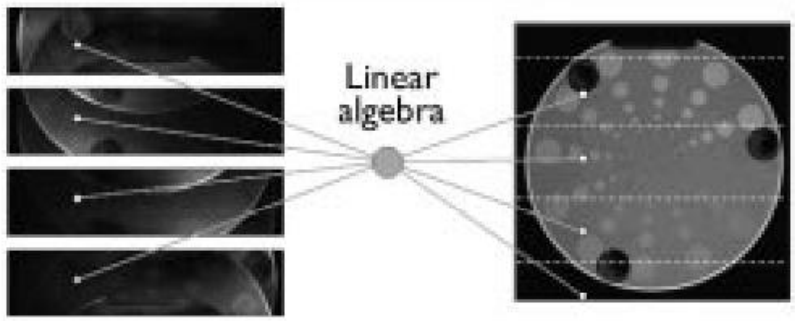
J. Bodurka, F. Ye, N Petridou, P. A. Bandettini, Mapping the MRI voxel volume in which thermal noise matches physiological noise – implications for fMRI. *NeuroImage*, 34, 542-549 (2007)

Technology



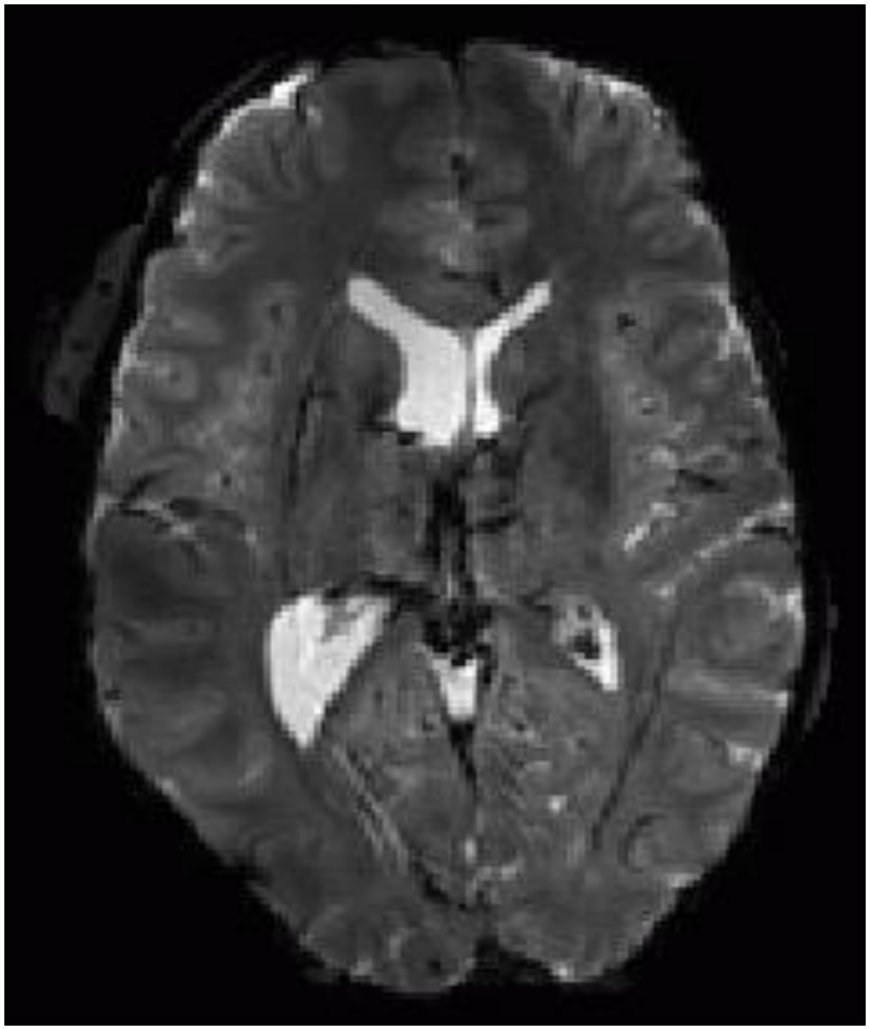
≈ 5 to 30 ms





Pruessmann, et al.

Technology



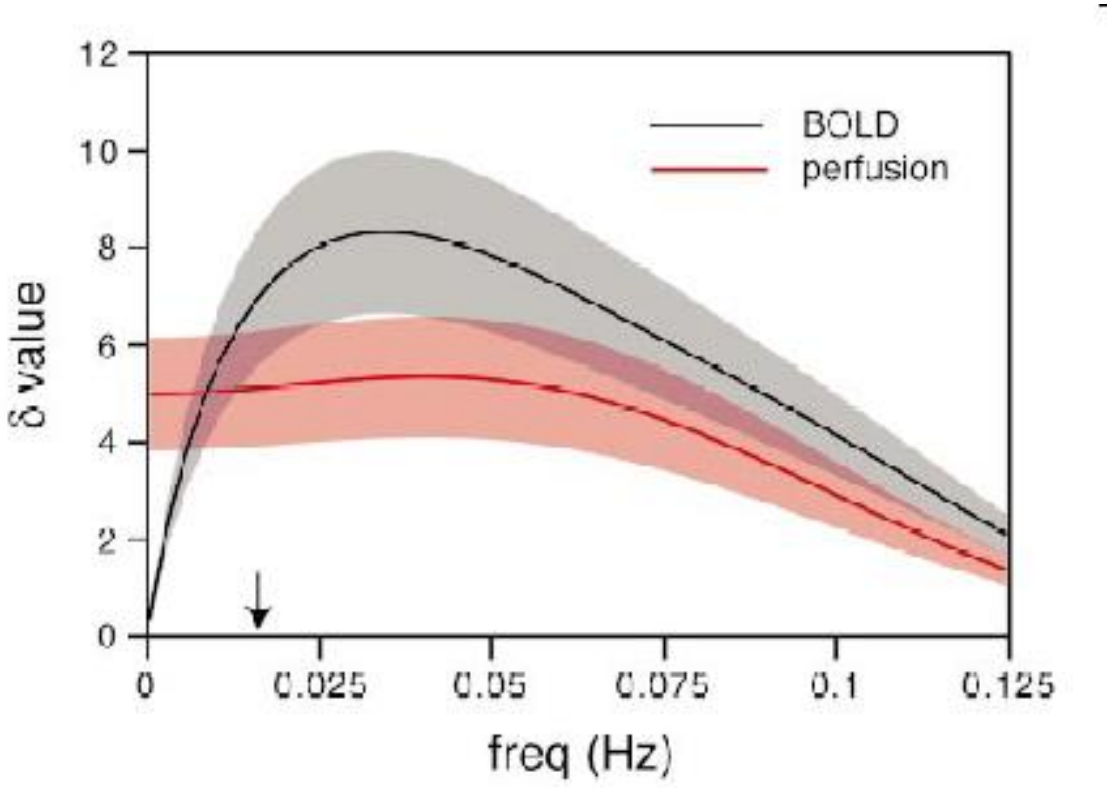
3T single-shot SENSE EPI using 16 channels: 1.25x1.25x2mm

fMRI Contrast

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

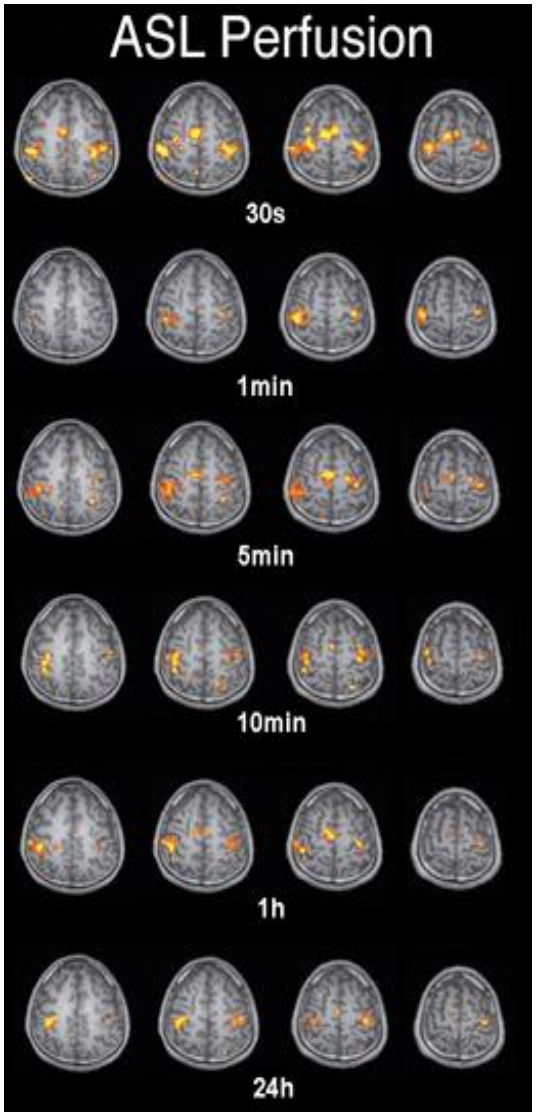
Perfusion (ASL)

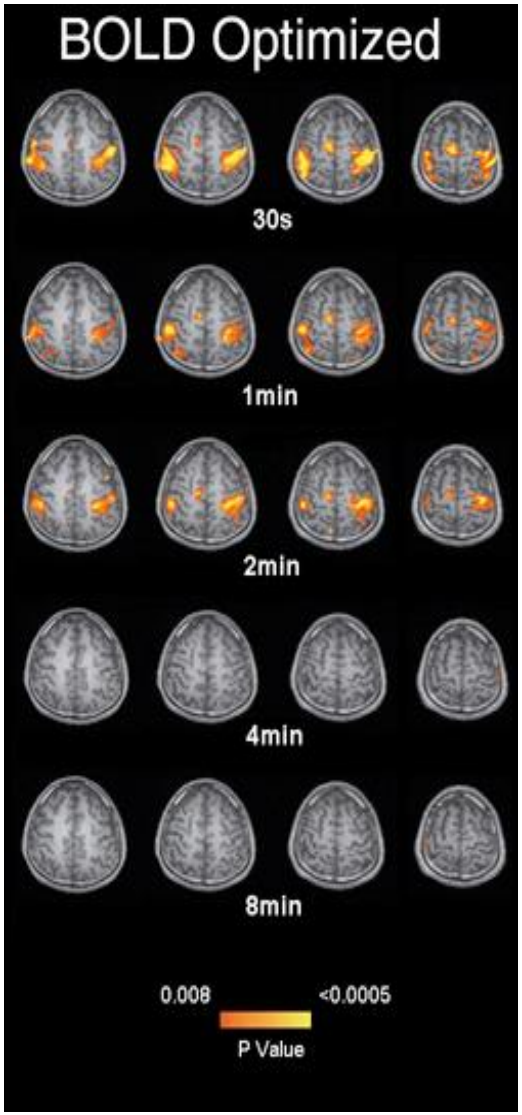
Better than BOLD for long duration activation…



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

Perfusion vs. BOLD: Low Task Frequency





BOLD effect to highlight veins: 3 Tesla

Bove-Bettis, et al (2004), SMRT

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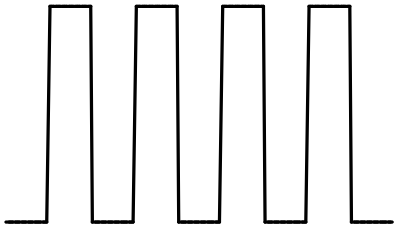
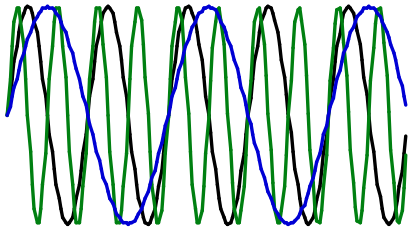
Applications

Neuronal Activation Input Strategies

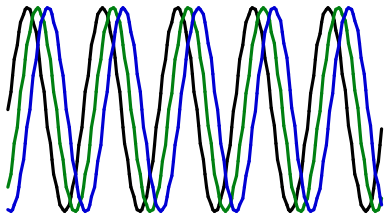
1. Block Design



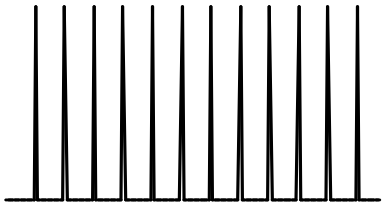
2. Frequency Encoding



3. Phase Encoding

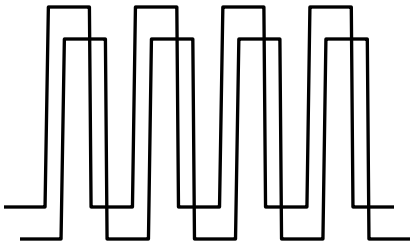


4. Event-Related



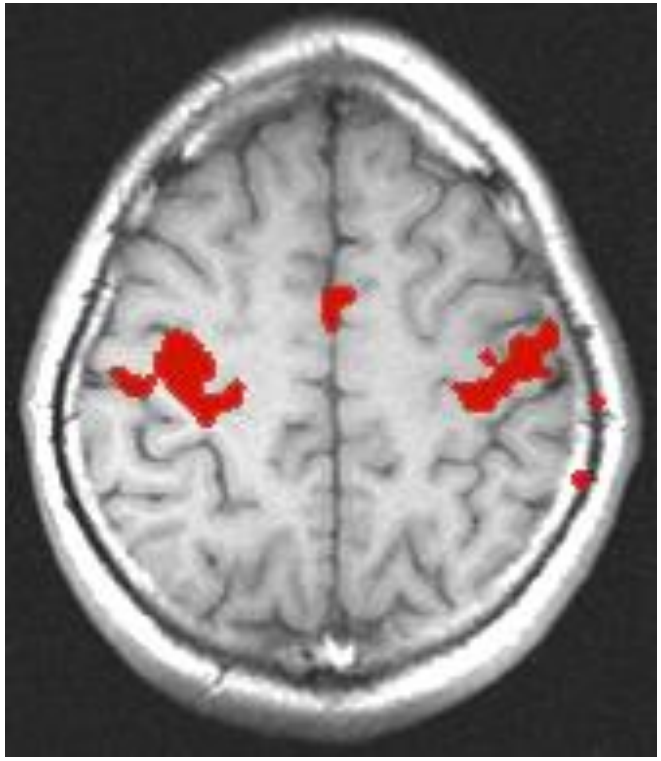
5. Orthogonal Block Design

6. Free Behavior Design.

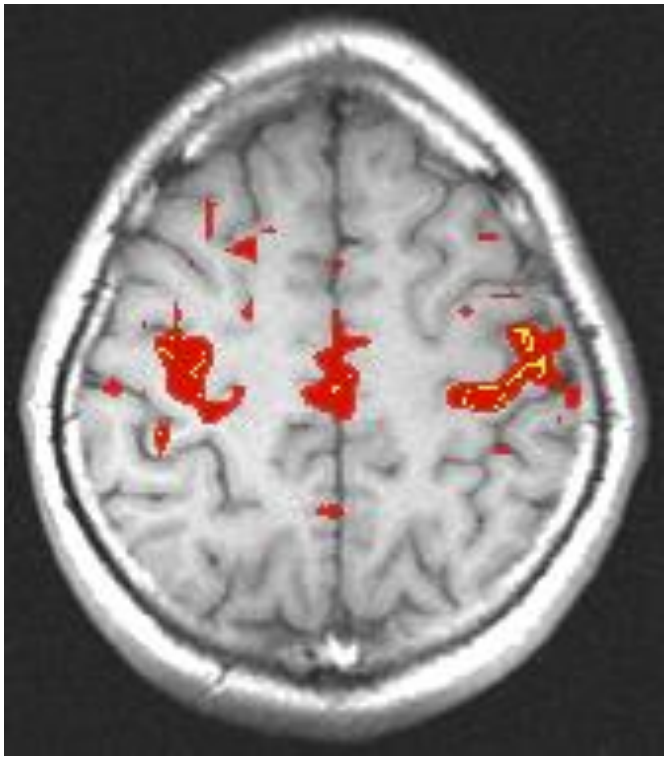


Methodology

Resting State Correlations



Activation:
correlation with reference function

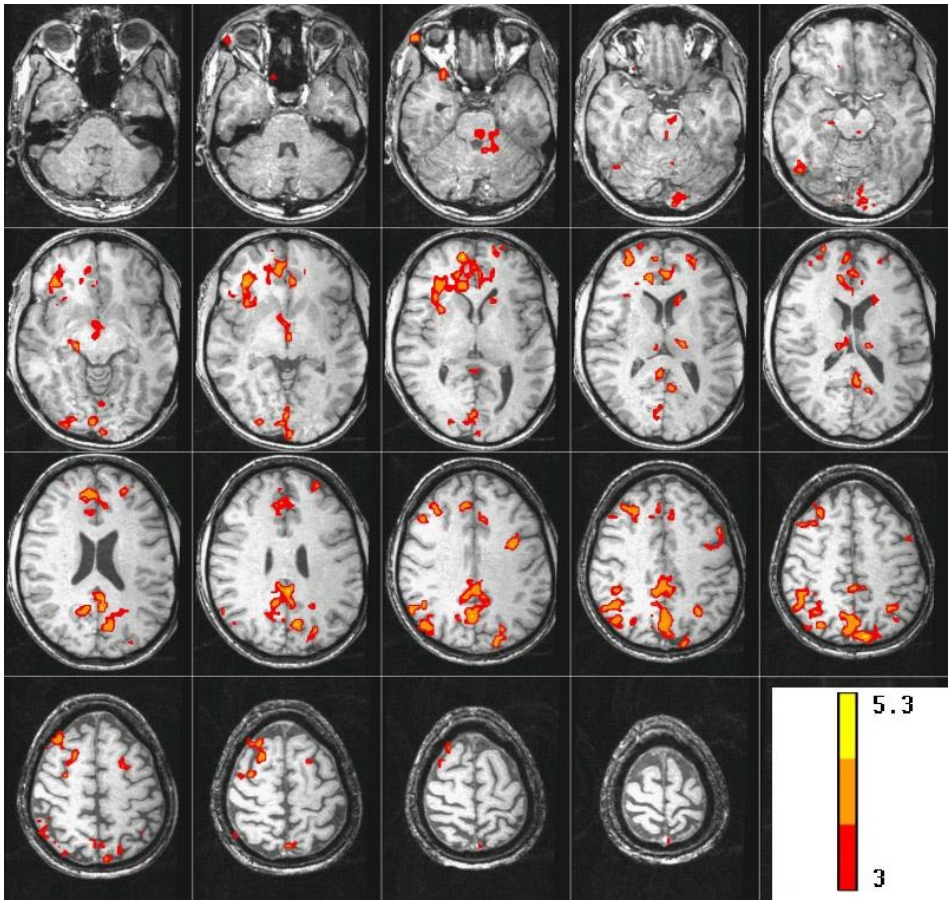


Rest:
seed voxel in motor cortex

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).*

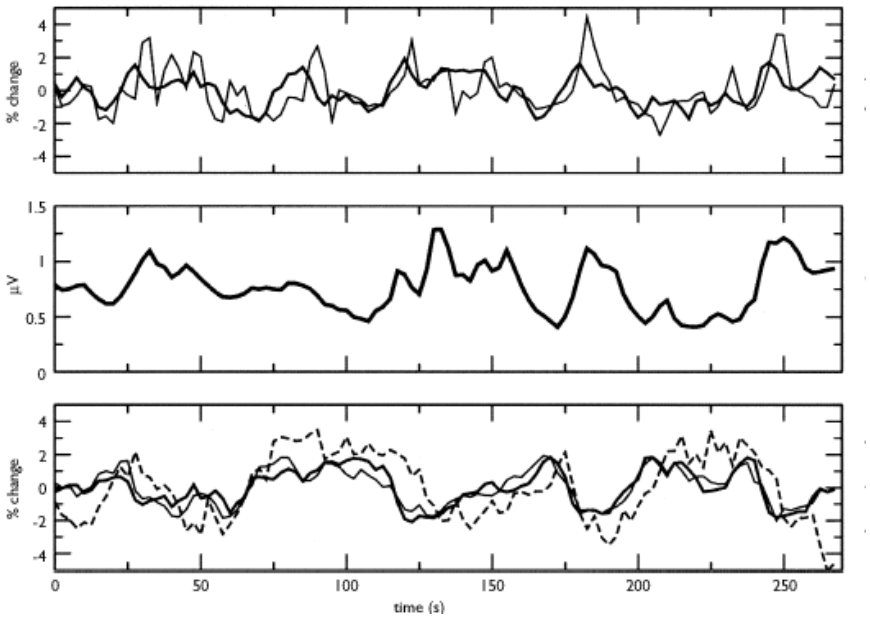
Methodology

BOLD correlated with 10 Hz power during "Rest"

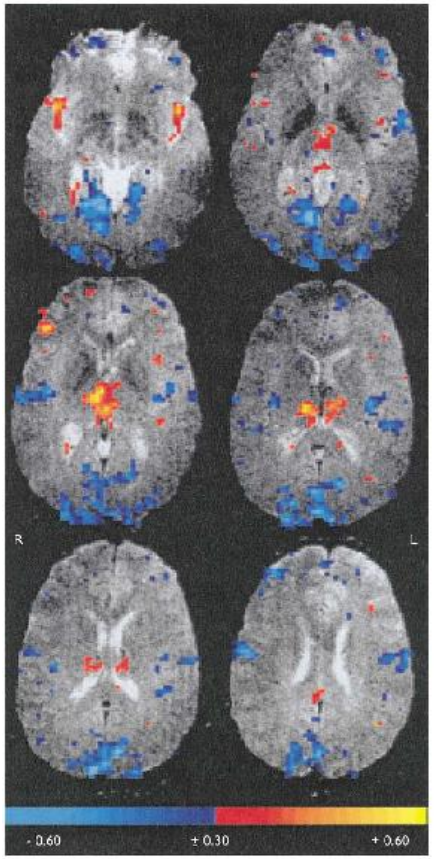
Positive

10 Hz power

Negative



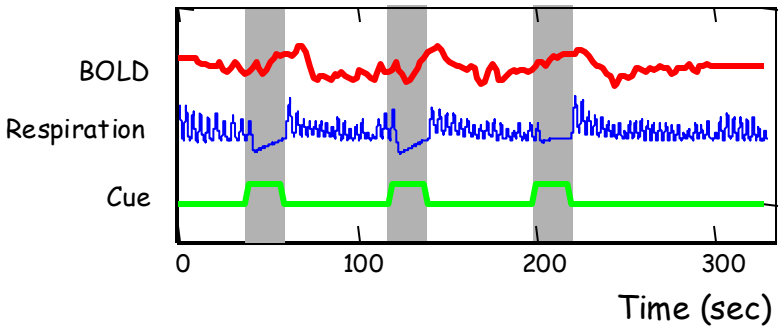
Goldman, et al (2002), Neuroreport



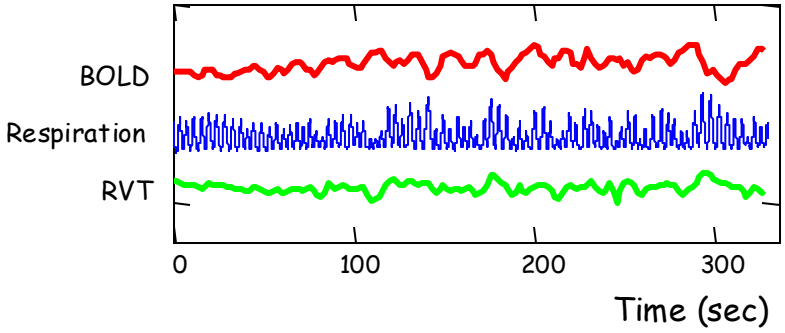
Methodology

Respiration induced signal changes

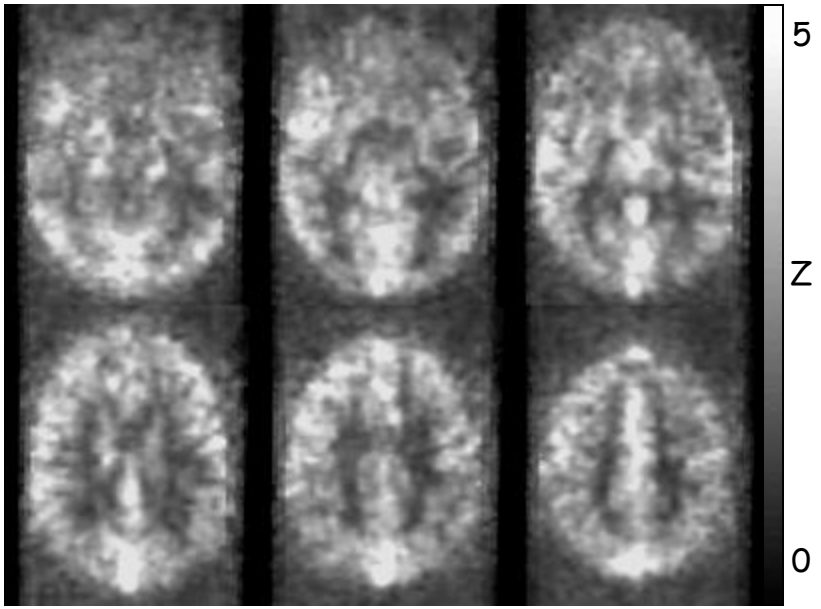
Breath-holding

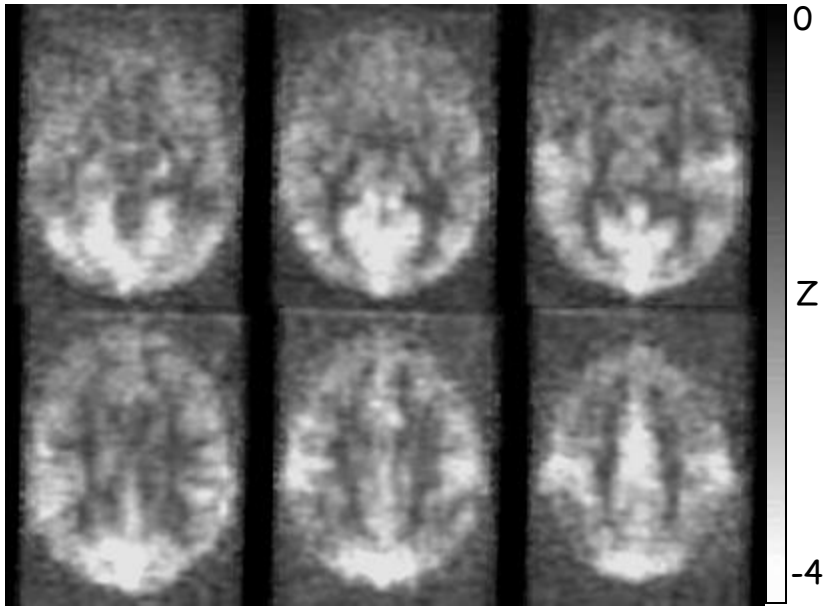


Rest



(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

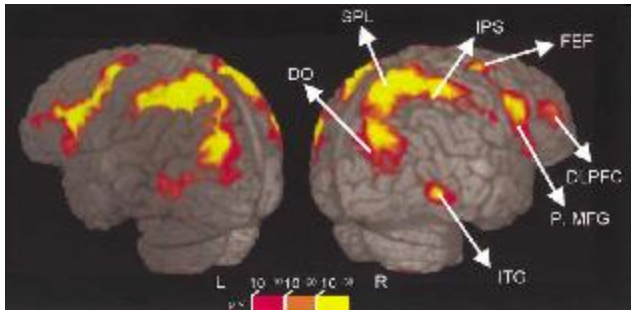
Mapping ⟷ "Reading"

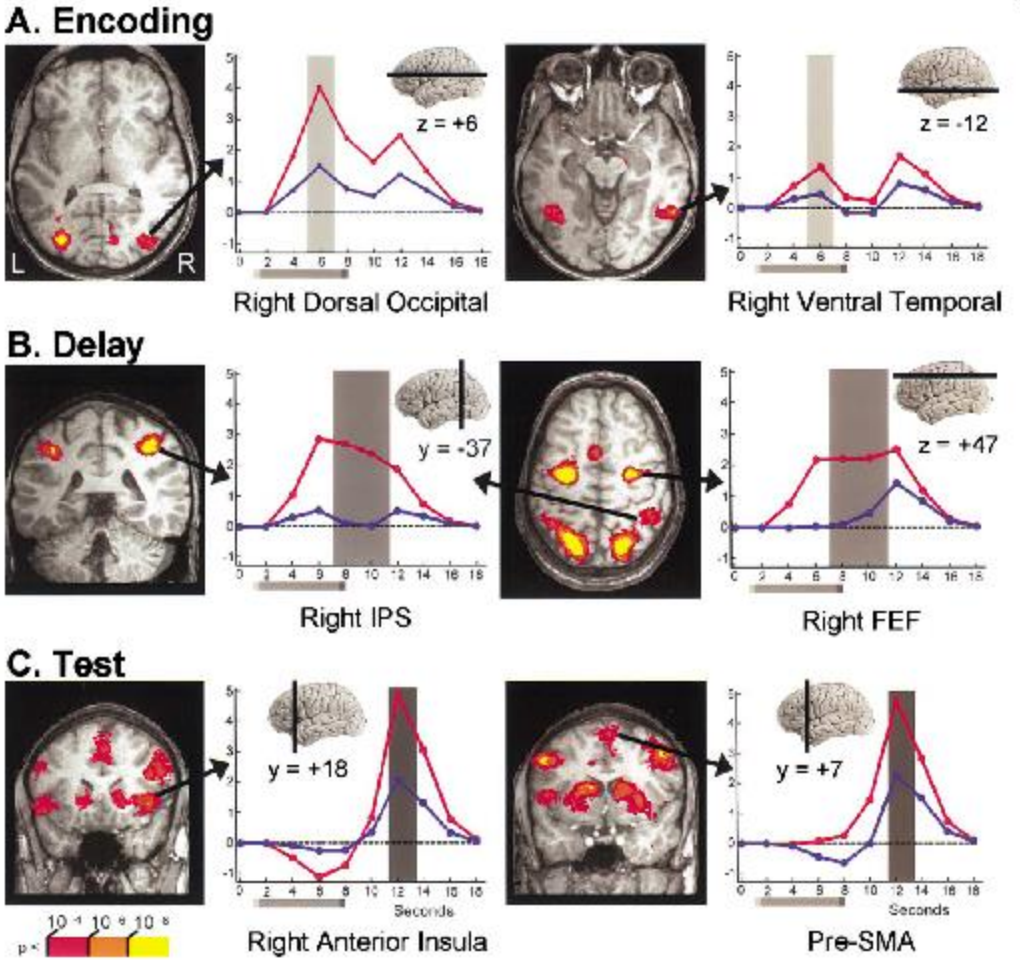
Methodology

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

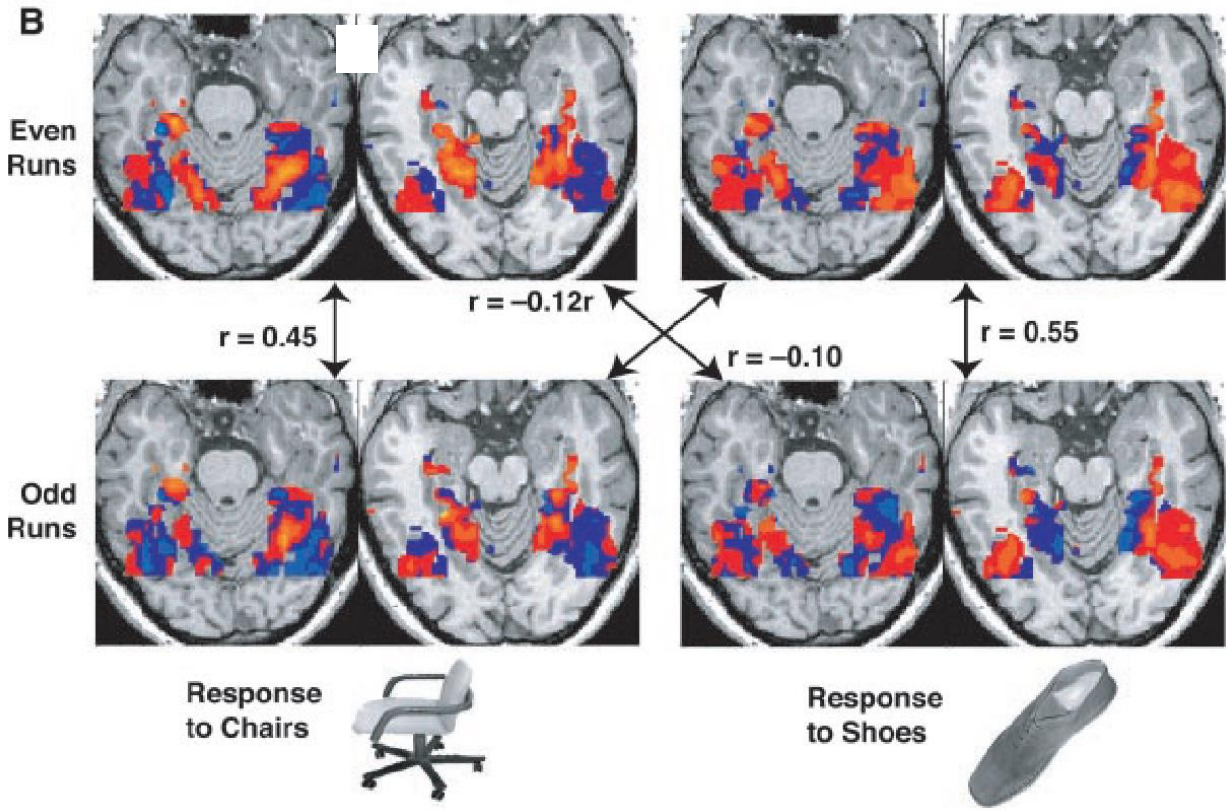




Methodology

Ventral temporal category representations

Object categories are associated with distributed representations in ventral temporal cortex



Haxby et al. 2001

Methodology

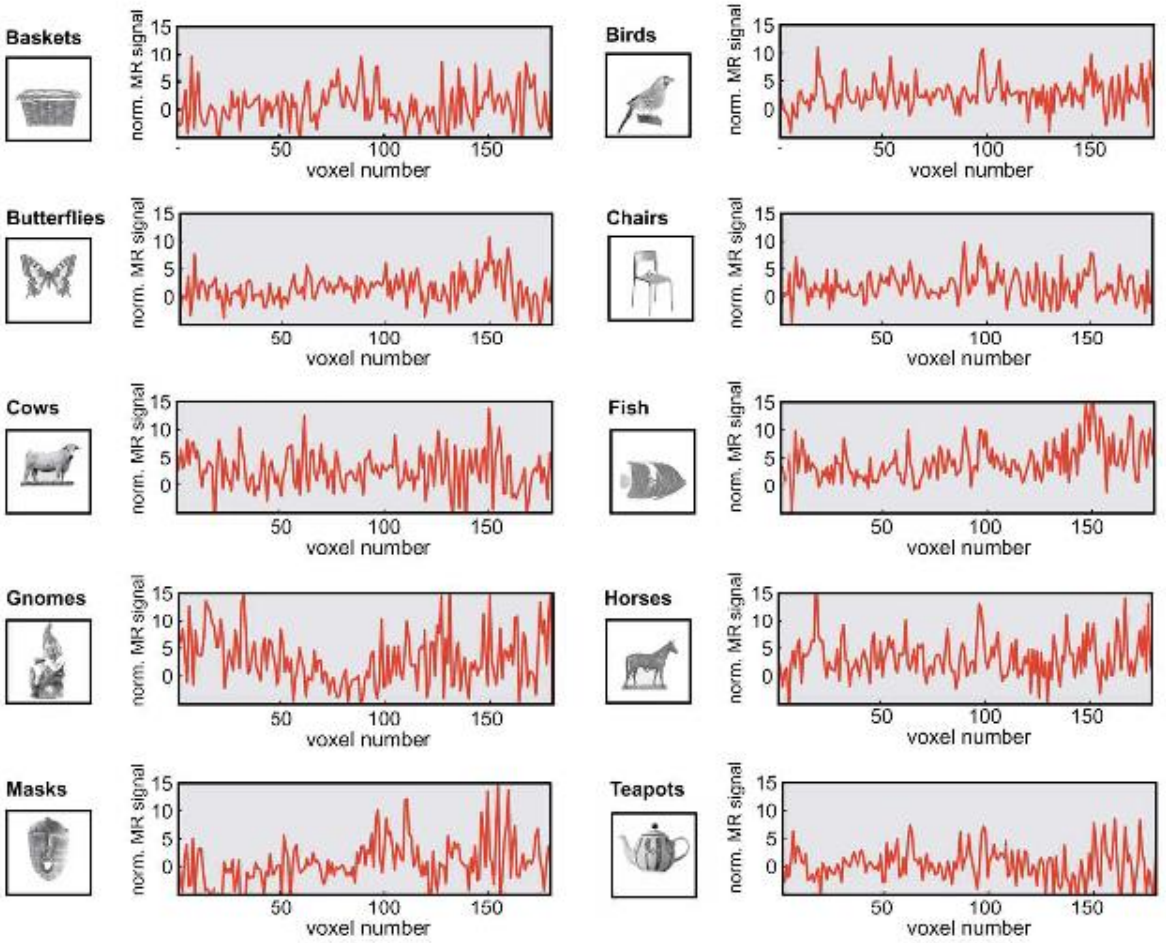
Functional magnetic resonance imaging (fMRI) "brain reading": detecting and classifying distributed patterns of fMRI activity in human visual cortex

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

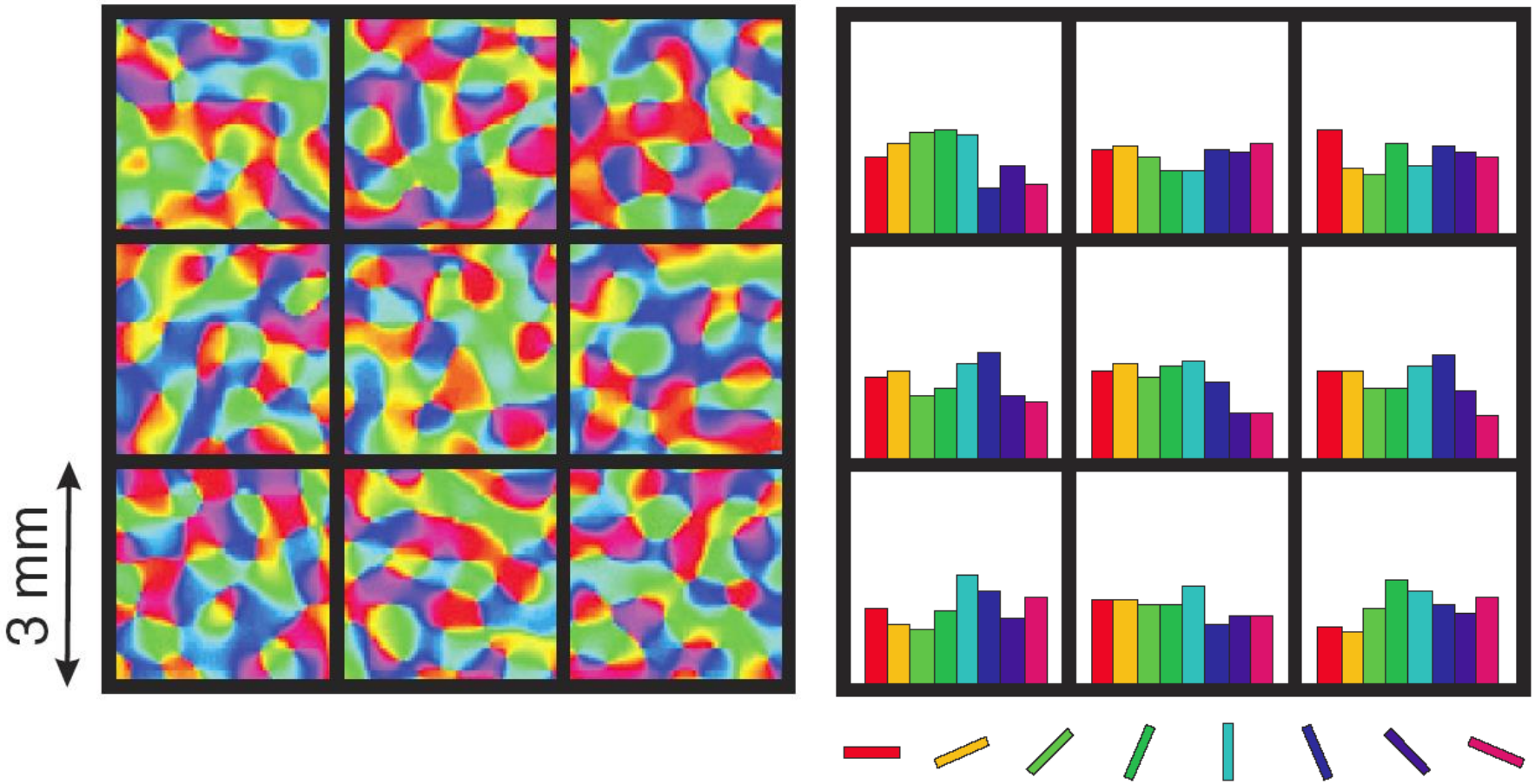
[a] Rowland Institute for Science, Cambridge, MA 02142, USA
[b] Athinoula A. Martinos Center for Structural and Functional Biomedical Imaging, Charlestown, MA 02129, USA
[c] HyperVision, Inc., P.O. Box 158, Lexington, MA 02420, USA

Received 15 July 2002; accepted 10 December 2002

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



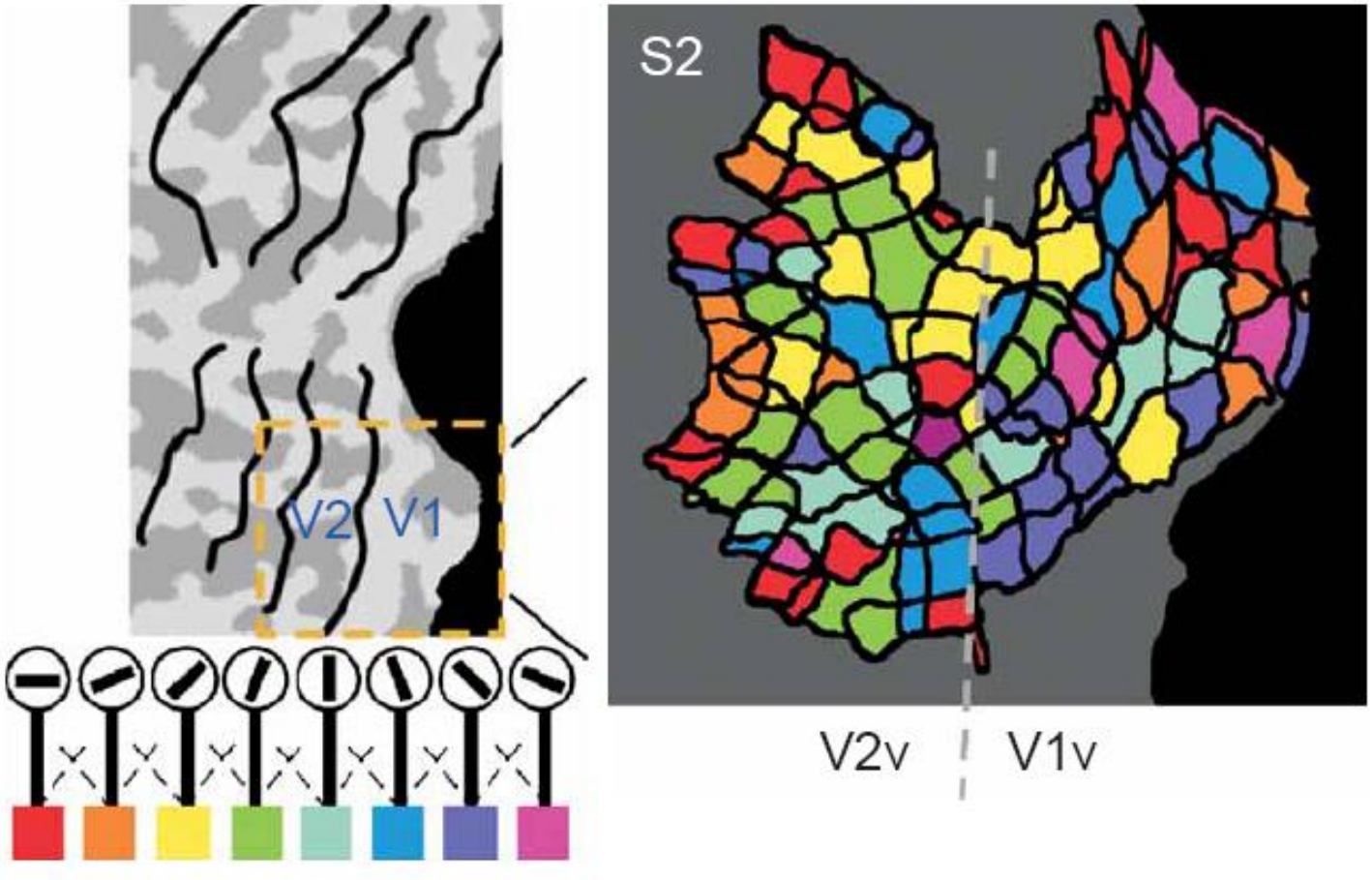
Methodology



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

Methodology

Lower spatial frequency clumping

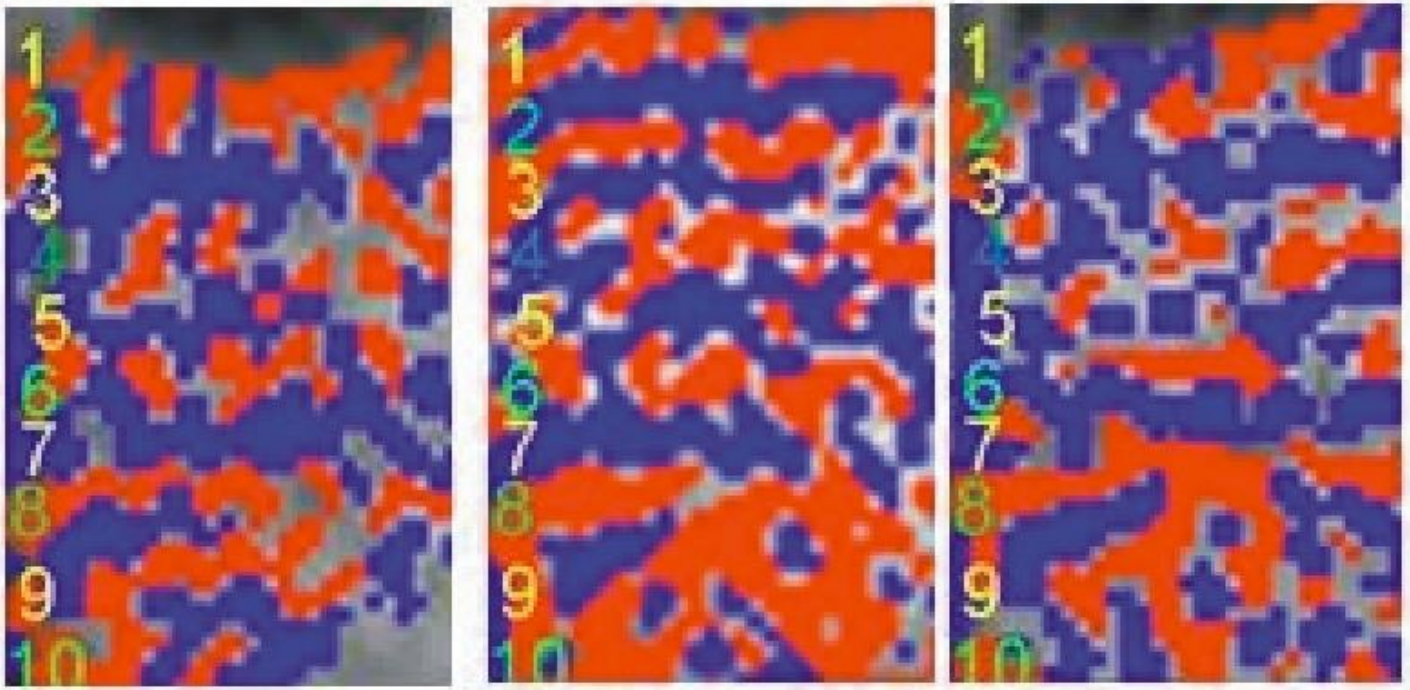


Kamitani & Tong (2005)

What to do with high resolution data?

HSE-BOLD demonstration of ocular dominance columns

human, 7T, 0.5×0.5×3 mm^3

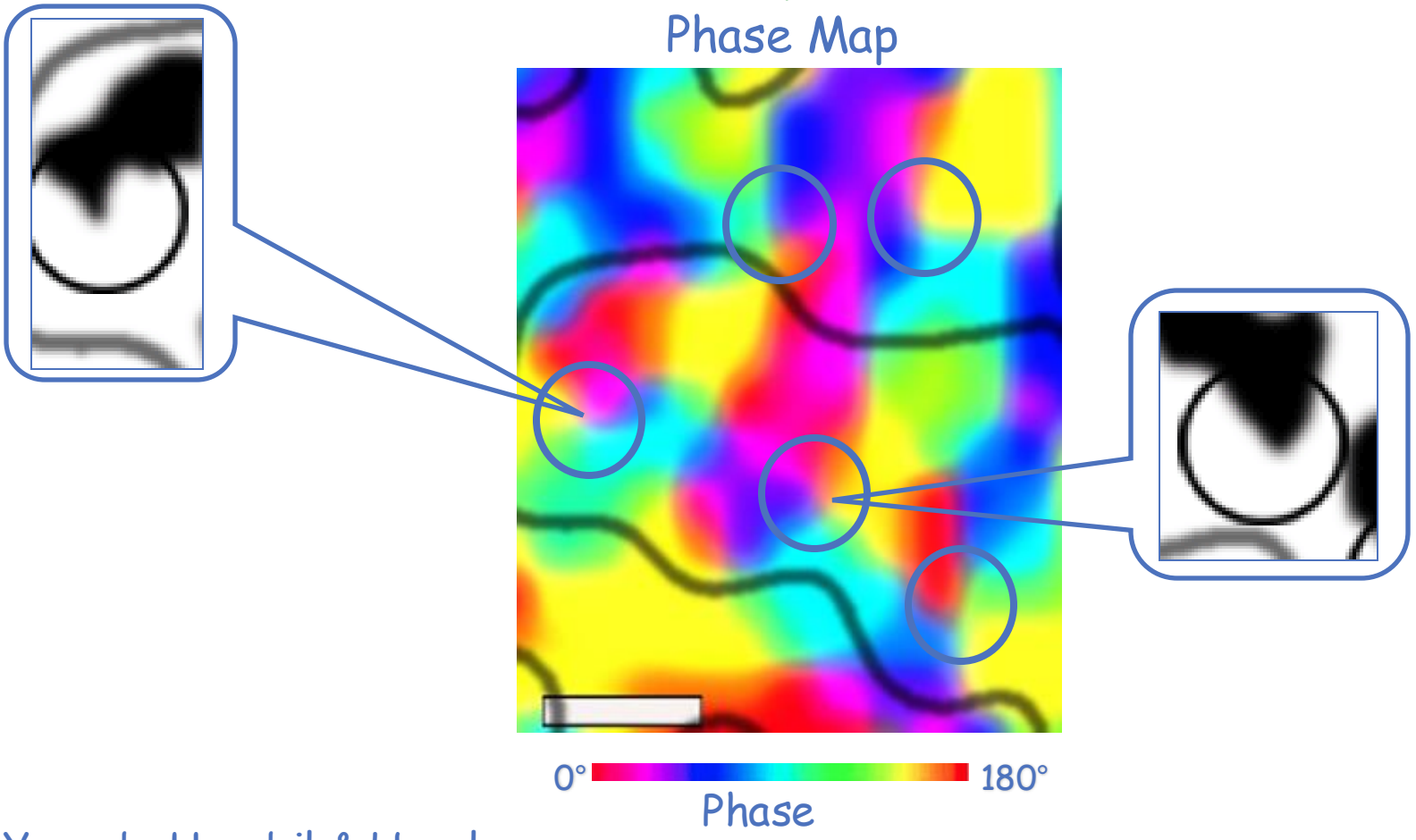


day 1 day 2 day 3

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

Methodology

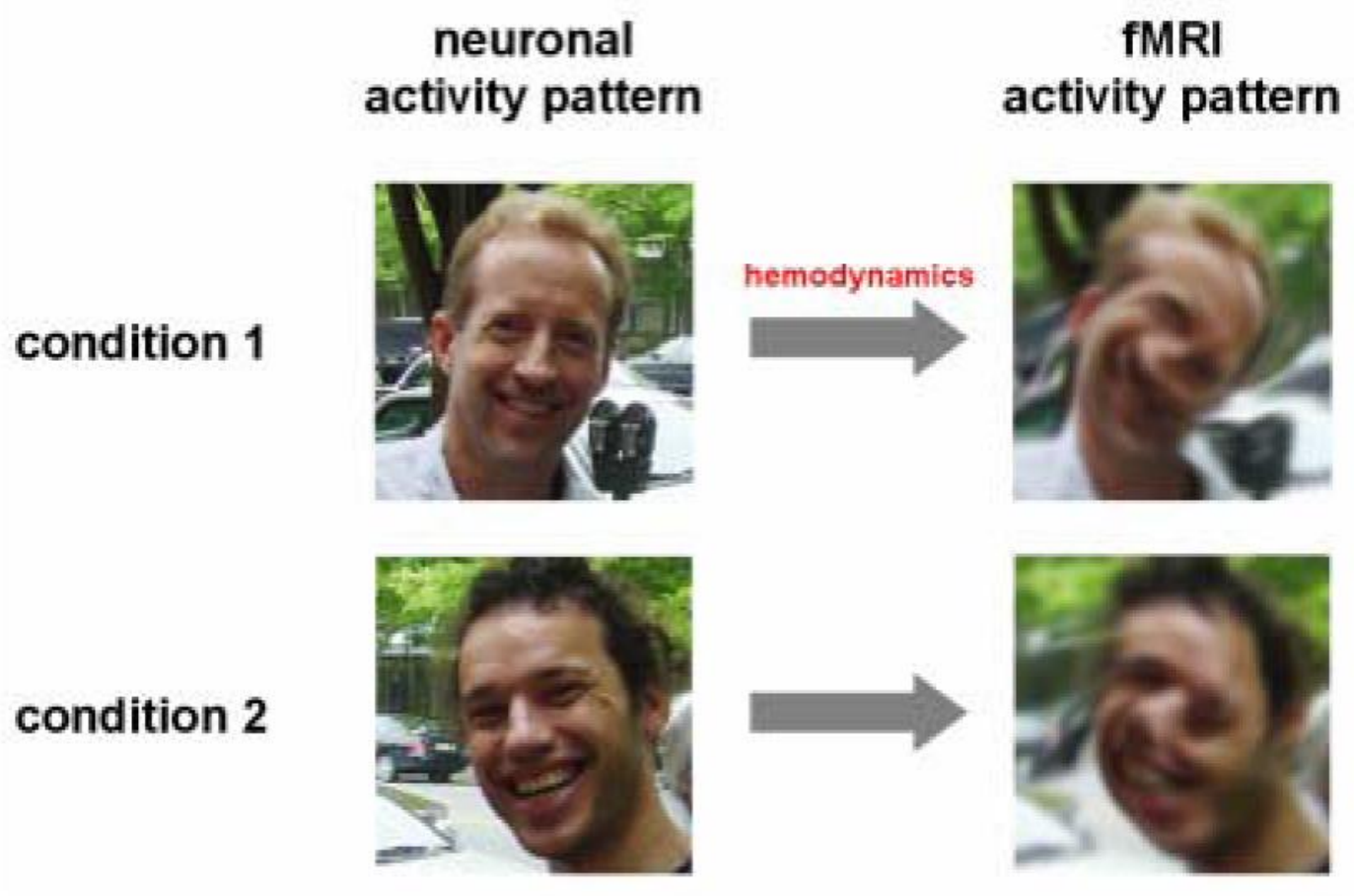
Orientation Columns in Human V1 as Revealed by fMRI at 7T



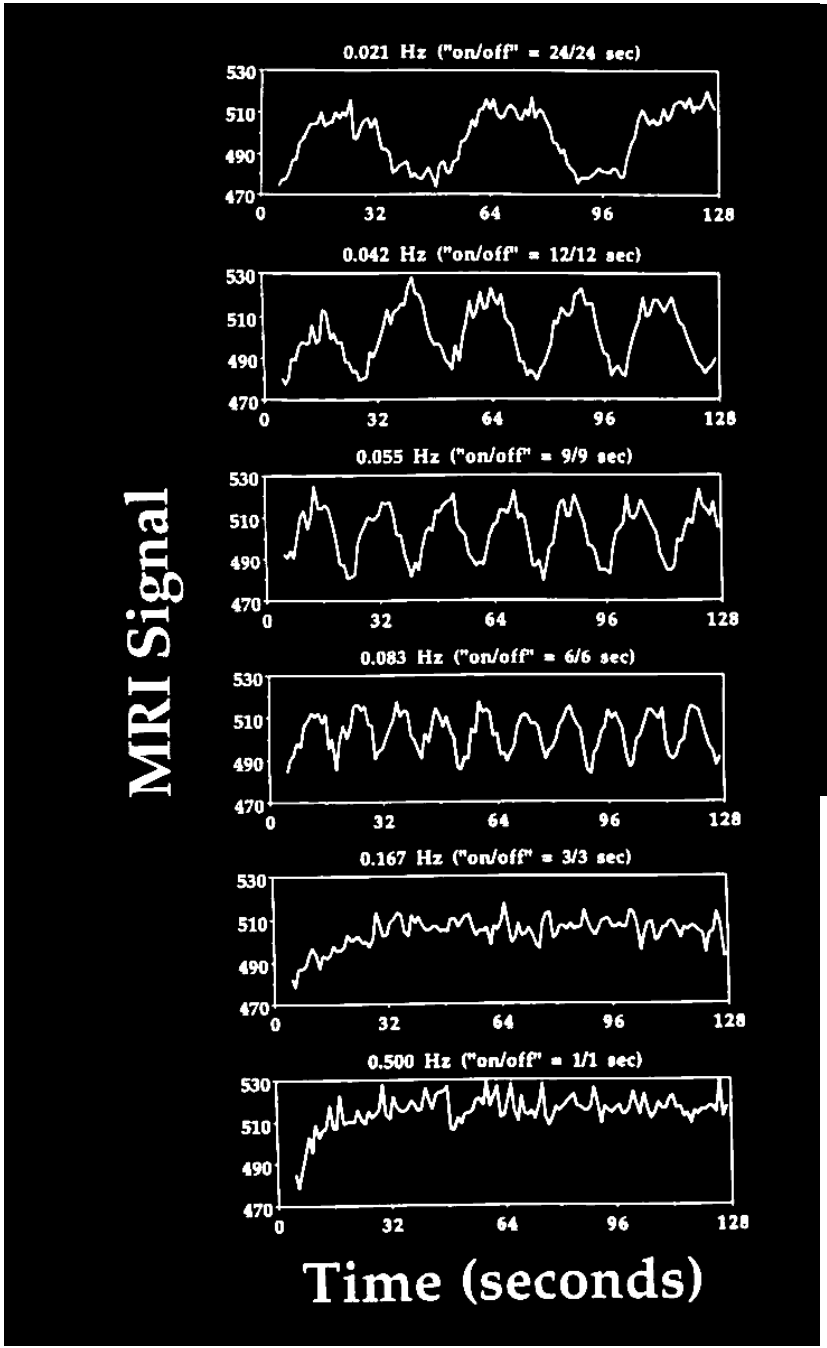
Yacoub, Ugurbil & Harel
University of Minnesota / CMRR
HBM 2006: Thursday, June 15, 2006 at 9:30

Scalebar = 0.5 mm

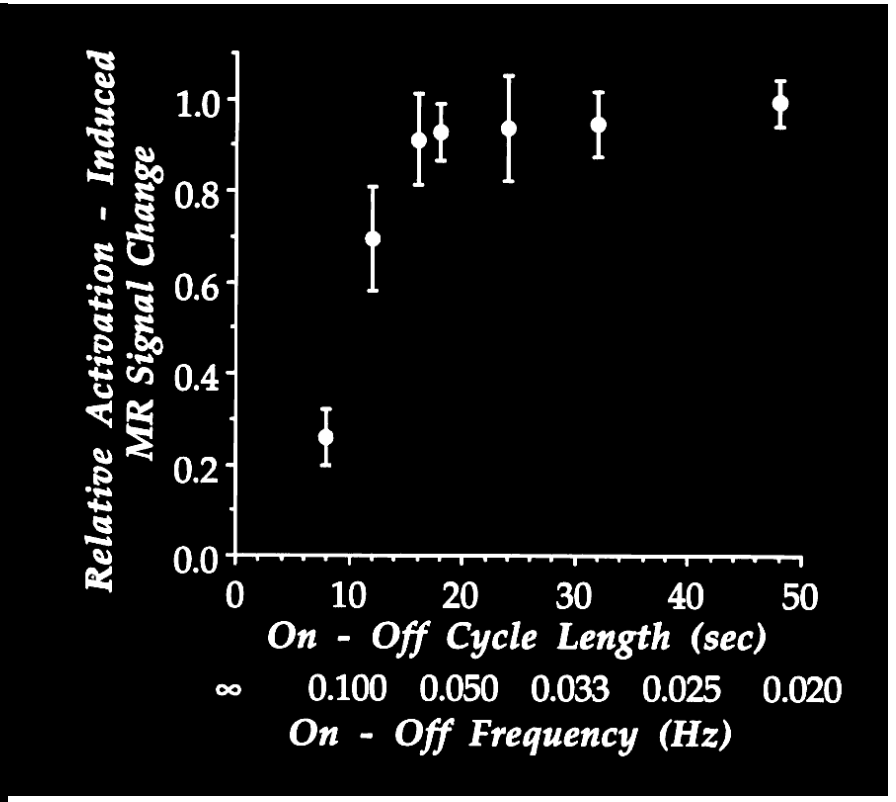
Methodology



Methodology



Temporal Resolution

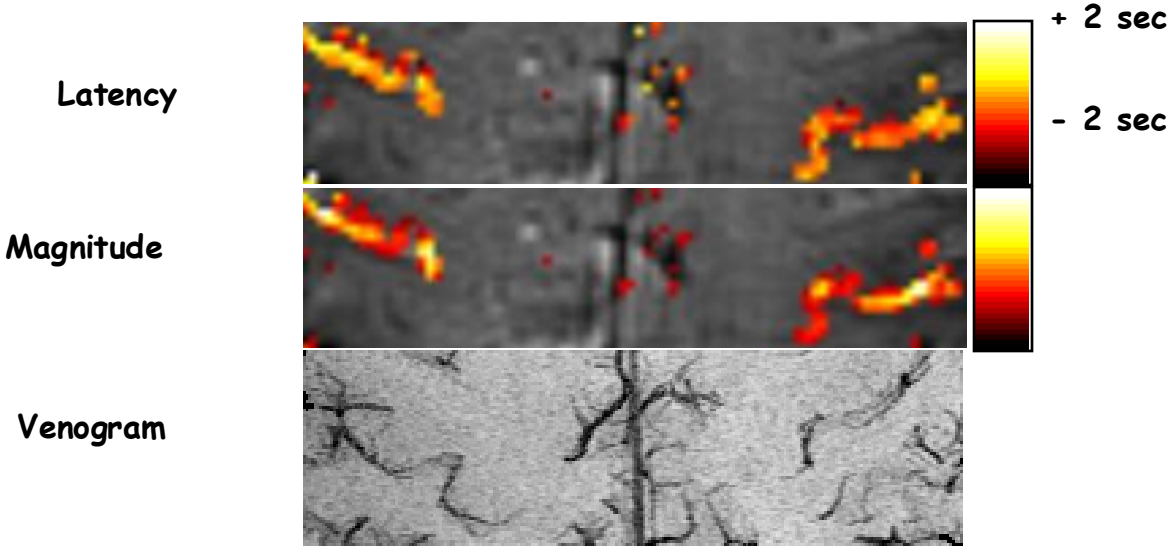


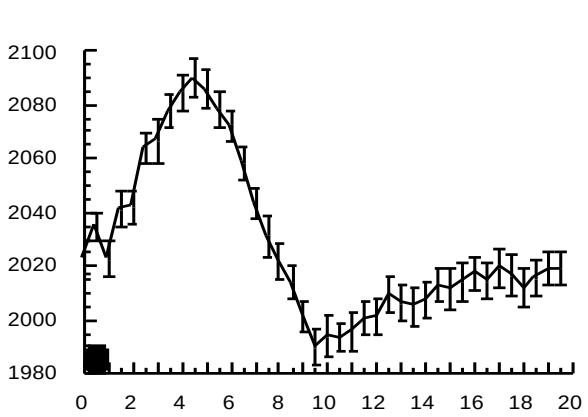
P. A. Bandettini, Functional MRI temporal resolution *in* "Functional MRI" (C. Moonen, and P. Bandettini., Eds.), p. 205-220, Springer - Verlag,. 1999.

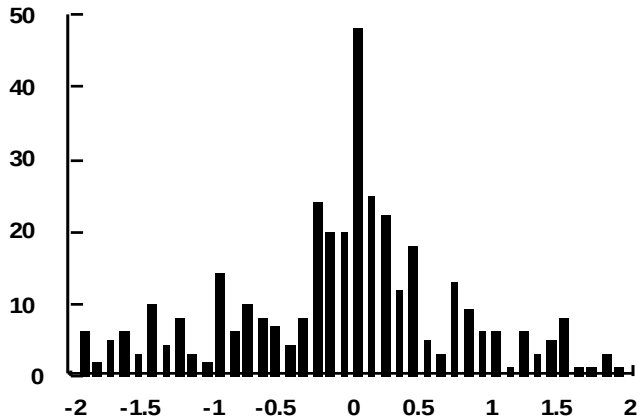
Methodology

Temporal Resolution

Latency Variation…



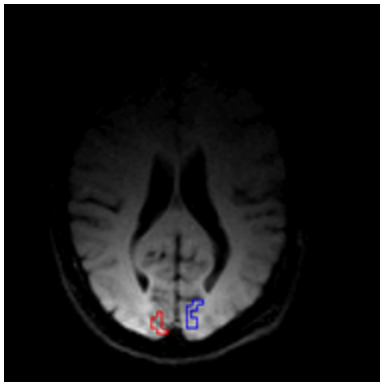




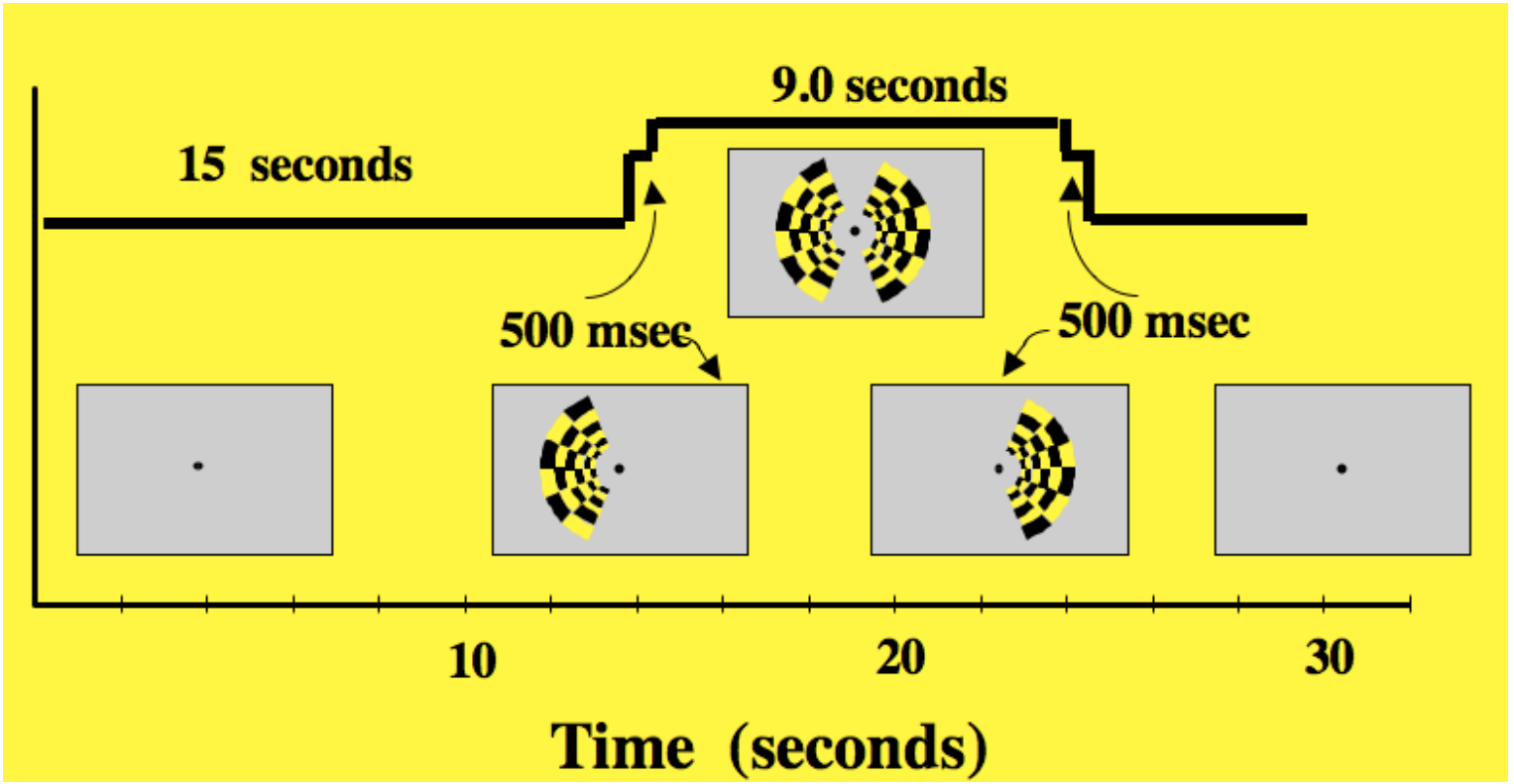
P. A. Bandettini, (1999) "Functional MRI" 205-220.

Hemi-Field Experiment

Right Hemisphere

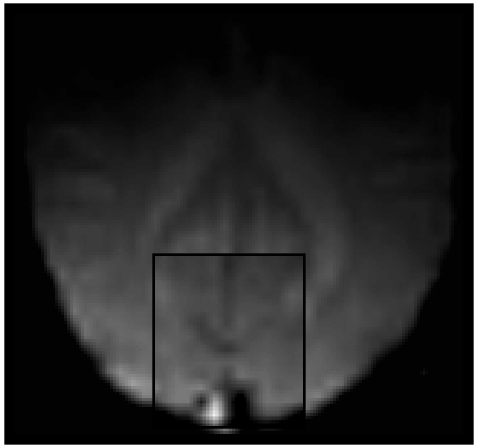


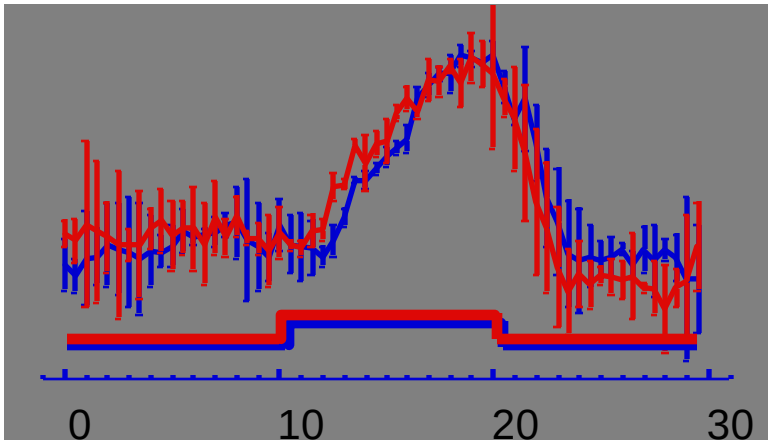
Left Hemisphere



Methodology

Temporal Resolution



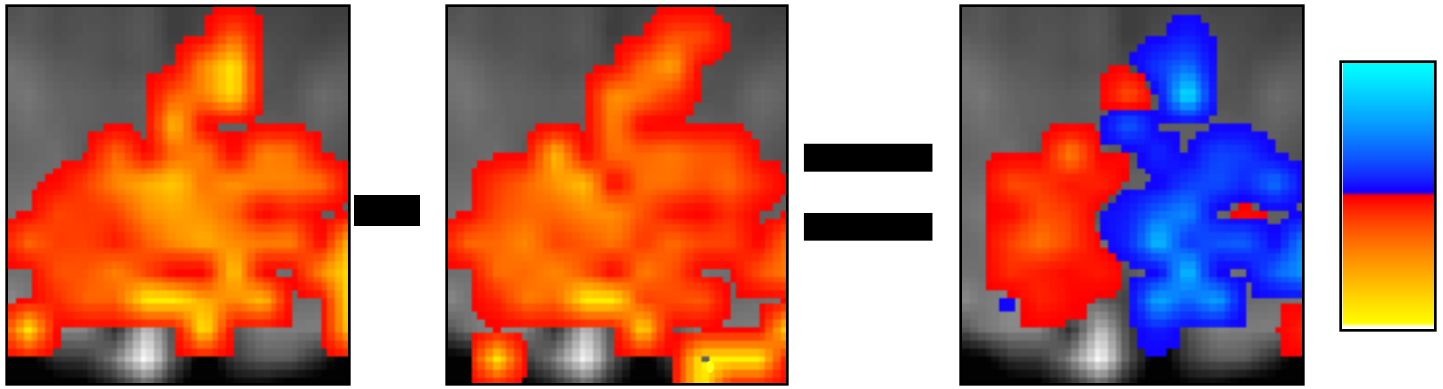


500 ms
||

500 ms
||

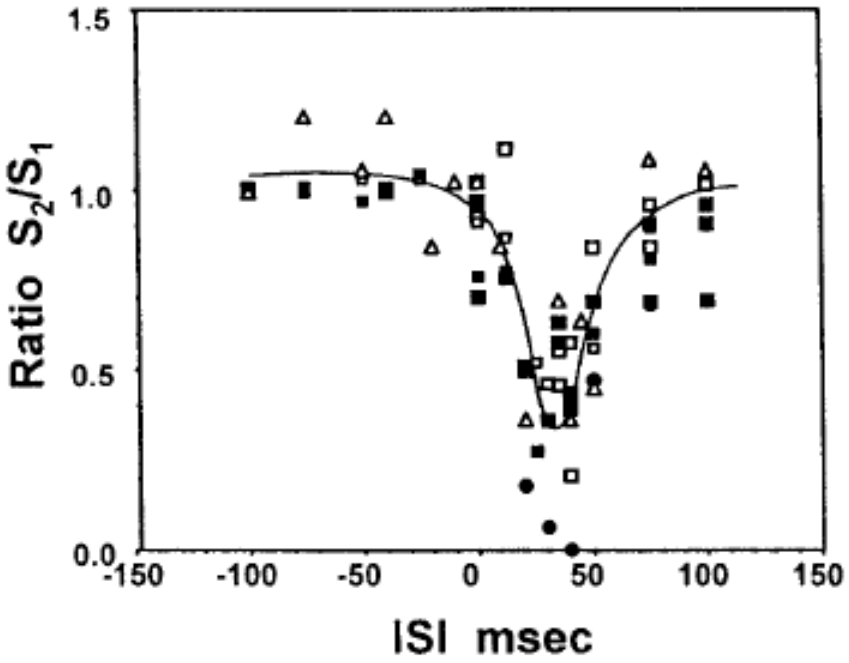
Right Hemifield

Left Hemifield



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
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

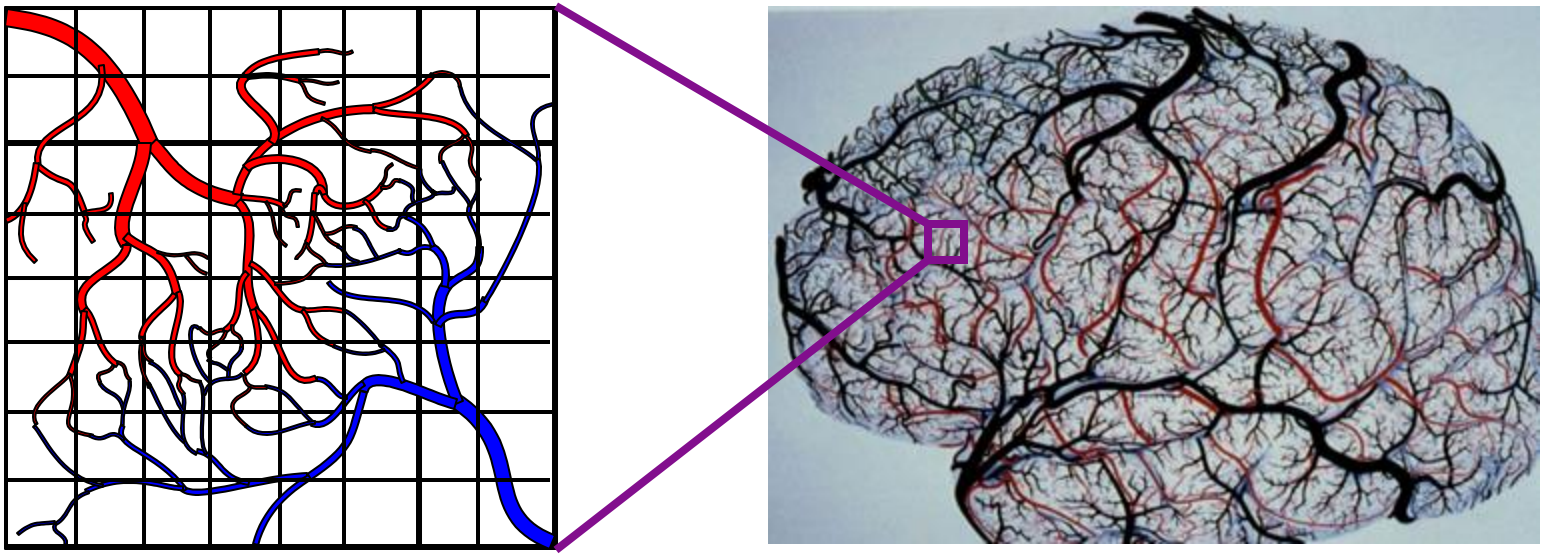
Applications

Interpretation

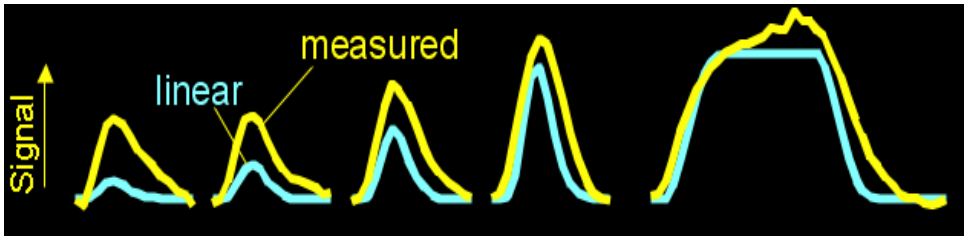
Neuronal Activation ? Measured Signal

? Hemodynamics ?

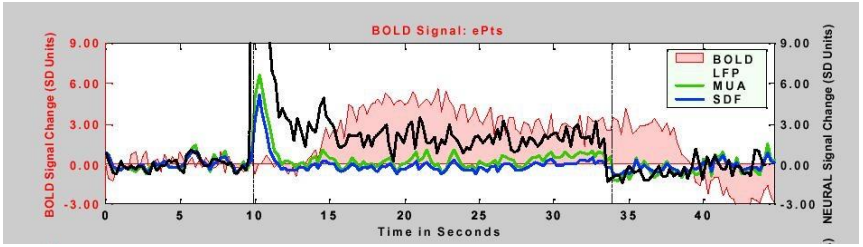
Noise ?



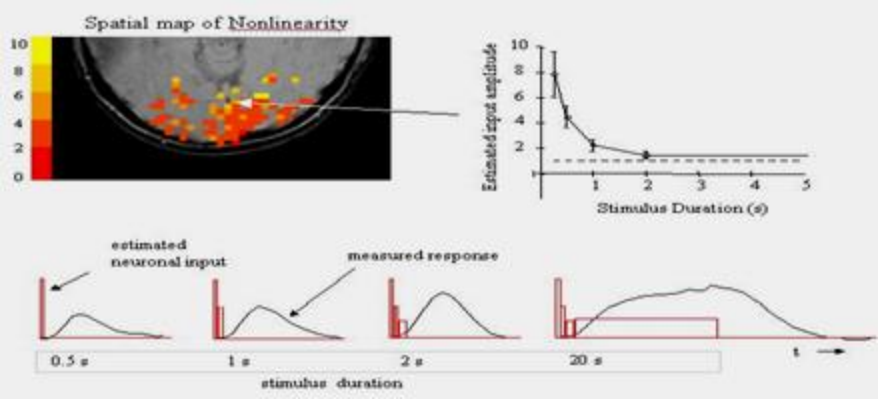
Interpretation



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



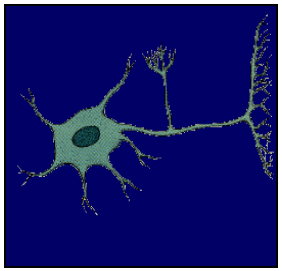
Logothetis et al. (2001) Nature, 412, 150-157.

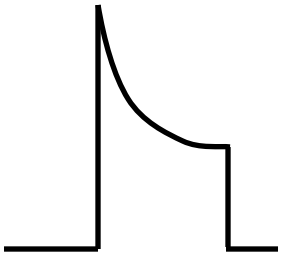


P. A. Bandettini et al, (2001) Nature Neuroscience, 4: 864-866.

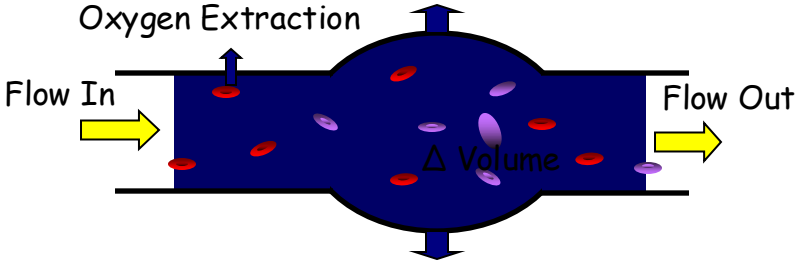
Sources of this Nonlinearity

- Neuronal

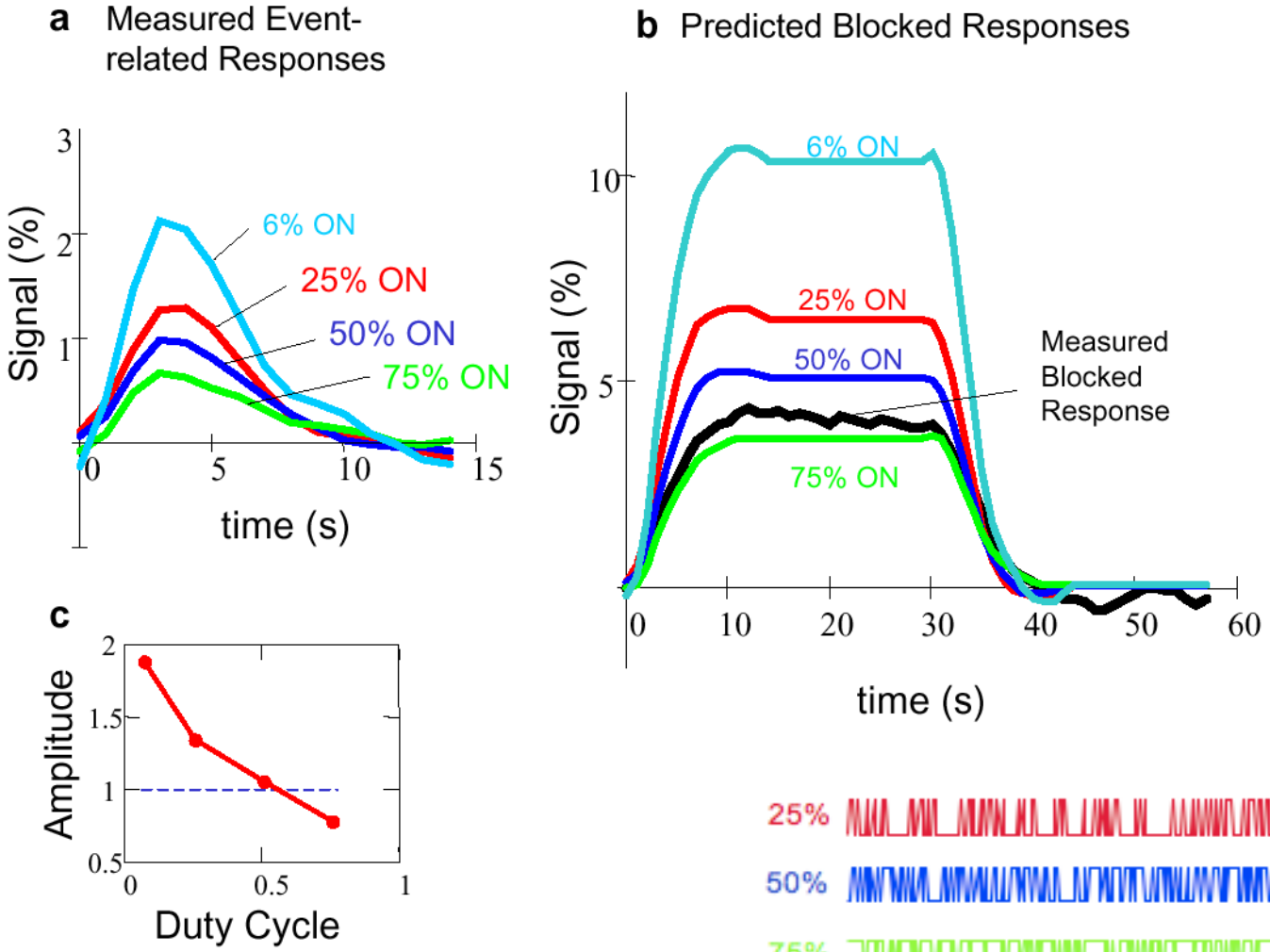




- Hemodynamic
  - -Oxygen extraction
  - -Blood volume dynamics

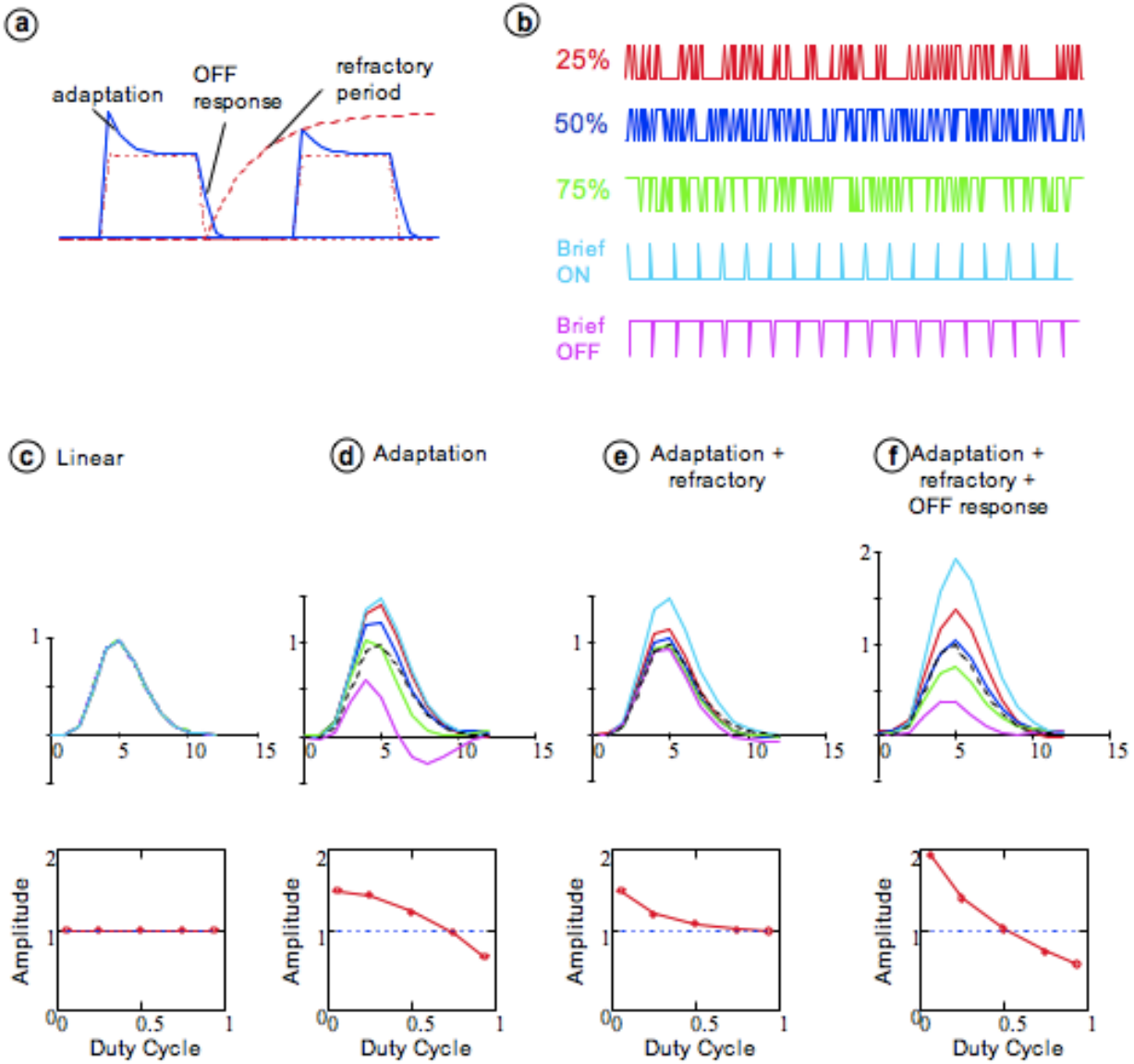


Interpretation Duty Cycle Effects

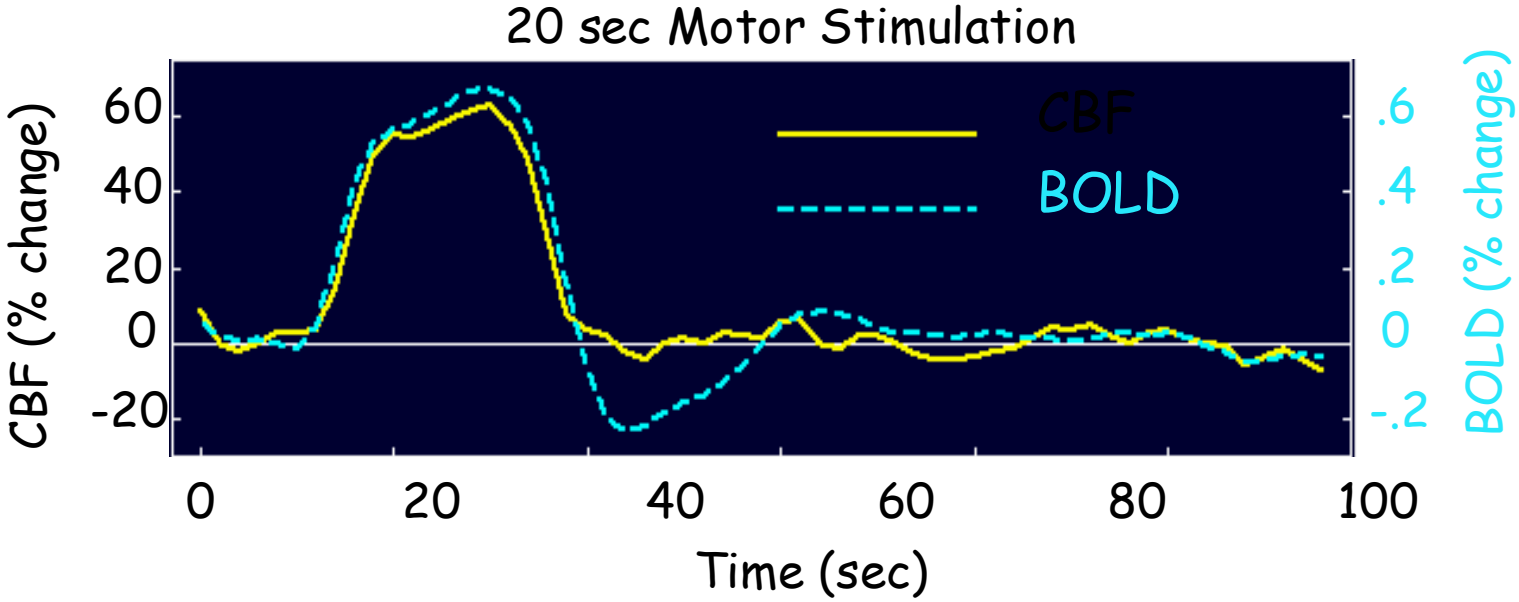


R.M. Birn, P. A. Bandettini, The effect of stimulus duty cycle and "off" duration on BOLD response linearity. *NeuroImage*, **27**, 70-82 (2005)

duty cycle effects



BOLD post-stimulus undershoot



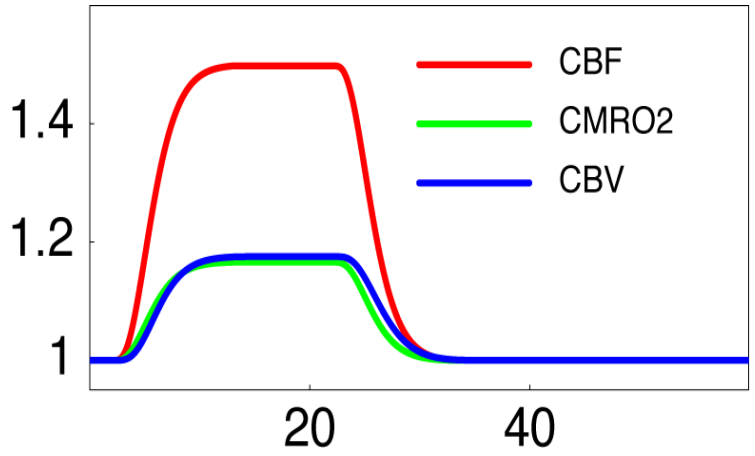
A BOLD undershoot without a CBF undershoot could be due to a slow return to baseline of either CBV or $CMRO_2$

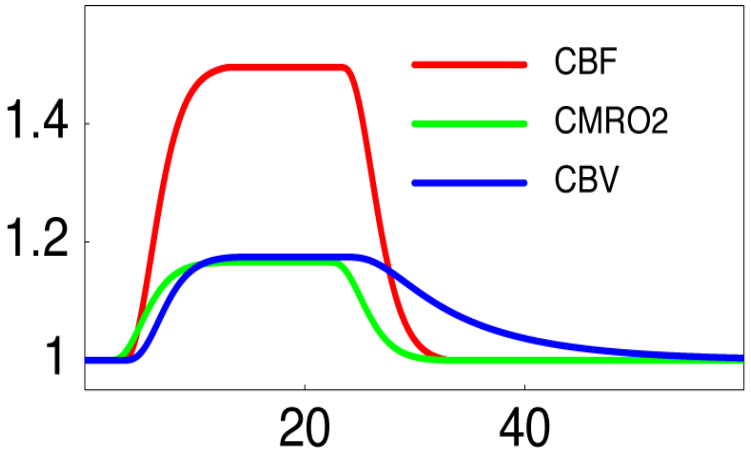
Courtesy Rick Buxton

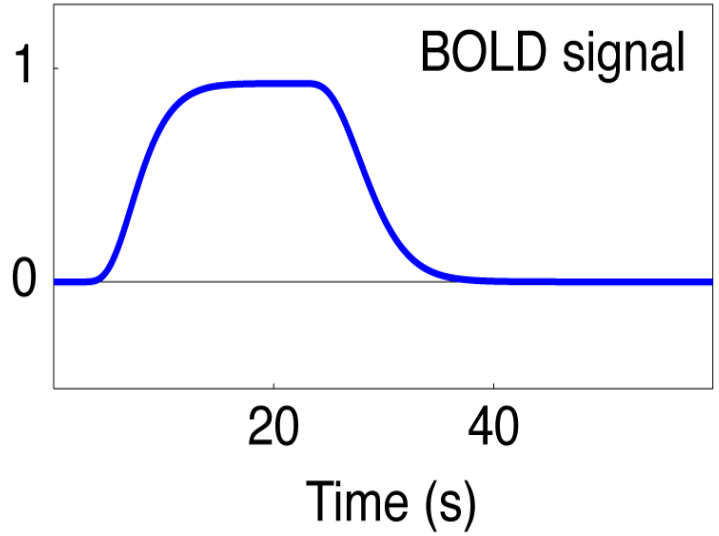
Interpretation

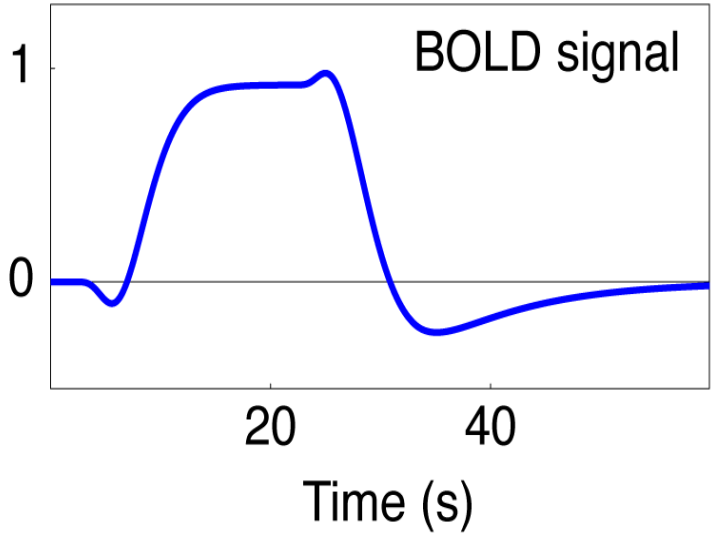
Post Undershoot

BOLD Signal Dynamics









Courtesy Rick Buxton

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Real time feedback
Task design

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Dynamics
Cross - modal comparison

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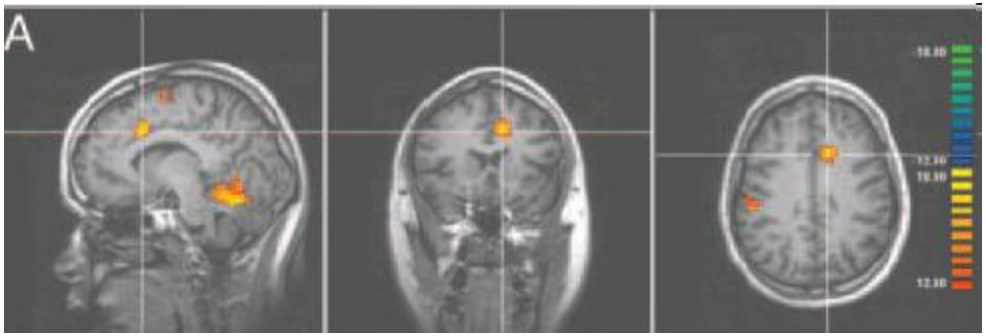
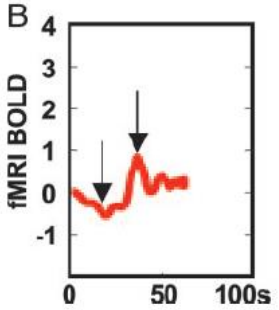
Basic Neuroscience
Behavior correlation/prediction
Pathology assessment

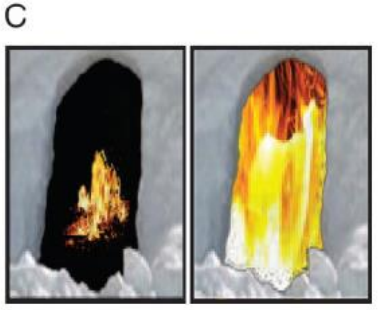
Applications

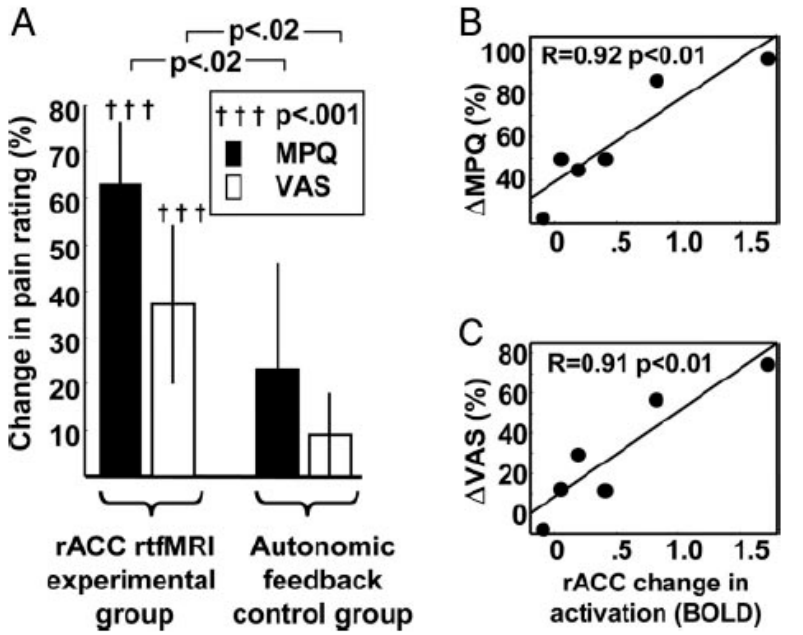
Applications

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

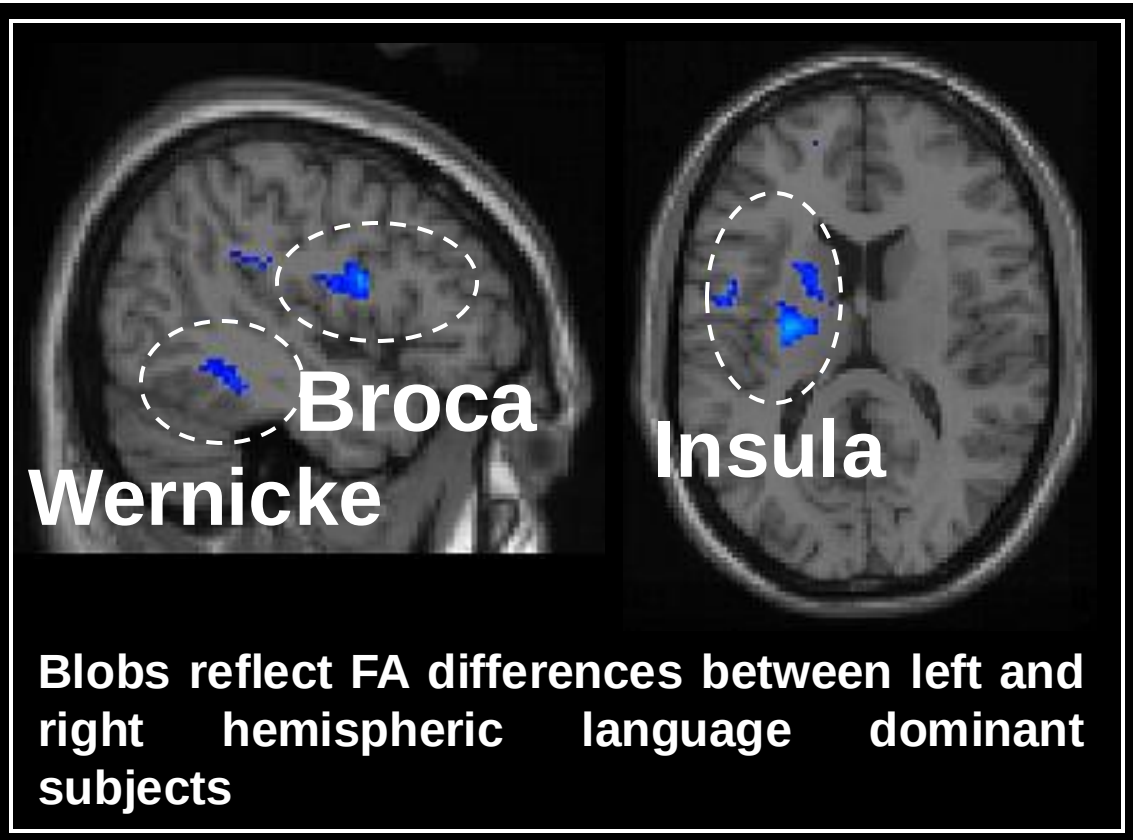
Section on Functional Imaging Methods & Functional MRI Facility Jan 19, 2007

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

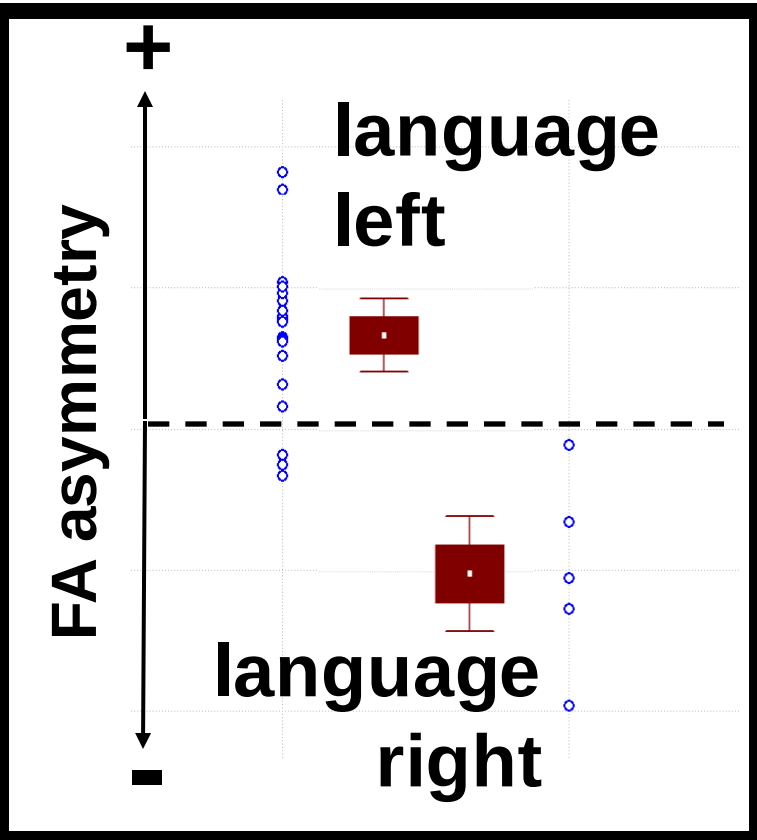
Anatomical correlates of right-hemispheric language processing: A DTI study

Monday – AM

S Mohammadi, A Jansen, W Schwindt, S Knecht, M Deppe
University of Münster, Germany



Blobs reflect FA differences between left and right hemispheric language dominant subjects



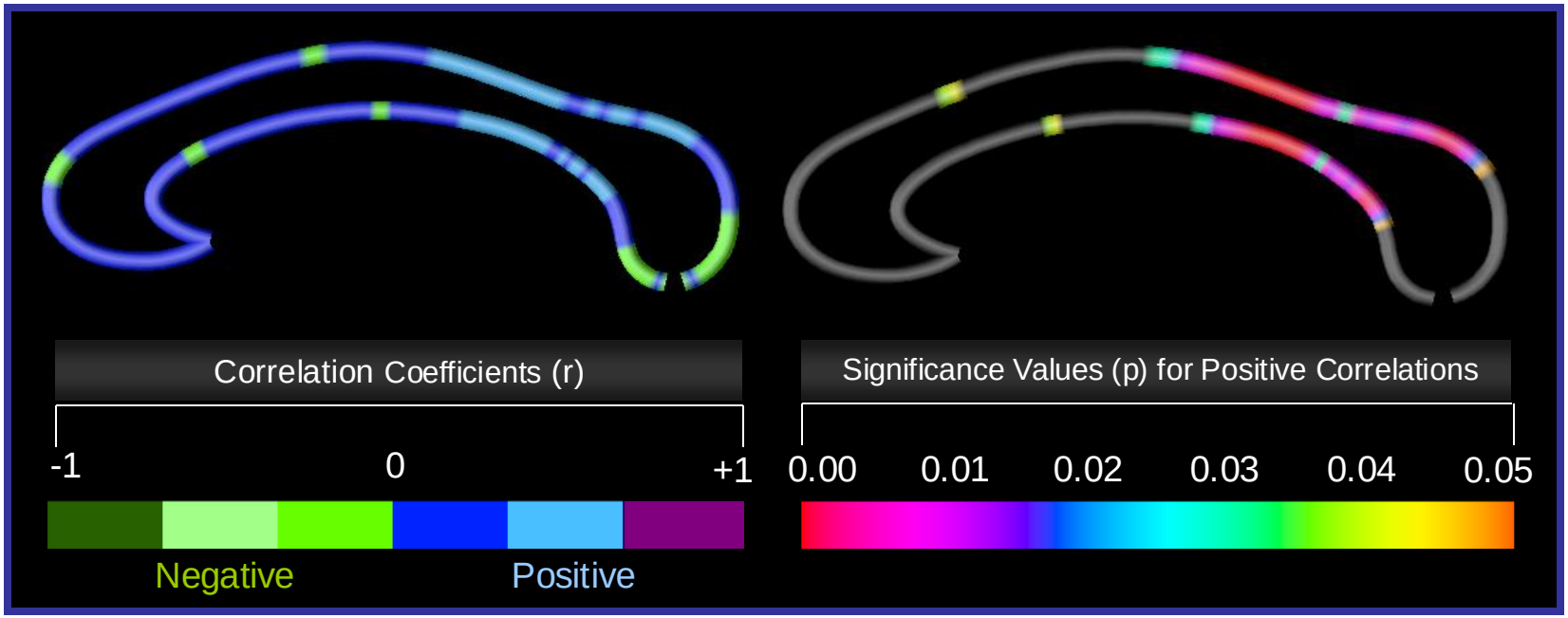
Results: language dominance was predicted by hemispheric FA asymmetry

Does callosal thickness correlate with intelligence?

(1) Intelligence and callosal thickness are correlated.

(2) Only positive correlations are significant.

(3) Positive correlations are most pronounced in the posterior half of the corpus callosum.

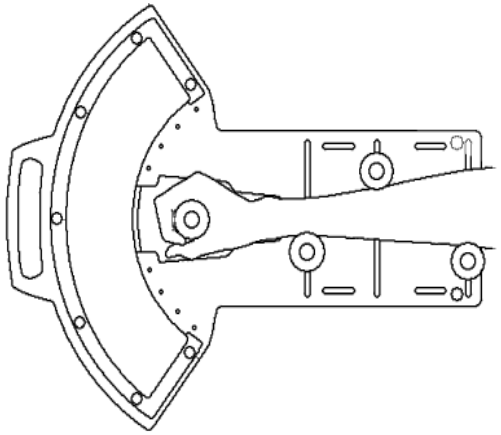


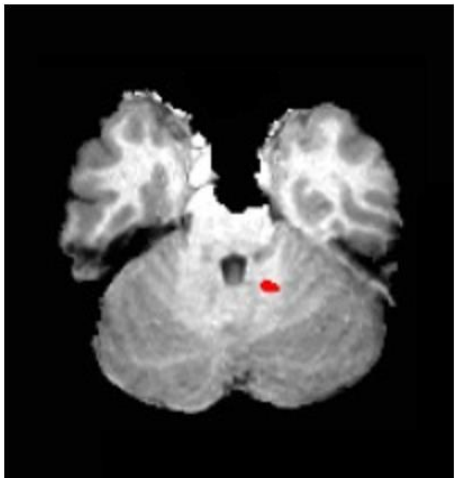
Luders, Narr, Bilder, Thompson, Szeszko, Hamilton, Gurbani, Toga

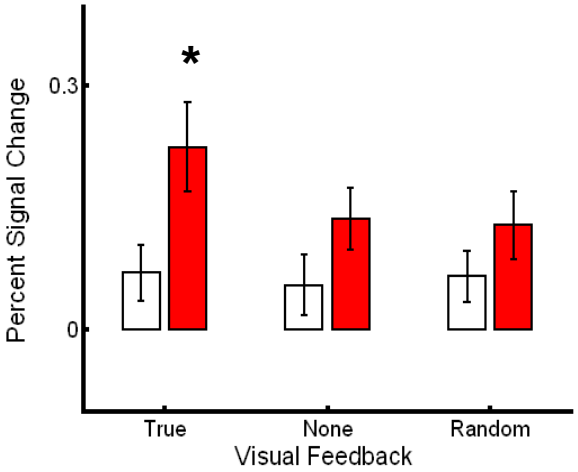
Poster #344; M-PM

Cerebellar and posterior parietal involvement in the integration of visual and proprioceptive feedback during stabilization of the wrist

A.J. Suminski[1], S.M. Rao[2], and R.A. Scheidt[1]
[1]Marquette Univ., Milwaukee, WI; [2]Medl College of Wisconsin, Milwaukee, WI







Activation in the ipsilateral dentate nucleus is ***enhanced*** when visual and proprioceptive feedback are ***correlated*** in time.

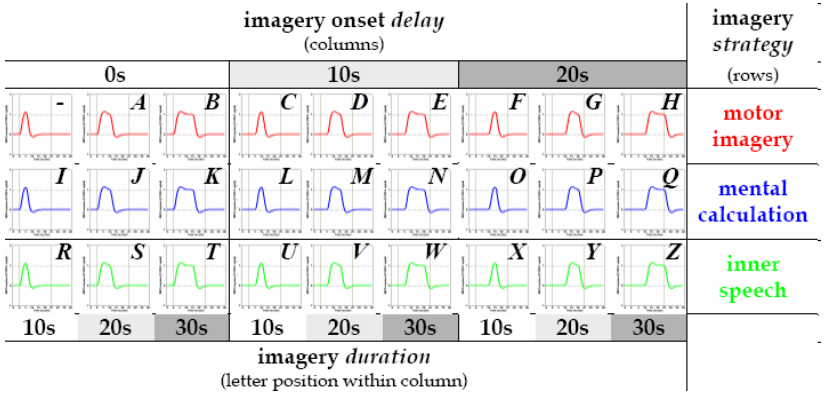
Reflective of it's role in ***integrating multiple sensory and feedforward estimates of limb state*** thereby producing a unified limb state estimate that can be used to correct for movement errors.

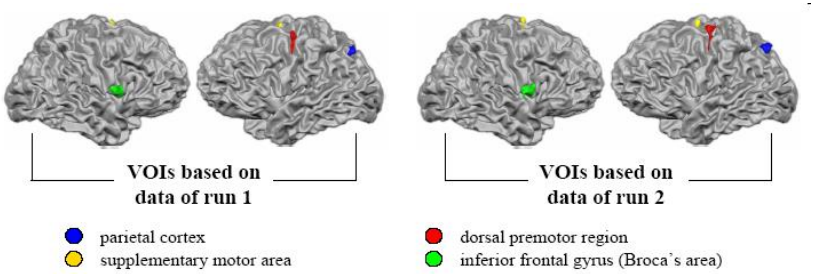
Supported by NSF BES0238442

BOLD communication: When the brain speaks for itself

Bettina Sorger, Brigitte Dahmen, Joel Reithler, Rainer Goebel

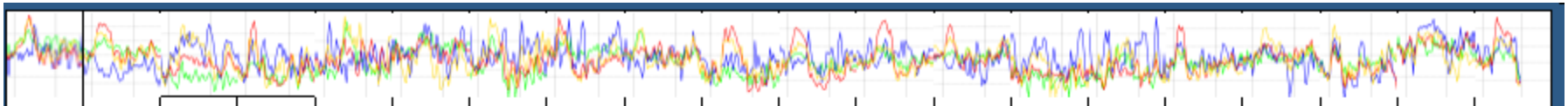
Cognitive Neuroscience Department, Maastricht University, The Netherlands
Maastricht Brain Imaging Center (M-BIC), Maastricht University, The Netherlands





	guided letter encoding				*phrase encoding*			
en-/ decoder	paradigm	delay	duration	letter	paradigm	delay	duration	letter
S1	.988	.981	.907	.889	.958	.986	.889	.840
S2	.938	.932	.870	.827	.784	.961	.804	.686
S3	.957	.981	.920	.883	.735	.931	.824	.608
R1	.966	.975	.932	.901	.869	.960	.869	.778
R2	.969	.957	.907	.877	.879	.990	.889	.788
R3	.944	.963	.858	.821	.800	.940	.798	.636
total	.961	.965	.899	.866	.852	.963	.852	.734

Fig. 3. Accuracy results of the *guided letter* and *phrase encoding* experiments (percentage of correct identification).



C	A	N	-	Y	O	U	-	R	E	A	D	-	M	Y	-	M	I	N	D
C/C/C	A/A/A	N/N/N	-/-/-	Y/Y/X	O/X/O	V/U/U	-/-/-	R/R/R	D/D/D	A/A/A	D/D/D	-/-/-	M/M/M	Y/Z/Y	-/-/-	M/M/U	I/I/I	N/N/N	D/D/D
C/C/C	A/A/A	N/N/N	-/-/-	Y/Y/Y	O/O/O	U/U/U	-/-/-	R/R/R	E/E/E	A/A/A	D/D/D	-/-/-	M/M/M	Y/Y/Y	-/-/-	M/M/M	I/I/I	N/N/N	D/D/D

Fig. 4. Results of the *phrase encoding* experiment (subject S1).
The first row displays the single-trial time courses of the four VOIs generated by the subject while encoding the letters indicated in the second row. The third (light-grey) row displays letter decoding results obtained independently by three raters (R1/R2/R3) evaluating the time courses in randomized trial order (without word context information), whereas the fourth (dark-grey) row illustrates the results obtained by using the original trial order (providing word context information).

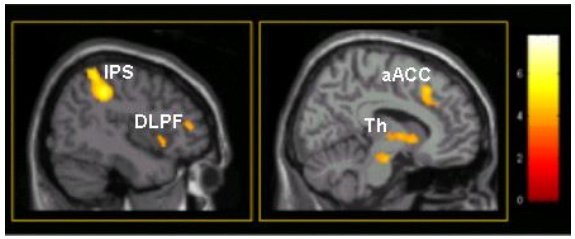
Baseline brain activity fluctuations predict somatosensory perception

M. Boly, E. Balteau, C. Schnakers, C. Degueldre, G. Moonen, A. Luxen, C. Phillips, P. Peigneux, P. Maquet, S. Laureys
Cyclotron Research Centre & Neurology Dept., University of Liège, Belgium

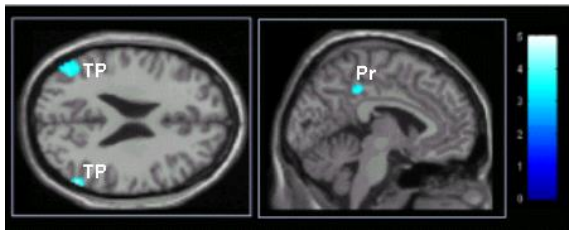
Poster #3 M-AM; Oral: "Cognition – Perception and Awareness" on Tuesday, June 12, 18:15.

3 seconds before stimulation:

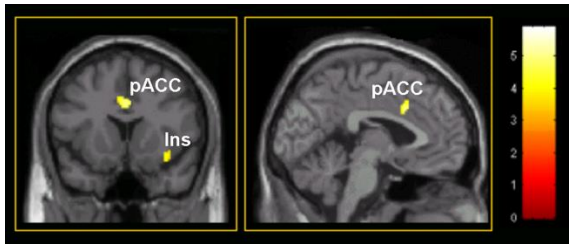
- Baseline *fronto-parietal* activity is high
  ⇒ stimulus will be *perceived*



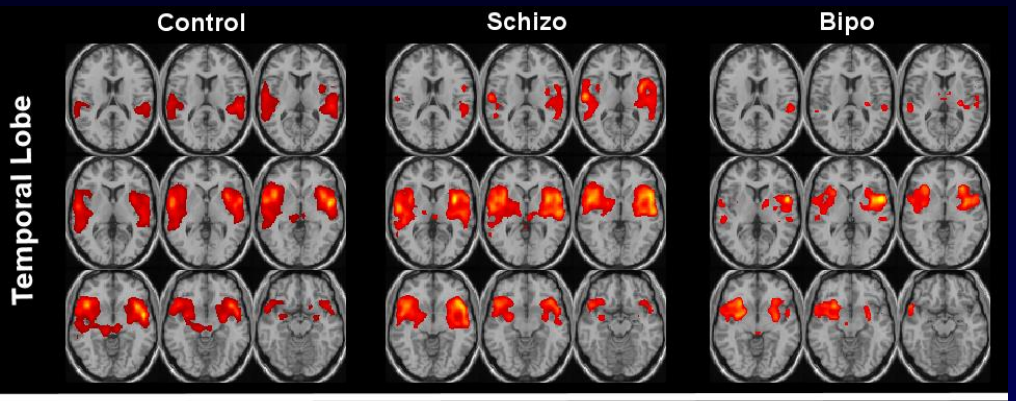
- Baseline *default network* activity is high
  ⇒ stimulus will be *missed*

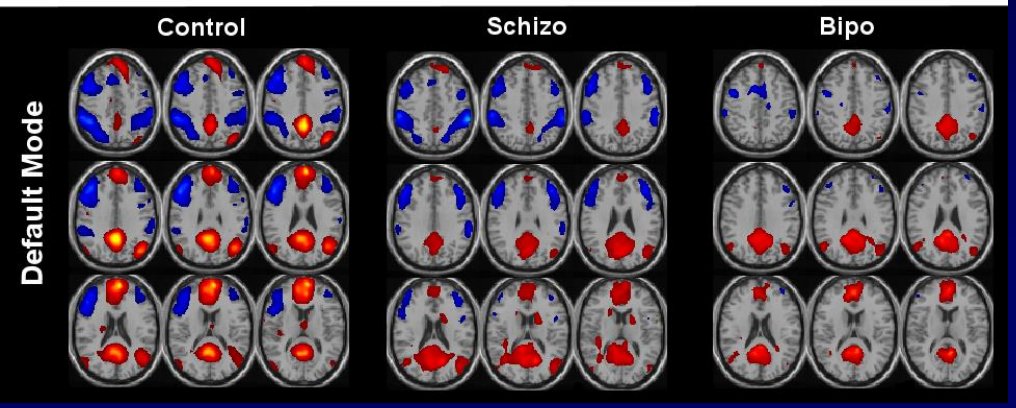


- Baseline *pain matrix* activity is high
  ⇒ stimulus will be *more painful*



Spontaneous baseline activity fluctuations foretell sensory and pain intensity perception.

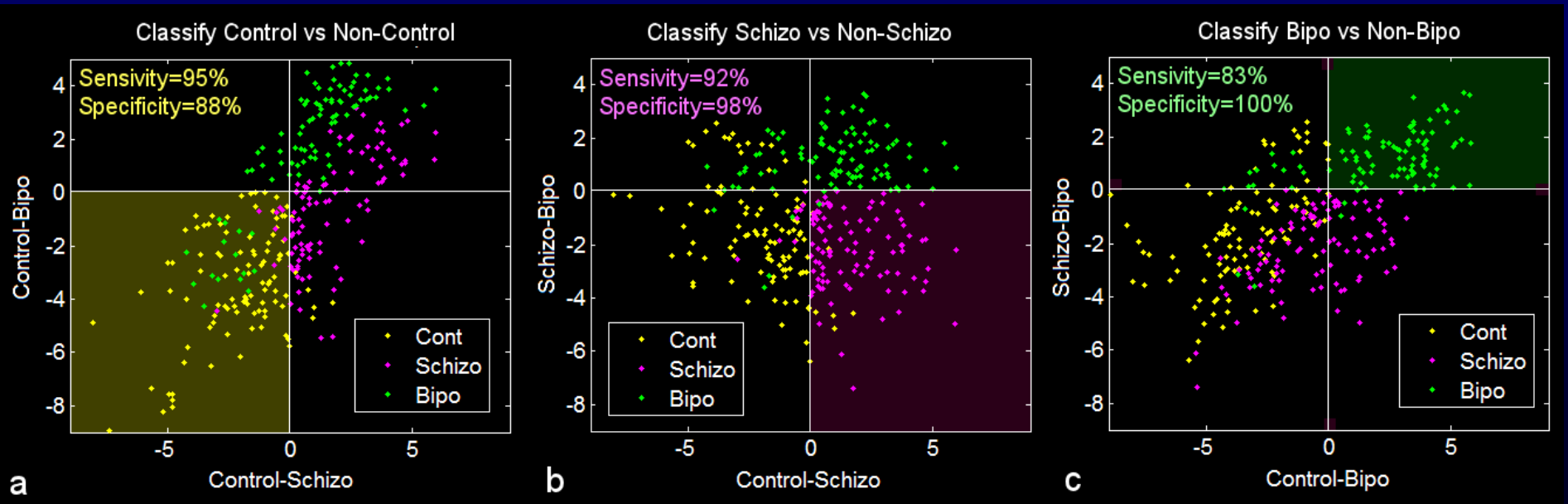




Vince Calhoun

Resting state ICA & classification for characterization of shizophrenia and bipolar patients

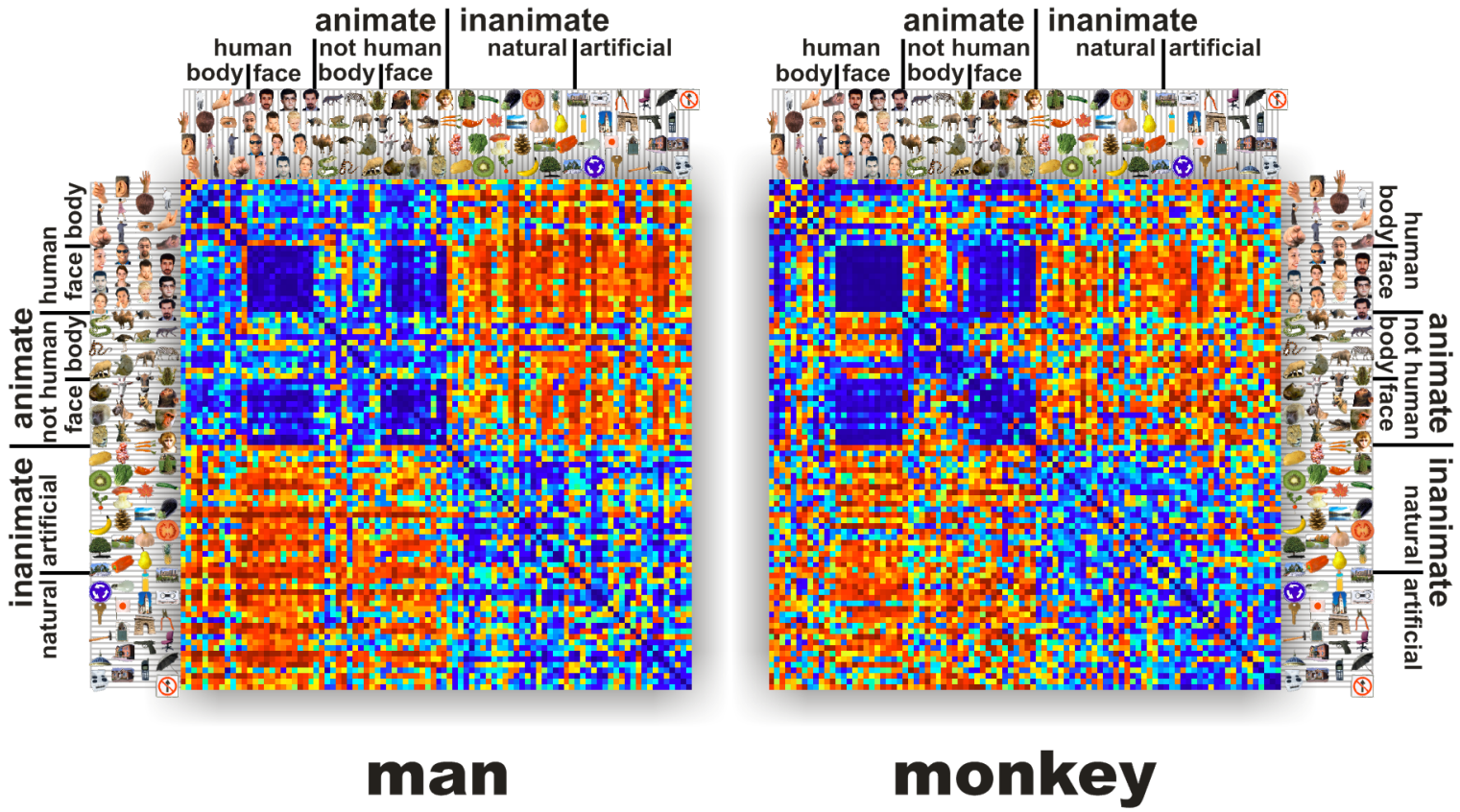
Results show a high average sensitivity (90%) and specificity (95%). Controls were correctly classified 95% of the time, schizophrenia patients 92%, and bipolar patients 81%.



Matching categorical object representations in IT cortex of man & monkey

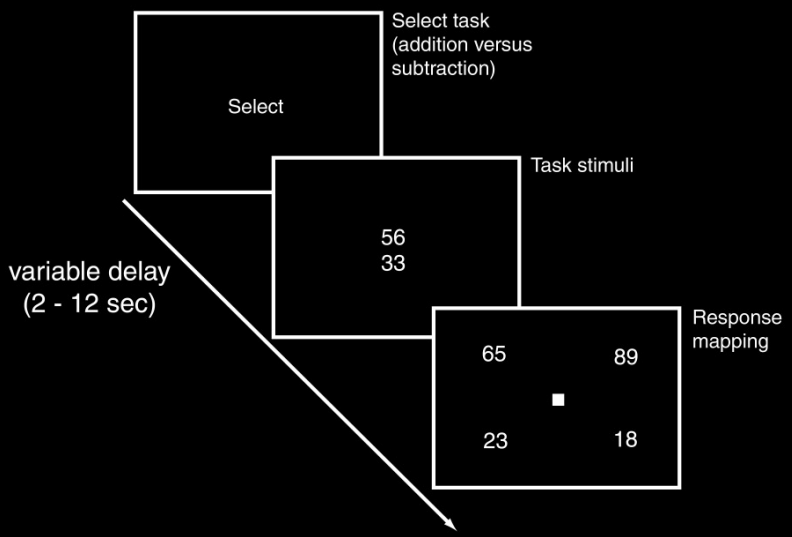
Kriegeskorte N, Mur M, Ruff D, Kiani R, Bodurka J, Bandettini P

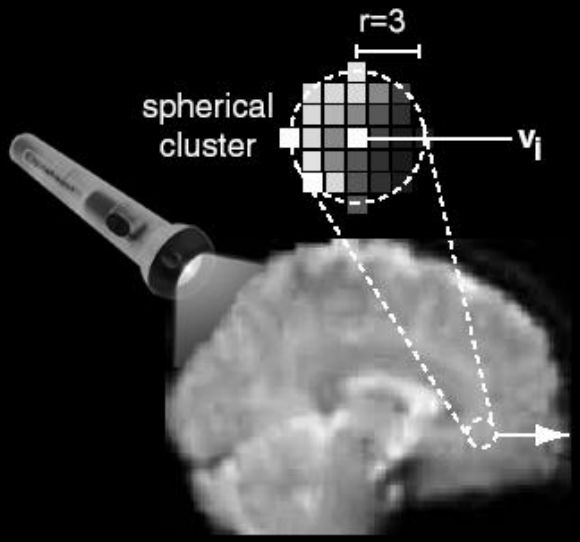
dissimilarity matrices

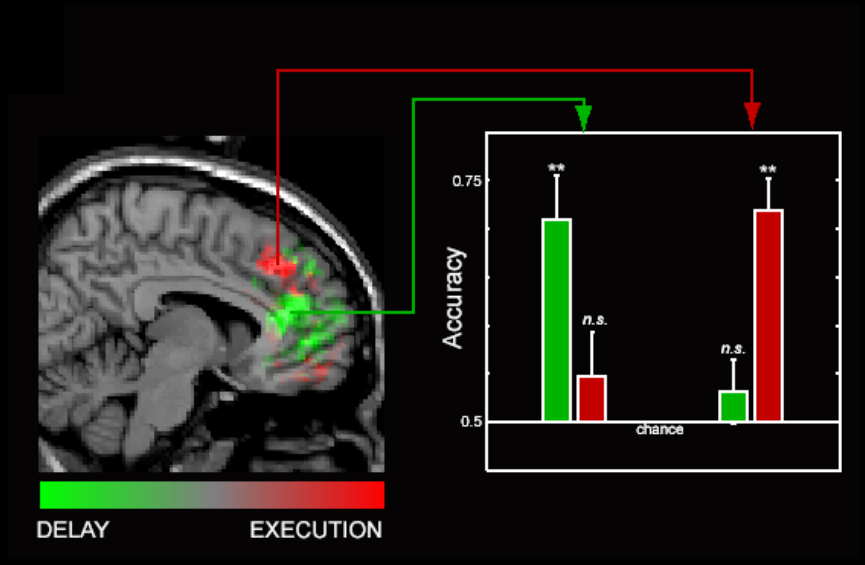


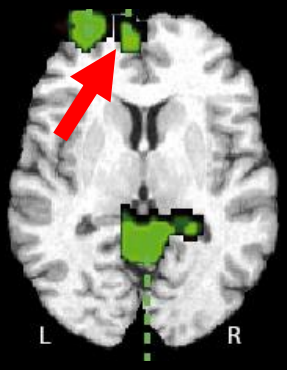
Reading hidden intentions in the human brain

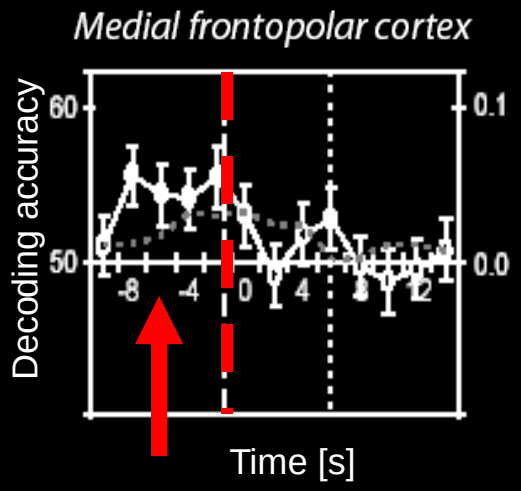
Thu 9.45: Cognition – Representation and Processes









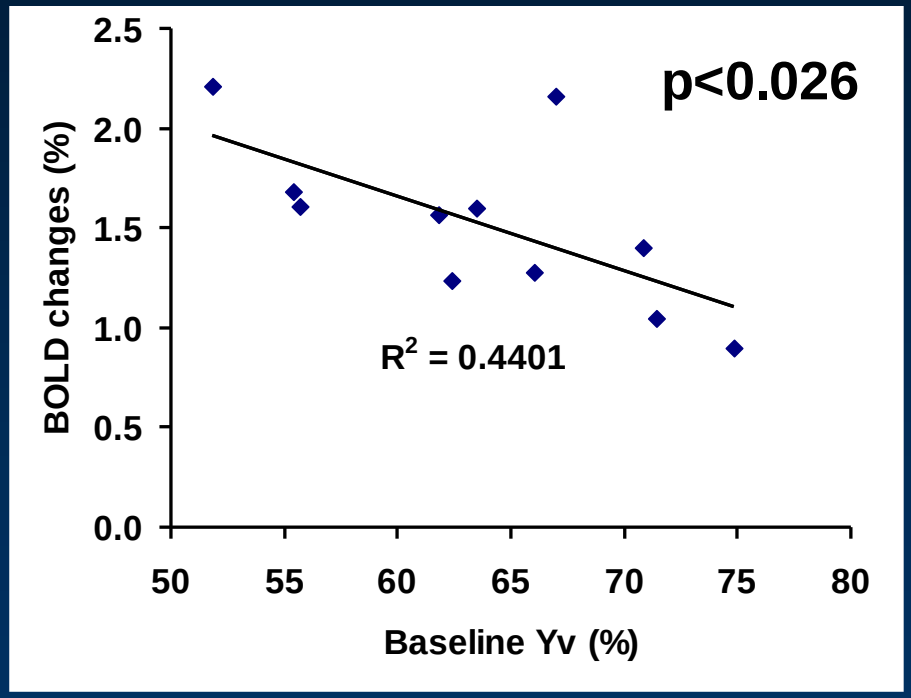


Haynes, Sakai, Rees, Gilbert, Frith & Passingham (Current Biology,2007)

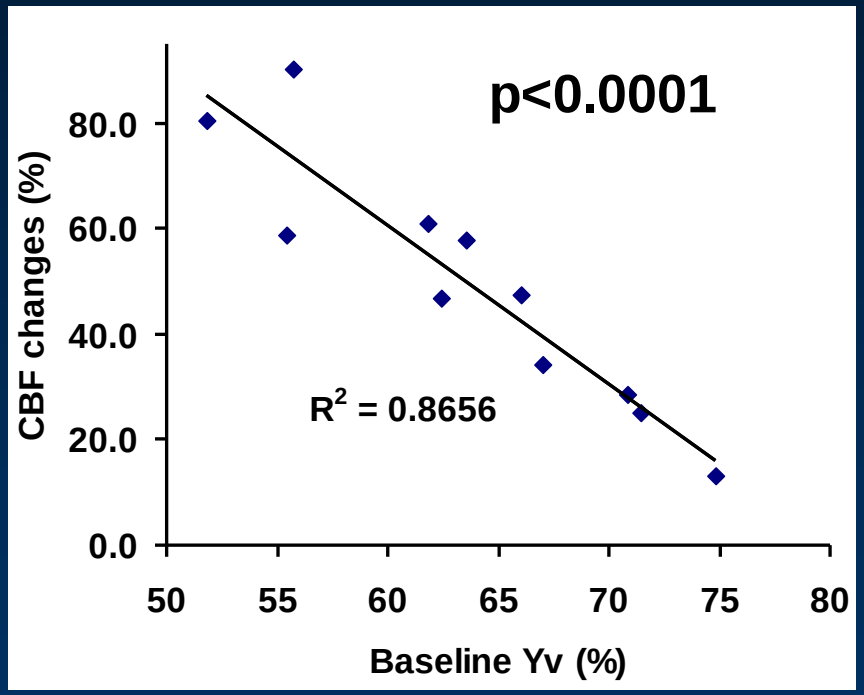
Soon, Brass, Heinze & Haynes (in preparation)

Baseline blood oxygenation modulates fMRI signals

BOLD fMRI



ASL fMRI



Individuals with higher baseline venous oxygenation tend to have smaller BOLD and CBF percentage signal changes

Hanzhang Lu et al. OHBM 2007, 278 - Thursday PM