fMRI Paradigm Designs and Processing Methods

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&

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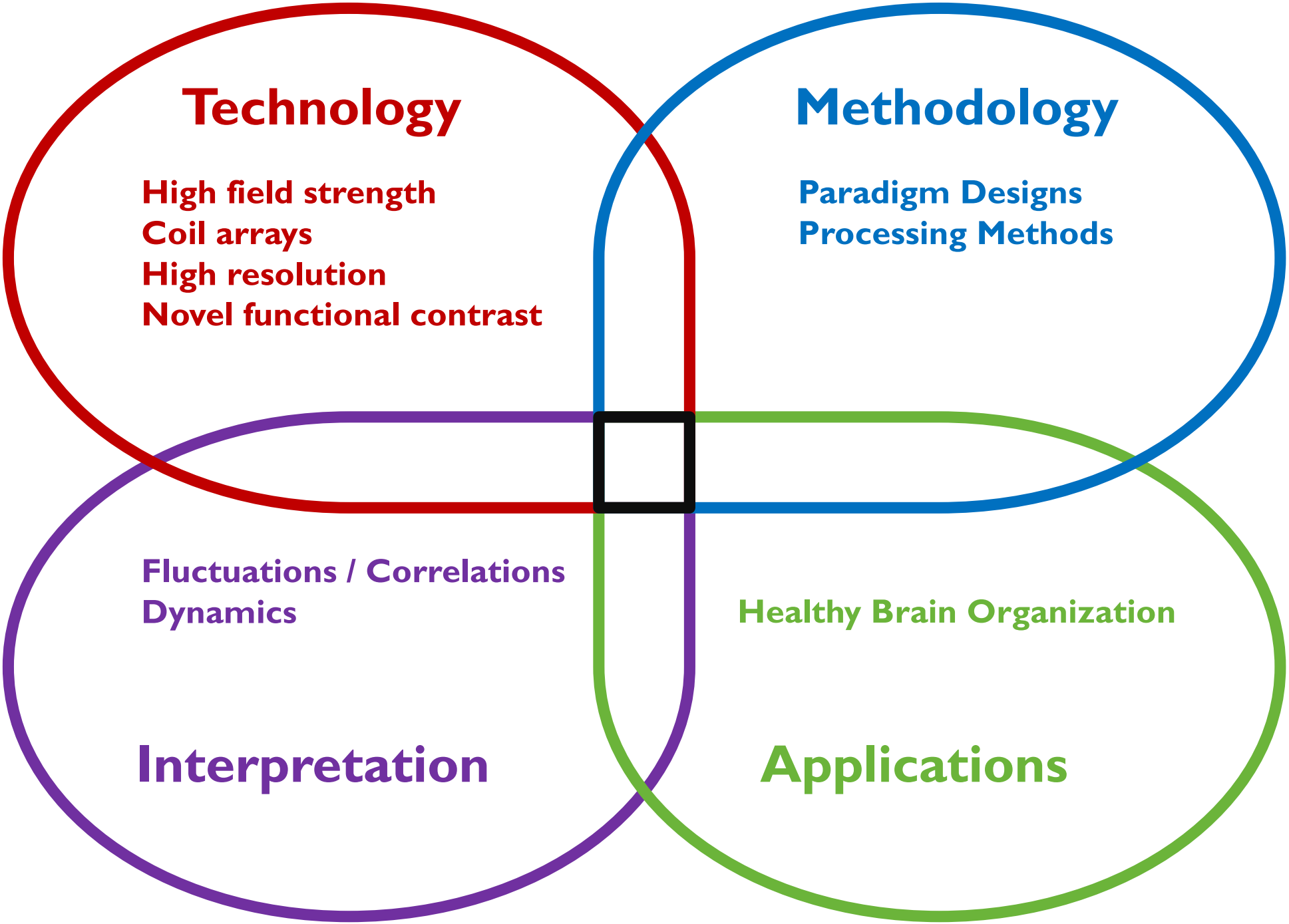
http://fmrif.nimh.nih.gov

Focus of this lecture

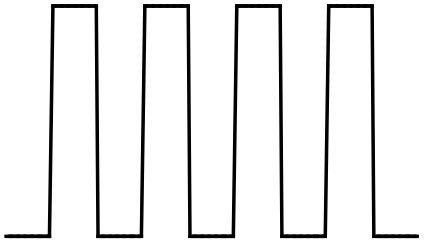


fMRI Paradigm Designs and Processing Strategies

1. Neuronal Activation Input Strategies
2. Resting State fMRI
3. fMRI Decoding

Neuronal Activation Input Strategies

1. Block Design



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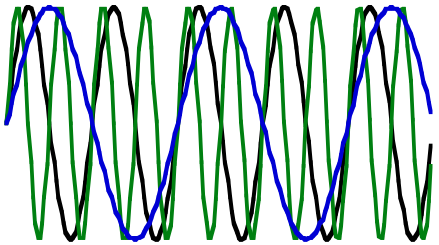
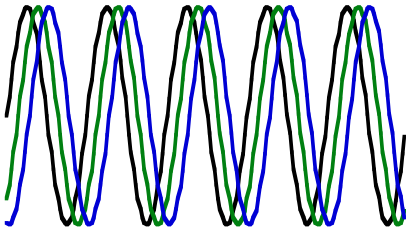


3. Phase Encoding



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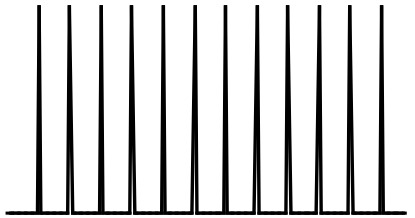
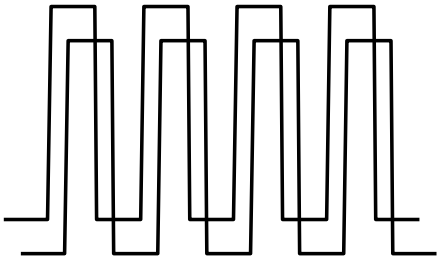


5. fMRI adaptation

6. Orthogonal Block Design



7. Free Behavior Design.

Neuronal Activation Input Strategies

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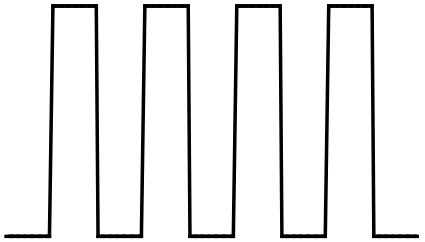

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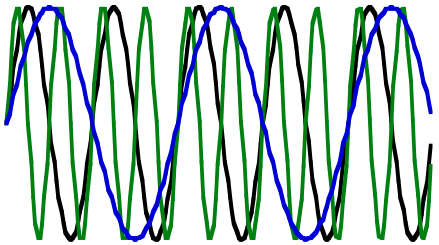

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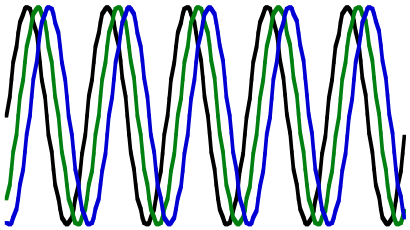

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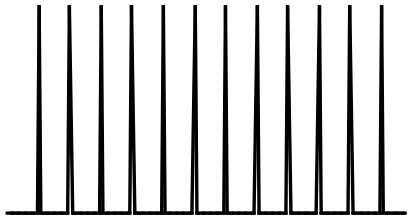

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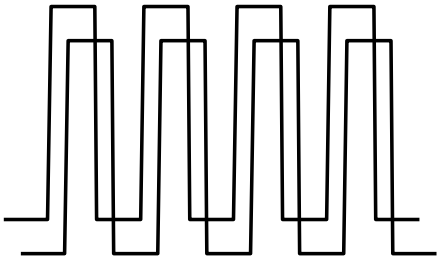

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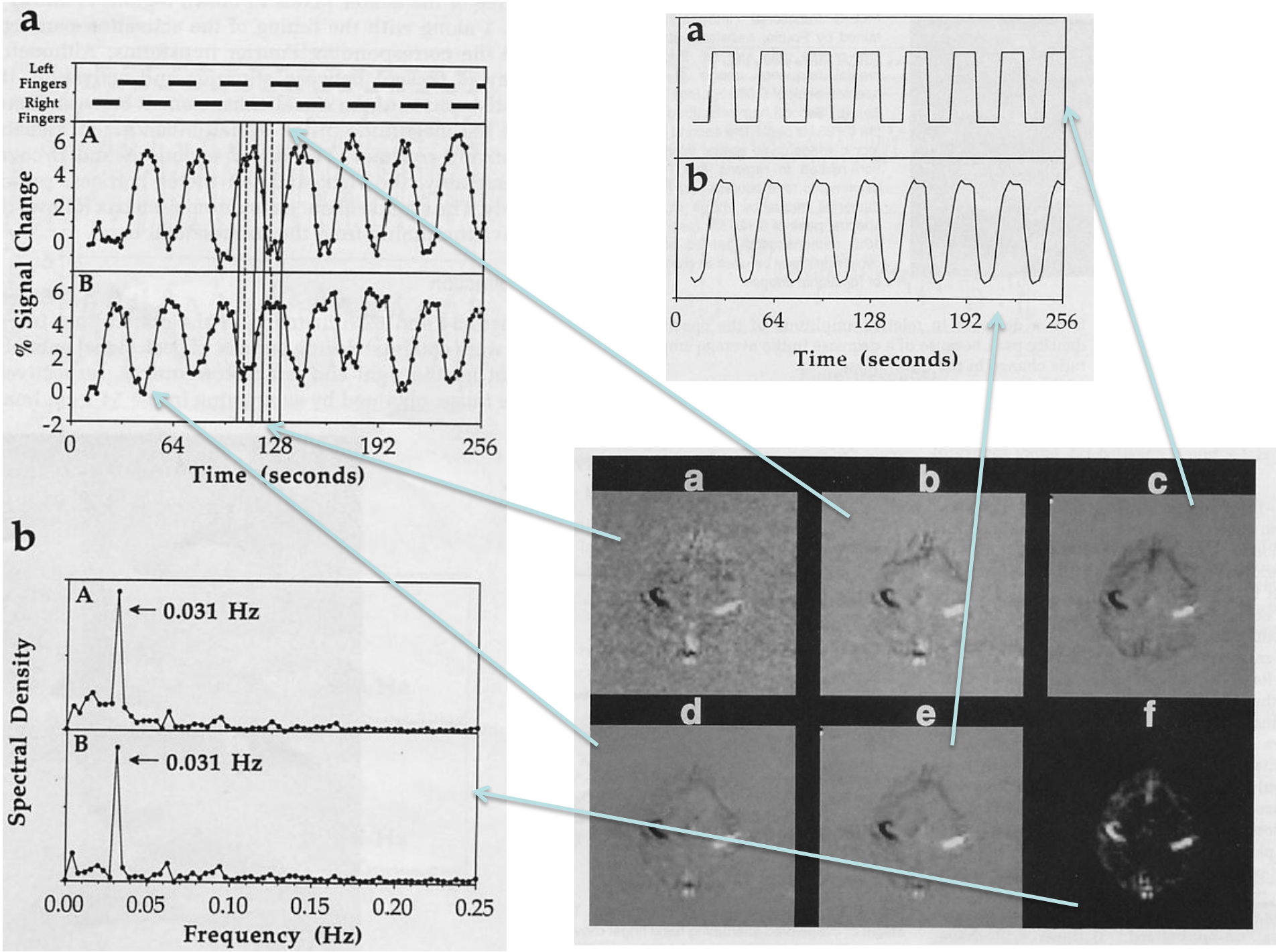
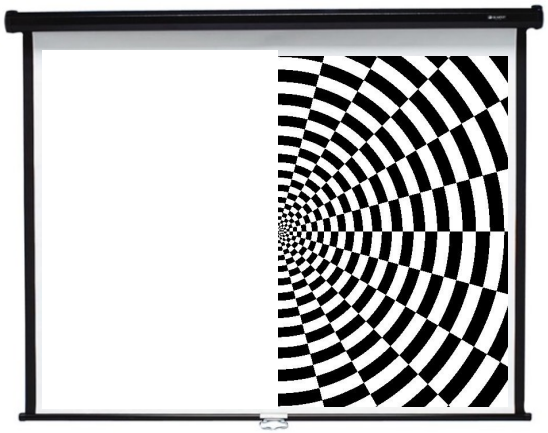
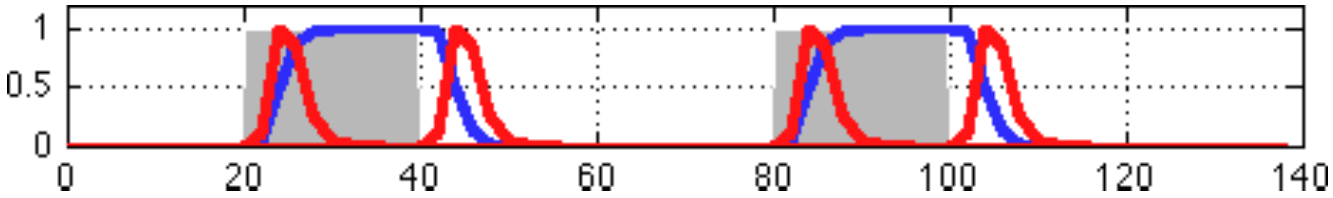


P. A. Bandettini, A. Jesmanowicz, E. C. Wong, J. S. Hyde, Processing strategies for time-course data sets in functional MRI of the human brain. *Magn. Reson. Med.* 30, 161-173 (1993).

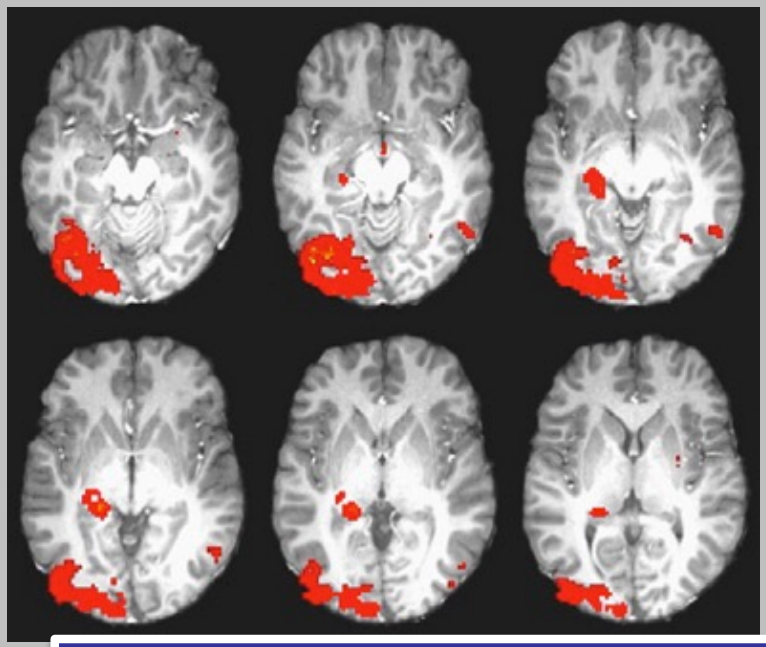
Predictive Response Model effect on fMRI Results (III)



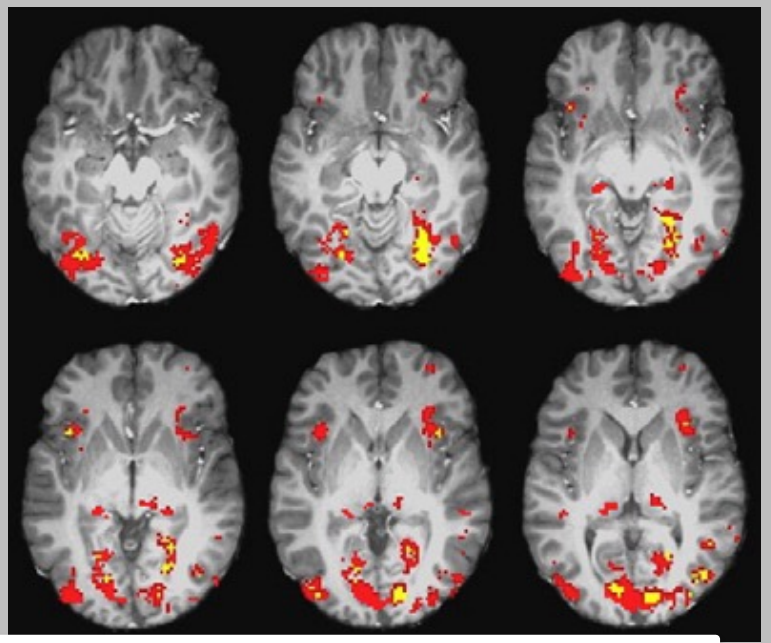
BLOCK DESIGN & HEMIFIELD VISUAL STIMULATION



SUSTAINED RESPONSE MODEL

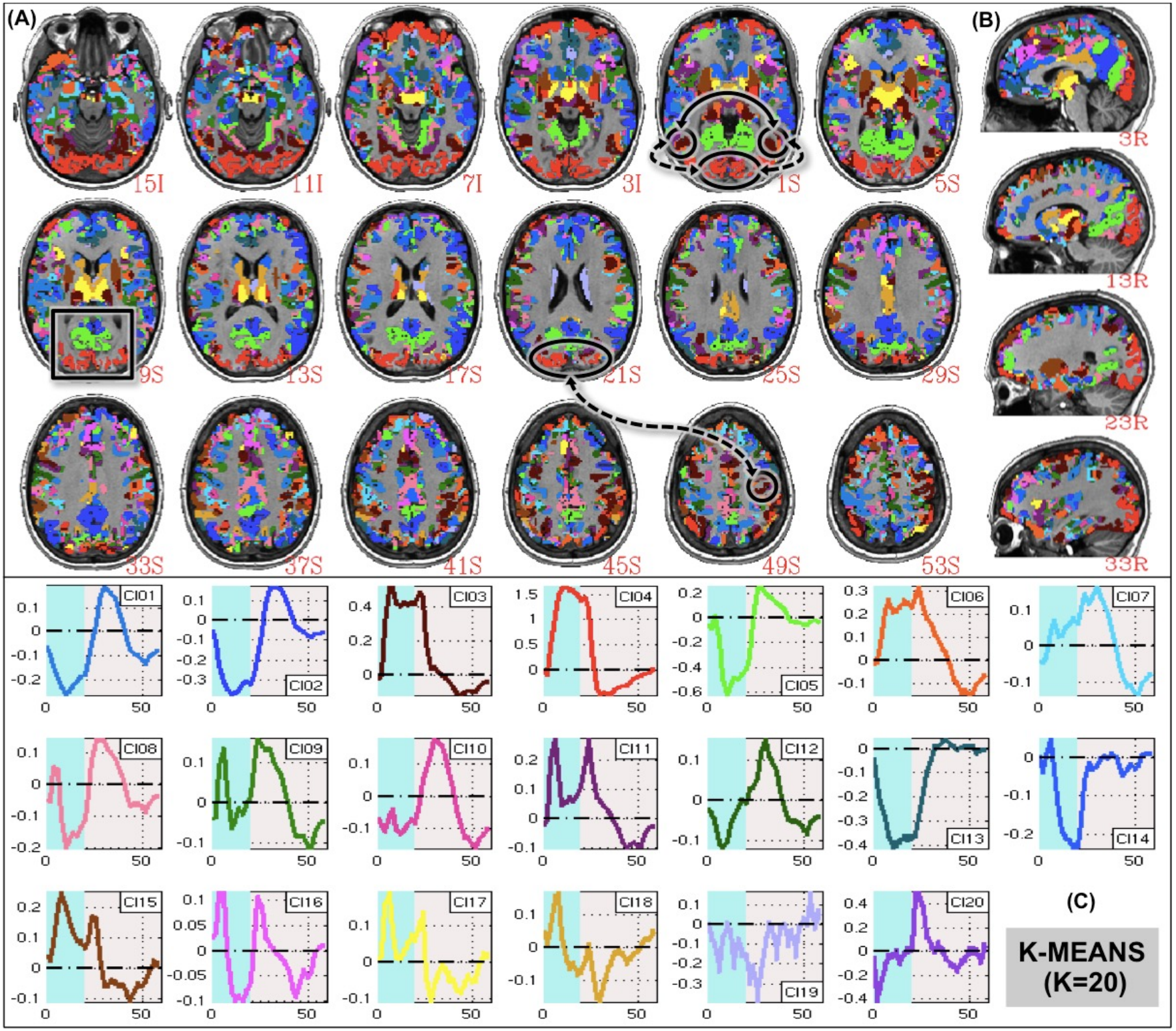


ONSET/OFFSET RESPONSE MODEL



DIFFERENT RESPONSE SHAPES ARE PRESENT ACROSS DIFFERENT REGIONS OF THE BRAIN FOR A SINGLE STIMULUS TYPE

Uludag et al. Magn Reson Imaging. 2008 Sep;26(7):863-9.


(A)
15I
11I
7I
3I
1I
5S
9S
13S
17S
21S
25S
29S
33S
37S
41S
45S
49S
53S
(B)
3R
13R
23R
33R
CI01
CI02
CI03
CI04
CI05
CI06
CI07
CI08
CI09
CI10
CI11
CI12
CI13
CI14
CI15
CI16
CI17
CI18
CI19
CI20
(C)
K-MEANS
(K=20)

Neuronal Activation Input Strategies

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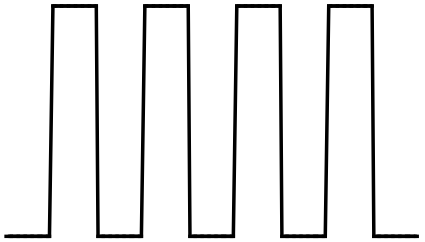

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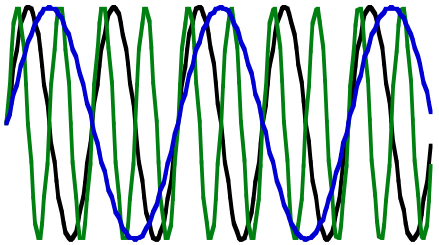
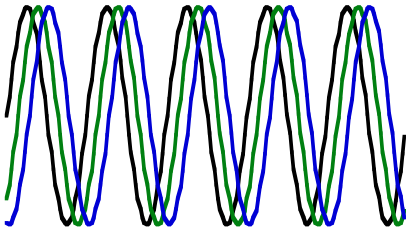


3. Phase Encoding



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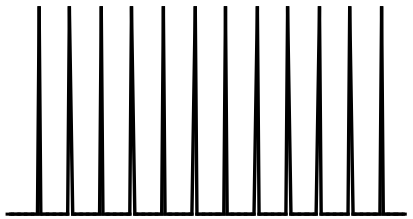
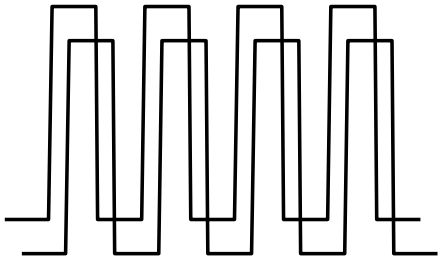
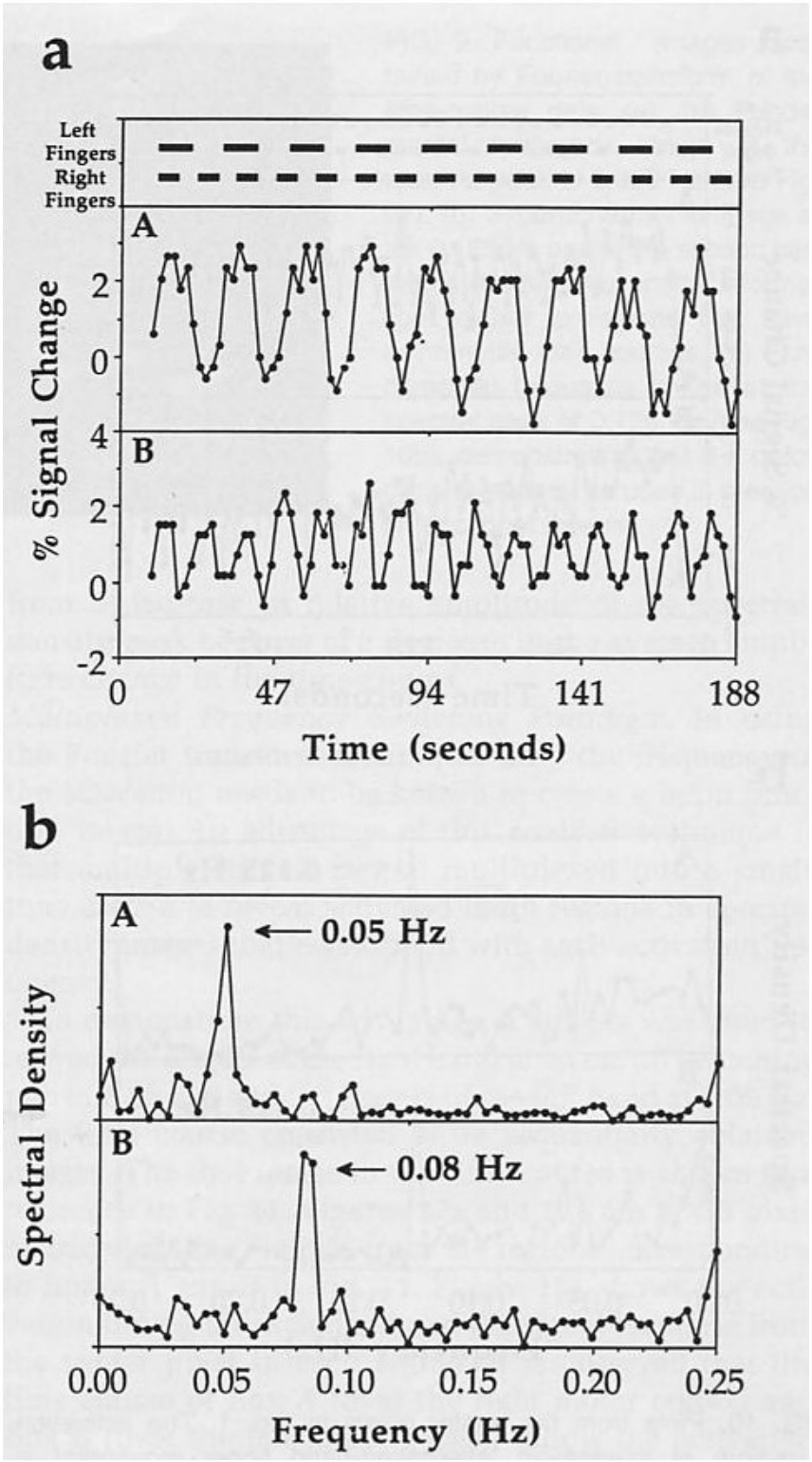


5. fMRI adaptation

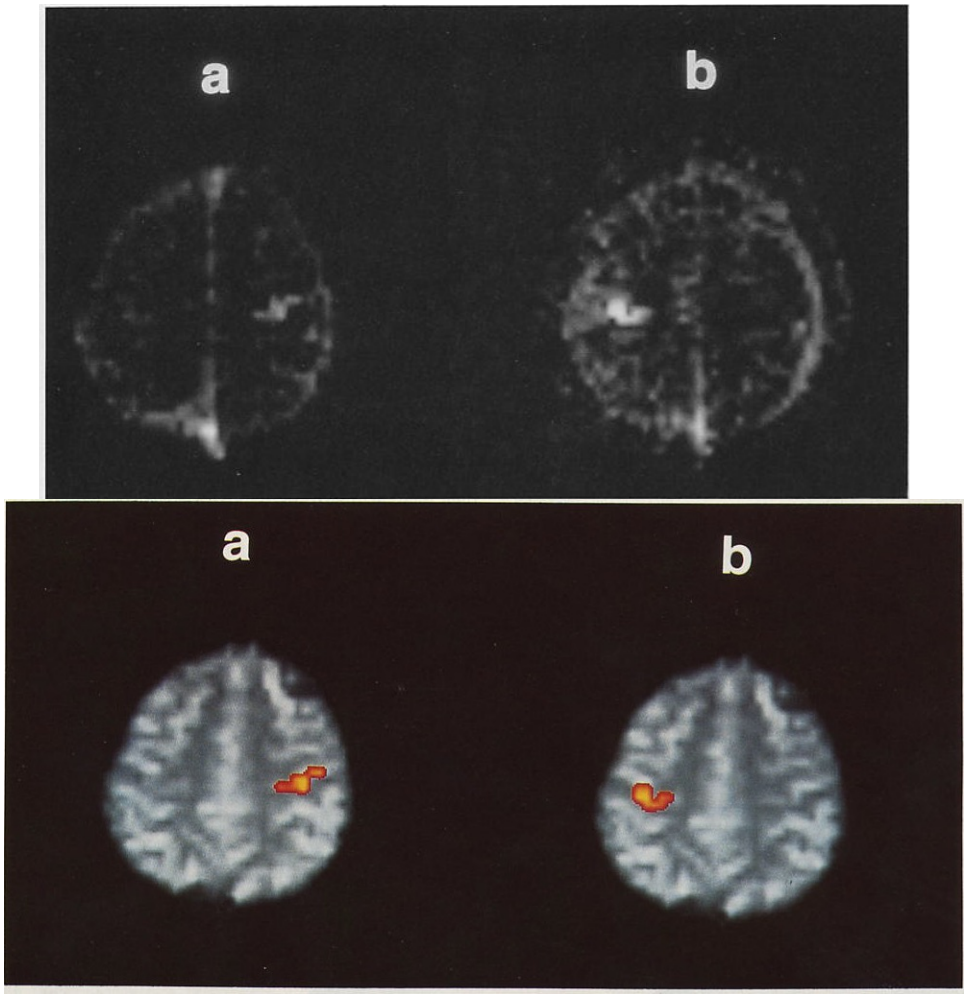


6. Orthogonal Block Design

7. Free Behavior Design.



Tapping left and right fingers at two different "on/off" frequencies



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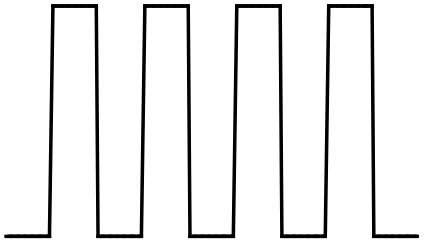

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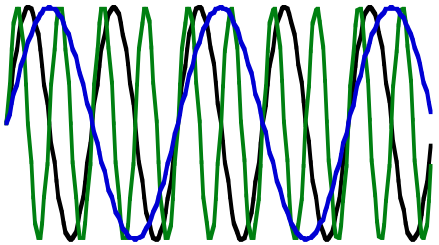

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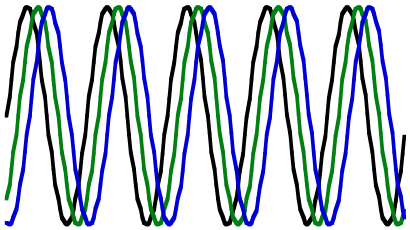

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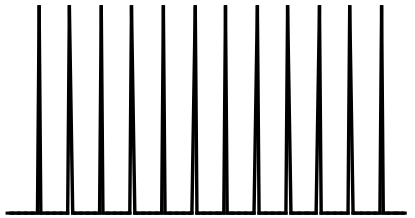

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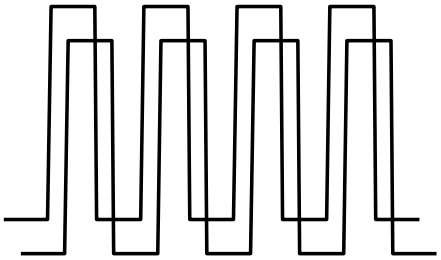

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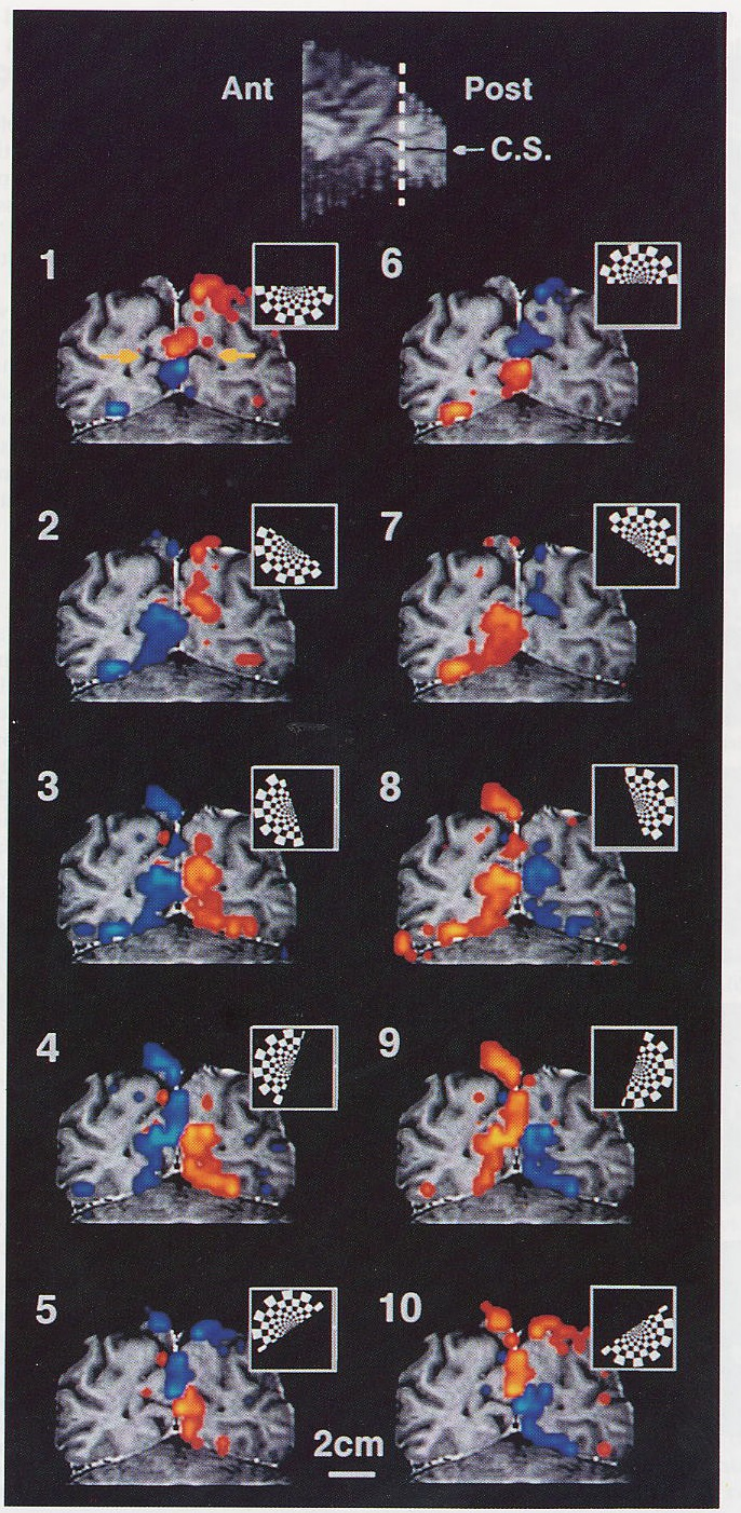
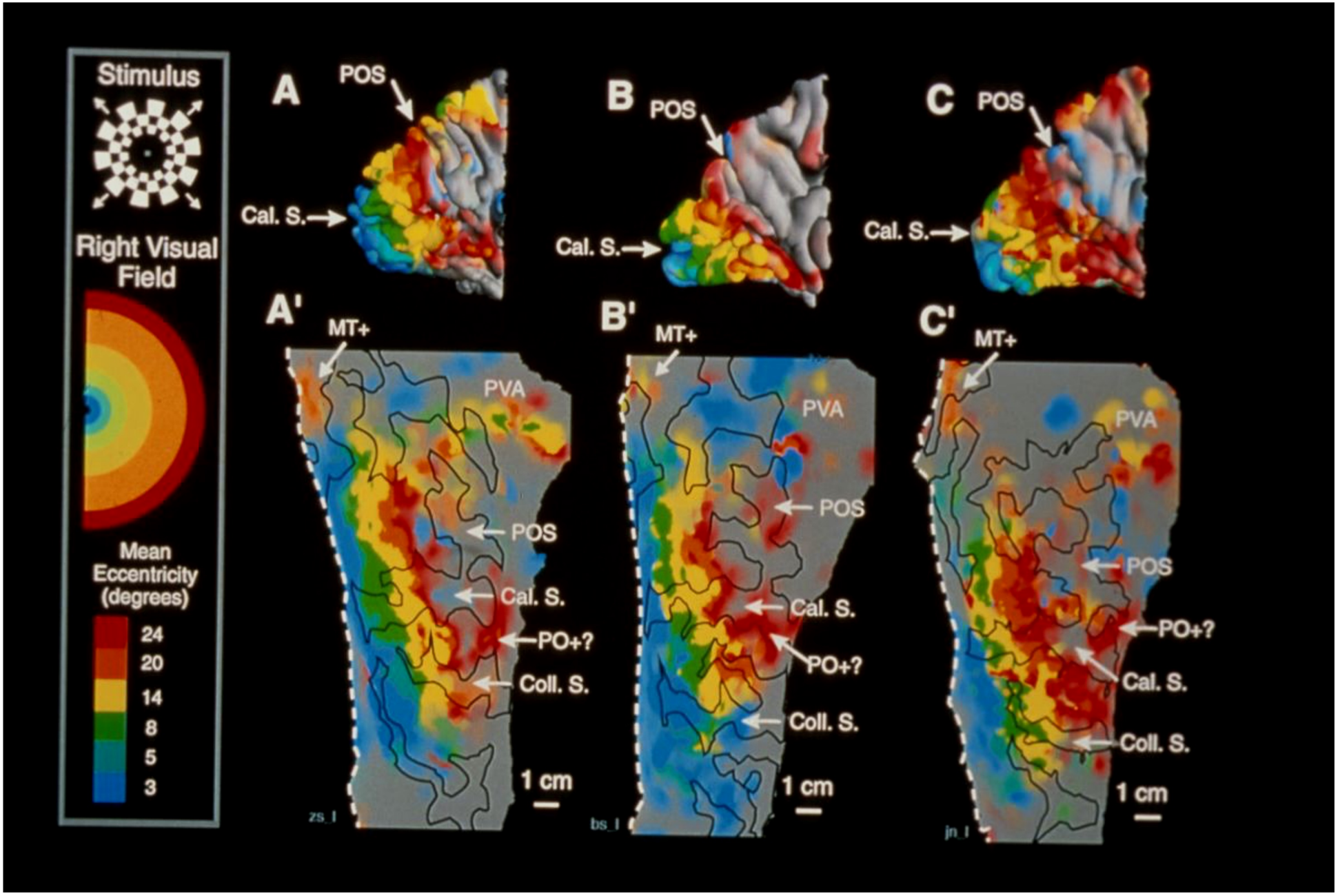


E. A. DeYoe, P. A. Bandettini, J. Nietz, D. Miller, P. Winas, Functional magnetic resonance imaging (FMRI) of the human brain. *J. Neuroscience Methods* 54, 171-187 (1994).



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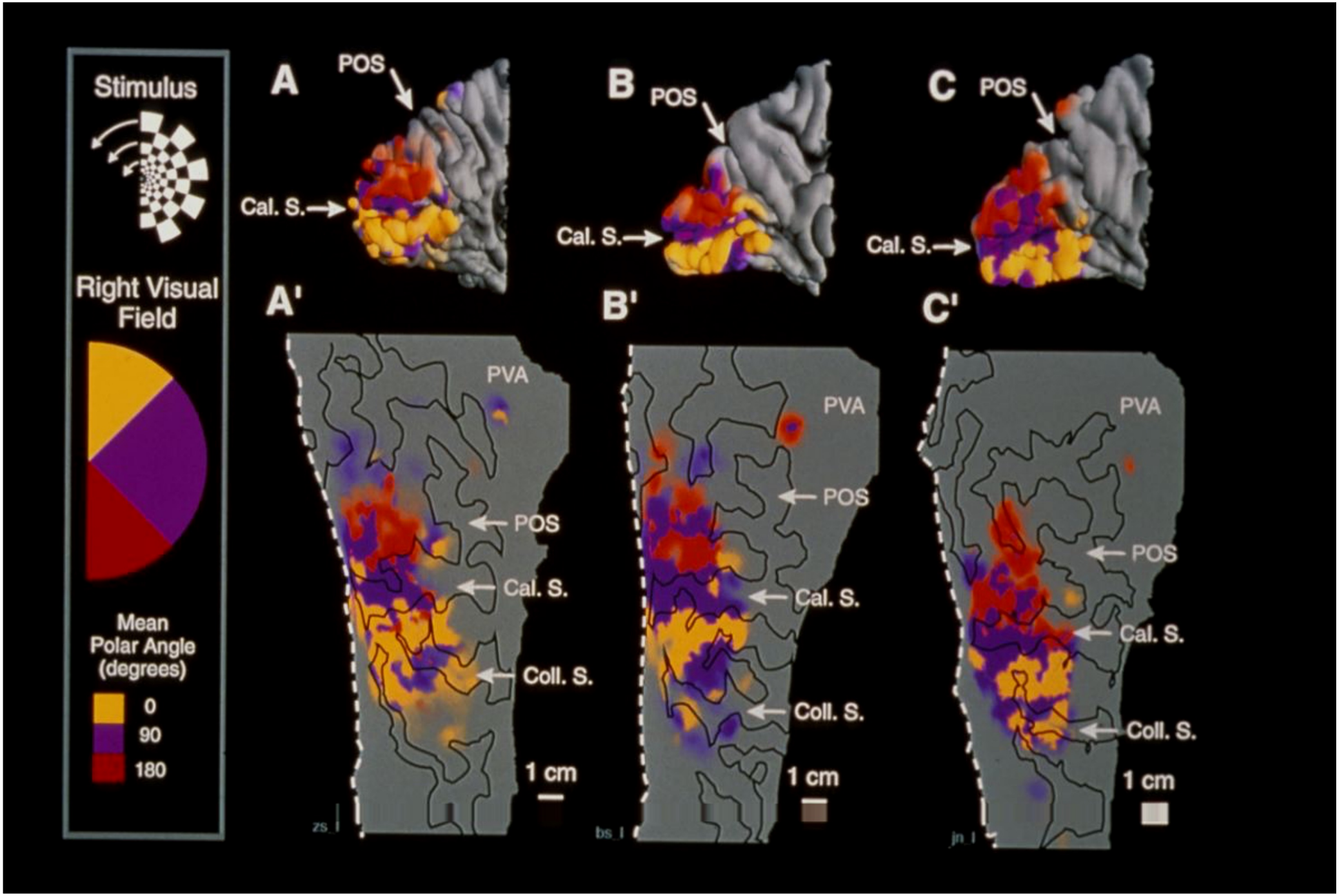

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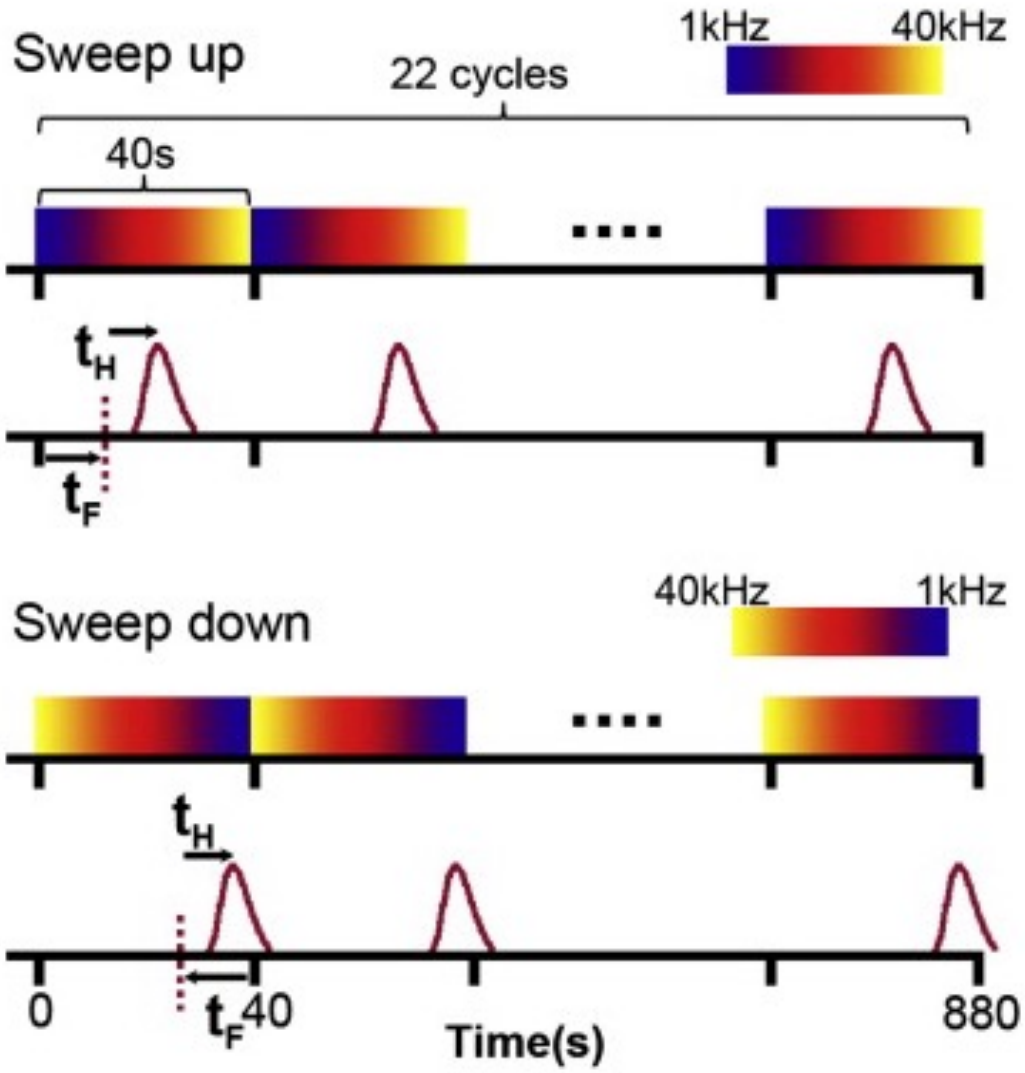
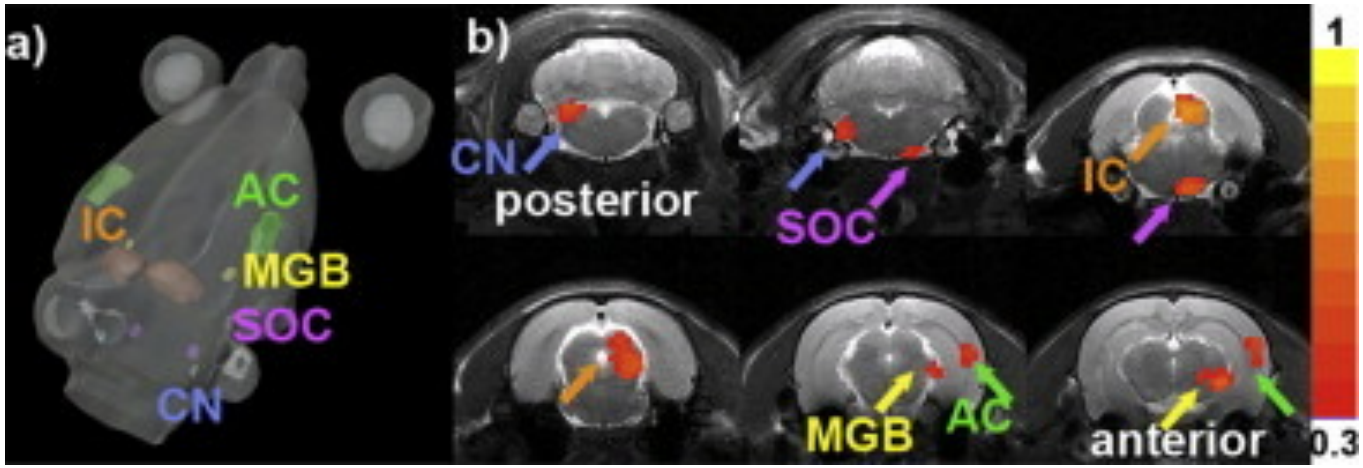
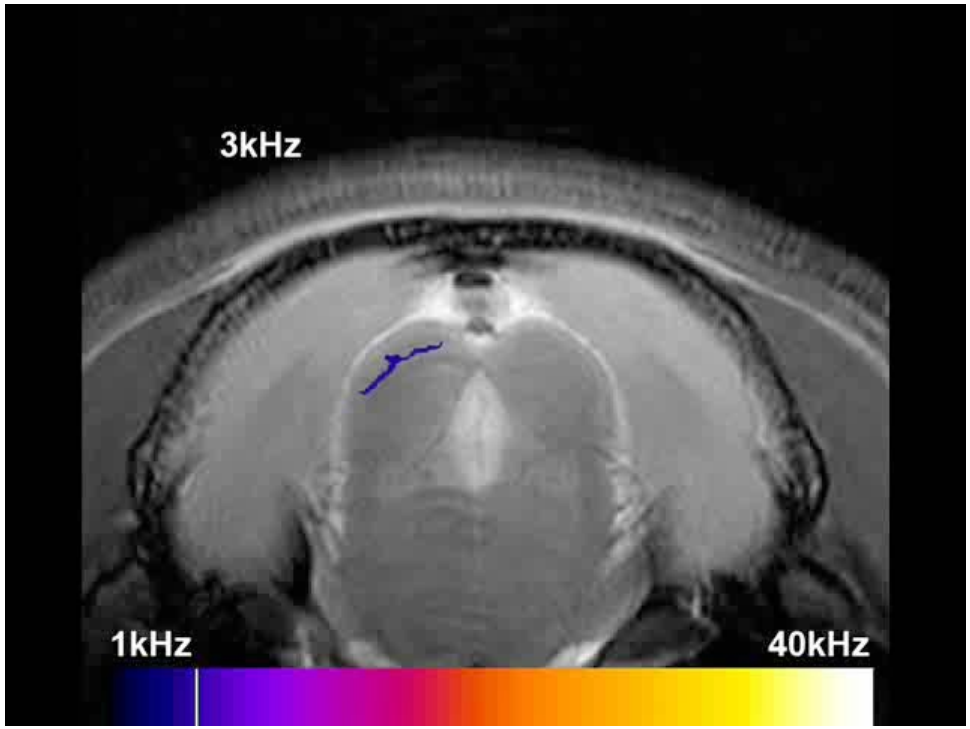


High fidelity tonotopic mapping using swept source functional magnetic resonance imaging, MM Cheung et al. NeuroImage Volume 61, Issue 4, 16 July 2012, Pages 978-986





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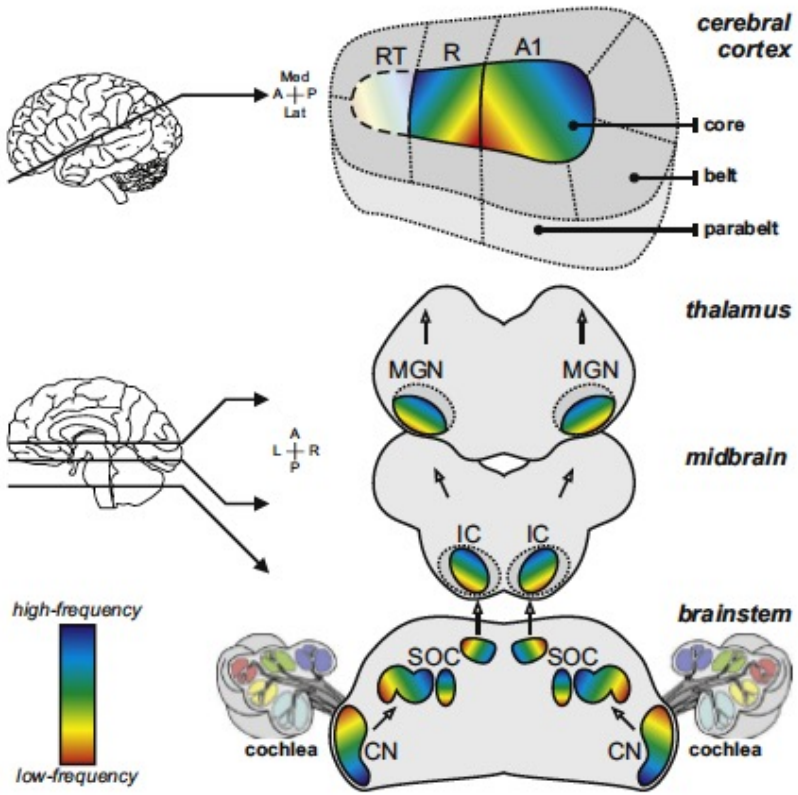
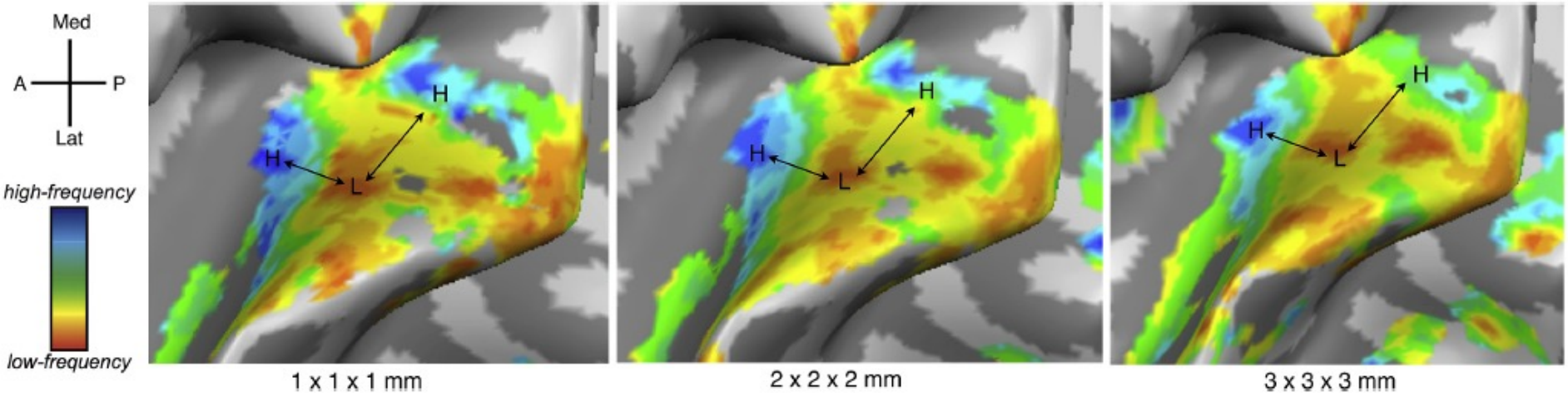
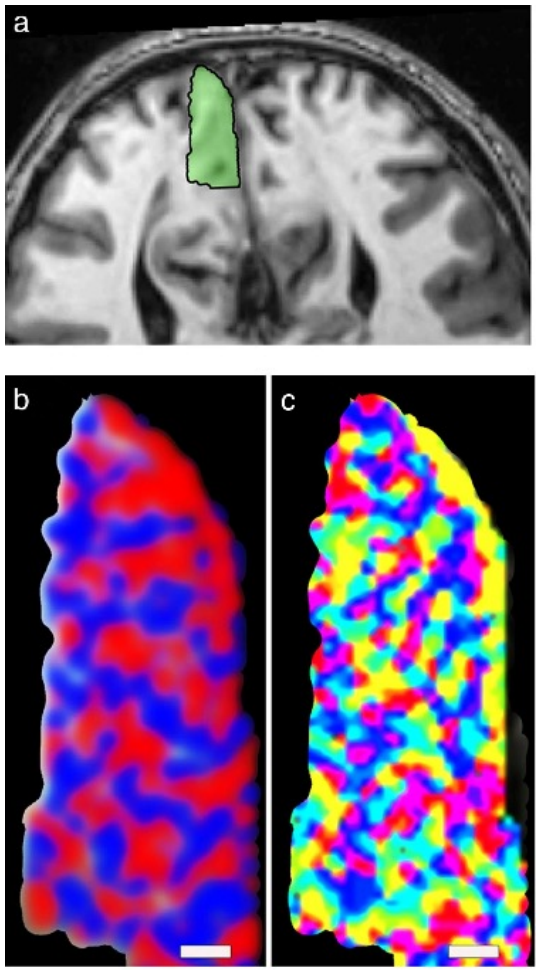
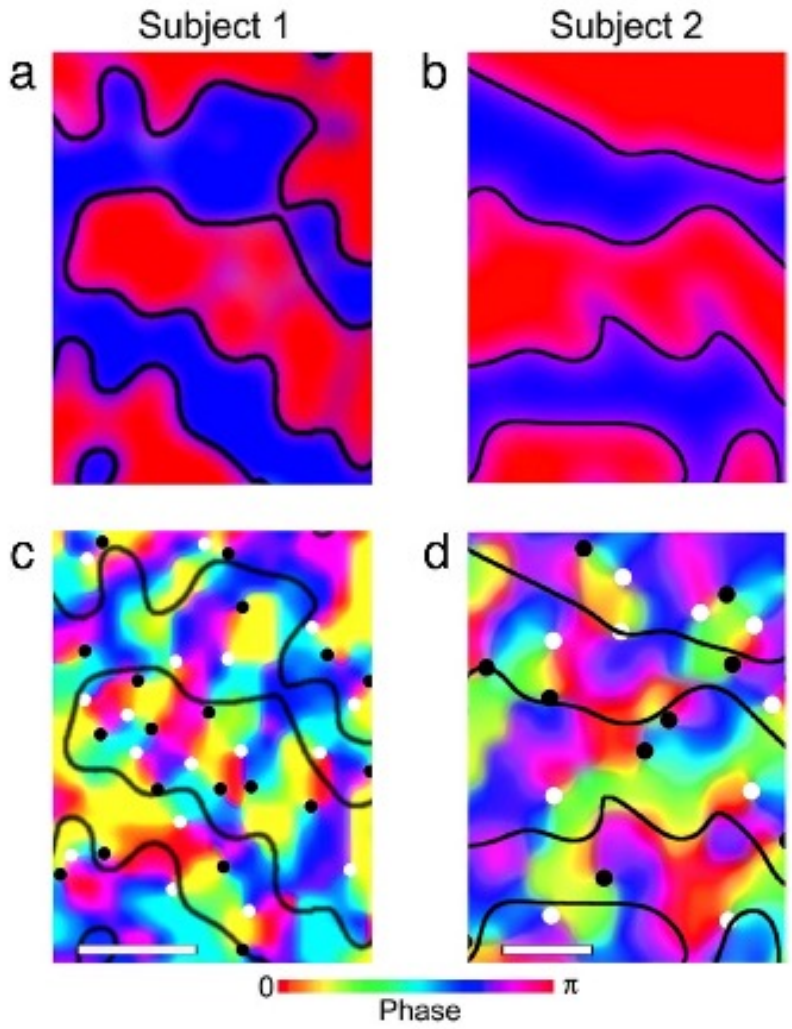
Tonotopic mapping of human auditory cortex
Melissa Saenz, Dave R.M. Langers, Hearing Research, 307, 42-52 (2014)





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





High-field fMRI unveils orientation columns in humans,
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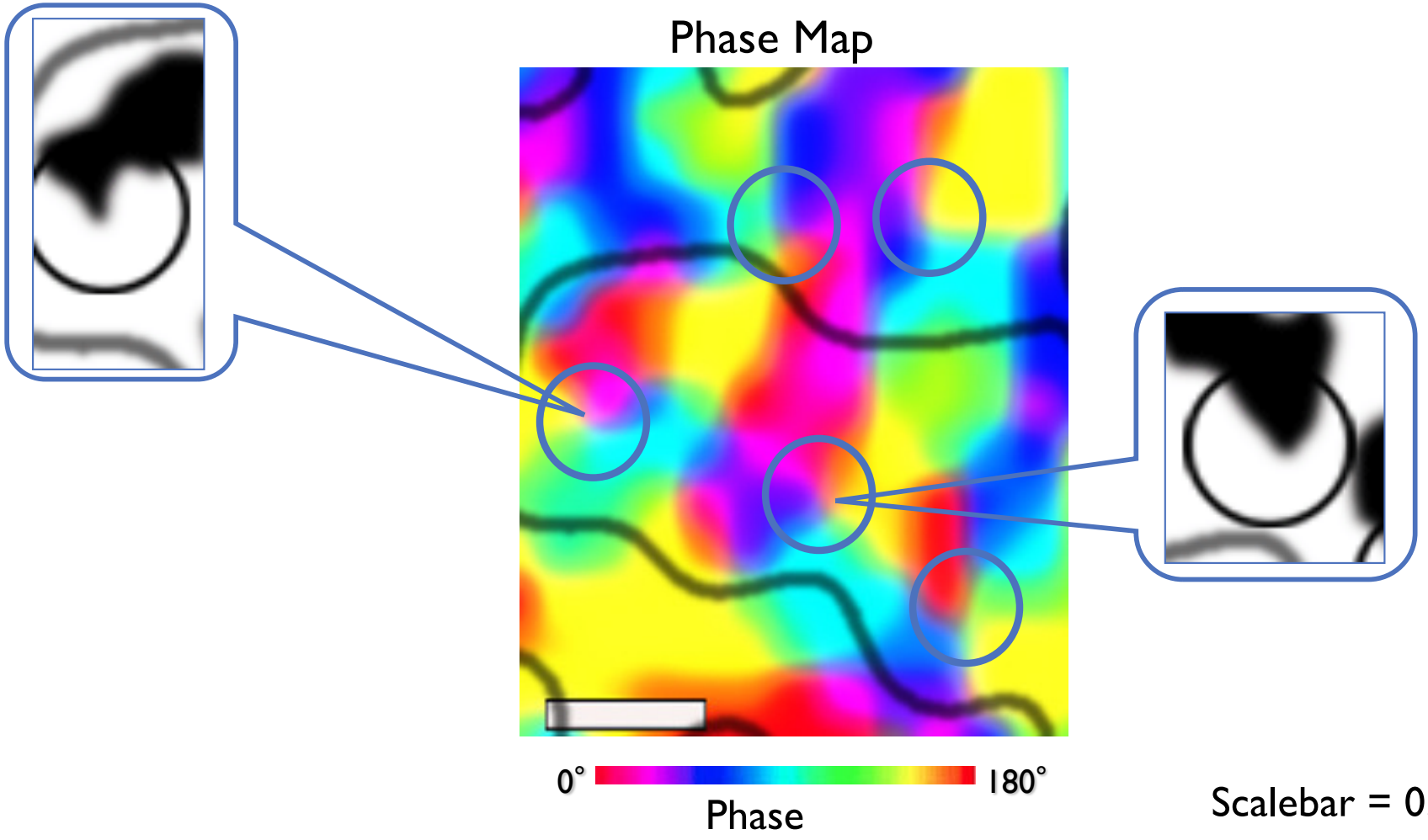

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Neuronal Activation Input Strategies

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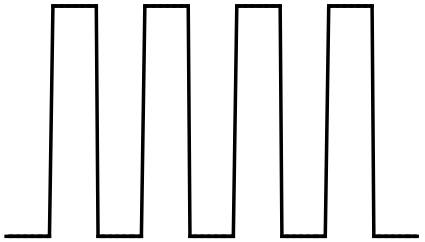

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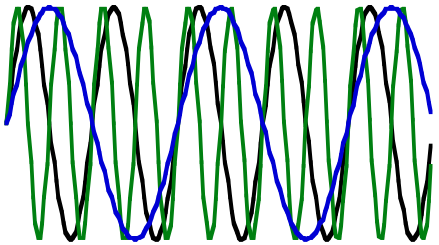

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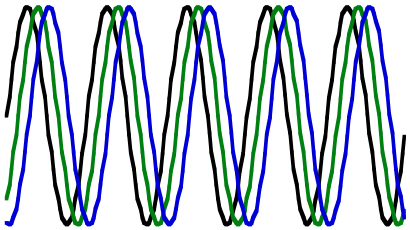

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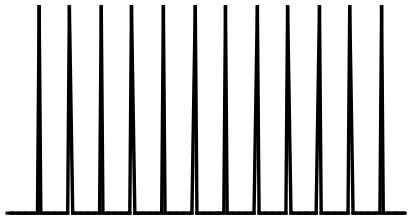

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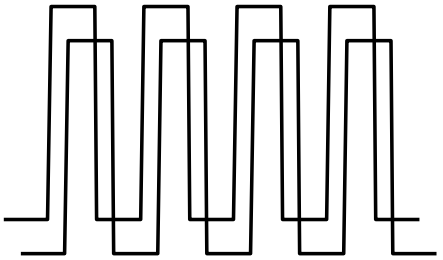

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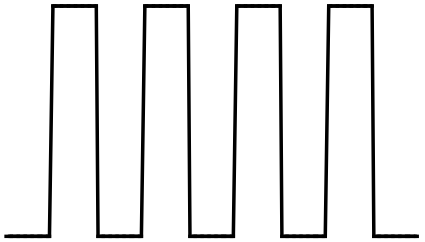

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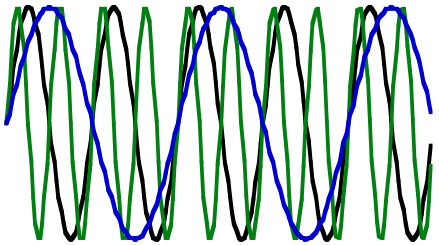

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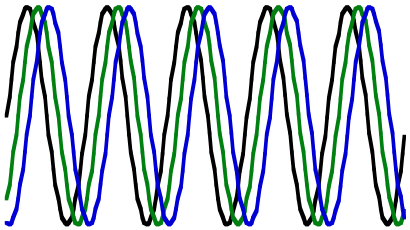

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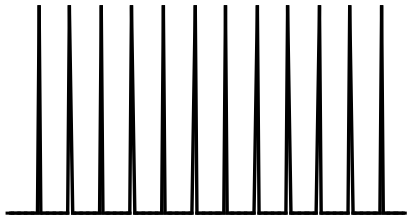

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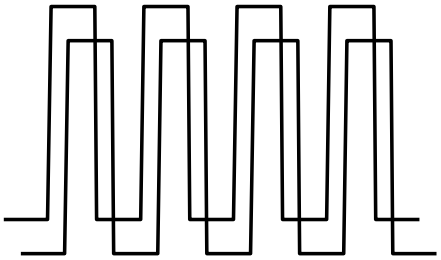

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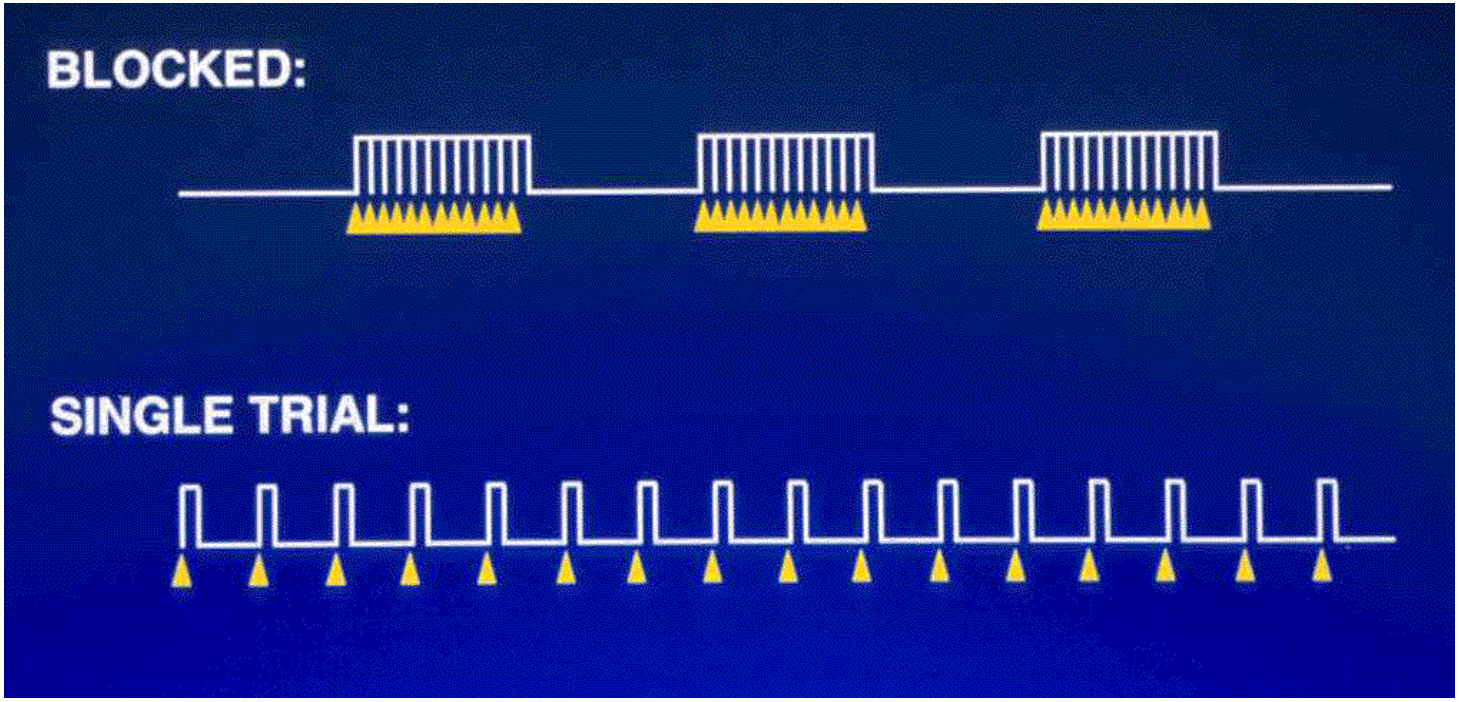
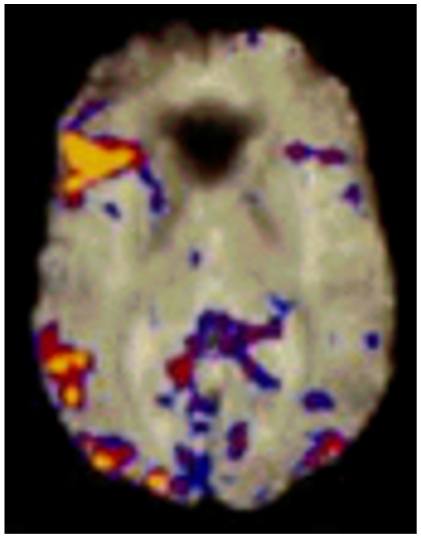
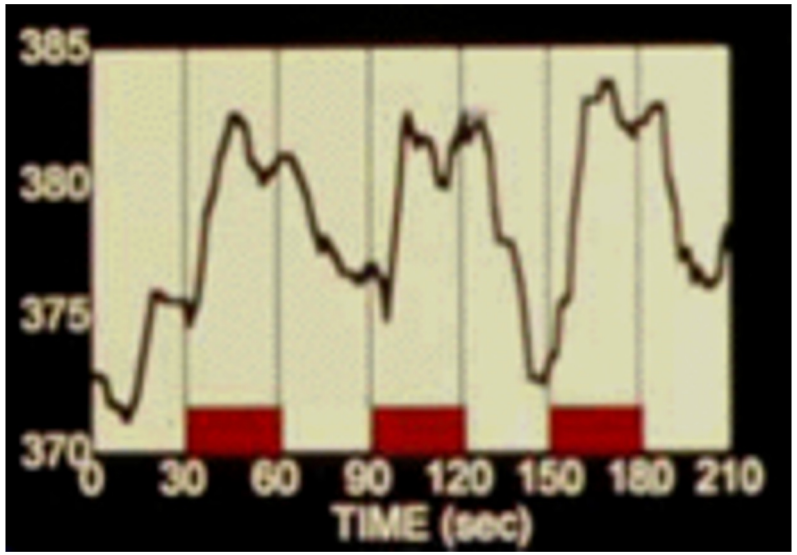
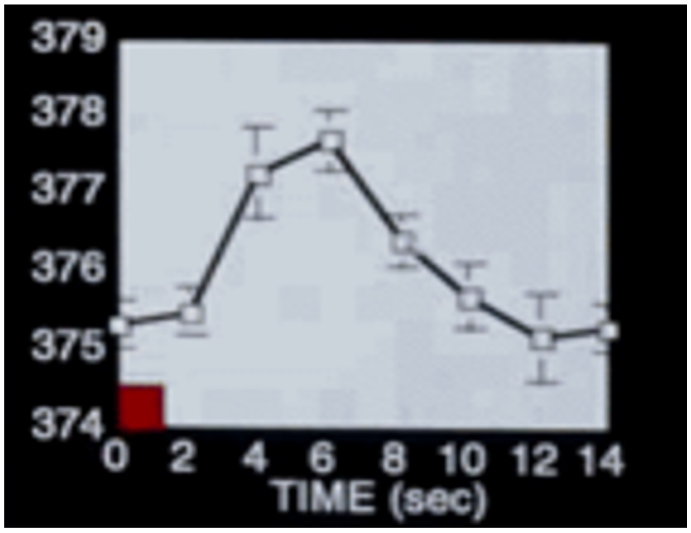
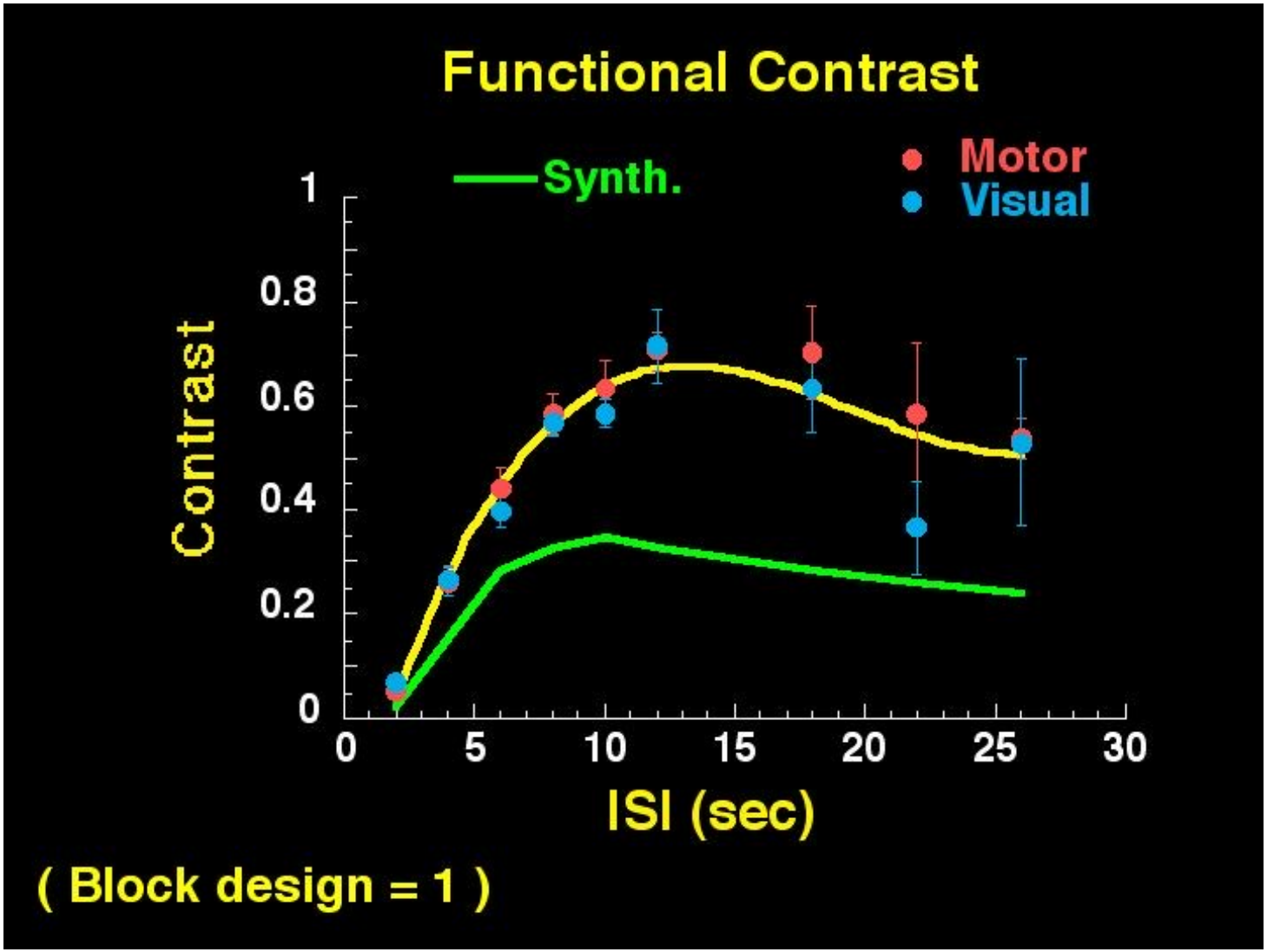








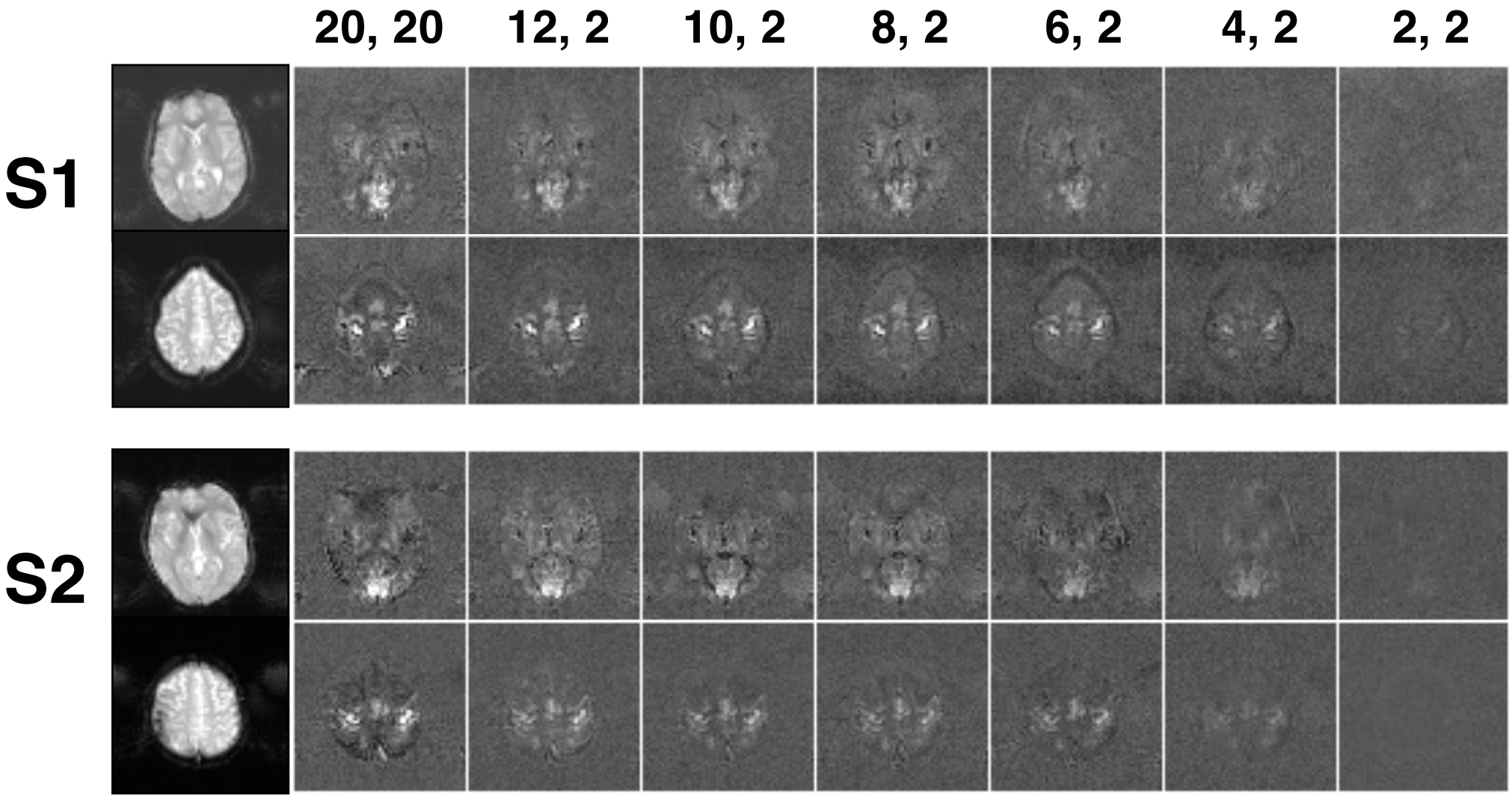
R. L. Buckner, P. A. Bandettini, K. M. O'Craven, R. L. Savoy, S. E. Peterson, M. E. Raichle, T. L. Brady, B. R. Rosen, fMRI detection and time course of distributed cortical activations during single trials of a cognitive task. *Proc. Nat'l. Acad. Sci. USA* 93, 14878-14883 (1996).



P. A. Bandettini, R. W. Cox. Functional contrast in constant interstimulus interval event - related fMRI: theory and experiment. *Magn. Reson. Med.* 43: 540-548 (2000).

Contrast to Noise Images

(ISI, SD)



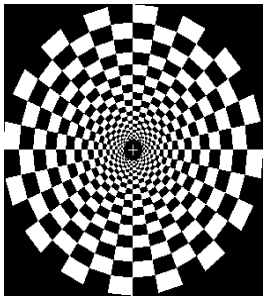
P. A. Bandettini, R. W. Cox. Functional contrast in constant interstimulus interval event - related fMRI: theory and experiment. *Magn. Reson. Med.* 43: 540-548 (2000).

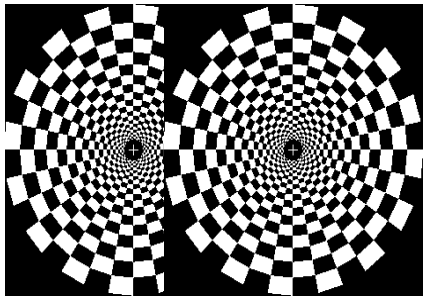
◆ Human Brain Mapping 5:329–340(1997) ◆

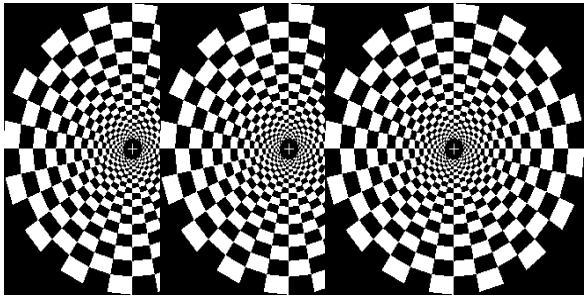
Selective Averaging of Rapidly Presented Individual Trials Using fMRI

Anders M. Dale* and Randy L. Buckner

Massachusetts General Hospital Nuclear Magnetic Resonance Center and the Department of Radiology, Harvard Medical School, Boston, Massachusetts 02129



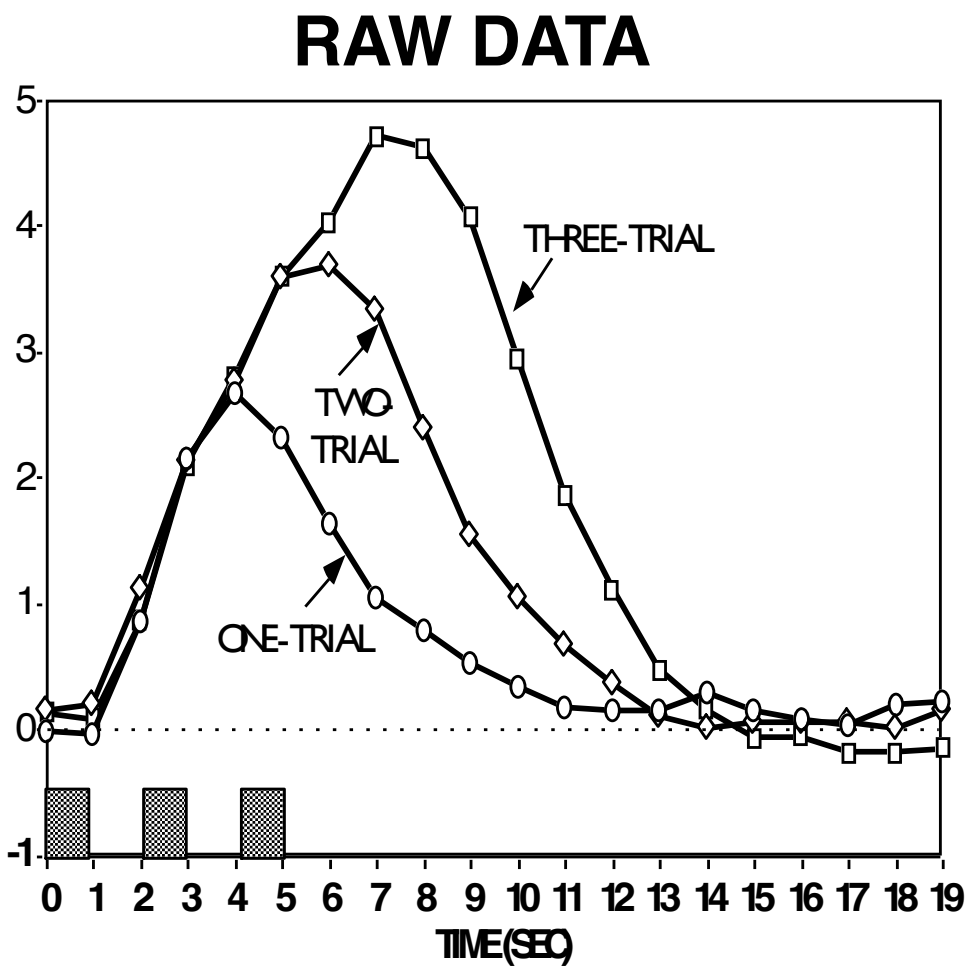


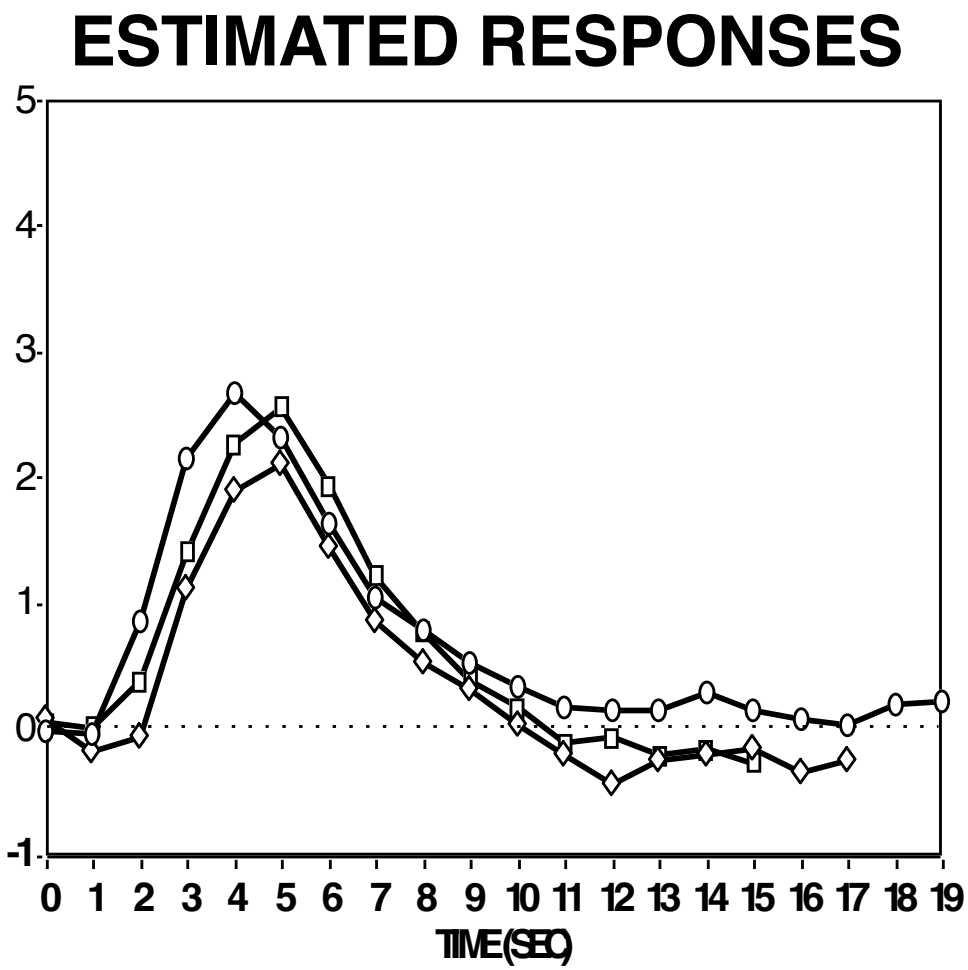


0 sec 20 sec

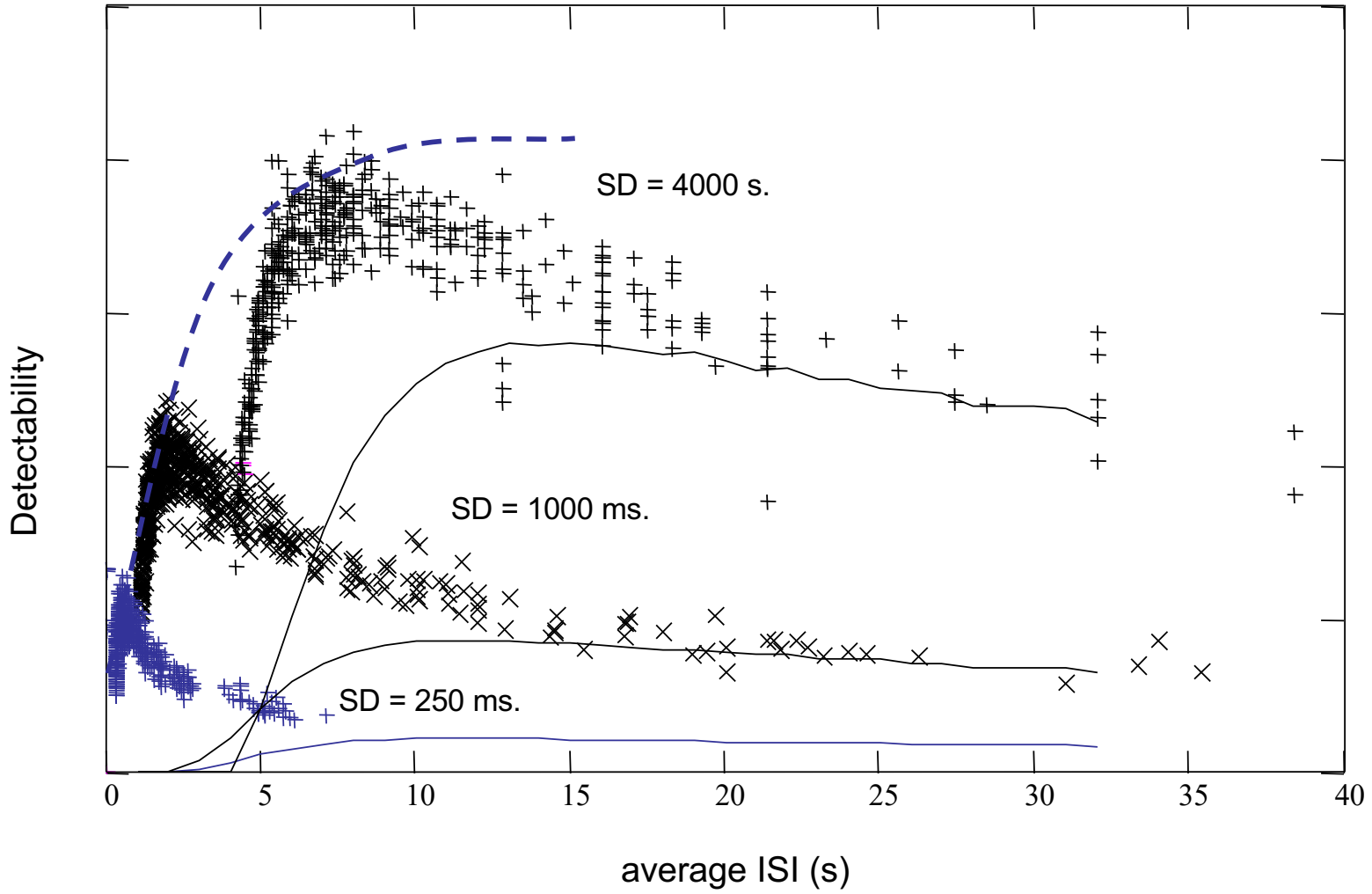
0 sec2 sec 20 sec

0 sec2 sec4 sec 20 sec


RAW DATA
5
4
3
2
1
0
-1
THREE-TRIAL
TWO-TRIAL
ONE-TRIAL
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
TIME(SEC)

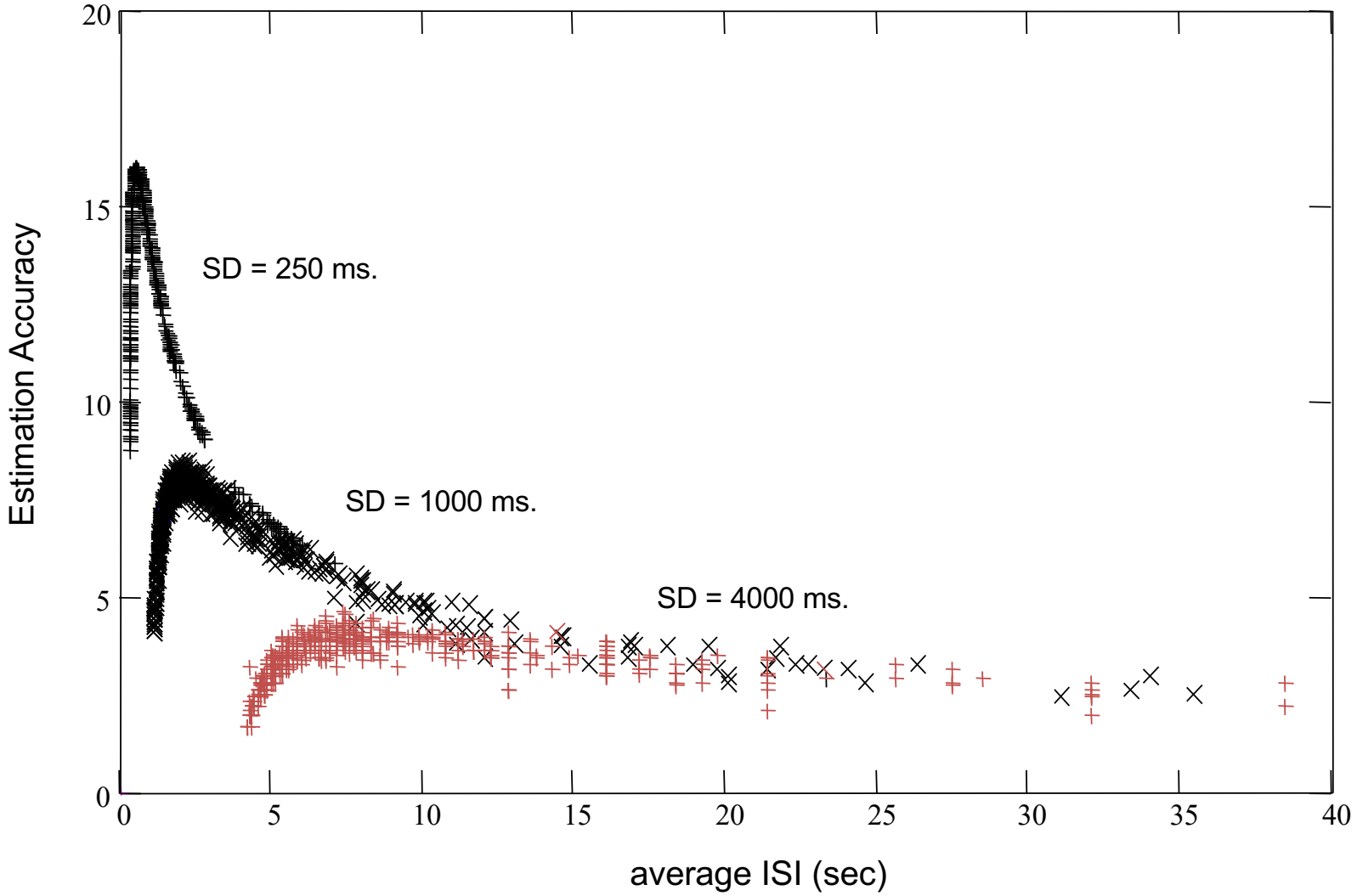

ESTIMATED RESPONSES
5
4
3
2
1
0
-1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
TIME(SEC)

Detectability vs. Average ISI



R. M. Birn, R. W. Cox, P. A. Bandettini, Detection versus estimation in Event-Related fMRI: choosing the optimal stimulus timing. *NeuroImage* 15: 262-264, (2002).

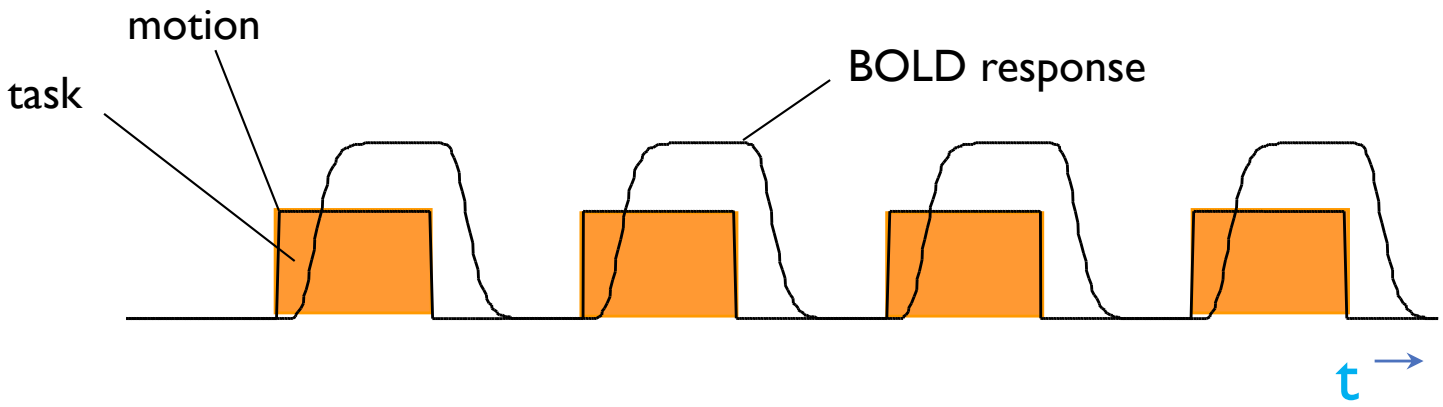
Estimation accuracy vs. average ISI



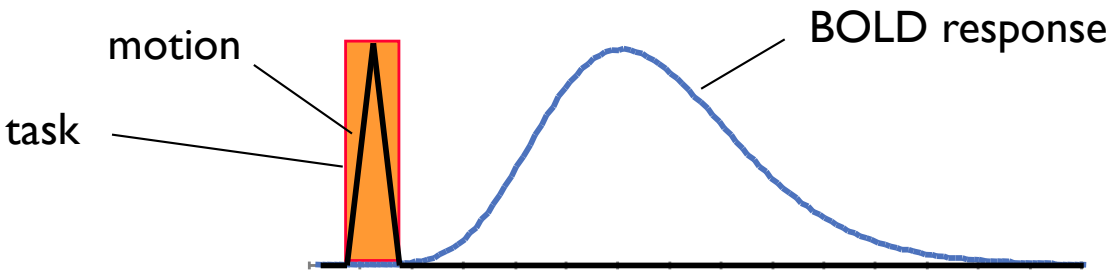
R. M. Birn, R. W. Cox, P. A. Bandettini, Detection versus estimation in Event-Related fMRI: choosing the optimal stimulus timing. *NeuroImage* 15: 262-264, (2002).

fMRI during tasks that involve brief motion

Blocked Design

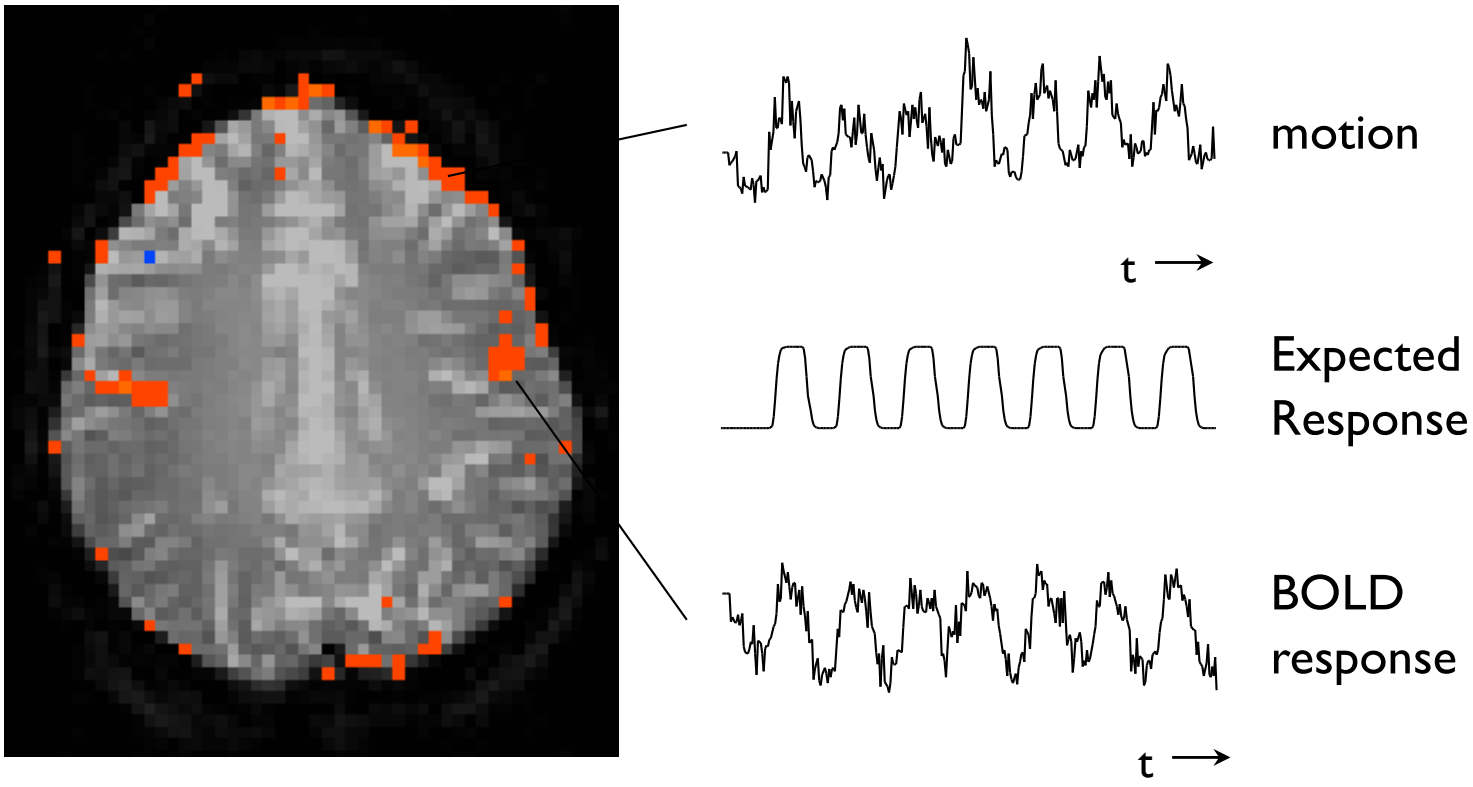


Event-Related Design



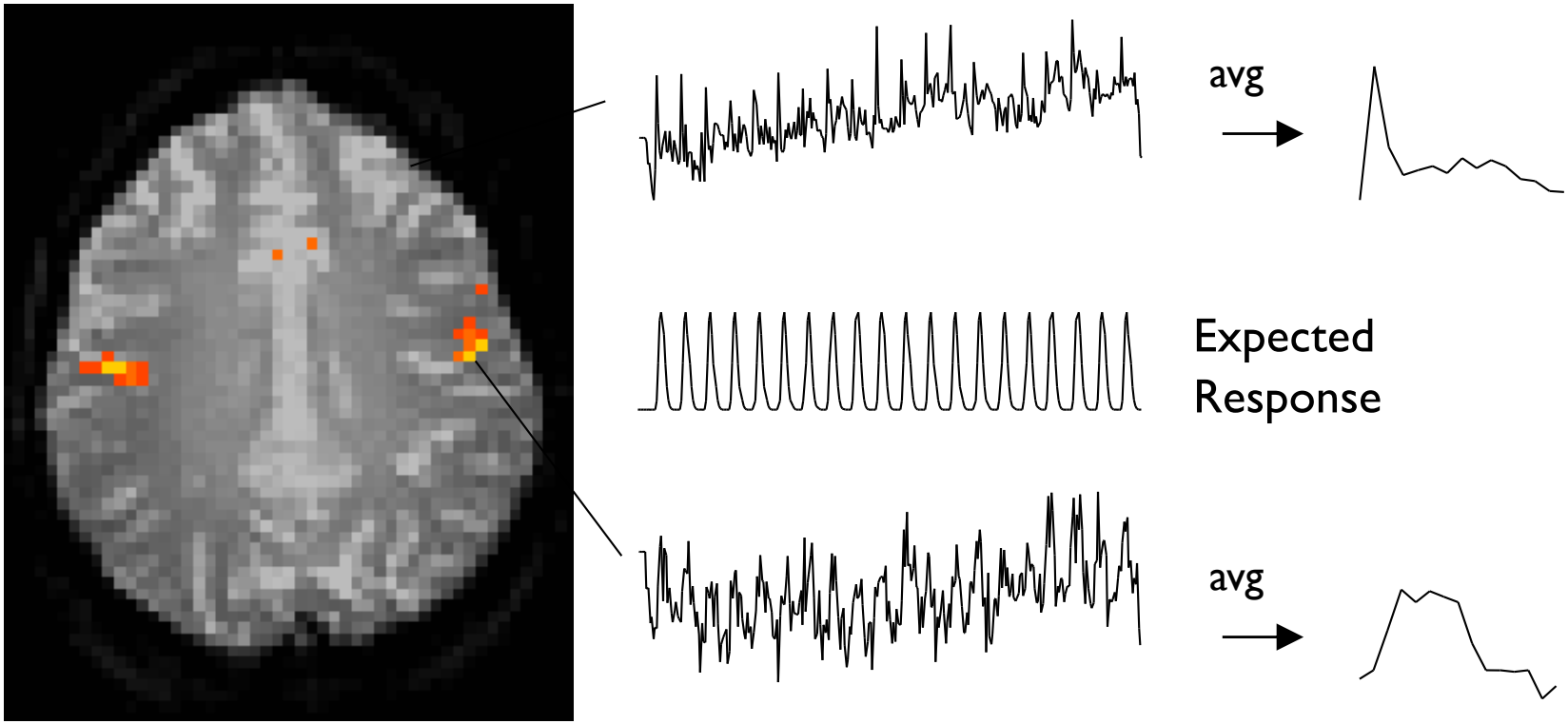
R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

Speaking - Blocked Trial



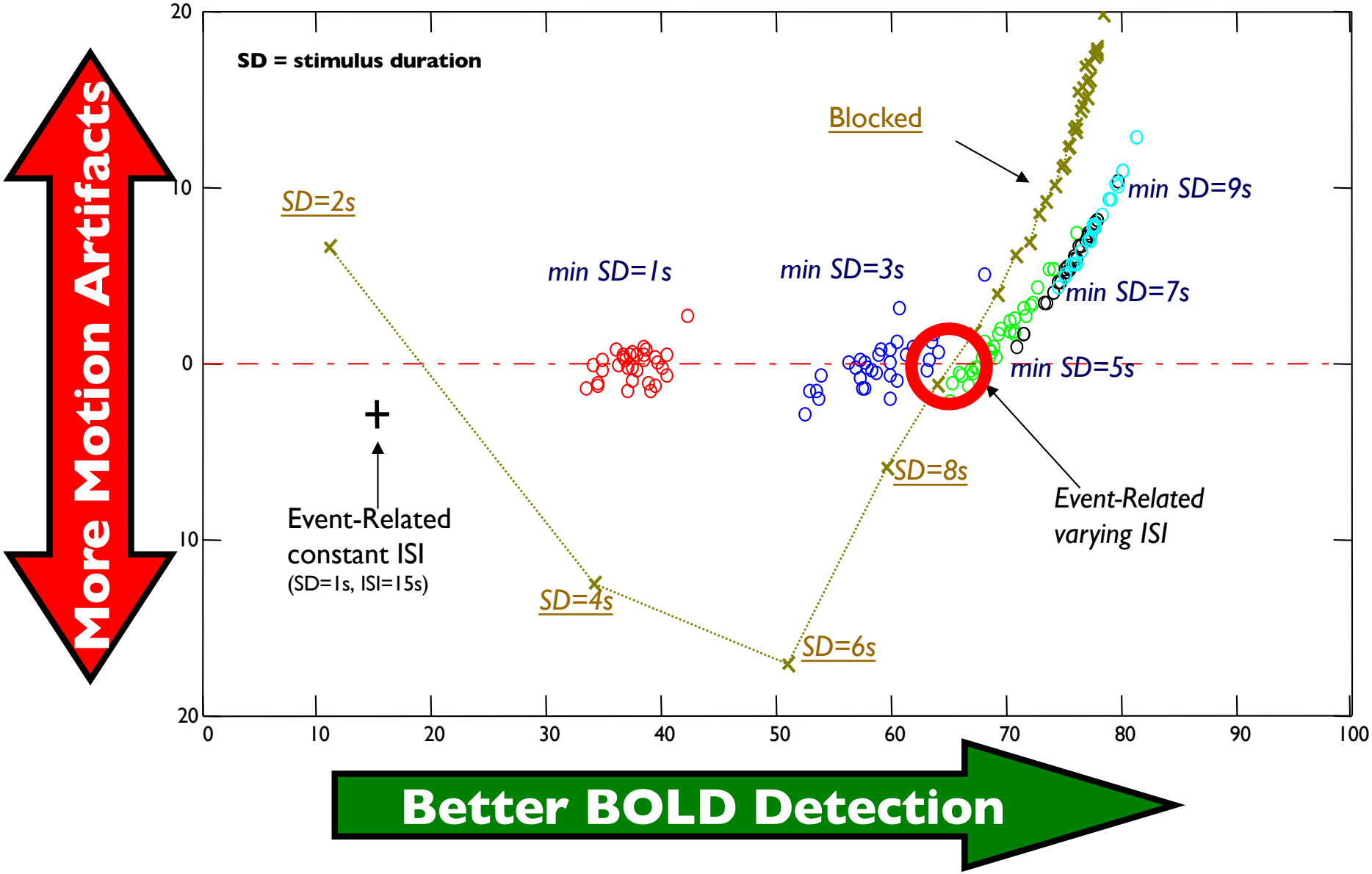
R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

Speaking - ER-fMRI



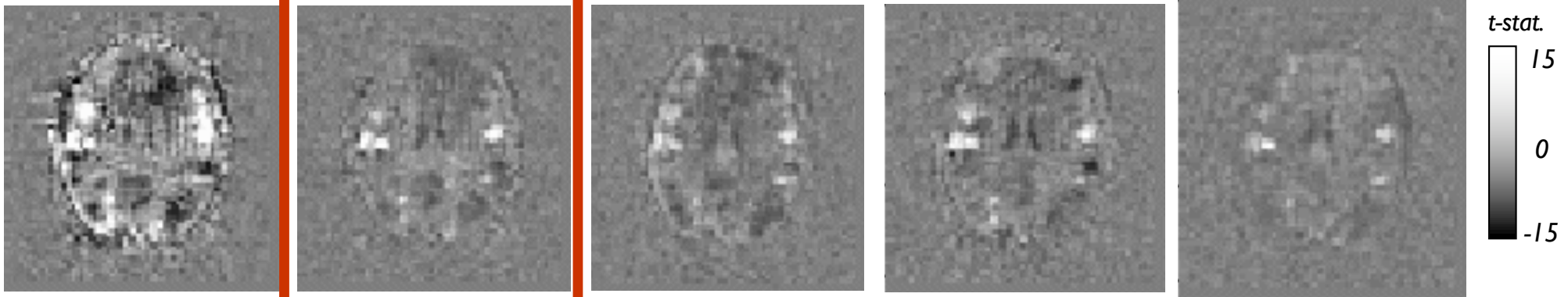
R. M. Birn, P. A. Bandettini, R. W. Cox, R. Shaker, Event - related fMRI of tasks involving brief motion. *Human Brain Mapping* 7: 106-114 (1999).

Overt Responses - Simulations



R.M. Birn, R.W. Cox, P.A. Bandettini, *NeuroImage,* 23, 1046-1058 (2004)

Overt Responses



Blocked design (30s/30s)

Blocked design (10s/10s)

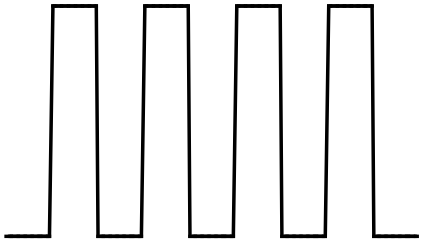
Event-related Varying ISI (1s min. SD)

Event-related Varying ISI (5s min. SD)

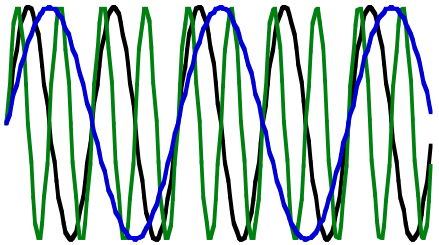
Event-related constant ISI (1s. SD, 15sISI)

Neuronal Activation Input Strategies

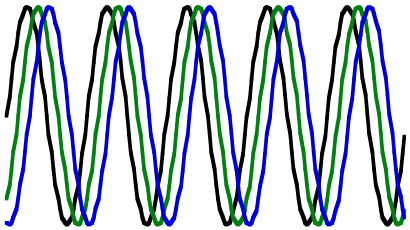
1. Block Design



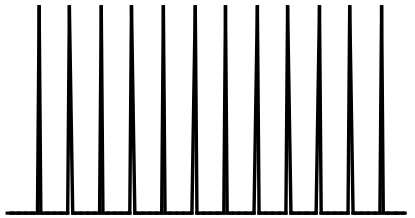
2. Frequency Encoding



3. Phase Encoding

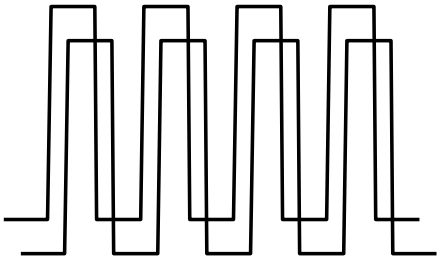


4. Event-Related



5. fMRI adaptation

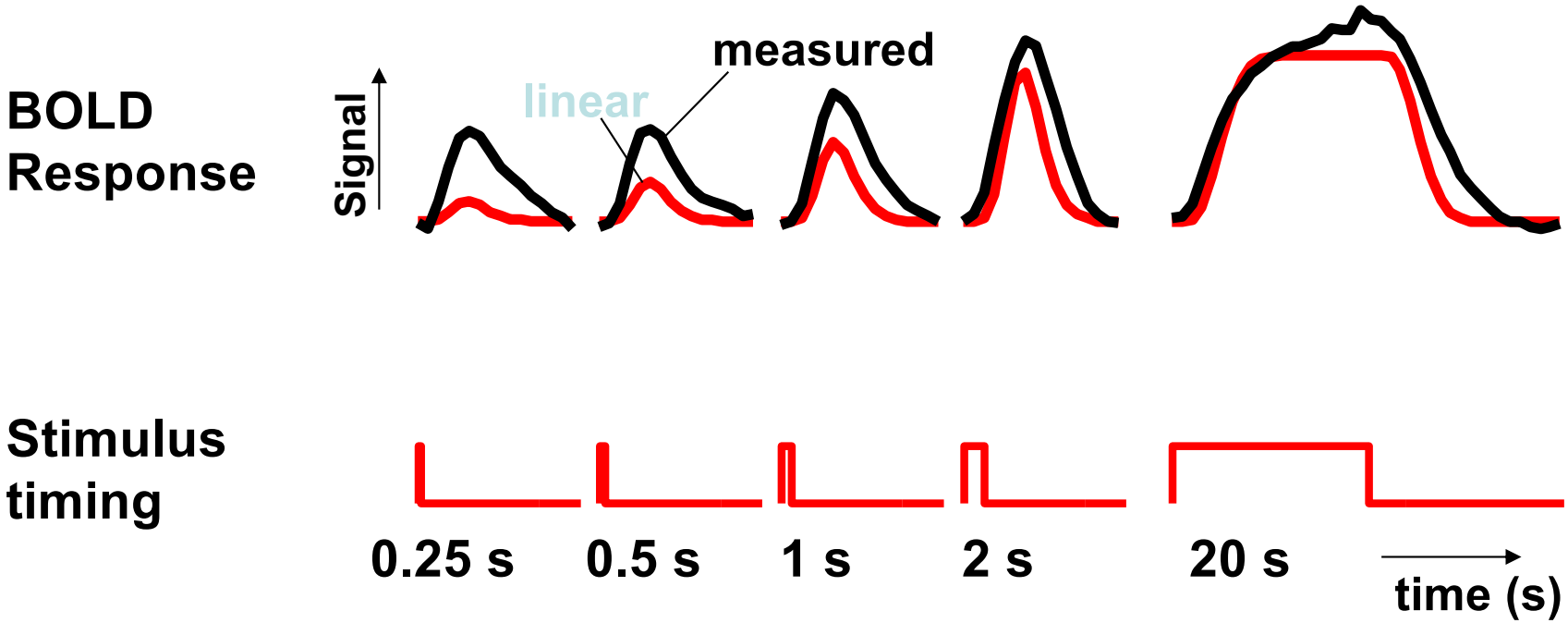
6. Orthogonal Block Design



7. Free Behavior Design.

Dynamic Nonlinearity Assessment

Different stimulus "ON" periods

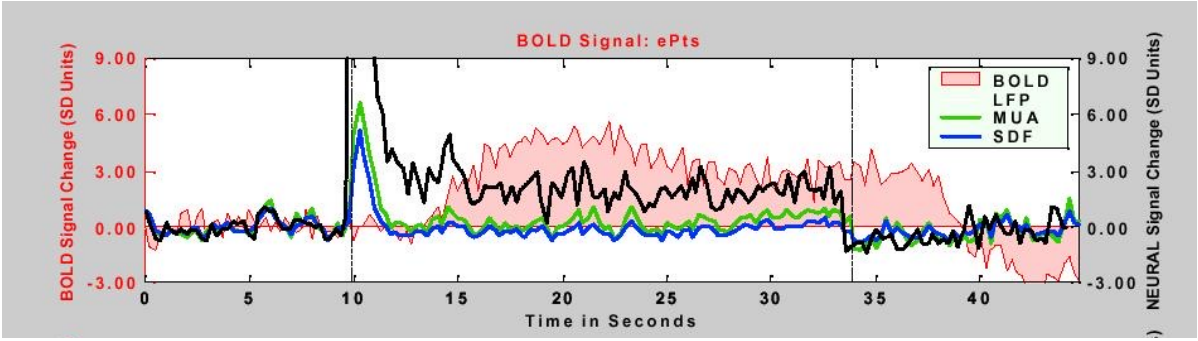


Brief stimuli produce larger responses than expected

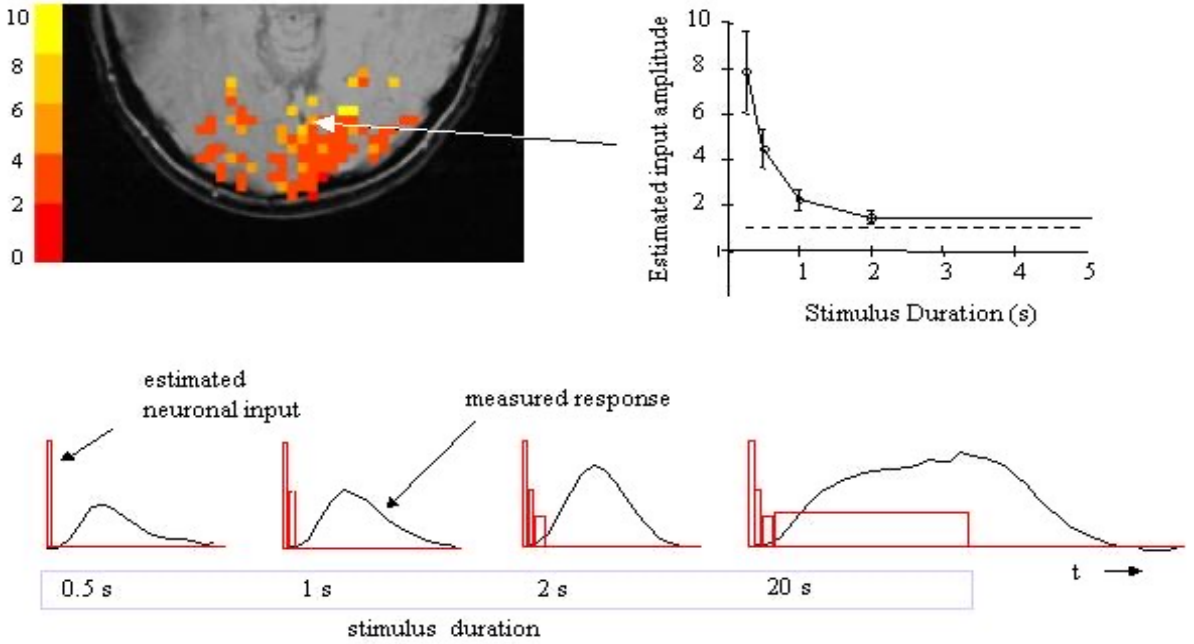
R. M. Birn, Z. Saad, P. A. Bandettini, (2001) "Spatial heterogeneity of the nonlinear dynamics in the fMRI BOLD response." *NeuroImage*, 14: 817-826.

BOLD Correlation with Neuronal Activity

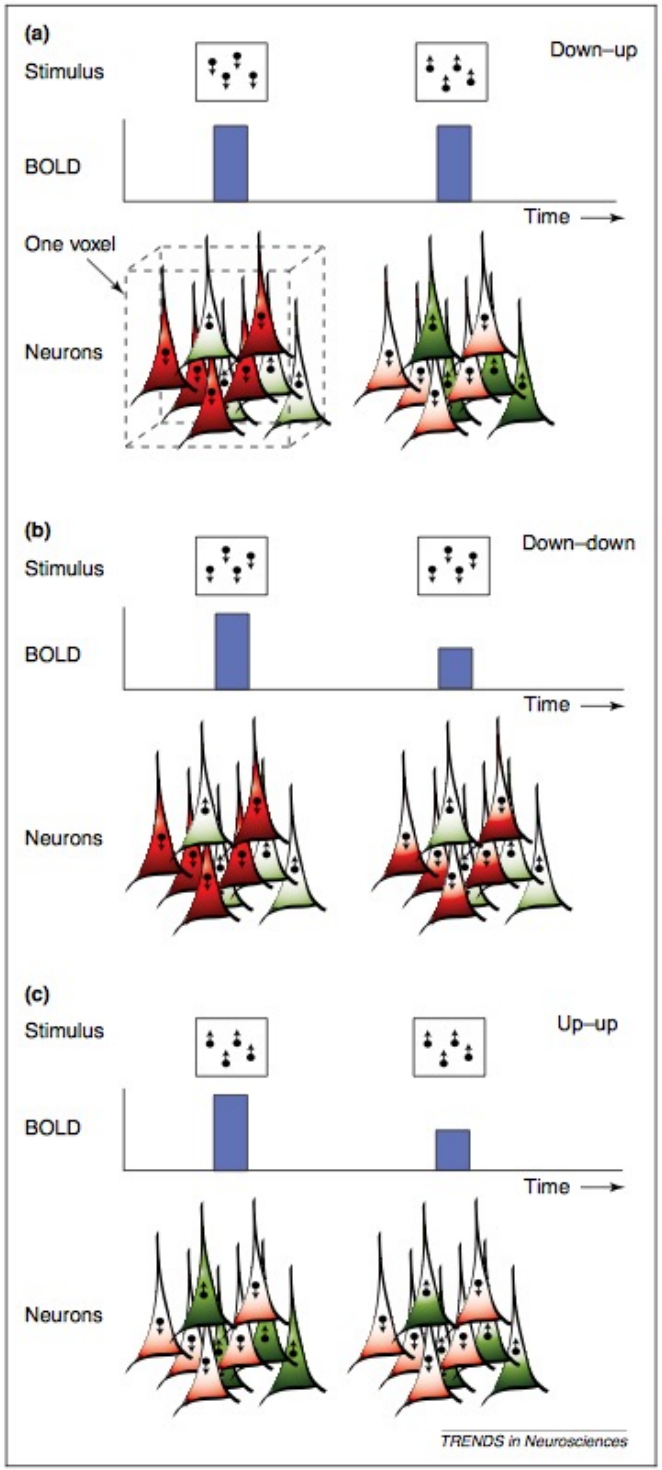
Logothetis et al. (2001) "Neurophysiological investigation of the basis of the fMRI signal" Nature, 412, 150-157.

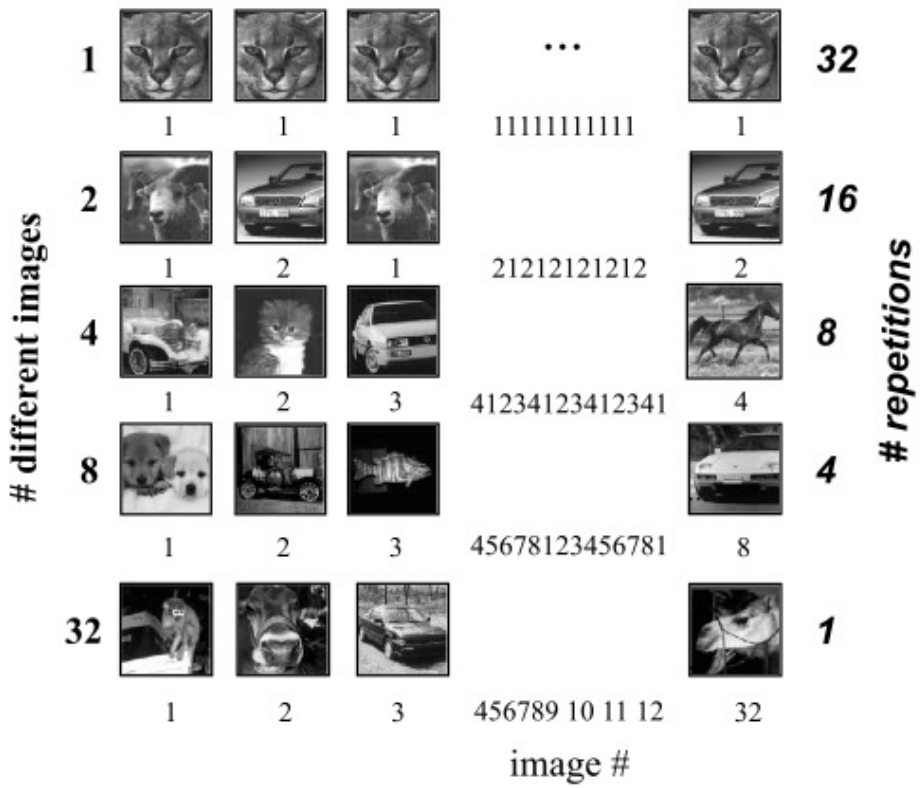


P. A. Bandettini and L. G. Ungerleider, (2001) "From neuron to BOLD: new connections." Nature Neuroscience, 4: 864-866.

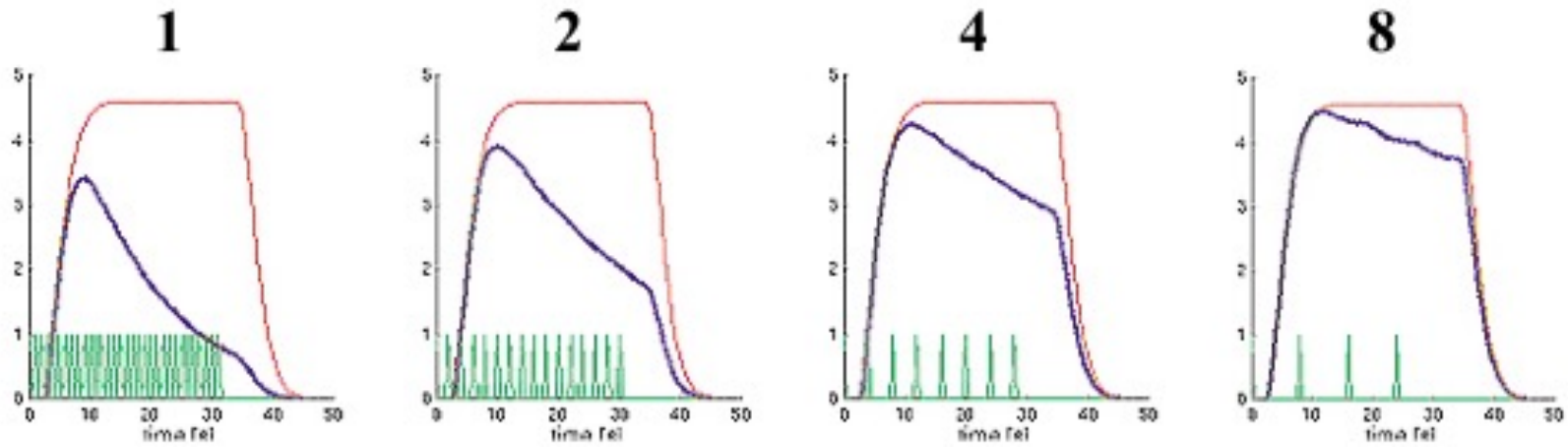


Adaptation: from single cells to BOLD signals, Bart Krekelberg, Geoffrey M. Boynton, and Richard J.A. van Wezel, Trends in Neurosciences, 29, 5, 2006



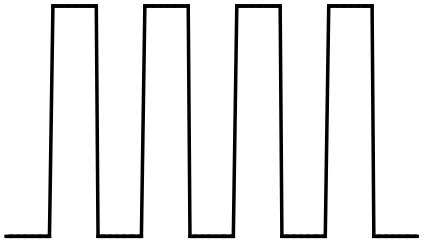


fMR-adaptation: a tool for studying the functional properties of human cortical neurons Kalanit Grill-Spector, Rafael Malach, Acta Psychologica, 107 (2001), 293-321

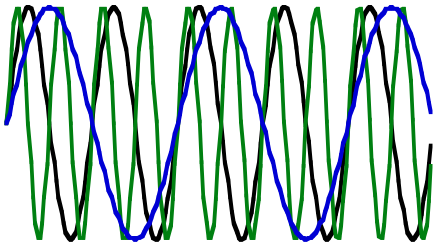


Neuronal Activation Input Strategies

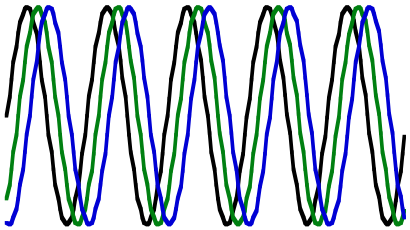
1. Block Design



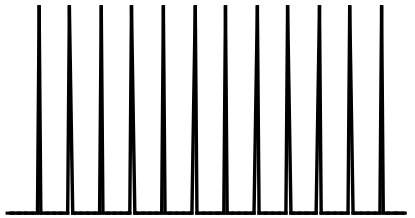
2. Frequency Encoding



3. Phase Encoding

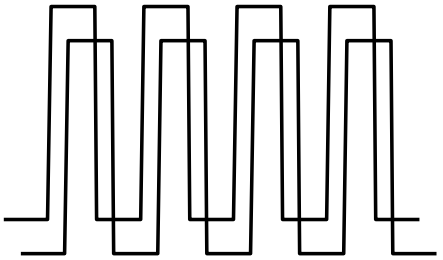


4. Event-Related



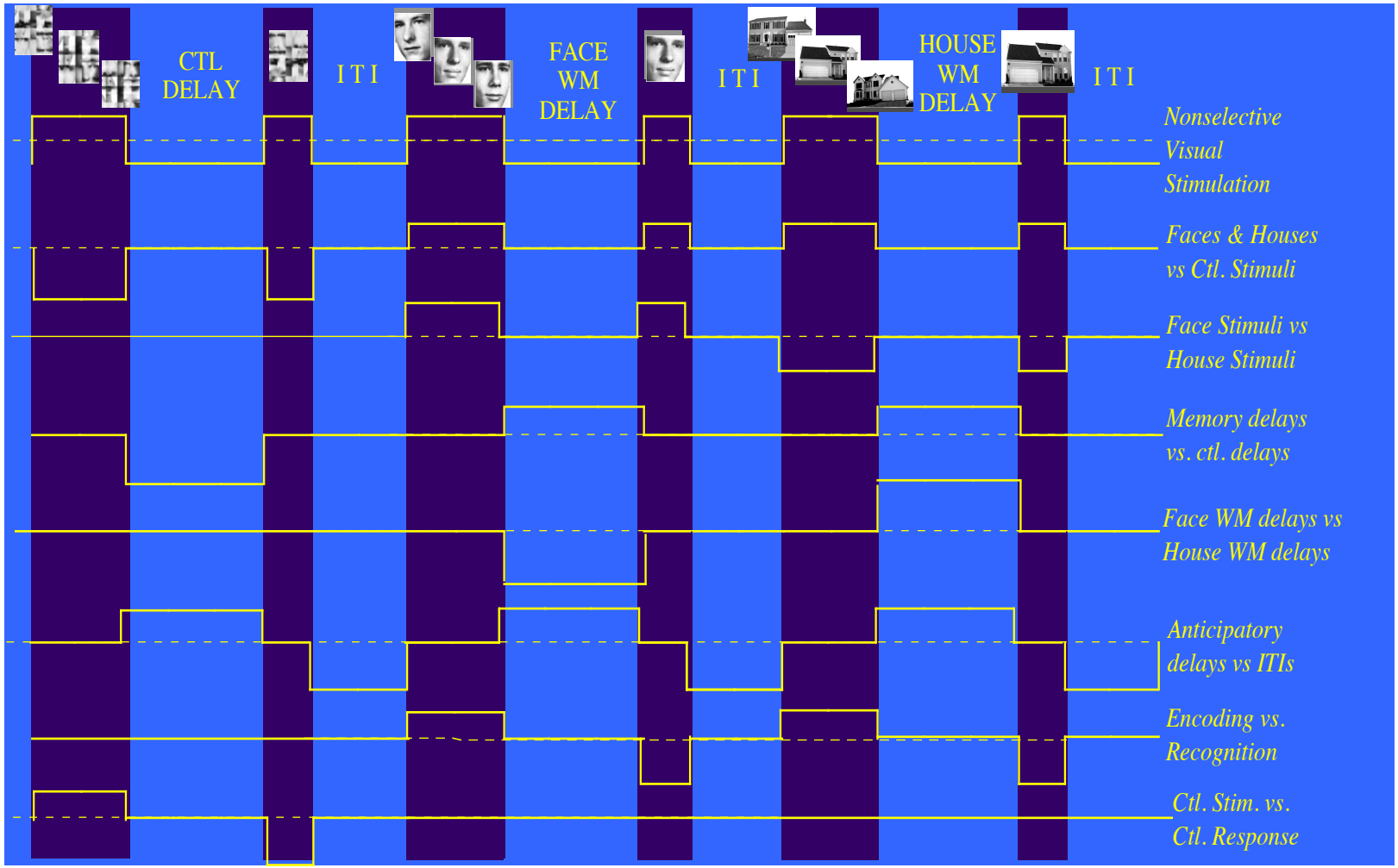
5. fMRI adaptation

6. Orthogonal Block Design



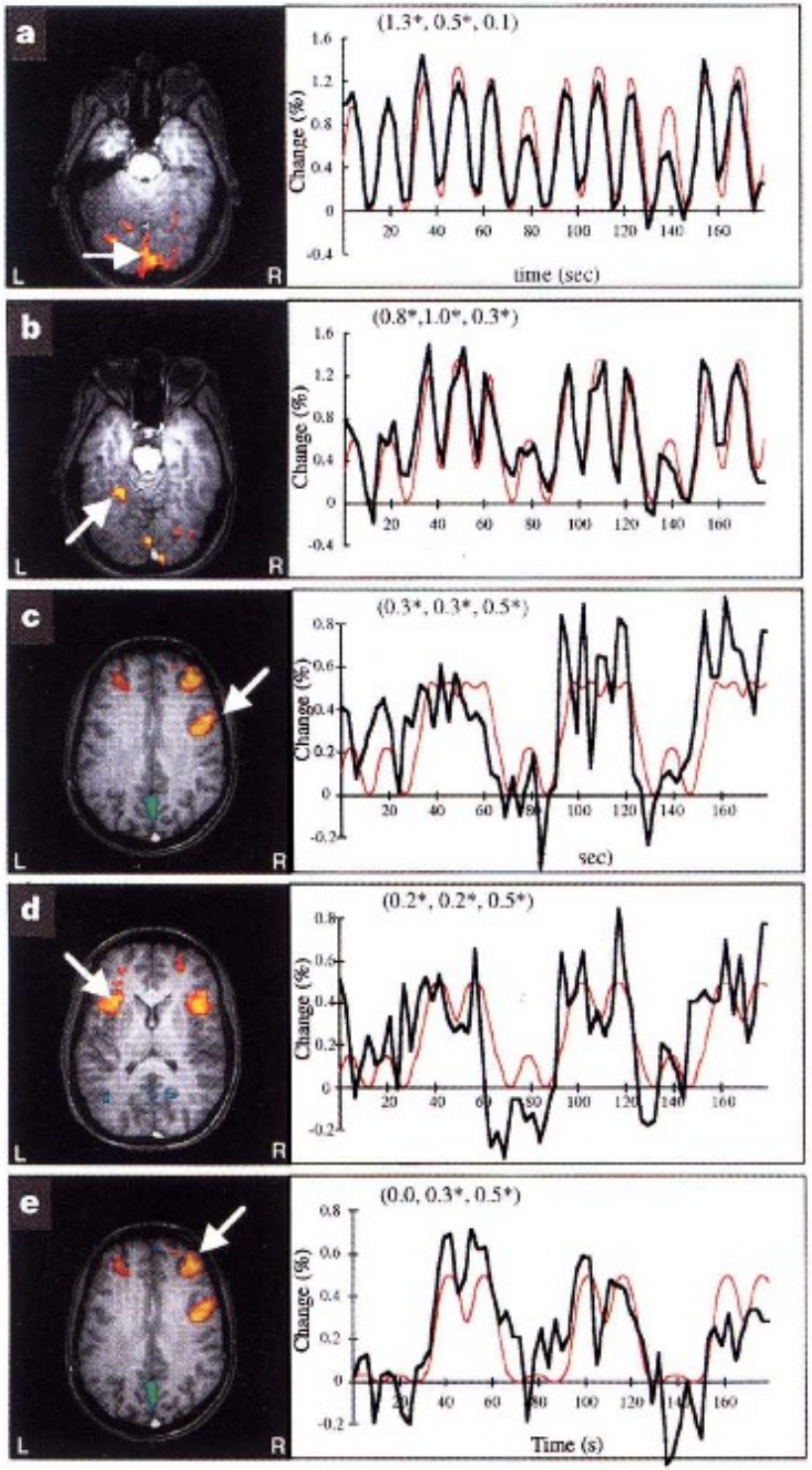
7. Free Behavior Design

Example of a Set of Orthogonal Contrasts for Multiple Regression



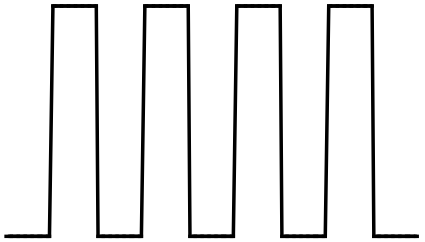
Transient and Sustained activity in a distributed neural system for human working memory, S. M. Courtney, L. G. Ungerleider, K. Keil, J. V. Haxby, Nature, 386, pp. 608-611

Transient and Sustained activity in a distributed neural system for human working memory, S. M. Courtney, L. G. Ungerleider, K. Keil, J. V. Haxby, Nature, 386, pp. 608-611



Neuronal Activation Input Strategies

1. Block Design



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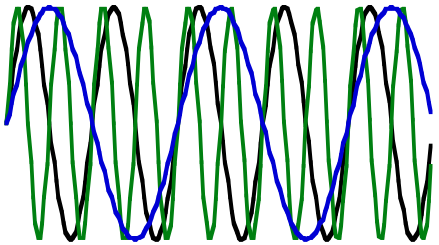
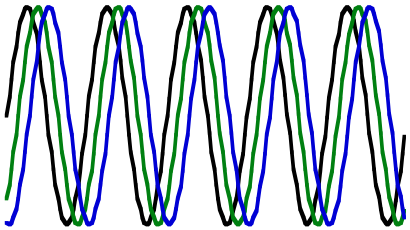
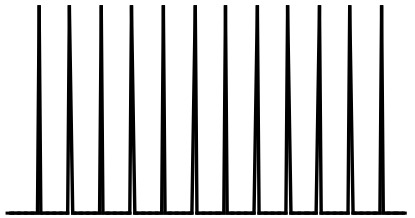


3. Phase Encoding

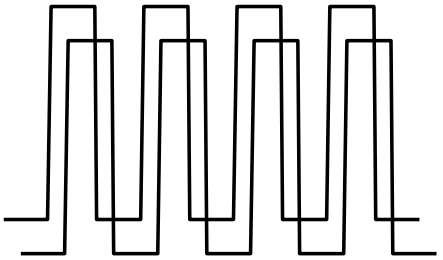


4. Event-Related



5. fMRI adaptation

6. Orthogonal Block Design



7. Free Behavior Design

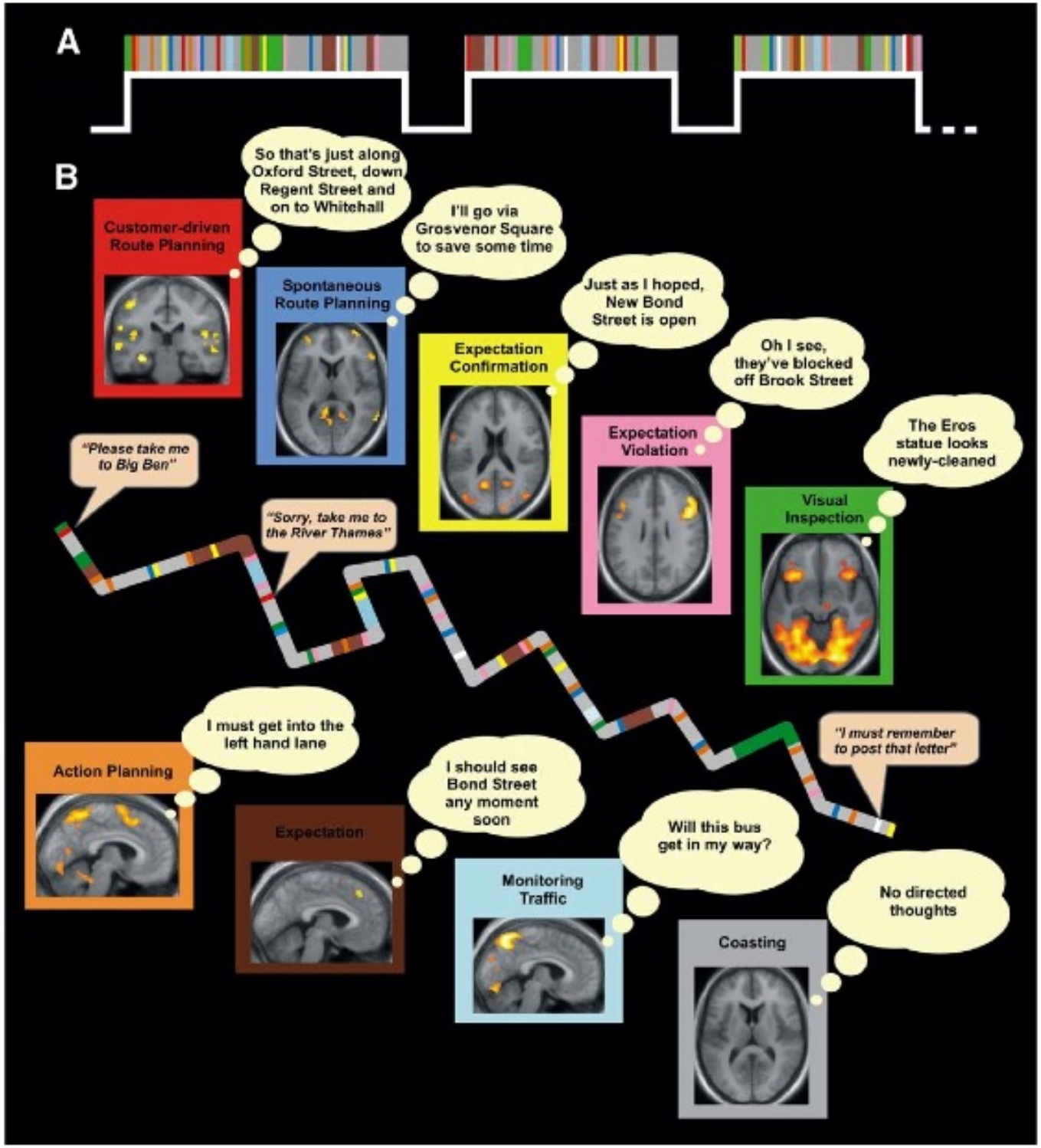
Free behavior or naturalistic or continuous stimuli

Maguire – navigation
U. Hasson – time reversal, cross subject
Gallant – semantic space multiple regression
DARPA competition – guess what's happening

Category	Definition	Mean number of occurrences (SD)
Customer-driven Route Planning	Planning a route to a given destination	16.6 (1.8)
Subtypes: Initial plan	Planning from the initial request	6.8 (0.8)
Change in plan	Planning after an en route request from a customer to alter the destination	9.8 (1.0)
Spontaneous Route Planning	Further planning en route, independent of customers	34.3 (10.9)
Subtypes: Filling in	Planning the next stage of the journey	17.7 (6.6)
Re-planning	Altering the current plan to adapt to the environment	16.7 (5.7)
Action Planning	Planning future movements with the vehicle	45.8 (15.1)
Expectation Confirmation	Detecting the presence of an expected environmental feature	28.6 (9.9)
Expectation Violation	Detecting the absence of an expected environmental feature	31.6 (10.5)
Expectation	Looking out for the next expected environmental feature	24.5 (8.5)
Visual Inspection	Visual inspection of an environmental feature	36.0 (11.8)
Monitoring Traffic	Watching moving traffic in the environment	11.4 (5.9)
Coasting	Navigating automatically without any directed thoughts	25.8 (7.5)
Customers' Navigationally-Irrelevant Statements	Navigationally-irrelevant statements by customers, (a control for Customer-driven Route Planning)	6.6 (0.9)

Thoughts, behaviour, and brain dynamics during navigation in the real world. Hugo J. Spiers and Eleanor A. Maguire, NeuroImage, 31 (2006), 1826-1840.

Thoughts, behaviour, and brain dynamics during navigation in the real world. Hugo J. Spiers and Eleanor A. Maguire, NeuroImage, 31 (2006), 1826-1840.

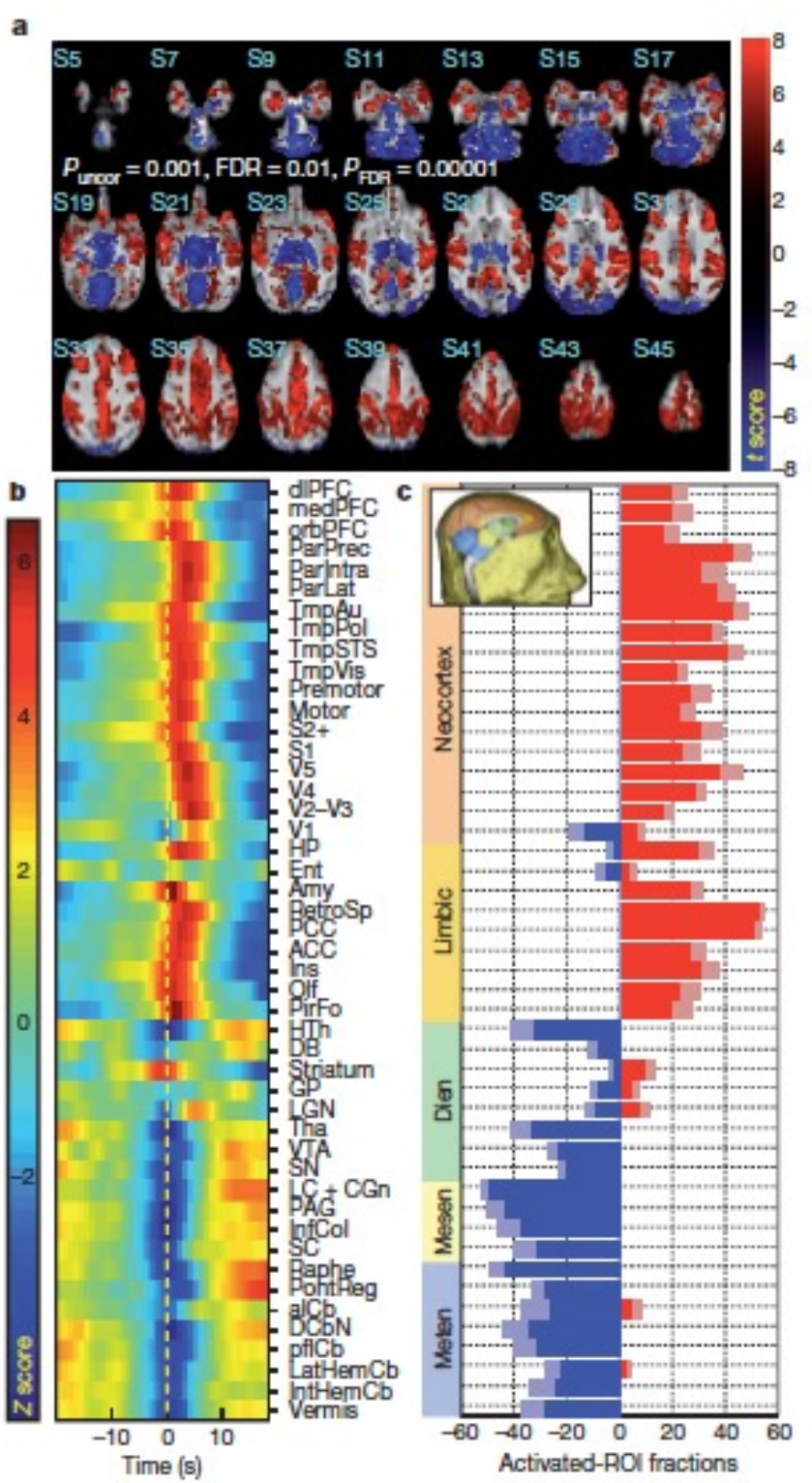


Multi-modal integration

Hippocampal–cortical interaction during periods of subcortical silence

N. K. Logothetis[1,2], O. Eschenko[1], Y. Murayama[1], M. Augath[1], T. Steudel[1], H. C. Evrard[1], M. Besserve[1,3] & A. Oeltermann[1]

By combining electrophysiological recordings in hippocampus with ripple-triggered functional magnetic resonance imaging, here we show that most of the cerebral cortex is selectively activated during the ripples, whereas most diencephalic, midbrain and brainstem regions are strongly and consistently inhibited

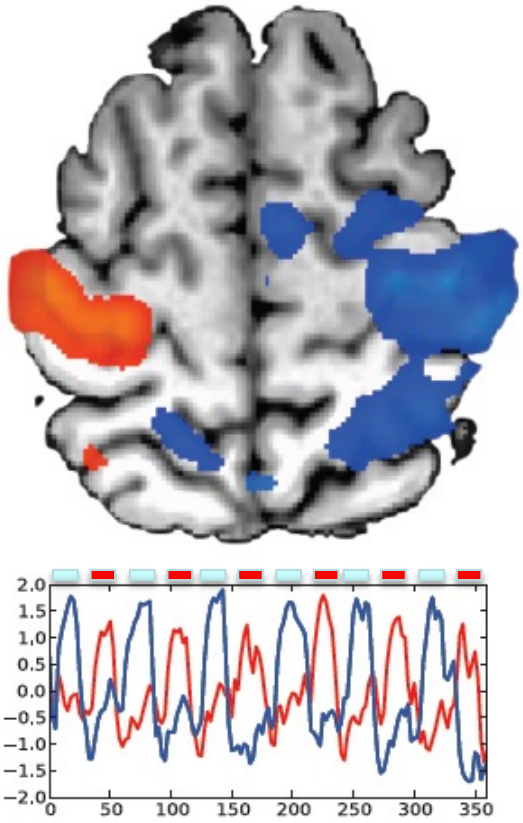


fMRI Paradigm Designs and Processing Strategies

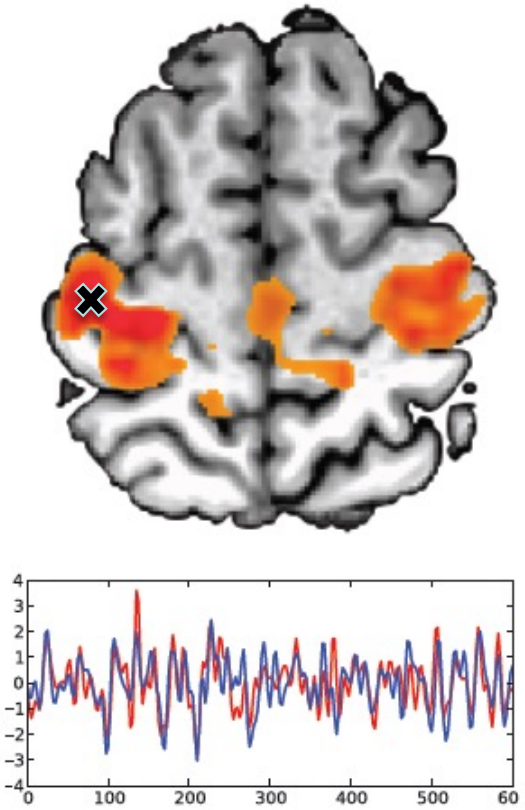
1. Neuronal Activation Input Strategies
2. Resting State fMRI
3. fMRI Decoding

Activation-based fMRI and “resting state” fMRI

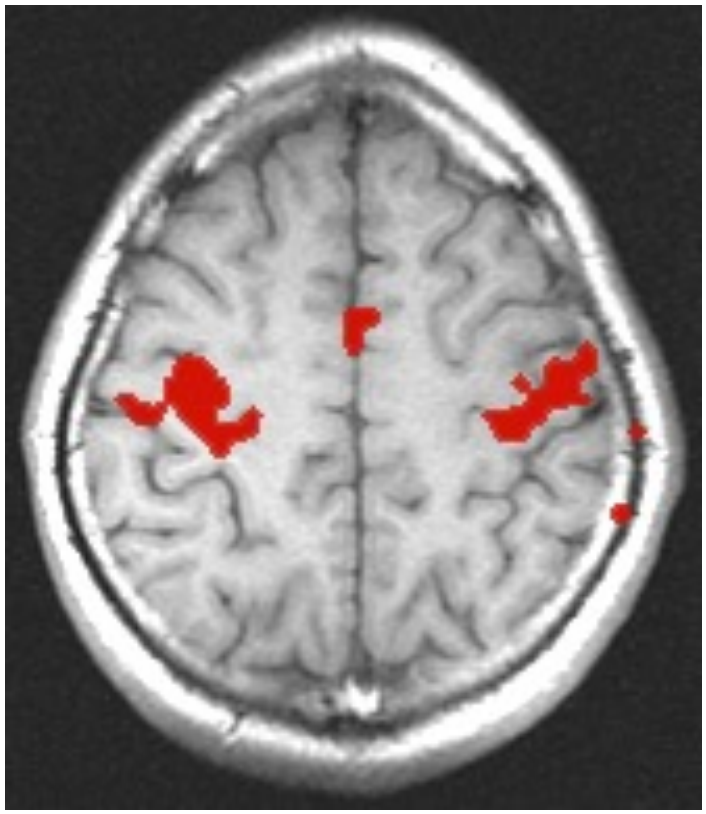
Task Activation
(Right vs. Left Hand Tapping)



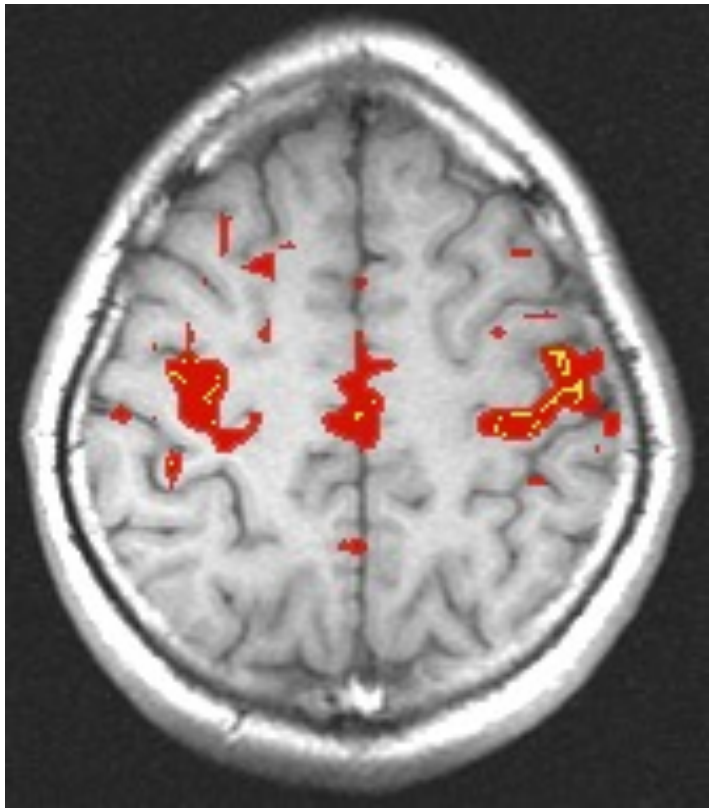
Resting Correlation
(Right Hand Seed)



Resting State Correlations



Activation:
correlation with reference function

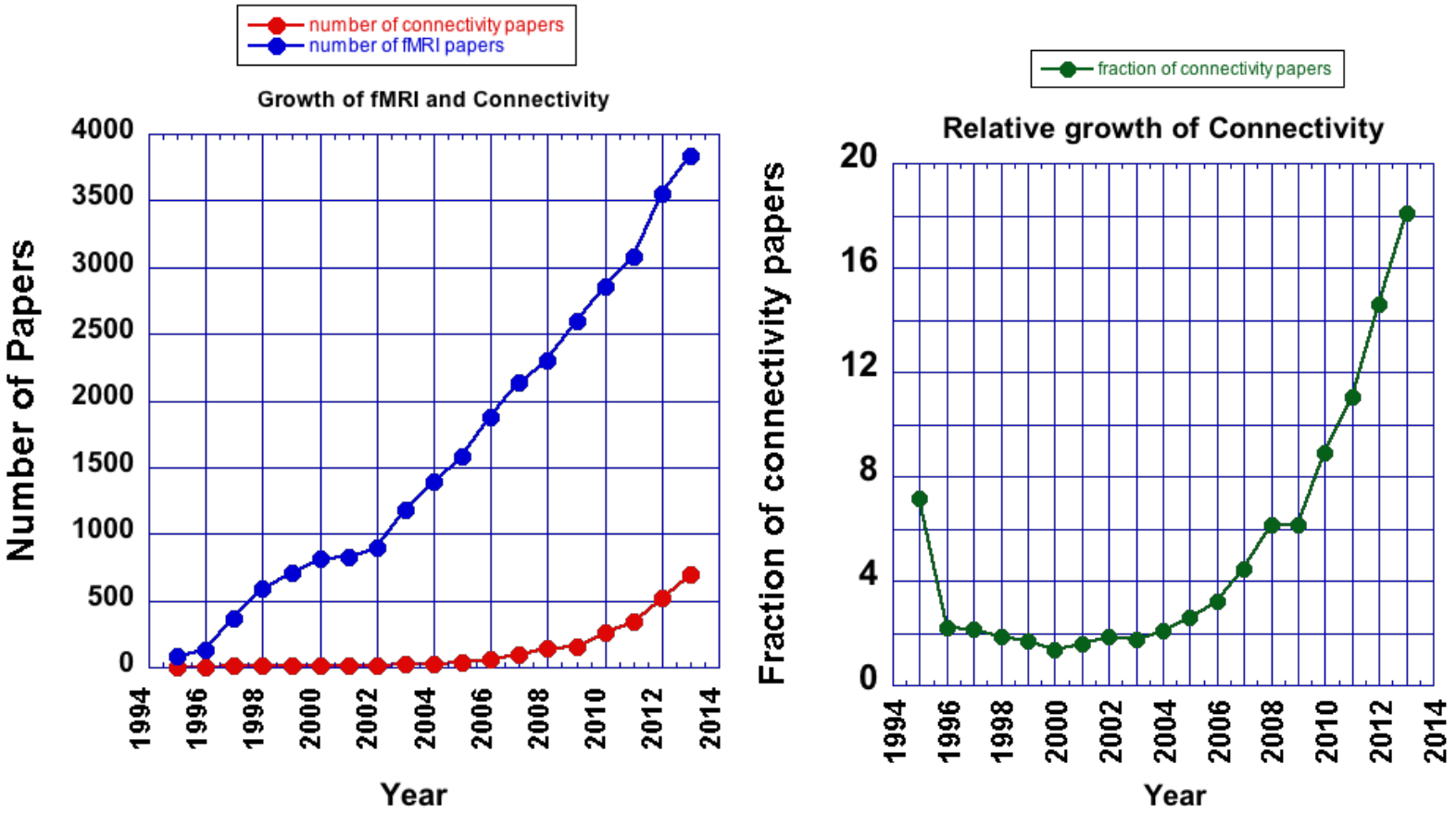


Rest:
seed voxel in motor cortex

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

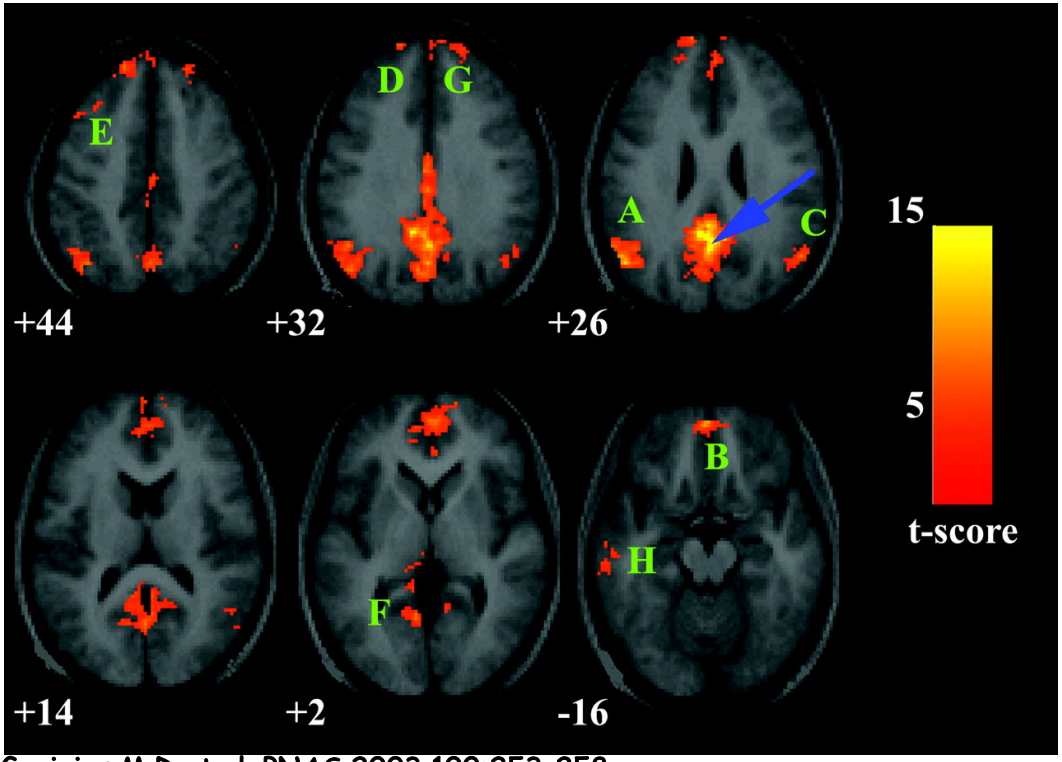
Resting state fMRI: Why is this area important?

- The number of papers and applications has exploded.
- Neuronal, psychiatric, and developmental disorders may relate to altered connectivity.
- Methods are in their infancy, and rapidly evolving.
- Neuronal correlates of spontaneous fluctuations are not fully understood.



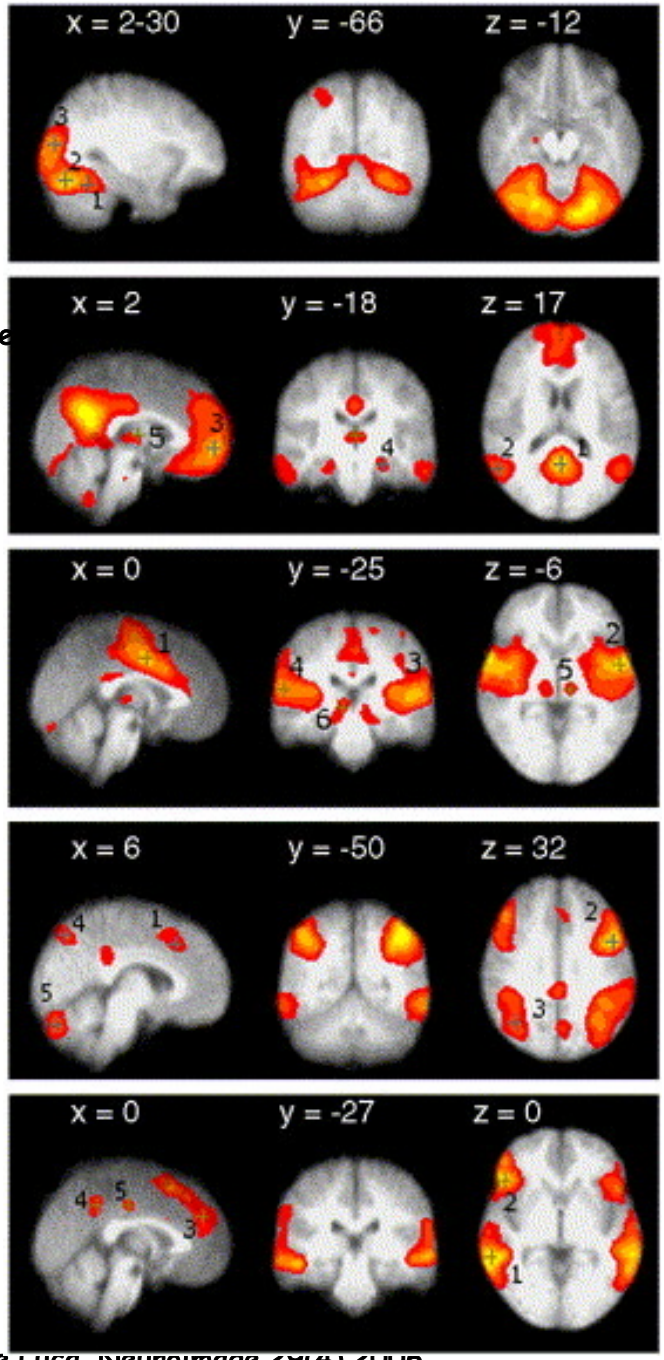
Seed Voxel

Seed Based Correlation from the Posterior Cingulate Cortex



Greicius M D et al. PNAS 2003;100:253-258

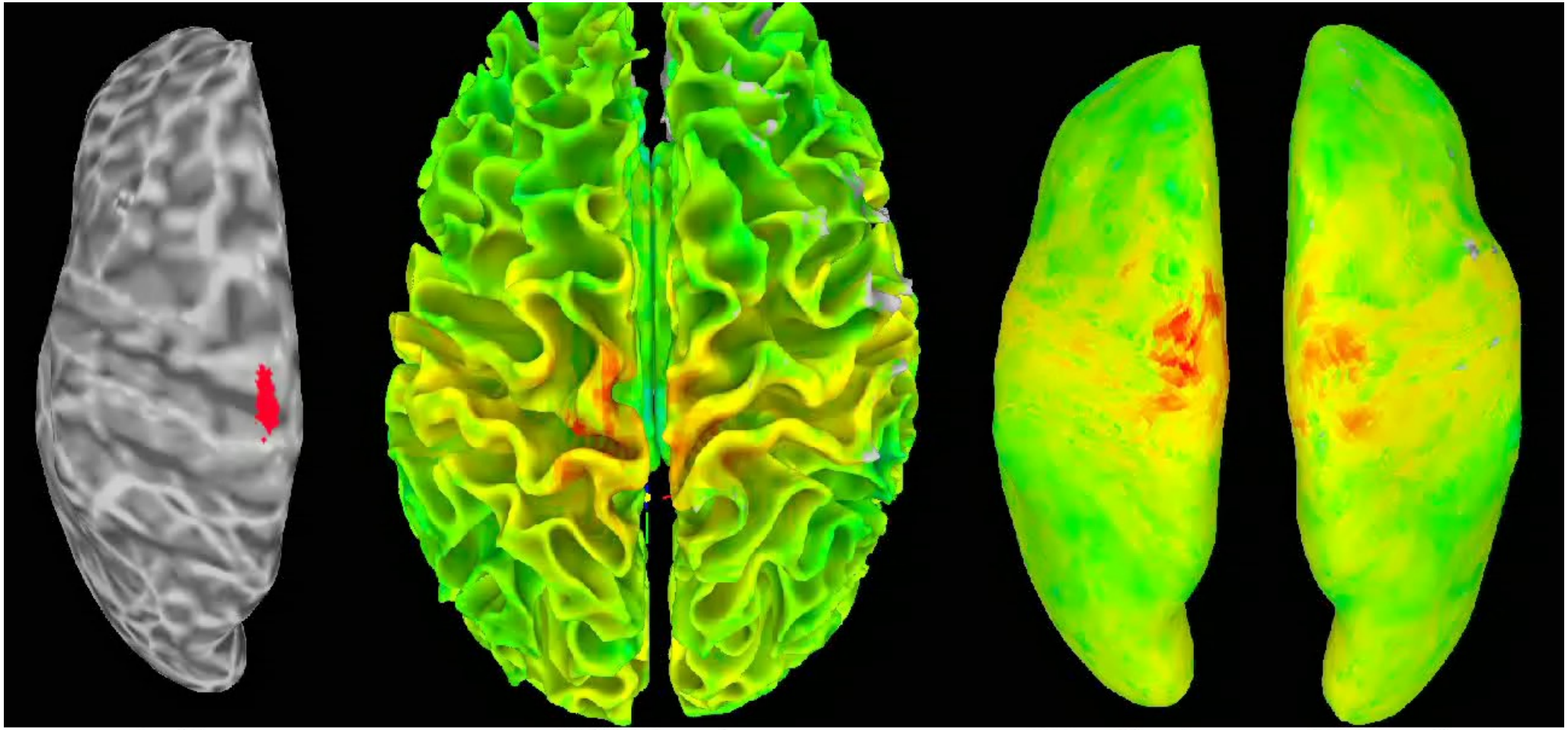
ICA



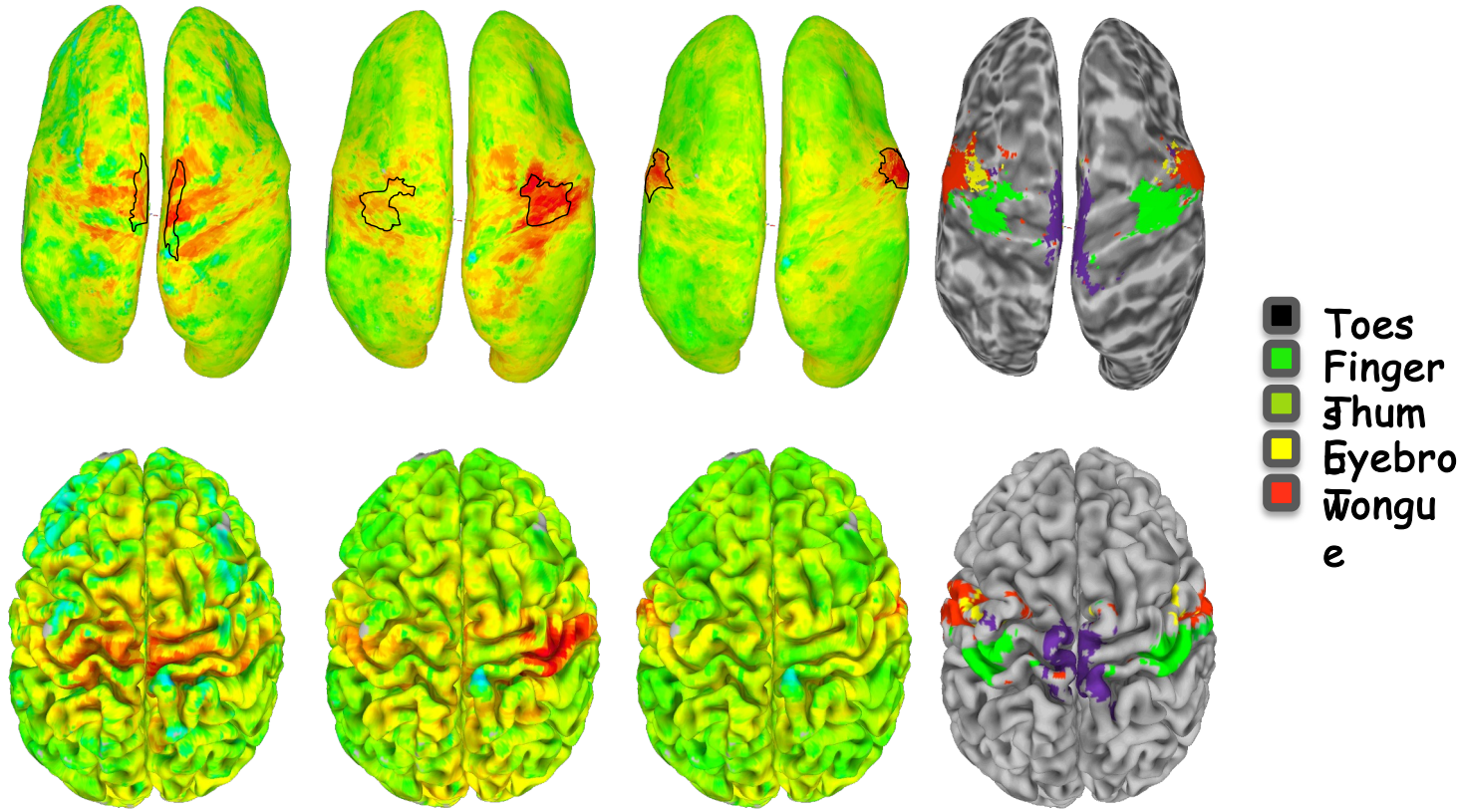
De Luca, Neuroimage 29(4) 2006

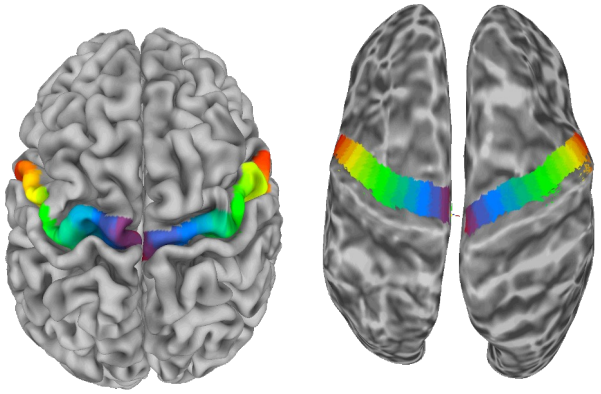
Sliding Seed Movies

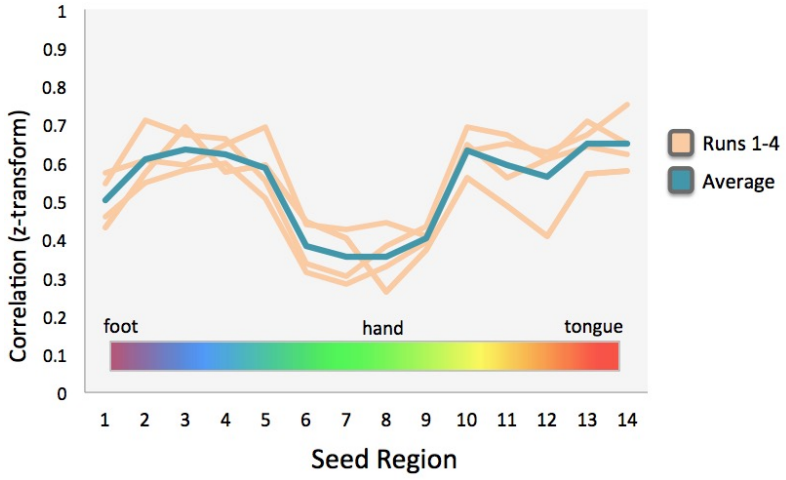
Relative correlation strength pattern obtained with a systematically shifted seed region



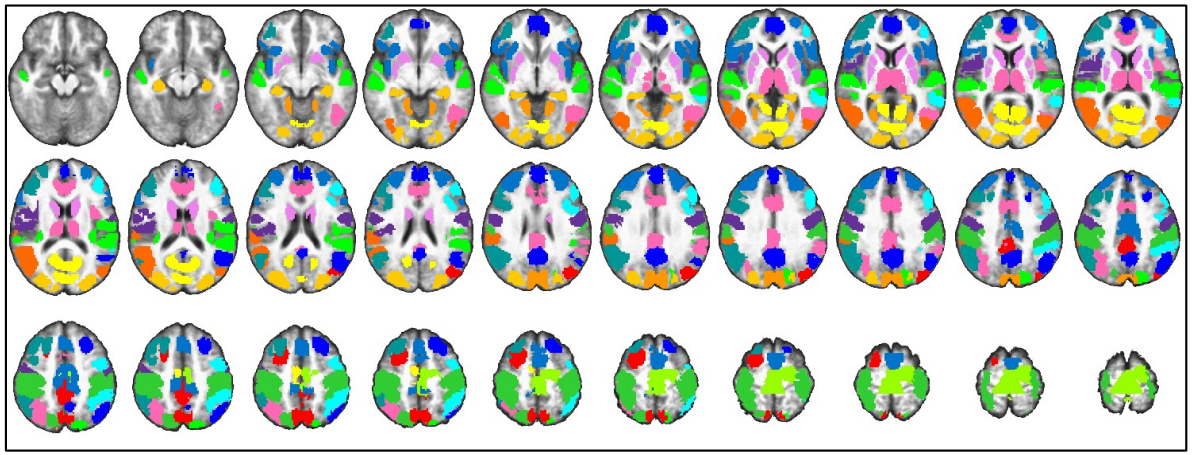
Seed 1 | GM/WM Boundary | LH (seed hemi) | RH (contra hemi)

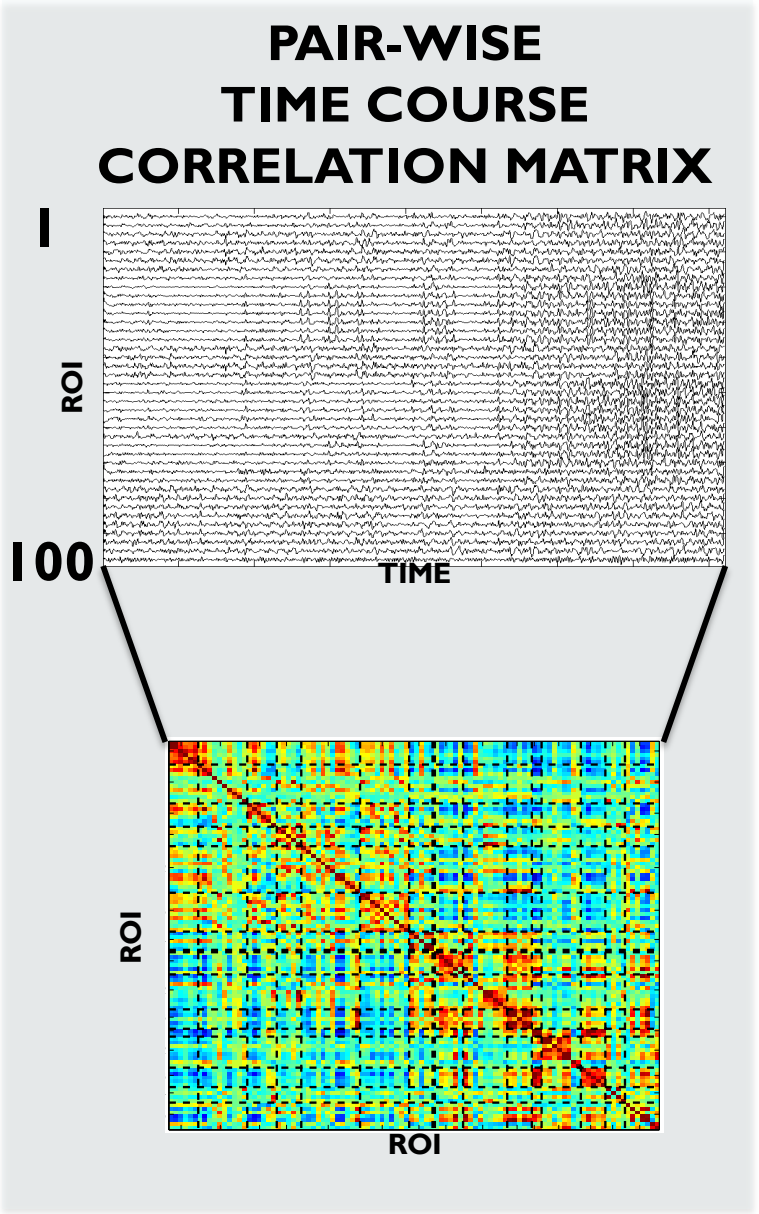

Toes
Finger
Thum
Eyebro
Tongu
e



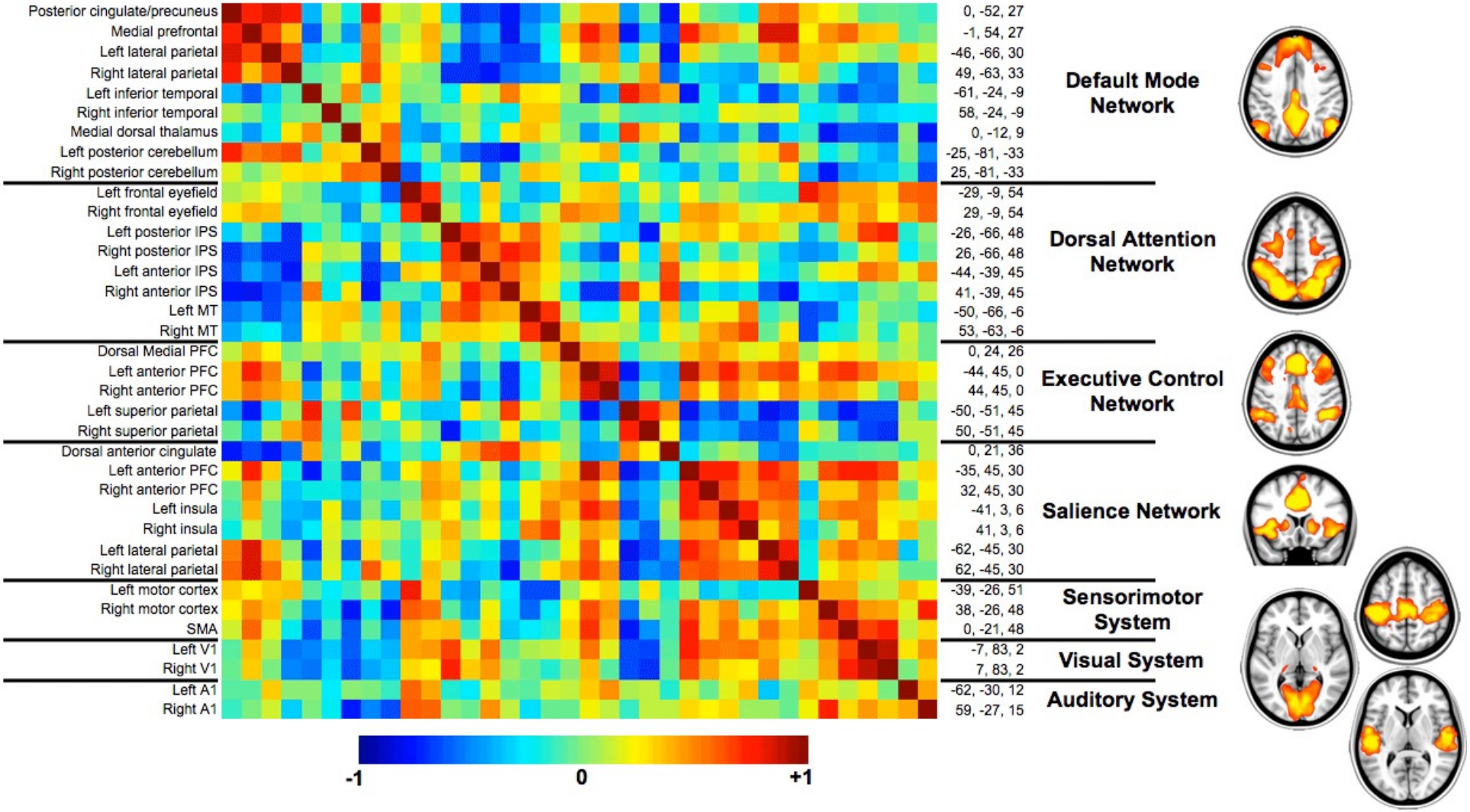

Correlation (z-transform)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
foot
hand
tongue
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Seed Region
Runs 1-4
Average

Time Course Correlation Matrix





http://www.nil.wustl.edu



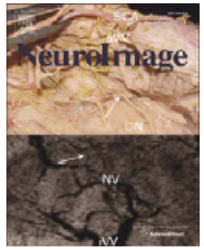
http://www.nil.wustl.edu/labs/raichle/images/Restless_Brain/correlation_matrix.html

NeuroImage 60 (2012) 1759–1770

Contents lists available at SciVerse ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg



Differentiating BOLD and non-BOLD signals in fMRI time series using multi-echo EPI

Prantik Kundu [a,c,*], Souheil J. Inati [b], Jennifer W. Evans [a,d], Wen-Ming Luh [b], Peter A. Bandettini [a,b]

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[b] Functional MRI Facility, National Institute of Mental Health, National Institutes of Health, Bethesda, MD, 20892 USA
[c] Department of Psychiatry, University of Cambridge, Addenbrooke's Hospital, Hills Road, Cambridge, CB2 2QQ UK
[d] Center for Neuroscience and Regenerative Medicine, Henry M. Jackson Foundation, Rockville, Maryland, 20852 USA

Integrated strategy for improving functional connectivity mapping using multiecho fMRI

Prantik Kundu[a,b,1], Noah D. Brenowitz[a], Valerie Voon[b], Yulia Worbe[b], Petra E. Vértes[b], Souheil J. Inati[c], Ziad S. Saad[d], Peter A. Bandettini[a,c,2], and Edward T. Bullmore[b,e,f,2]

[a]Section on Functional Imaging Methods, [c]Functional MRI Core Facility, and [d]Biomedical and Scientific Computing Core, National Institute of Mental Health, Bethesda, MD 20814; [b]Behavioural and Clinical Neuroscience Institute, University of Cambridge, Cambridge CB2 1QP, United Kingdom; [e]National Institute of Health Research Cambridge Biomedical Research Centre, Cambridgeshire Peterborough National Health System Foundation Trust, Cambridge SW1A 2NS, United Kingdom; and [f]Clinical Unit Cambridge, GlaxoSmithKline, Cambridge CB2 0QQ, United Kingdom

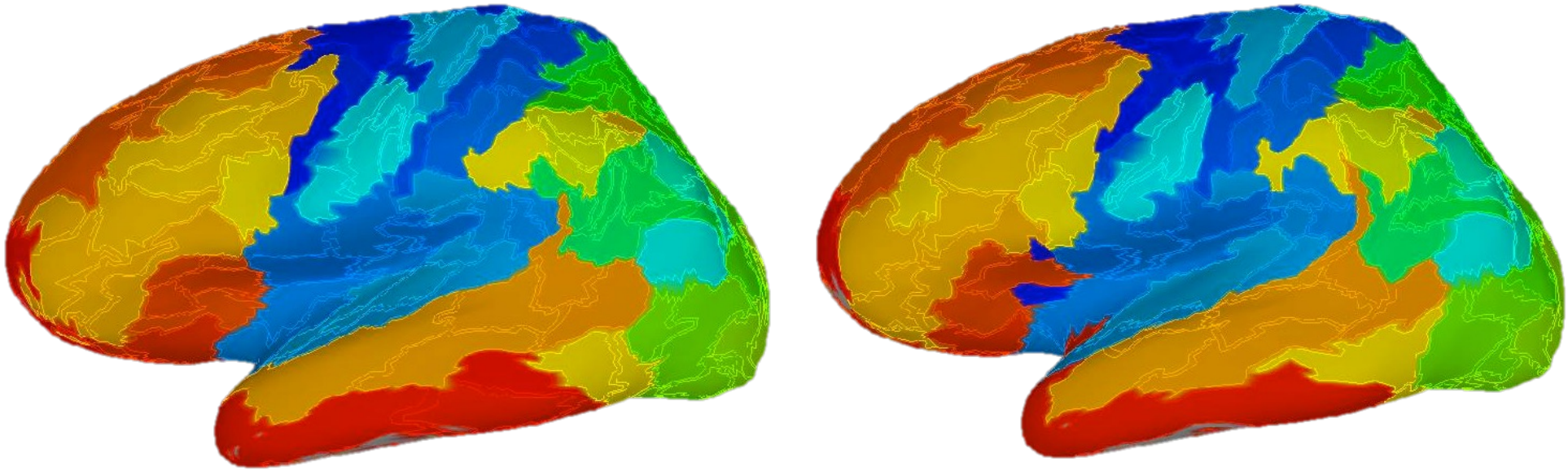
Edited by Marcus E. Raichle, Washington University in St. Louis, St. Louis, MO, and approved July 31, 2013 (received for review January 29, 2013)

PNAS Vol 110, No 40, 16187-16192

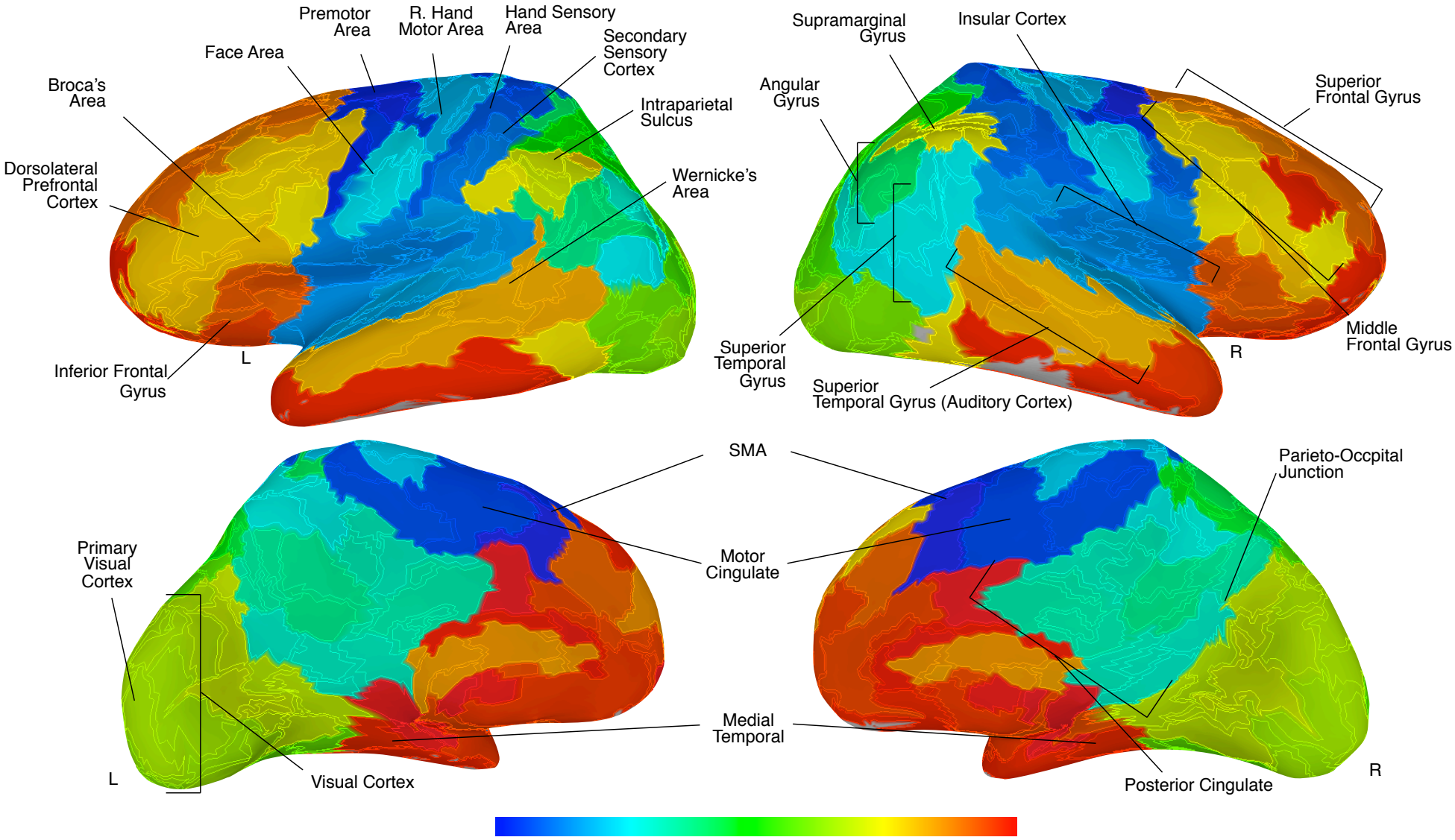
Test-retest of **group** clustering at 350 clusters

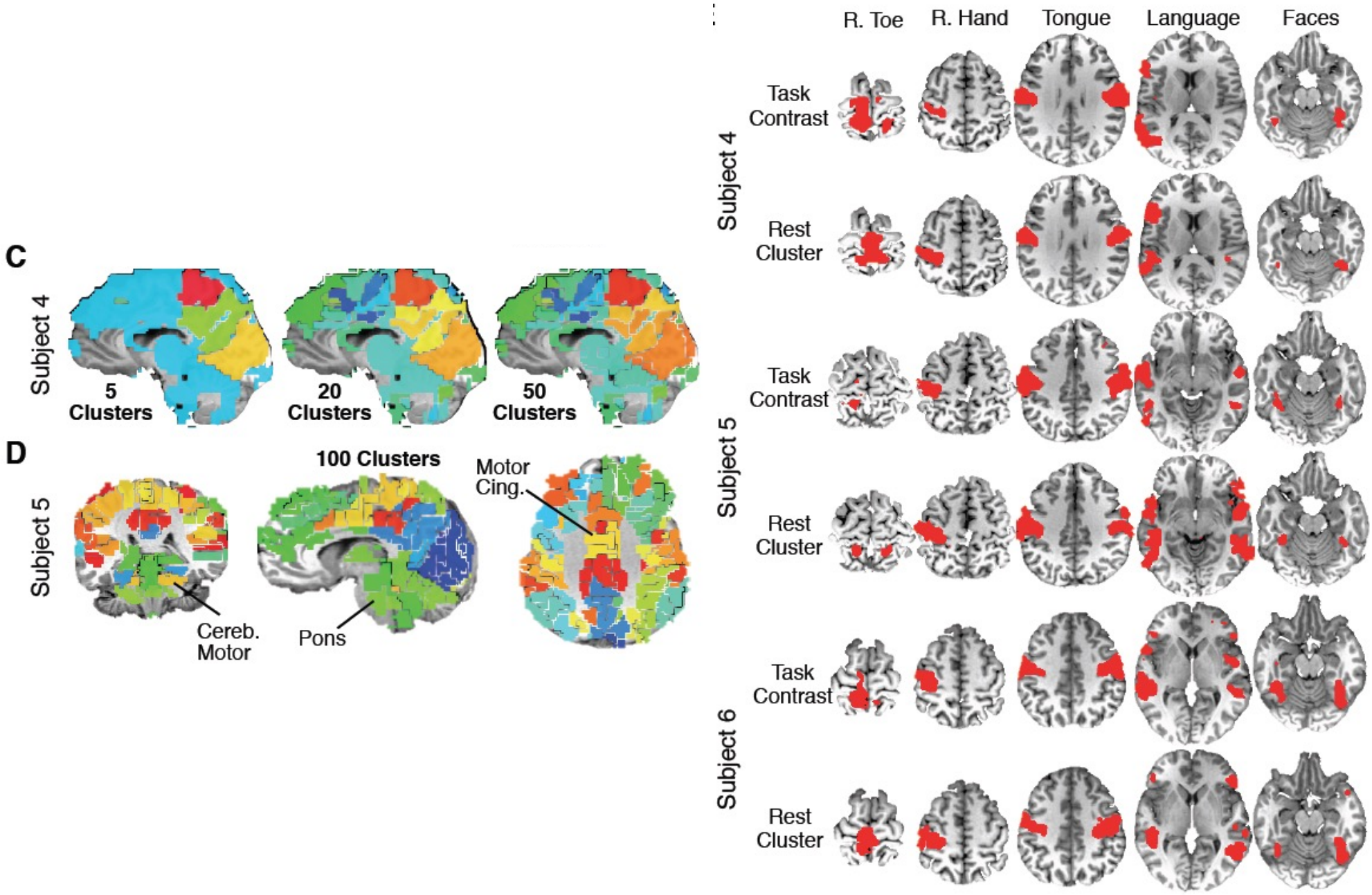
Rest 1

Rest 2
(color matched to Rest 1)



Clustering based on Resting State



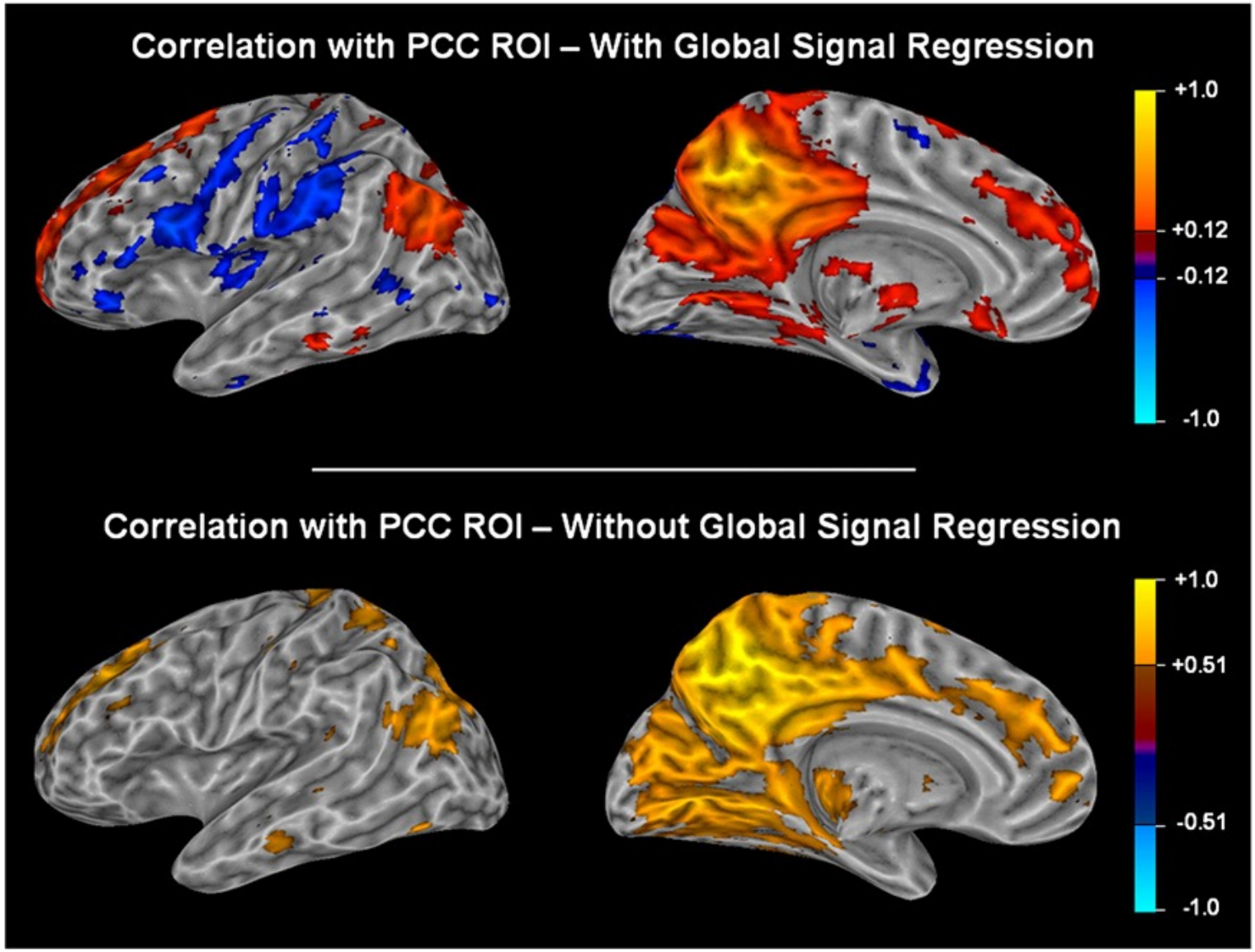

C
Subject 4
5 Clusters
20 Clusters
50 Clusters
D
Subject 5
100 Clusters
Motor Cing.
Cereb. Motor
Pons
R. Toe
R. Hand
Tongue
Language
Faces
Subject 4
Task Contrast
Rest Cluster
Subject 5
Task Contrast
Rest Cluster
Subject 6
Task Contrast
Rest Cluster

Two other issues with imaging resting state fluctuations:

1. Global signal correction or not?

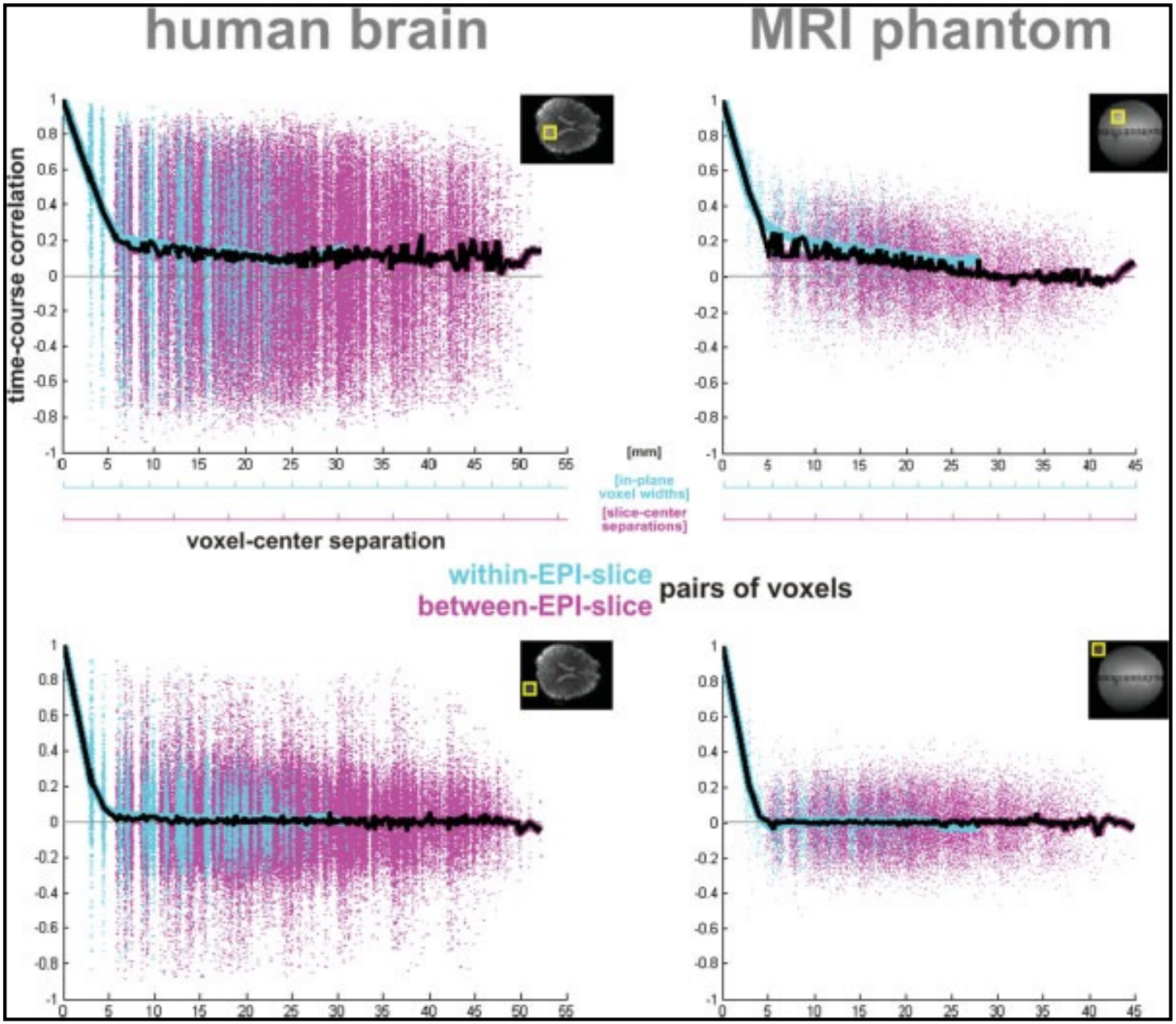
2. Short range correlations may be scanner-related.

The issue of global signal regression



K. Murphy, R. M. Birn, D. A. Handwerker, T. B. Jones, P. A. Bandettini, NeuroImage, 44, 893-905 (2009)

The issue of correlation across voxels due scanner instabilities



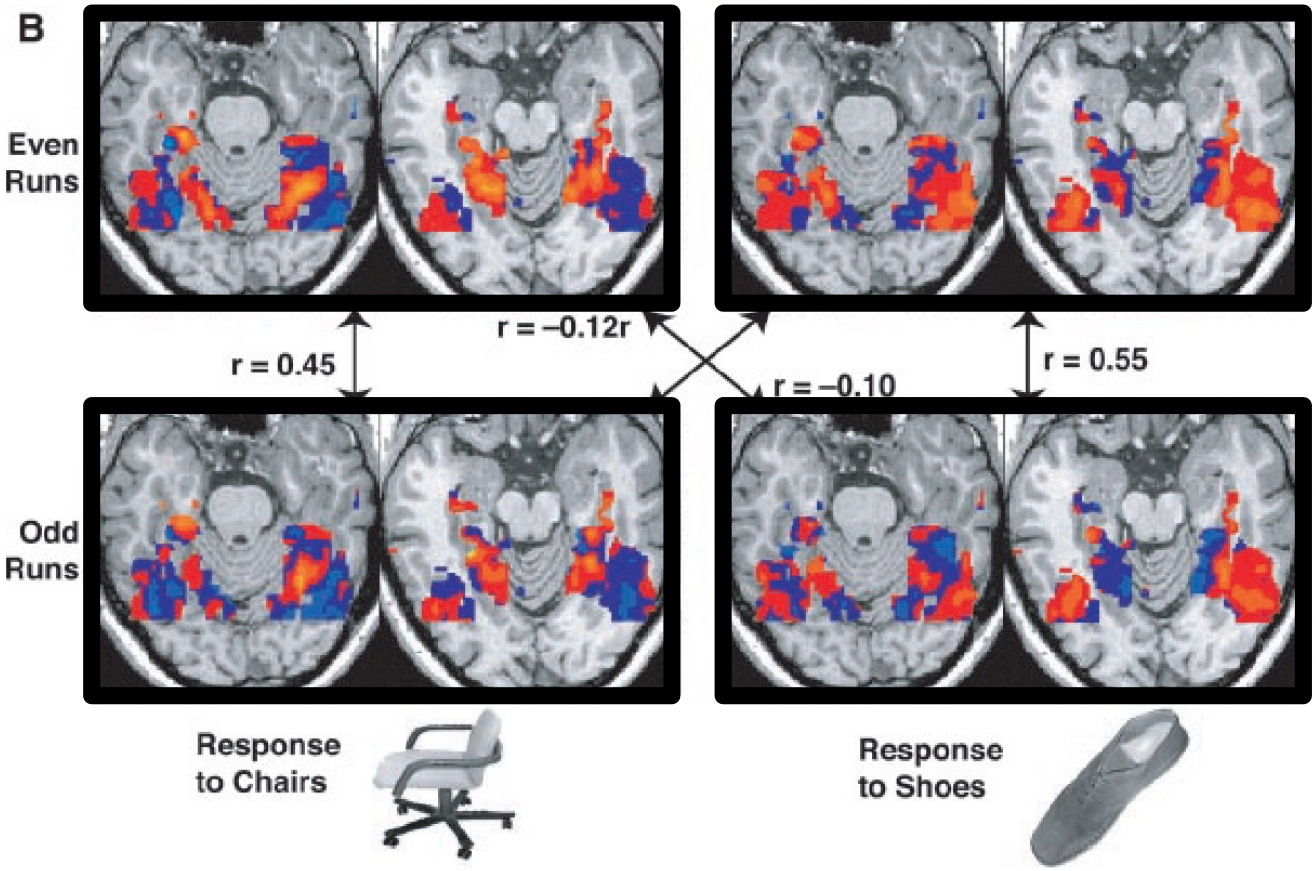
N. Kriegeskorte, J. Bodurka, P. Bandettini, International Journal of Imaging Systems and Technology, 18 (5-6), 345-349 (2008)

fMRI Paradigm Designs and Processing Strategies

1. Neuronal Activation Input Strategies
2. Resting State fMRI
3. fMRI Decoding

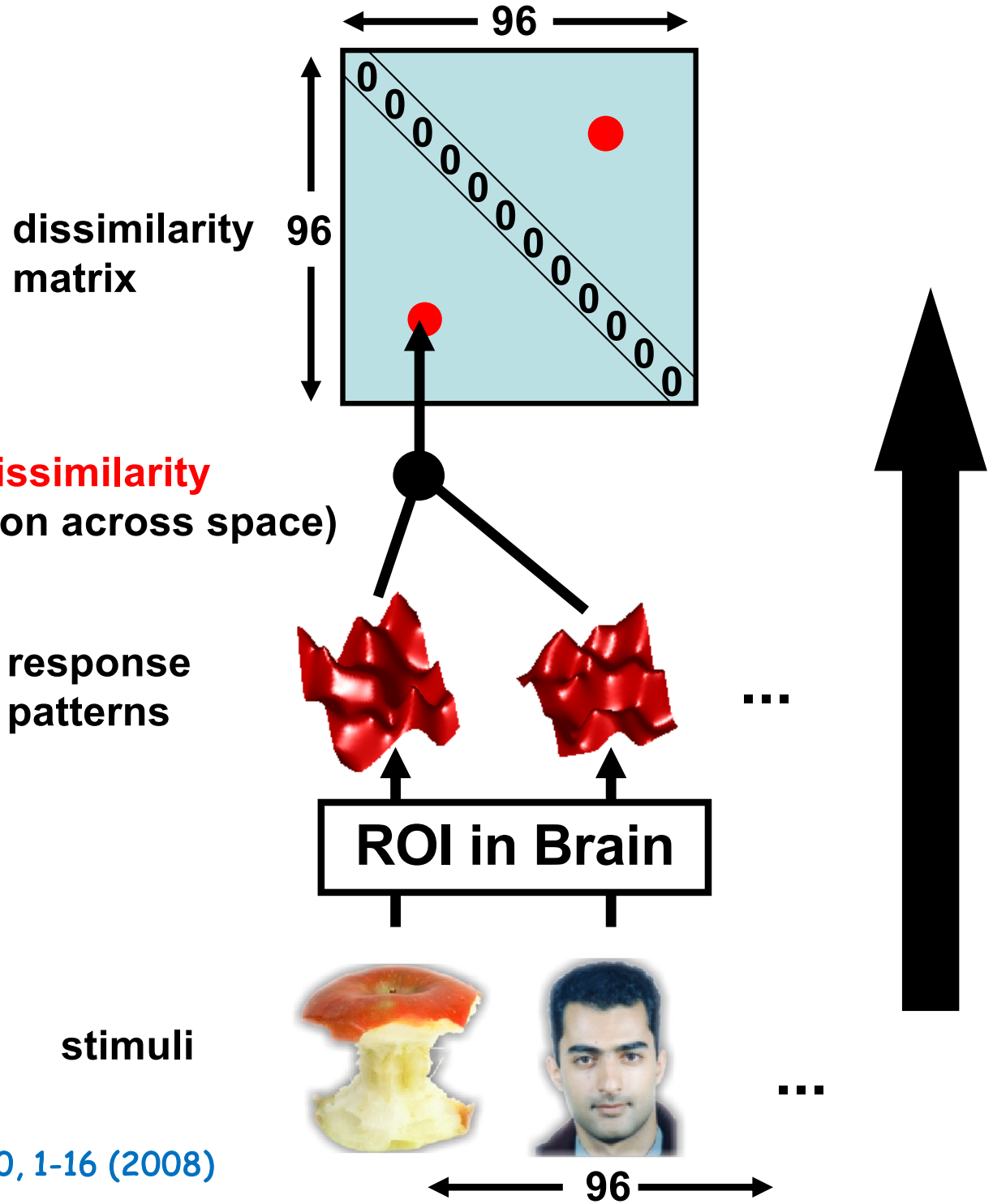
Ventral temporal category representations

Object categories are associated with distributed representations in ventral temporal cortex



Haxby et al. Nature 2001

Dissimilarity Matrix Creation

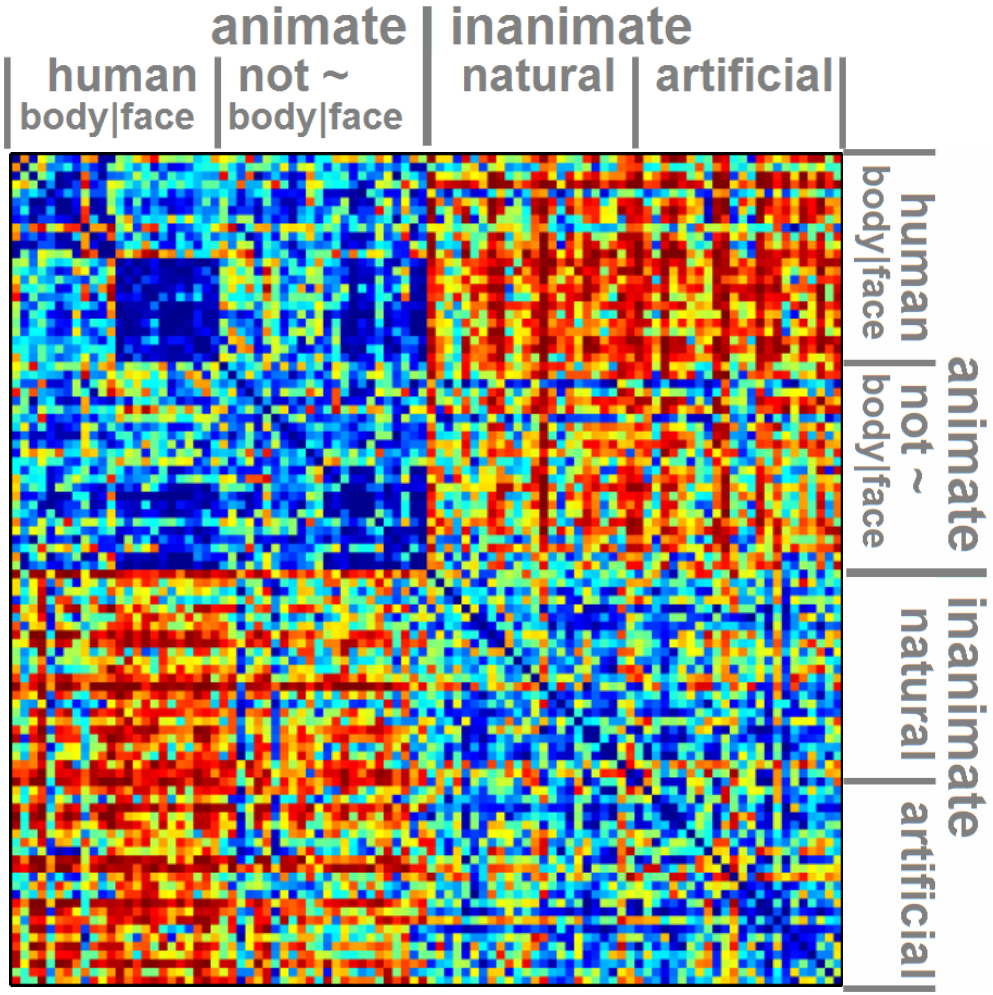


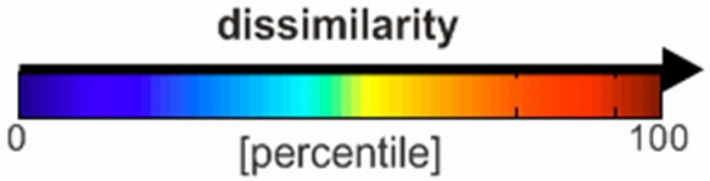
N. Kriegeskorte, et al, Neuron 60, 1-16 (2008)

Visual Stimuli

Human IT

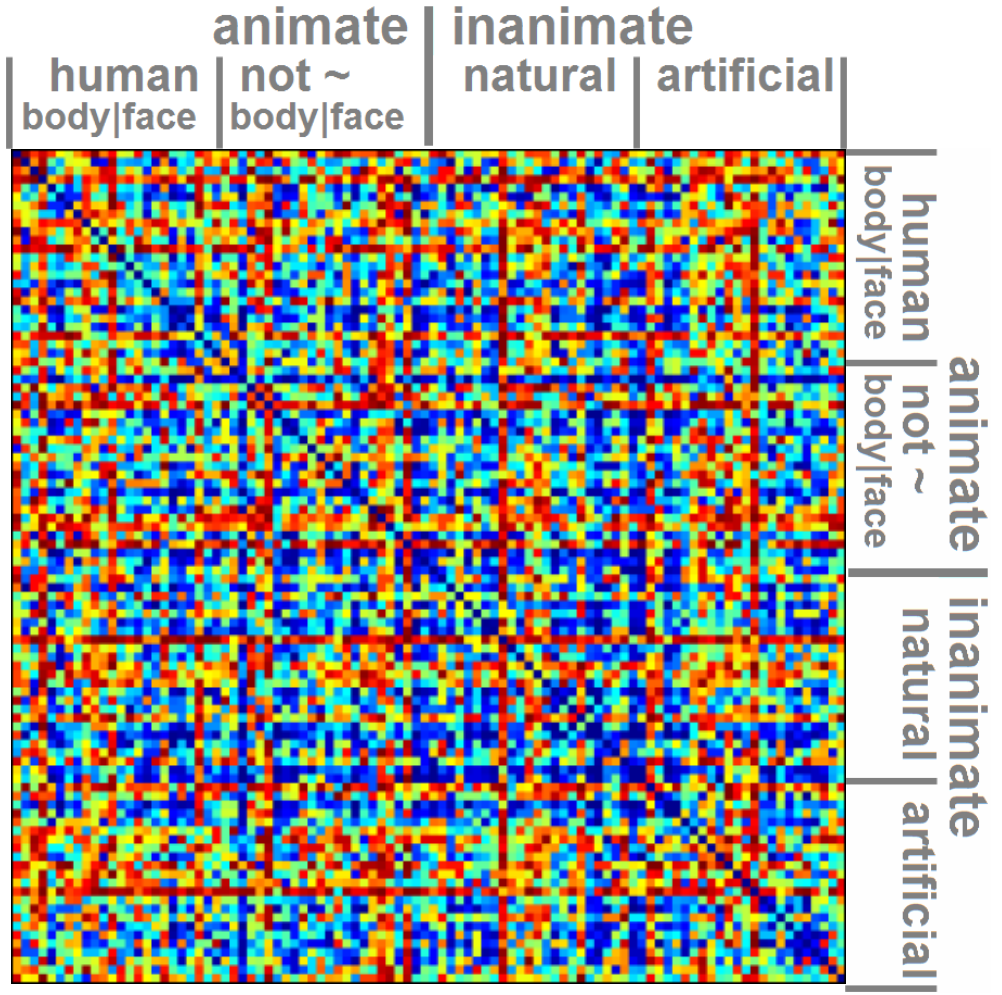
(1000 visually most responsive voxels)





Human Early Visual Cortex

(1057 visually most responsive voxels)



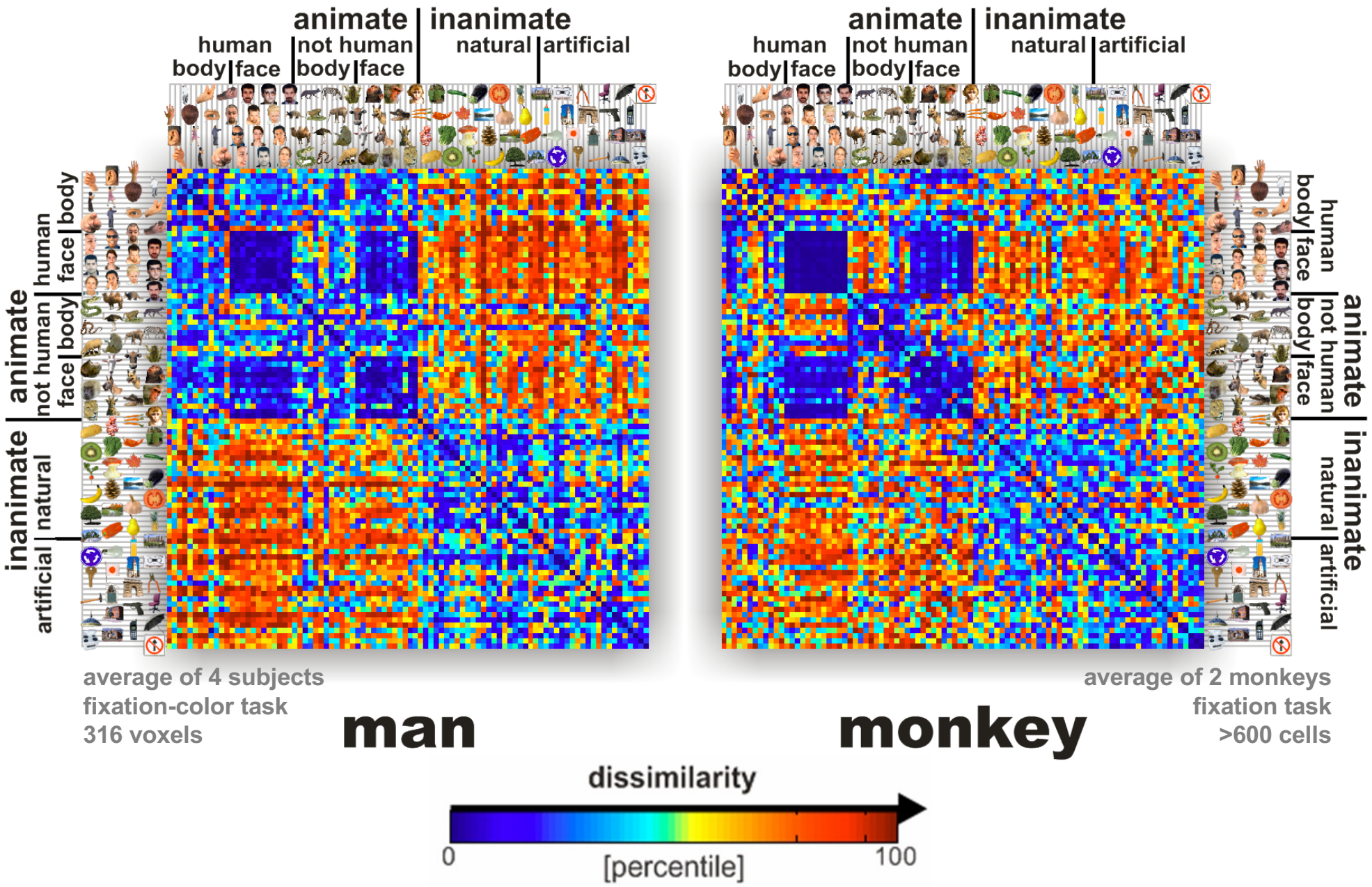
Monkey-Human Comparison Procedure

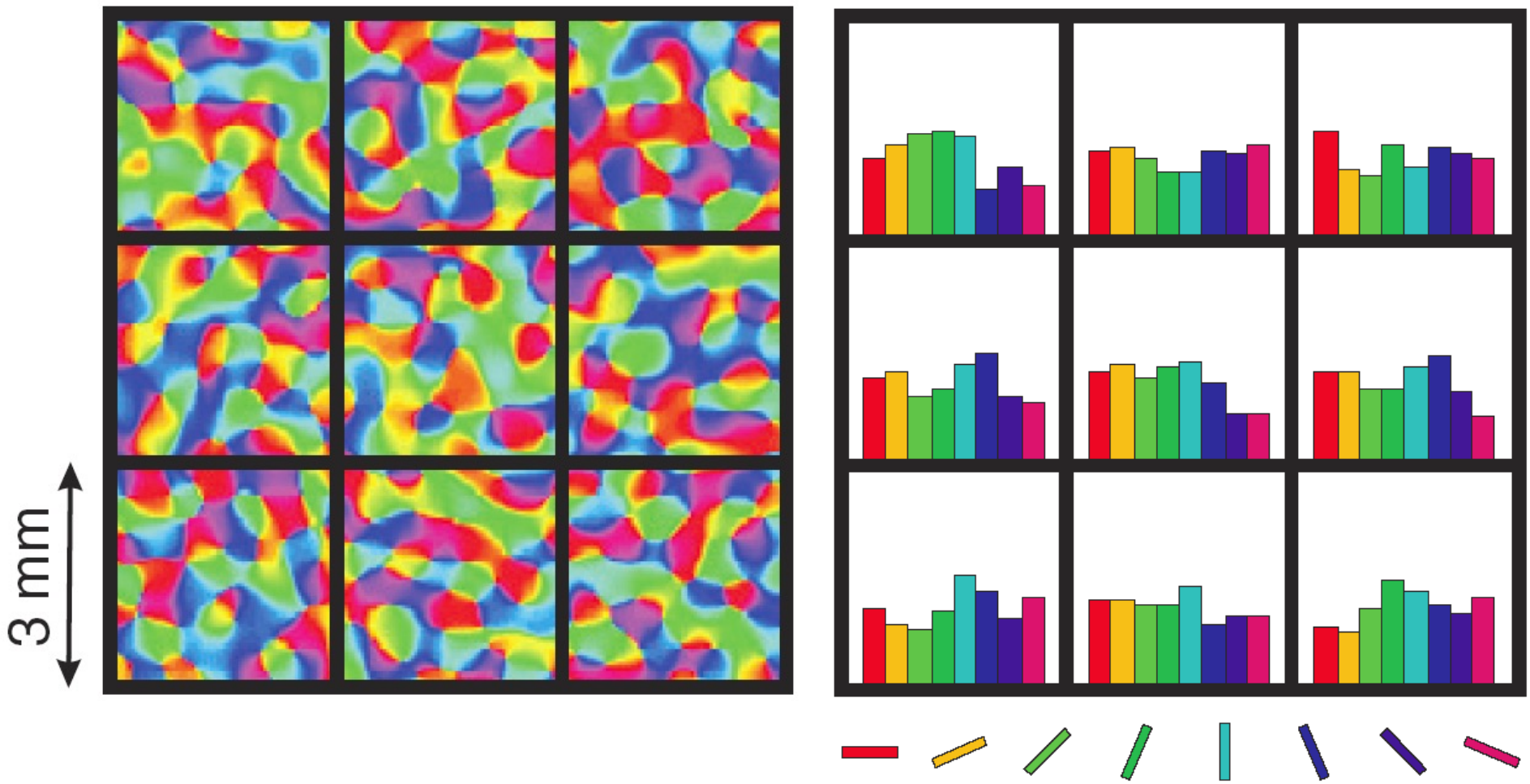
Human

- fMRI in four subjects
  (repeated sessions,
  >12 runs per subject)
- "quick" event-related design
  (stimulus duration: 300ms,
  stimulus onset asynchrony: 4s)
- fixation task
  (with discrimination of fixation-point color changes)
- occipitotemporal measurement slab
  (5-cm thick)
- small voxels ($1.95 \times 1.95 \times 2 mm^3$)
- 3T magnet, 16-channel coil
  (SENSE, acc. fac. 2)

Monkey (Kiani et al. 2007)

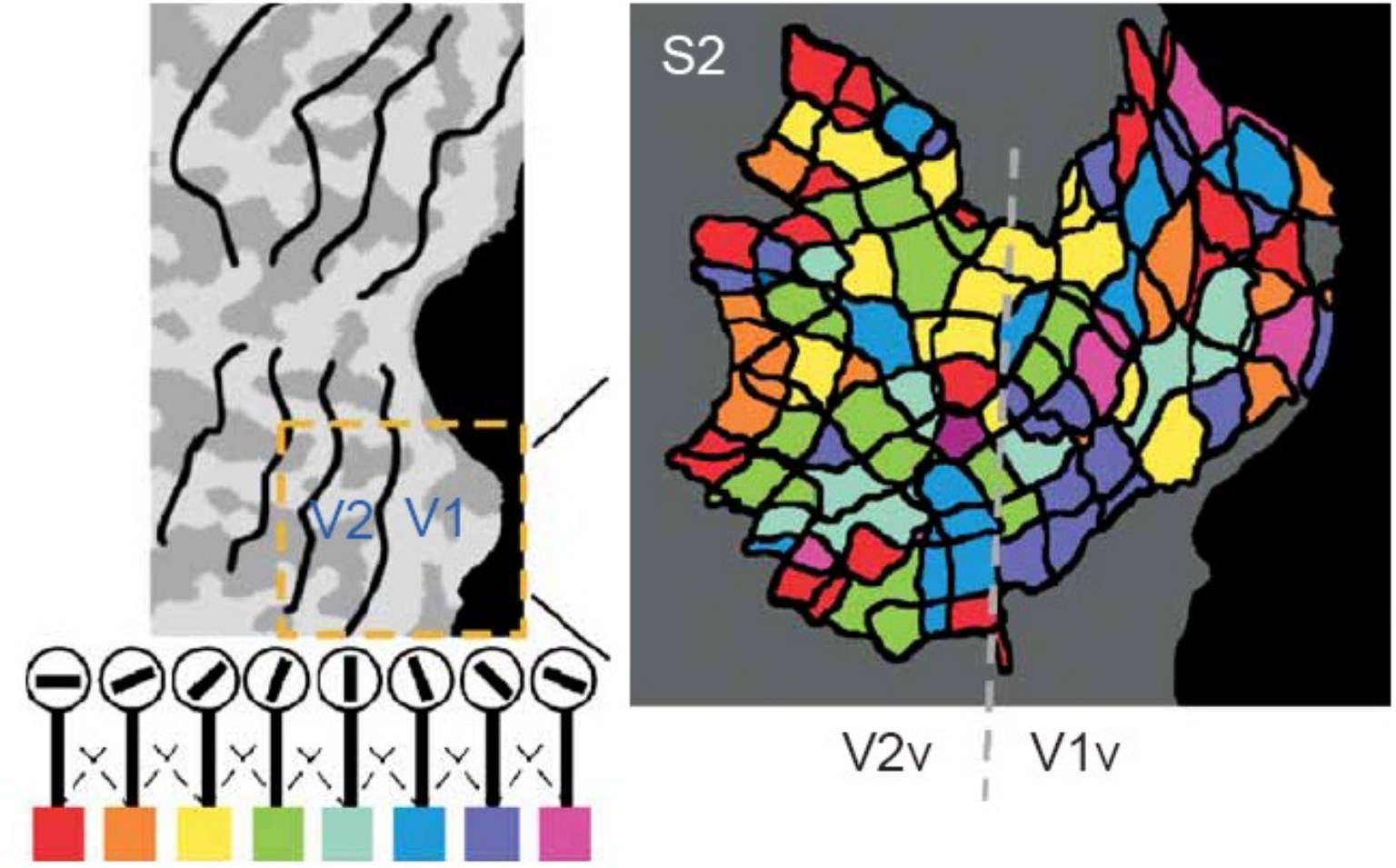
- single-cell recordings in two monkeys
- rapid serial presentation
  (stimulus duration: 105ms)
- fixation task
- electrodes in anterior IT
  (left in monkey 1, right in monkey 2)
- 674 cells total
- windowed spike count
  (140-ms window starting 71ms after stimulus onset)


animate
inanimate
human body
human face
not human body
not human face
natural
artificial
average of 4 subjects
fixation-color task
316 voxels
man
monkey
average of 2 monkeys
fixation task
>600 cells
dissimilarity
0
[percentile]
100



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

Lower spatial frequency clumping



Kamitani & Tong (2005)

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