What fMRI Can, Can't, and Might Do

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Overview of fMRI

Functional Contrast:
    Blood volume
    Blood flow/perfusion
    Blood oxygenation

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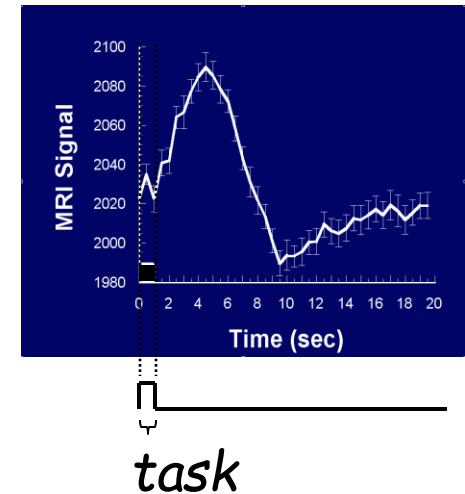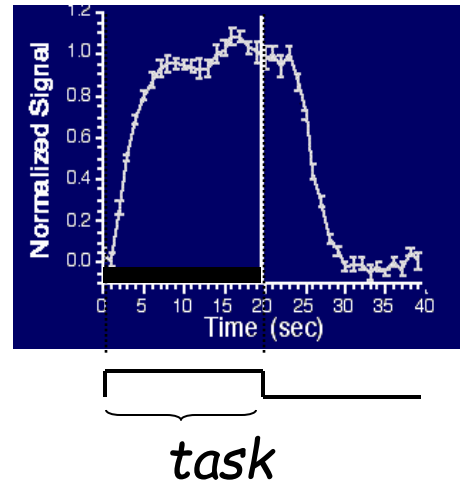   Typical: 3 mm^3
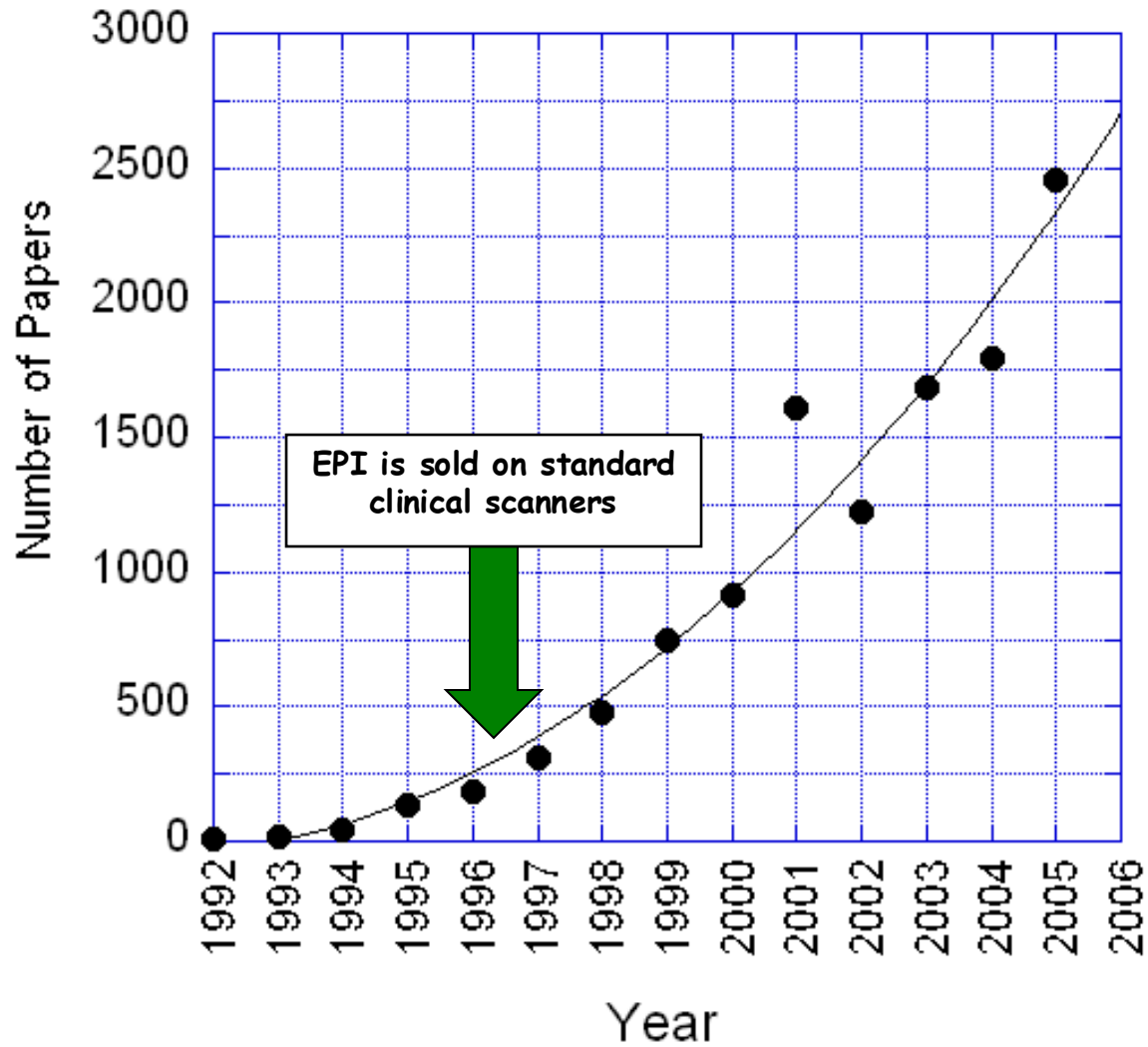   Upper: 0.5 mm^3

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

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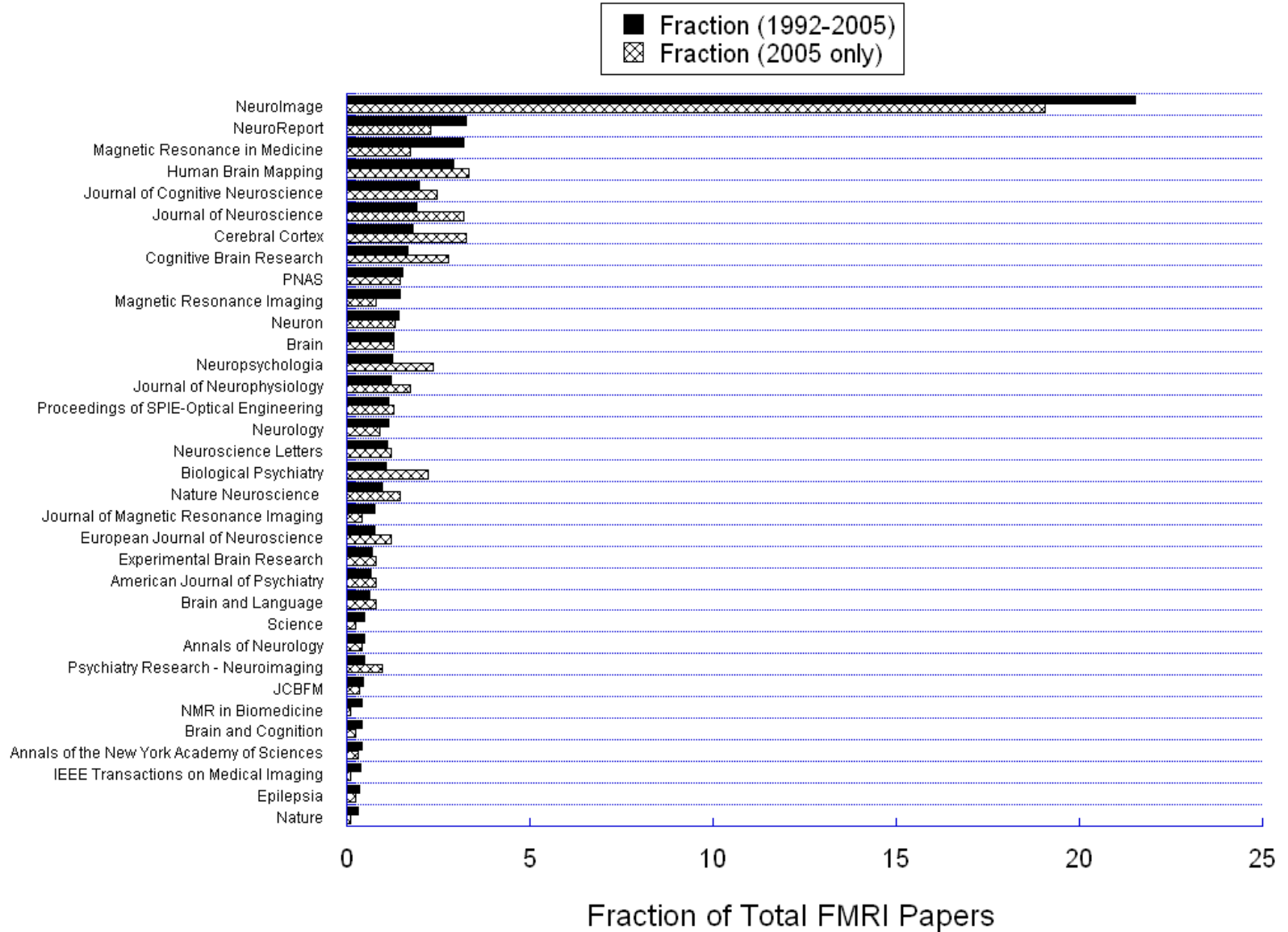   physiologic noise, motion and other artifacts, etc..


task

task

fMRI Papers Published per Year

EPI is sold on standard clinical scanners

"fMRI" or "functional MRI"

Breakdown of fMRI papers by Journal

Legend:
- Fraction (1992-2005)
- Fraction (2005 only)

Journals (top to bottom):
NeuroImage, NeuroReport, Magnetic Resonance in Medicine, Human Brain Mapping, Journal of Cognitive Neuroscience, Journal of Neuroscience, Cerebral Cortex, Cognitive Brain Research, PNAS, Magnetic Resonance Imaging, Neuron, Brain, Neuropsychologia, Journal of Neurophysiology, Proceedings of SPIE-Optical Engineering, Neurology, Neuroscience Letters, Biological Psychiatry, Nature Neuroscience, Journal of Magnetic Resonance Imaging, European Journal of Neuroscience, Experimental Brain Research, American Journal of Psychiatry, Brain and Language, Science, Annals of Neurology, Psychiatry Research - Neuroimaging, JCBFM, NMR in Biomedicine, Brain and Cognition, Annals of the New York Academy of Sciences, IEEE Transactions on Medical Imaging, Epilepsia, Nature
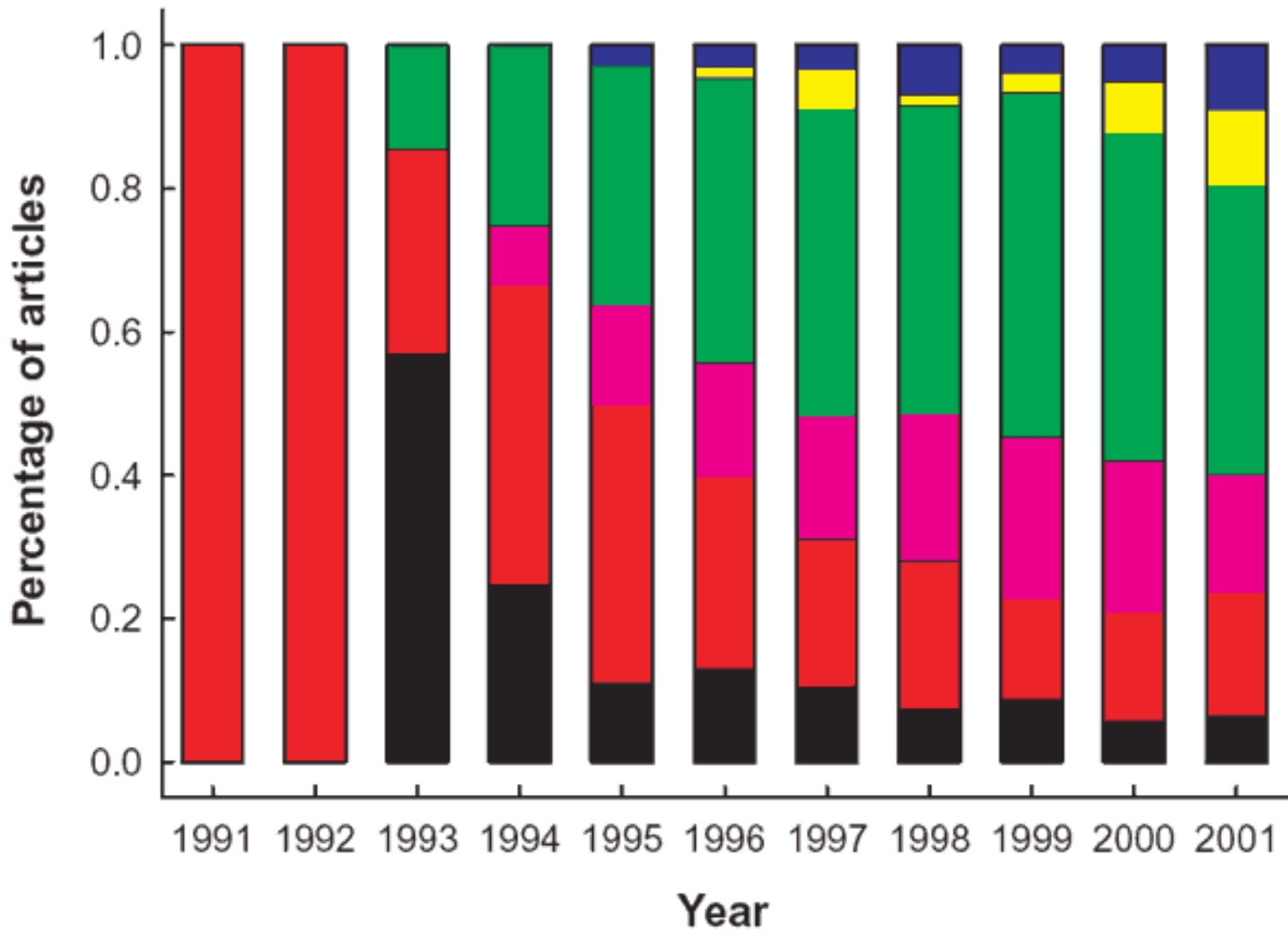
X-axis: Fraction of Total FMRI Papers (0, 5, 10, 15, 20, 25)

Percent Change in fMRI Publications of 2005 relative to Average (1992 - 2005) for Each Journal
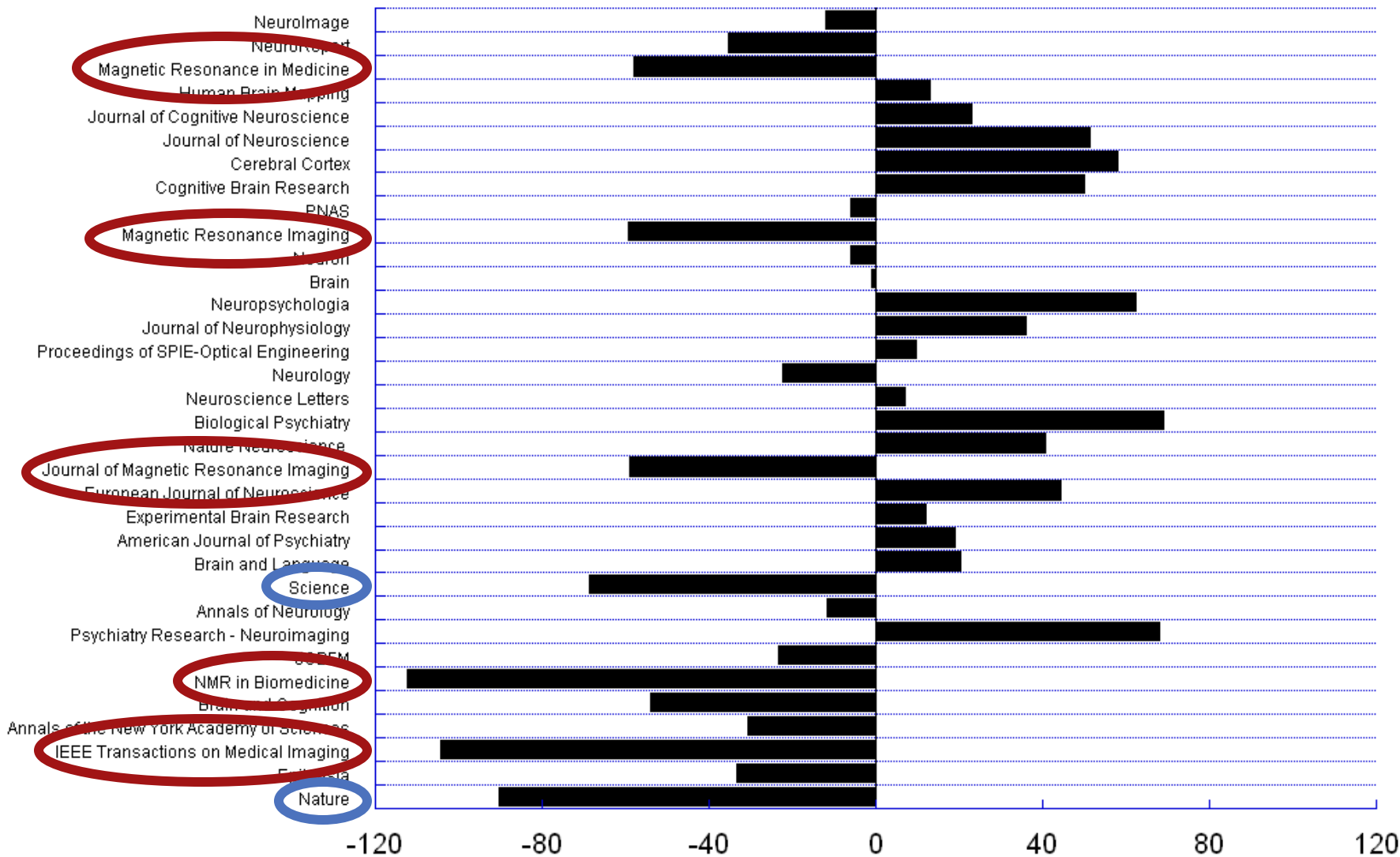
Percent Change (2005 relative to average from 1992 to 2005)

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

NIH Users

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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
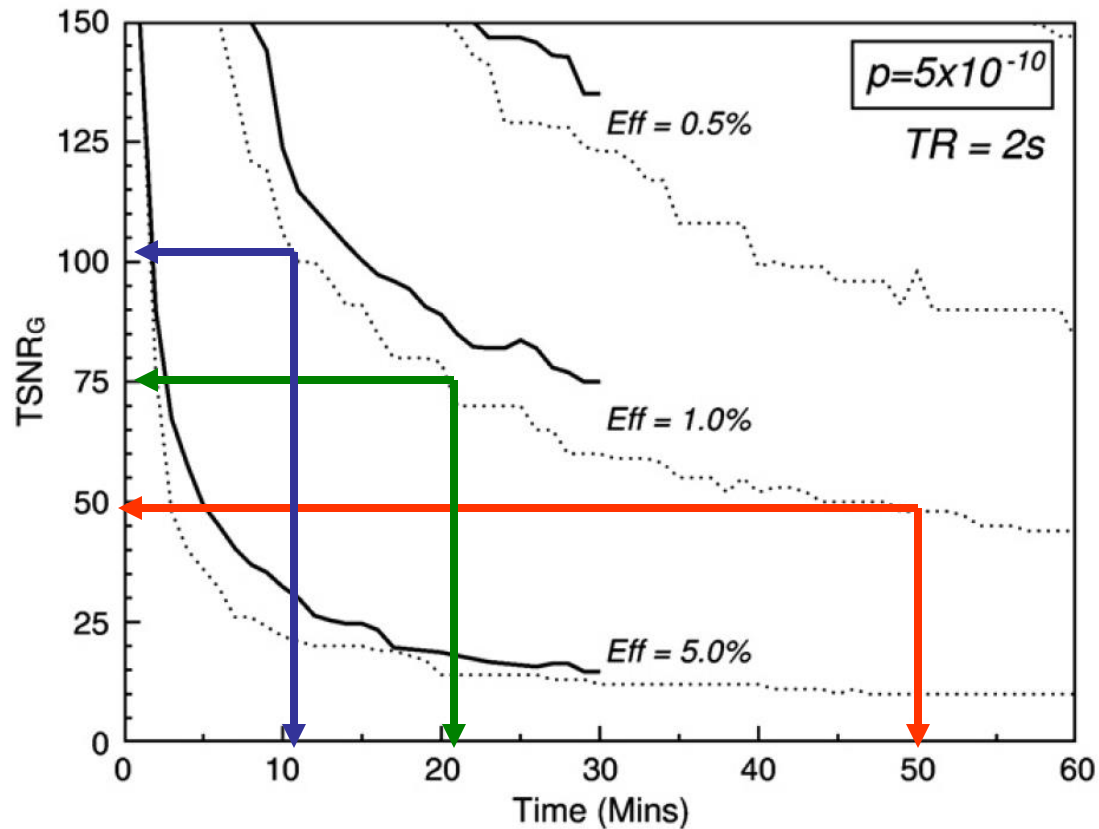Behavior correlation/prediction
Pathology assessment

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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

A

B

C

D

16 CH Array   28CM ID Birdcage

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)

fMRI Contrast

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

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Resting State Correlations
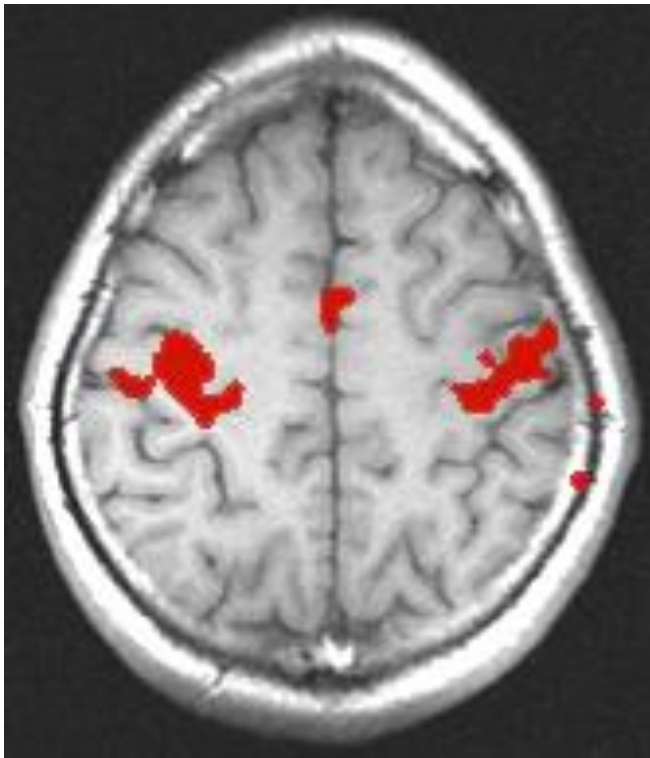
Activation:
correlation with reference function
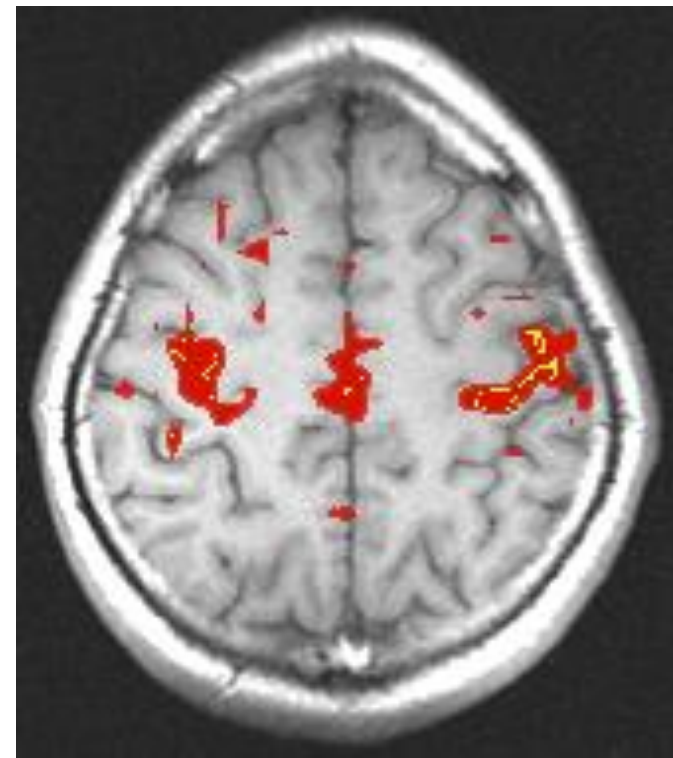
Rest:
seed voxel in motor cortex

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

Methodology

BOLD correlated with SCR during "Rest"
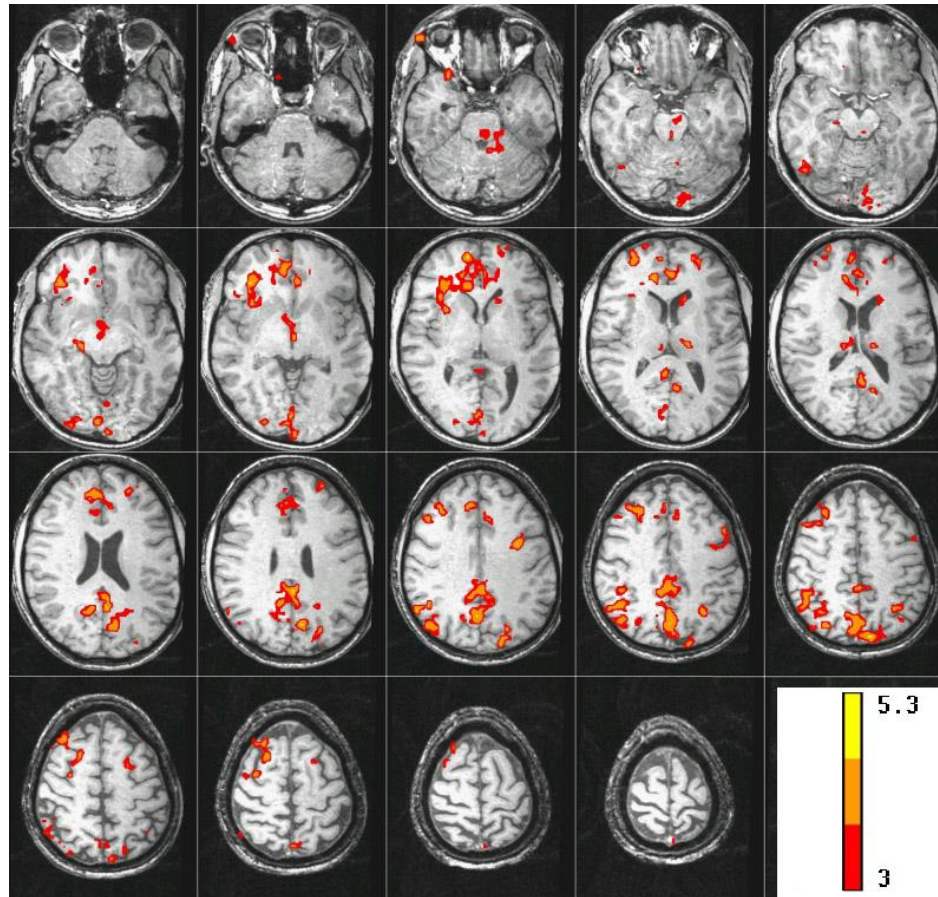
J. C. Patterson II, L. G. Ungerleider, and P. A Bandettini, *NeuroImage 17: 1787-1806, (2002).*

Methodology

BOLD correlated with 10 Hz power during "Rest"
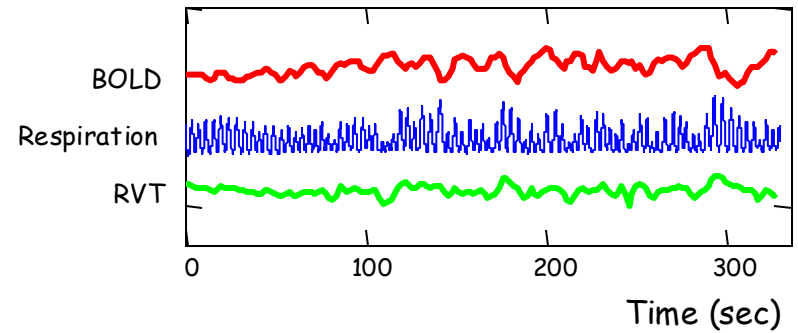
Positive

10 Hz power

Negative
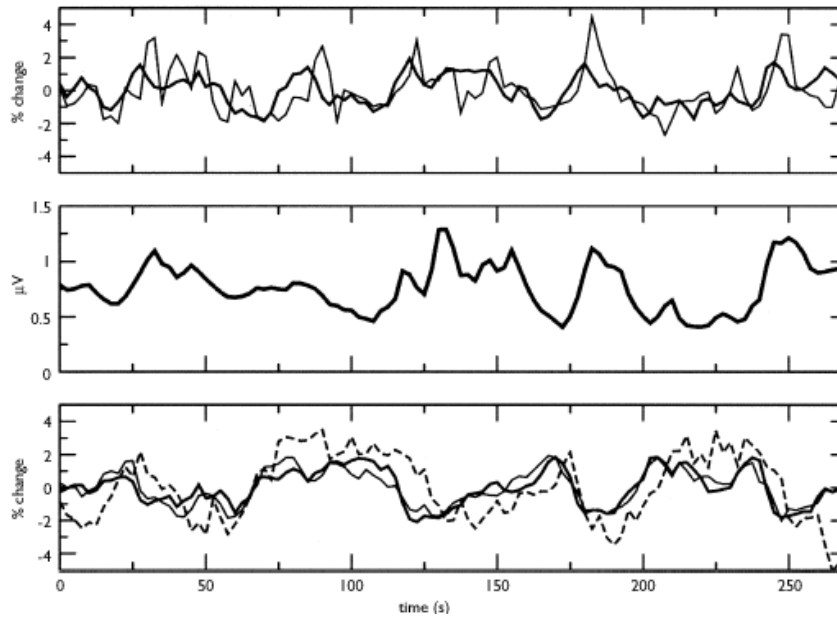
Goldman, et al (2002), Neuroreport
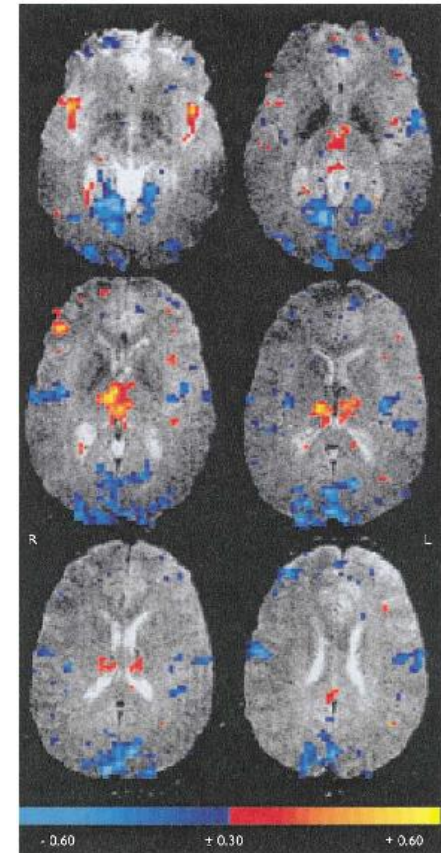
Methodology

Respiration induced signal changes

Breath-holding

Rest

(N=7)
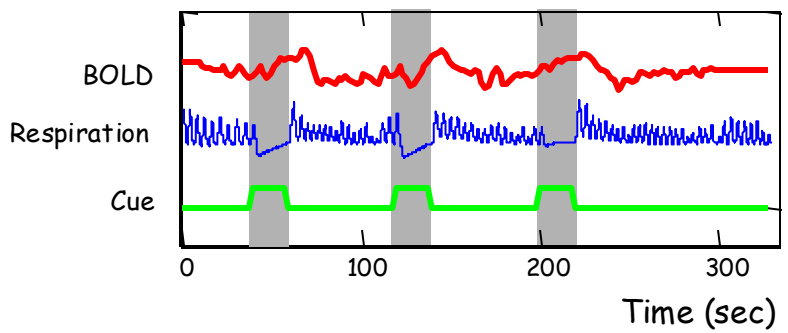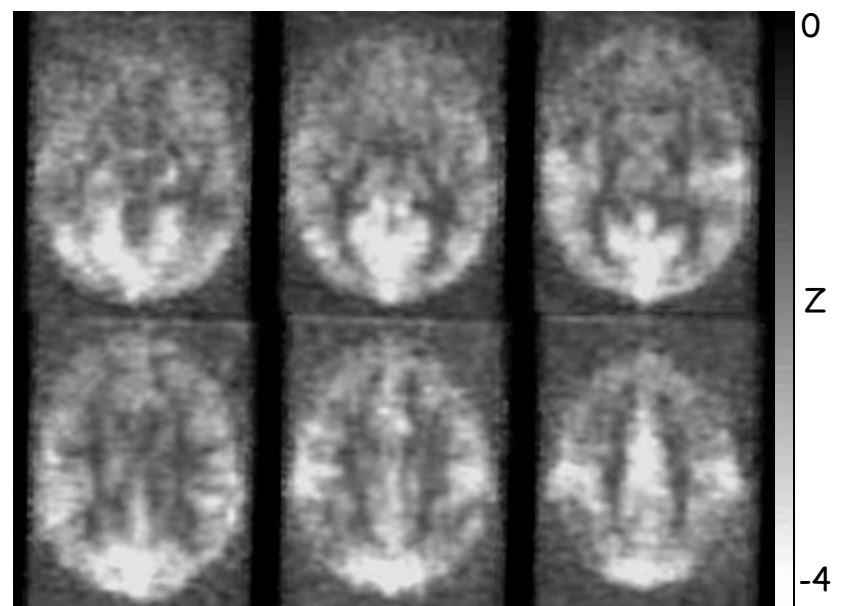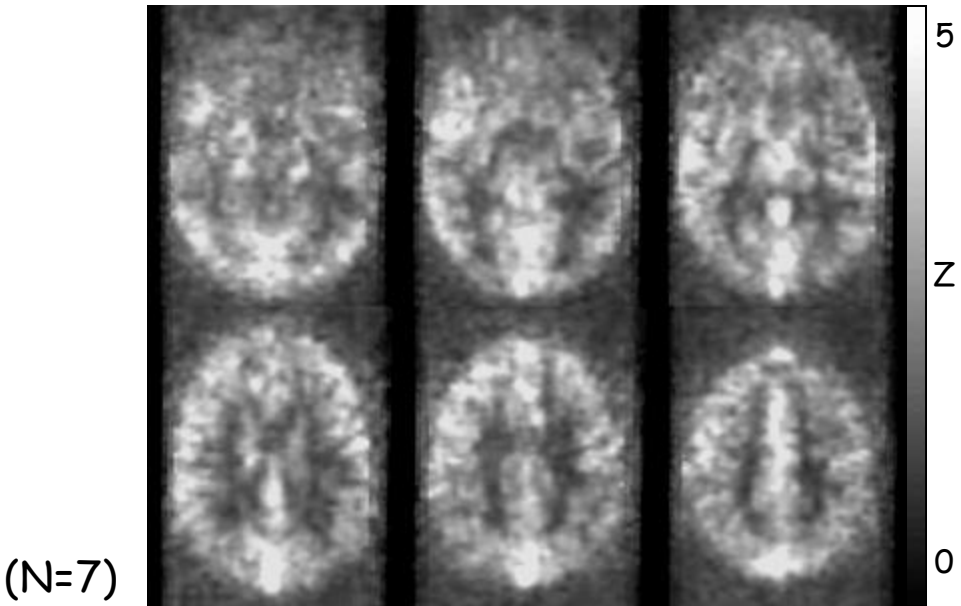
R. M. Birn, J. B. Diamond, M. A. Smith, P. A. Bandettini, Separating respiratory variation-related fluctuations from neuronal activity-related fluctuations in fMRI, NeuroImage 31, 1536-1548 (2006)

Mapping ⟷ "Reading"

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
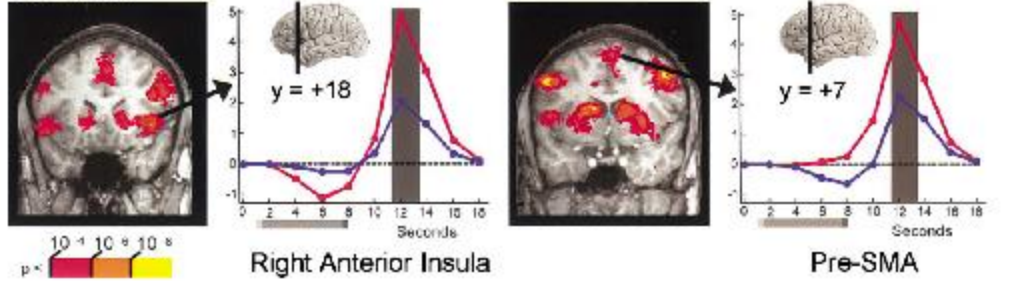National Institutes of Health
Bethesda, Maryland 20892

A. Encoding

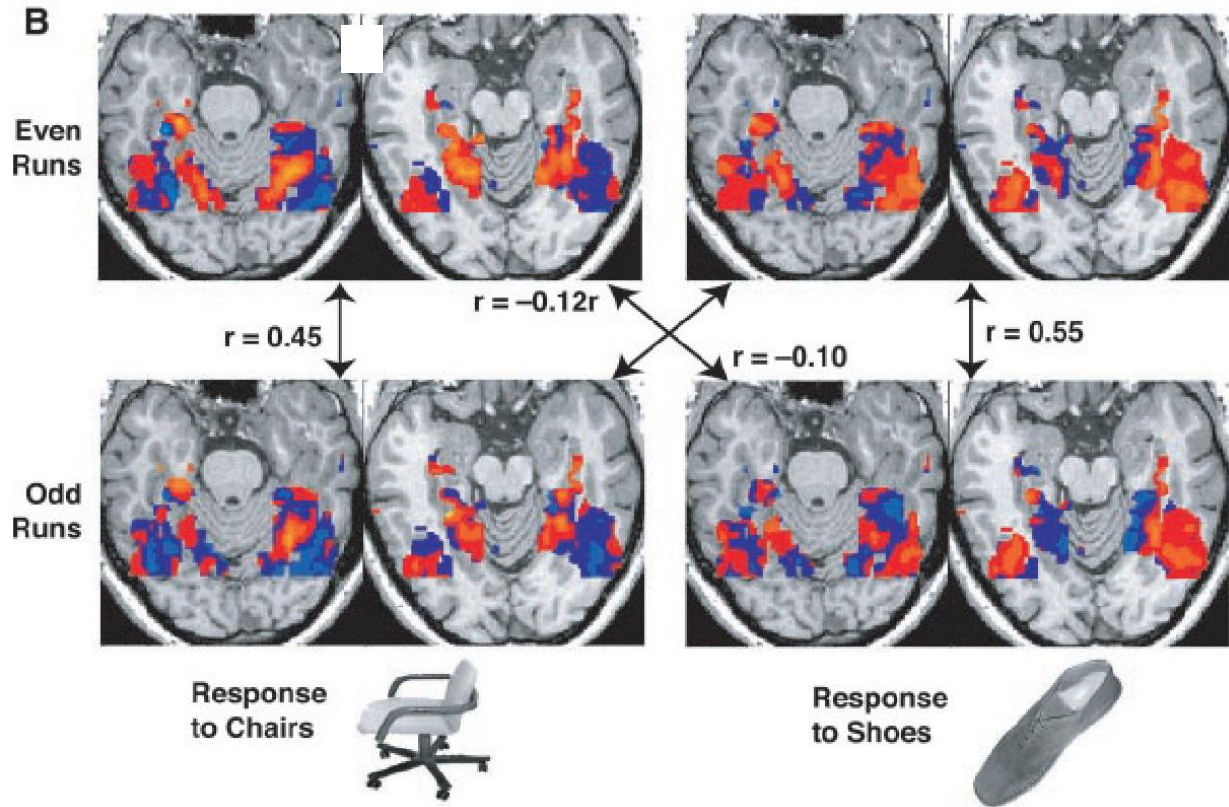Right Dorsal Occipital $z = +6$

Right Ventral Temporal $z = -12$

B. Delay

Right IPS $y = -37$

Right FEF $z = +47$

C. Test

Right Anterior Insula $y = +18$

Pre-SMA $y = +7$
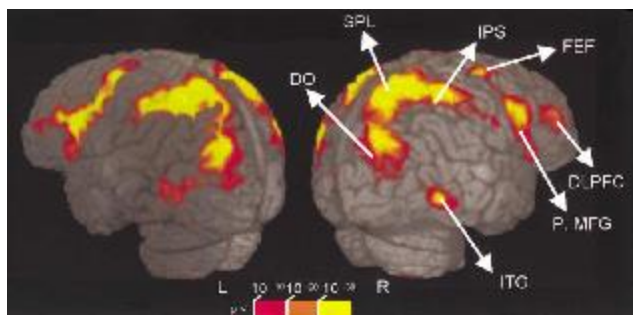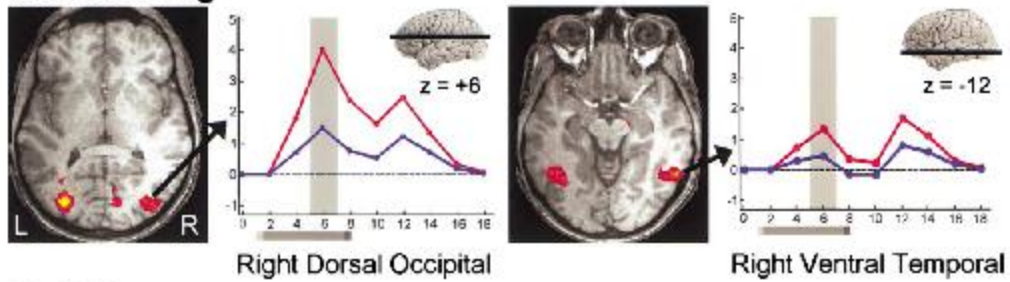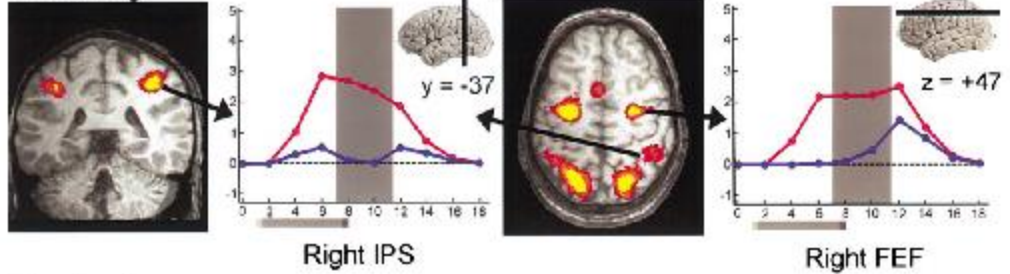
Ventral temporal category representations

Object categories are associated with distributed
representations in ventral temporal cortex

Response to Chairs

Response to Shoes

Haxby et al. 2001

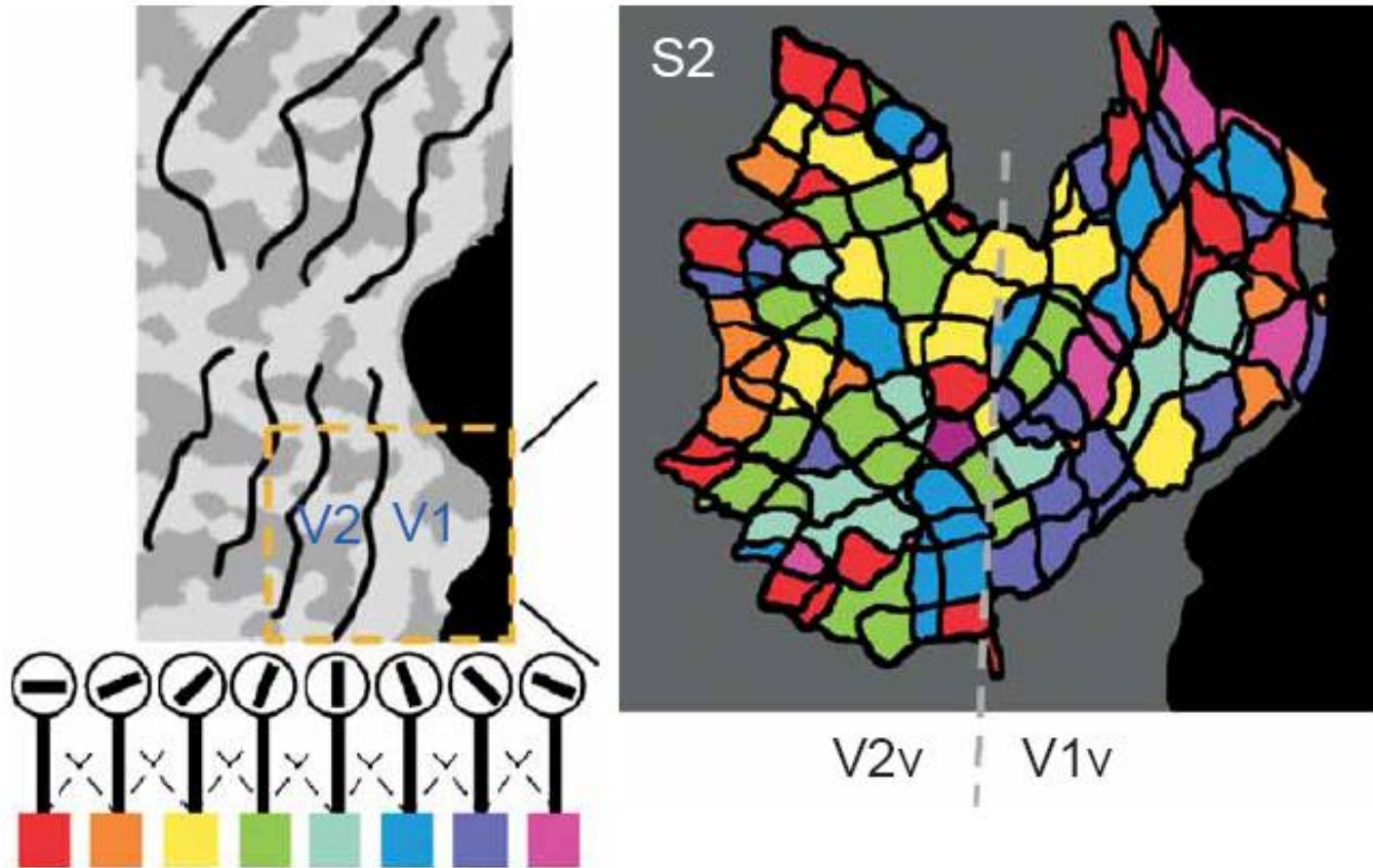# Methodology

NEUROIMAGE 19 (2): 261-270 Part 1 JUN 2003
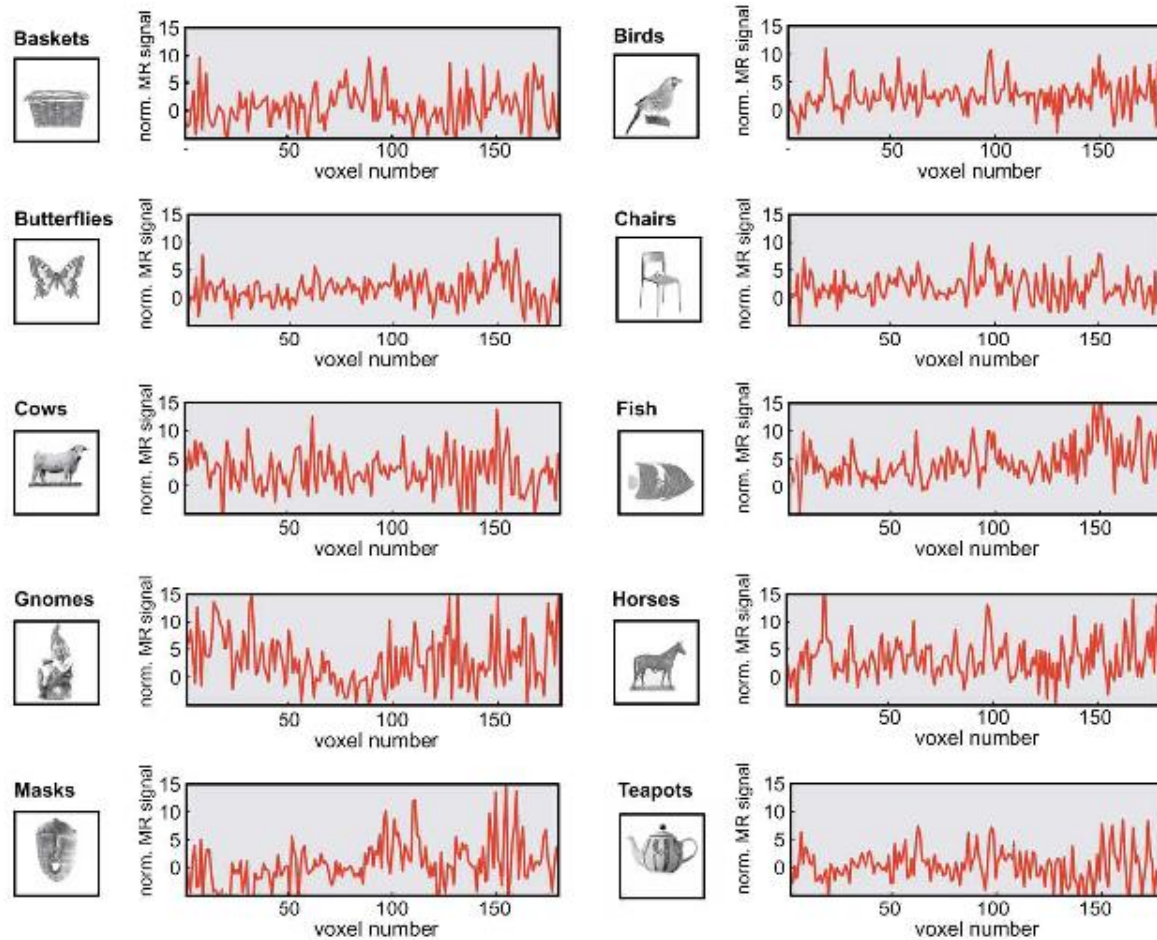
Methodology
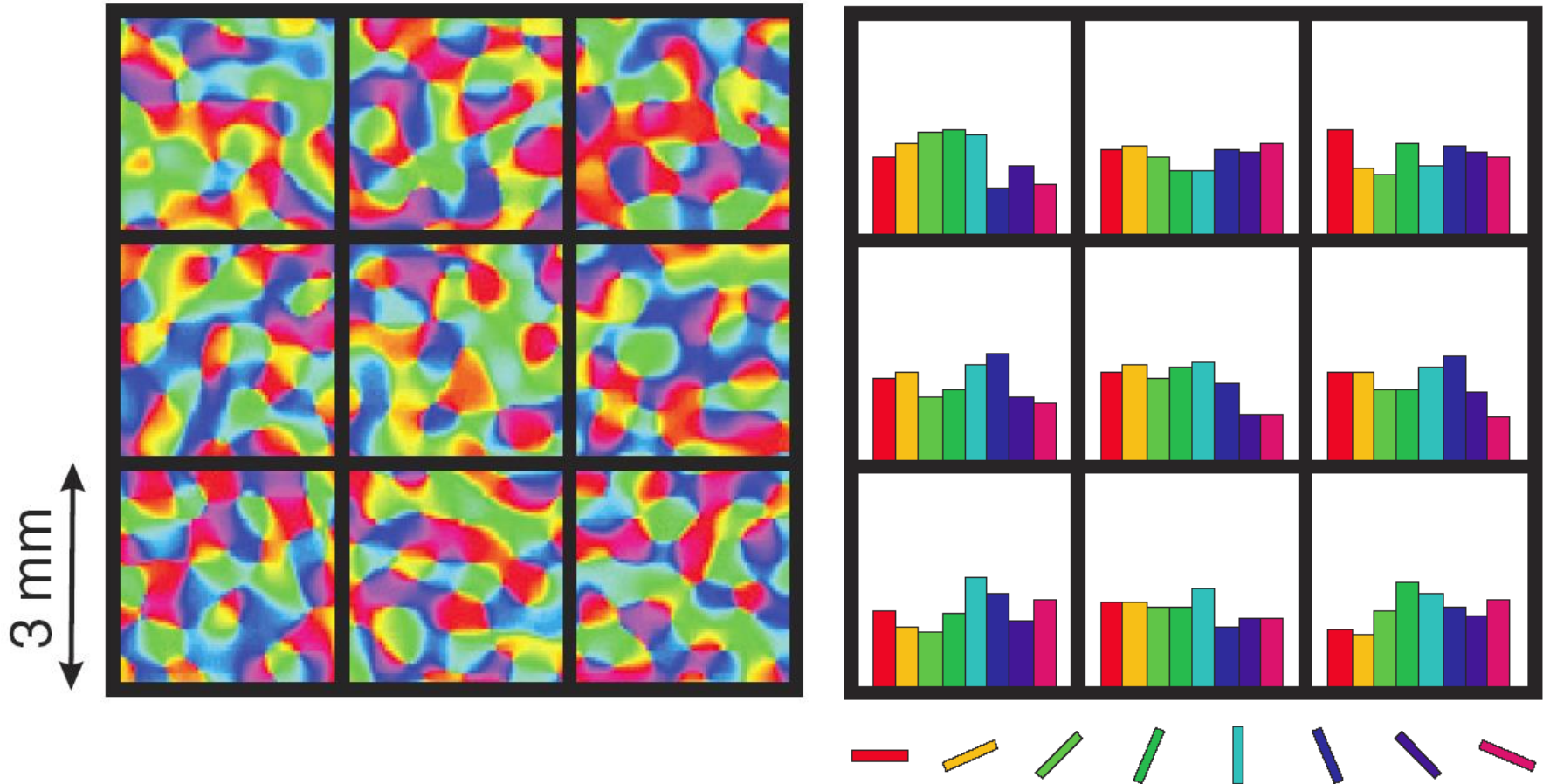
Boynton (2005), News & Views on Kamitani & Tong (2005) and Haynes & Rees (2005)
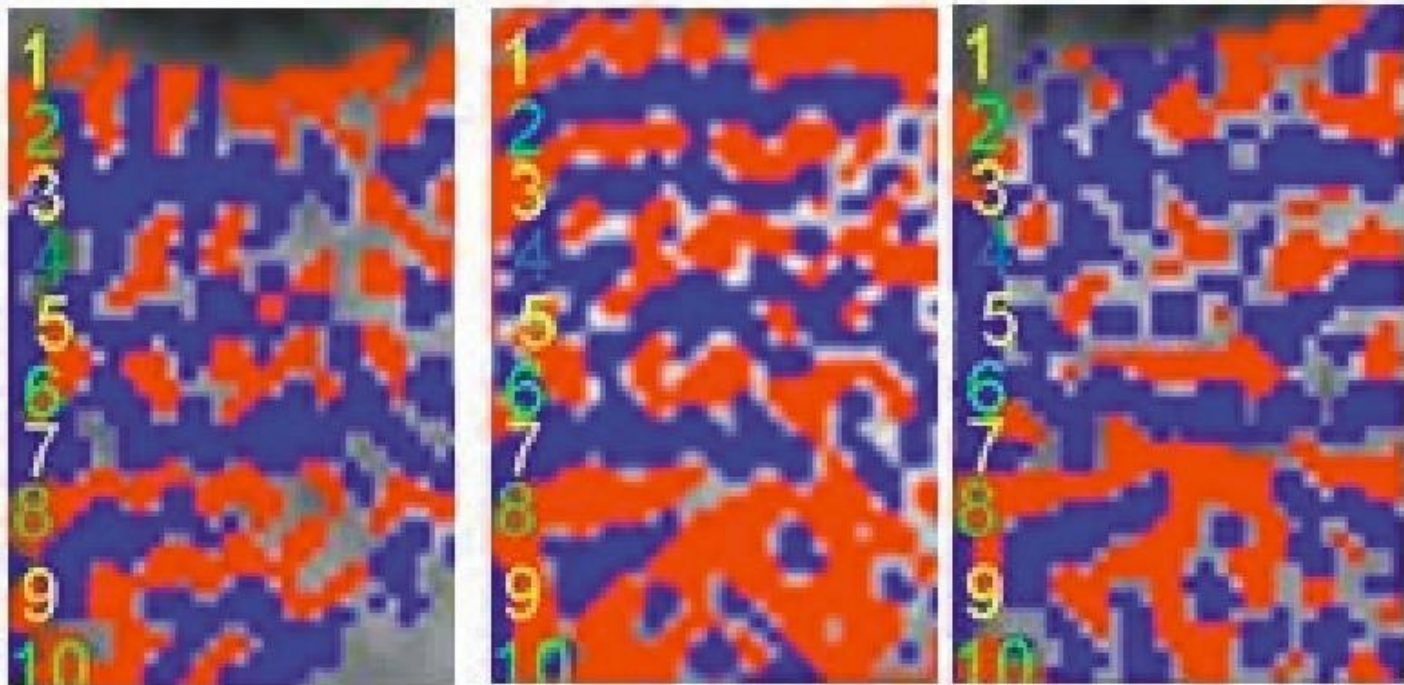
Lower spatial frequency clumping

Kamitani & Tong (2005)

What to do with high resolution data?

HSE-BOLD demonstration of ocular dominance columns
human, 7T, $0.5 \times 0.5 \times 3$ mm^3

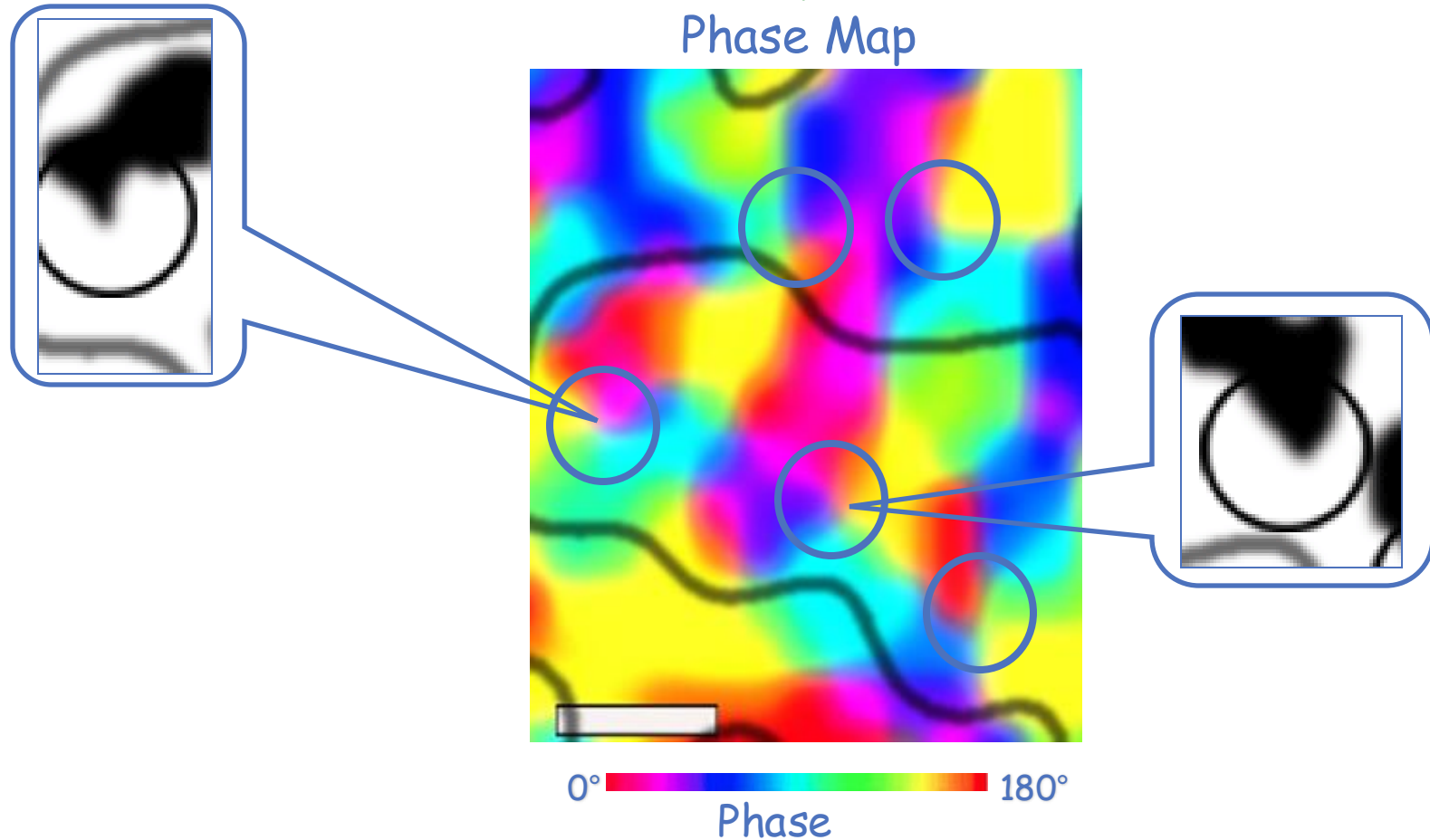day 1   day 2   day 3

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

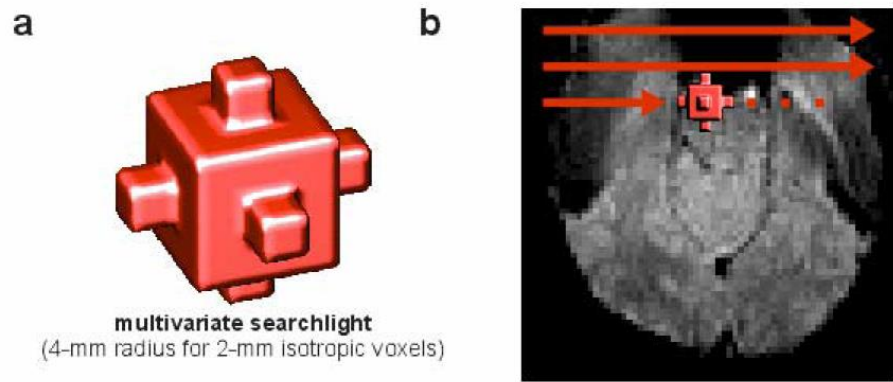Orientation Columns in Human V1 as Revealed by fMRI at 7T

Methodology

Methodology

a

multivariate searchlight
(4-mm radius for 2-mm isotropic voxels)

b

c

Information-based searchlight map with t-map texture (FDR q<0.05)

d

Unsmoothed-data t map (same number of voxels marked)

event-related
spatial response patterns

fMRI response

voxel 2 activity

voxel 3 activity

voxel 1 activity
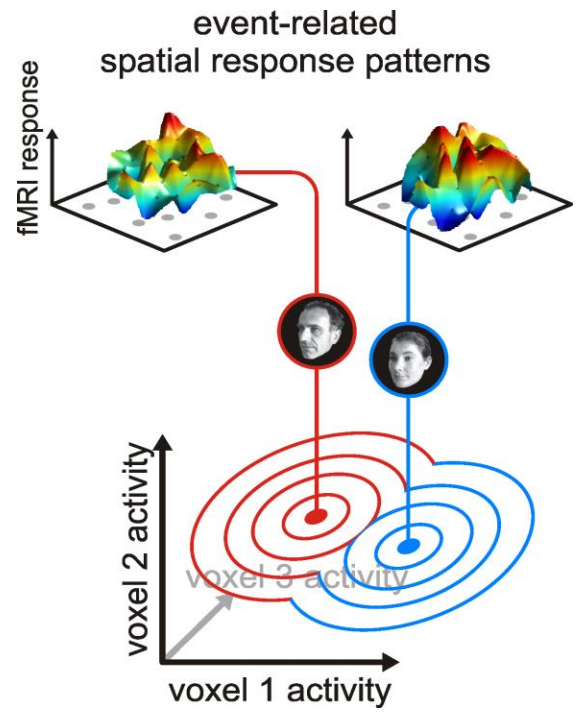
N. Kriegeskorte, R. Goebel, P. Bandettini,
Information-based functional brain mapping.
Proc. Nat'l. Acad. Sci. USA, **103**, 3863-
3868 (2006).

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Fluctuations
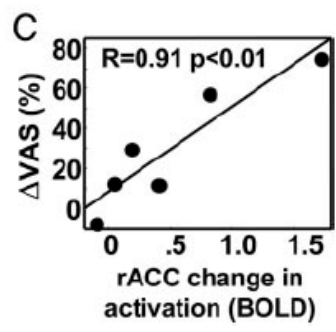**Dynamics**
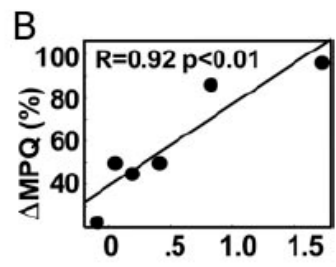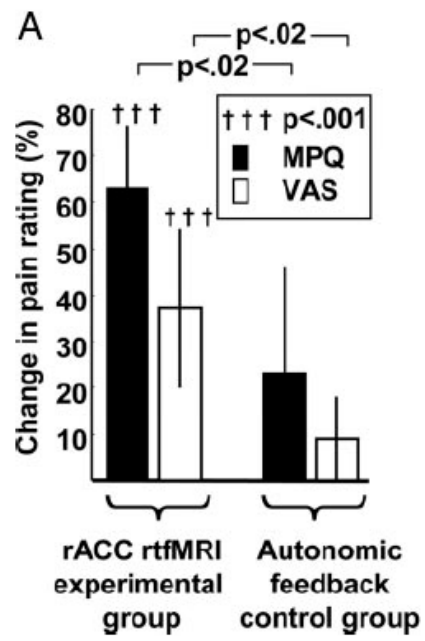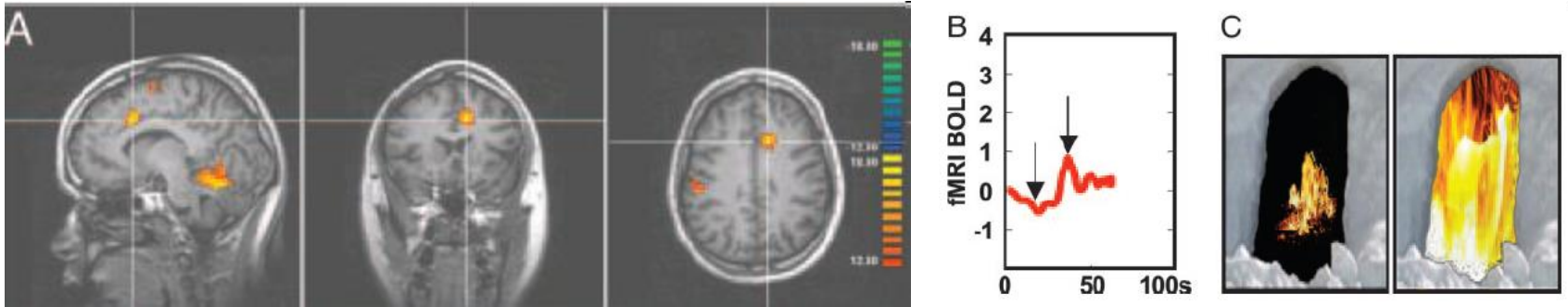**Cross - modal comparison**

Basic Neuroscience
Behavior correlation/prediction
Pathology correlation

Interpretation

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

How most fMRI studies are performed

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

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

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

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

How fMRI might be be performed

MRI parameters:

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

Paradigm:

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

Analysis:

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

Hypothesis:

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