Brain Reading with fMRI

07.31.15

Chris Baker

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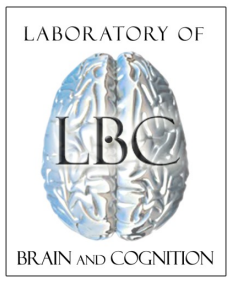
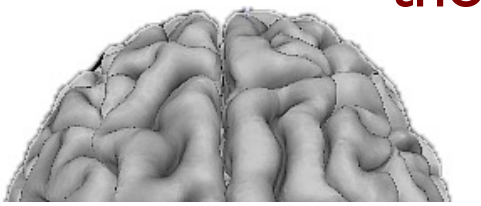
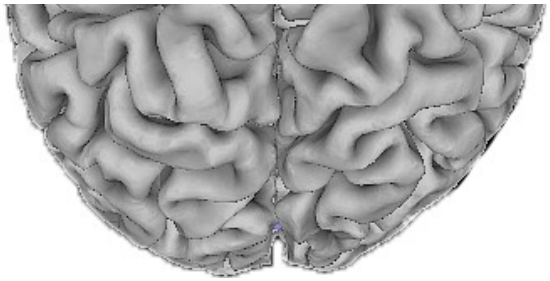


I Saw That on TV…..

“mind reading” “thought identification”



What can we really do?



“prediction” “decoding”

Why read brains?

1) Law enforcement
   - Lie detection
   - Interrogation
2) Marketing
   - Consumer
   - Political
3) Brain-computer interface
   - Prosthetic devices
   - Googling with the mind
4) Communicating with patients
   - Disorders of consciousness
5) Understanding how information is represented in the brain

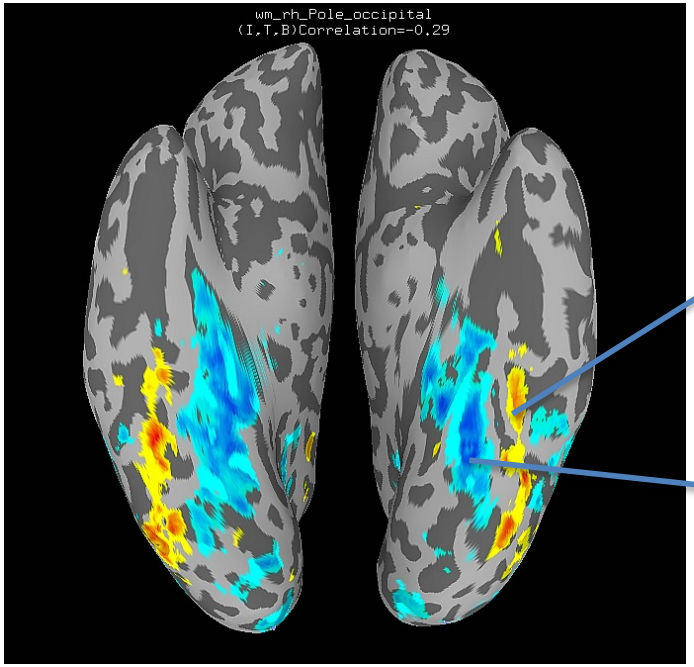
Building a Brain Reader

1) Train
   - Learn to associate fMRI responses with specific conditions
2) Test
   - Validate brain reader and show generalization to new data

Your Turn!

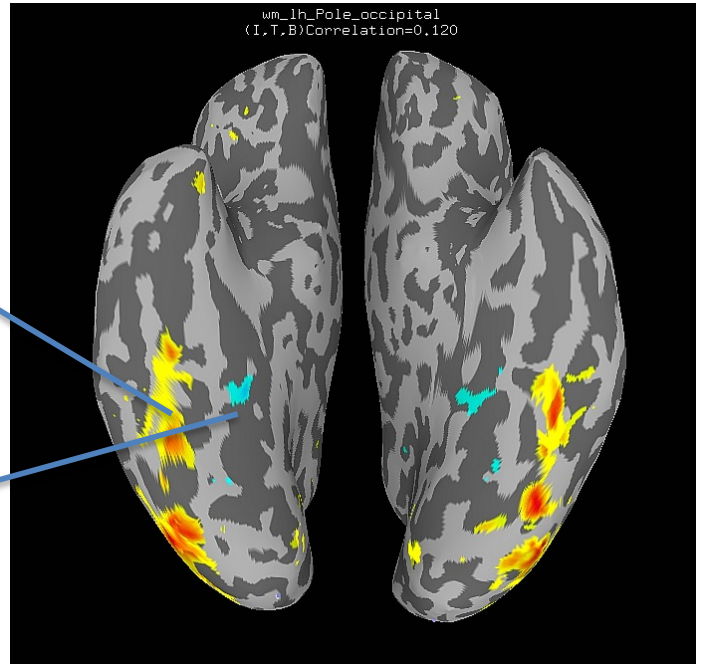
1) Training

vs.



Fusiform Face Area (FFA)

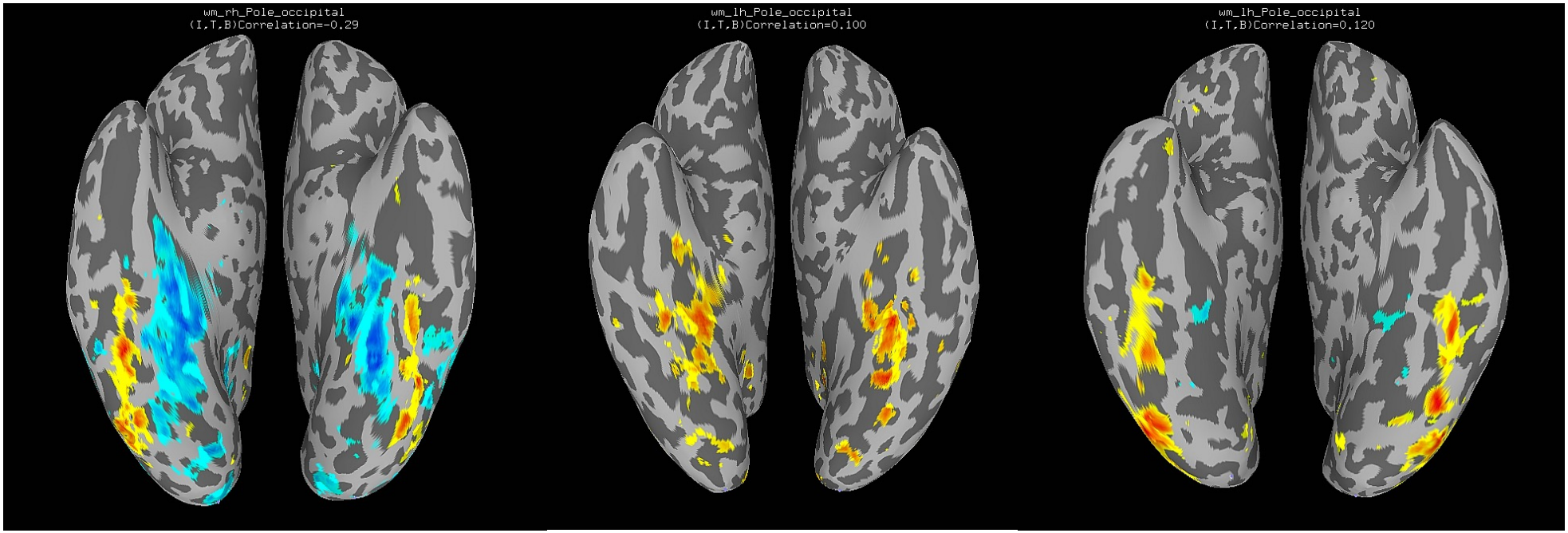
Parahippocampal Place Area (PPA)



Courtesy of Annie Chan

1) Testing

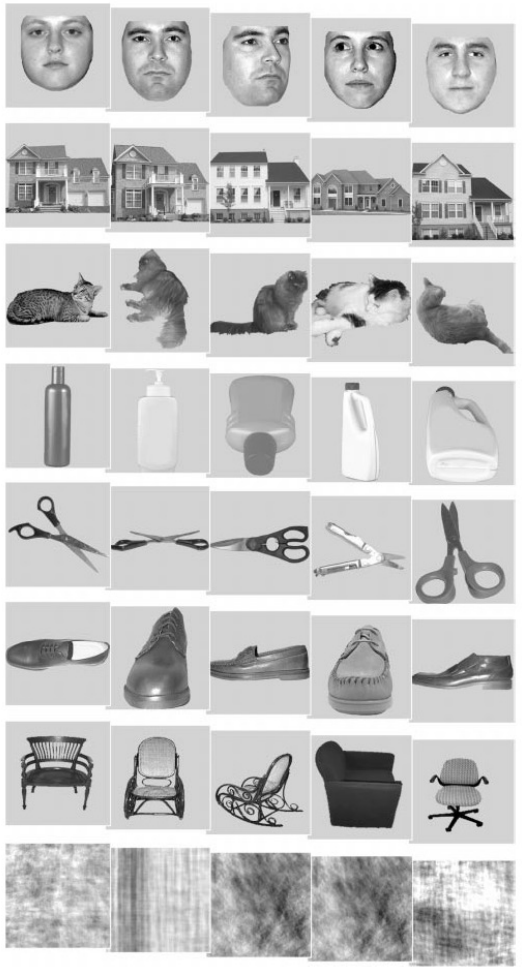
A > B



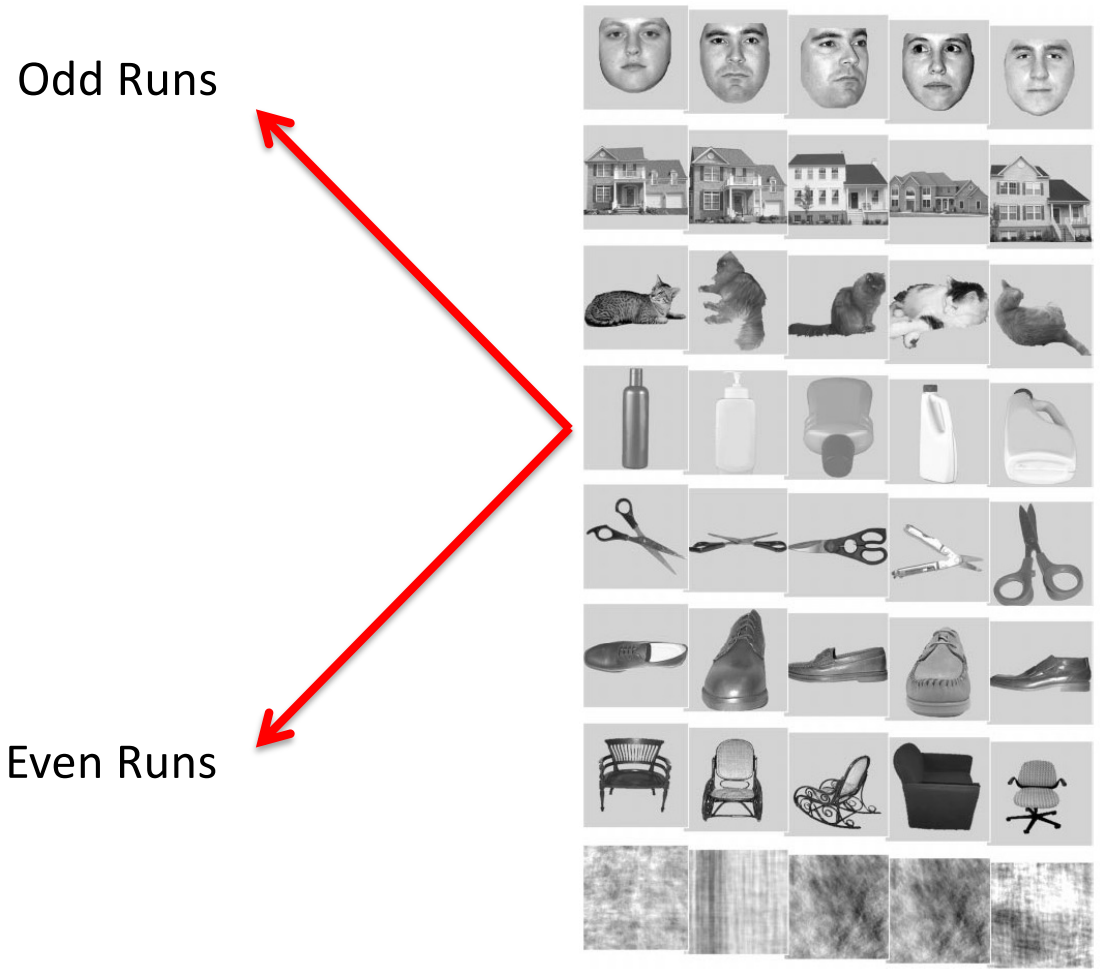
Courtesy of Annie Chan

Object representations in ventral temporal cortex (Haxby et al, 2001)

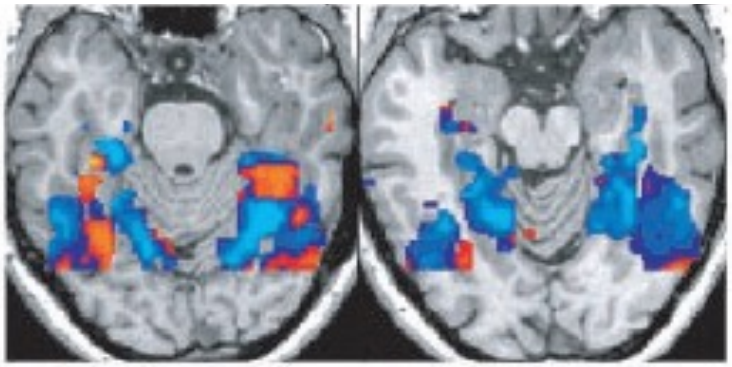
- Participants viewed blocks of images from 8 categories
- 1-back task
- Split-half correlation analysis

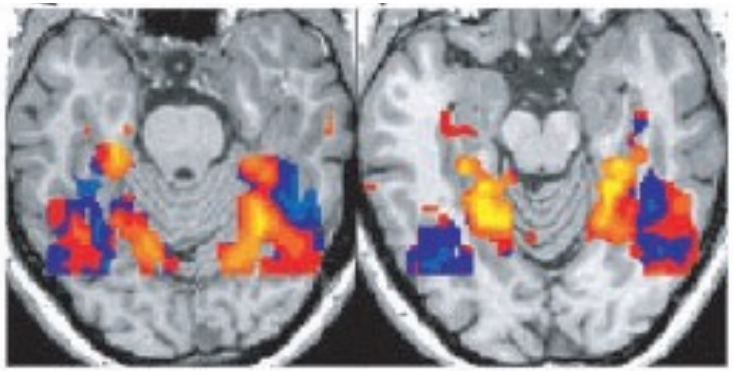


Object representations in ventral temporal cortex (Haxby et al, 2001)



Odd Runs

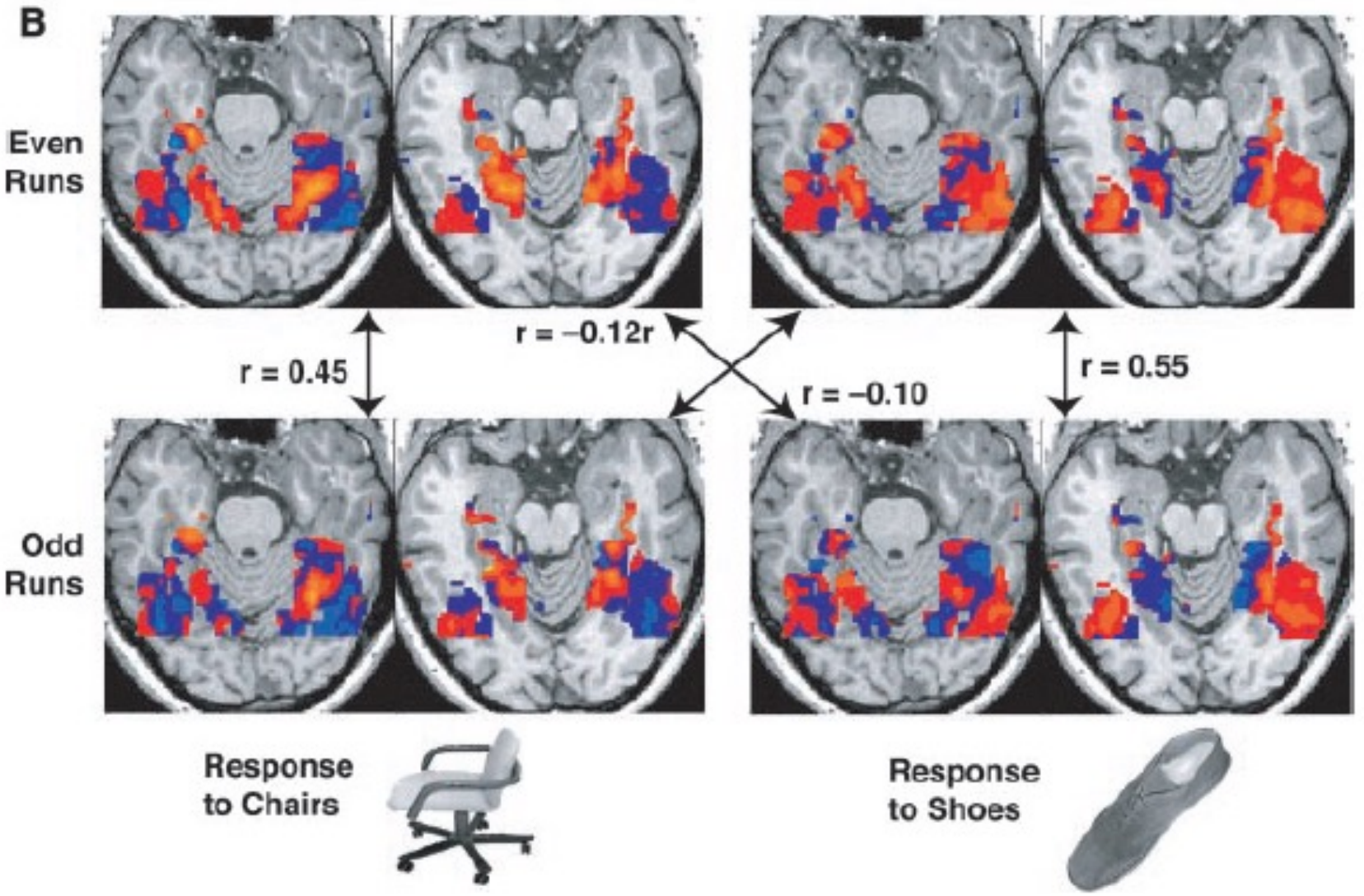




Response to Faces

Response to Houses

Category Discrimination



What about individual objects?

10 common objects



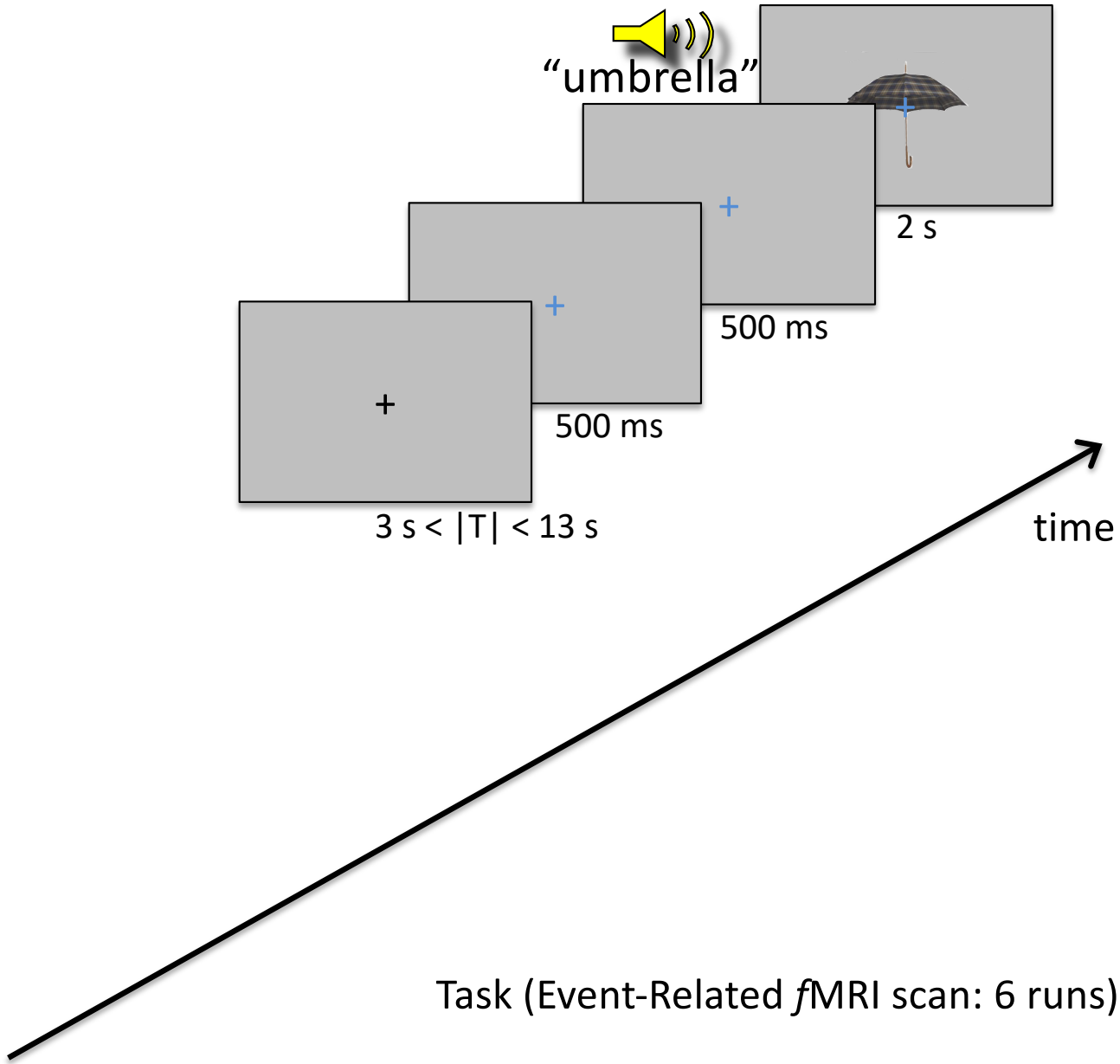







Lee et al (2012). Neuroimage.

Experimental Design

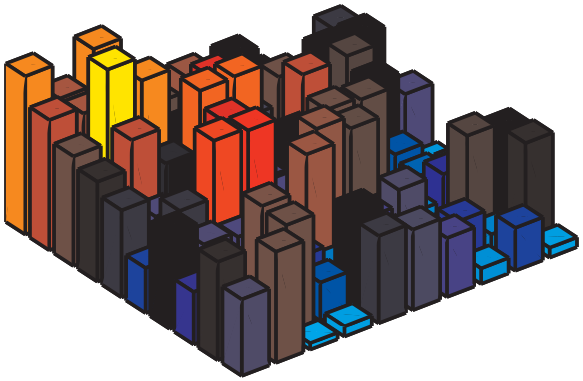


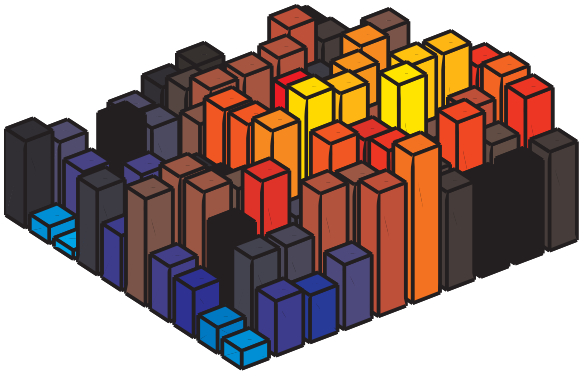
Task (Event-Related *f*MRI scan: 6 runs)

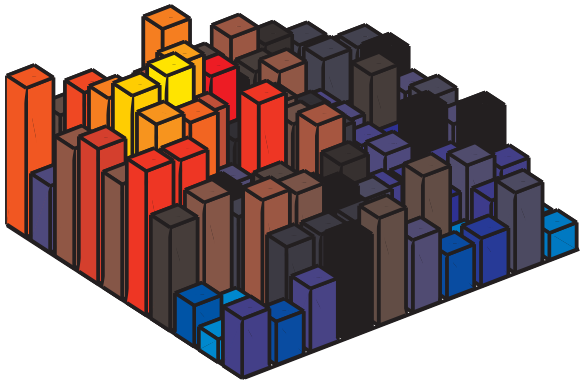
Split A

Split B

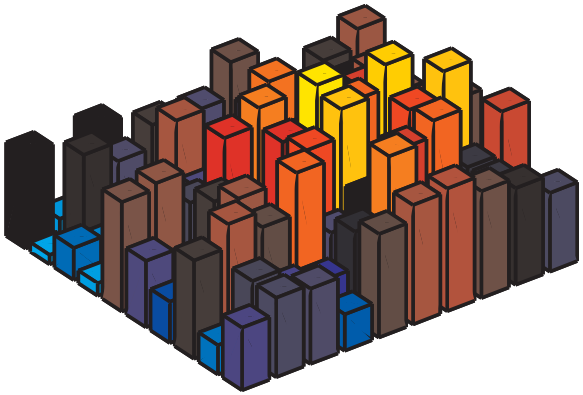
Split A



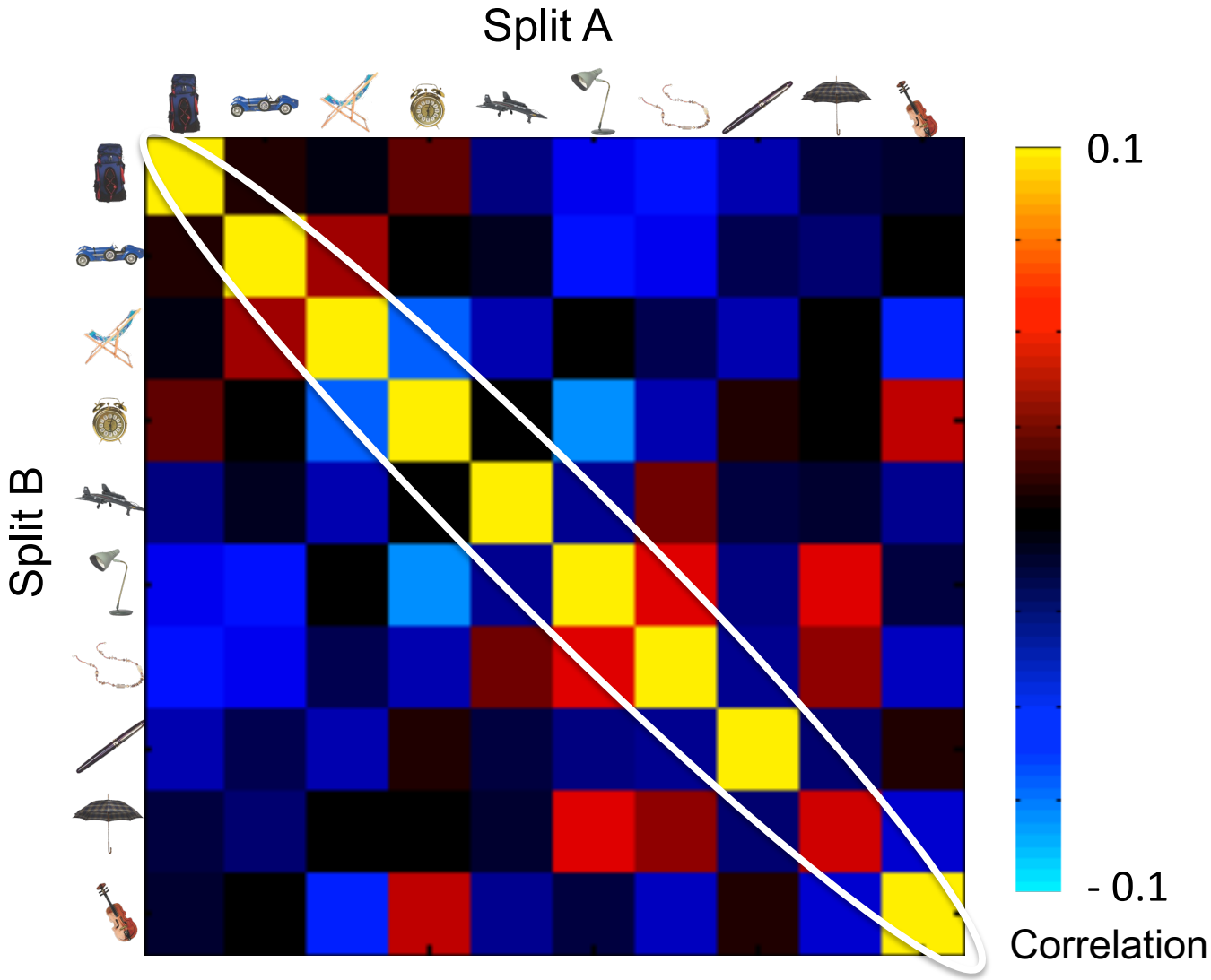




Split B

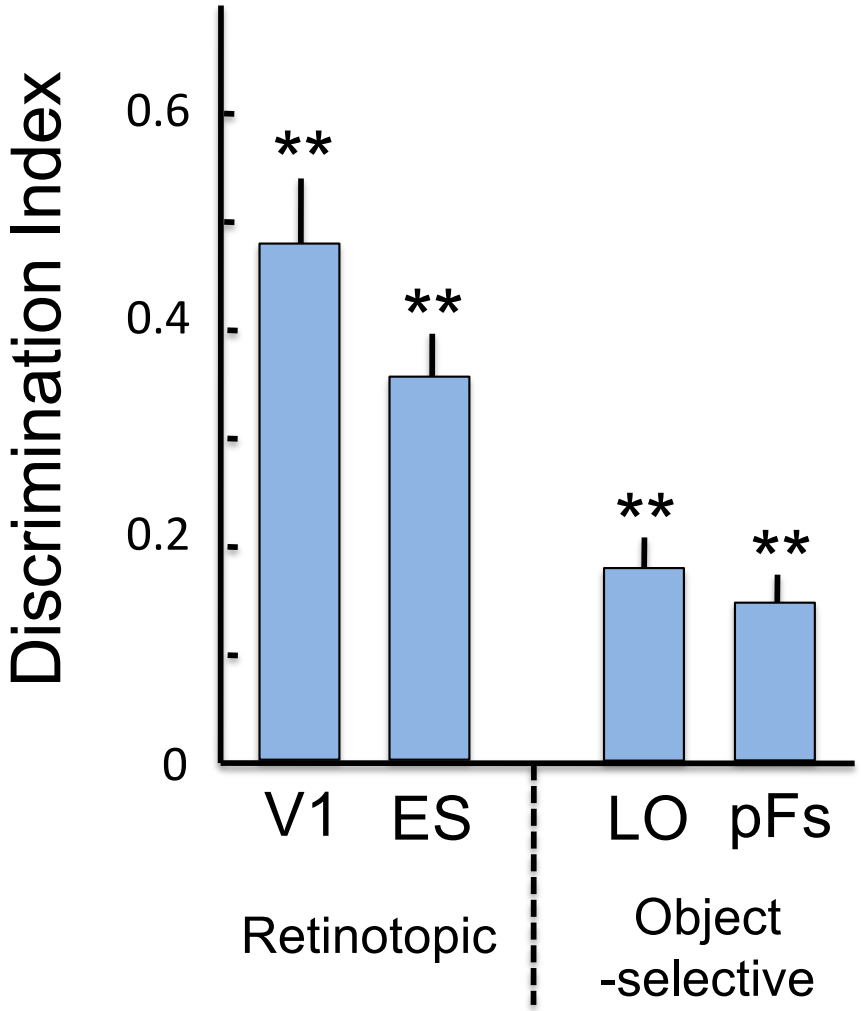


Object-selective cortex

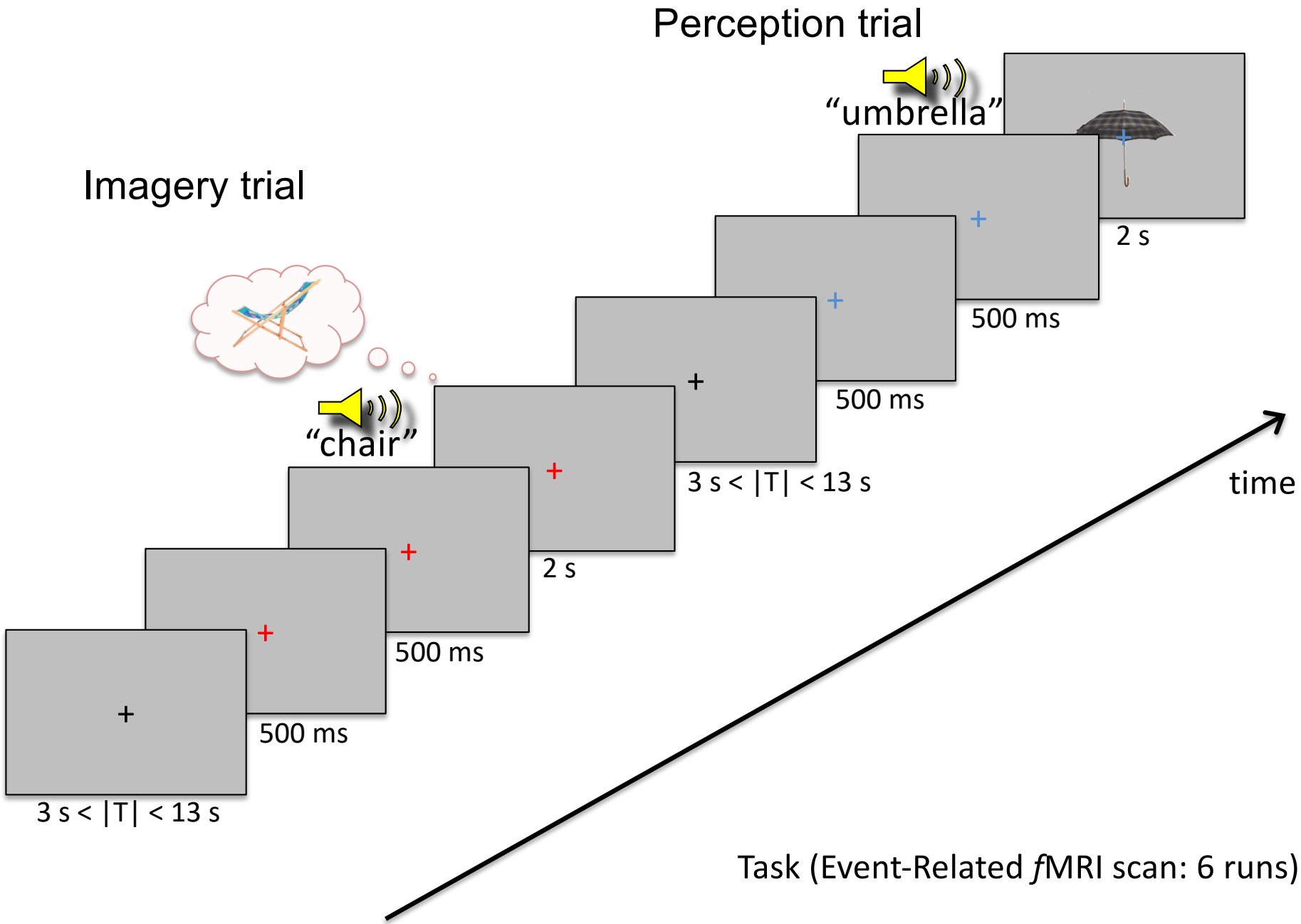


Discrimination Index = Within Correlation – Between Correlation

Discrimination of individual objects

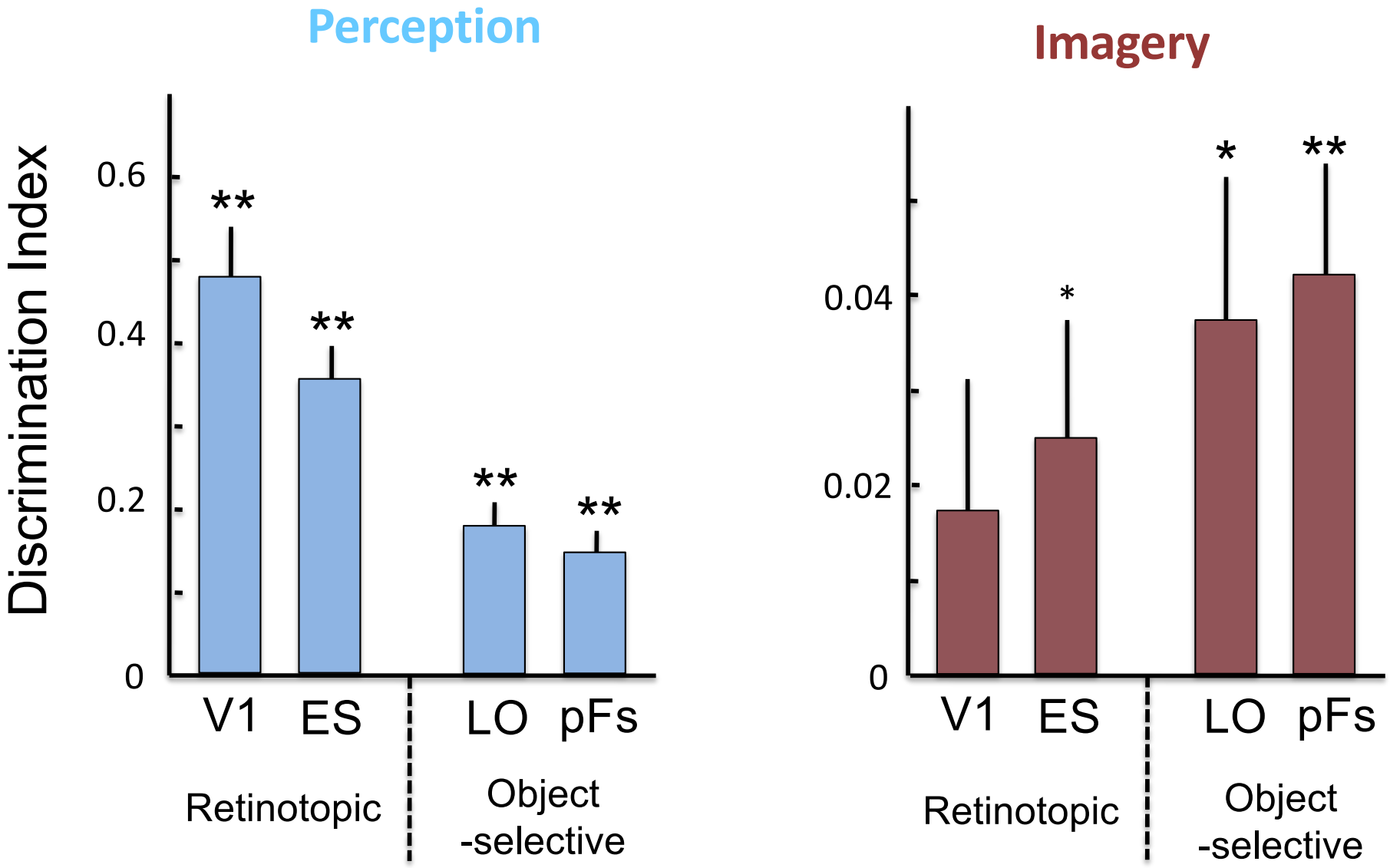


Experimental Design

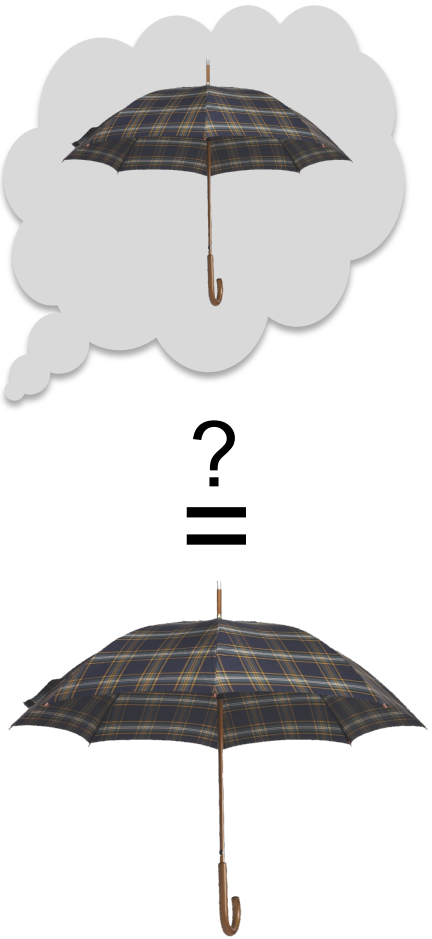


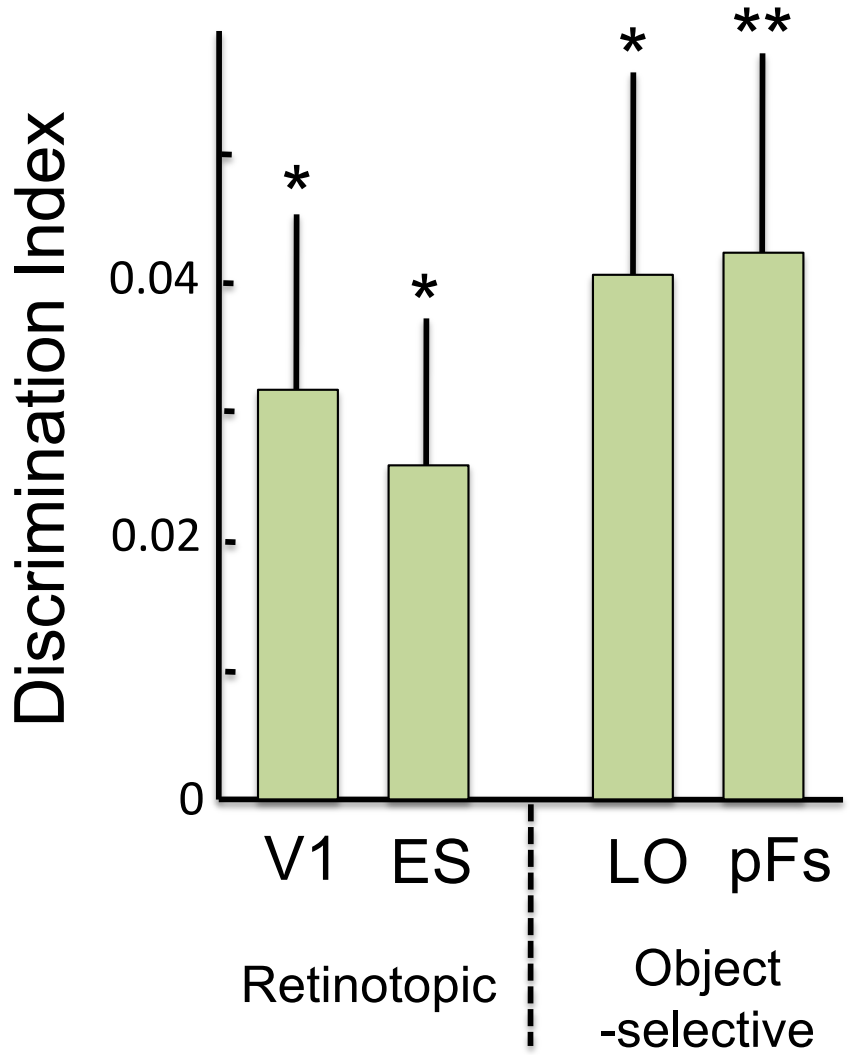
Task (Event-Related *f*MRI scan: 6 runs)

Discrimination of imagined objects

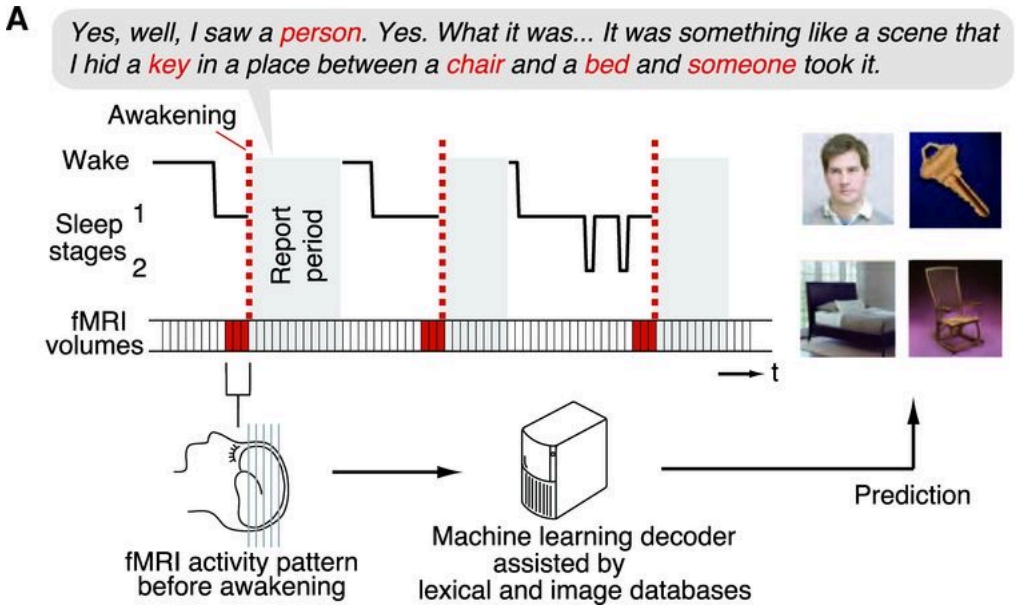


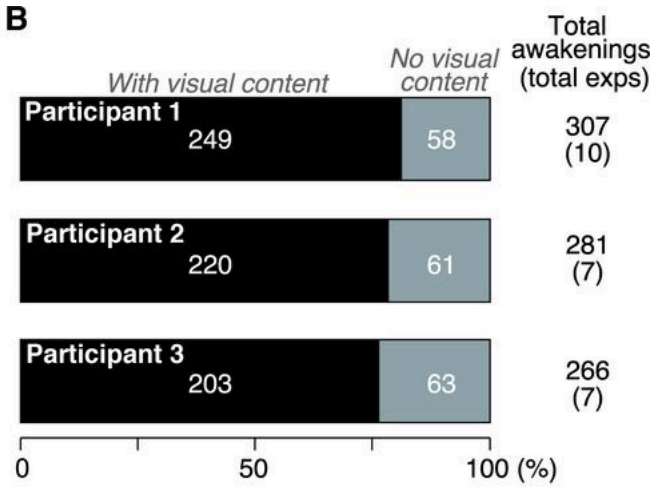
Similar representations during imagery and perception





Decoding Dreams (Horikawa et al, 2013)

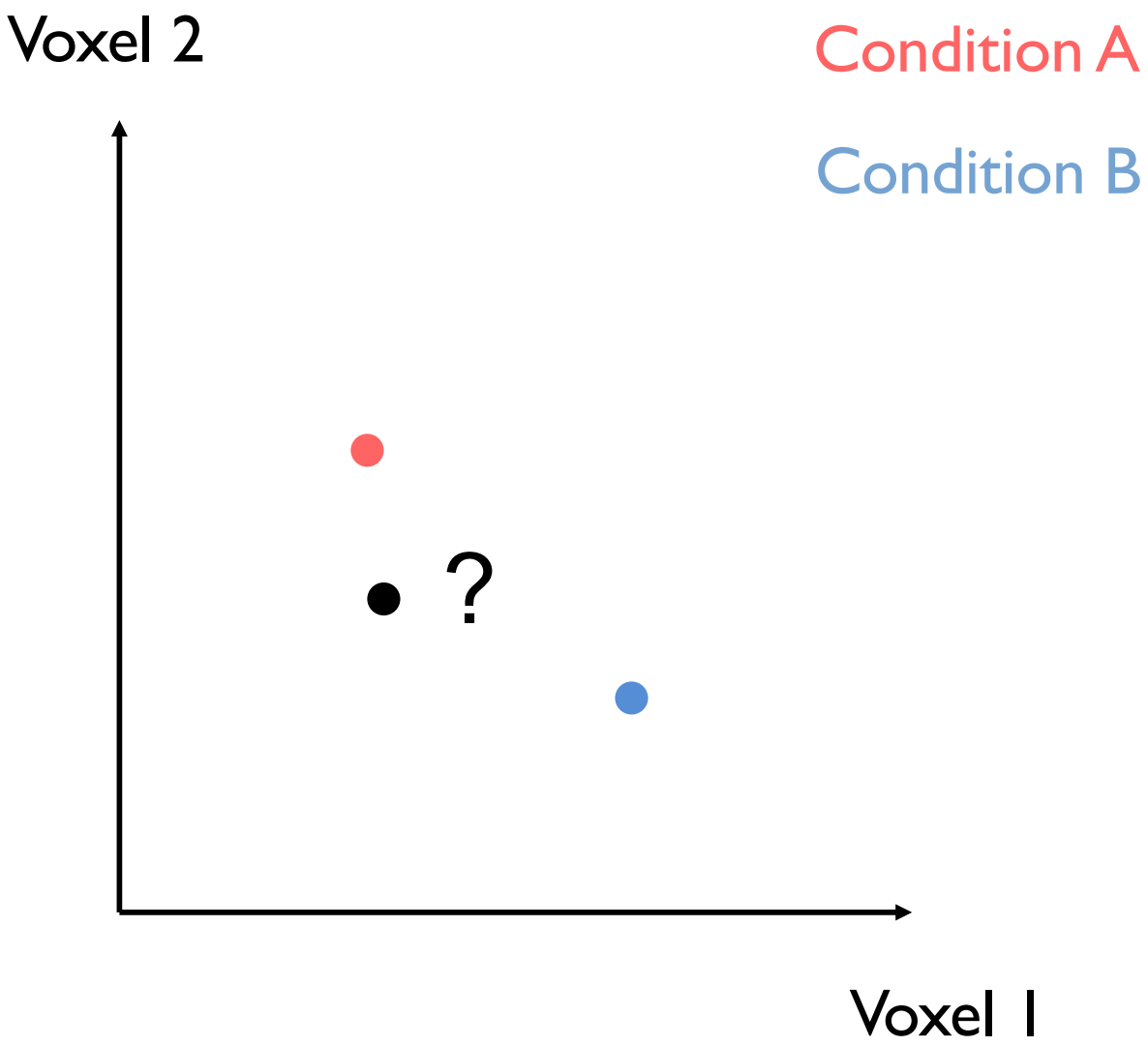




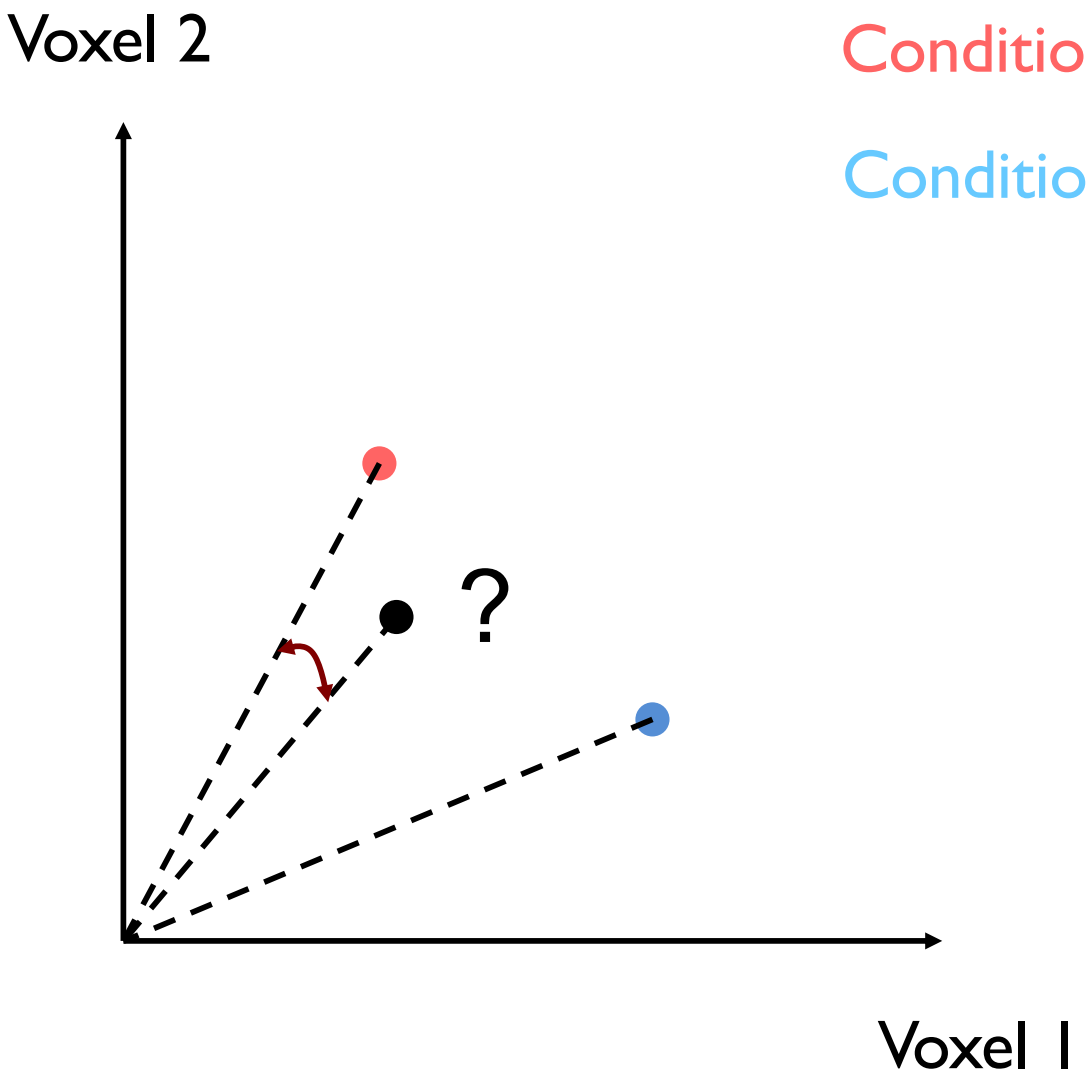
Varieties of brain reading

- Decoding models
  - Uses voxel activity to predict stimulus information
  - Linear classifiers

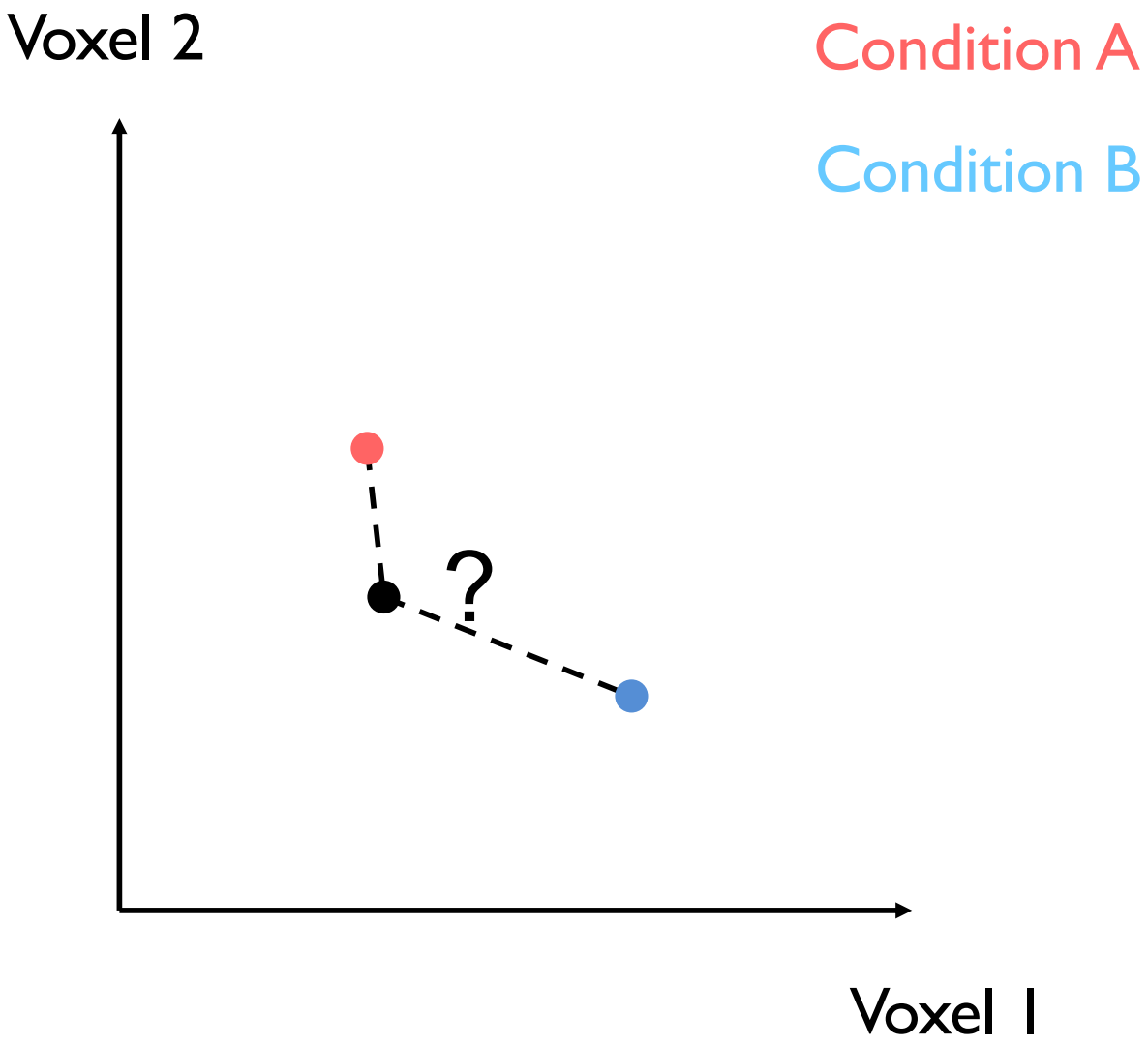
Naselaris et al (2011). Neuroimage.


Voxel 2
Condition A
Condition B
?
Voxel 1

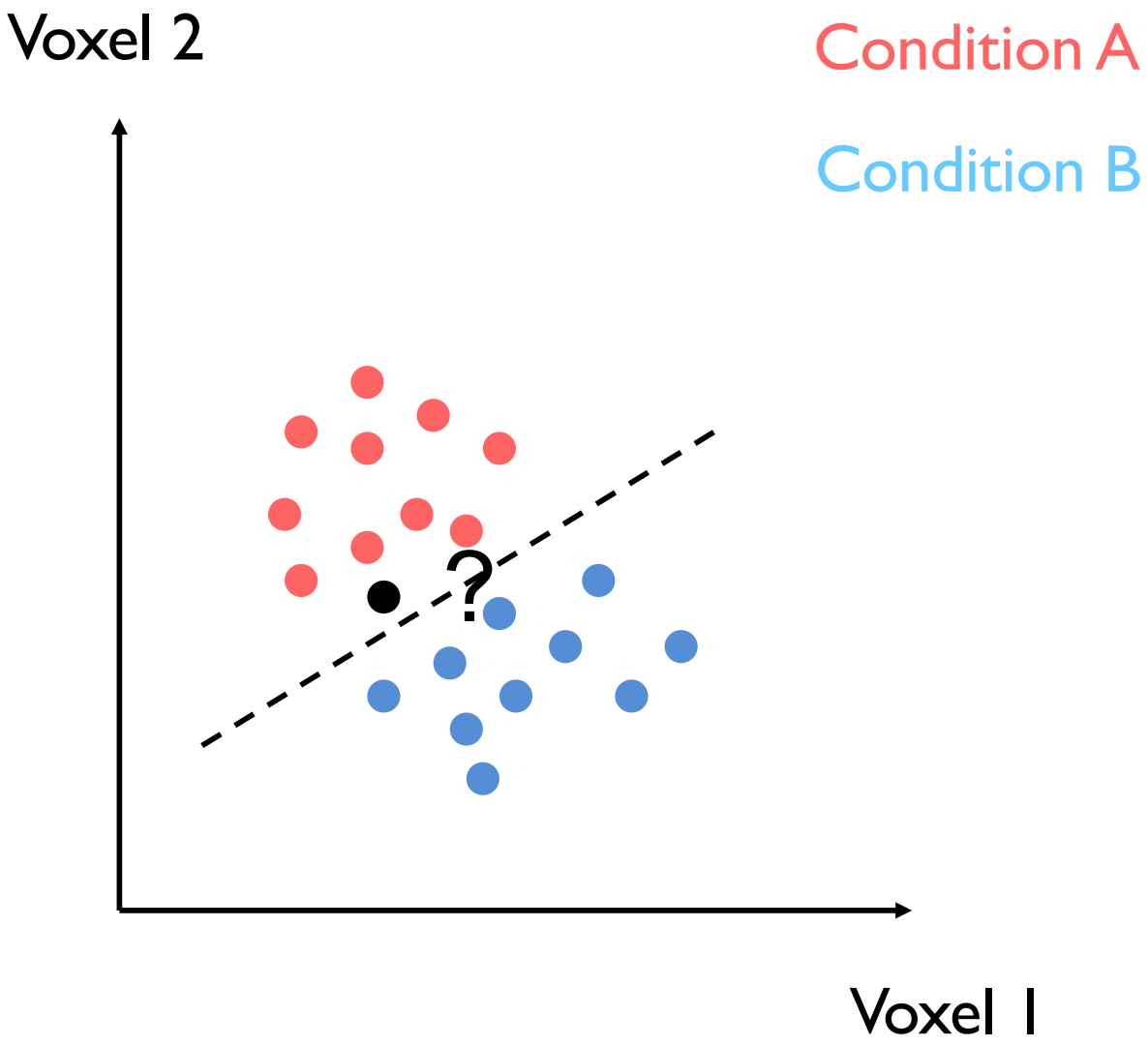
Correlation



Euclidean Distance



Support Vector Machine (SVM)



Linear Classifiers

- Euclidean distance
- Correlation
- Linear SVM
- Fisher Least Discriminant Analysis
- Neural networks (without hidden layer)
- Gaussian Naïve Bayes Classifiers

Non-linear classifiers increase risk of overfitting

Varieties of brain reading

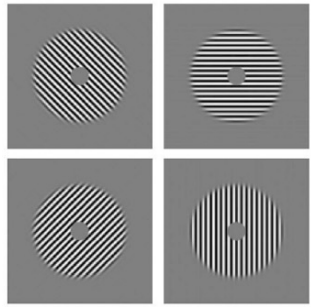
- Decoding models
  - Uses voxel activity to predict stimulus information
  - Linear classifiers

Naselaris et al (2011). Neuroimage.

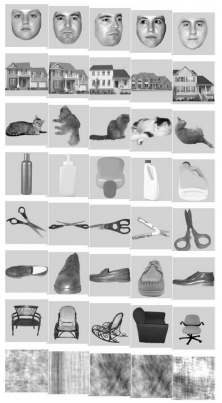
Limitations of Decoding Studies

- Restricted stimulus domains
  - Oriented lines
  - Small number of selected categories

Kamitani and Tong (2005)



Haxby et al (2001)



- No decoding of novel stimuli or categories [but see Spiridon and Kanwisher(2002)]

Varieties of brain reading

- Decoding models
  - Uses voxel activity to predict stimulus information
  - Linear classifiers

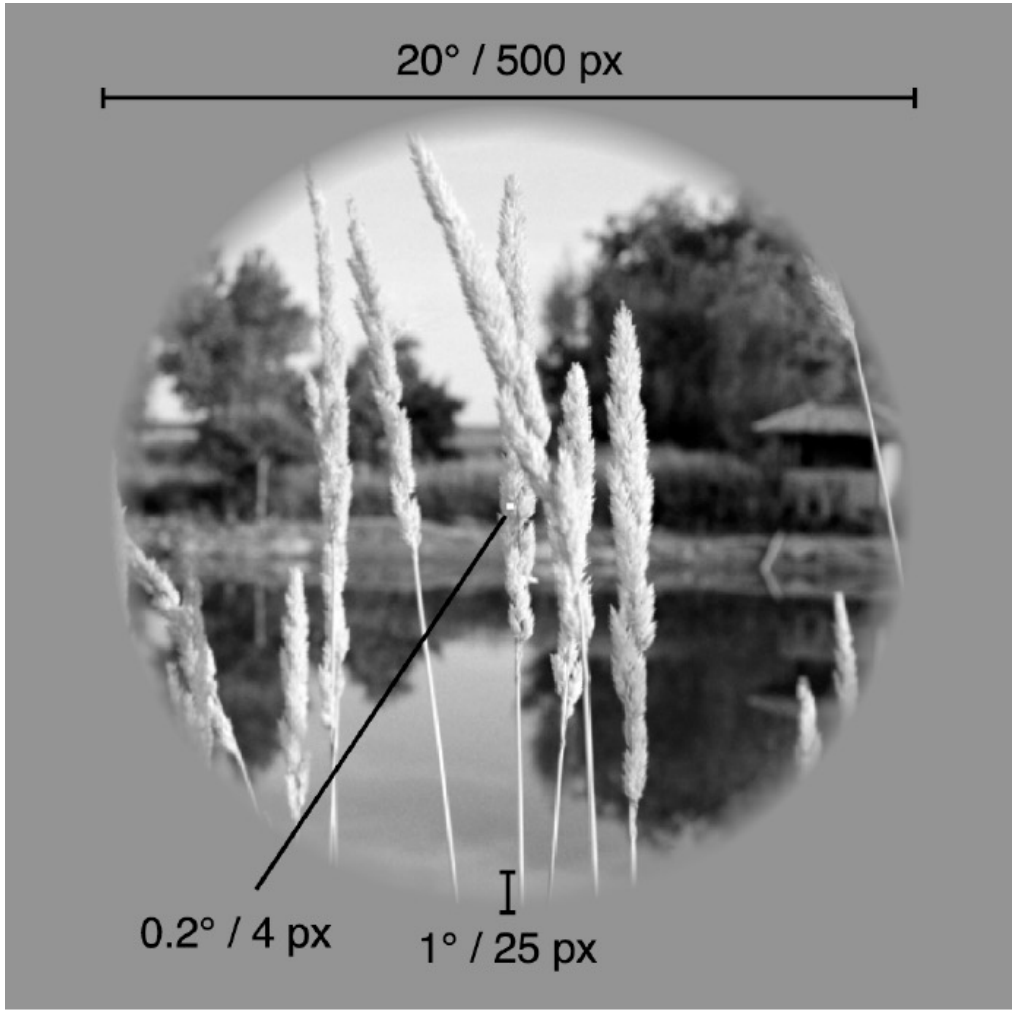
- Encoding models
  - Explicit description of how information is represented in activity of single voxels

Naselaris et al (2011). Neuroimage.

Encoding model-based approach (Kay et al, 2008)

1) Characterize relationship between visual stimuli and fMRI activity (i.e. build a model)
   - Complex, natural visual images
   - Early retinotopic visual cortex
2) Measure fMRI activity to one of many possible novel images
3) Compare actual activity to predicted activity for full set of novel images to determine which image was viewed

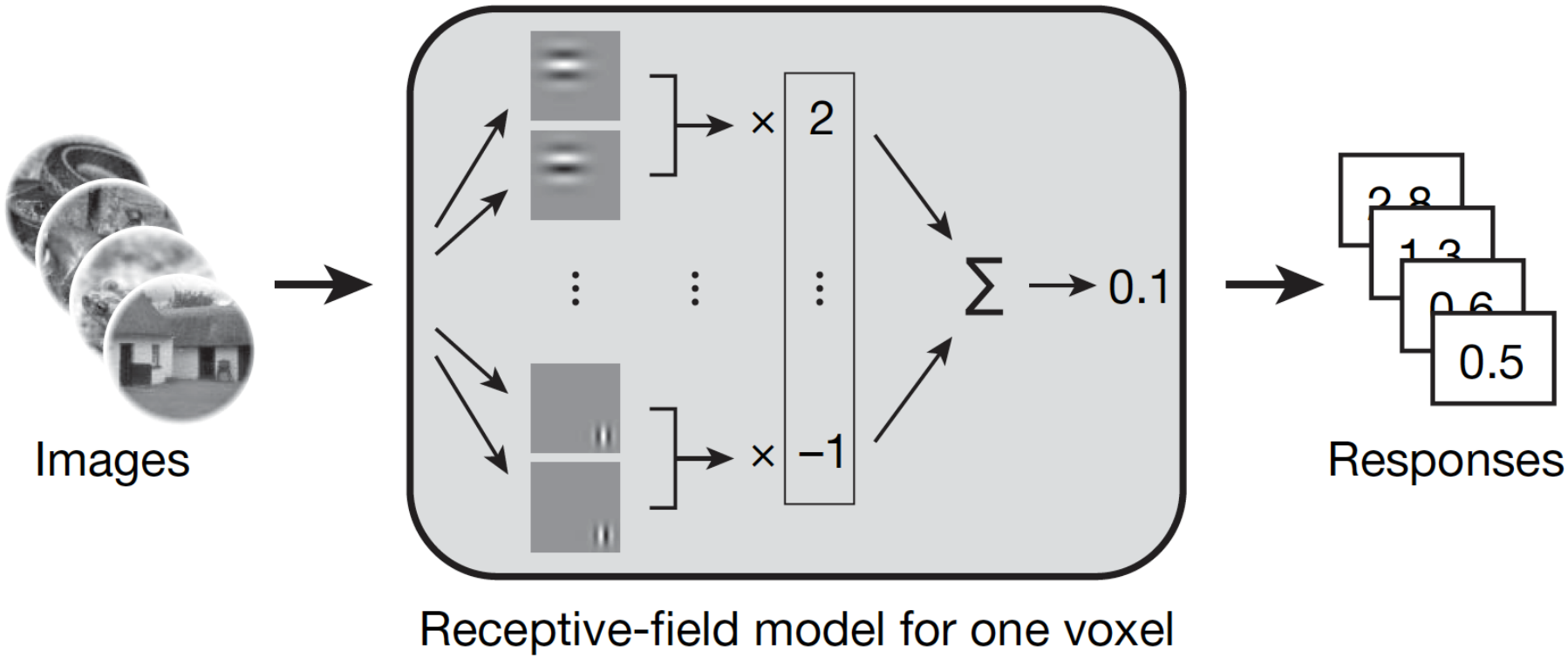
Large gray-scale images



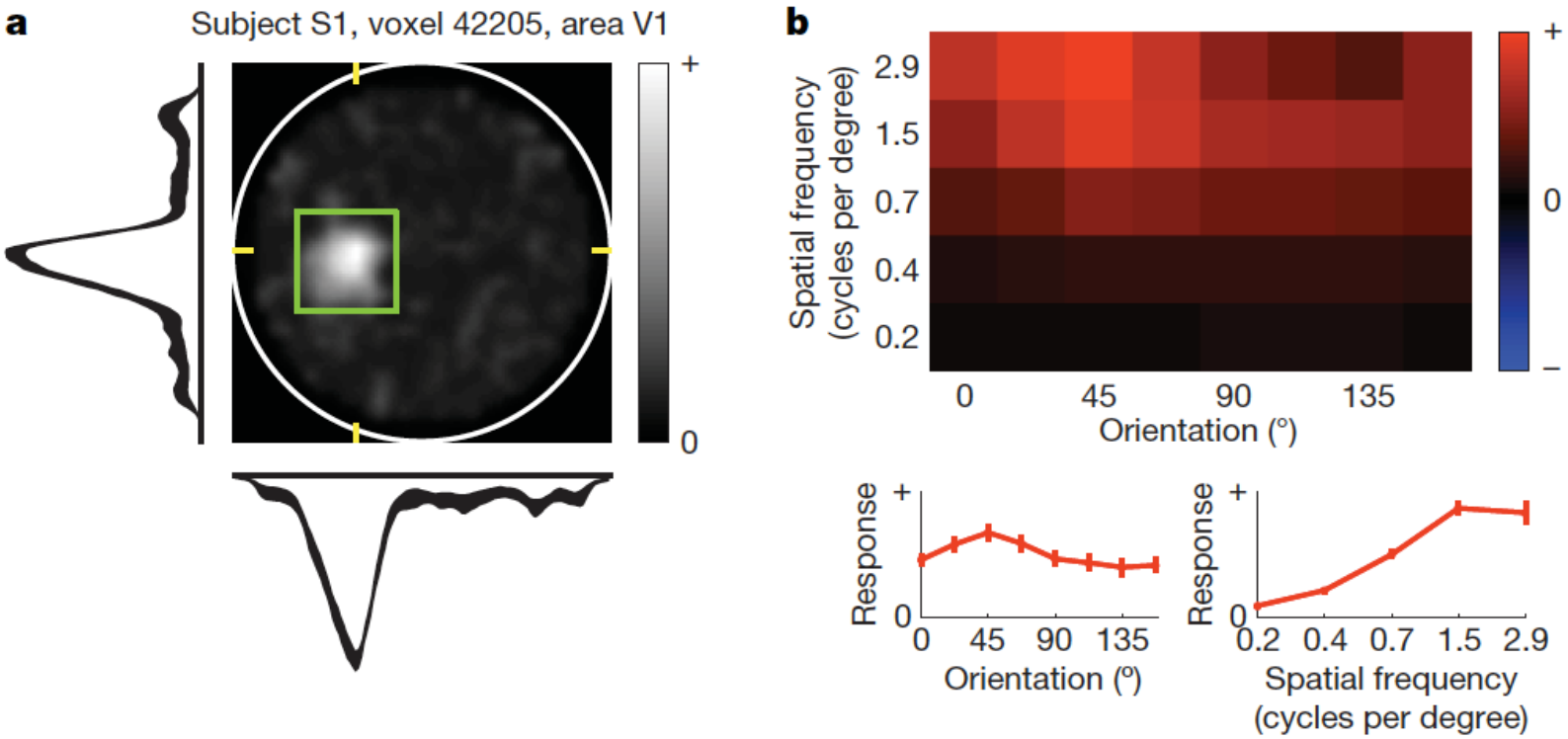
1) Build a Model

Stage 1: model estimation

Estimate a receptive-field model for each voxel



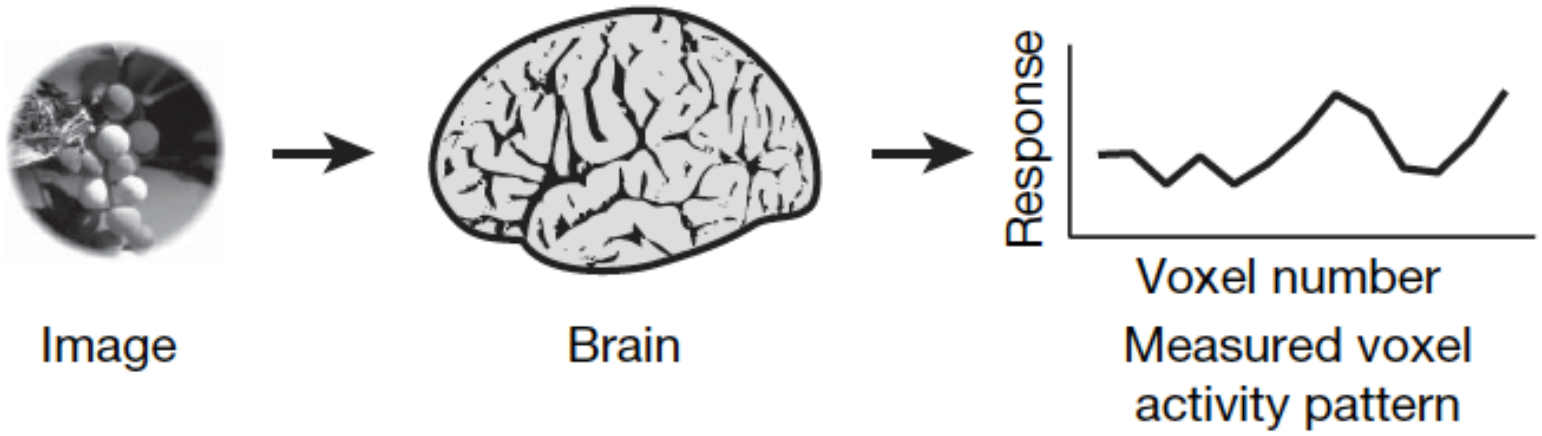
RF model for one voxel



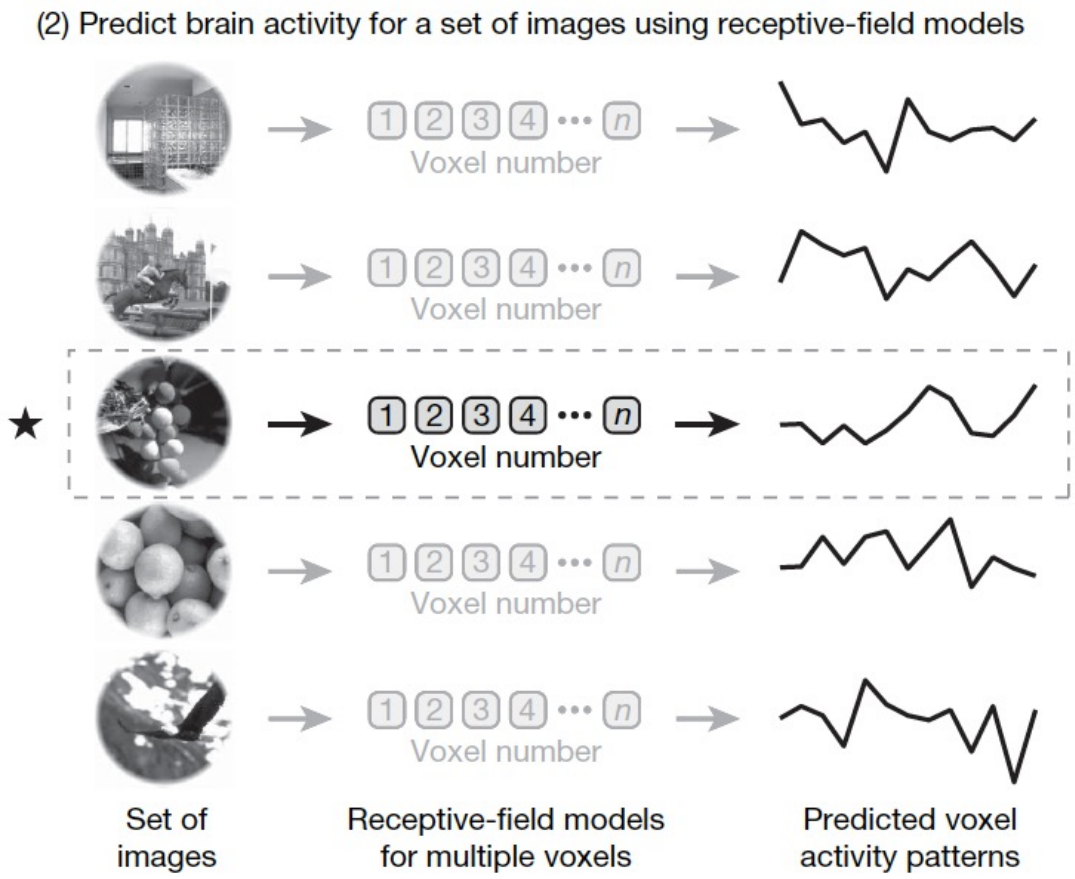
Novel Image to be Identified

Stage 2: image identification

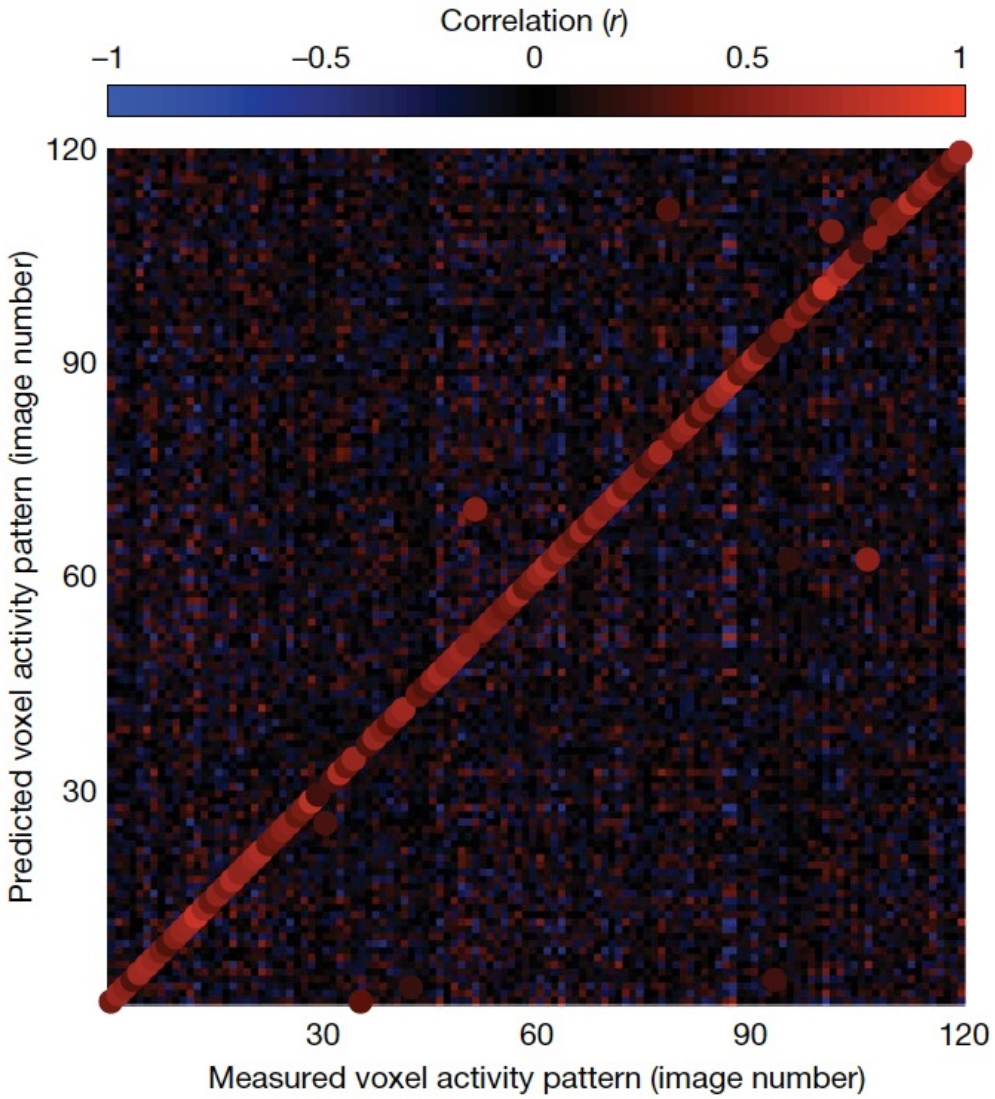
(1) Measure brain activity for an image



Compare observed to predicted activity



Performance



Additional results

- Works on single trials
- Not just retinotopy
- Accurate even with long delay between model fitting and testing

Limitations of Kay et al.

- Still requires comparison with set of candidate images
- Will likely fail with more homogeneous images (e.g. two faces)
- Whole image comparison
  - What about same central object on different backgrounds?
- How sensitive to fixation differences?
- Novel subjects?
- Visual perception is dynamic

Reconstructing dynamic movies

Nishimoto et al (2011). Current Biology.

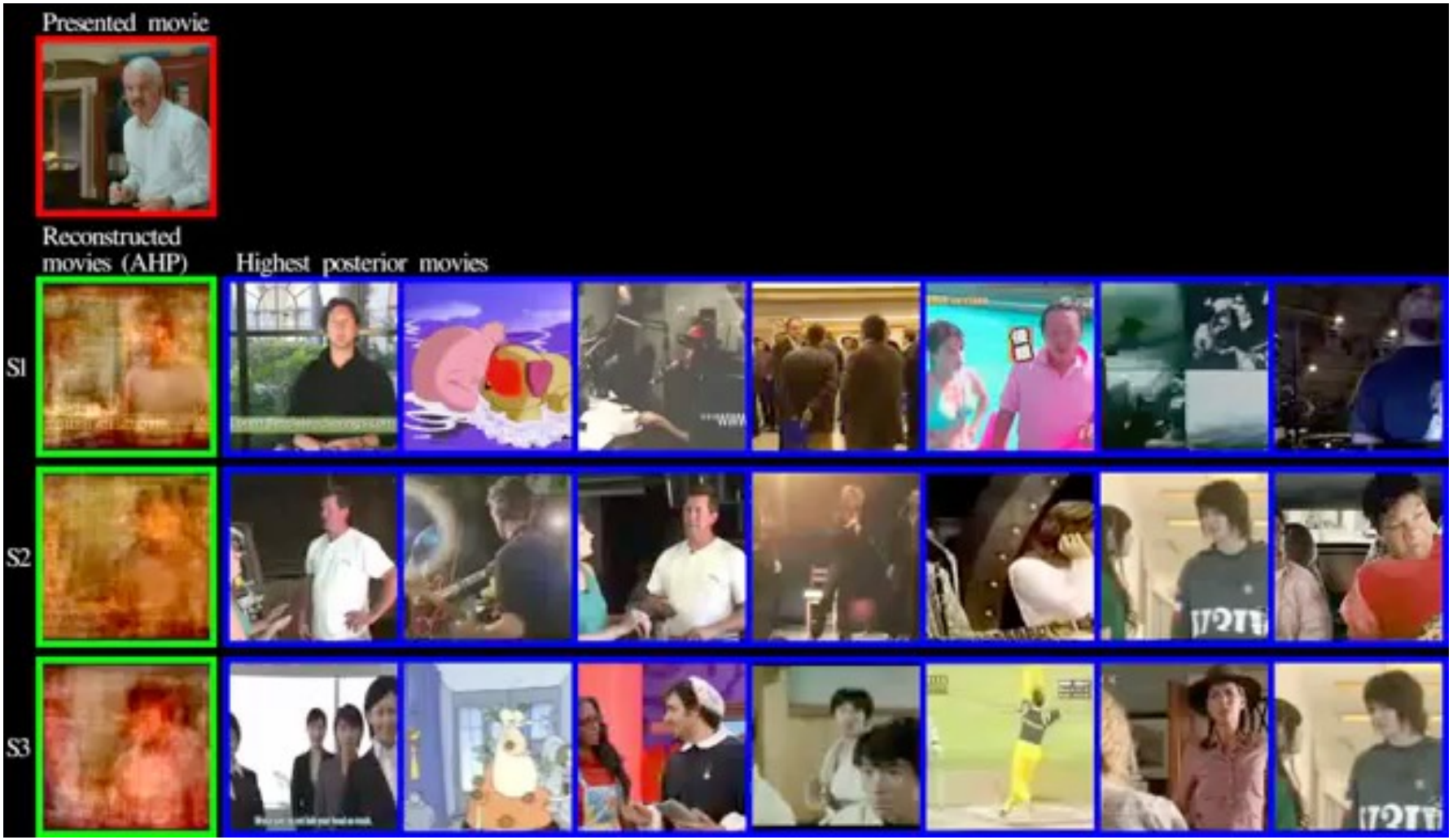
Reconstructing dynamic movies

Presented clip

Clip reconstructed from brain activity

Nishimoto et al (2011). Current Biology.

Reconstructing dynamic movies

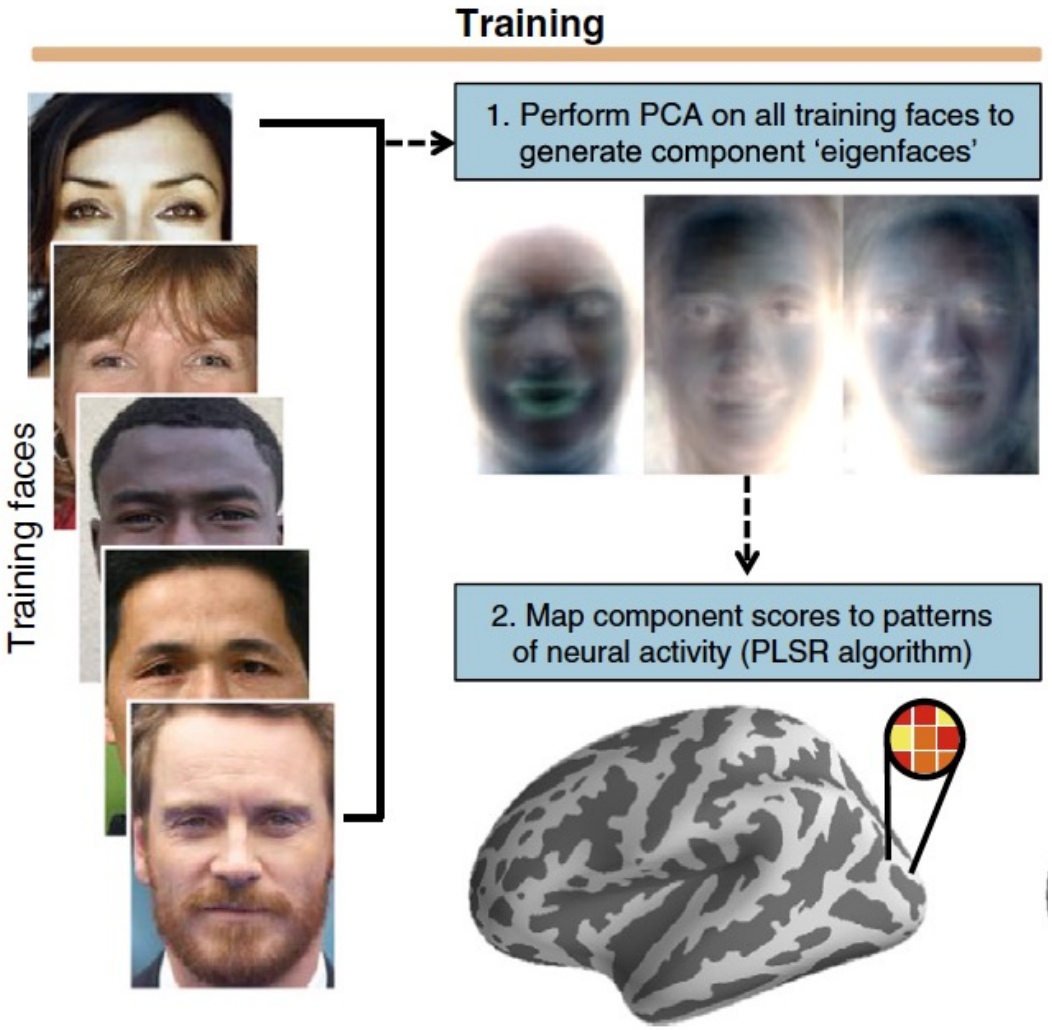


Nishimoto et al (2011). Current Biology.

Semantic space

- Huth et al (2012). A continuous semantic space describes the representation of thousands of object and action categories across the human brain. *Neuron.*
- http://gallantlab.org/brainviewer/

Reconstructing Faces

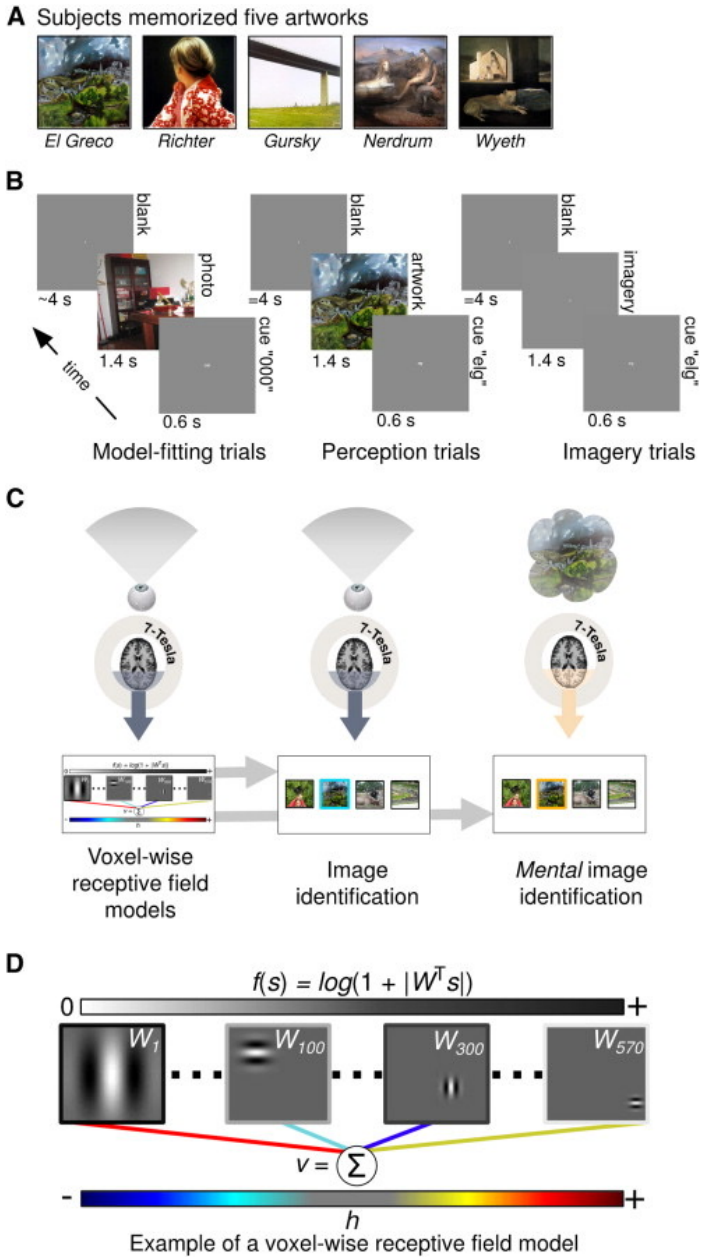


Cowen et al (2014). Neuroimage.

Reconstructing Faces

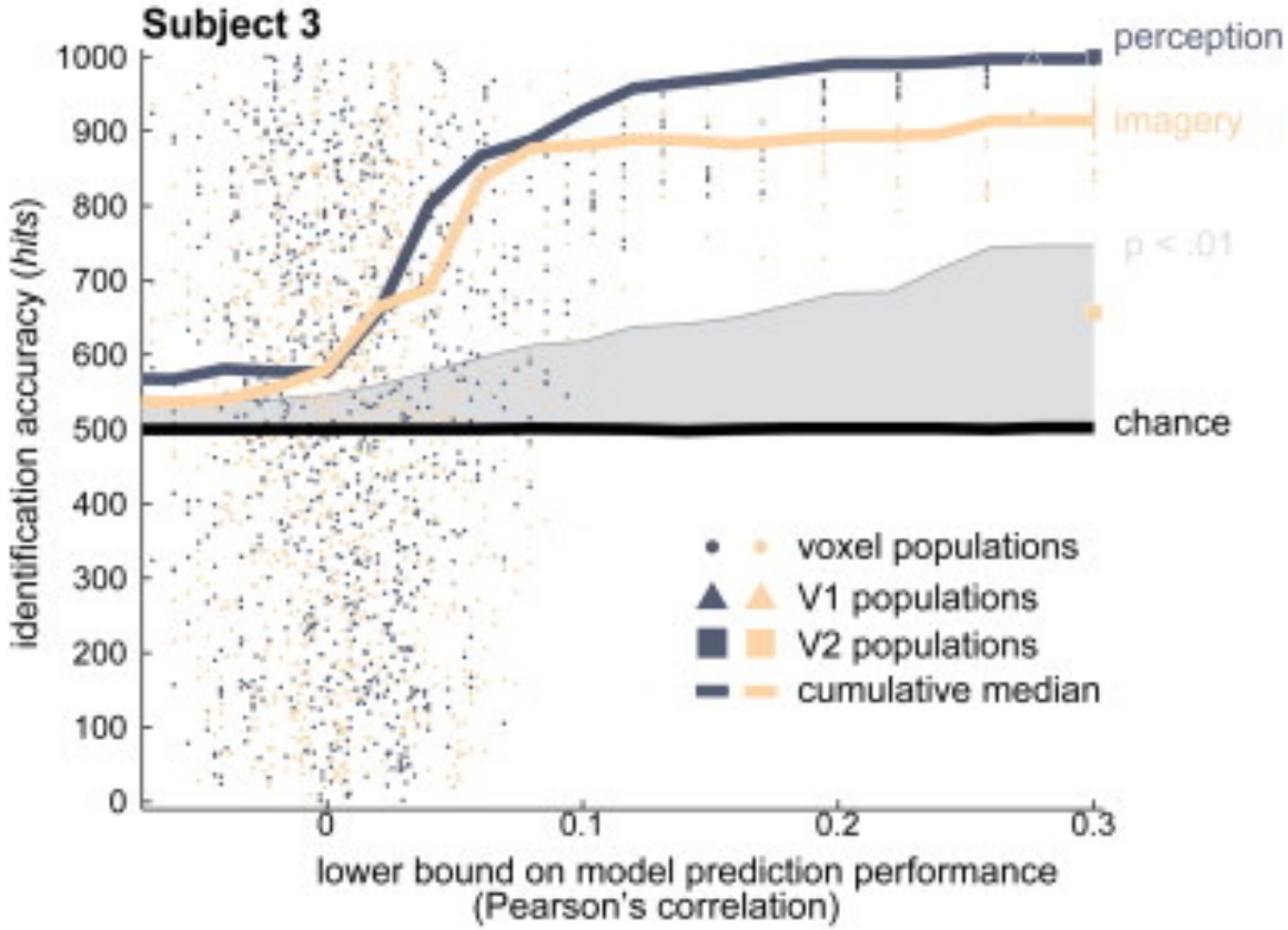
Cowen et al (2014). Neuroimage.

Using encoding models to investigate imagery



Thomas Naselaris, Cheryl A. Olman, Dustin E. Stansbury, Kamil Ugurbil, Jack L. Gallant
A voxel-wise encoding model for early visual areas decodes mental images of remembered scenes
NeuroImage, Volume 105, 2015, 215–228

http://dx.doi.org/10.1016/j.neuroimage.2014.10.018



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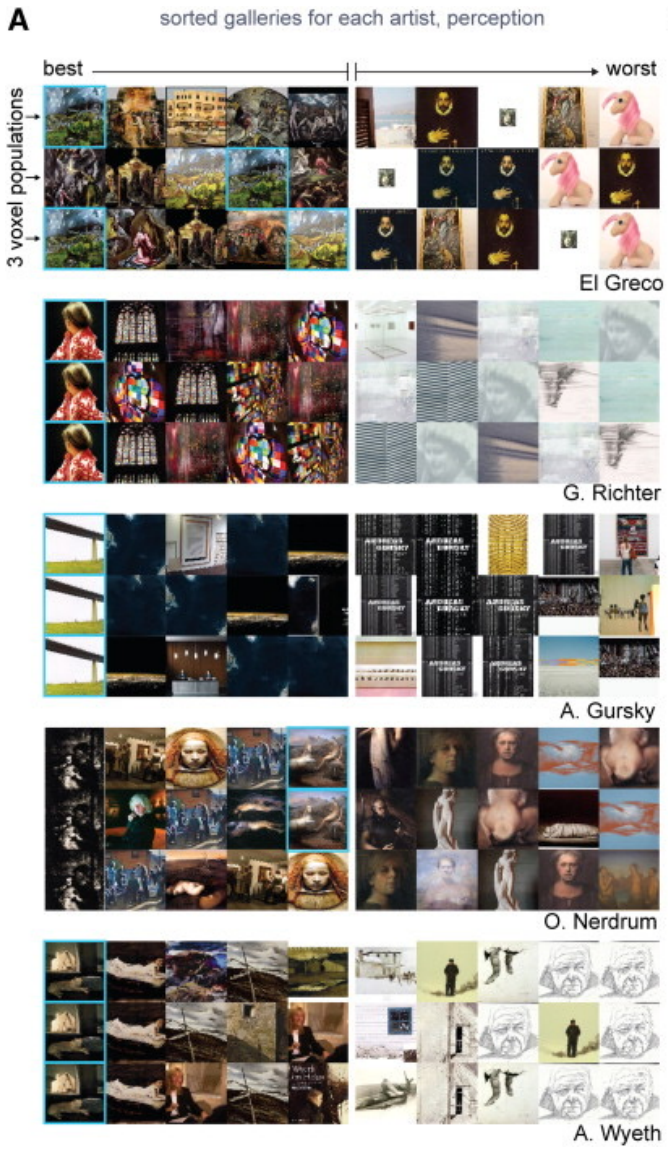

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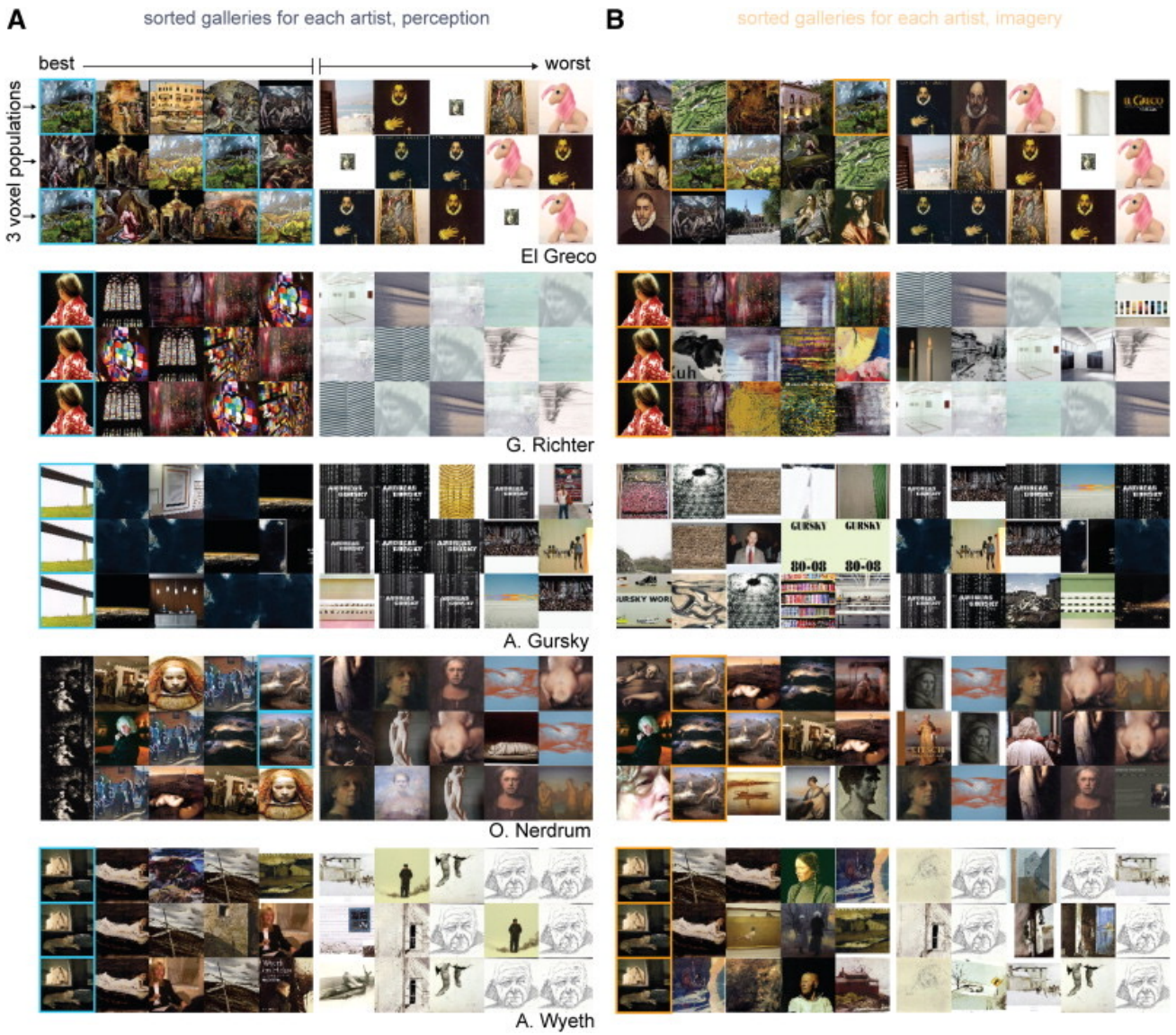

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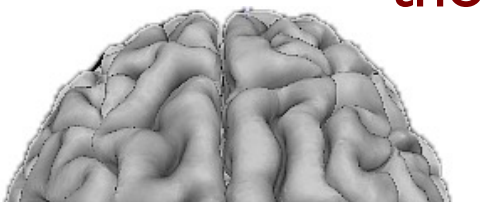
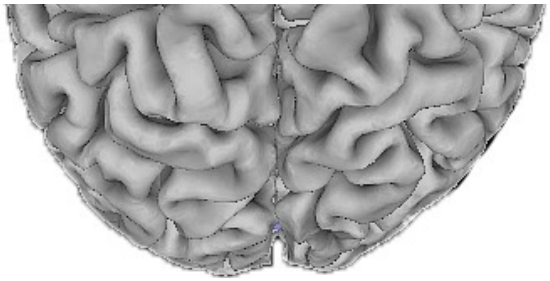


What can we really do?



“prediction” “decoding”

Disorders of consciousness

- Vegetative state
- Locked-in syndrome
- Enabling communication in the absence of overt motor behavior

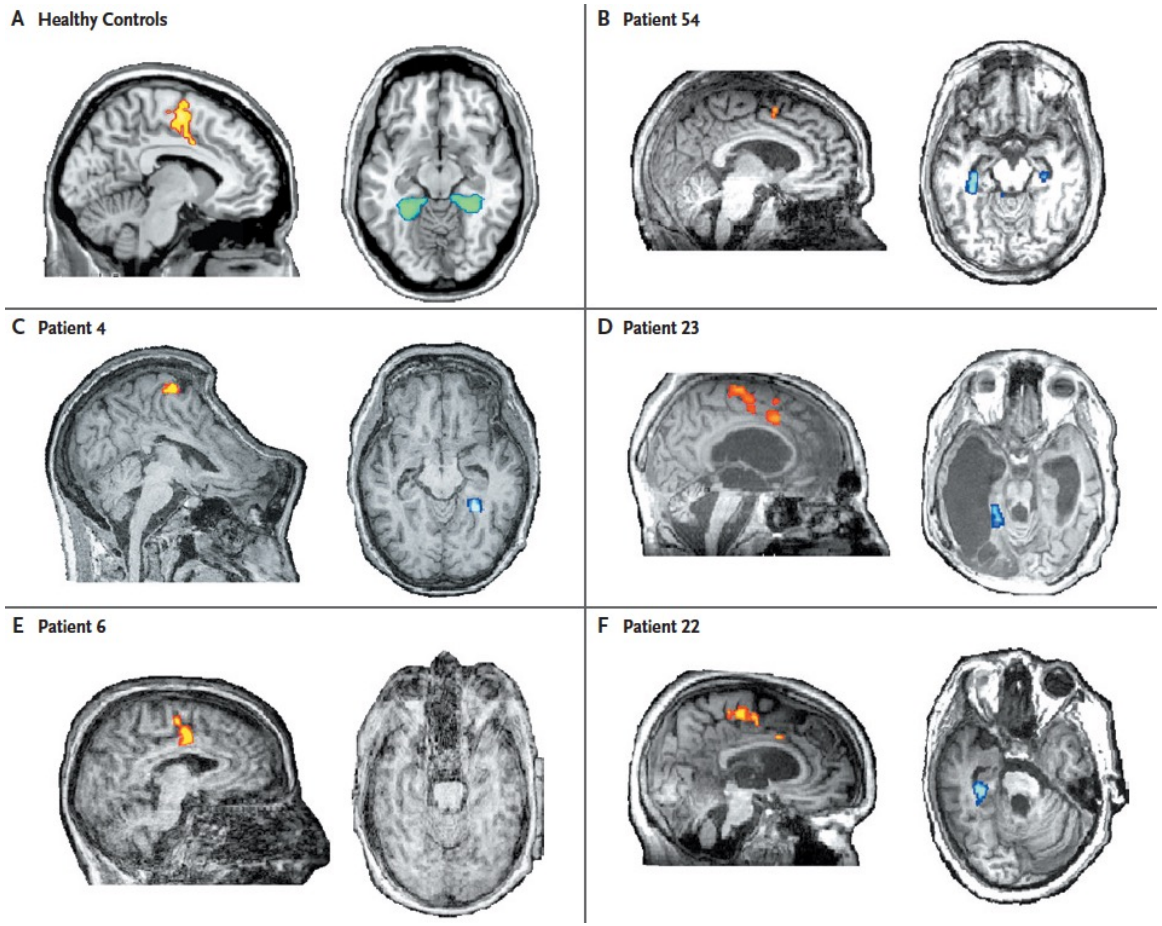
Decoding Tasks

Motor Imagery
(playing tennis)

Spatial Imagery
(walking house)

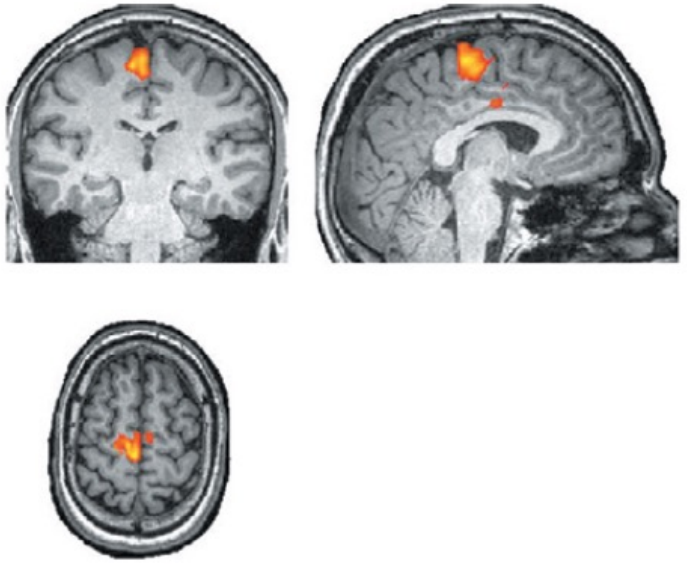
Owen et al (2006); Monti et al (2010)

54 patients with severe brain injury



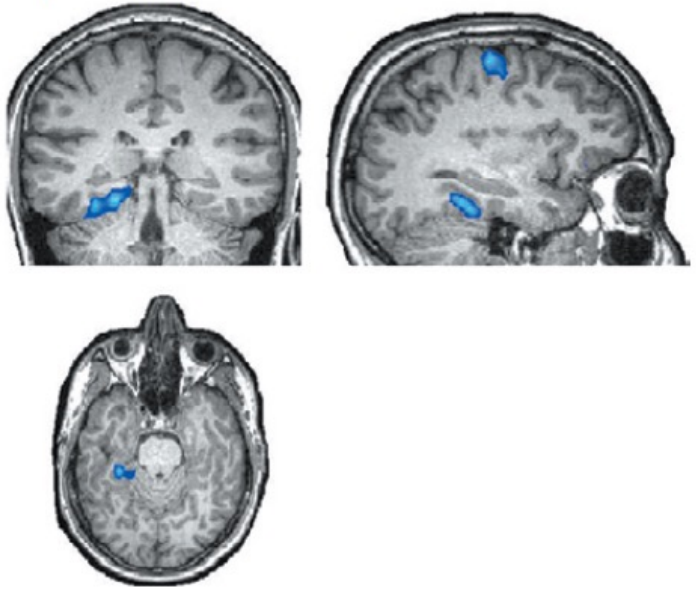
B "Do you have any brothers?" "Yes" response with the use of motor imagery

Control

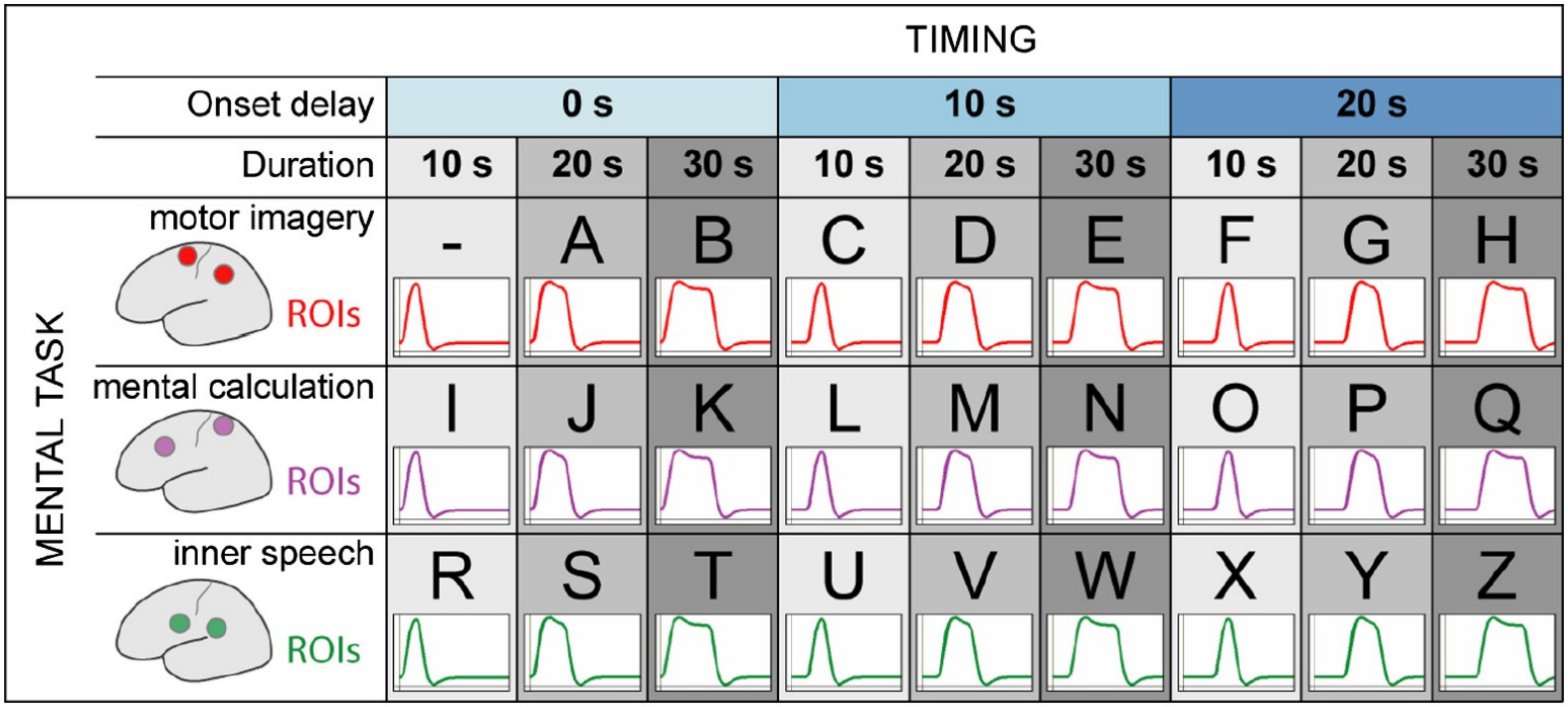


D "Do you have any sisters?" "No" response with the use of spatial imagery

Control



Real time fMRI spelling

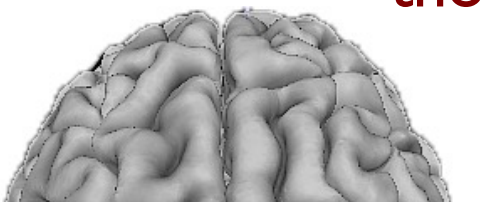


Sorger et al (2012)

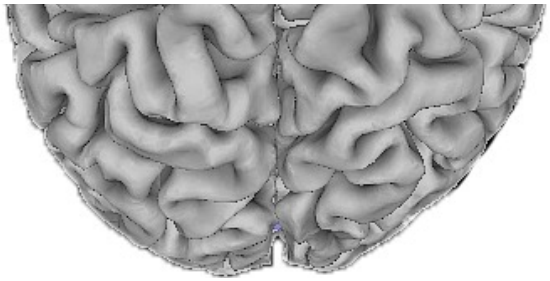
Real time fMRI spelling

participant	initial question		follow-up question	
	stated question	decoder output/ human interpreter's decision	stated question	decoder output/ human interpreter's decision
1	"What is your hobby?"	P H O T O G R A P H Y - - Q G M X X E I C N G W R R N E P S V H S - Y Z X I I P H O T O G R A P H Y - -	"What did you PHOTOGRAPH last?"	- O Y - H O M E - R M W R Z M O G R A T Z S G V T W A - M Y - H O M E -
2	"Where did you spend your most recent vacation?"	- I N D C N E R C A - A F Q F M M G S I - A I R O B O O F J D C B - I N D O N E S I A -	"What did you like most in INDONESIA?"	- T E K P L E S - I R G M X U O J I A S O L Q M G R A - T E M P L E S -
3	"Where did you spend your most recent vacation?"	- I N D I A - S - E B - C A U A M E A B B - I N D I A -	"What do you consider most typical for INDIA?"	- C L O S H I N G - A A J X T G R M E A R O U P R E A V O R - C L O T H I N G -
4	"What is your hobby?"	- O R S C U S R R N G - R C I T U S U S I P E R A B - R S T R U F M F I - O I S C U S S I N G -	"What is your favorite DISCUSSION topic?"	- A W Y T H I N G - A - N Z S G R P E I B K P W V Z J W H A - A N Y T H I N G -
5	"What are you interested in?"	- X O V I O R A V M U R E S I M X W - N J - M O V I E S	"Which MOVIE did you watch last?"	T O P F U N - V X N N L M I U Y O G J P A T O P G U N -
6	"Where did you spend your most recent vacation?"	- - U O - O F S T - I A V C A P C U U I A B C F B Y O R V A - B U O A P E S T -	"What did you like most in BUDAPEST?"	- S W N - F O F U F - A U X L A G X E V O A J T Y M O F M G S C R - S Y N A G O G U E -

“mind reading” “thought identification”



What can we really do?



“prediction” “decoding”

Key Readings

Overviews and Methods

- Cox and Savoy (2003). Functional magnetic resonance imaging (fMRI) "brain reading": detecting and classifying distributed patterns of fMRI activity in human visual cortex. *Neuroimage*, 19, 261-270.
- Haynes (2015). A primer on pattern-based approaches to fMRI: principles, pitfalls, and perspectives. *Neuron*, 87, 257-270.
- Mur et al. (2008). Revealing representational content with pattern information fMRI - an introductory guide. *Social Cognitive and Affective Neuroscience*, 4, 101-109.
- Norman et al. (2006). Beyond mind-reading: multi-voxel pattern analysis of fMRI data. *Trends in Cognitive Sciences*, 10, 424-430.
- Sorger et al. (2012). A real-time fMRI-based spelling device immediately enabling robust motor-independent communication. *Current Biology*, 22, 1333-1338.
- Naselaris et al (2011). Encoding and decoding in fMRI. *Neuroimage, 56,* 400-410.

Specific Studies

- Albers et al (2013). Shared representations for working memory and mental imagery in early visual cortex. *Current Biology*, 23, 1427-1431.
- Chun et al. (2014). Neural portraits of perception: reconstructing face images from evoked brain activity. *Neuroimage*, 94, 12-22.
- Haxby et al. (2001). Distributed and overlapping representations of faces and objects in ventral temporal cortex. *Science*, 293, 2425-2430.
- Kamitani and Tong (2005). Decoding the visual and subjective contents of the human brain. *Nature Neuroscience*, 8, 679-685.
- Kay et al (2008). Identifying natural images from human brain activity. *Nature*, 452, 352-355.
- Kay and Gallant (2009). I can see what you see. *Nature Neuroscience*, 12, 245-246.
- Lee et al (2012). Disentangling visual imagery and perception of real-world objects. *Neuroimage*, 59, 4064-4073.
- Miyawaki et al (2008). Visual image reconstruction from human brain activity using a combination of multiscale local image decoders. *Neuron*, 60, 915-929.

Specific Studies

- Naselaris et al (2015). A voxel-wise encoding model for early visual areas decodes mental images of remembered scenes. *Neuroimage*, 105, 215-228.
- Nishimoto et al. (2011). Reconstructing visual experiences from brain activity evoked by natural movies. *Current Biology*, 21, 1641-1646.

Disorders of Consciousness

- Monti et al. (2010). Willful modulation of brain activity in disorders of consciousness. *New England Journal of Medicine*, 362, 579-589.
- Owen et al. (2006). Detecting awareness in the vegetative state. *Science*, 313, 1402

Resources

- SVM toolbox
  - http://www.csie.ntu.edu.tw/~cjlin/libsvm/
- Python MVPA toolbox
  - http://www.pymvpa.org/
- Princeton MVPA toolbox
  - http://code.google.com/p/princeton-mvpa-toolbox/