What fMRI Can, Can't, and Might Do

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&

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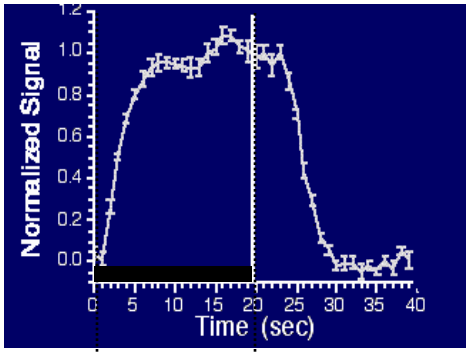
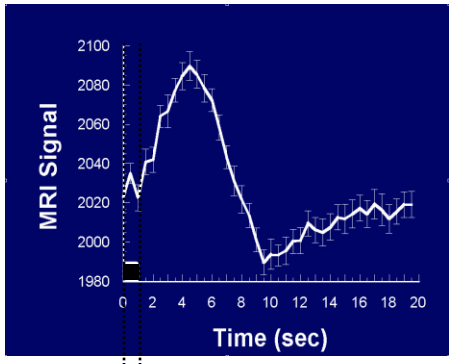
http://fmrif.nimh.nih.gov

Overview of fMRI

Functional Contrast:

- Blood volume
- Blood flow/perfusion
- Blood oxygenation





task *task*

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

Sensitivity:

- tSNR = 40/1 to 120/1
- fCNR = 1/1 to 6/1

Interpretability issues:

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

What fMRI Is Currently Being Used For

Research Applications

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

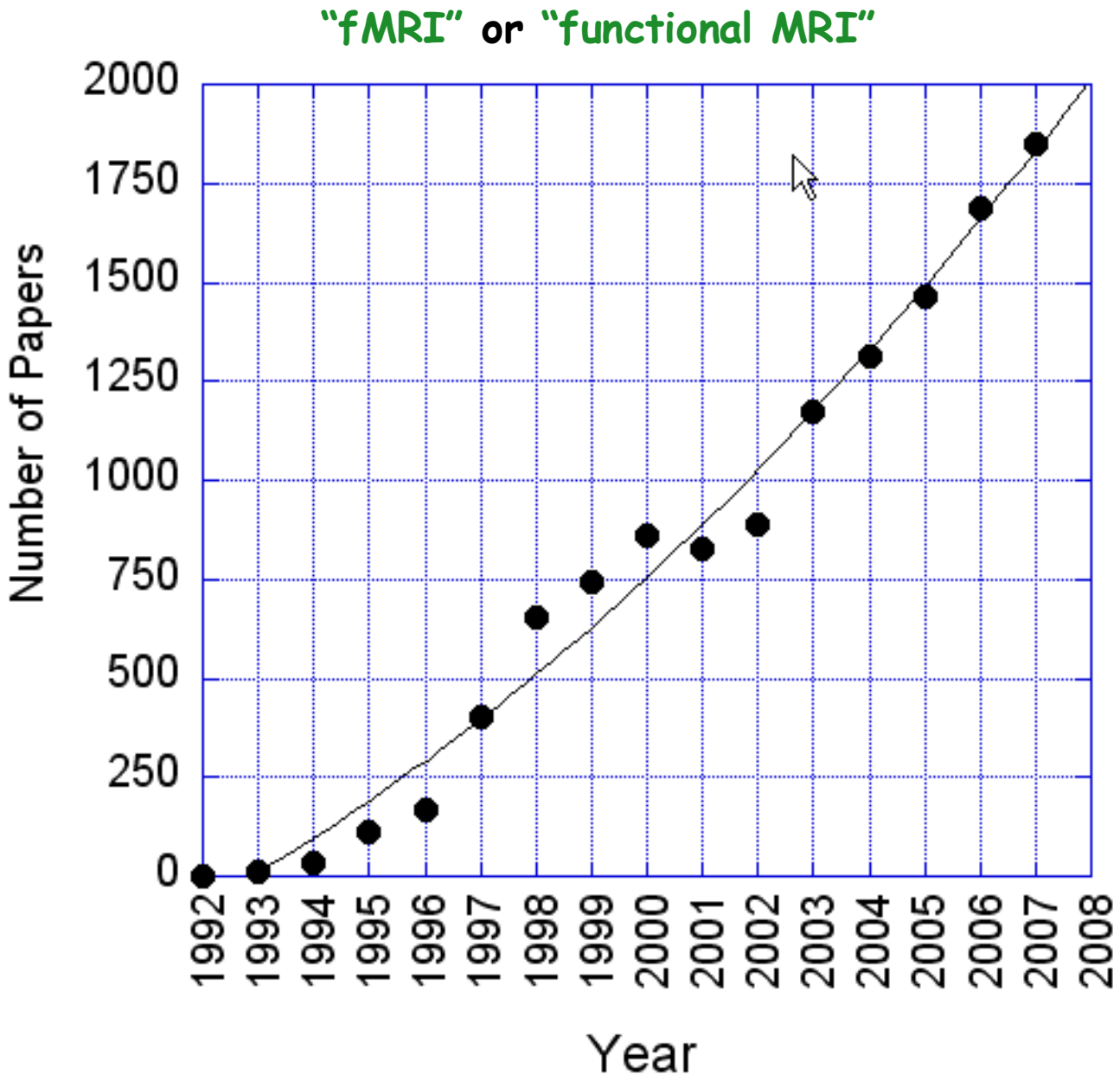
Clinical Research

- -clinical population characterization (probe task or resting state)
- -assessment of recovery and plasticity
- -attempts to characterize (classify) individuals

Clinical Applications

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

Scopus: Articles or Reviews Published per Year



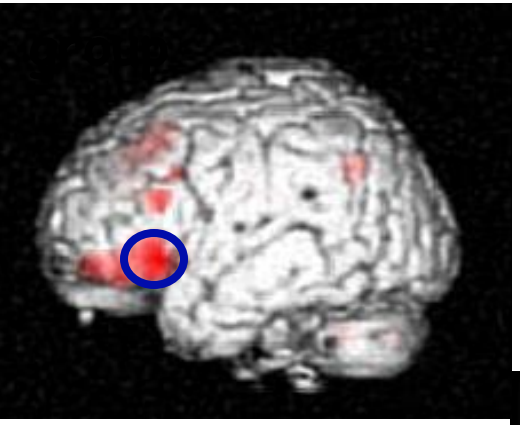
What fMRI Can't Do

What some would argue are shortcomings with fMRI

- Too low SNR vs subject/patient limits of compliance (about 2 hours)
- Requires motivated subjects/patients (motion sensitivity)
- Too low spatial resolution (each voxel has several million neurons)
- Any higher resolution than 3 mm^3 lost with subject averaging.
- Too low temporal resolution (hemodynamics are variable and sluggish)
- Too inconsistent activation patterns
- Anatomical images for fMRI are low quality (dropout/distortion)
- Requires a task (BOLD cannot look at baseline maps)
- Too confined space and high acoustic noise (environment non-optimal).
- Too many physiologic variables influence signal.

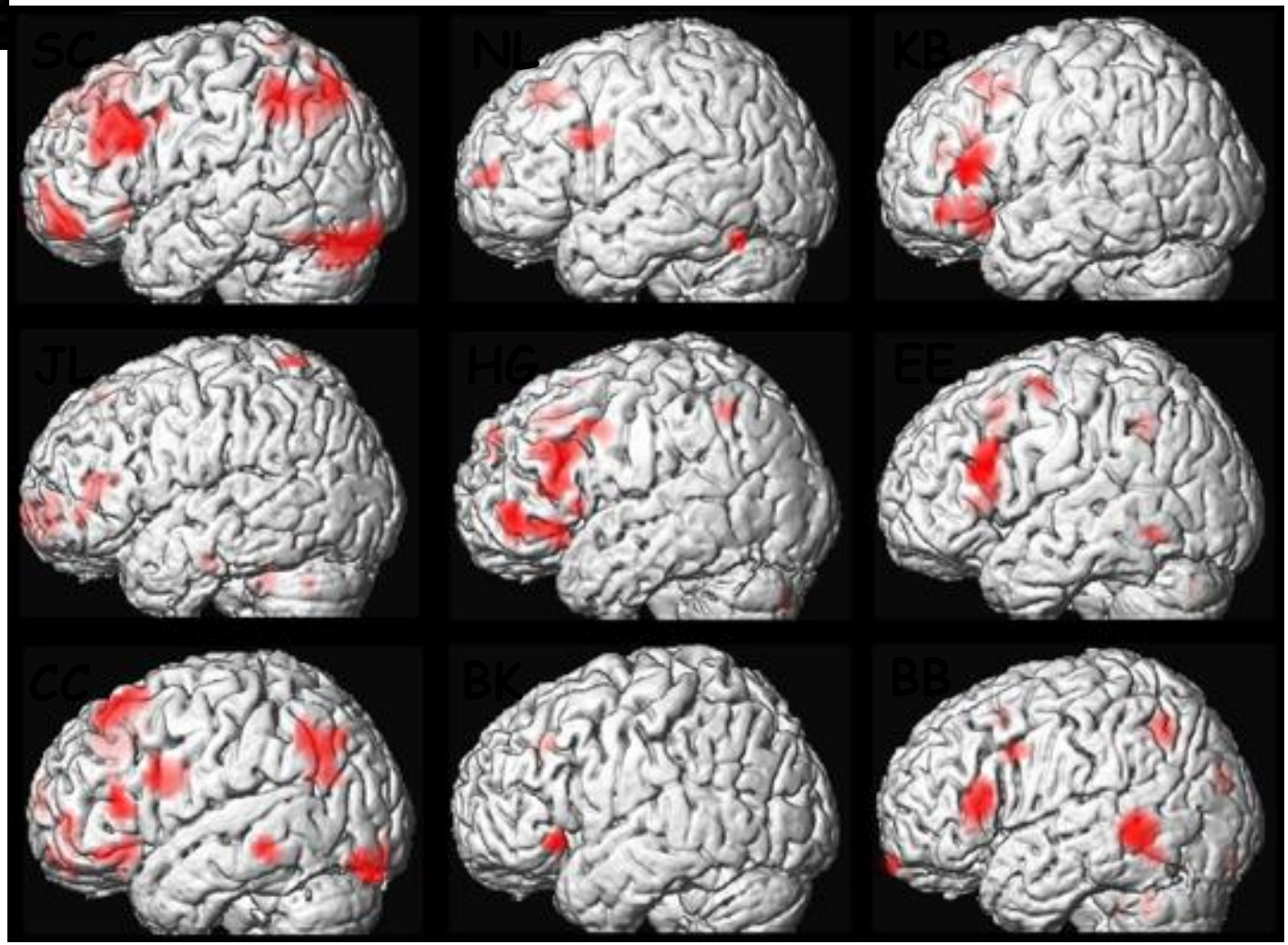
Altered neurovascular coupling: Pathology, drugs

Pathologic state / Drug	**Reference**
Carotid occlusion	Röther et al. 2002
Transient global ischemia	Schmitz et al. 1998
Penumbra of cerebral ischemia	Mies et al. 1993, Wolf et al. 1997
Subarachnoid hemorrhage	Dreier et al. 2000
Trauma	Richards et al. 2001
Epilepsy	Fink et al. 1996, Brühl et al. 1998, von Pannwitz et al. 2002
Alzheimer´s disease	Hock et al. 1996, Niwa et al. 2000
Theophylline	Ko et al. 1990, Dirnagl et al. 1994
Scopolamine	Tsukada et al. 1998

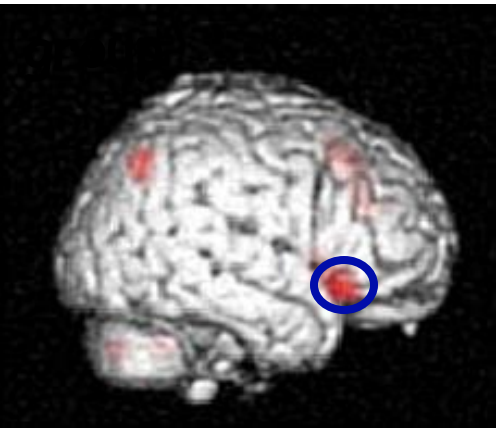


Individual Differences in Brain Activations During Episodic Retrieval Miller et al., 2002

Individual activations from the left hemisphere of the 9 subjects

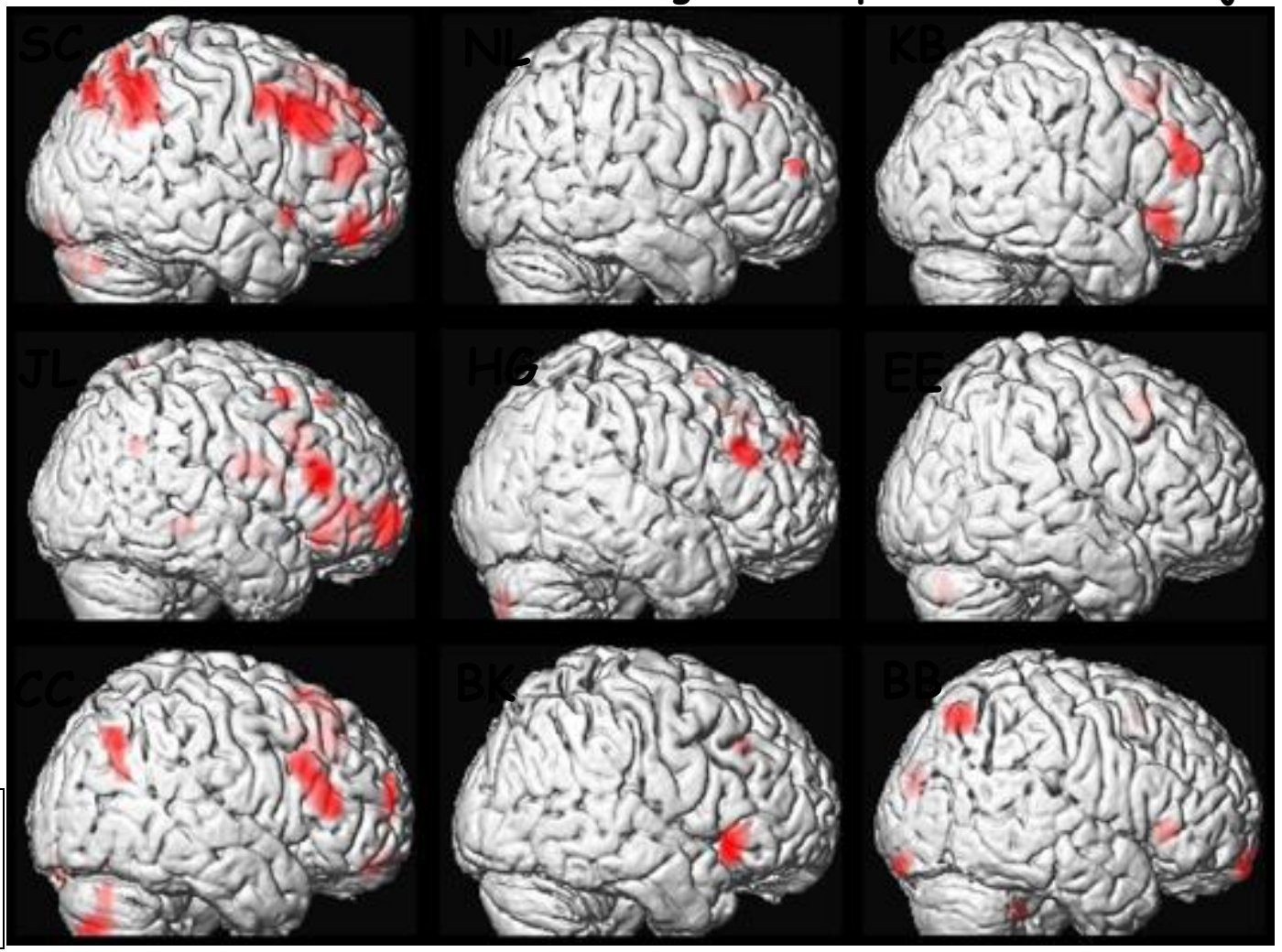


Courtesy, Mike Miler, UC Santa Barbara and Jack Van Horn, fMRI Data Center, Dartmouth University



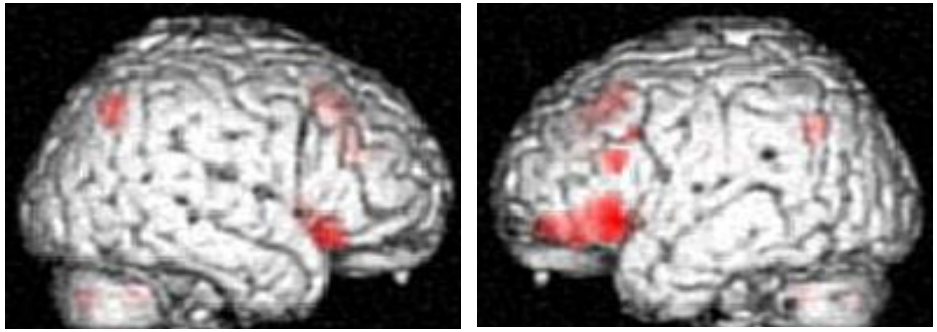
Individual Differences in Brain Activations During Episodic Retrieval Miller et al., 2002

Individual activations from the right hemisphere of the 9 subjects

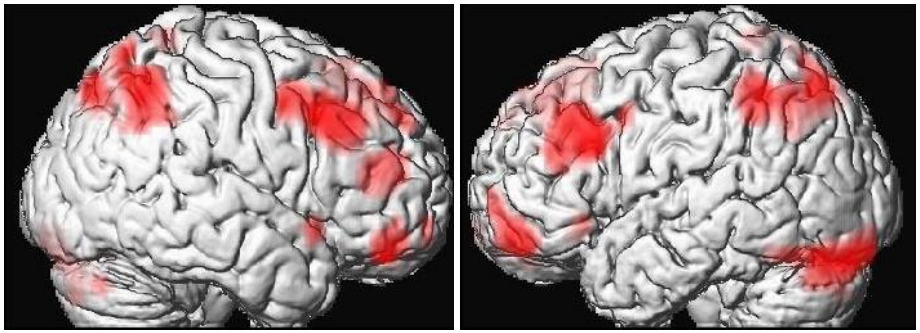


Courtesy, Mike Miler, UC Santa Barbara and Jack Van Horn, fMRI Data Center, Dartmouth University

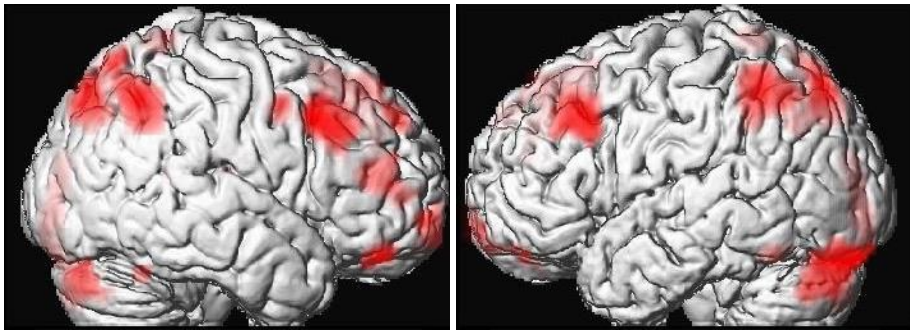
These individual patterns of activations are stable over time



Group Analysis of Episodic Retrieval



Subject SC



Subject SC 6 months later

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

Four Aspects of fMRI Advancement:

Increased sensitivity and resolution

Understanding and characterization of variability and noise….then classification or calibration

Develop more sophisticated paradigms/processing methods

More than just "mapping"

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 (fMRIa…)

Fluctuations
Dynamics
Spatial patterns

Interpretation

Basic Neuroscience
Behavior correlation/prediction
Pathology assessment

Applications

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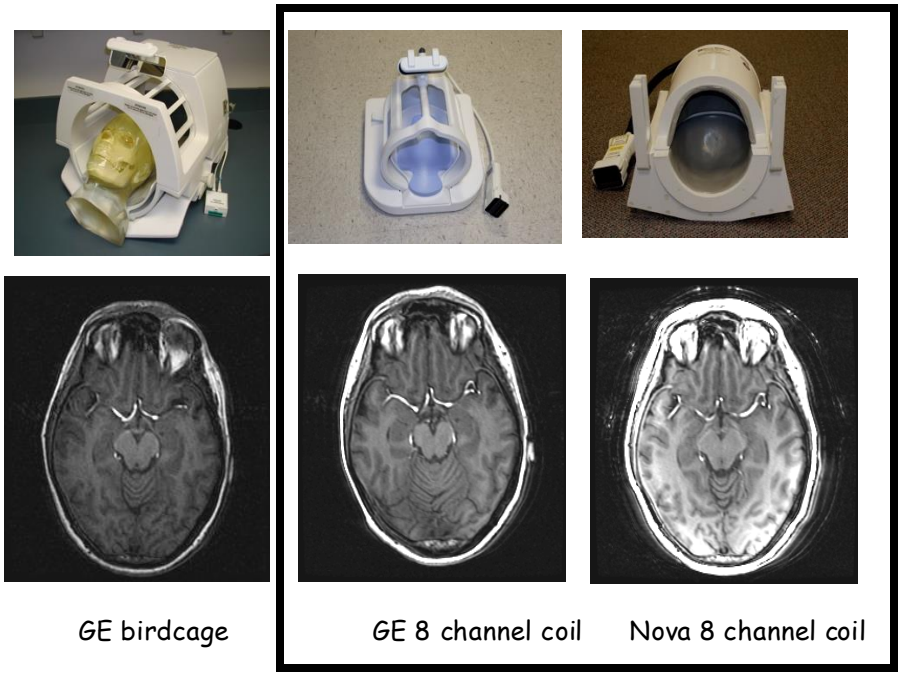
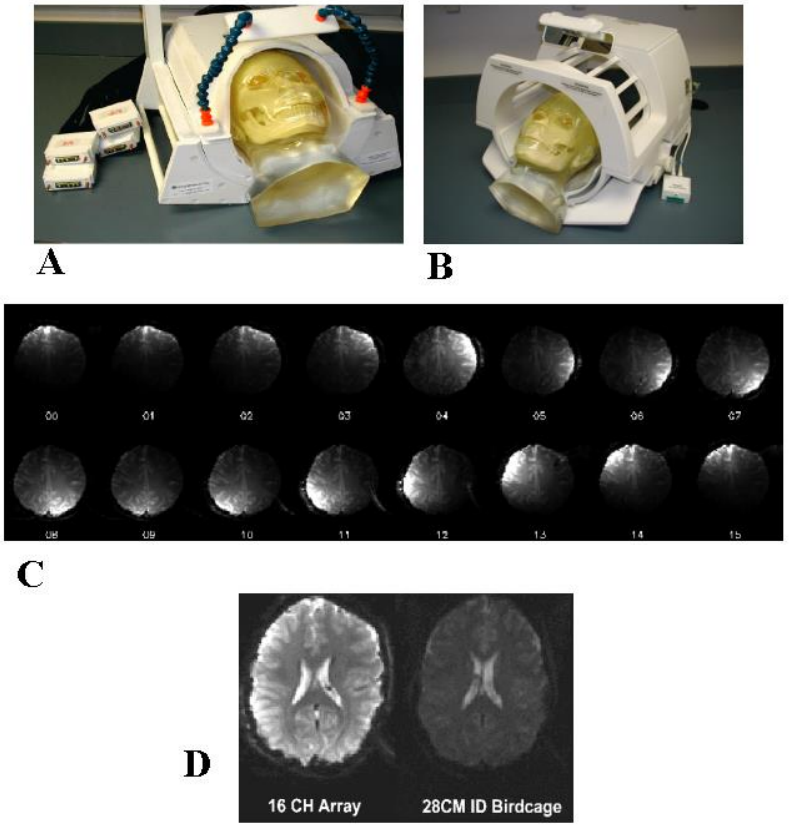
Technology

8 channel parallel receiver coil



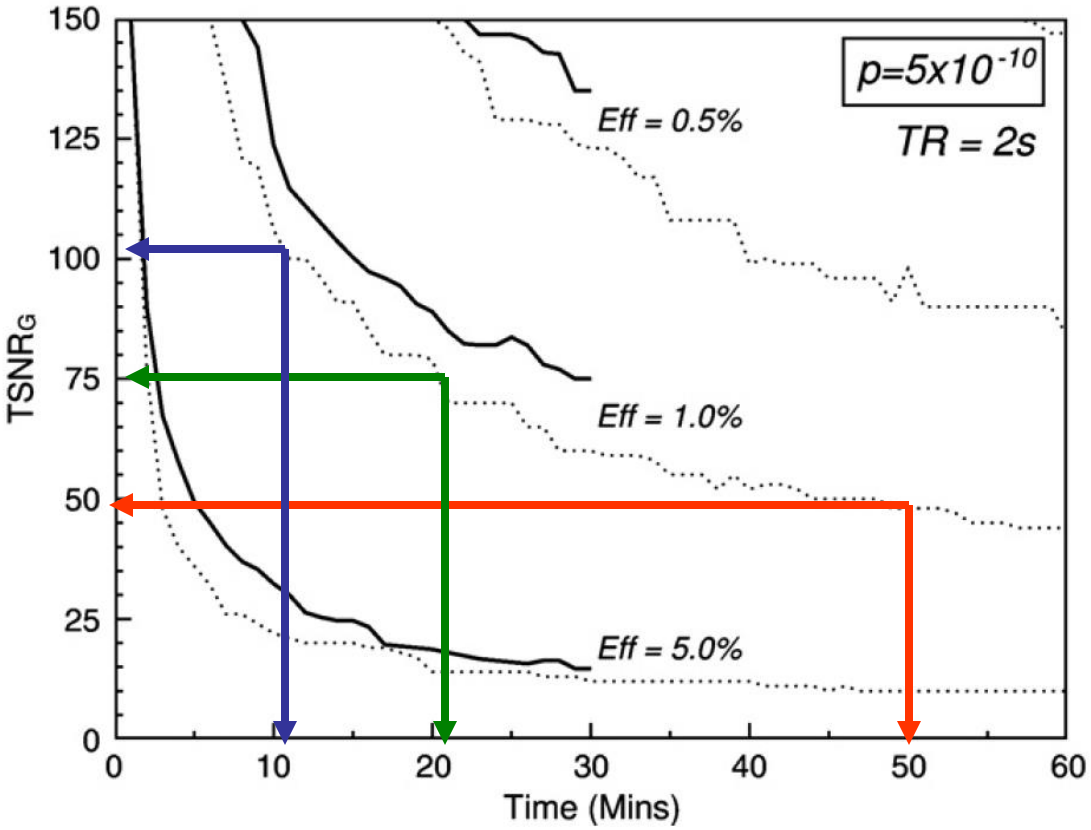
GE birdcage | GE 8 channel coil | Nova 8 channel coil

16 channel parallel receiver coil



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

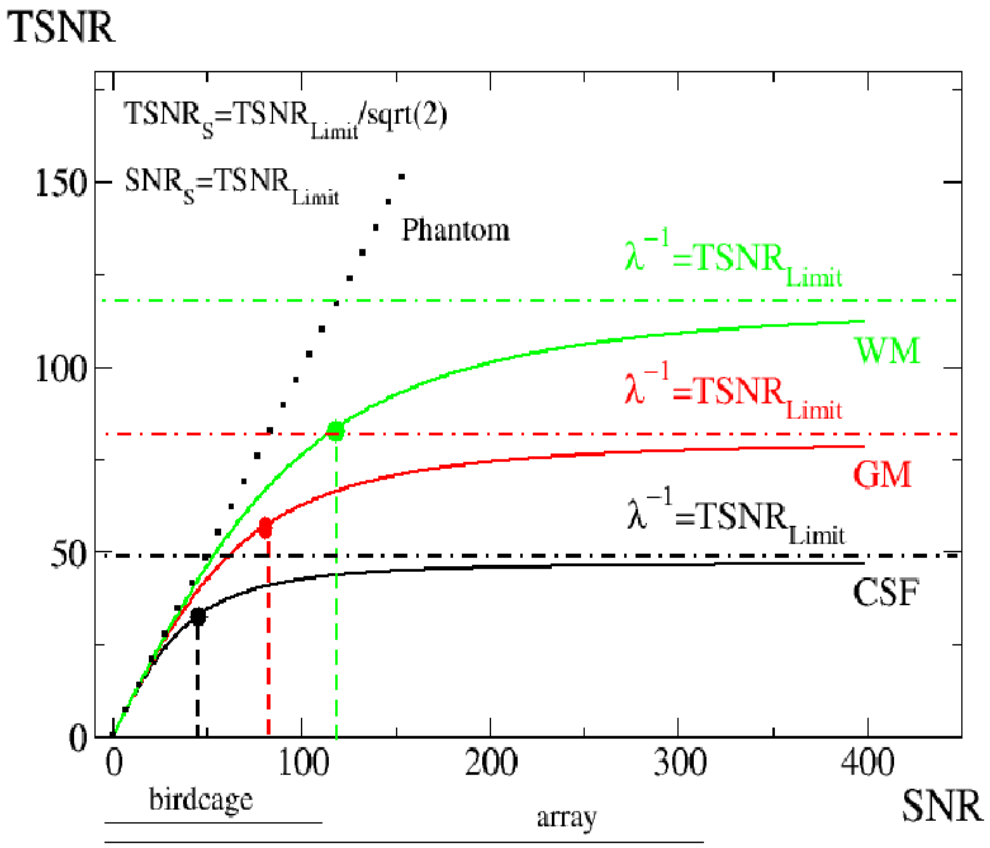
Technology



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)

Technology

Temporal Signal to Noise Ratio (TSNR) vs. Signal to Noise Ratio (SNR)

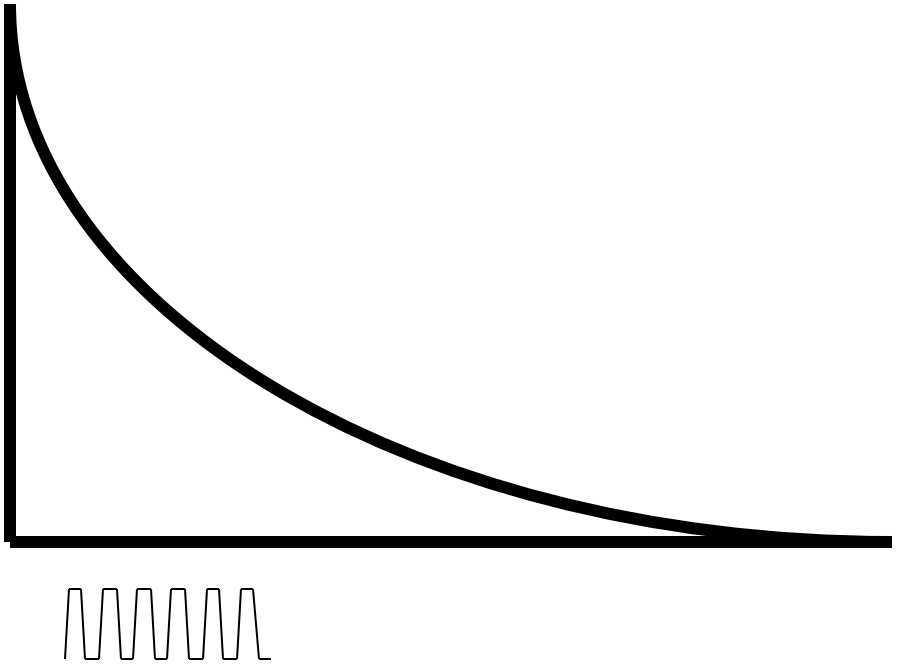


suggested voxel volume

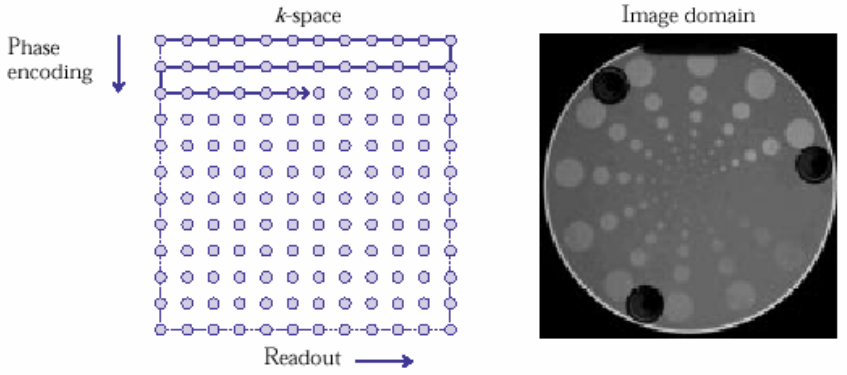
3T, birdcage:	2.5 mm^3
3T, 16 channel:	1.8 mm^3
7T, 16 channel:	1.4 mm^3

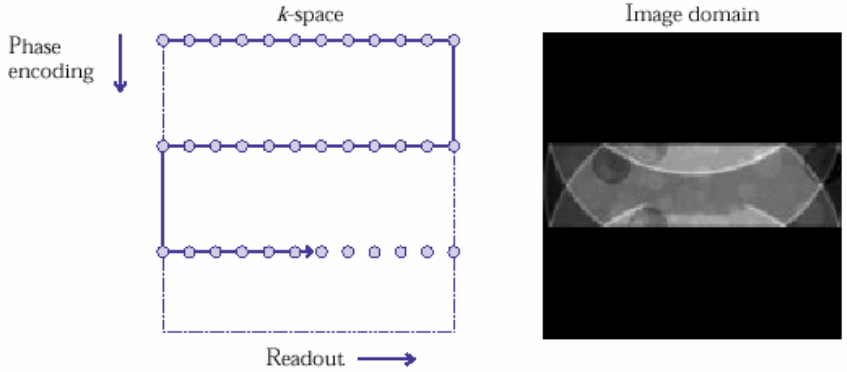
J. Bodurka, F. Ye, N Petridou, K. Murphy, P. A. Bandettini, *NeuroImage*, 34, 542-549 (2007)

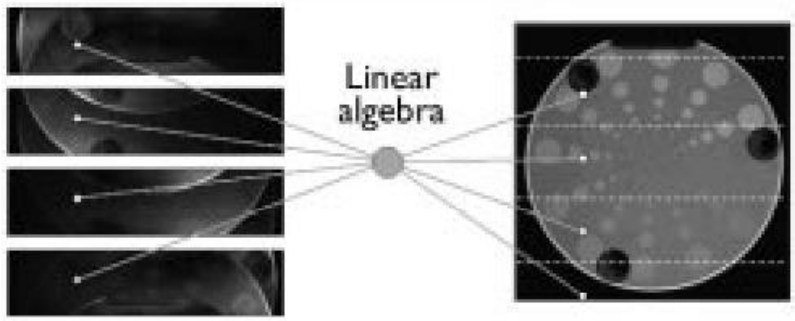
Technology



≈ 5 to 30 ms

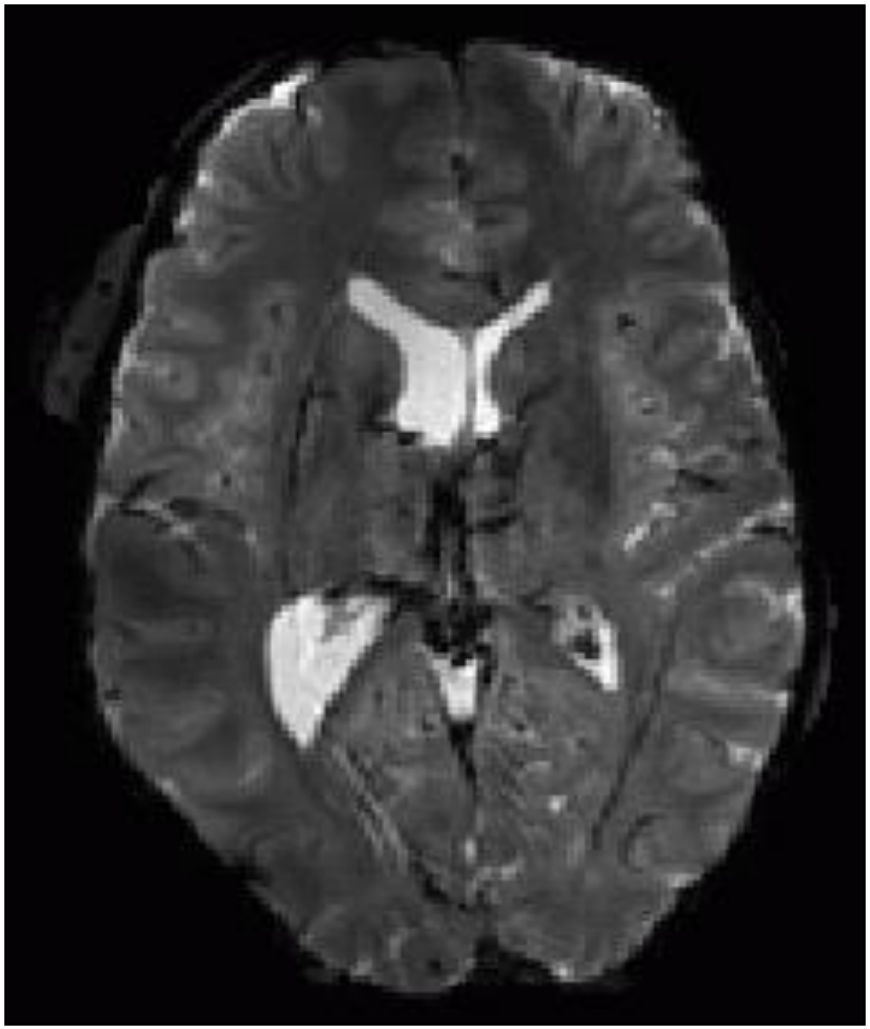






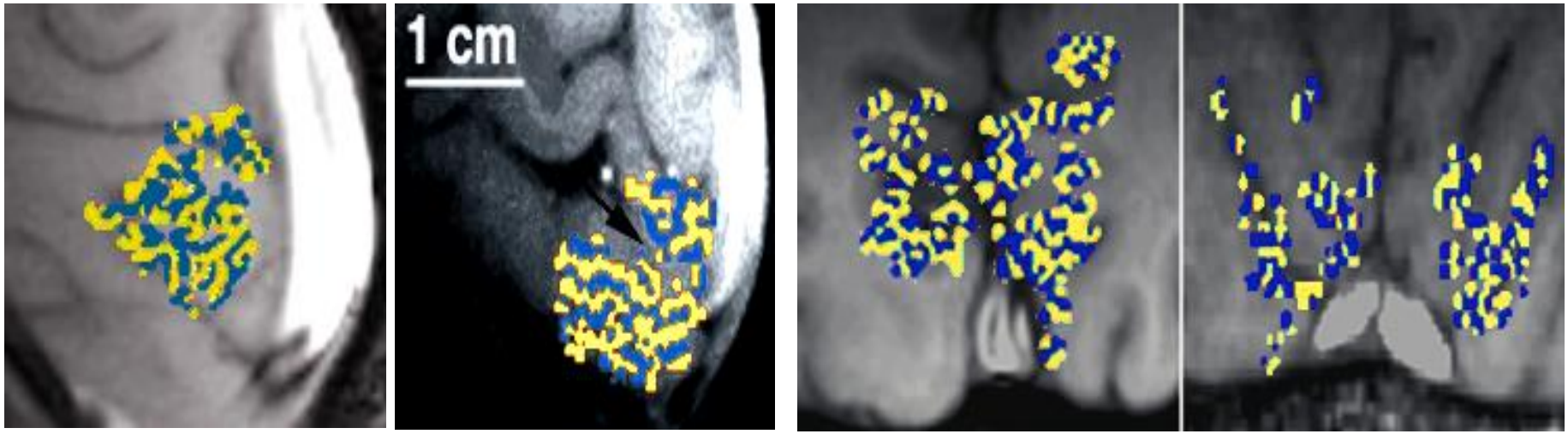
Pruessmann, et al.

Technology

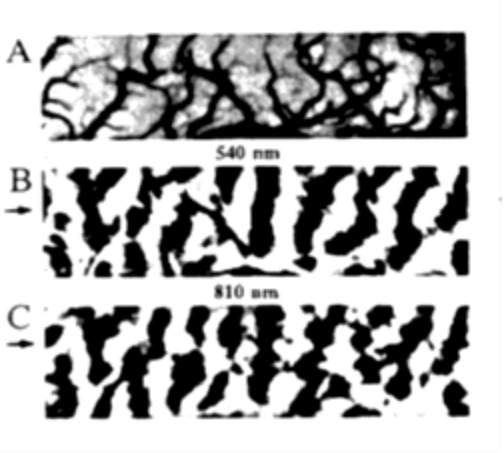


3T single-shot SENSE EPI using 16 channels: 1.25x1.25x2mm

Ocular Dominance Column Mapping using fMRI



Menon, R. S., S. Ogawa, et al. (1997). "Ocular dominance in human V1 demonstrated by functional magnetic resonance imaging." J Neurophysiol 77(5): 2780-7.

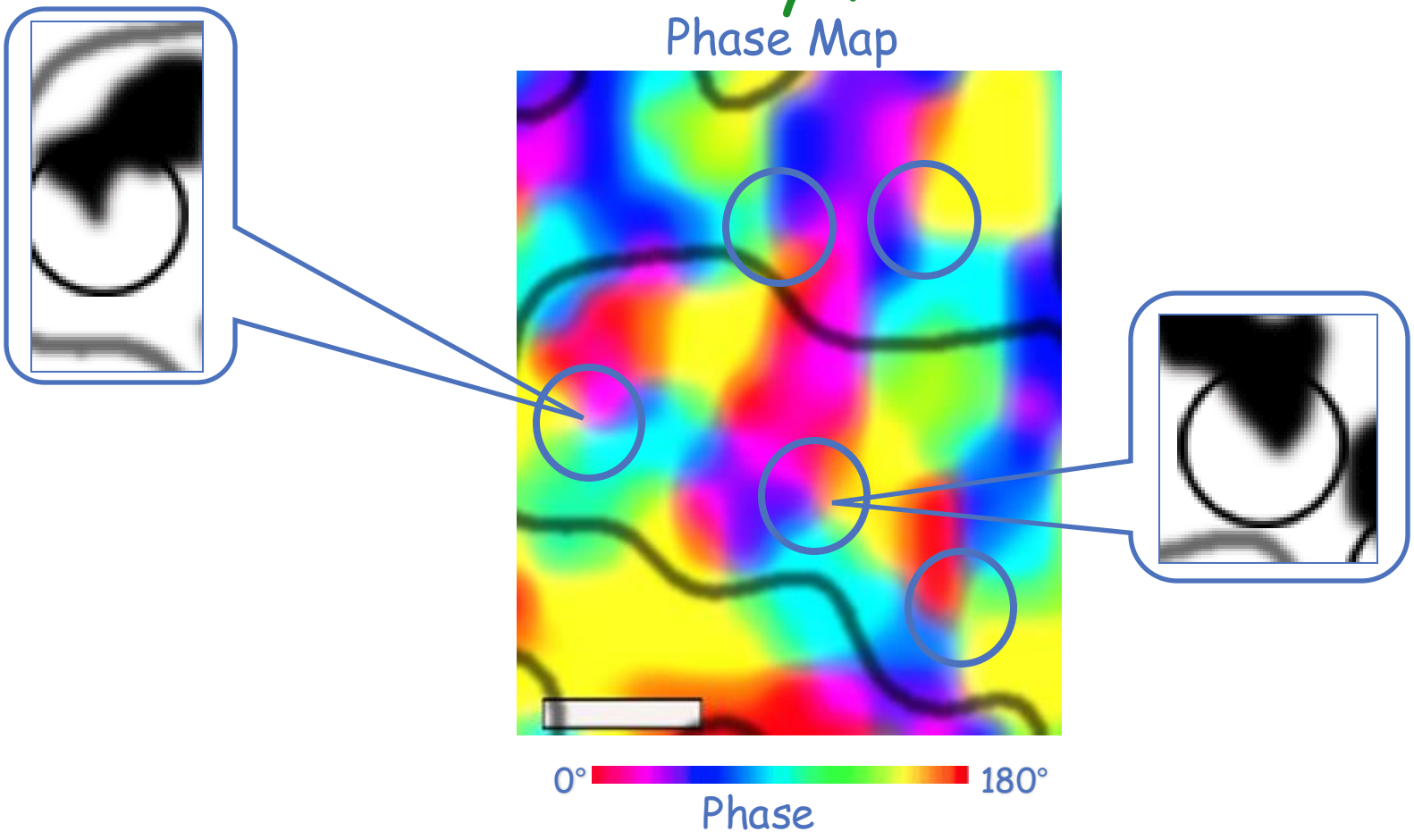


Optical Imaging

R. D. Frostig et. al, PNAS 87: 6082-6086, (1990).

Technology

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



Yacoub, Ugurbil & Harel

Scale bar = 0.5 mm

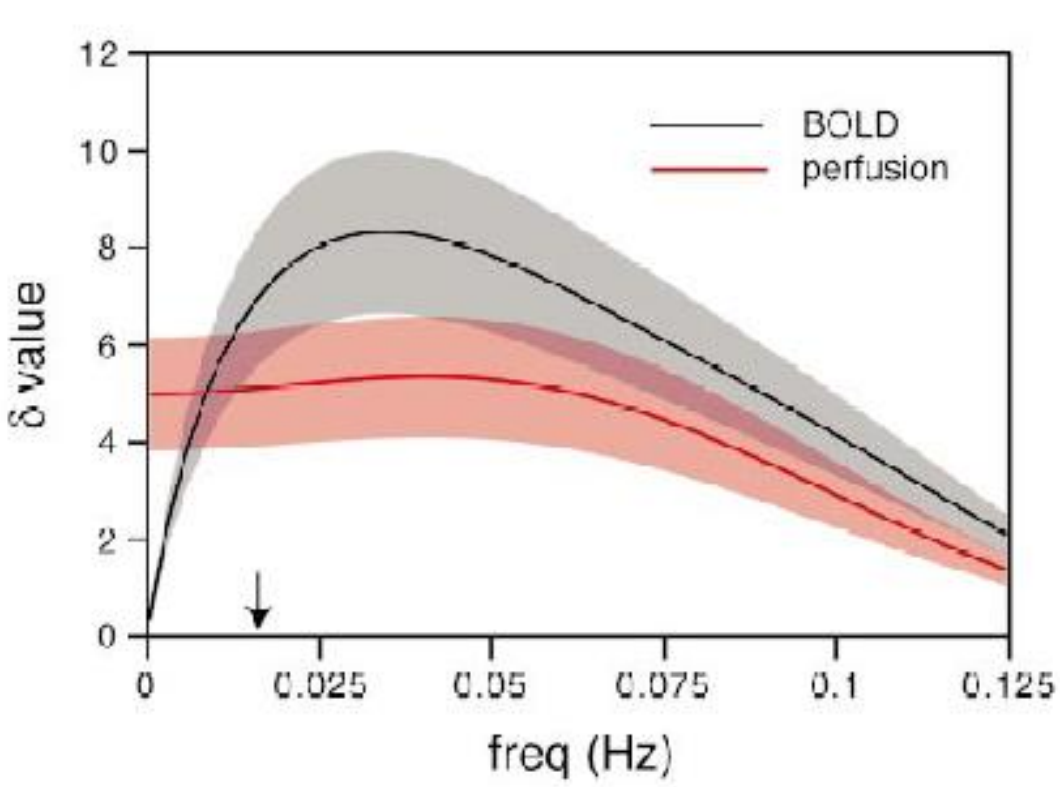
fMRI Contrast

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

Technology

Perfusion (ASL)

Better than BOLD for long duration activation…



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

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 (fMRIa…)

Fluctuations
Dynamics
Spatial patterns

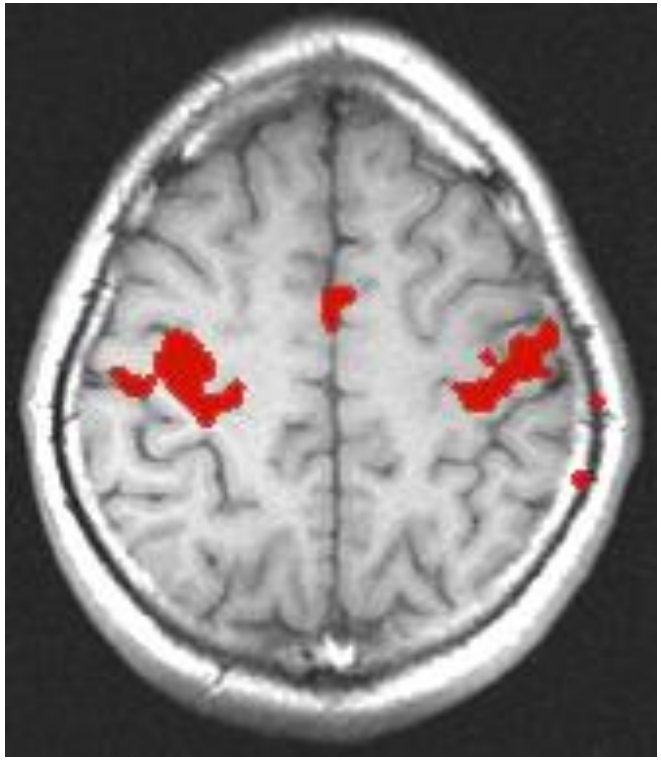
Interpretation

Basic Neuroscience
Behavior correlation/prediction
Pathology assessment

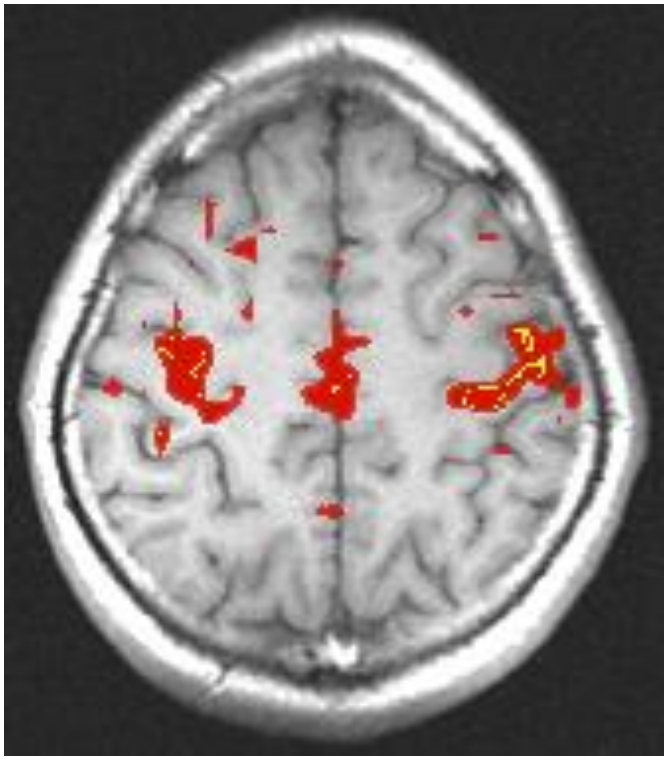
Applications

Methodology

Resting State Correlations



Activation:
correlation with reference function



Rest:
seed voxel in motor cortex

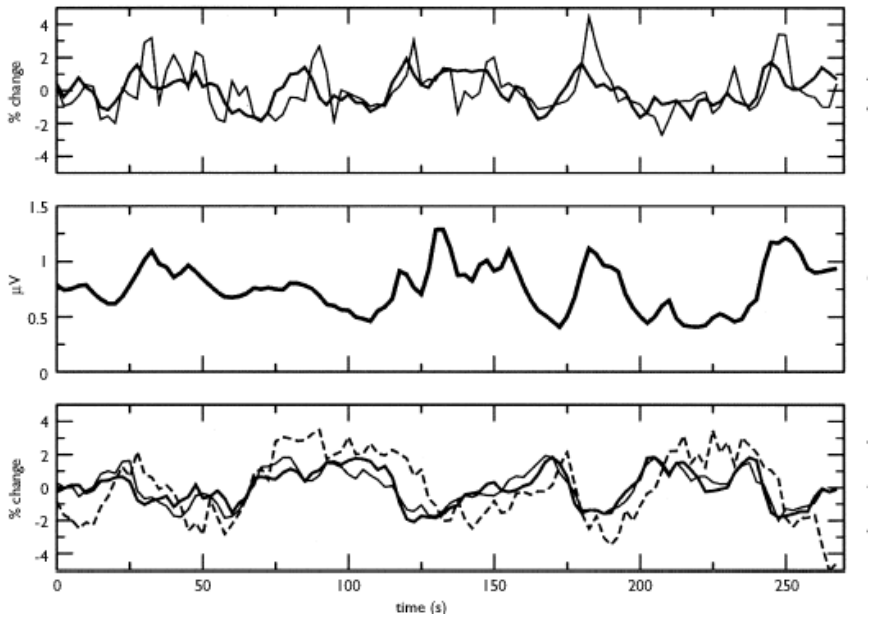
B. Biswal *et al.*, MRM, 34:537 (1995)

BOLD correlated with 10 Hz power during "Rest"

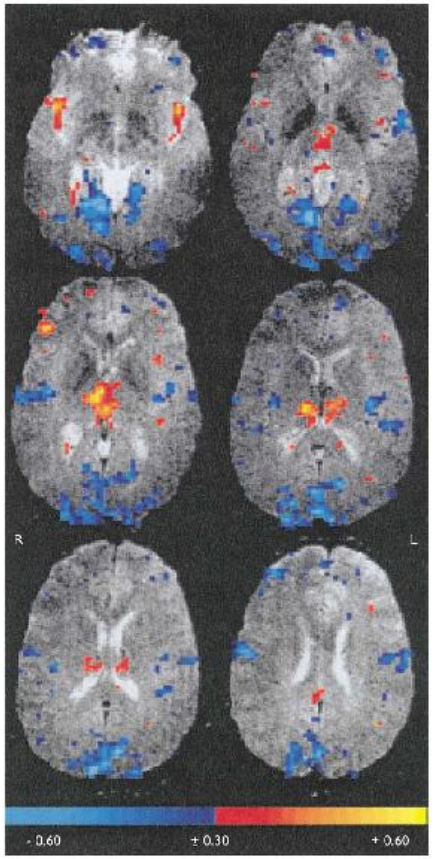
Positive

10 Hz power

Negative



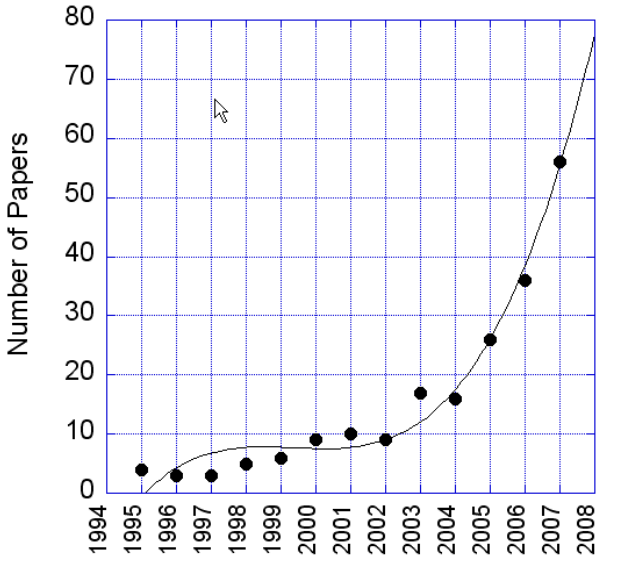
Goldman, et al (2002), Neuroreport

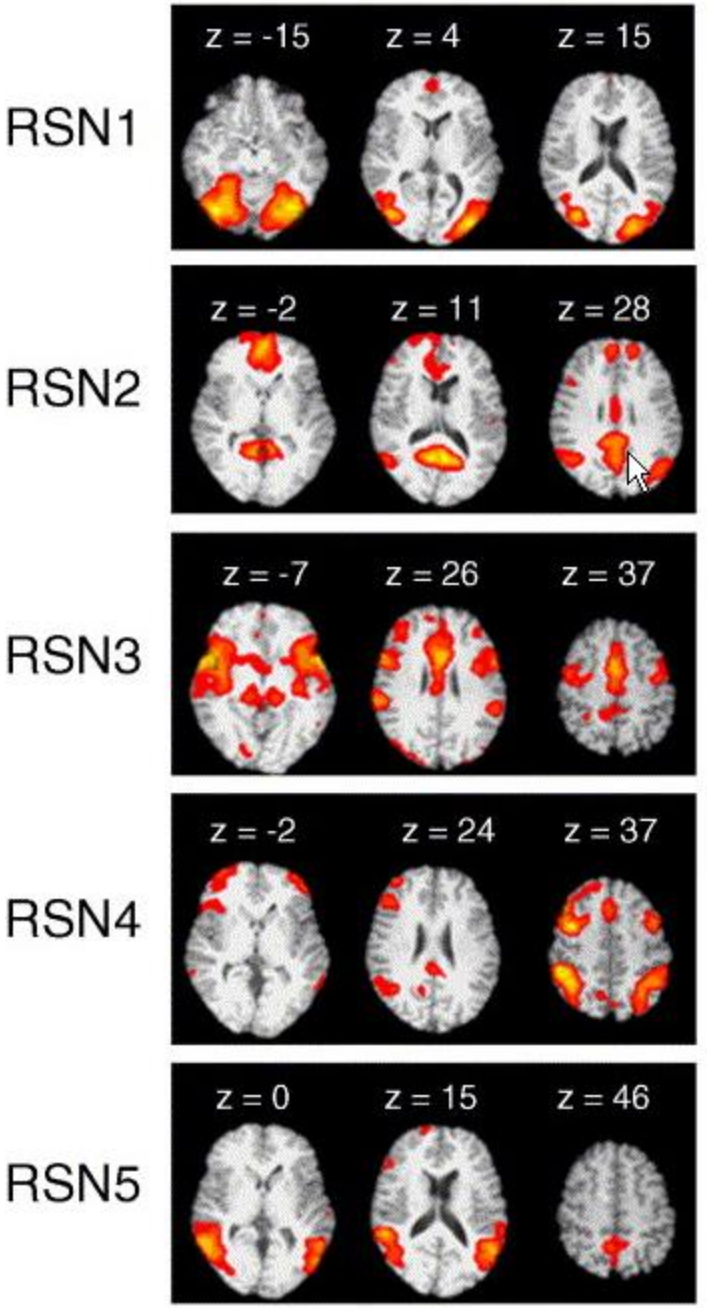


Methodology

Resting state networks identified with ICA

M. DeLuca, C.F. Beckmann, N. De Stefano, P.M. Matthews, S.M. Smith, fMRI resting state networks define distinct modes of long-distance interactions in the human brain. NeuroImage, 29, 1359-1367



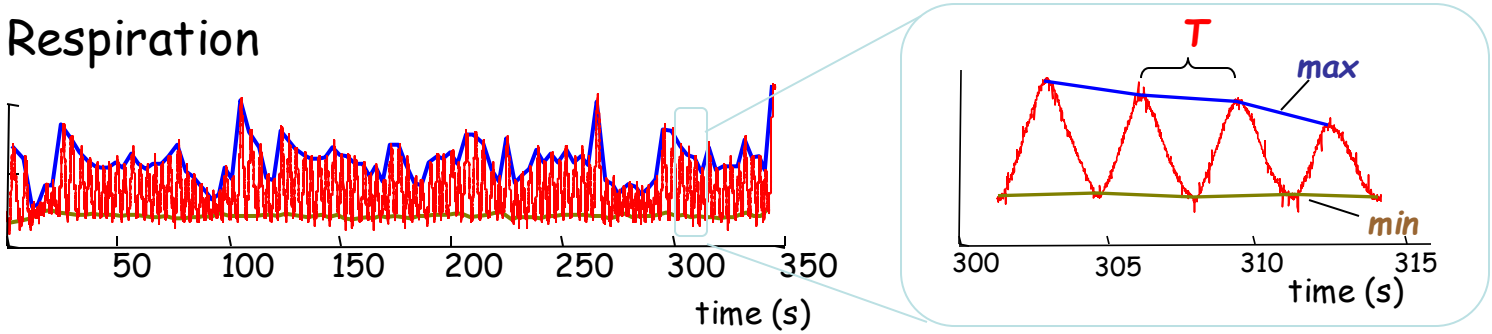


Interpretation

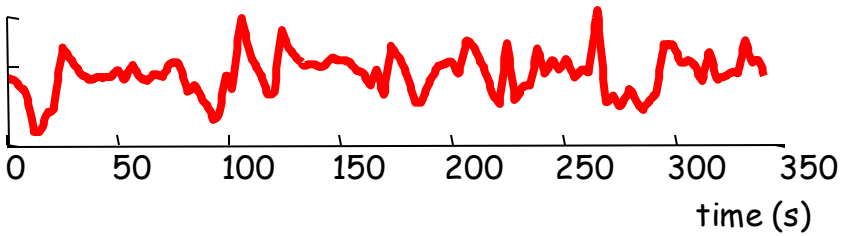
Sources of time series fluctuations:

- Blood, brain and CSF pulsation
- Vasomotion
- Breathing cycle (B_0 shifts with lung expansion)
- Bulk motion
- Scanner instabilities
- Changes in blood CO_2 (changes in breathing)
- Spontaneous neuronal activity

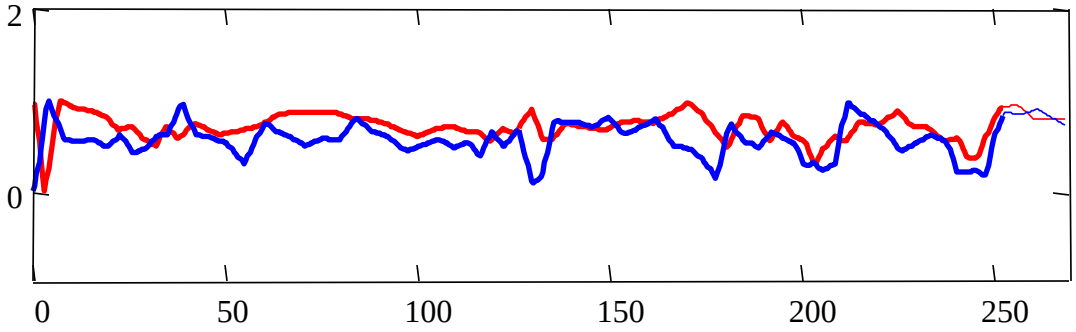
Estimating respiration volume changes



Respiration Volume / Time (**RVT**)

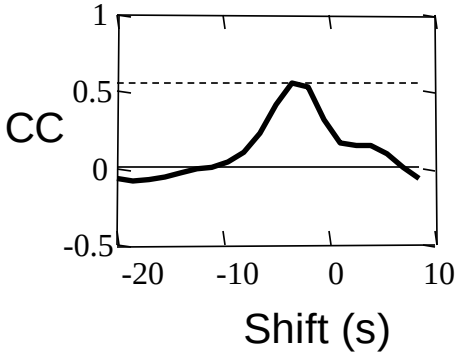


$$RVT = \frac{max - min}{T}$$



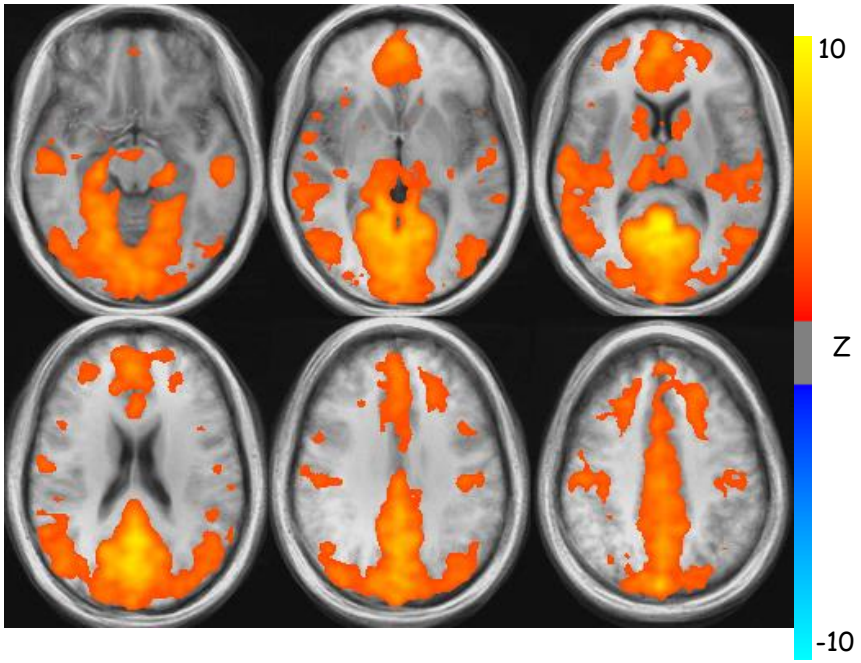
– CO_2

– RVT

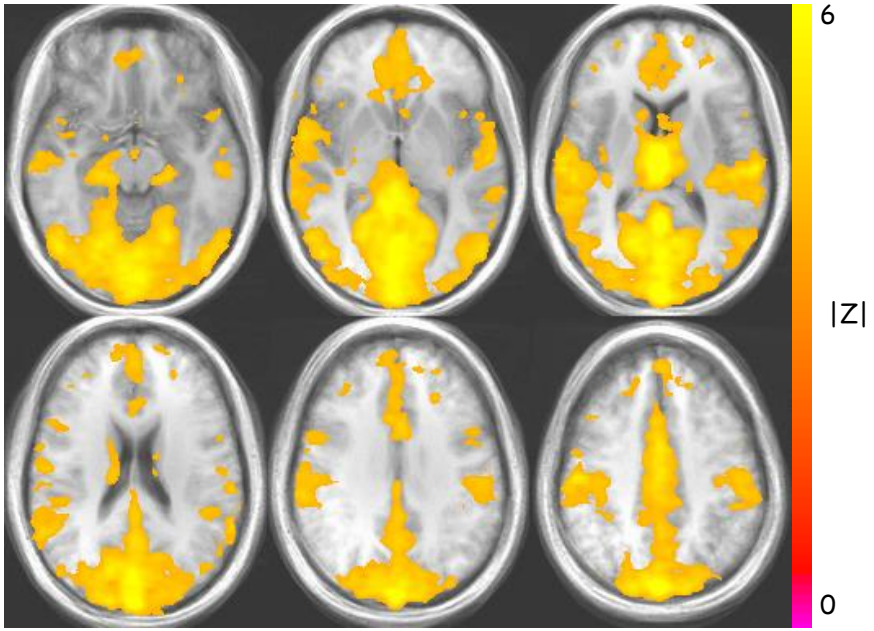


RVT precedes end tidal CO_2 by 5 sec.

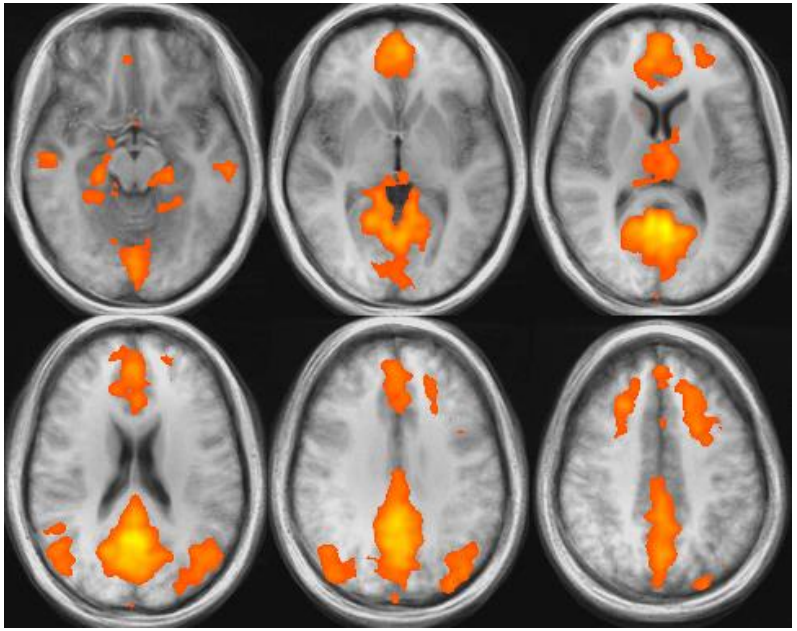
Resting state correlation with RVT signal



Resting state correlation with
signal from posterior cingulate



Resting state correlation with
signal from posterior cingulate… constant respiration



R.M. Birn, J. A. Diamond, M. A. Smith, P. A. Bandettini, *NeuroImage*, 31, 1536-1548

Methodology

Beyond Mapping

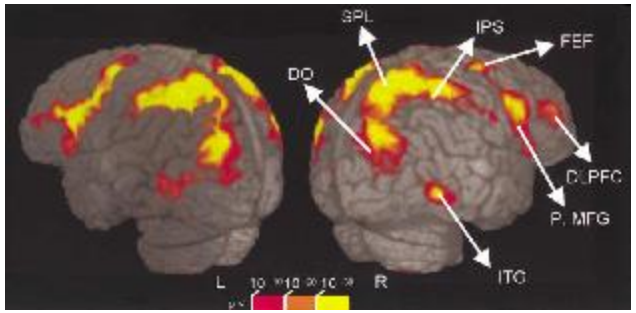
Mapping ⟷ "Reading"

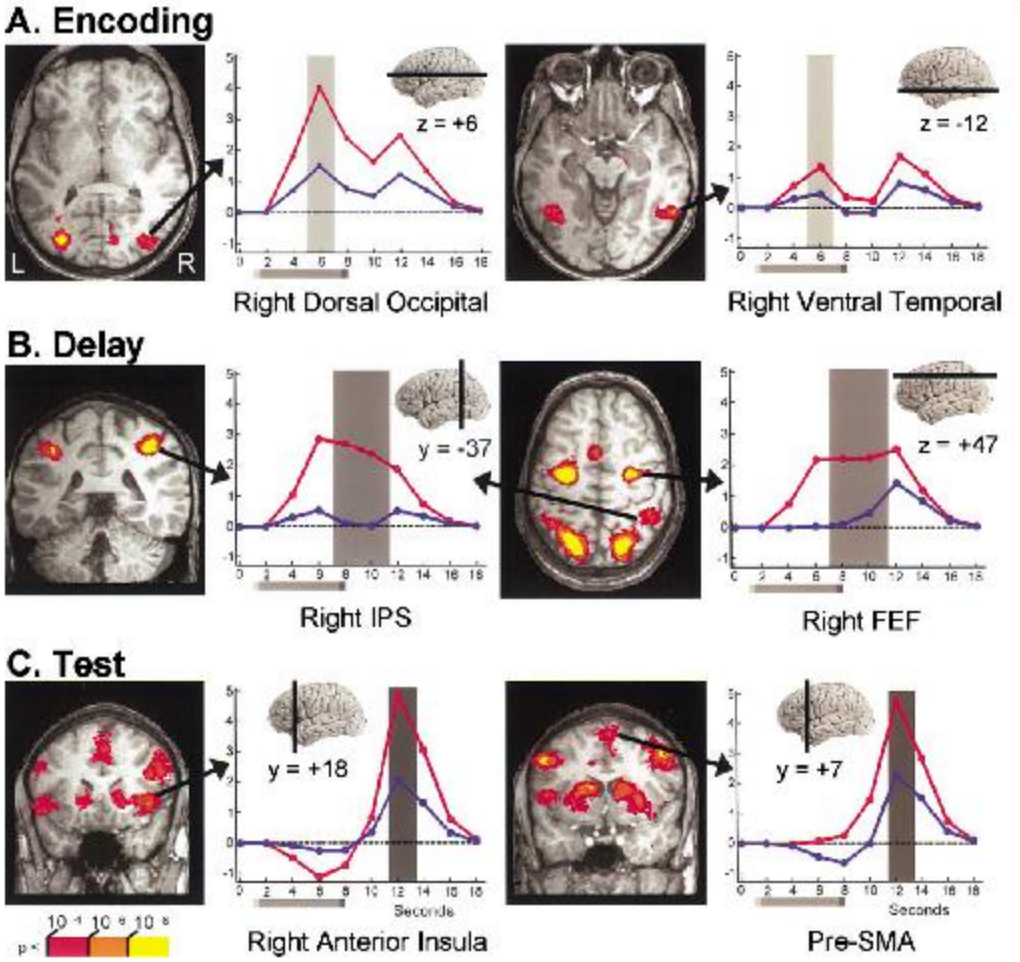
Methodology

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

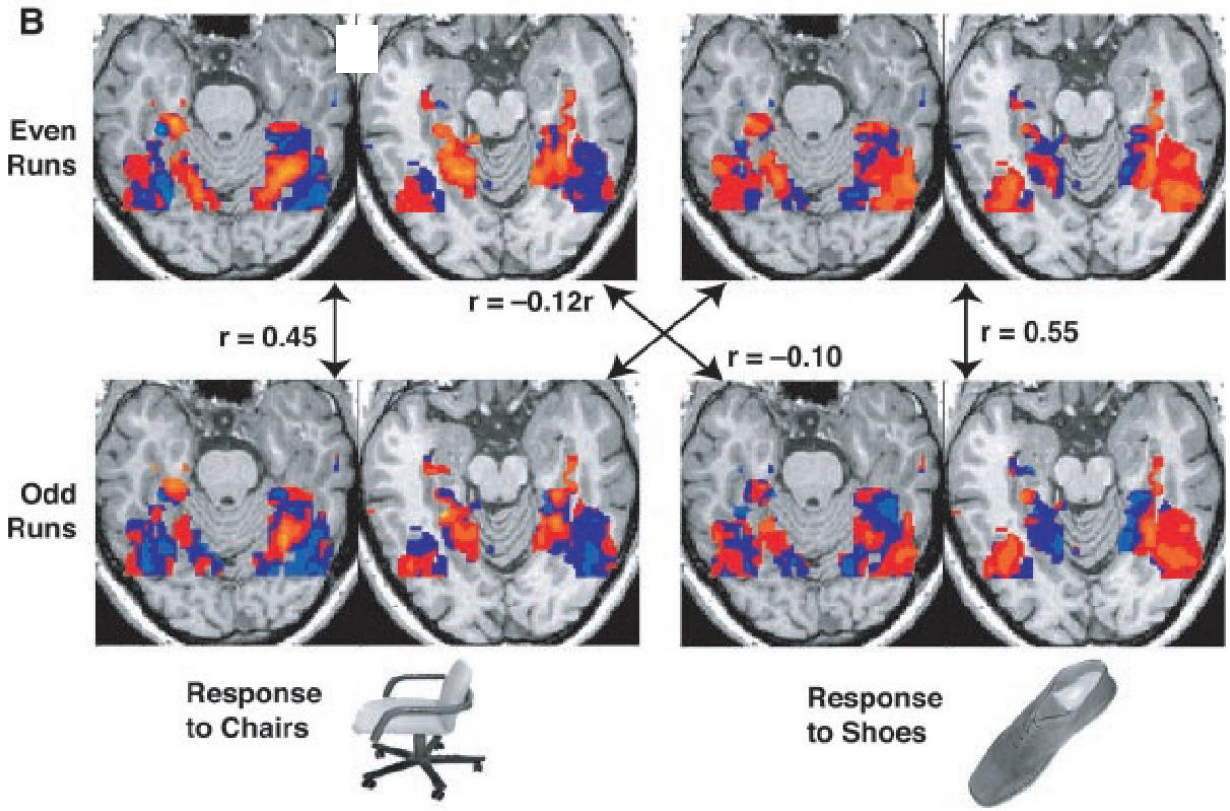




Methodology

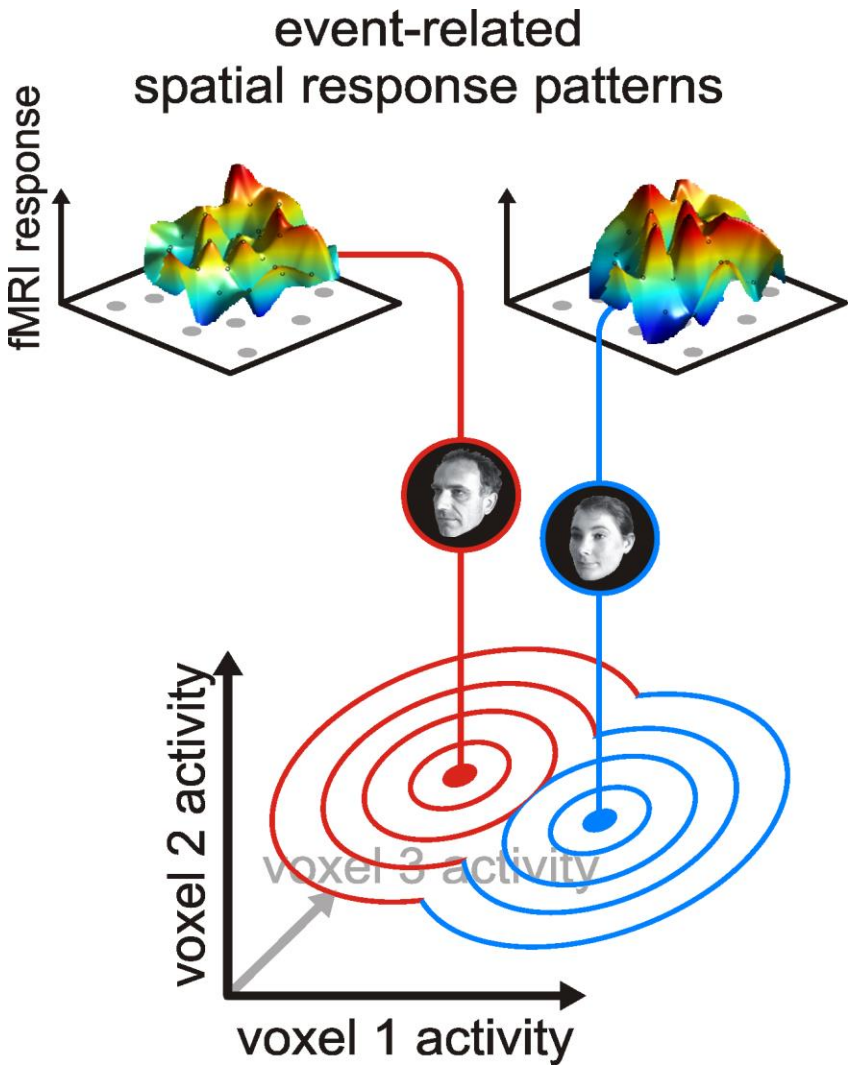
Ventral temporal category representations

Object categories are associated with distributed representations in ventral temporal cortex

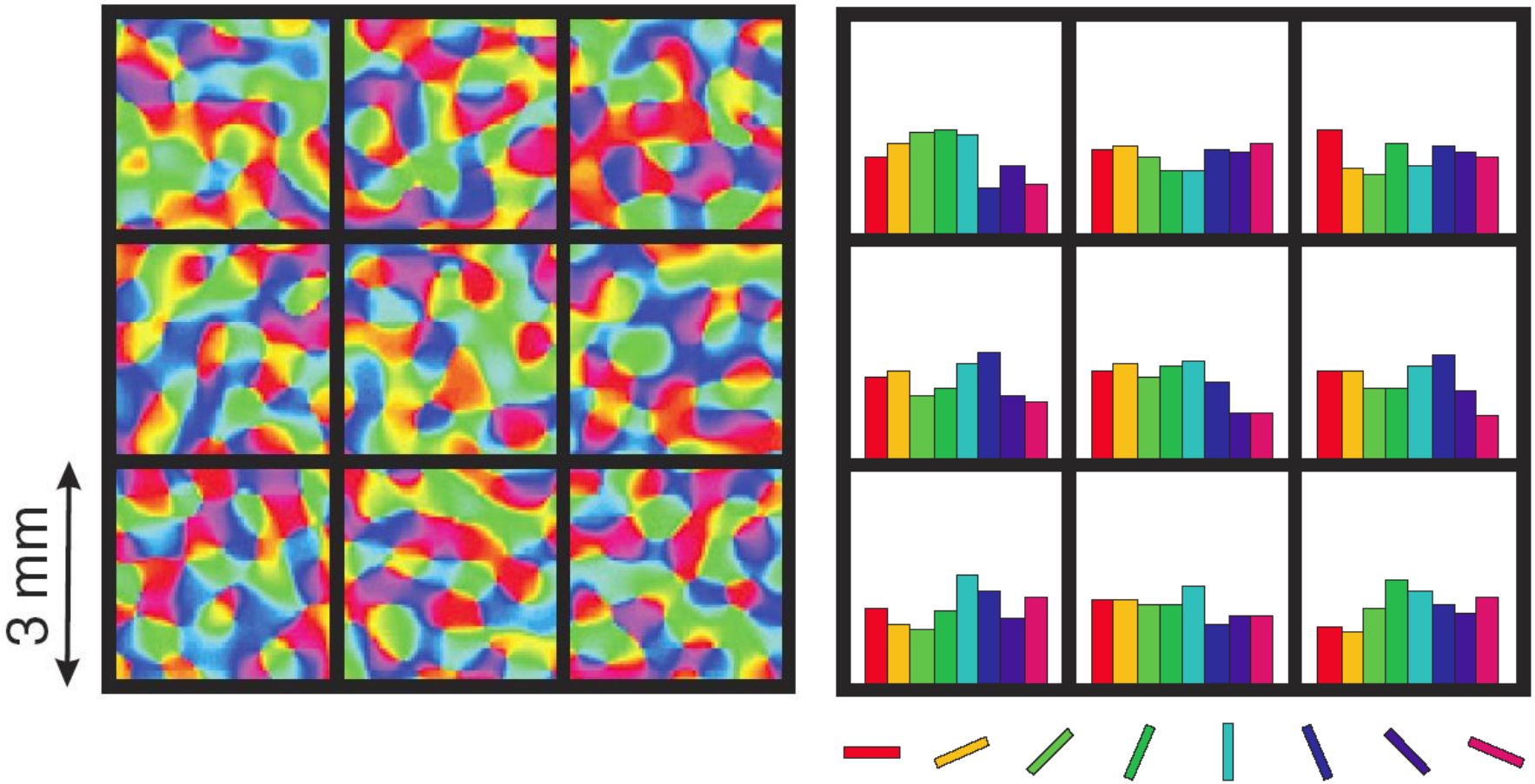


Haxby et al. 2001

Pattern Information Mapping



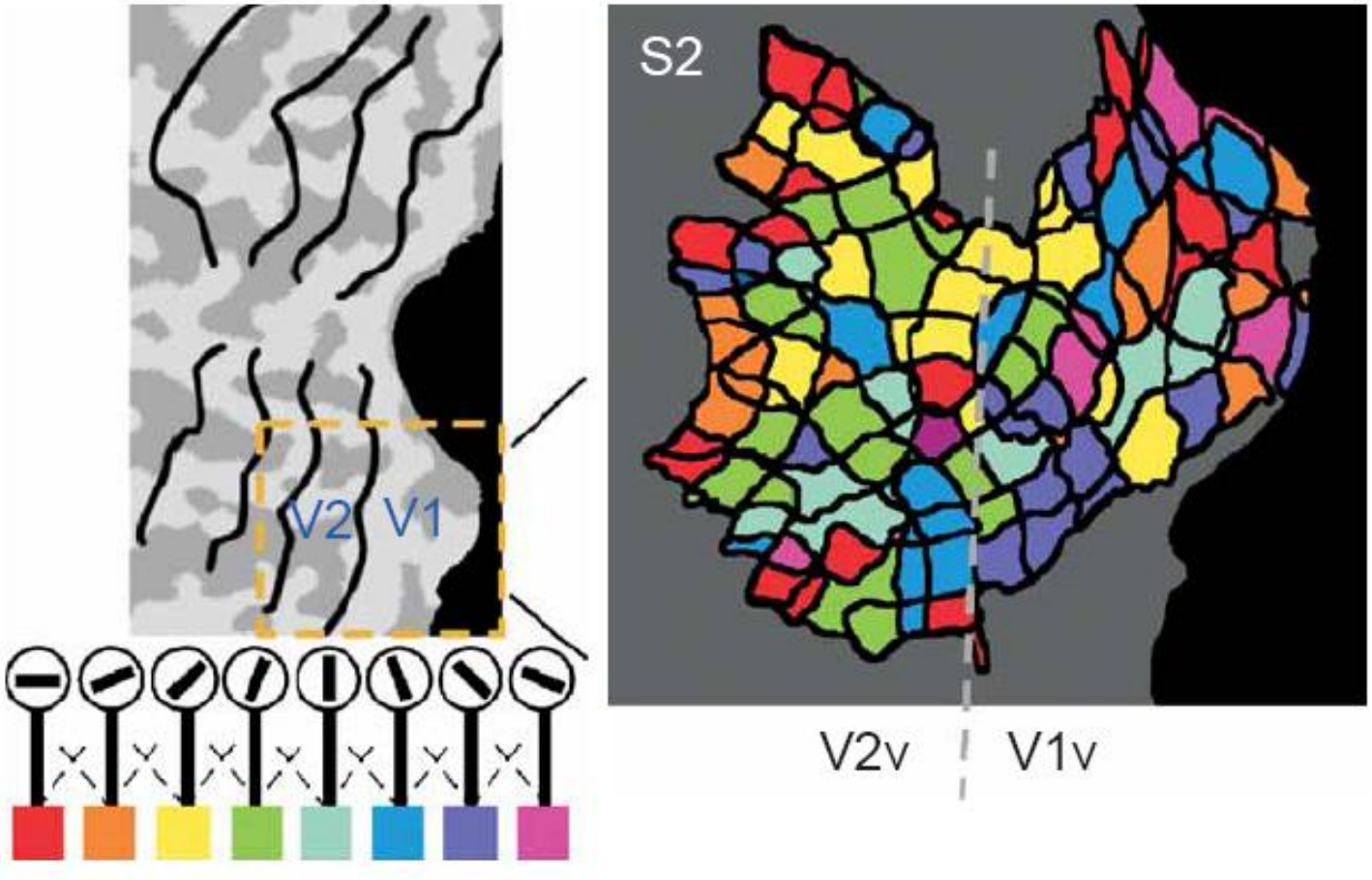
Methodology



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

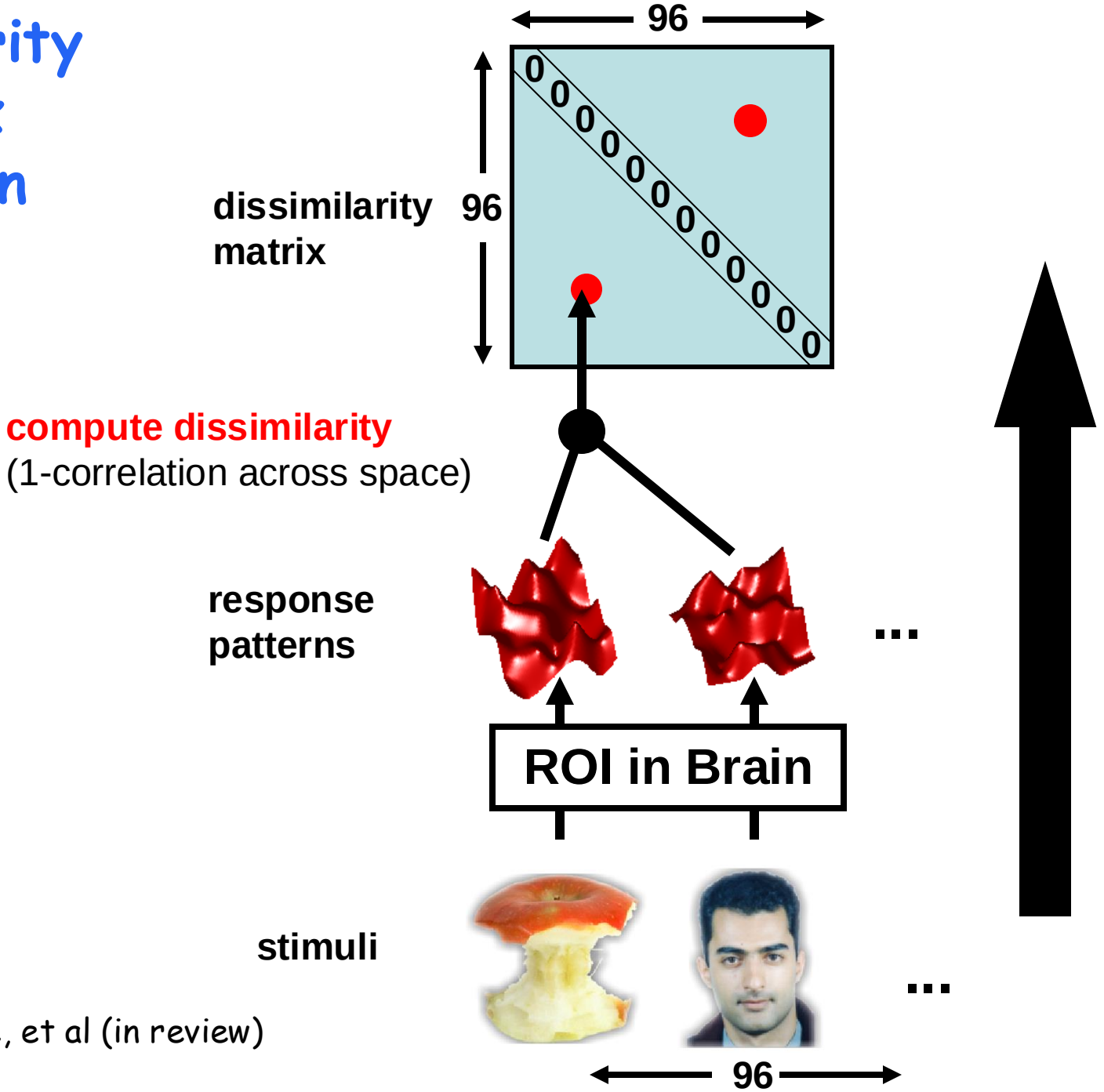
Methodology

Lower spatial frequency clumping



Kamitani & Tong (2005)

Dissimilarity Matrix Creation

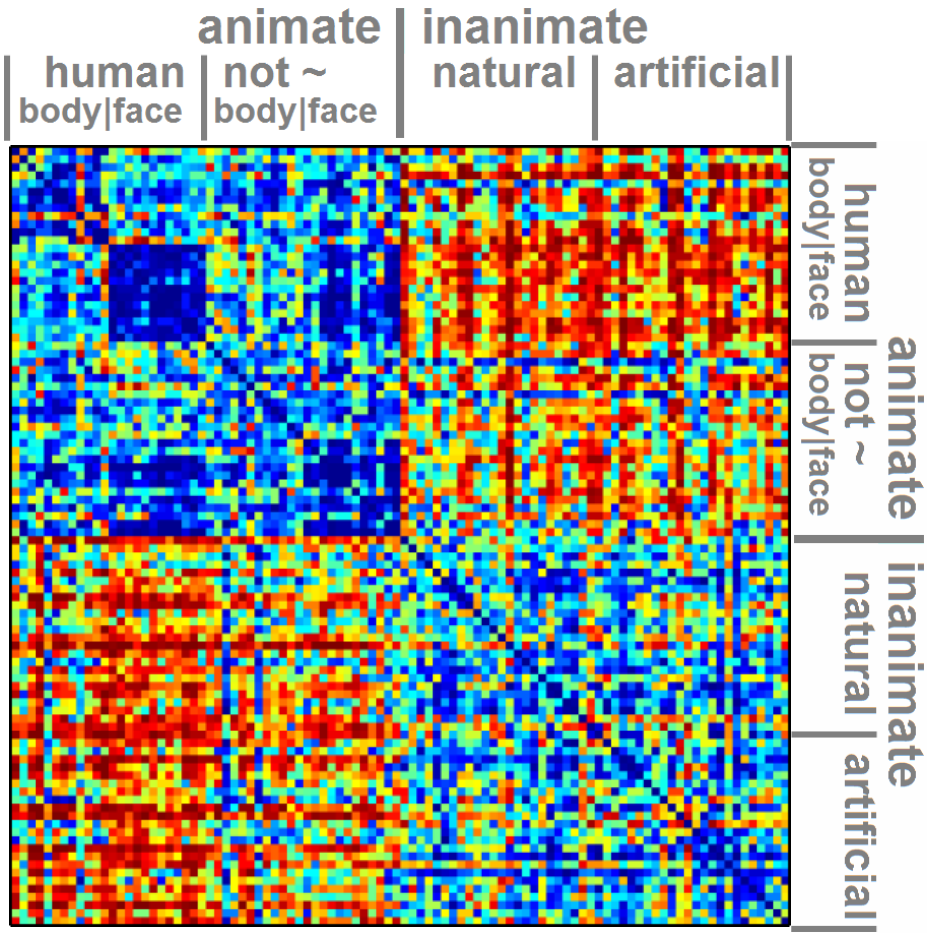


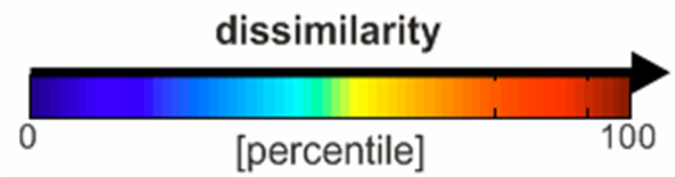
N. Kriegeskorte, et al (in review)

Visual Stimuli

Human IT

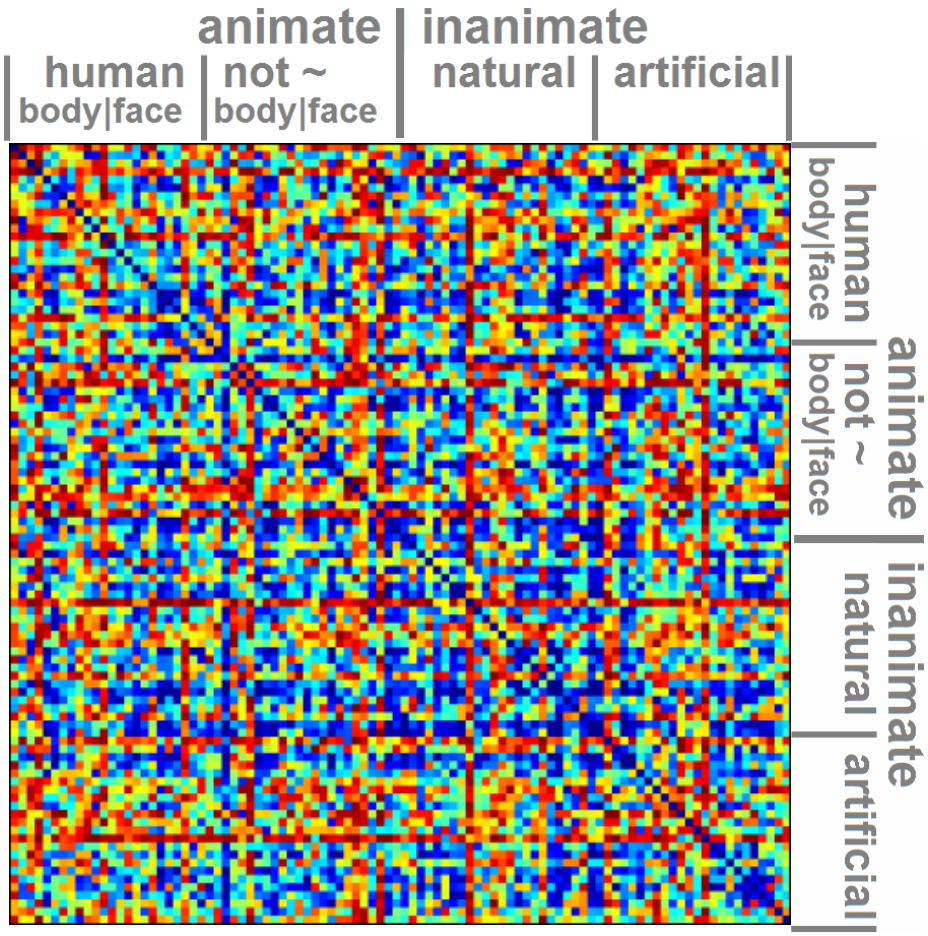
(1000 visually most responsive voxels)





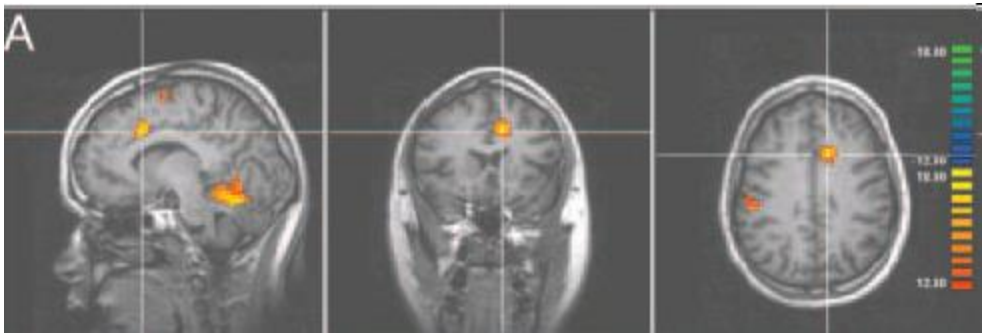
Human Early Visual Cortex

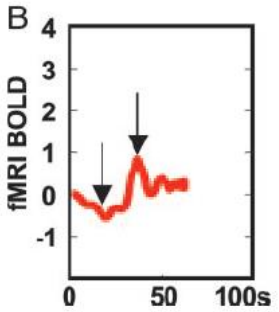
(1057 visually most responsive voxels)

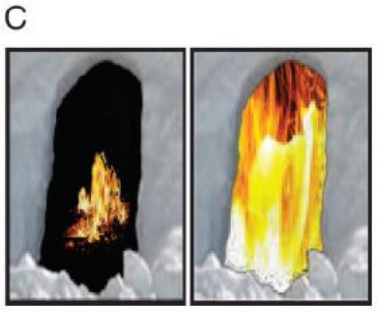


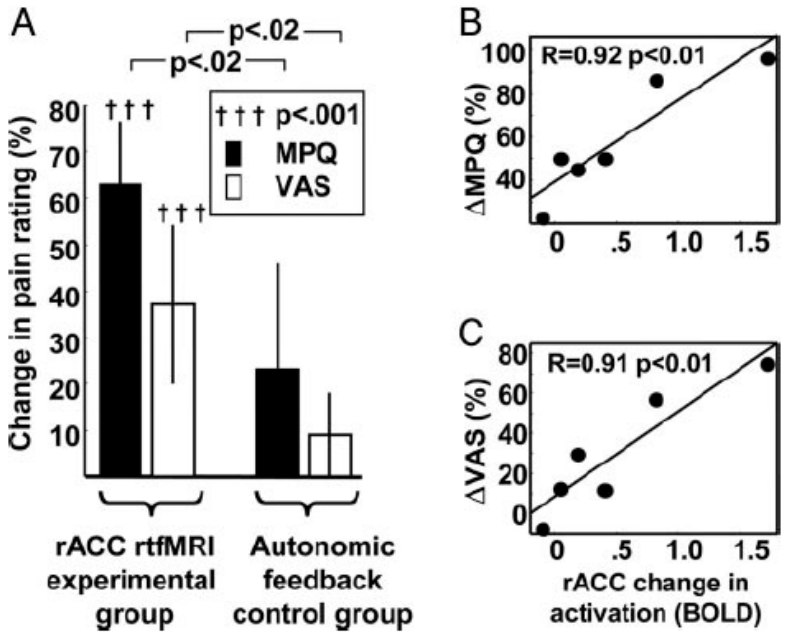
Applications

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)

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, fMRI-adaptation, 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 - calibration, 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.

What fMRI Might Do

Complementary use for clinical use

-usage of clinical research findings for more effective diagnoses, prediction, characterization, and intervention

Clinical treatment and assessment of therapy

-better understanding of the specific pathology mechanism
-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