Paradigms, Pulse Sequences, and Processing: Pushing the Limits with fMRI

Peter A. Bandettini, Ph.D.
Nikolaus Kriegeskorte, Ph.D.

Section on Functional Imaging Methods
in the Laboratory of Brain and Cognition
http://fim.nimh.nih.gov

- Brief summary of fMRI
- Where the technology has taken us
- Neuronal Activity and Hemodynamics
- Demystifying "Brain reading" and multivariate analysis
- Open questions and future directions…

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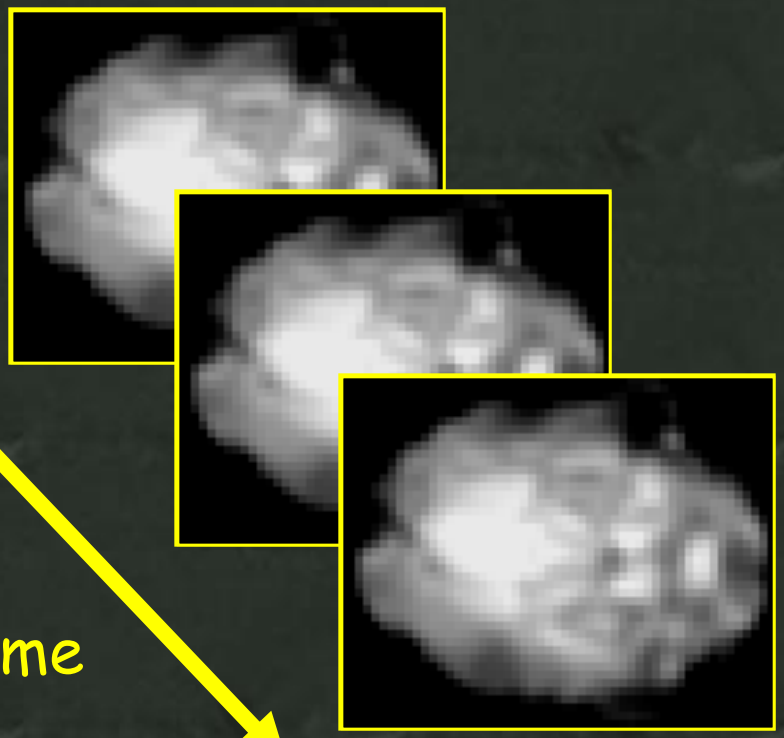
MRI vs. fMRI

MRI

one image

high resolution
(1 mm or less)

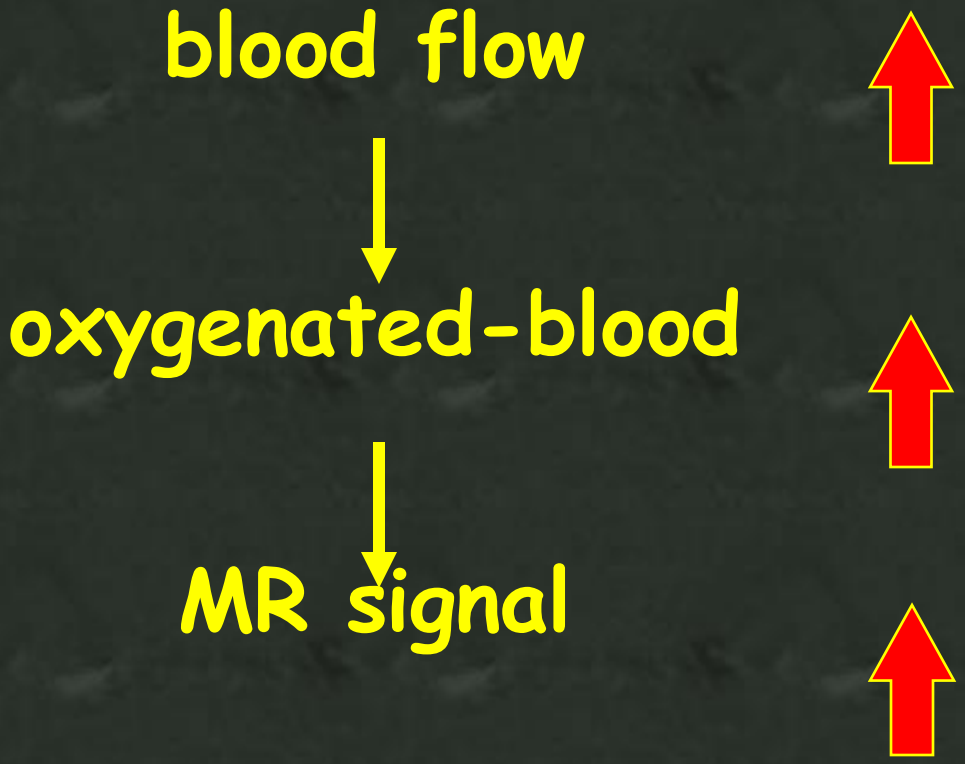
fMRI

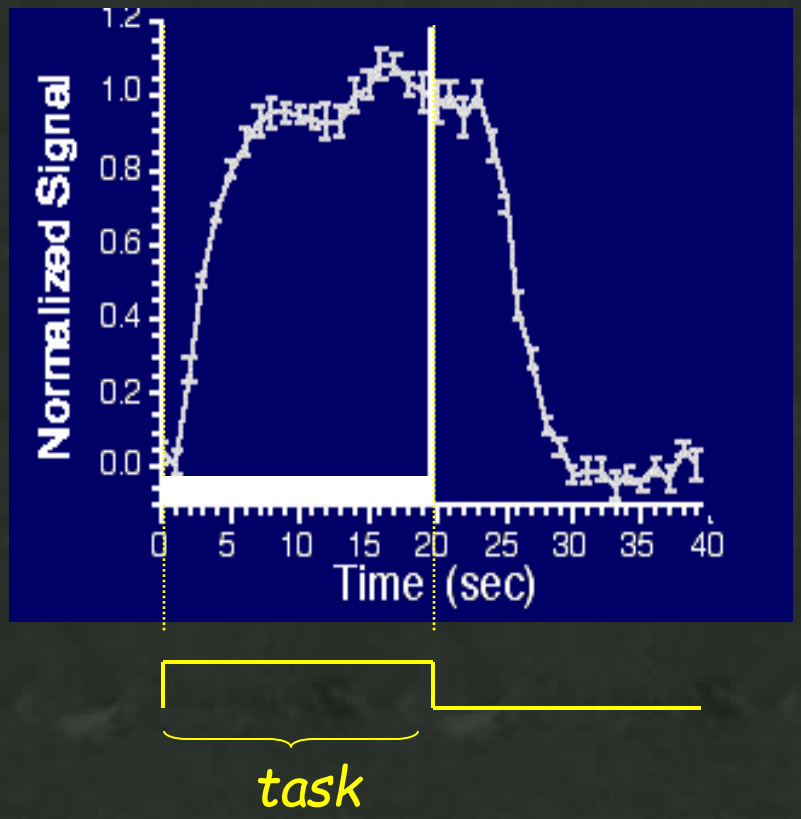


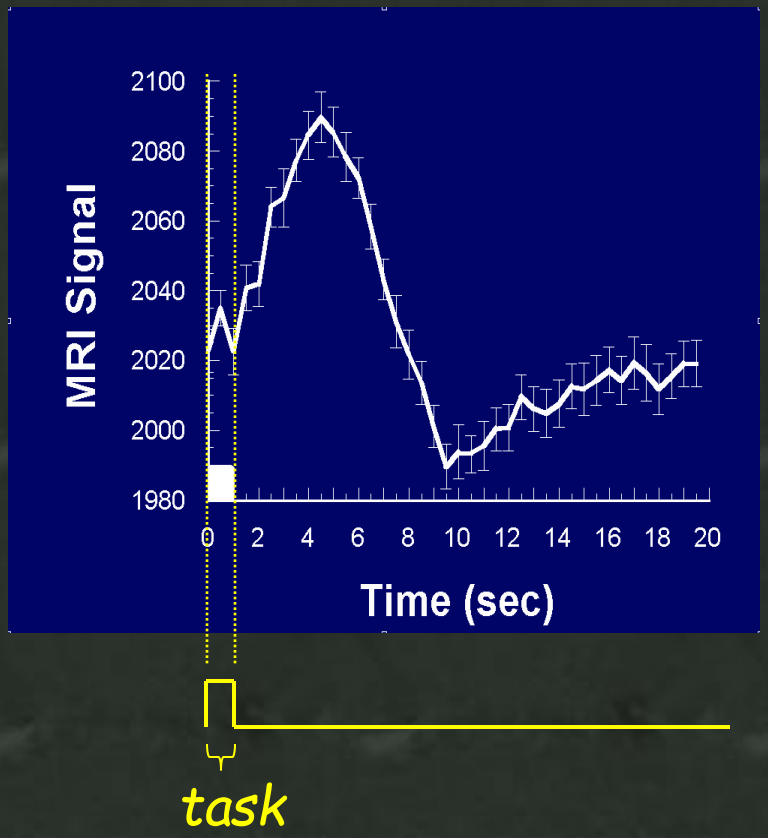
many images
(e.g., every 2 sec for 5 mins)

low resolution
(1.5 to 4 mm)

BOLD (Blood Oxygen Level Dependent) Contrast




Normalized Signal
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
Time (sec)
task


MRI Signal
2100
2080
2060
2040
2020
2000
1980
0
2
4
6
8
10
12
14
16
18
20
Time (sec)
task

1991

Functional images

~2s

fMRI Signal (% change)

ROI Time Course

Time

Condition

Condition 1

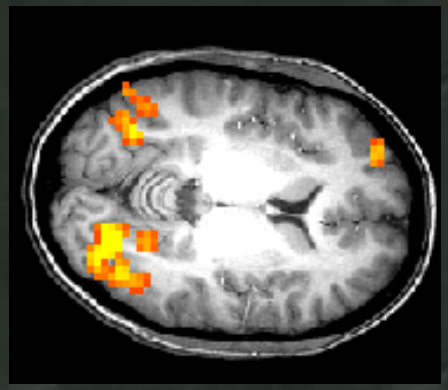
Condition 2

Time

~ 5 min

Region of interest (ROI)

Statistical Map
superimposed on anatomical MRI image



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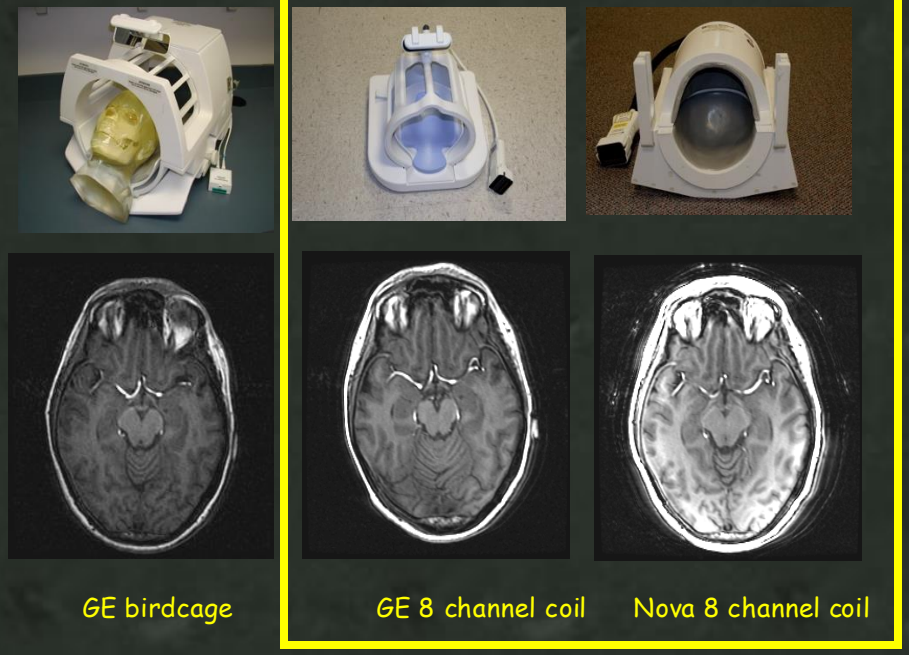
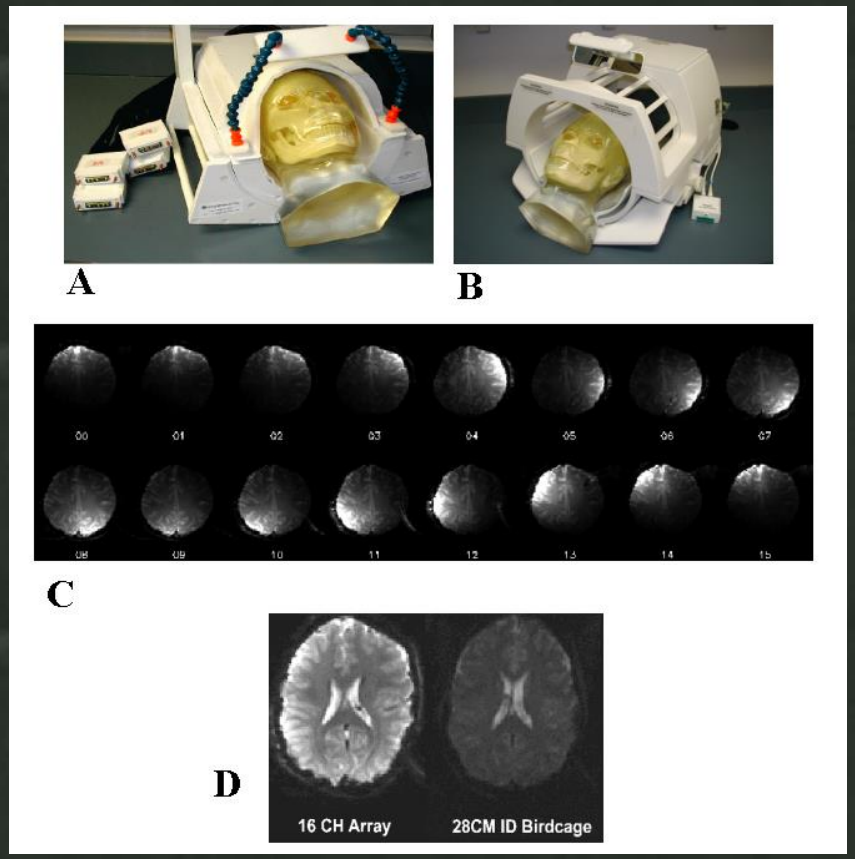
8 channel parallel receiver coil



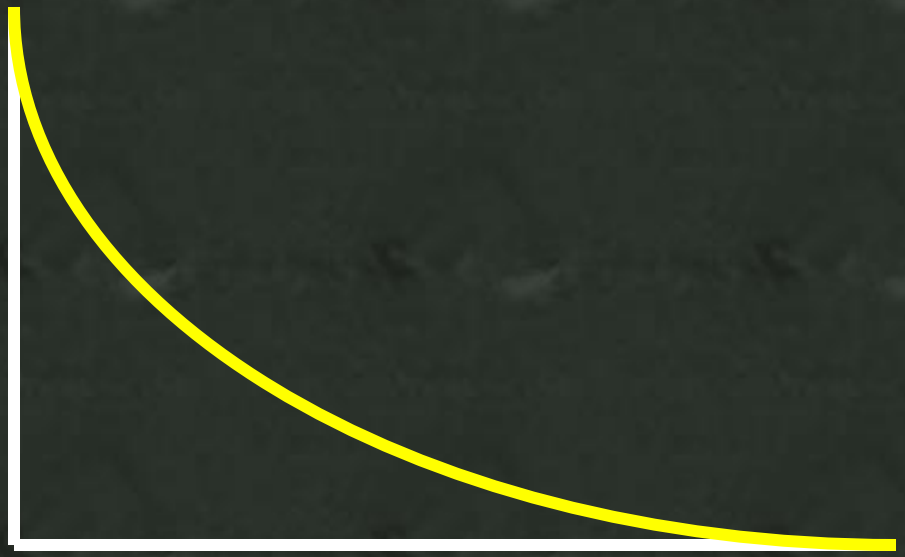
GE birdcage | GE 8 channel coil | Nova 8 channel coil

16 channel parallel receiver coil

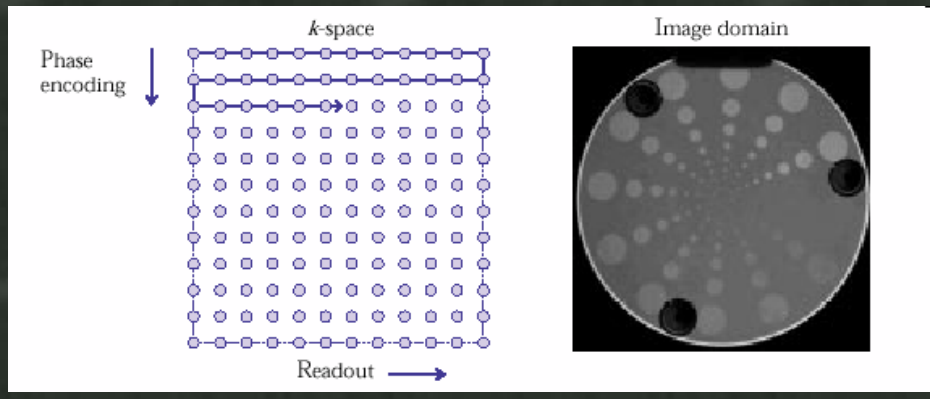


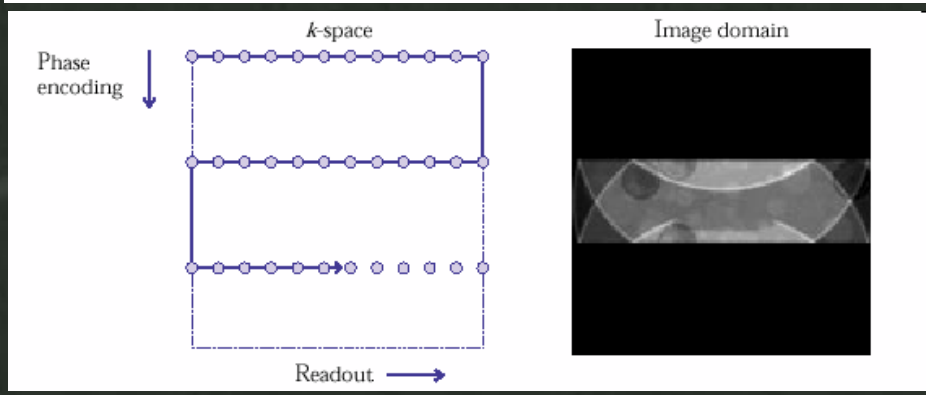
J. Bodurka, et al, Magnetic Resonance in Medicine 51 (2004) 165-171.

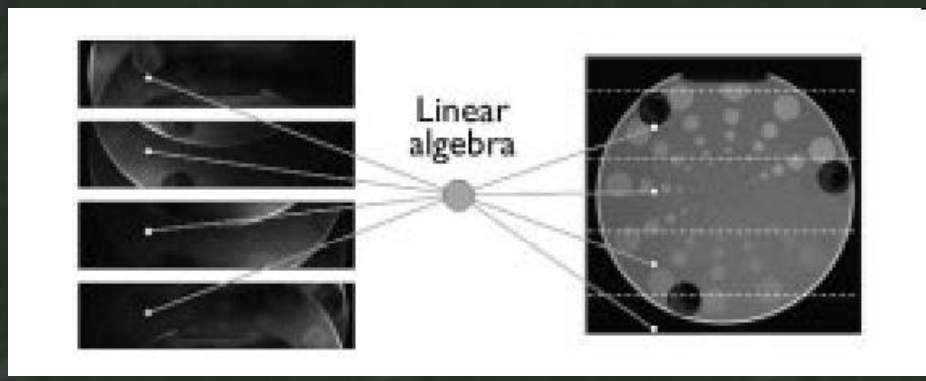
SENSE Imaging



≈ 5 to 30 ms





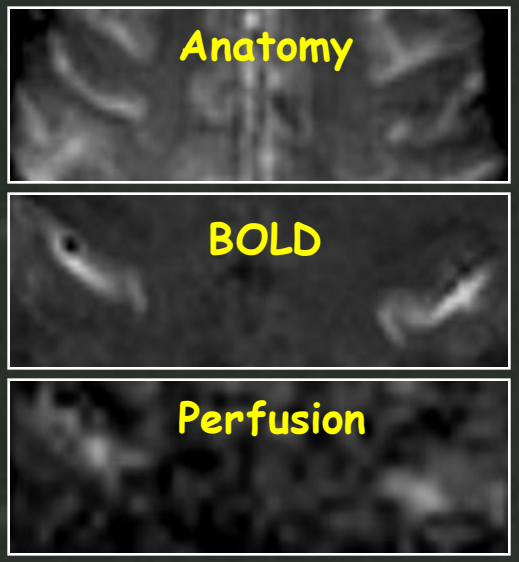


Pruessmann, et al.

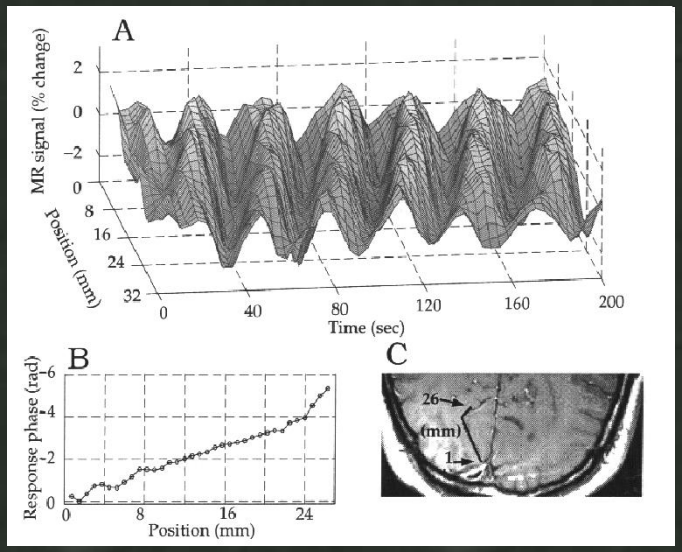
SENSE Imaging

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

PSF FWHM = 3.5mm

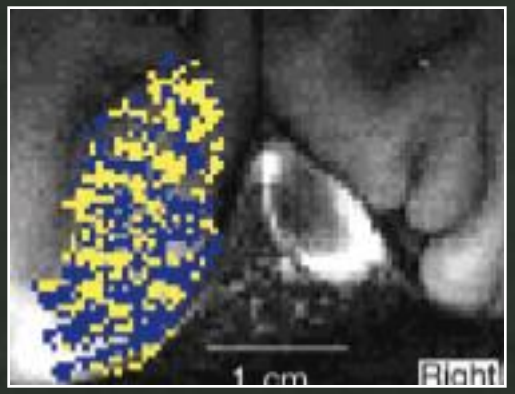


P. A. Bandettini, (1999) "Functional MRI" 205-220.



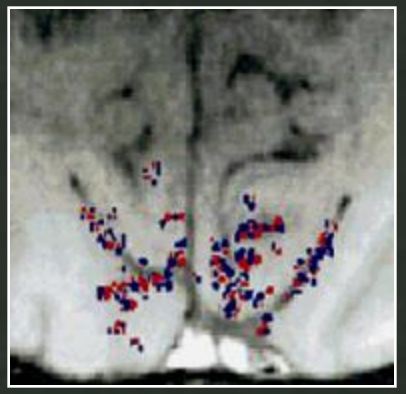
S.A. Engel, et al. Investigative Ophthalmology & Visual Science 35 (1994) 1977-1977.

0.47 x 0.47 in plane resolution



Cheng, et al. (2001) Neuron,32:359-374

0.54 x 0.54 in plane resolution

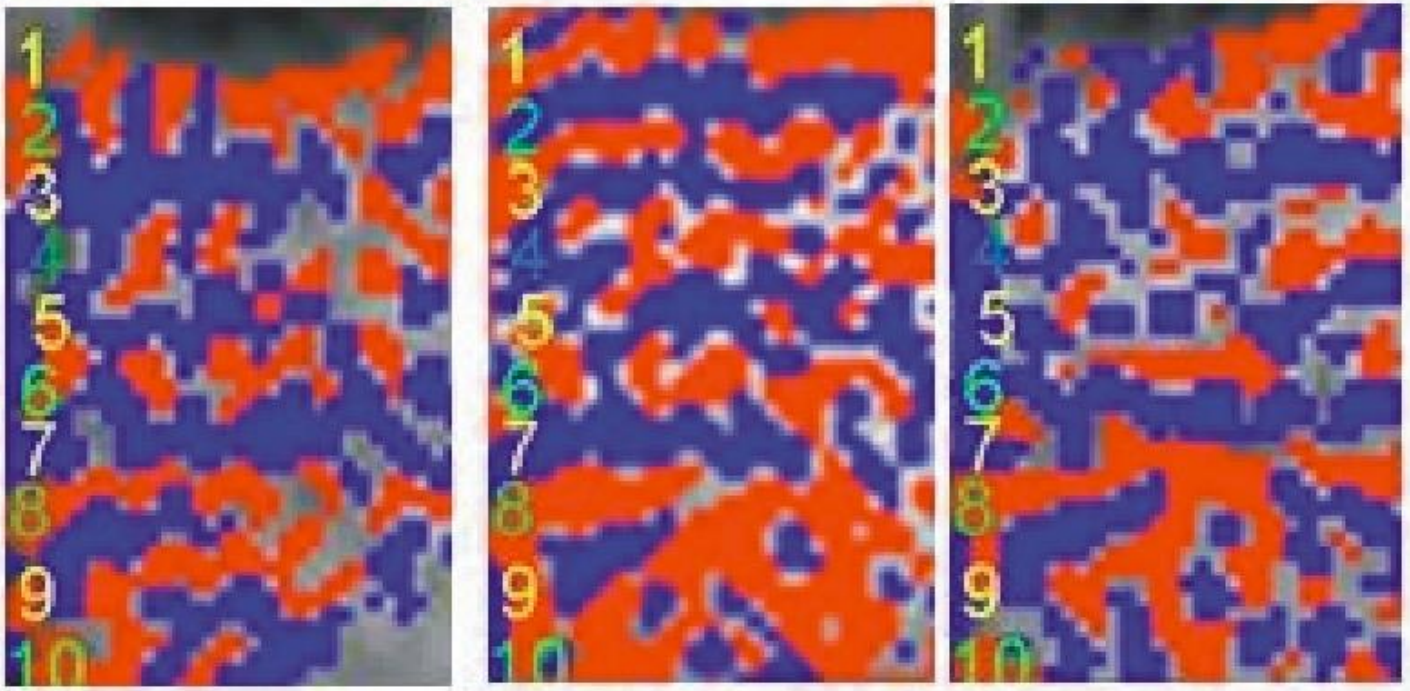


Menon et al, (1999) MRM 41 (2): 230-235

Multi-shot with navigator pulse

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

Three challenges posed by hi-res fMRI

1. fine-scale neuronal activity patterns may be inaccurately depicted (although irregularly spaced subvoxel patterns are able to be detected).
2. small voxels yield noisy responses (and spatial smoothing would lower resolution)
3. voxel-to-voxel interindividual correspondency mapping unkown. (standard normalization, and averaging across subject doesn't work)

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Neuronal Activation

?

Measured Signal

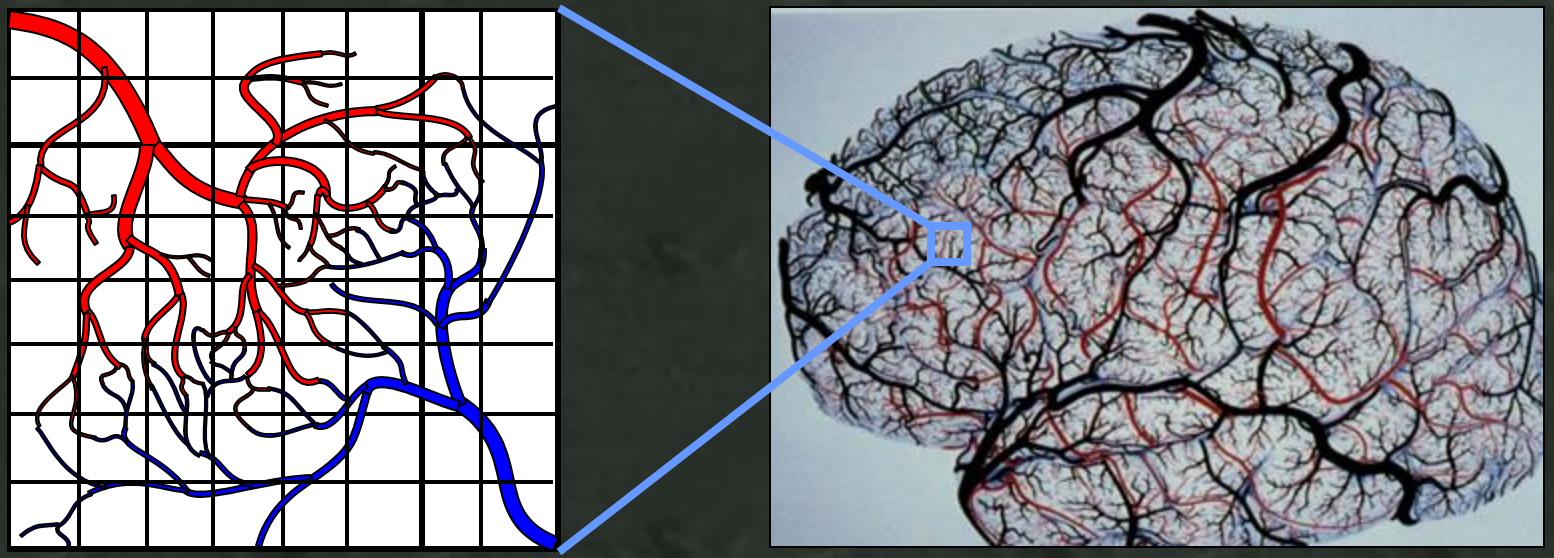
?

?

?

Hemodynamics

Noise



What we know about fMRI signal changes:

- fMRI amplitude is proportional to neuronal activity (synaptic activity)
- Other variables influence signal: blood volume in each voxel, field strength, pulse sequence…
- Δflow, Δoxygenation, and Δvolume are controlled on spatial scale of neuronal activity (columns) but do not necessarily correspond in a precise manner spatially.

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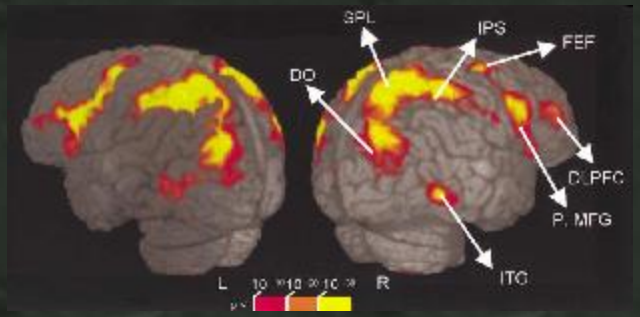
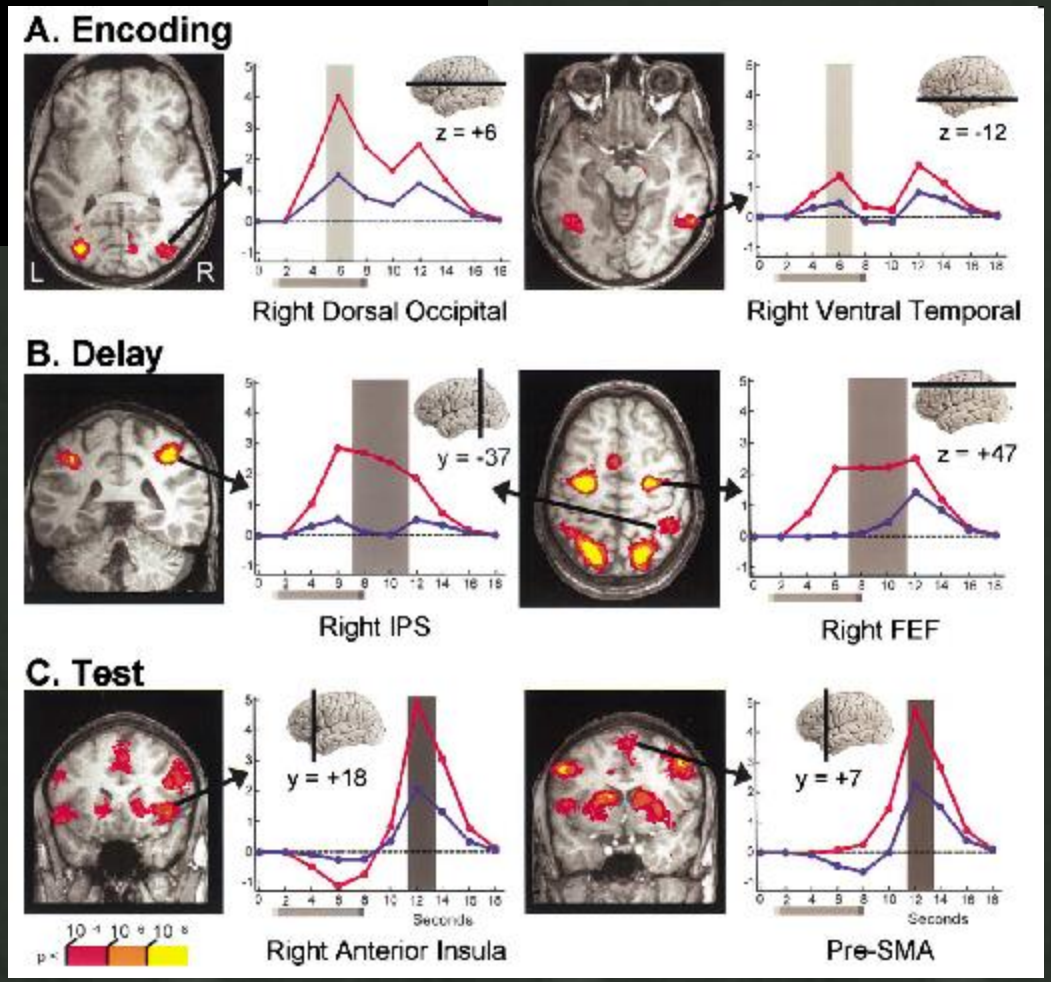
Mapping ⟷ "Reading"

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





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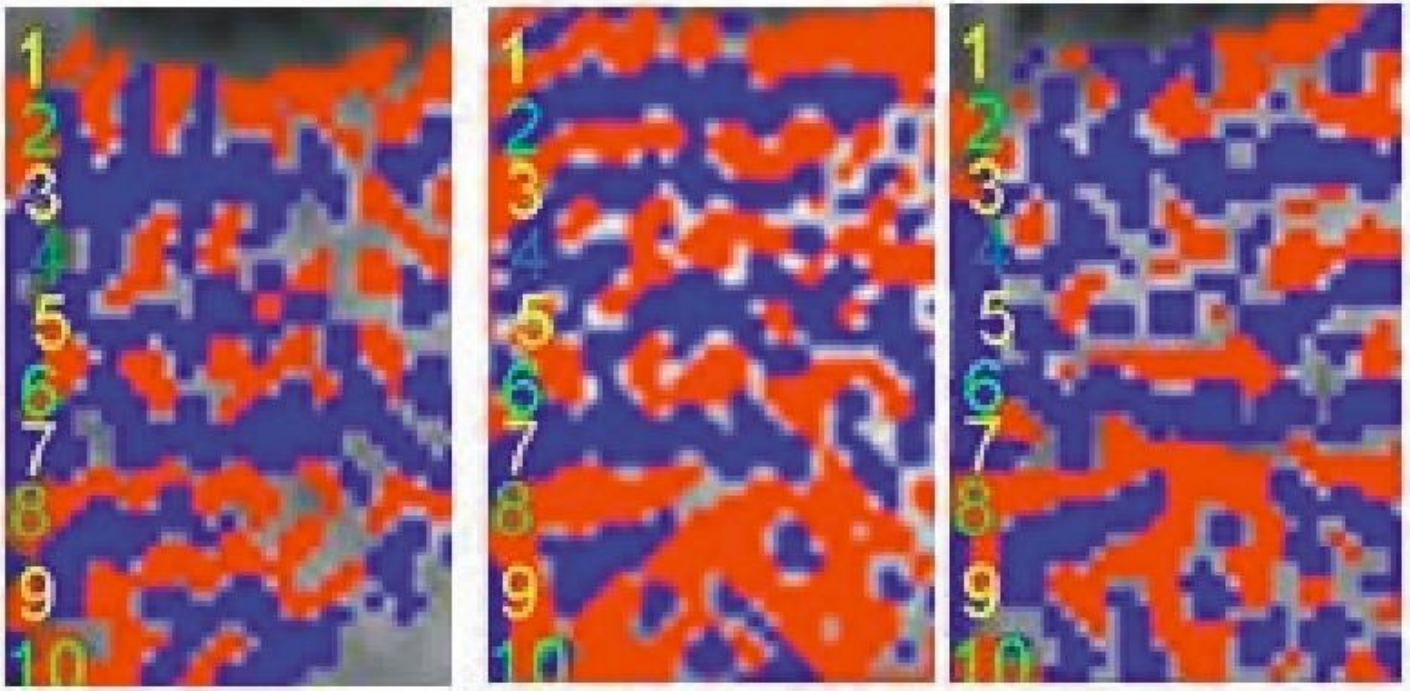

day 1 **day 2** **day 3**

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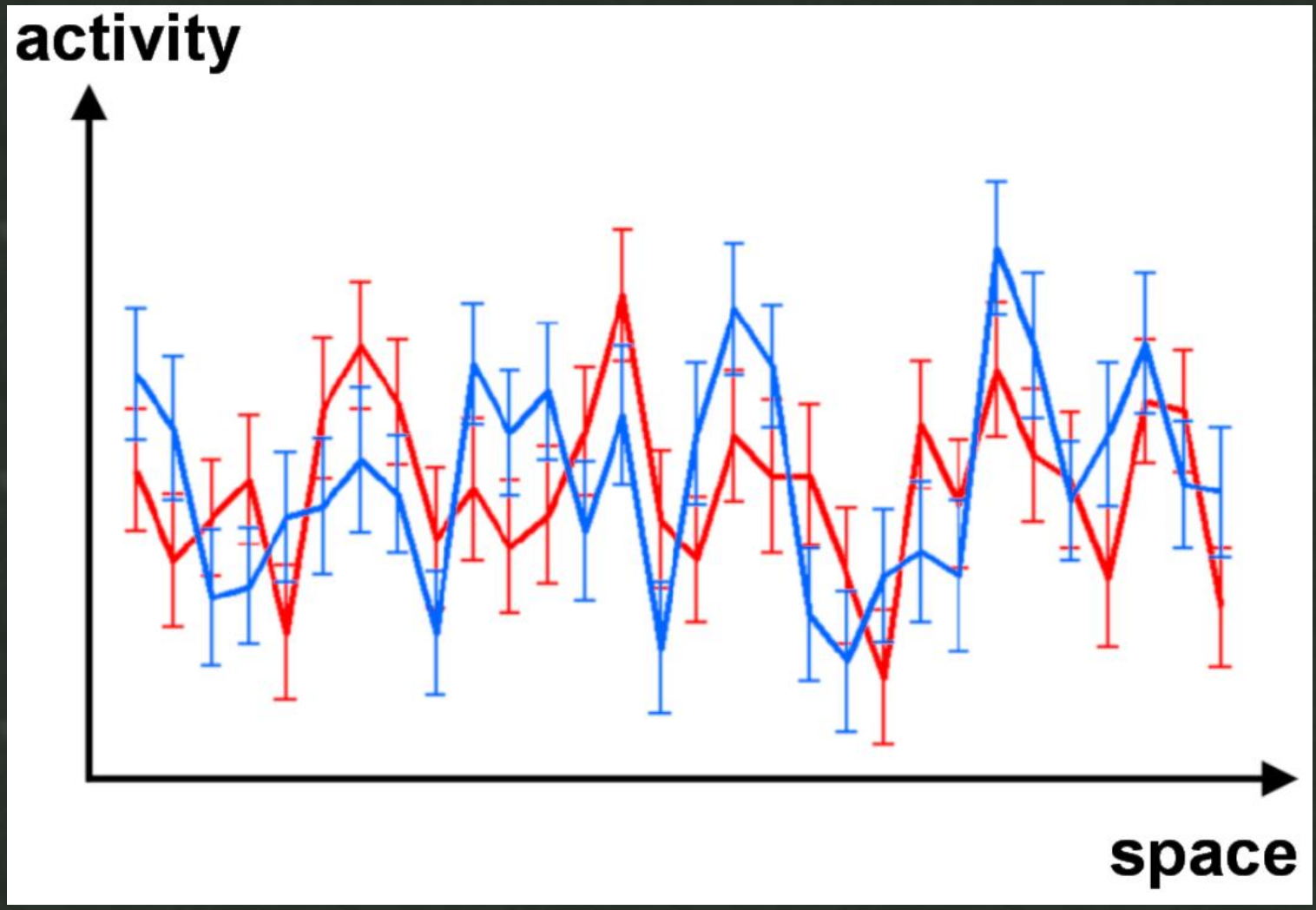

activity
space

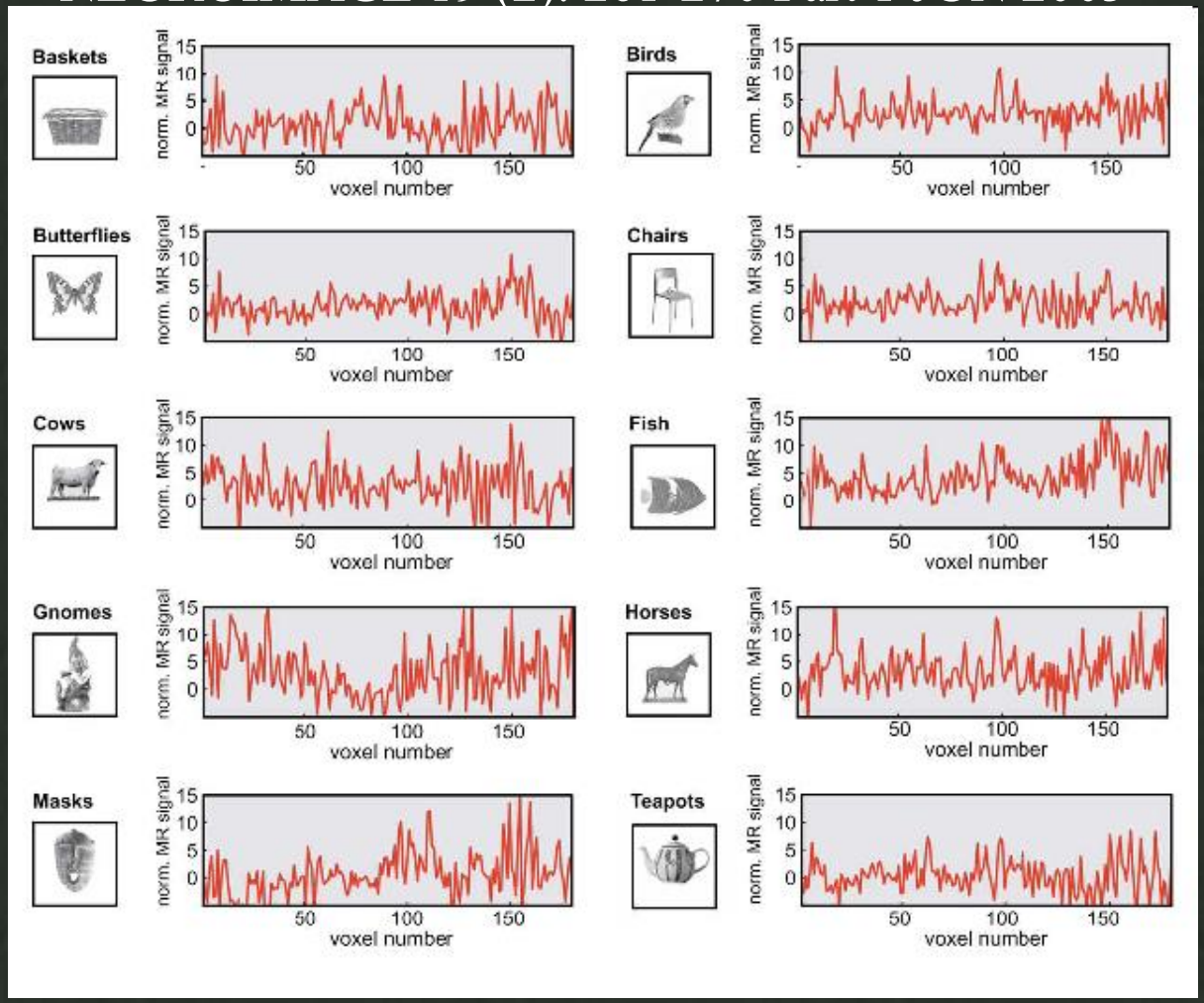
Functional magnetic resonance imaging (fMRI) "brain reading": detecting and classifying distributed patterns of fMRI activity in human visual cortex

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

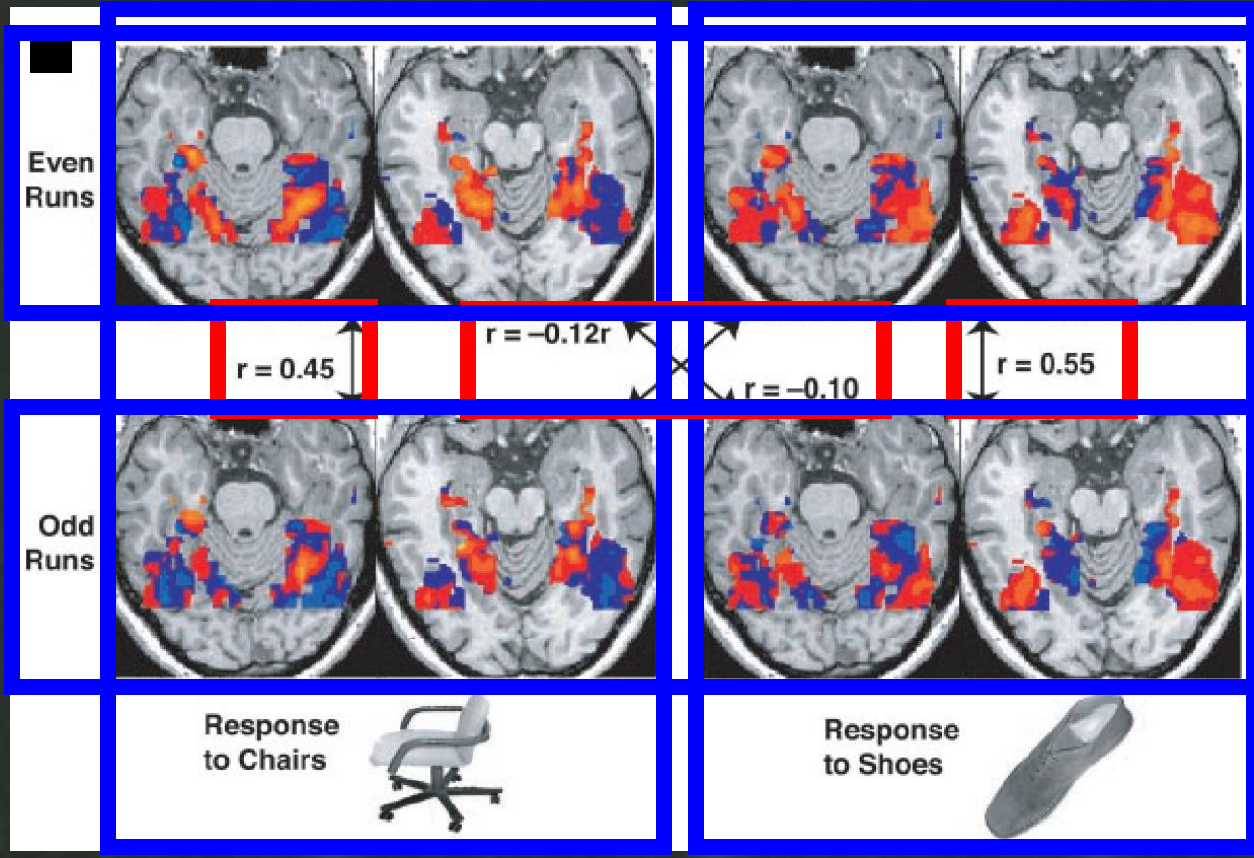
Received 15 July 2002; accepted 10 December 2002

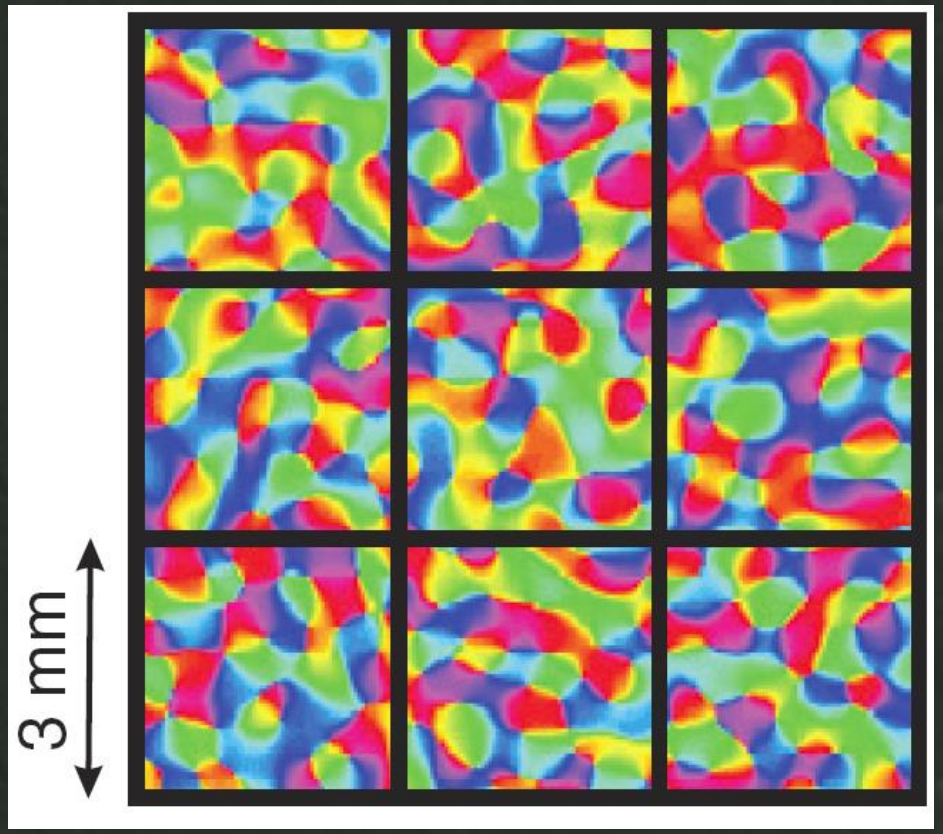
NEUROIMAGE 19 (2): 261-270 Part 1 JUN 2003

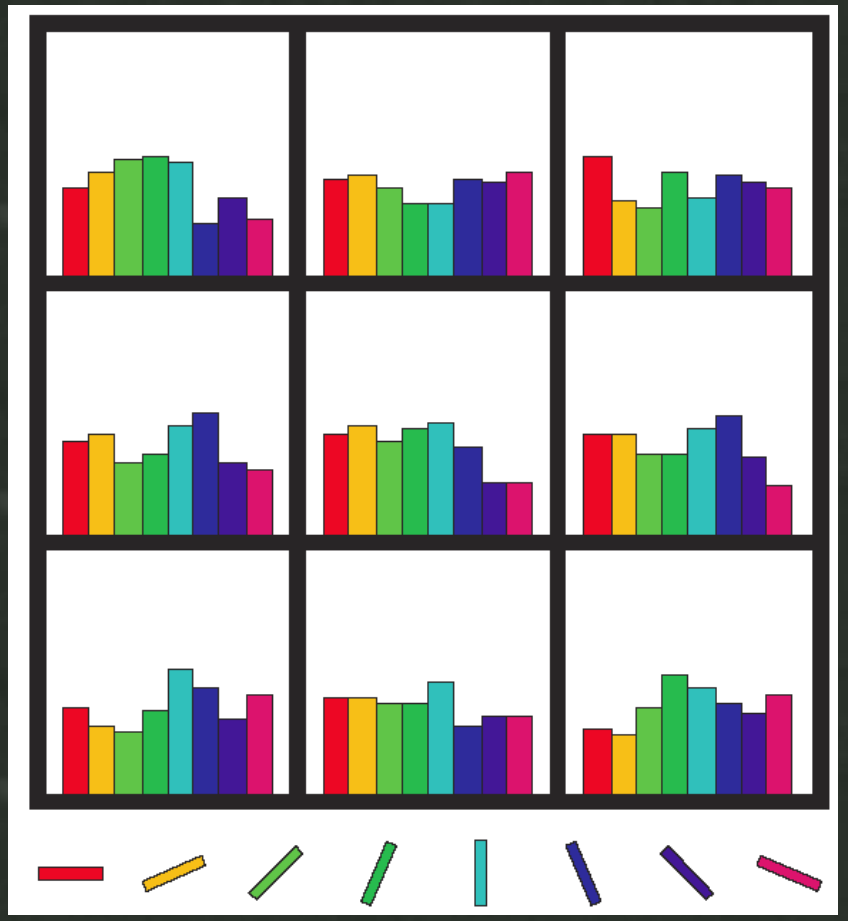


Ventral temporal category representations

- Object categories are associated with distributed representations in ventral temporal cortex
  - Present photos of common objects **blocked by category**.
  - Use fMRI to measure the pattern of high and low responses across large areas of ventral temporal cortex.
  - Observe **stable**, distributed "category representations"

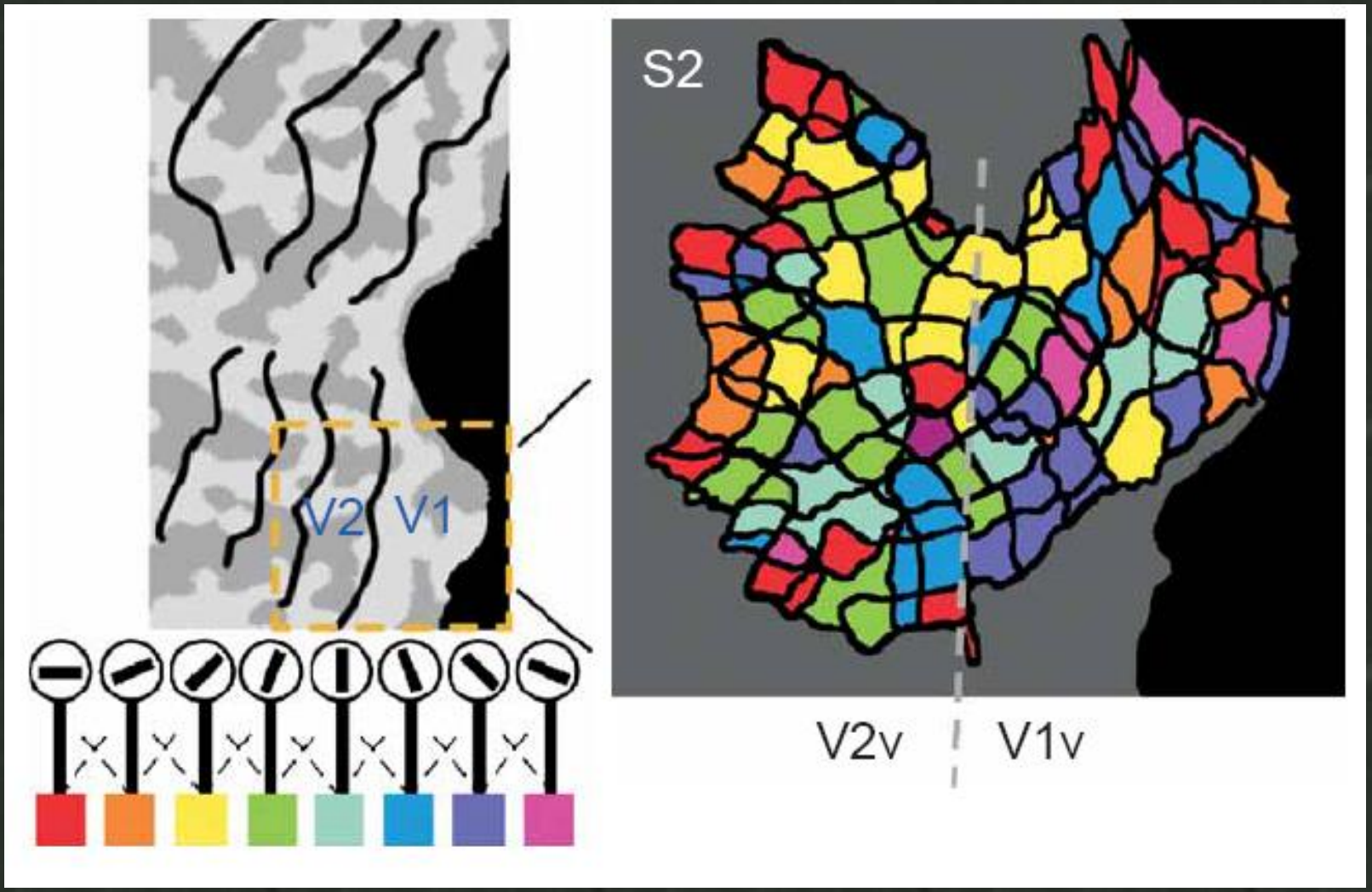




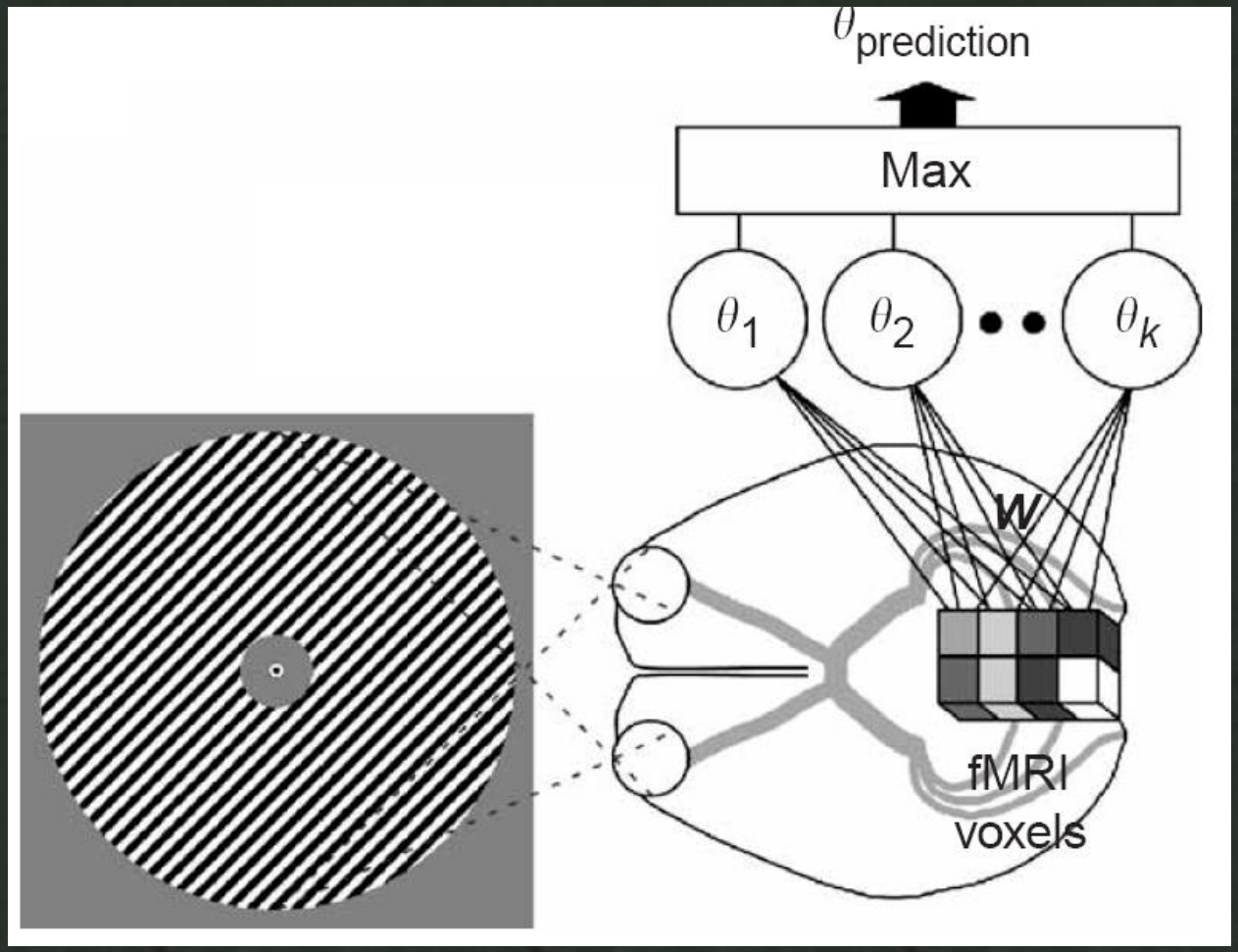


Boynton (2005), News & Views on Kamitani & Tong (2005) and Haynes & Rees (2005)

Lower spatial frequency clumping



Iso-orientation domains are not resolved,
but the viewed orientation can be predicted



Mapping vs Prediction

-they are opposite sides of the same thing
-prediction/repeat correlation are used when maps are less obvious (which is more often as columnar organization is assessed)
-prediction/repeat correlation establish that the patterns contain information

Univariate vs Multivariate

-taking the entire activation pattern over space as a whole substantially increases detection/prediction power

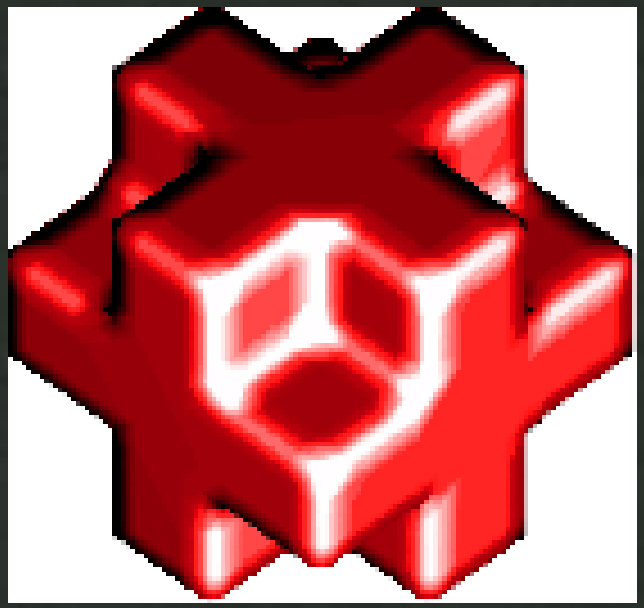
Pattern-recognition analysis of fMRI activity patterns

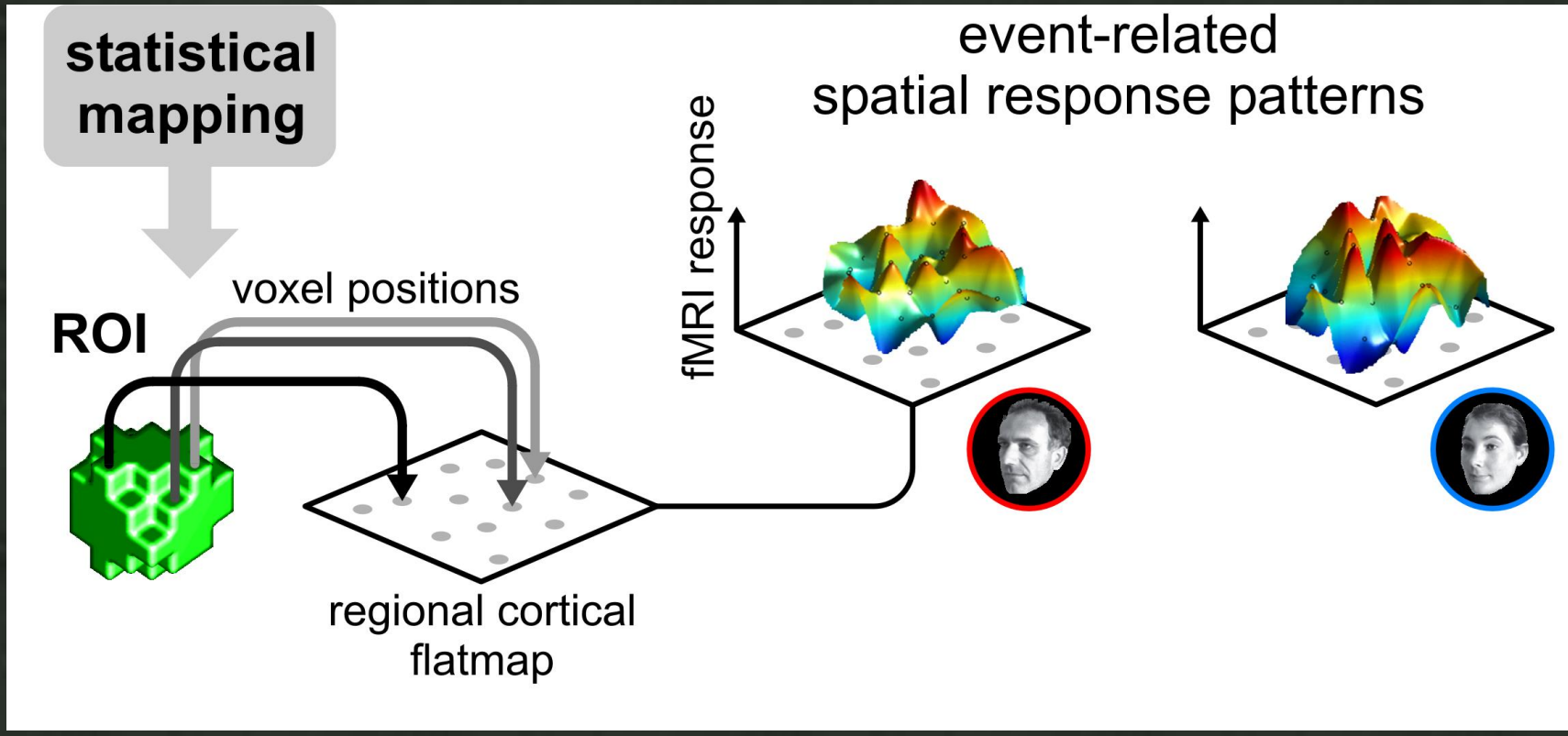
- Haxby et al. (2001)
- Cox & Savoy (2003)
- Carlson et al. (2003)
- Kamitani & Tong (2005)
- Haynes & Rees (2005)

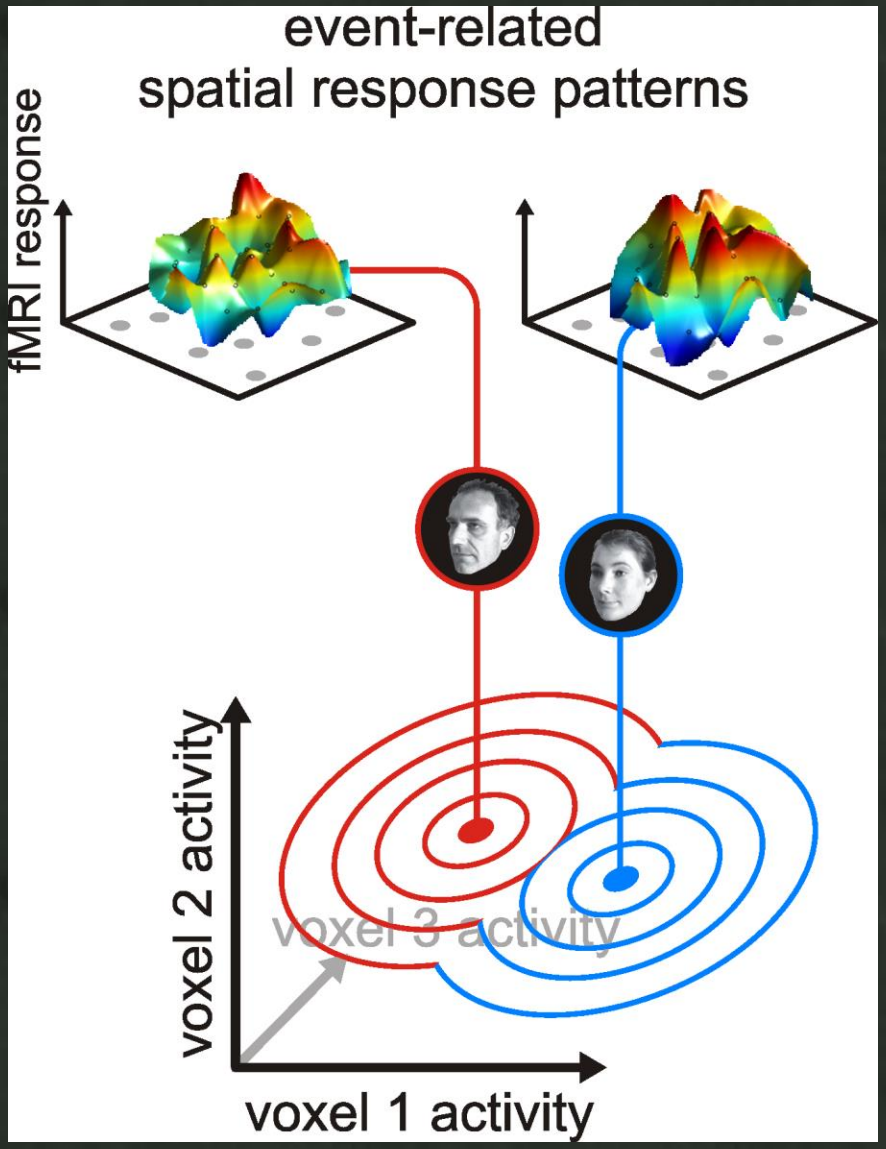
1. fine-scale neuronal activity patterns may be inaccurately depicted (although irregularly spaced subvoxel patterns are able to be detected) (no longer look like "blobs" - no longer "mapping")
2. small voxels yield noisy responses (multivatiate) (and spatial smoothing would lower resolution)
3. voxel-to-voxel interindividual correspondency mapping unkown. (standard normalization, and averaging across subject doesn't work) (we need a new method)

Multivariate Searchlight Approach

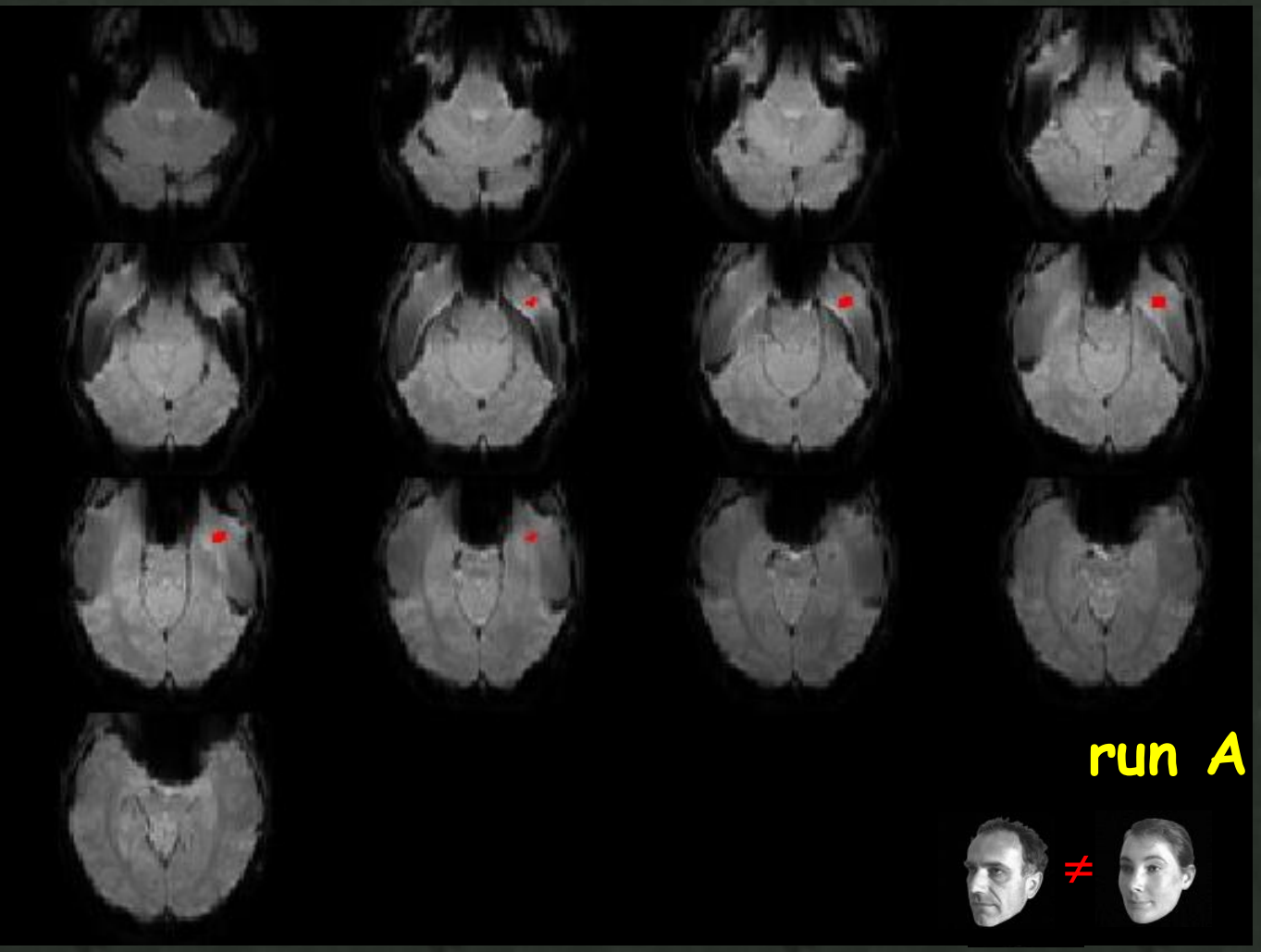
Kriegeskorte et al.




statistical mapping
ROI
voxel positions
regional cortical flatmap
fMRI response
event-related
spatial response patterns


event-related
spatial response patterns
fMRI response
voxel 2 activity
voxel 3 activity
voxel 1 activity

Anterior inferotemporal face-exemplar region

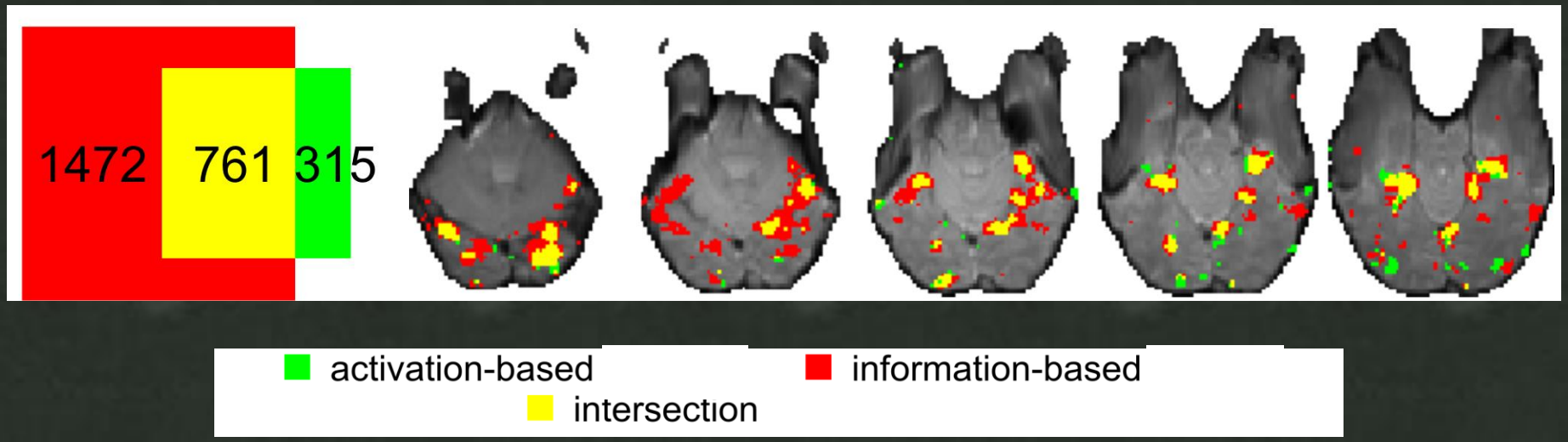


run B

Talairach: 33, -8, -33

spatial mean removed, fisherAtestB: single-sided test and info estimate

Application to Typical fMRI data to increase sensitivity



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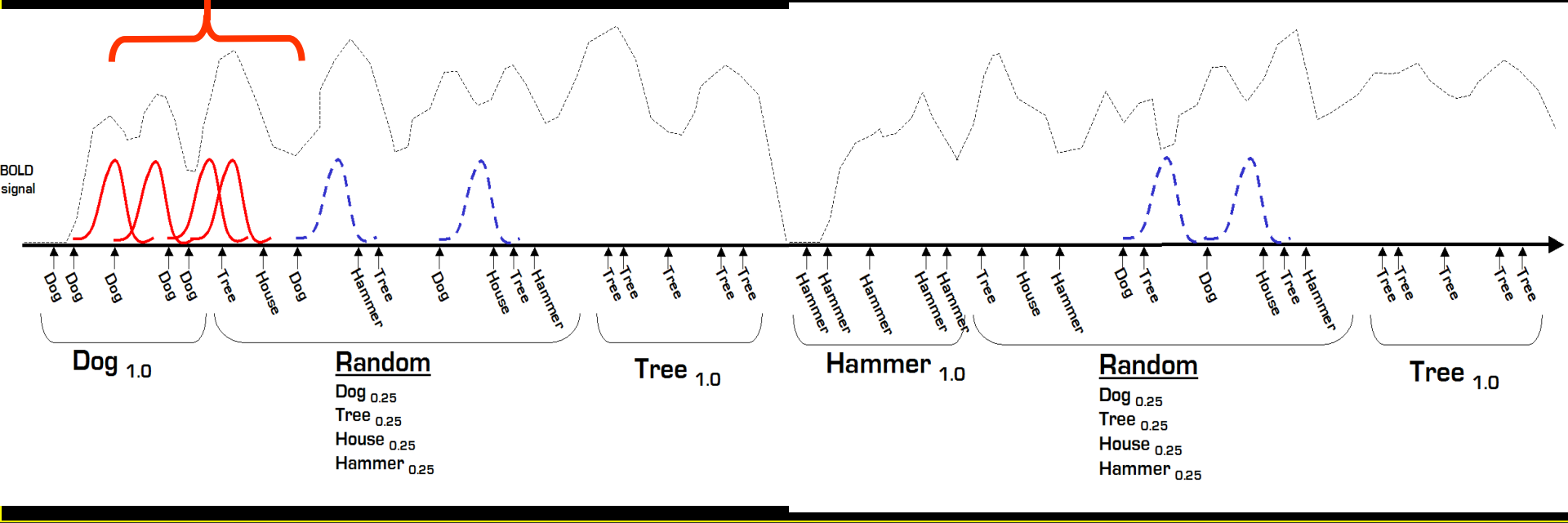
Category expectations alter ventral temporal category representations

W. Kyle Simmons
Lawrence W. Barsalou
Emory University

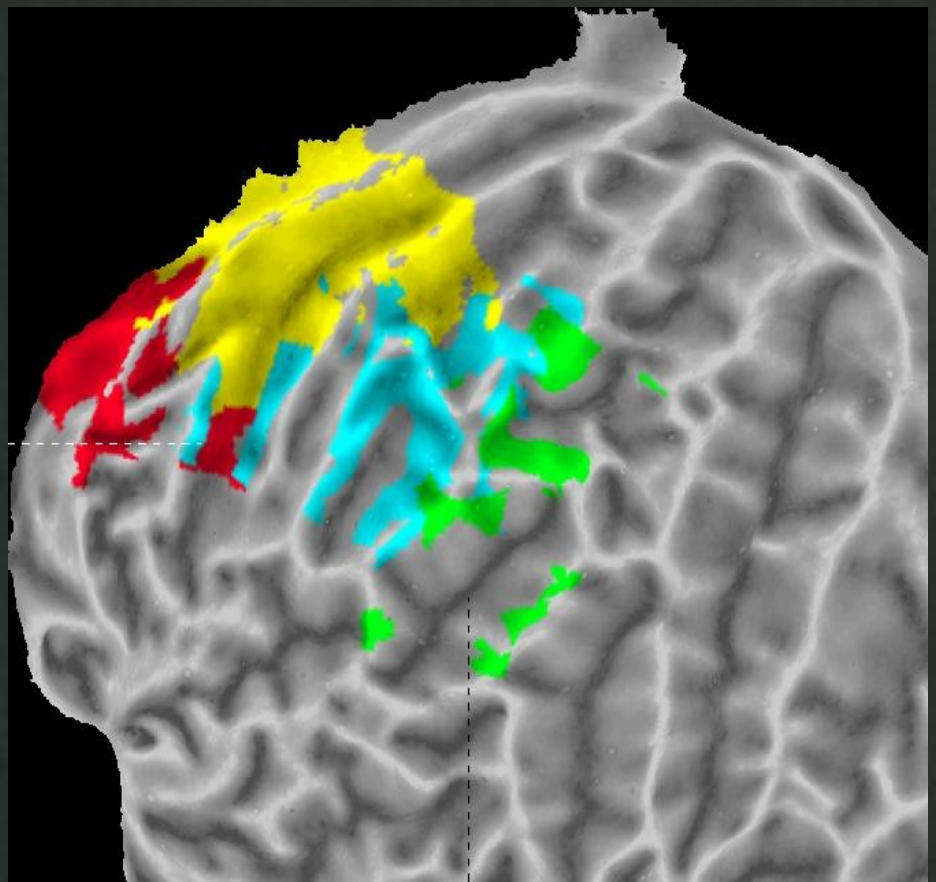
Note: These are called "blocks", but they are in an event-related design

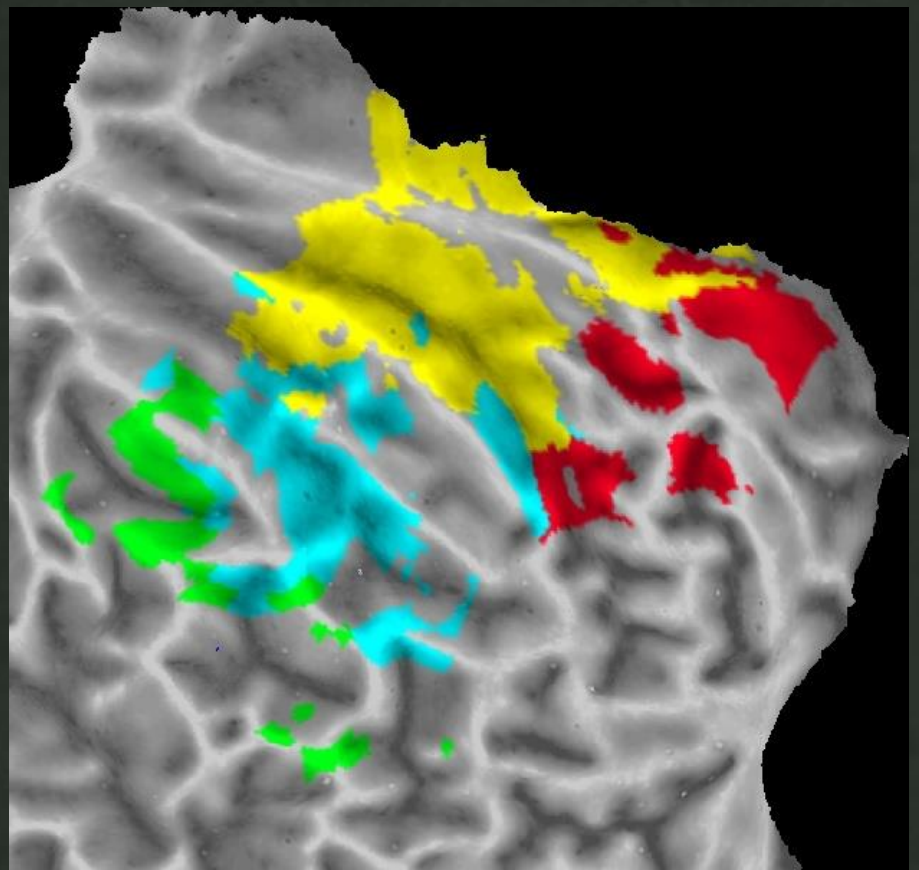


Designs were optimized in optseq2 and simulations were run to ensure equivalent estimation efficiencies for blocked and random conditions.

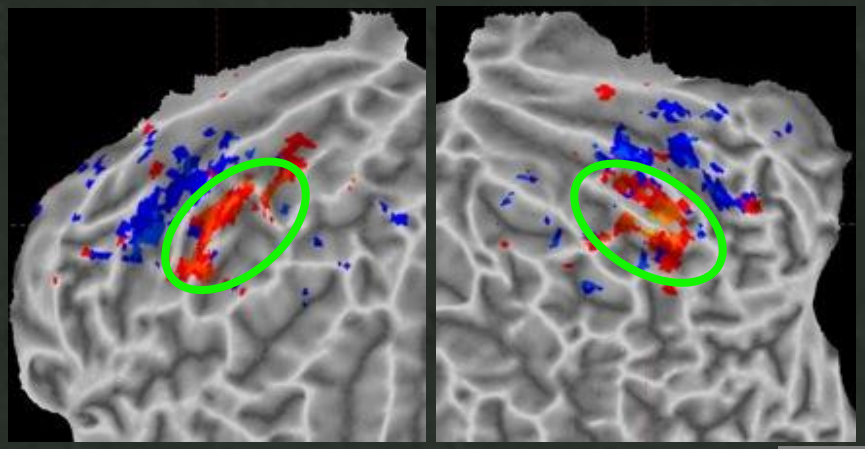
Ventral temporal cortex includes:

1) lingual gyrus
2) fusiform gyrus
3) parahippocampal gyrus
4) inferior temporal gyrus

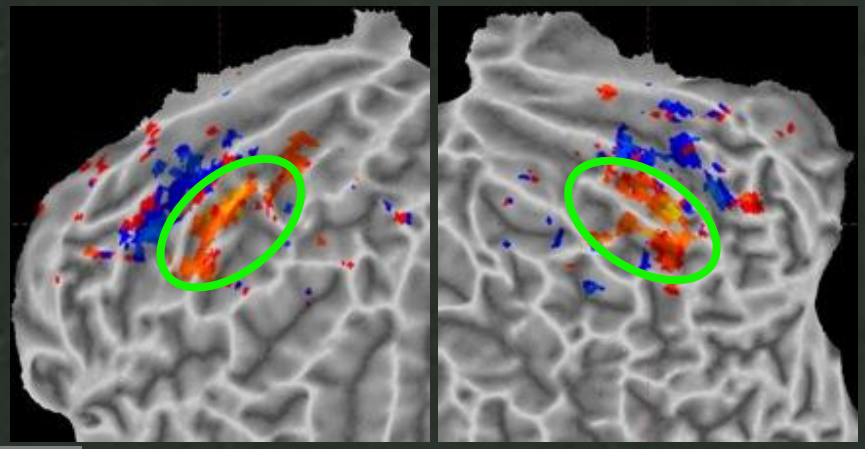


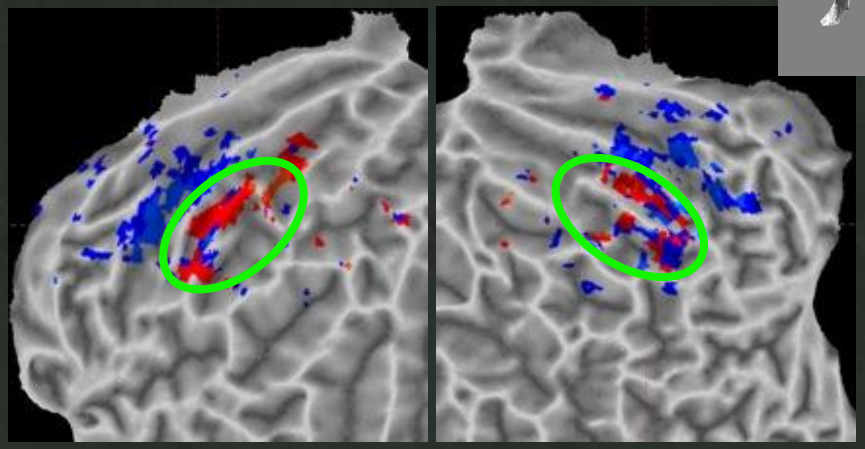


Dog – Block - Odd

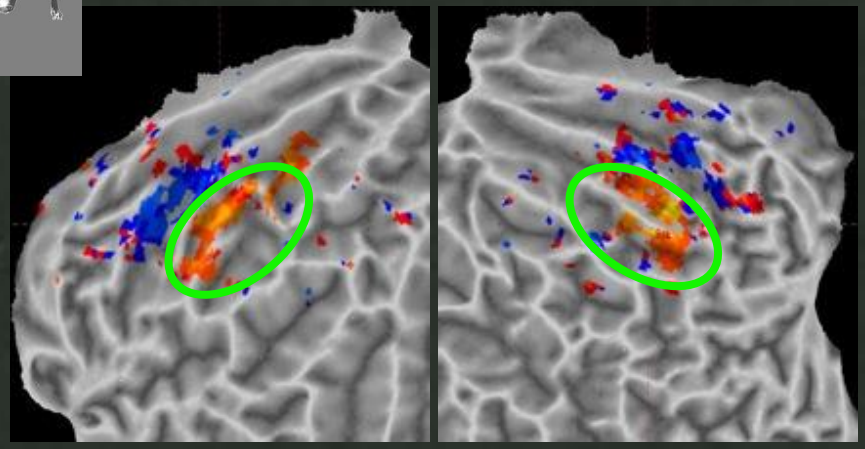


Dog – Random - Odd



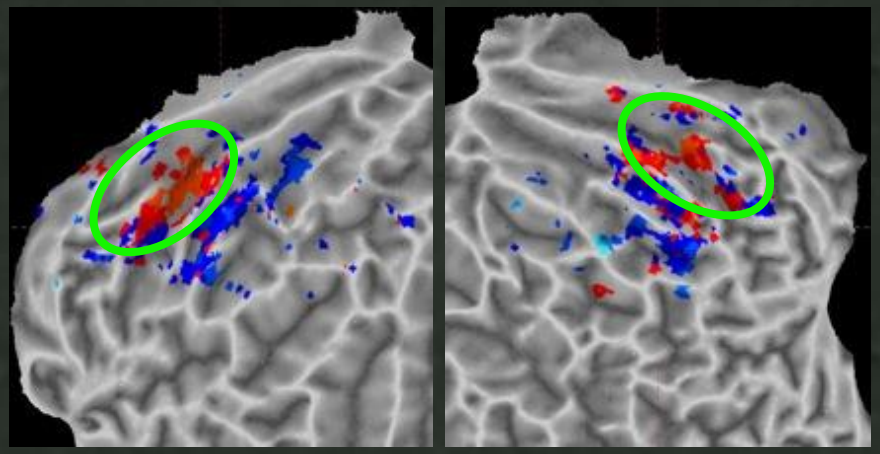


Dog – Block - Even

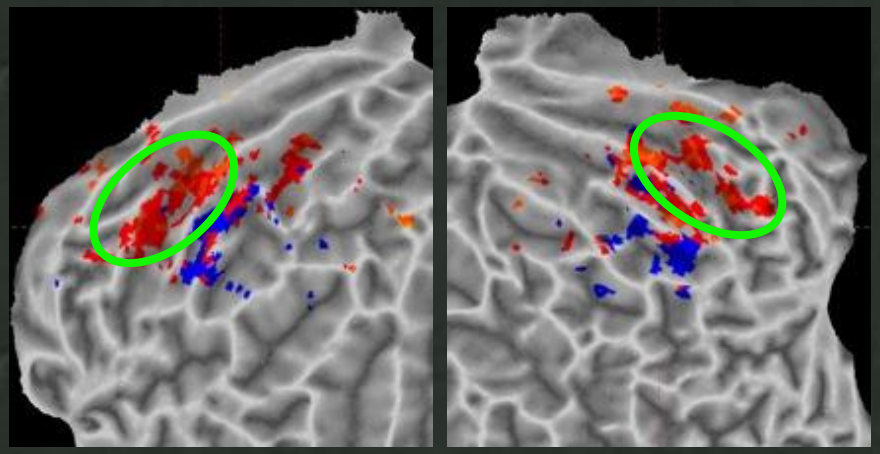


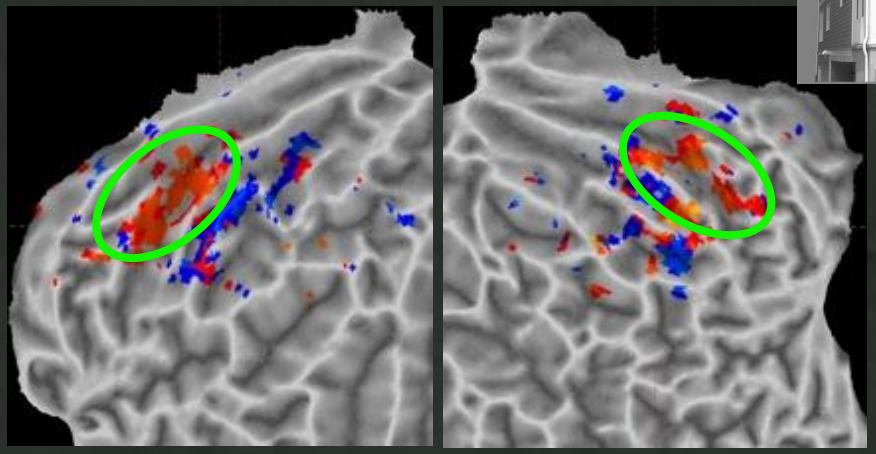
Dog – Random - Even

House – Block - Odd

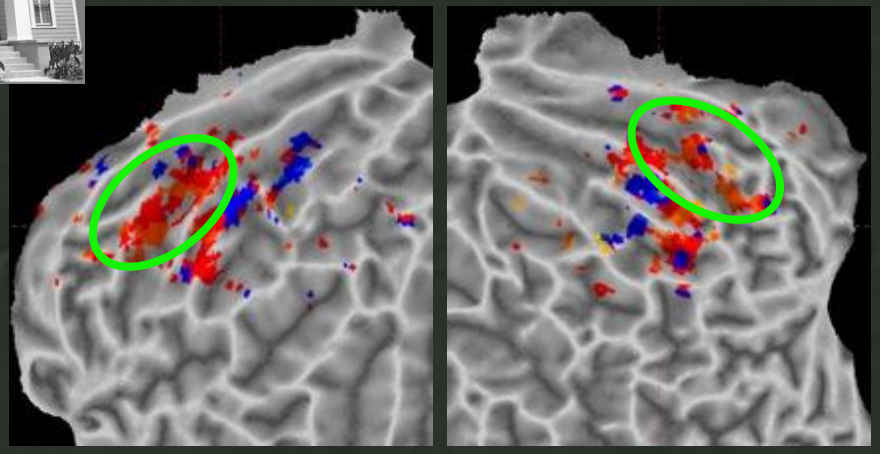


House– Random - Odd





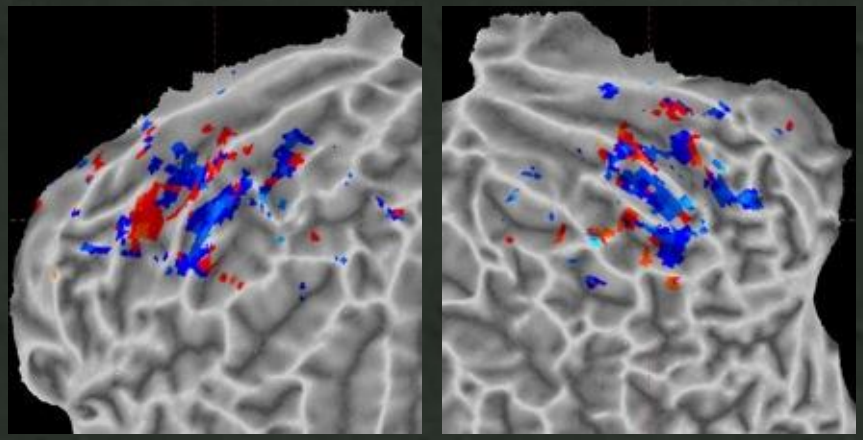
House– Block - Even



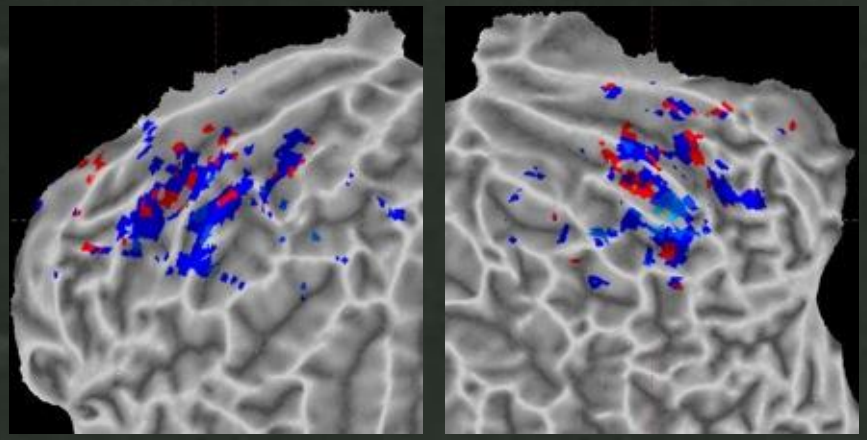
House– Random - Even

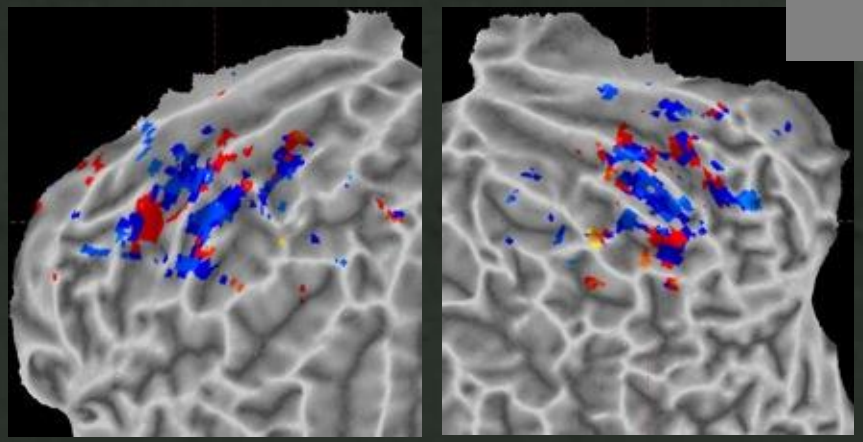
Note: These data are from a single subjec

Hammer – Block - Odd

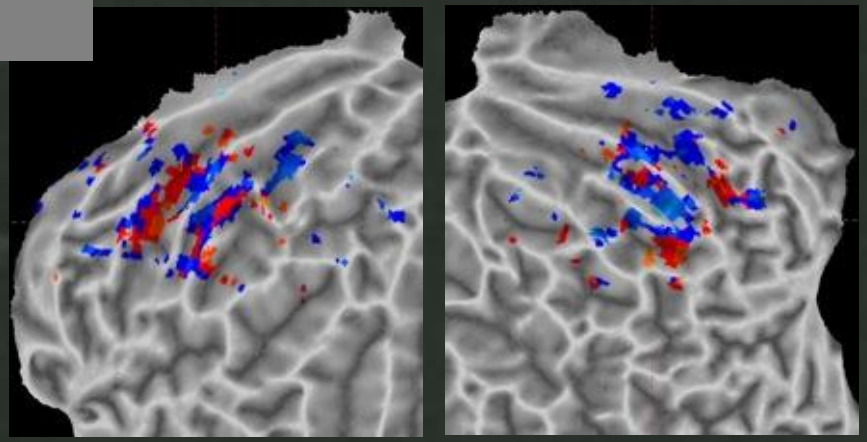


Hammer– Random - Odd





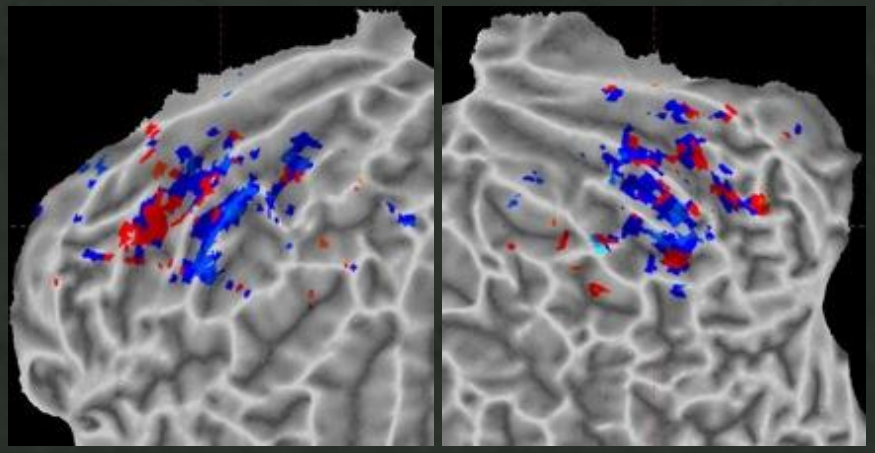
Hammer– Block - Even



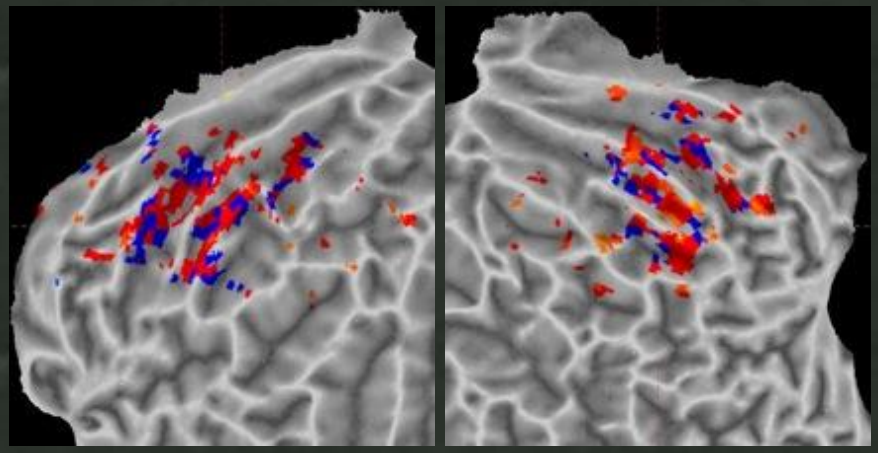
Hammer– Random - Even

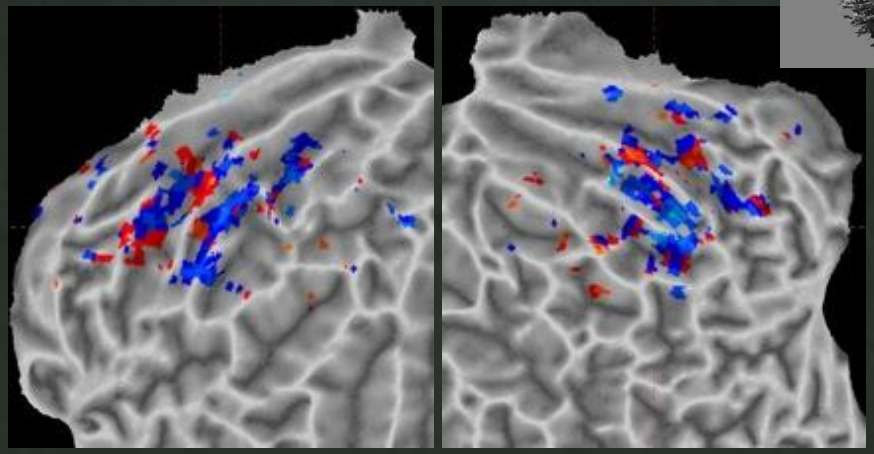
Note: These data are from a single subjec

Tree – Block - Odd

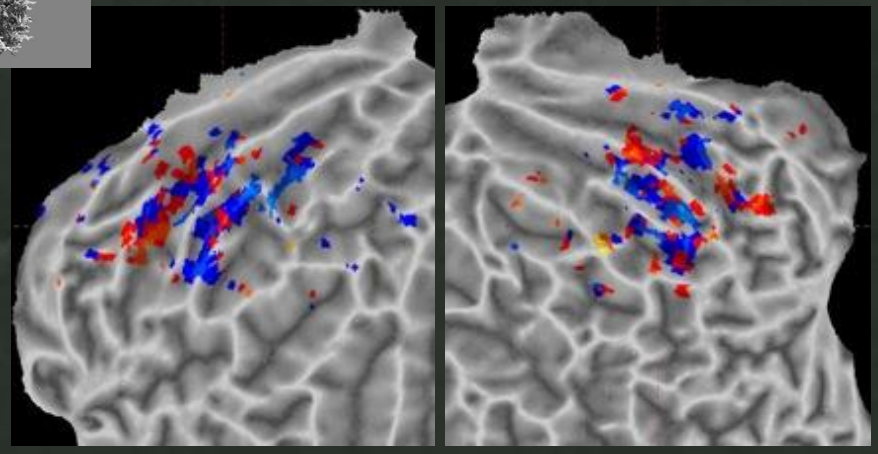


Tree – Random - Odd





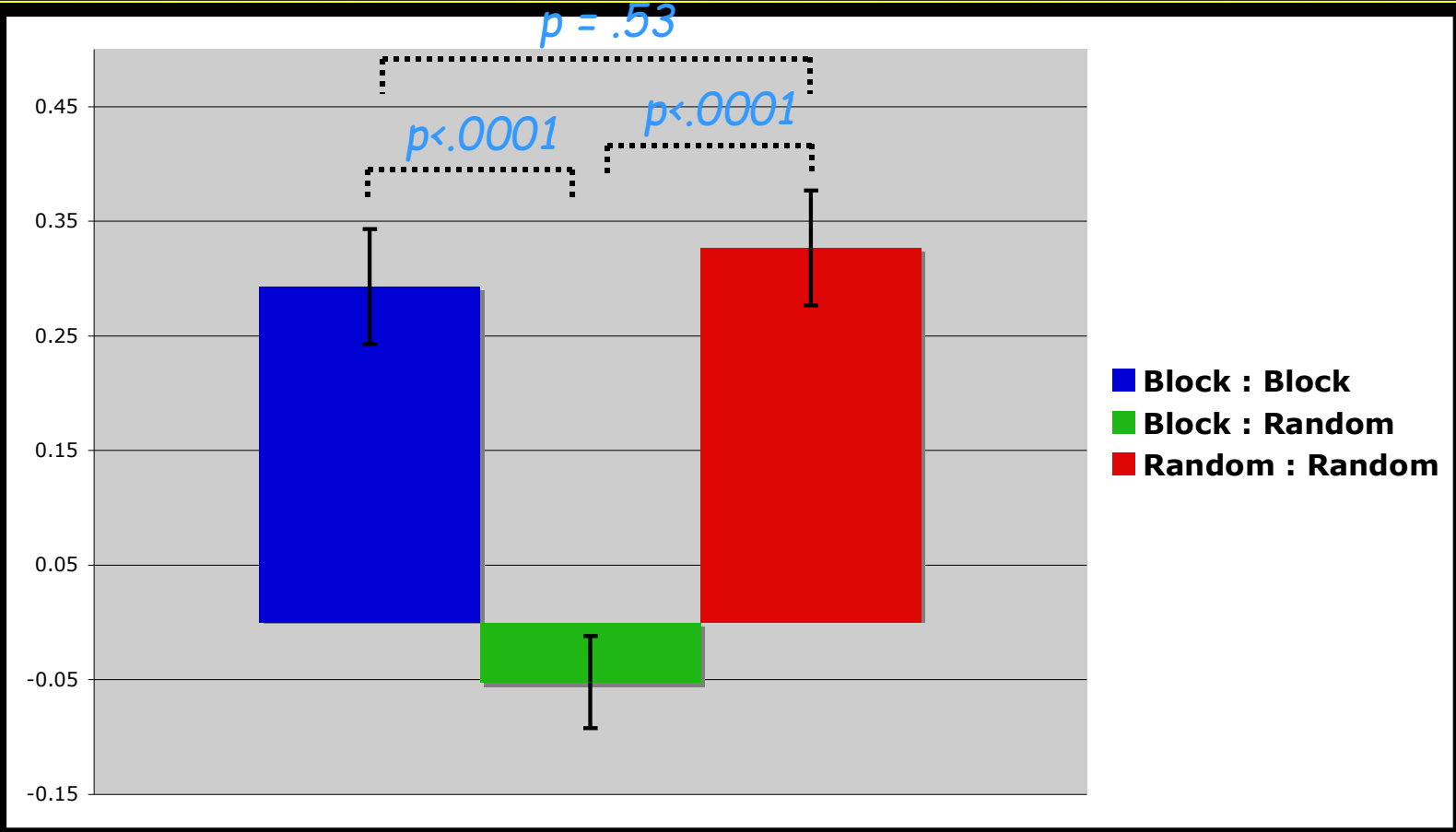
Tree – Block - Even



Tree – Random - Even

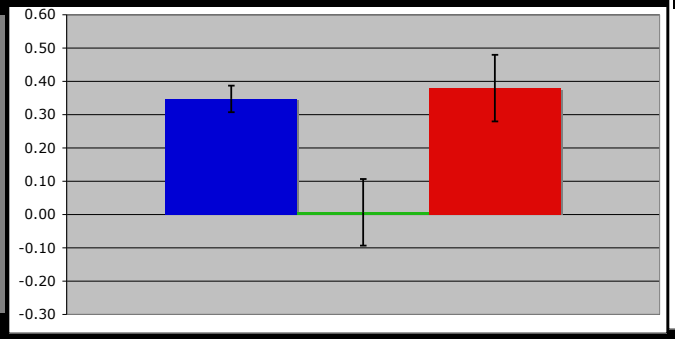
Note: These data are from a single subjec

Correlations between versus within contexts

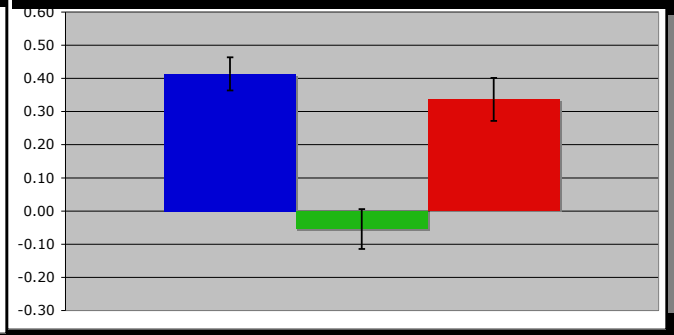


Correlations between versus within contexts for each category

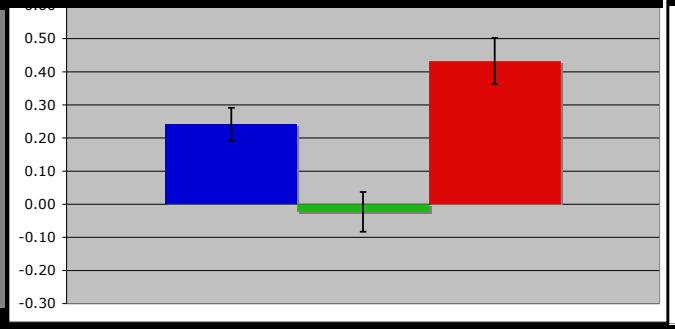
DOG



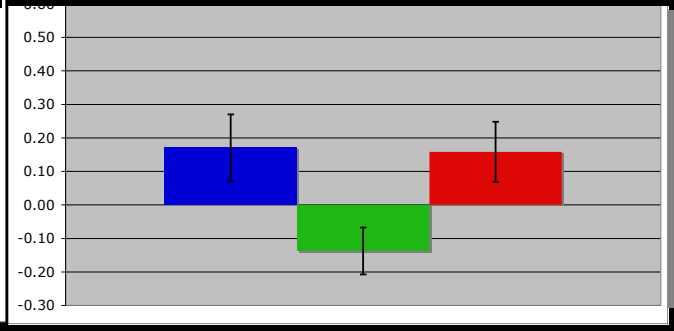
HOUSE



HAMMER



TREE



Block : Block
Block : Random
Random : Random