The proactive brain: Predictions in visual cognition

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Supported by NINDS RO1 NS44319, RO1 NS50615, and by the James S. McDonnell Foundation - 21st Century Science Award

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Visual Cognition













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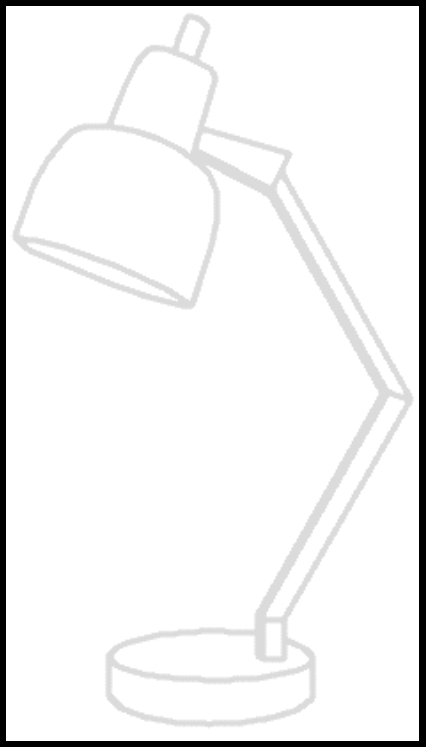
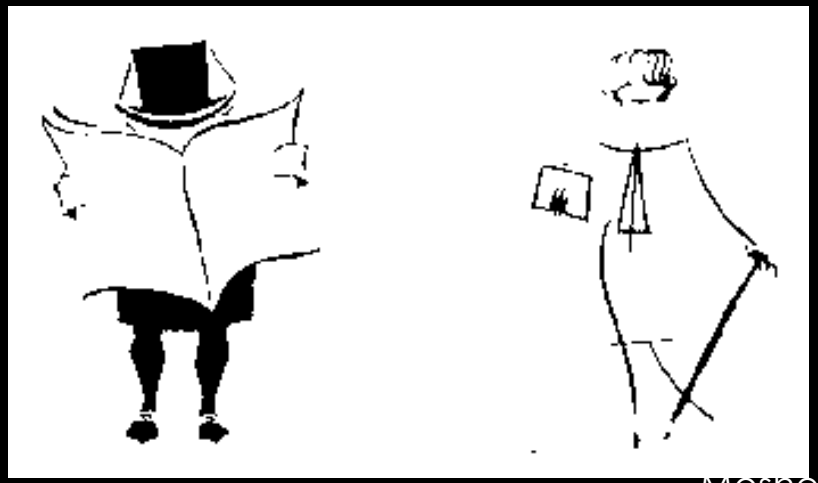
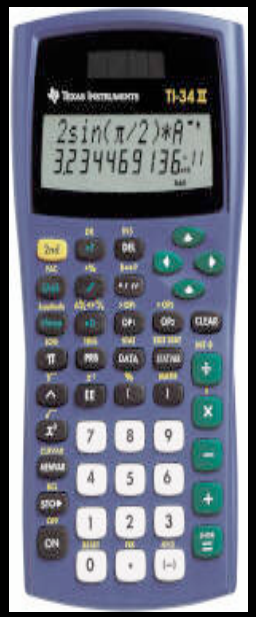
Visual Cognition







Visual Cognition







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Visual Cognition



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The (artificial) distinction between perception and cognition

or

two textbook "myths" in connecting brain to cognition

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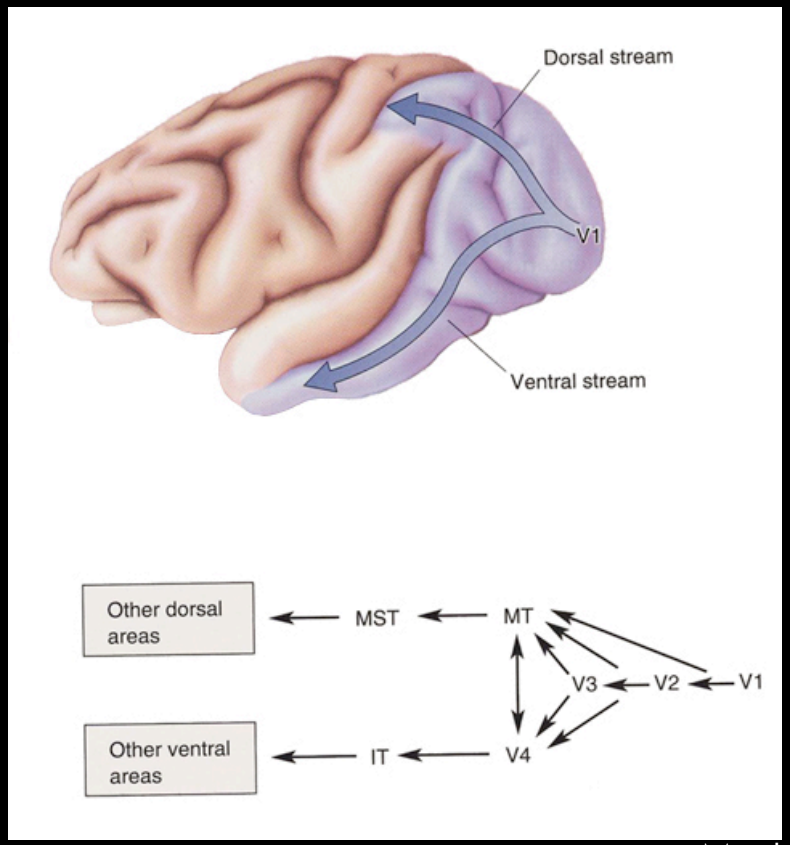
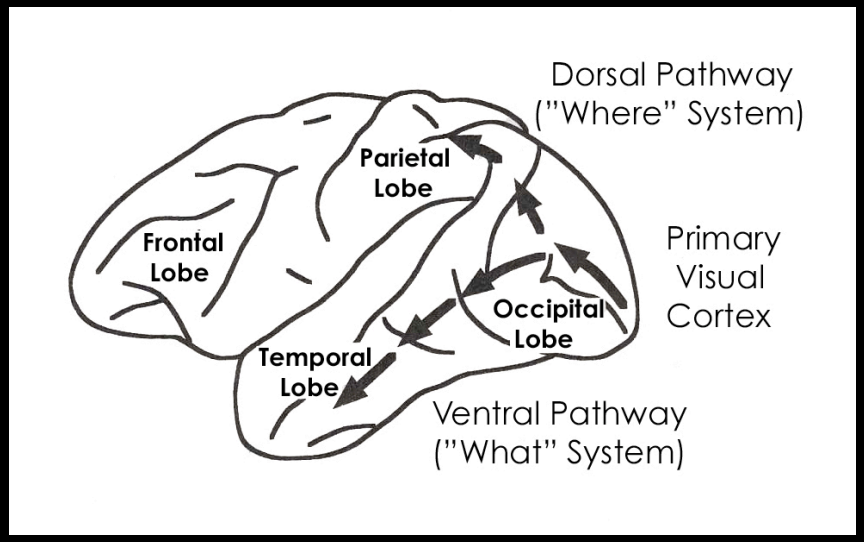
- The brain is a reactive organ





Massive reciprocal connections

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Our reciprocal anatomical connections in action



We cannot stop memory from going beyond the information given

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- The brain is a responsive organ
- Recognition, or classification, is the goal

What is this?



What is this **like**? analogies

Visual recognition as analogical mapping

- facilitate recognition
- connect to associations

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TODAY	TOMORROW	WED	THU	FRI	6-10 DAY
Mostly Clear	Mostly Cloudy	Sunny	Snow	Partly Cloudy/Wind	Extended Forecast
High: 26°	High: 36°	High: 20°	High: 21°	High: 12°	
Low: 16°	Low: 21°	Low: 10°	Low: 2°	Low: 3°	

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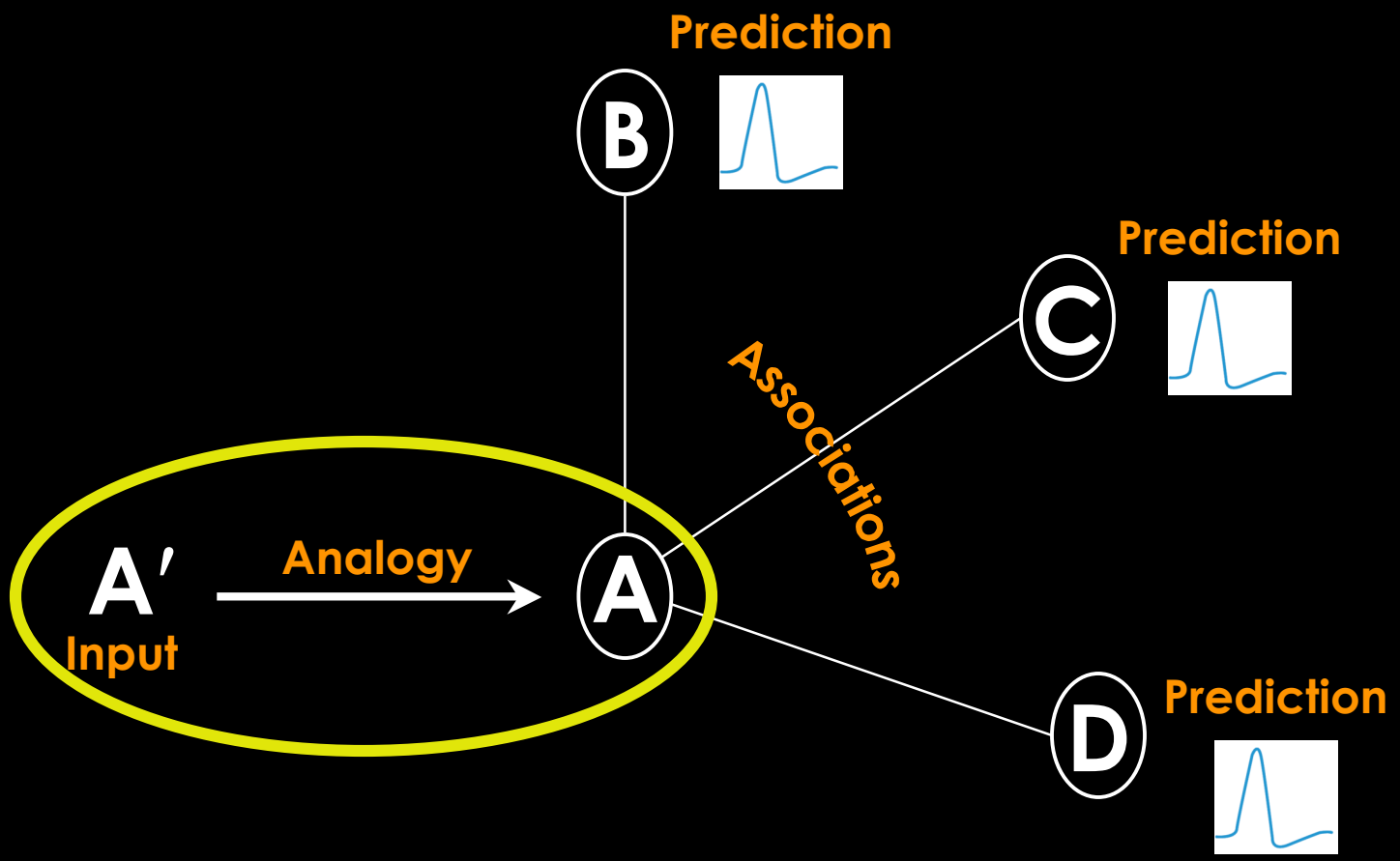
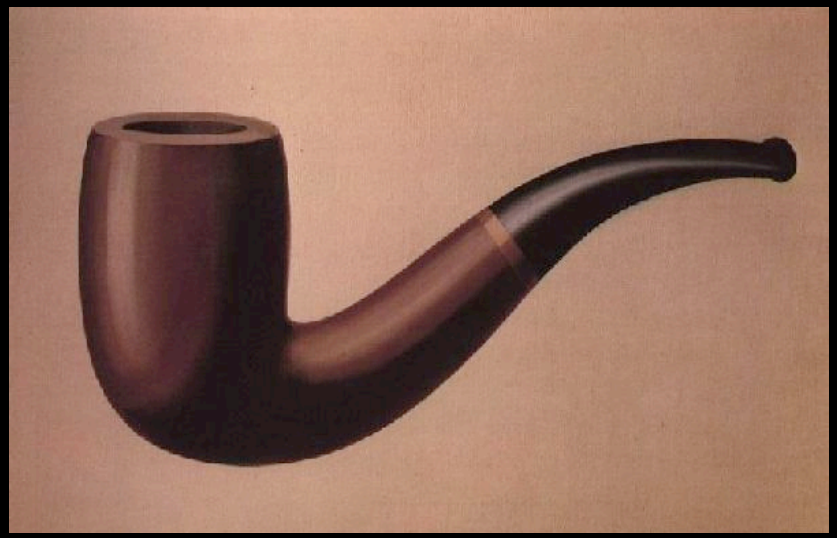


Bar, *Trends in Cognitive Sciences*, 2007

Predictions in object recognition
(recognition as analogy)



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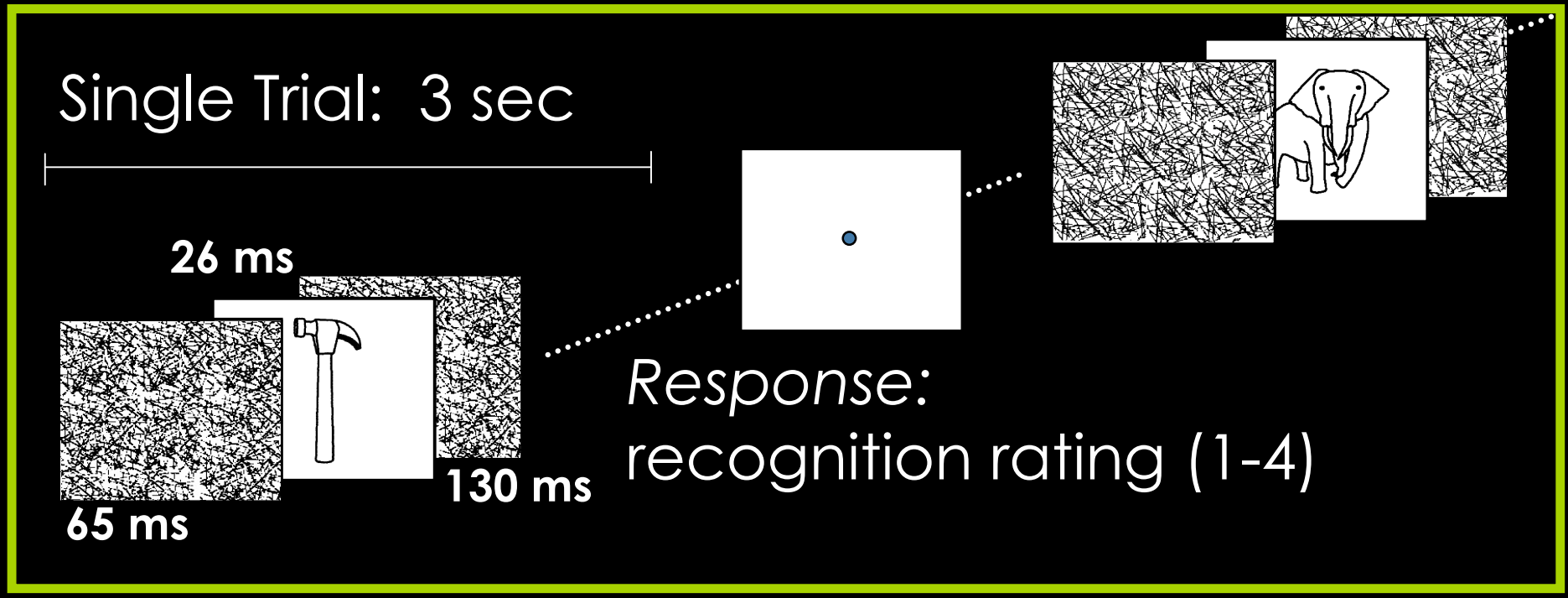
the cortical mechanism specific to conscious object recognition



(Bar et al., Neuron 2001)

- Event-related design
- Five, randomly intermixed repetitions
- Subliminal Visual Priming (Bar & Biederman,1998)

Ventral View



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Recognized Objects
vs.
'Almost' Recognized Objects



$p<10^{-9}$

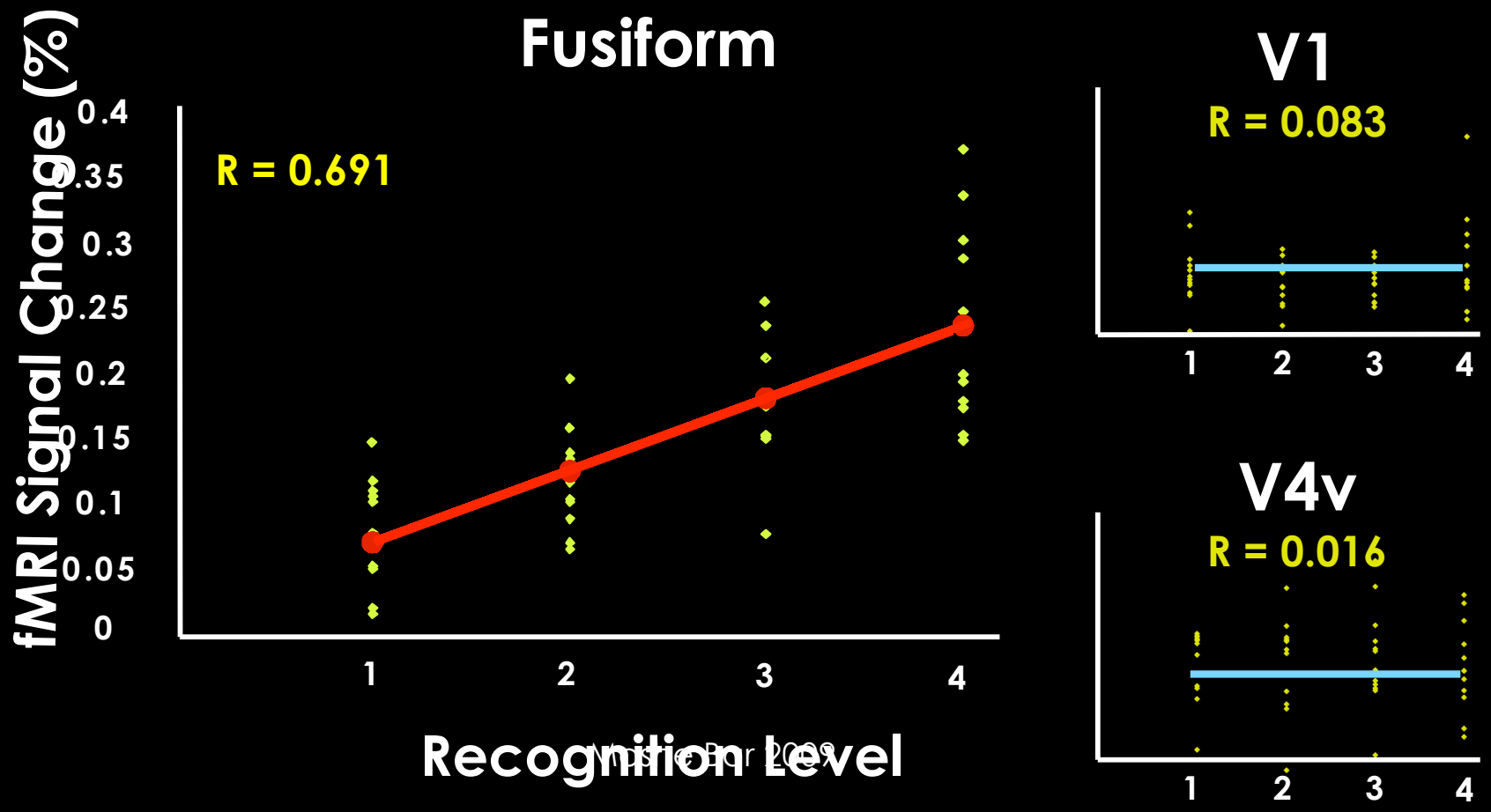
$p<10^{-4}$

Averaged Map (N=12)

left

Bar et al., *Neuron*, 2001

fMRI signal in the fusiform gyrus was linearly correlated with recognition performance



Recognized Objects
vs.
'Almost' Recognized Objects



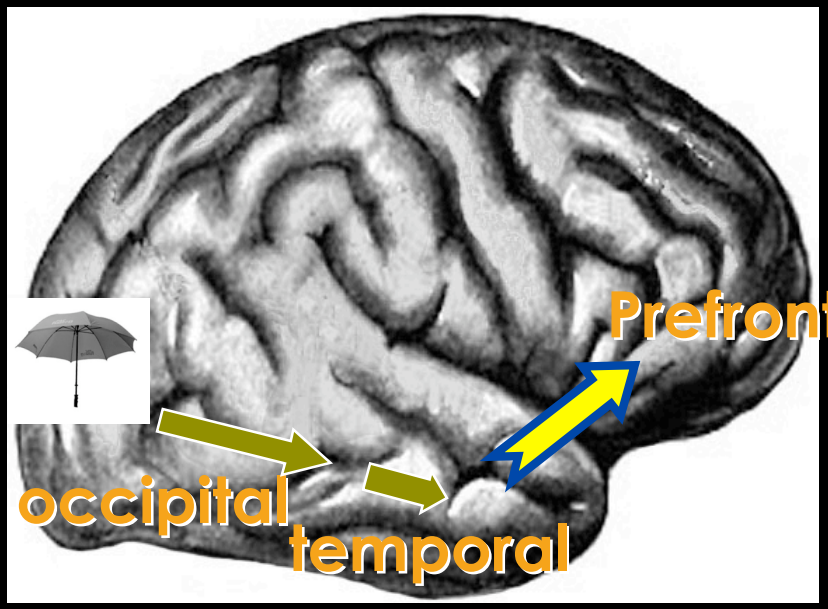
Orbitofrontal Cortex (OFC)

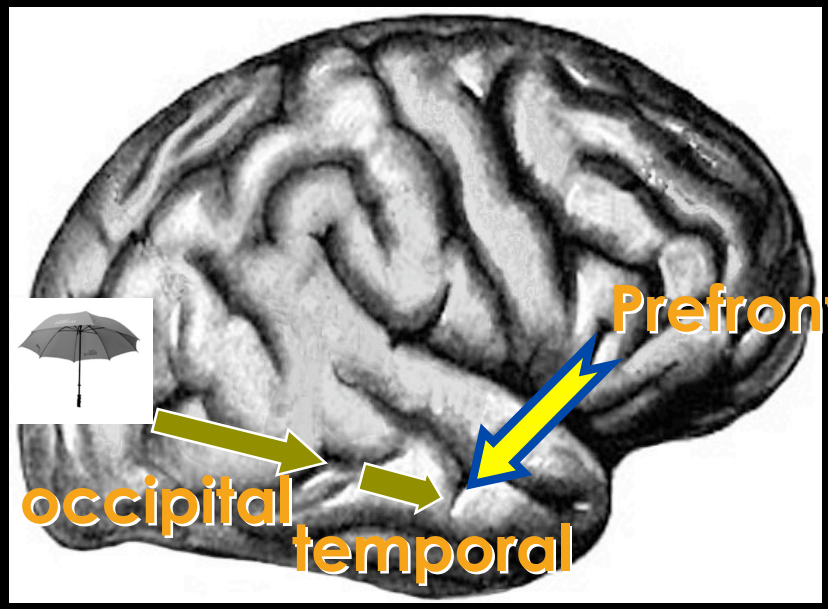
Role of prefrontal activation

Post-recognition
high-level processing

?

Pre-recognition
Top-down facilitation





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Minimizing the search: Deciding "what is this like" based on very little





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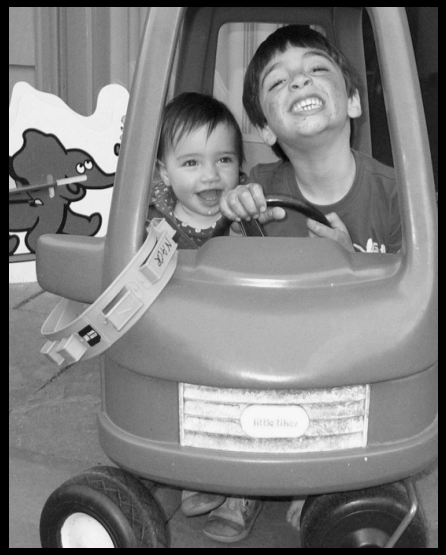
Spatial frequencies



low spatial frequencies





high spatial frequencies

Different timecourses (Magnocellular pathway).
Initial guess for first impressions.

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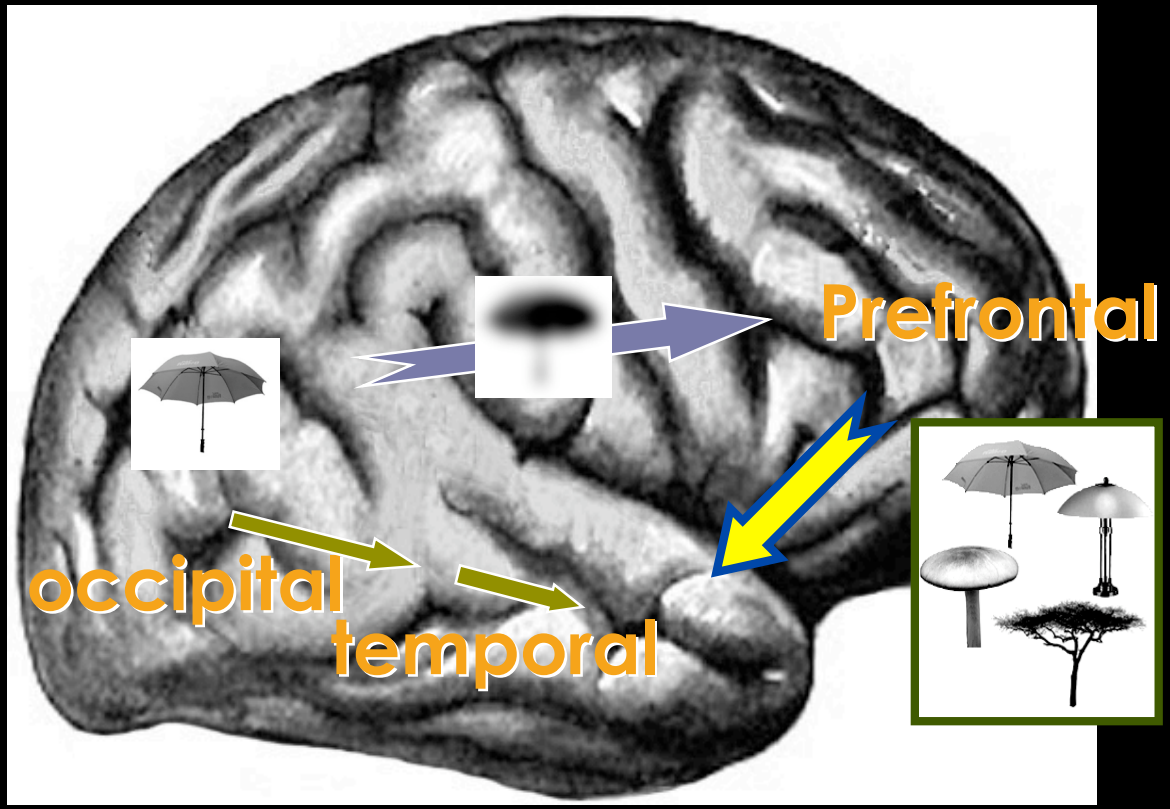
A Mechanism for Triggering Top-Down Processing in Object Recognition



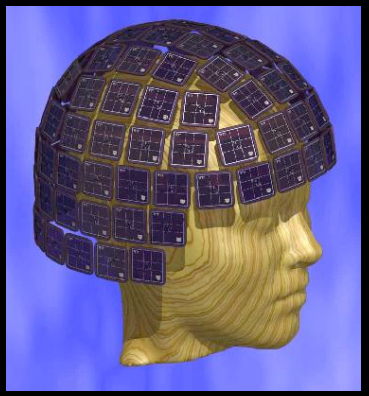
Bar, *Journal of Cognitive Neuroscience* (2003)

Key Predictions

1. PFC activity related to object recognition develops before recognition is accomplished.

Magnetoencephalography (MEG)

NeuroMag Vectorview system





- Contains 306 sensors (2 planar gradiometers and 1 magnetometer at 102 locations)
- Measured with SQUIDs (superconducting quantum interference devices) @ –269°C
- Brain signals are ~10^{-14} T, urban noise is ~10^{-7} T

Karim Kassam

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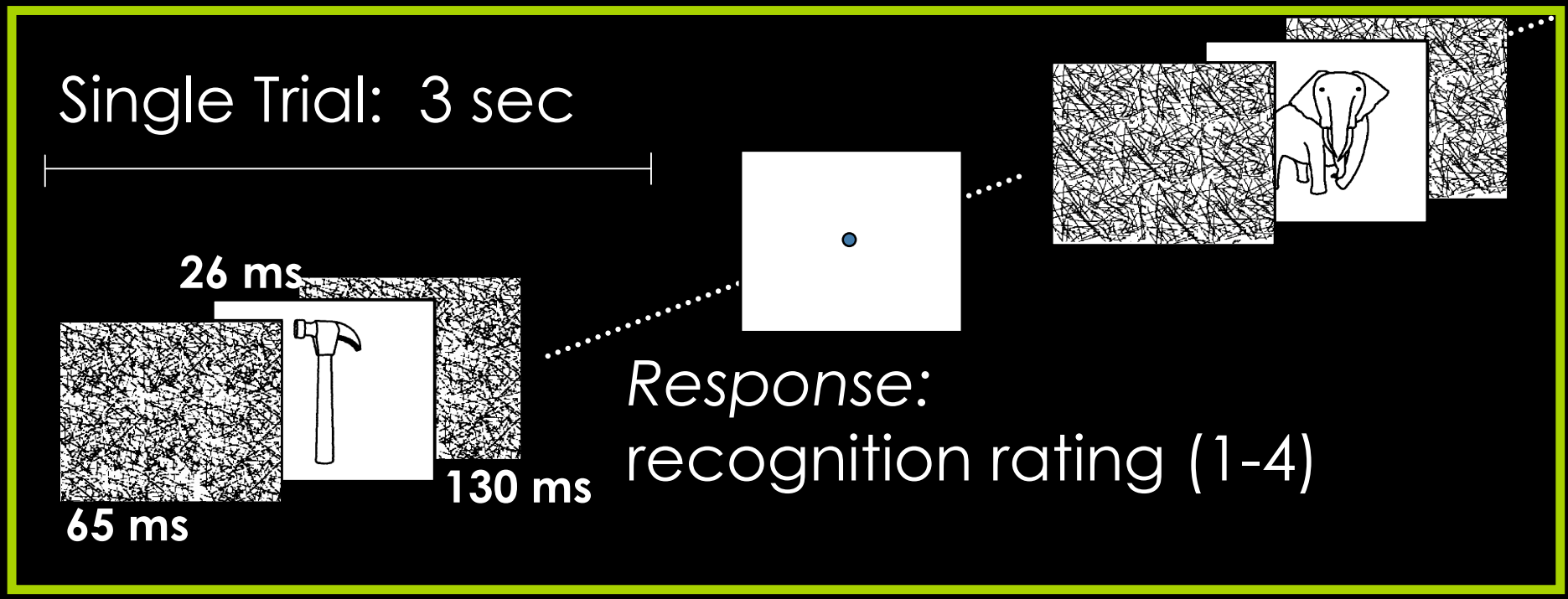
cortical mechanism specific to conscious object recognition



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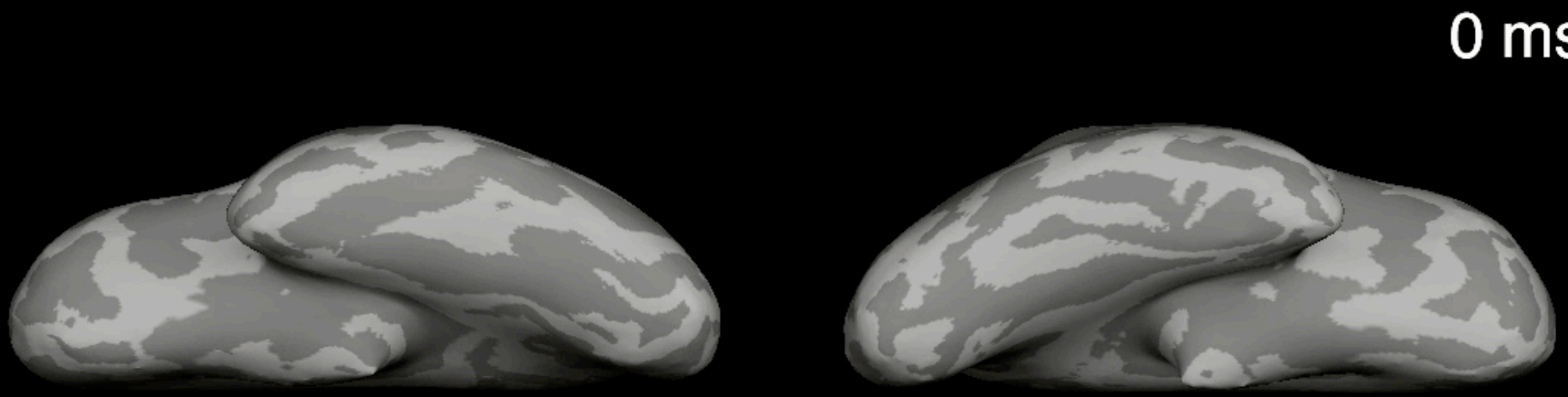
Recognized *vs.* Non-Recognized Trials



(magnetoencephalography; MEG)

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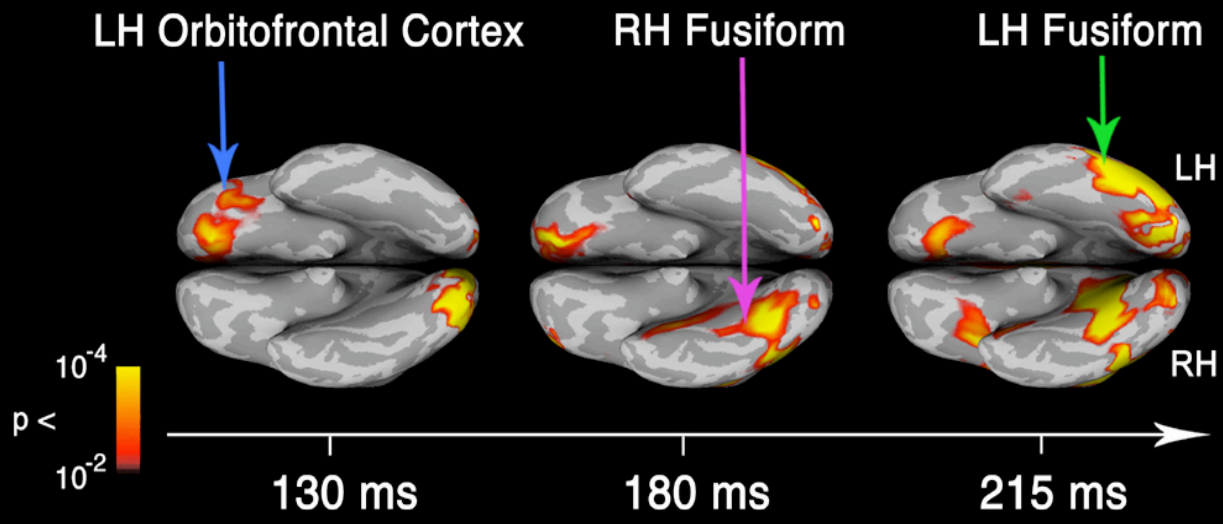
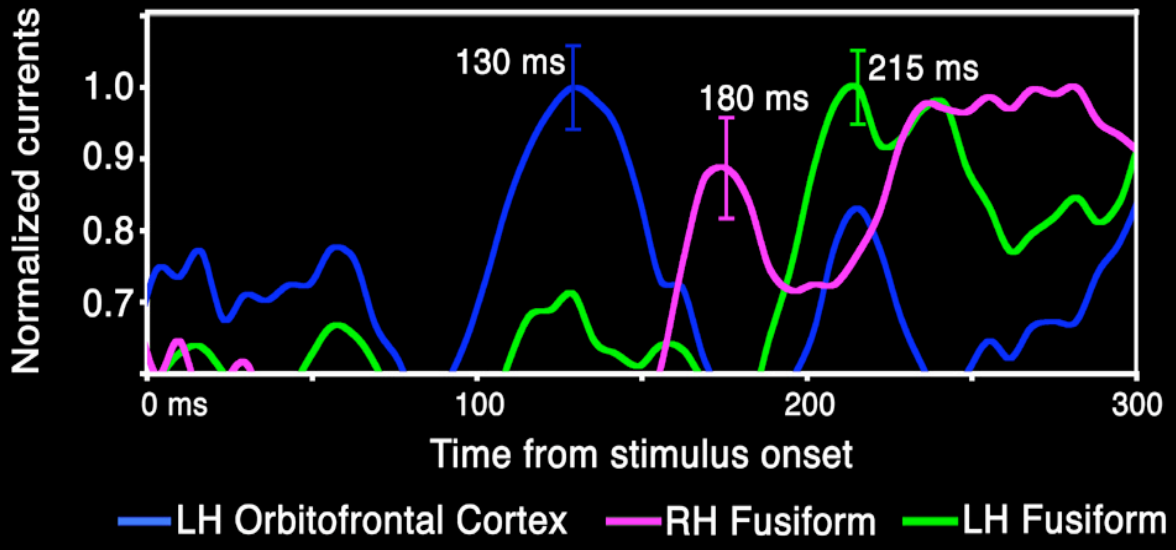
(Bar et al., PNAS 2006)

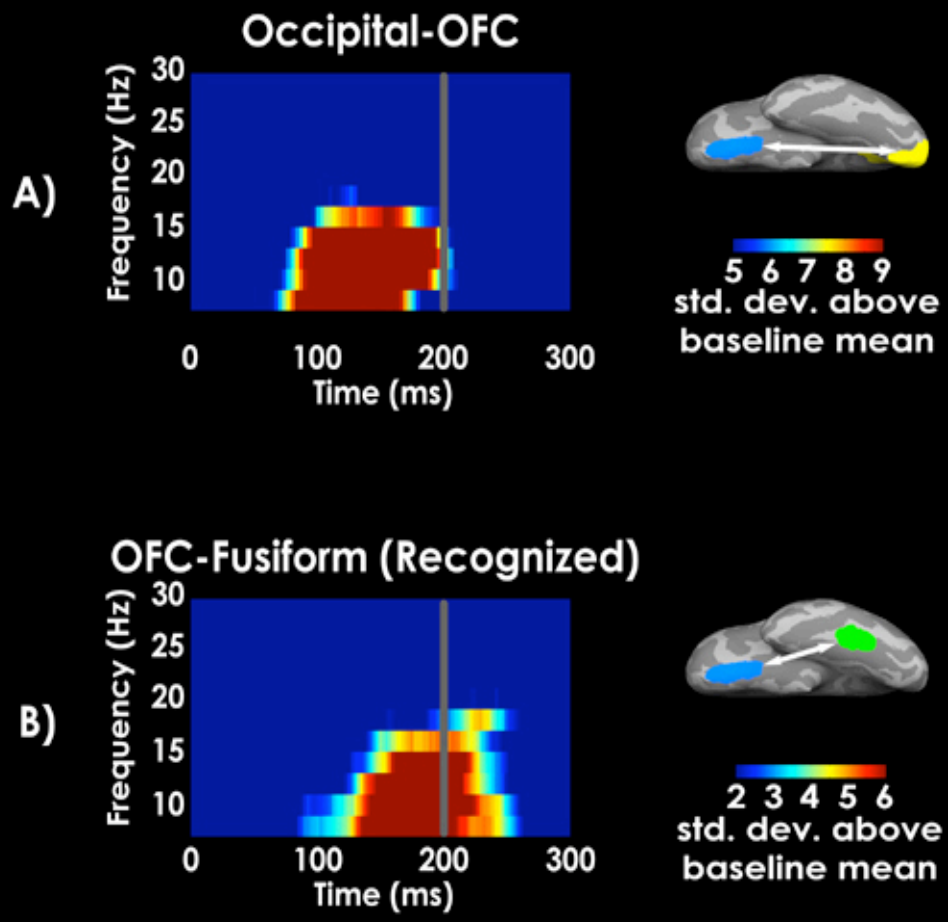
Recognized vs. Non-Recognized Trials





(Bar et al., PNAS 2006)

Cortical Interactions as Indicated by Phase-Locking Values



(Bar et al., 2006)

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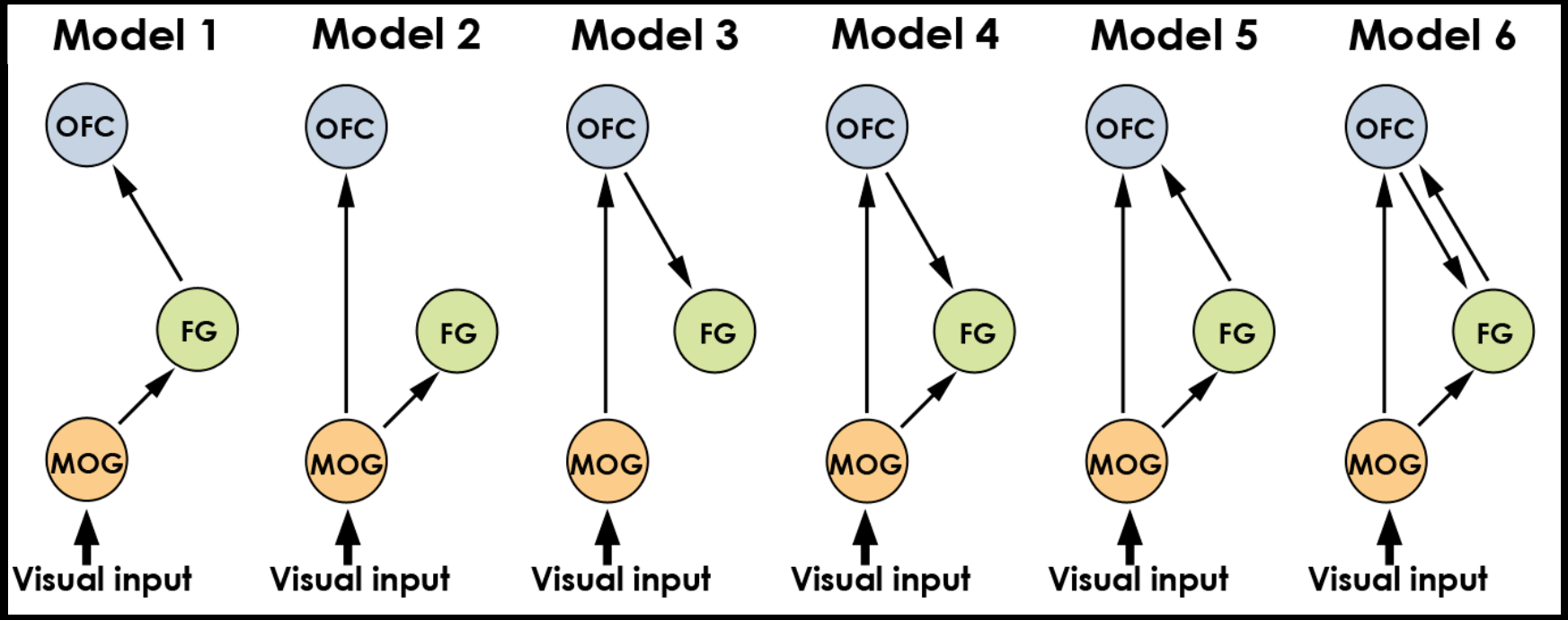
Magno vs. Parvo (J. Neuroscience 2007)

Studying connectivity with Dynamic Causal Modeling



MOG - middle occipital gyrus
FG - fusiform gyrus
OFC - orbitofrontal cortex

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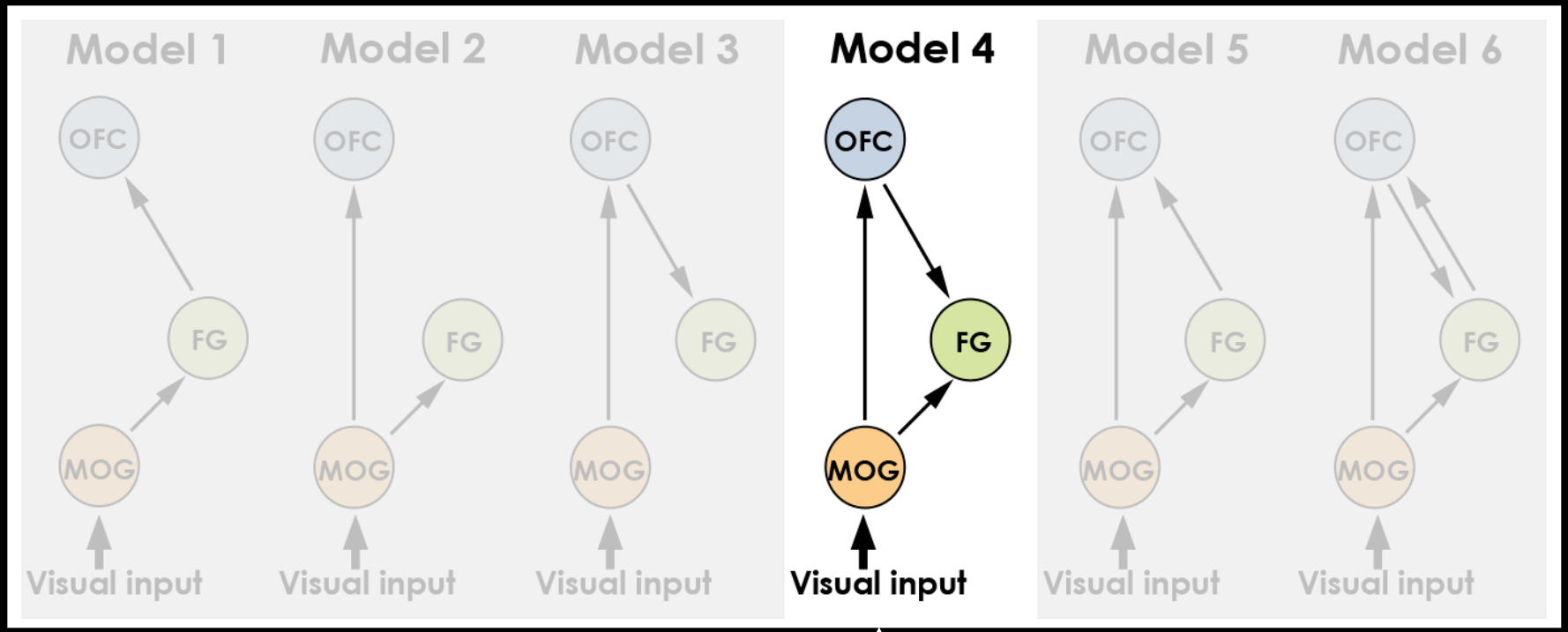
Kveraga, Boshyan, Bar, 2007

Studying connectivity with Dynamic Causal Modeling



MOG - middle occipital gyrus
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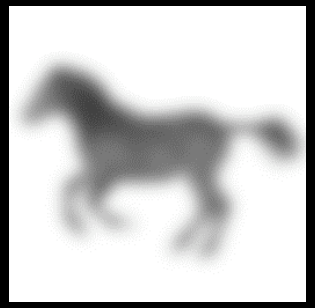
Kveraga, Boshyan, Bar, 2007

Key Predictions

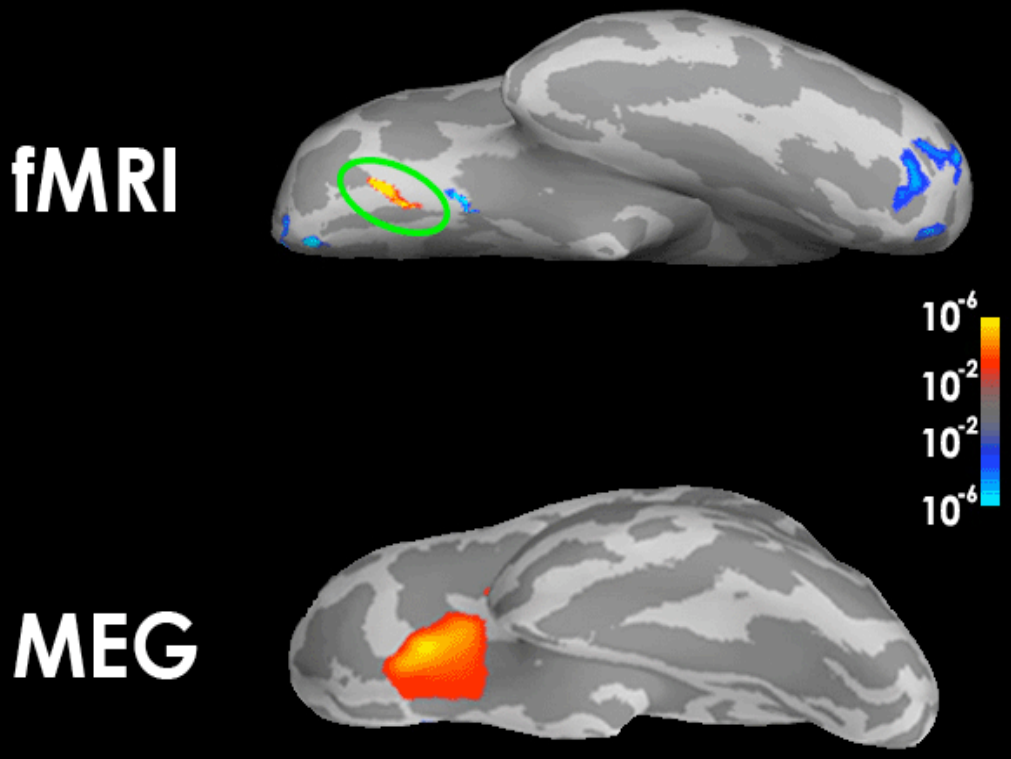
1. PFC activity related to object recognition develops before recognition is accomplished.

2. This early PFC activity is driven by low spatial frequencies in the image.

Low vs. High spatial frequencies







⇒ OFC activity is early and driven by LSF

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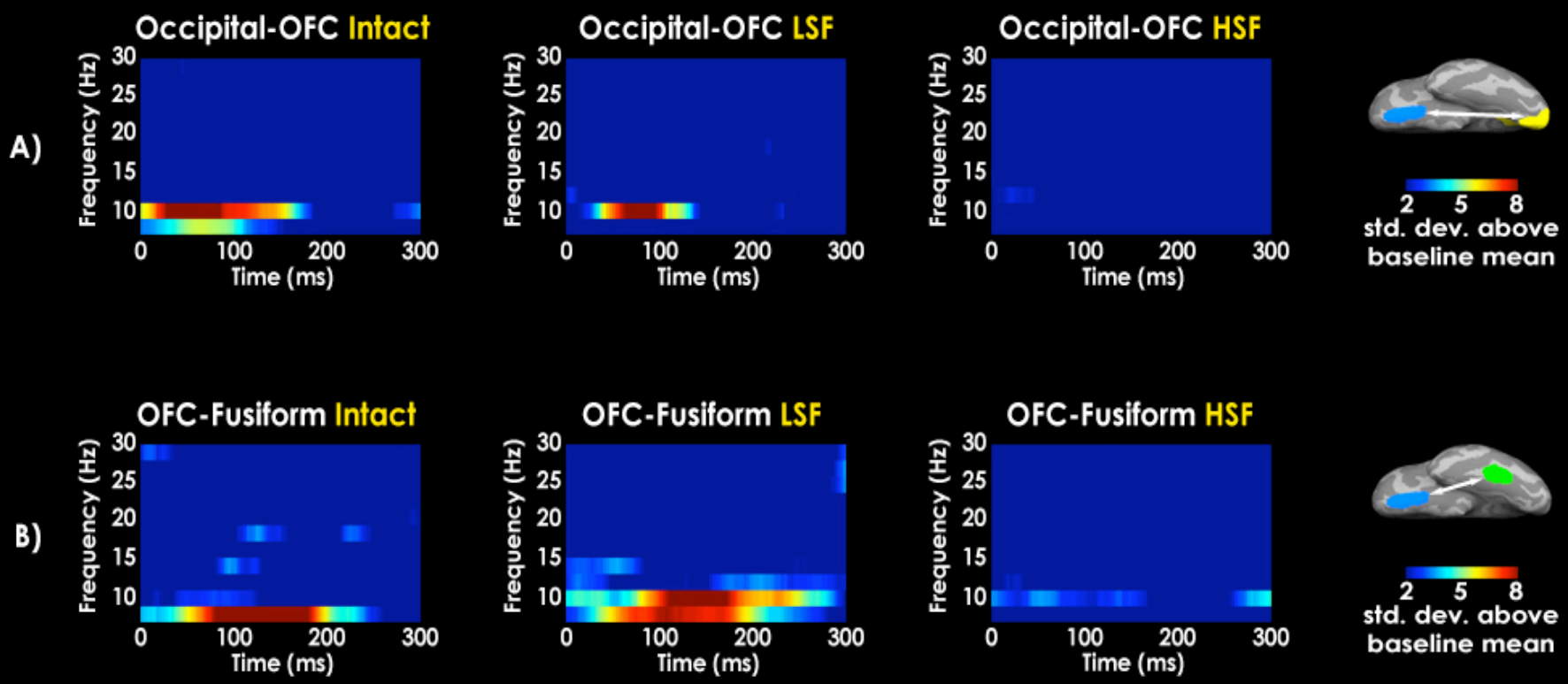
Cortical Interactions as Indicated by Phase-Locking Values



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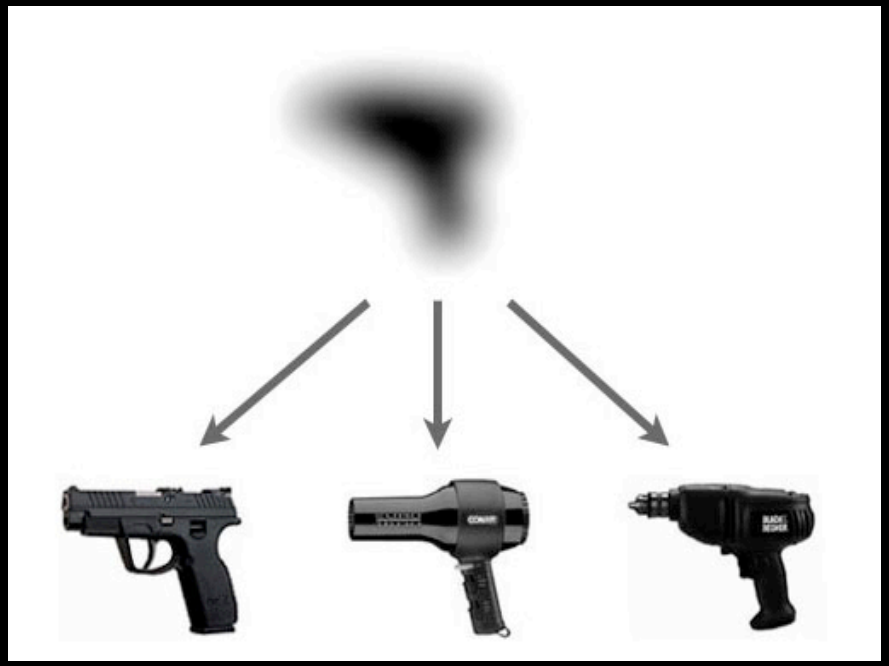
Key Predictions

1. PFC activity related to object recognition develops before recognition is accomplished.

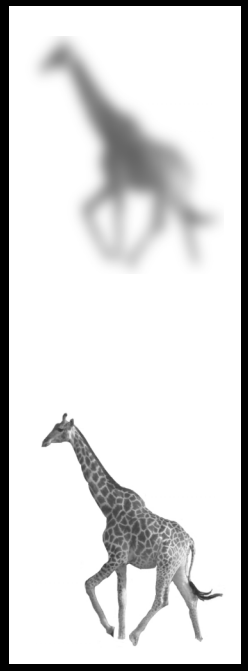
2. This early PFC activity is driven by low spatial frequencies in the image.

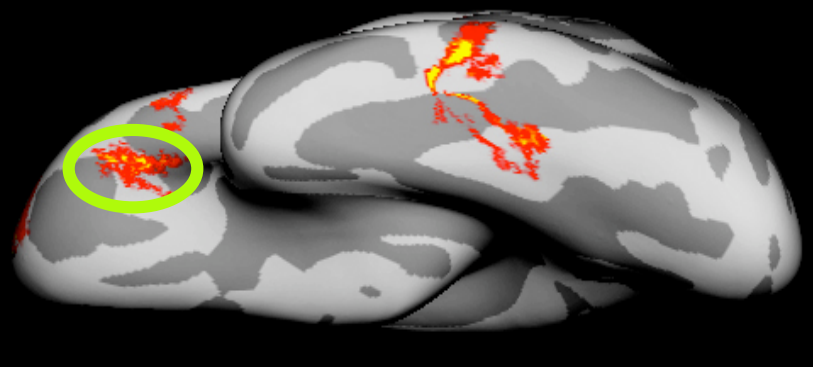
3. Increased number of candidates results in a stronger PFC activation.

Number of candidates and OFC activation



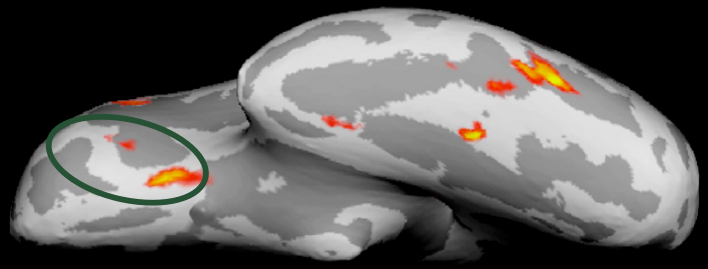
vs.





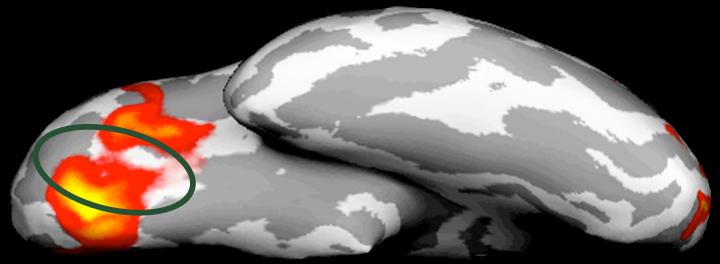
Orbitofrontal Cortex and Recognition

Masked Recognition (fMRI)



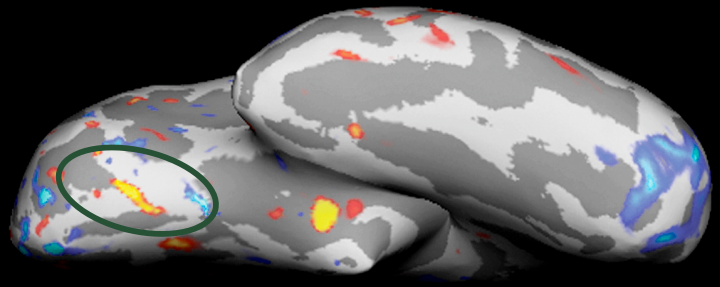
$p < 10^{-9}$ to 10^{-4}

Masked Recognition (MEG at 130 ms)



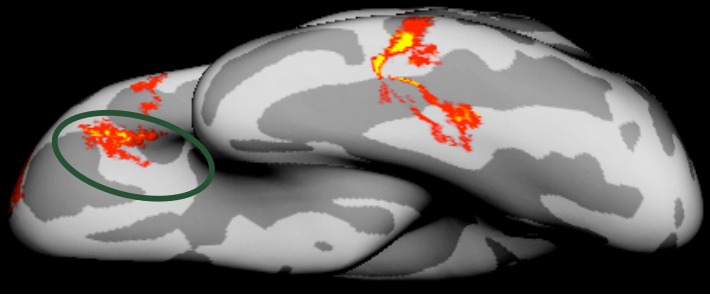
$p < 10^{-4}$ to 10^{-2}

Spatial Frequency (fMRI and MEG)



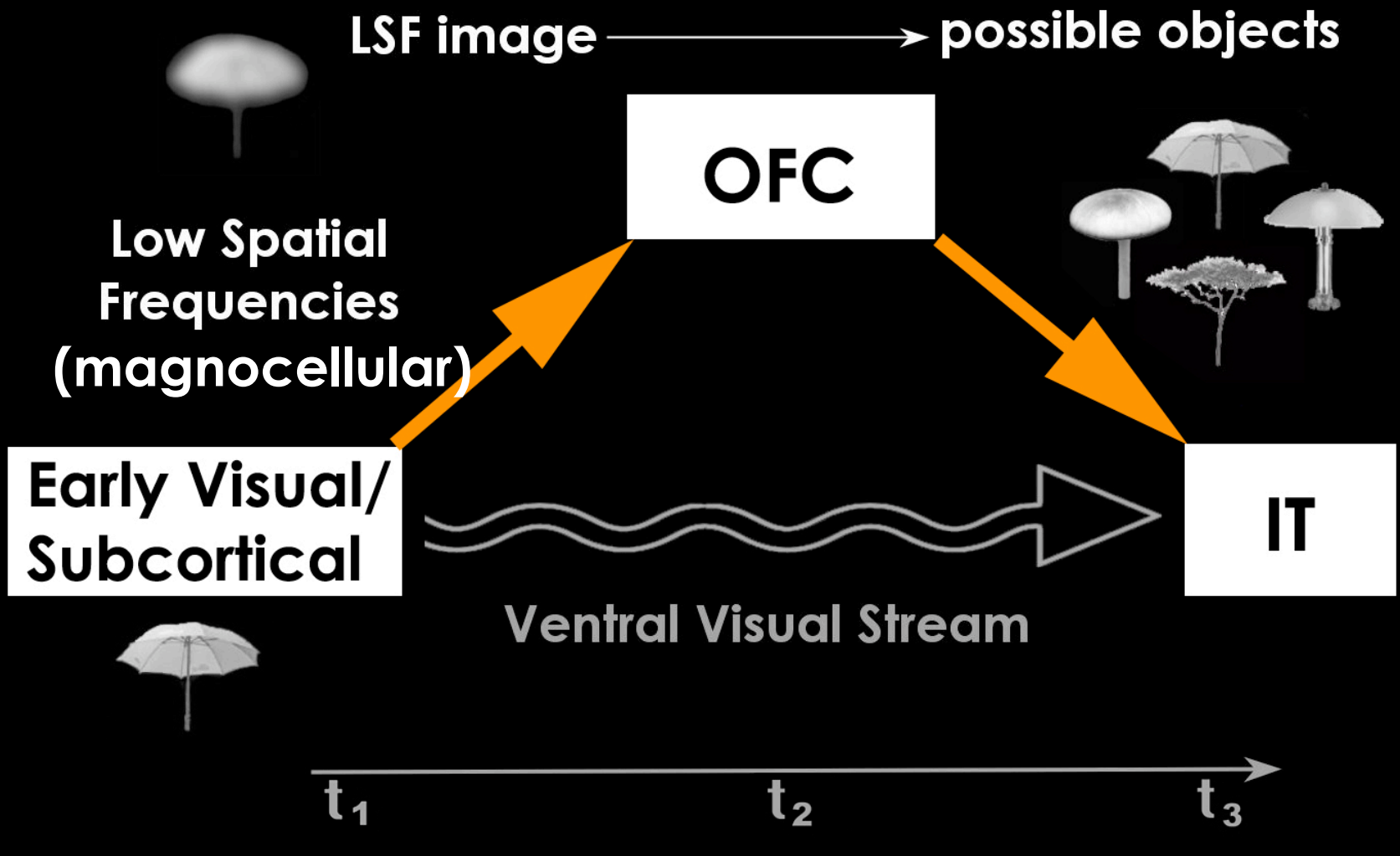
$p < 10^{-6}$ to 10^{-2}

Number of candidates (fMRI)

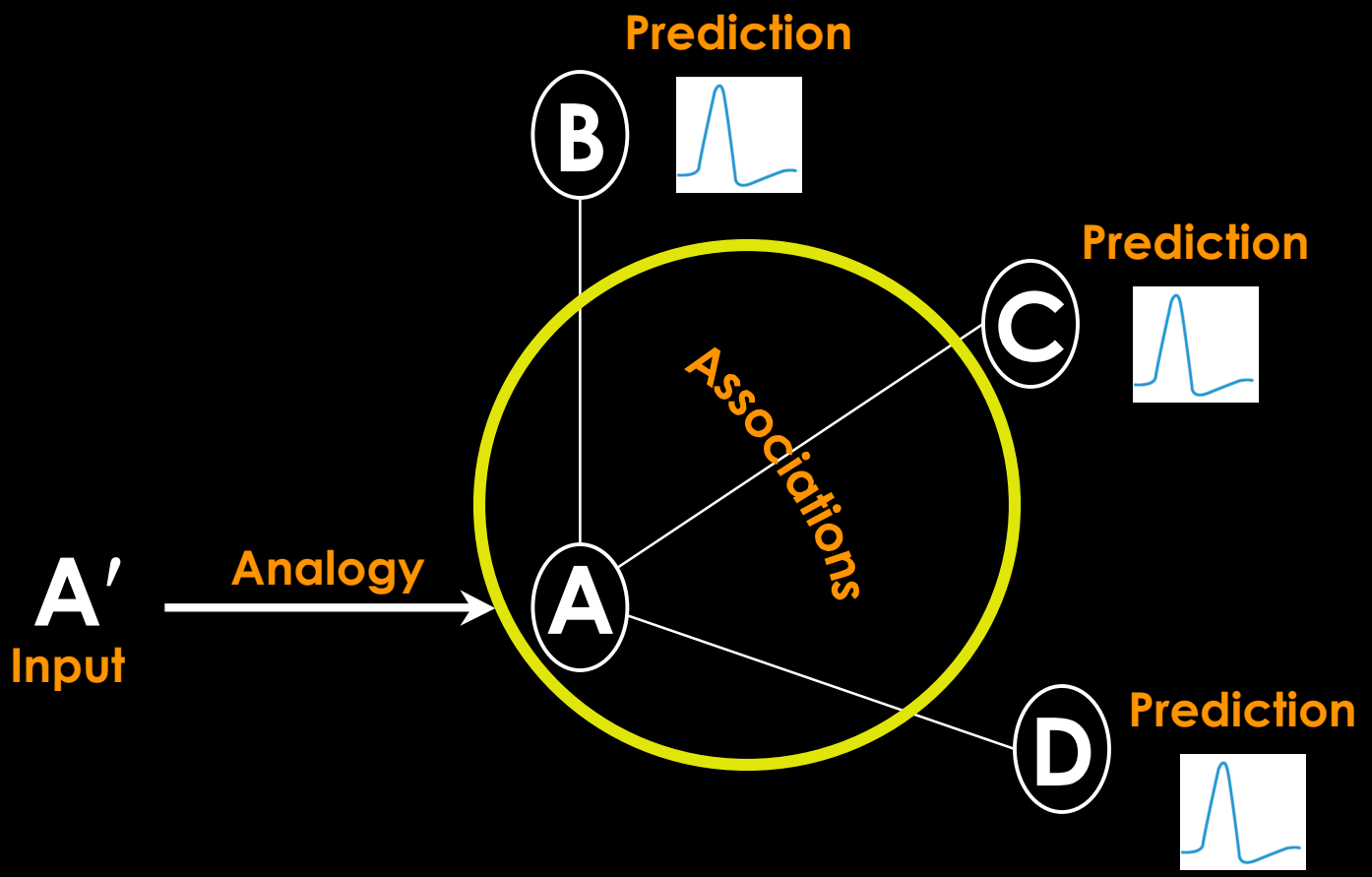


$p < 10^{-5}$ to 10^{-2}

Top-down facilitation model



Bar, 2003



Bar, *Trends in Cognitive Sciences*, 2007

Objects in our environment do not appear in isolation,

but rather in typical contexts.





Such statistical regularities can be used for the generation of predictions

Contextual knowledge helps us detect what is expected (and thus can save processing resources), what does not belong, and what is rare.

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Strong Context







vs.

Weak Context









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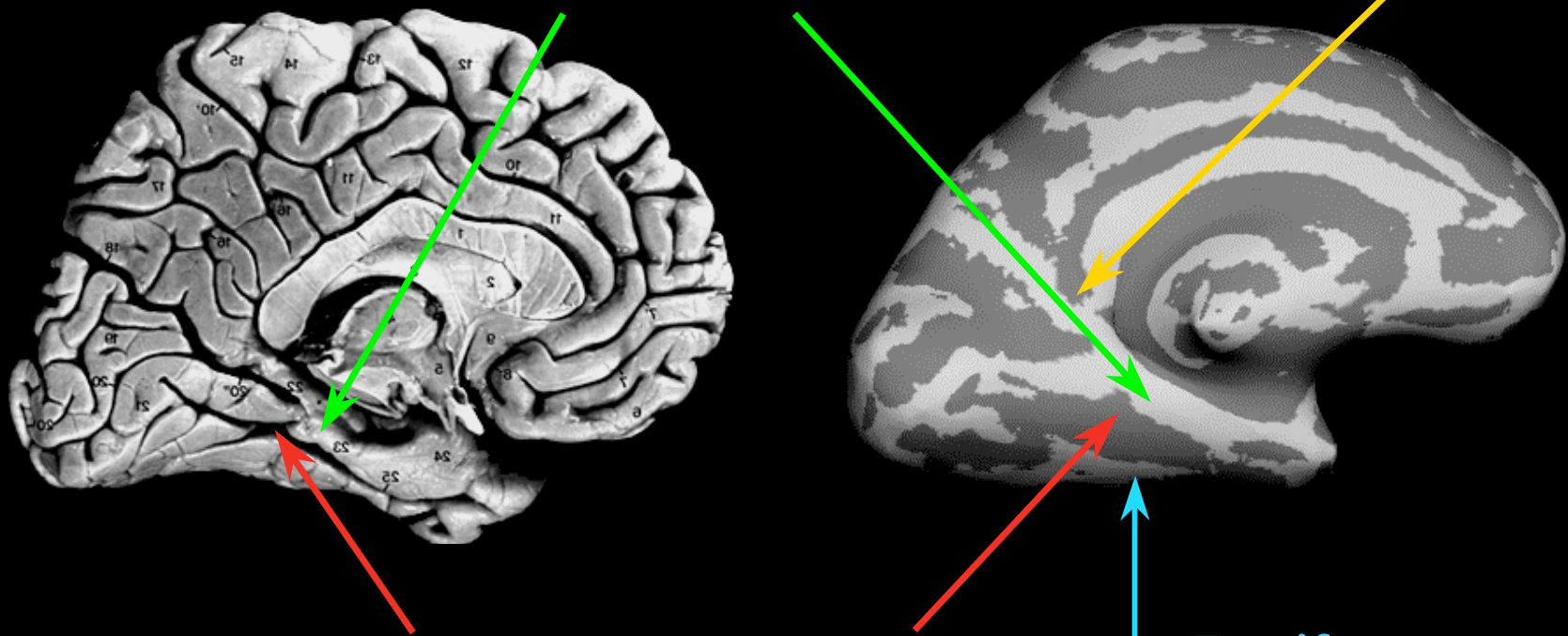
Bar and Aminoff, Neuron 2003

Medial view (LH)



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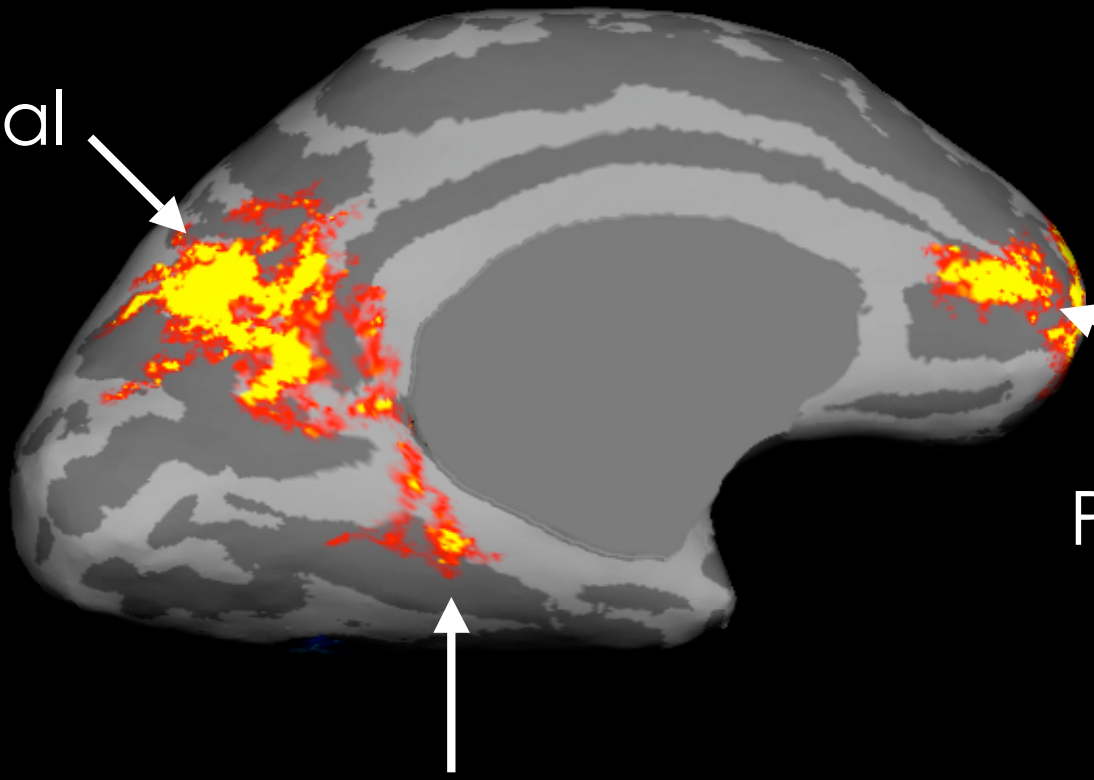
Neural network mediating contextual associative processing



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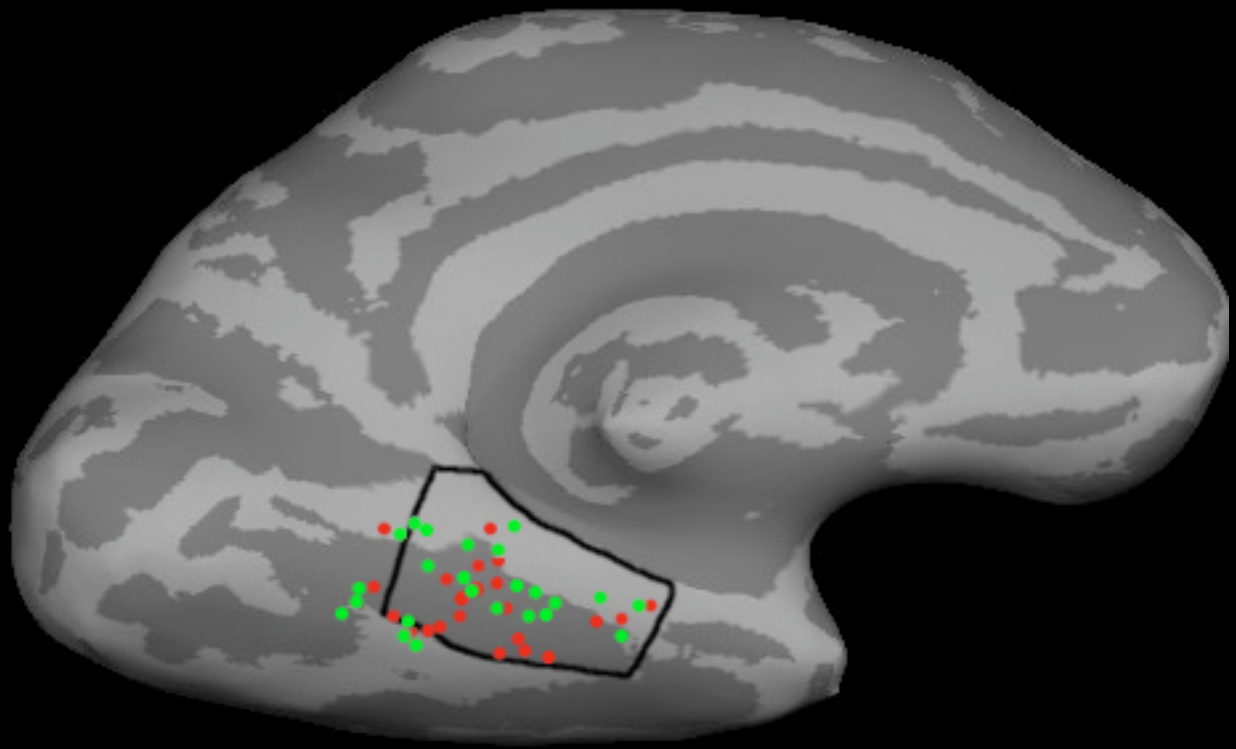
Parahippocampal Cortex

Spatial Processing
(20 studies)

Episodic Memory
(18 studies)



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How could the same cortical region mediate such seemingly different cognitive processes?

Contextual associations as a bridge

Comparing spatial with non-spatial contexts

Spatial



Casino



Construction Site



Beach

Non-Spatial



Patriotism



Romance



Winter

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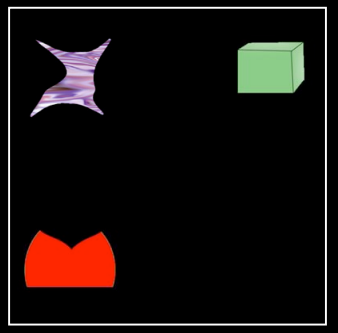
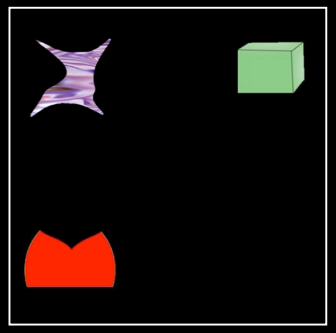
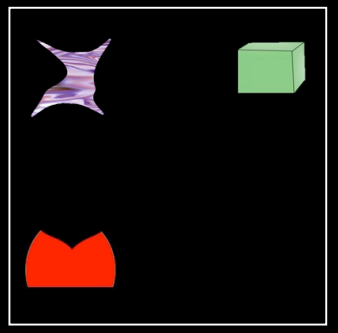
Experimental Conditions

Spatial Context

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Non-Spatial Context





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Individual (no-context, control)





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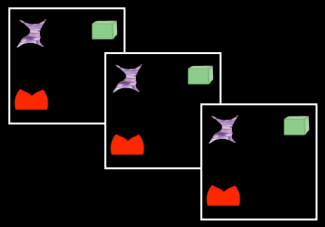
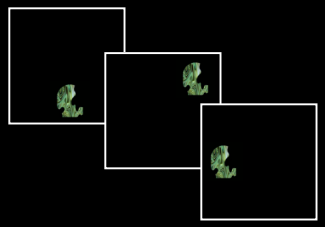
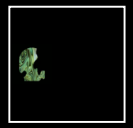
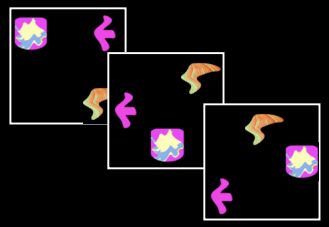
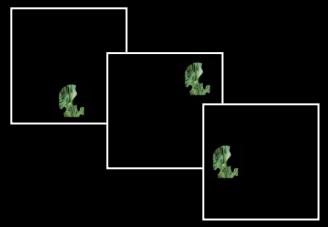
Contextual activity

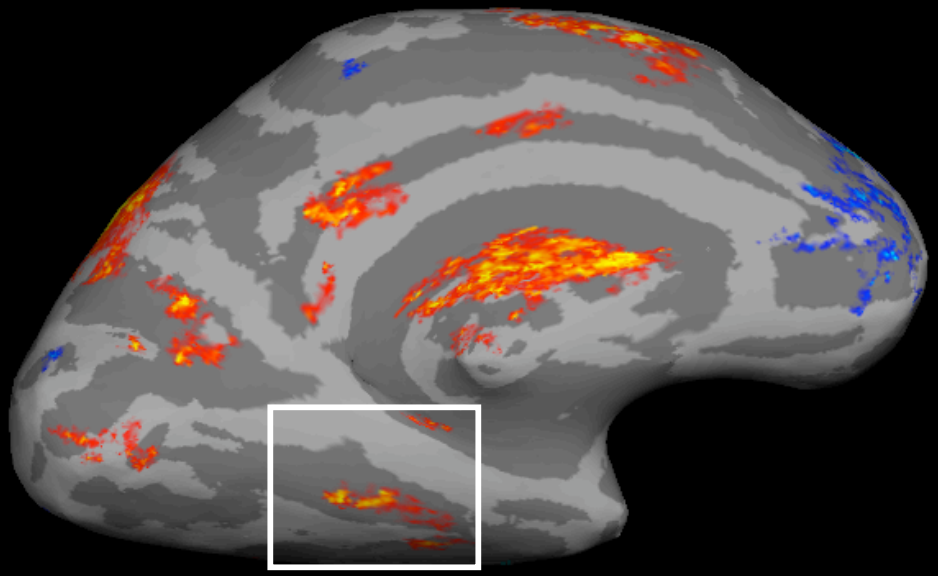
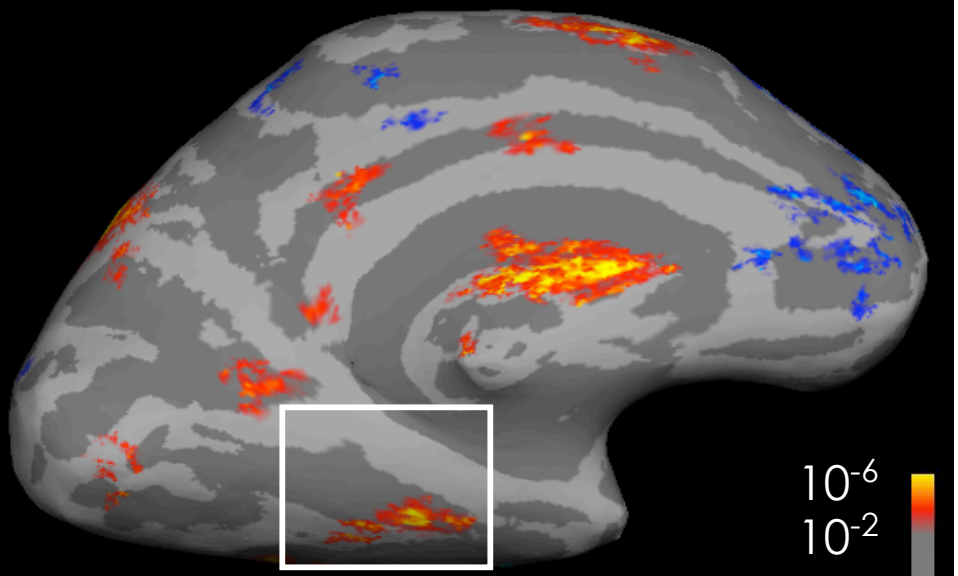
Spatial vs. Individual

Non-Spatial vs. Individual



10^{-6}
10^{-2}

10^{-2}
10^{-6}

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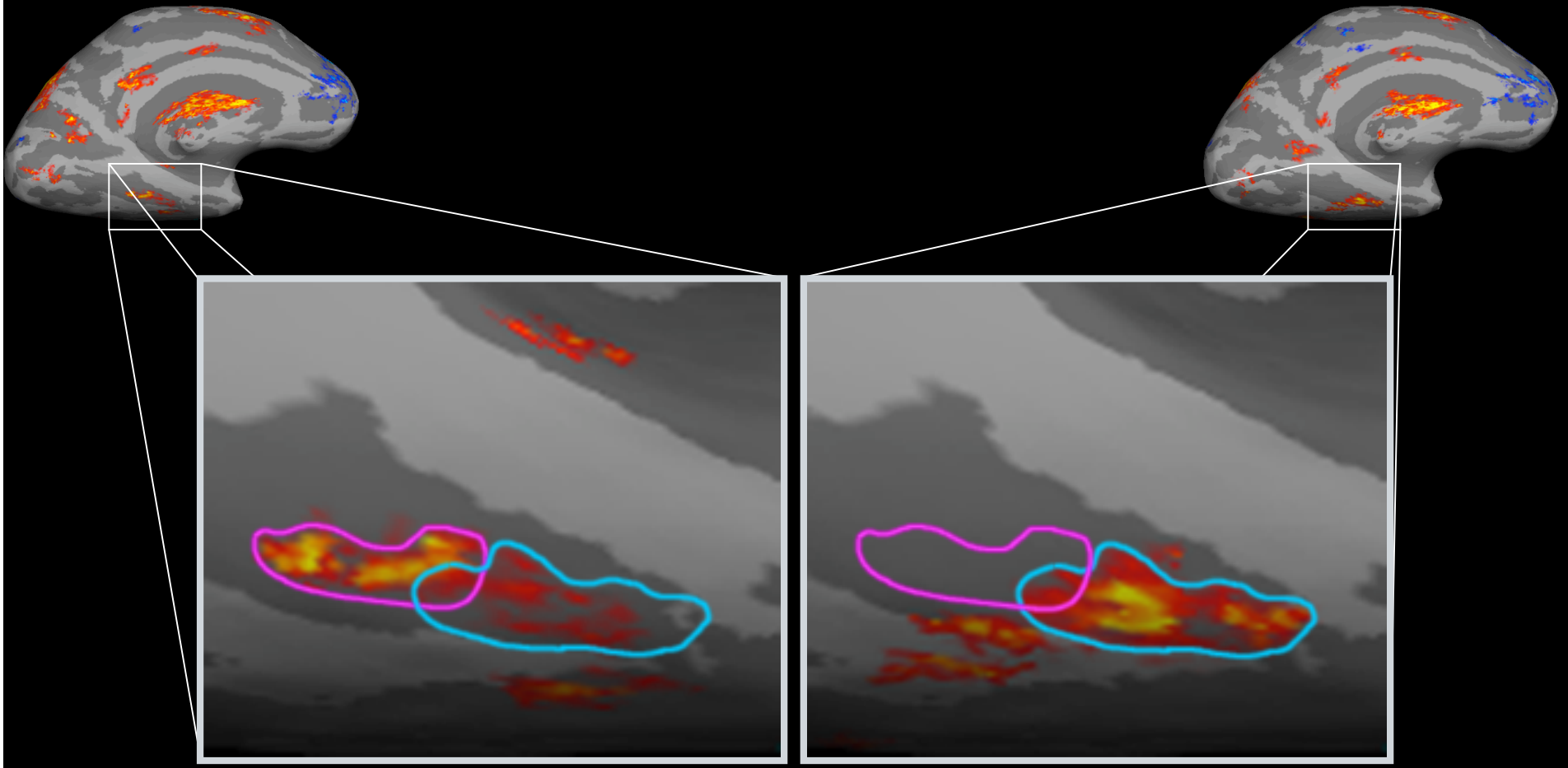
Contextual activity

Spatial vs Individual

Non-Spatial vs Individual



Spatial Activation

Non-Spatial Activation

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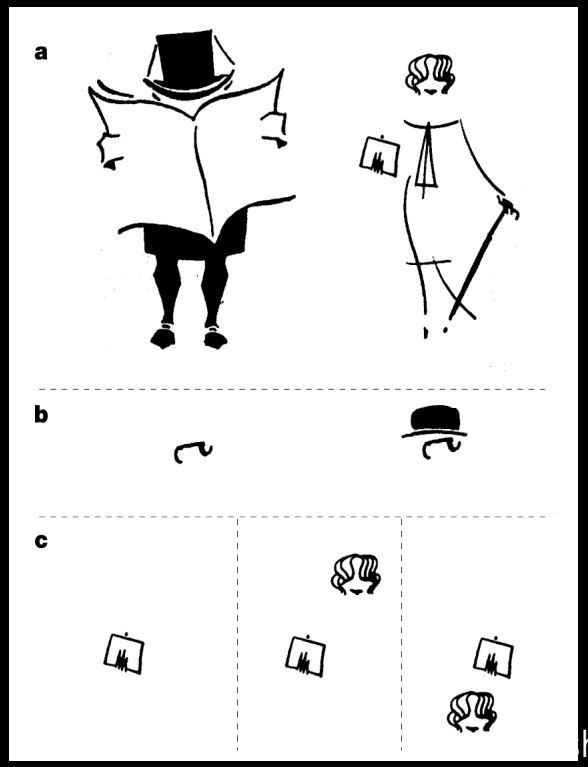
Context frames capture environmental regularities learned with experience (identities and relations).



Bar and Ullman, 1996

Predictions in recognition
using associative *Context Frames*

Capture environmental regularities learned with experience (identities and relations).

Activated rapidly by preliminary information in the image (e.g., "key" objects, global features).

Minimizing the search: Deciding "what is this like" based on very little

Oliva
Torralba
Schyns

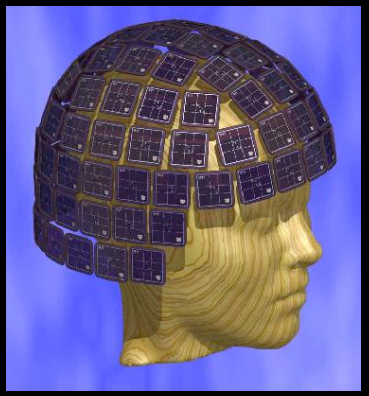






Magnetoencephalography (MEG)

NeuroMag Vectorview system





- Contains 306 sensors (2 planar gradiometers and 1 magnetometer at 102 locations)
- Measured with SQUIDs (superconducting quantum interference devices) @ –269°C
- Brain signals are ~10^{-14} T, urban noise is ~10^{-7} T

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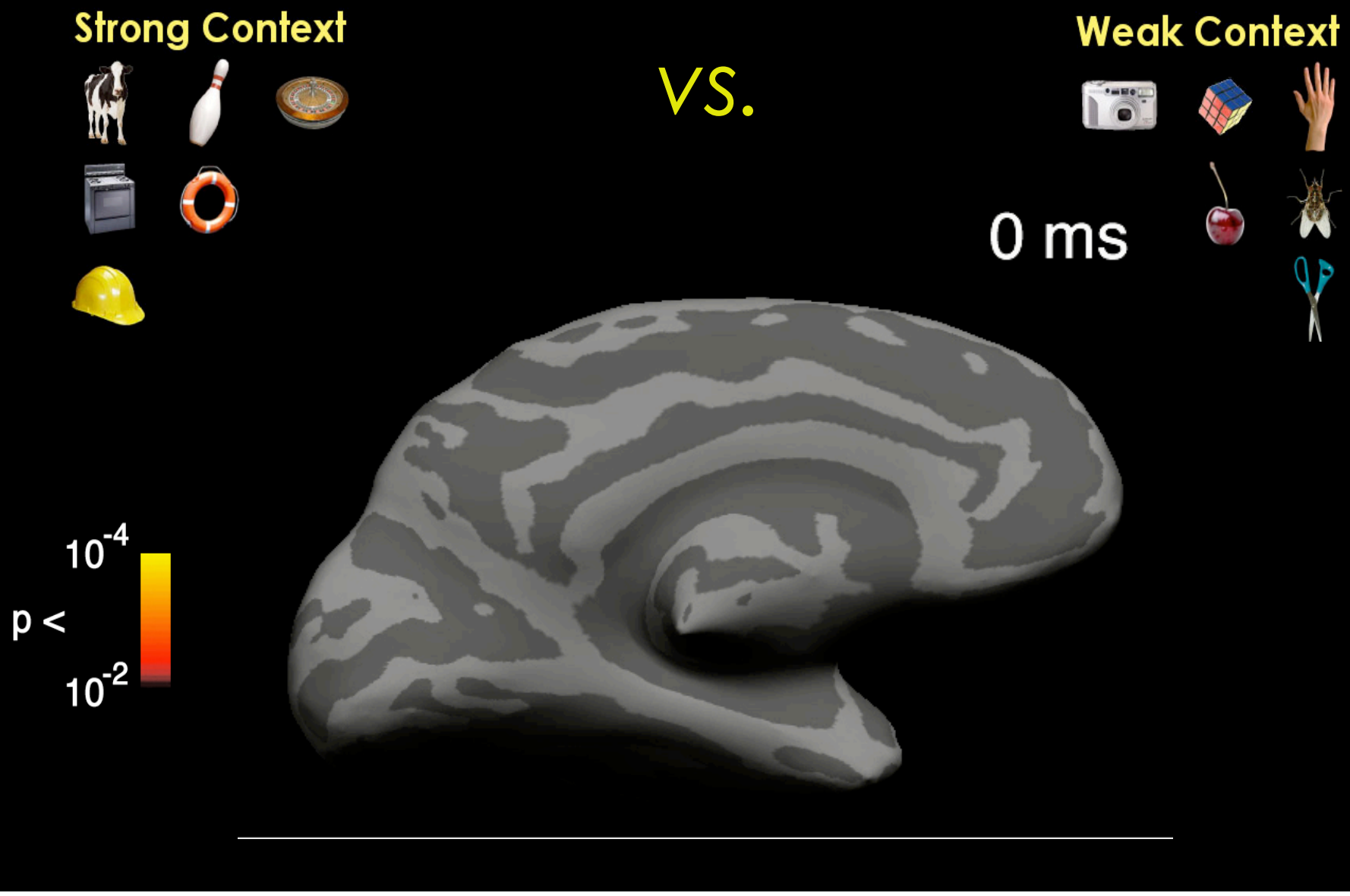
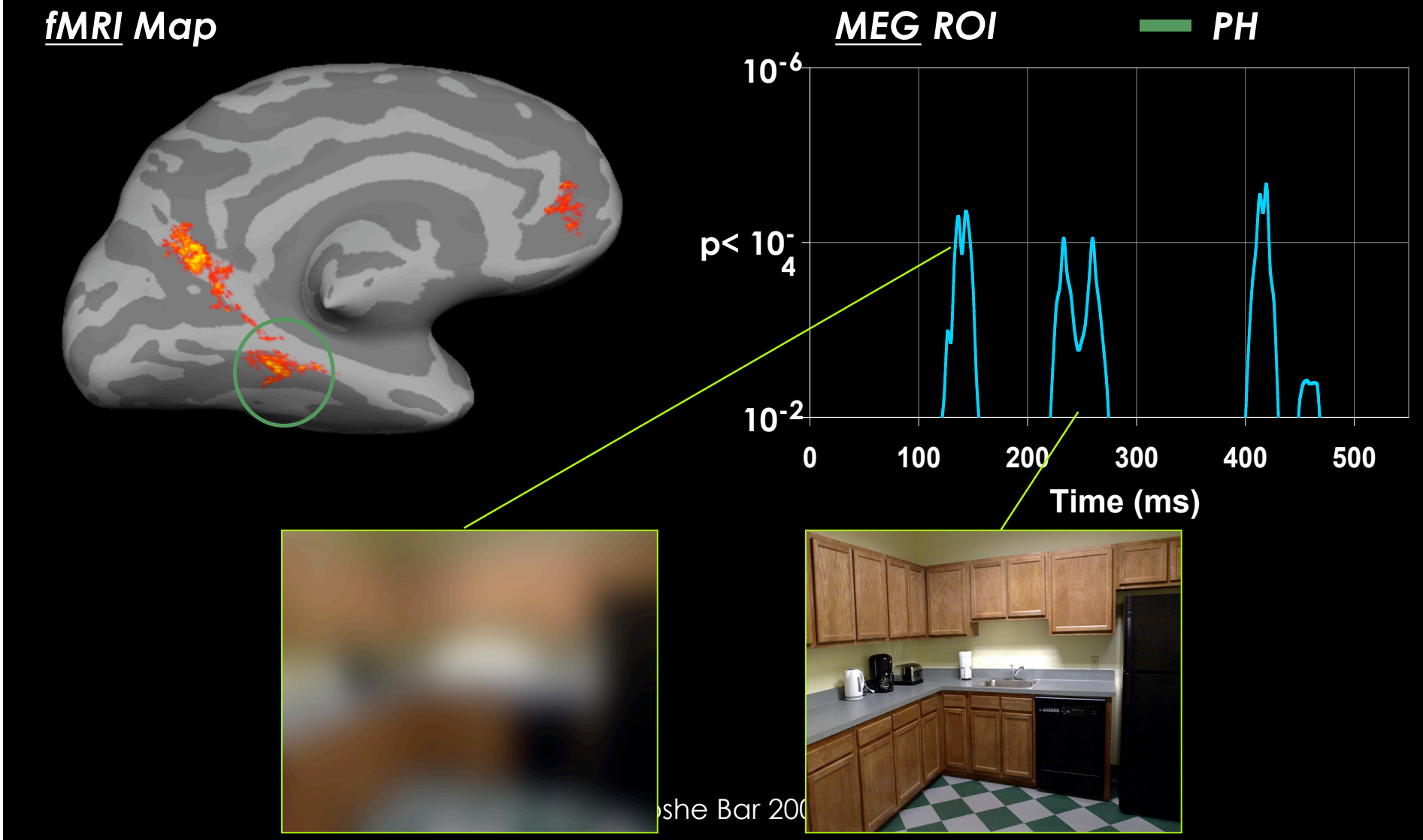
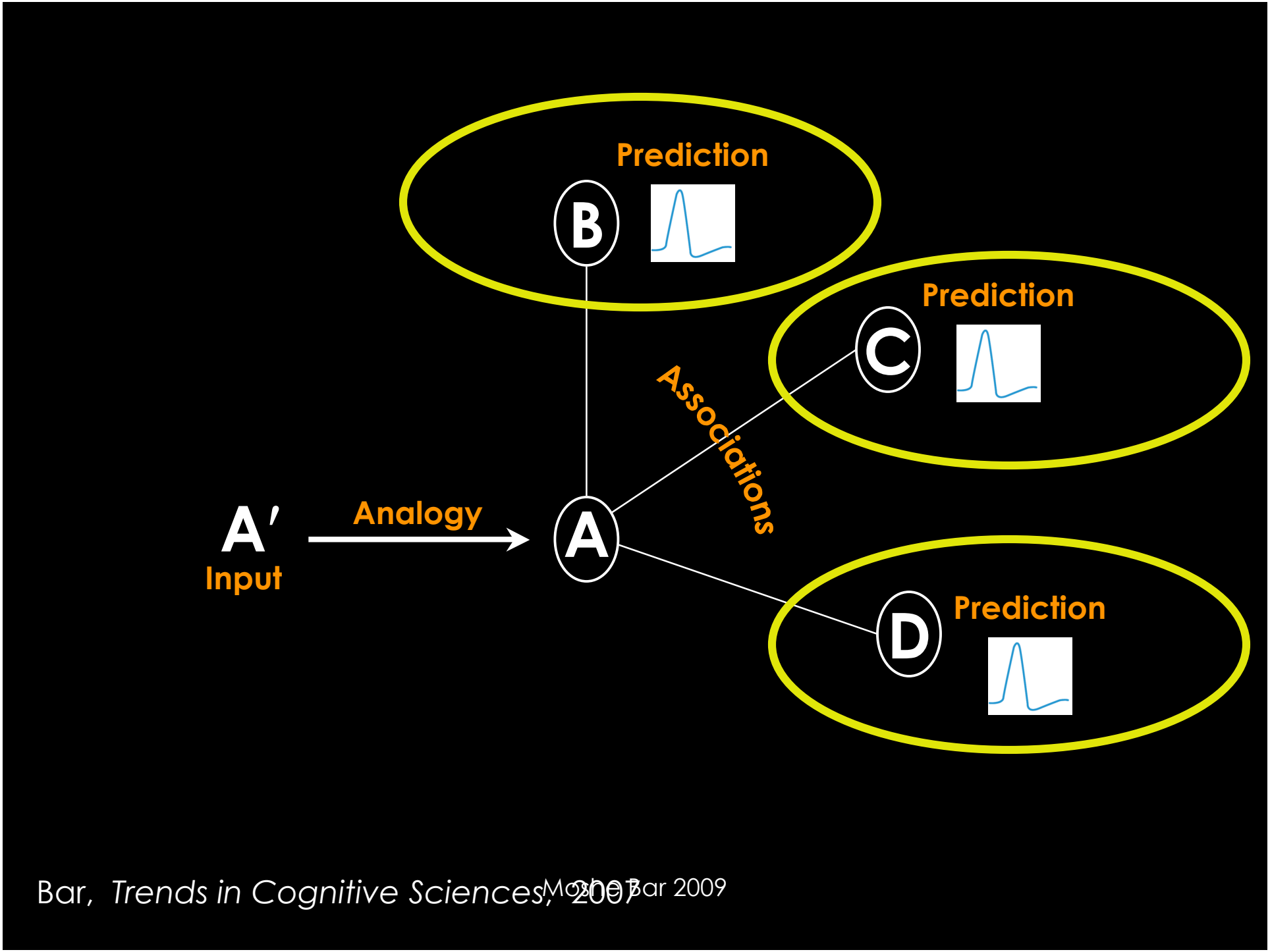
MRI constrained MEG



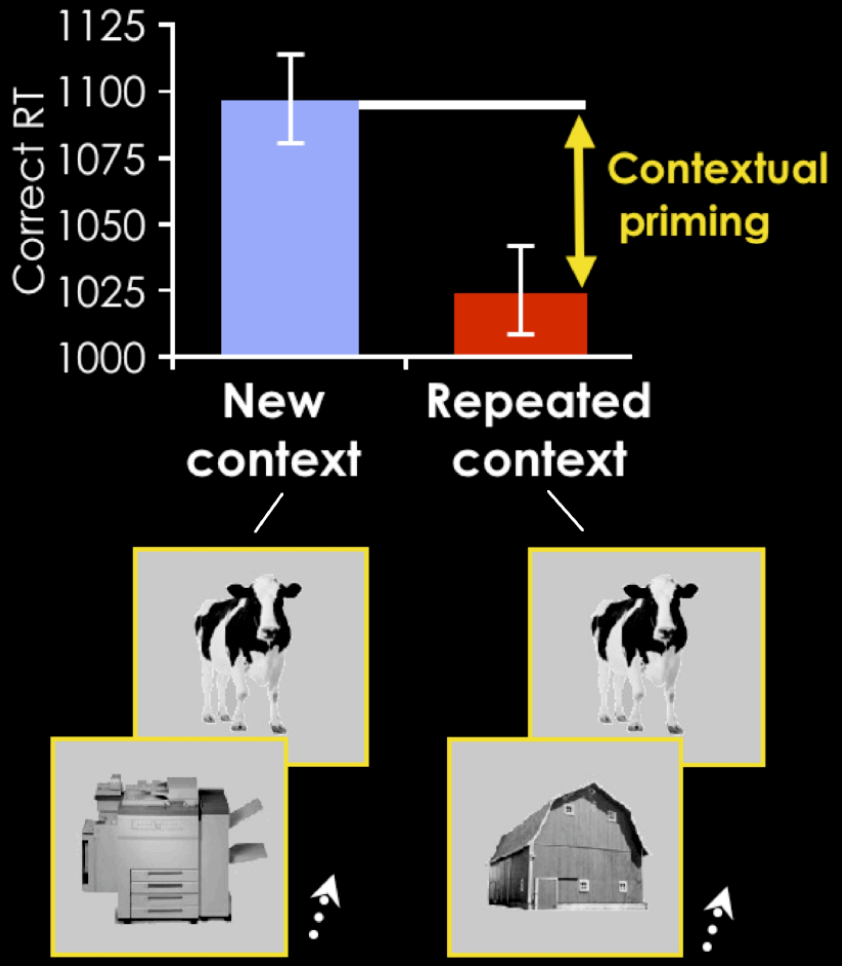
Strong Context vs. Weak Context

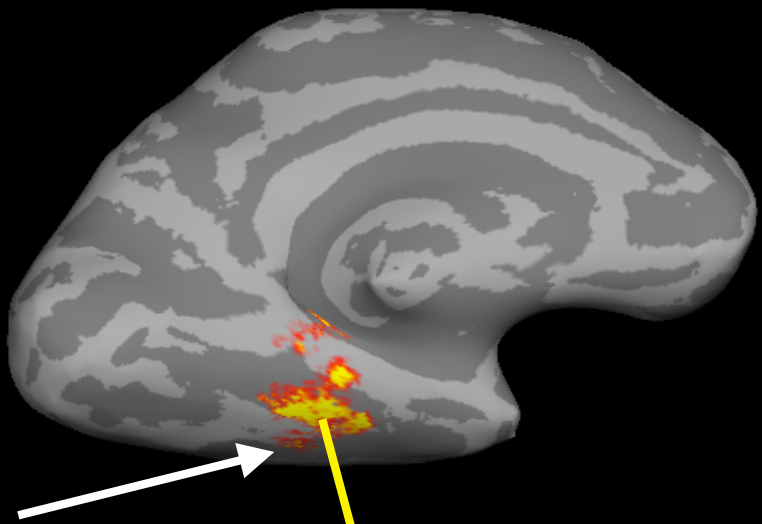


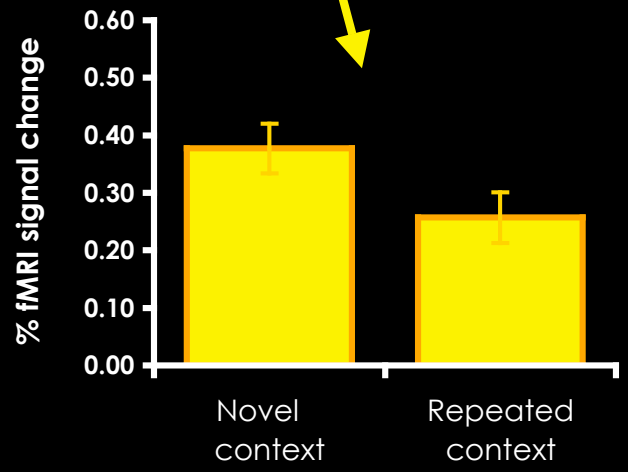


Bar, *Trends in Cognitive Sciences*, 2007

Contextual facilitation of object recognition.







Moshe Bar 2007

Can a  prime a  ?



Input

Cursory analysis



"Initial Guesses"
(Possible Objects)









Priming across contexts?

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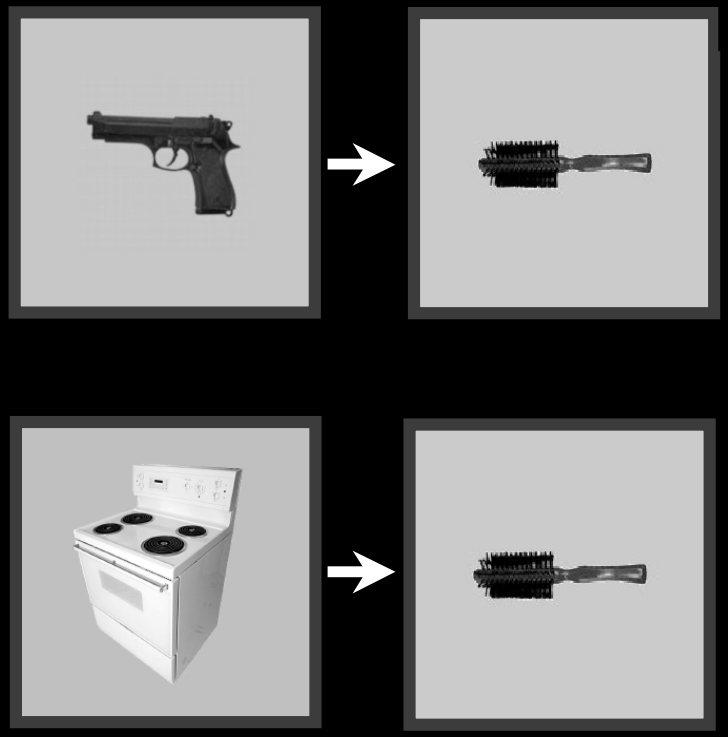
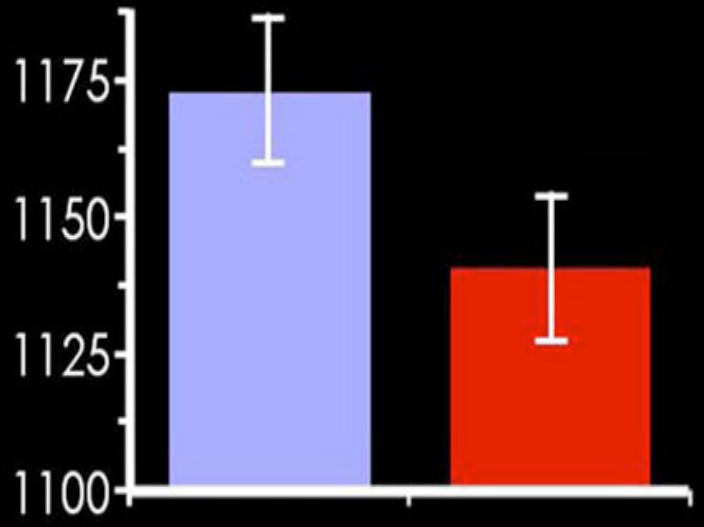
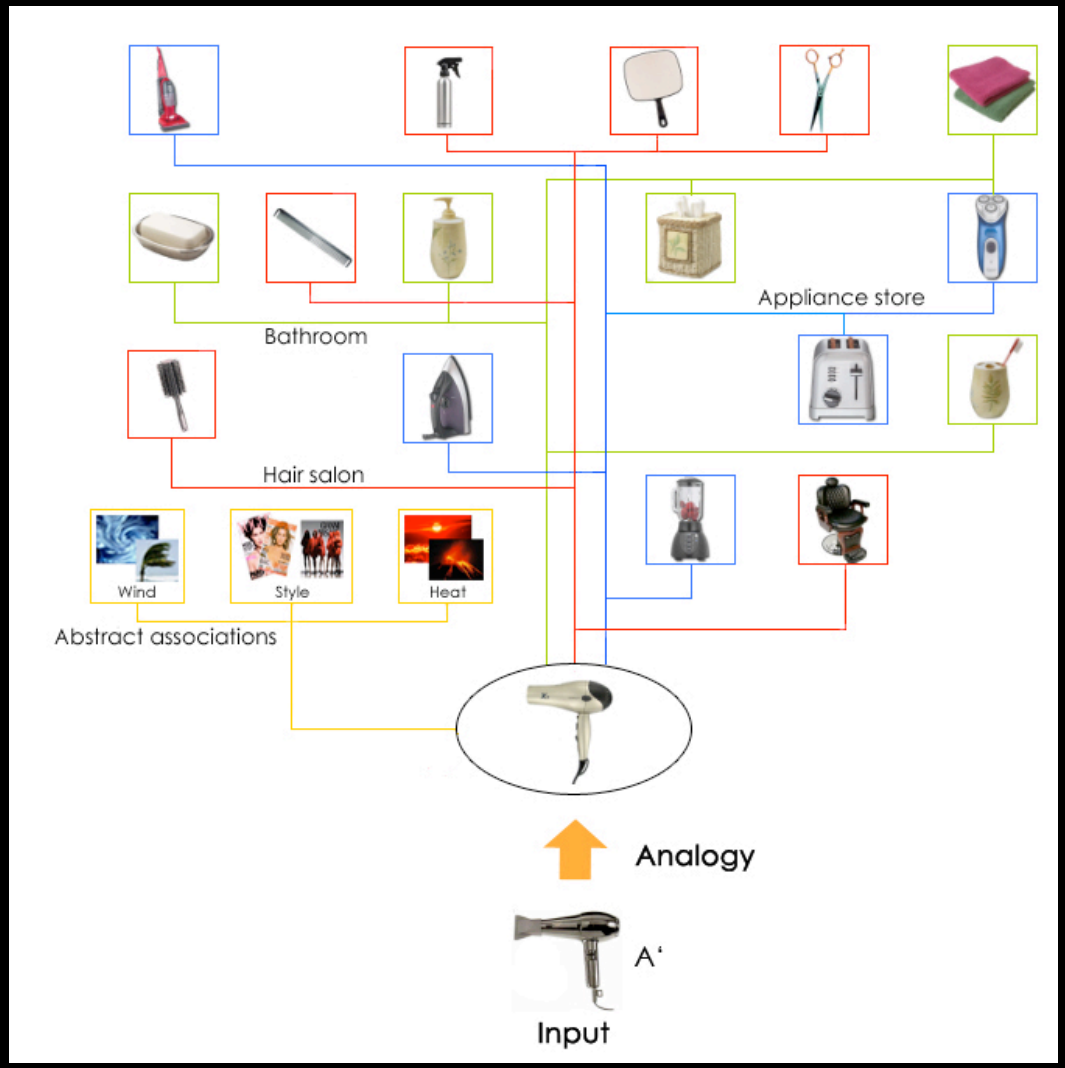
"Initial guess" contextual priming





Language (CAPT: captain-captive; BANK: money-river).
Only for short (125ms) exposures;
longer exposures (1500ms) resulted in negative priming.



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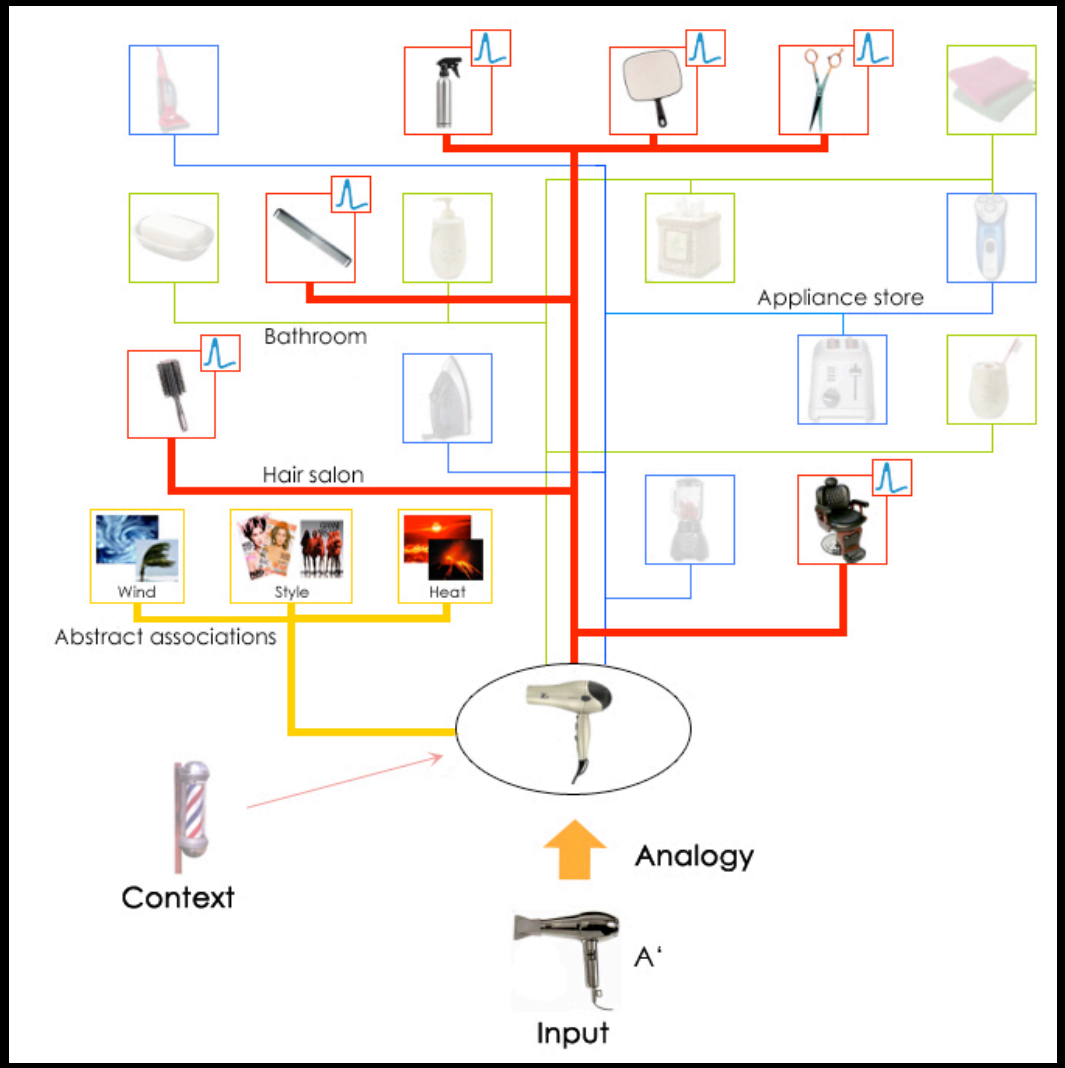


The co-activation of associated representations, combined with informed inhibition, provides focused predictions

Moshe Bar 2009

Associations as the building blocks of predictions

If generating predictions is a continuous, proactive, "default" operation of the brain,

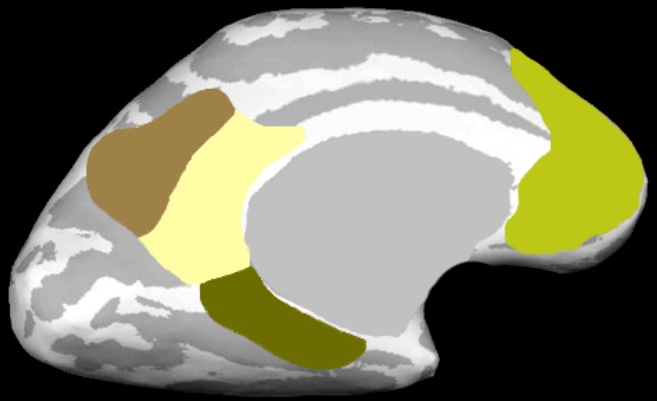
and it relies on associative activation,

then one needs to show that associative activation is a continuous, "default" process in human thought.

Default network

Precuneus

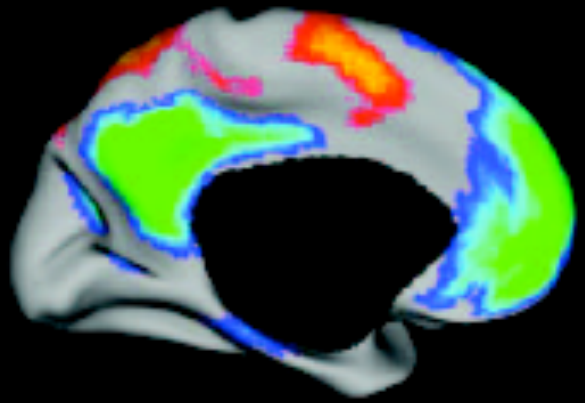
RSC/PCC

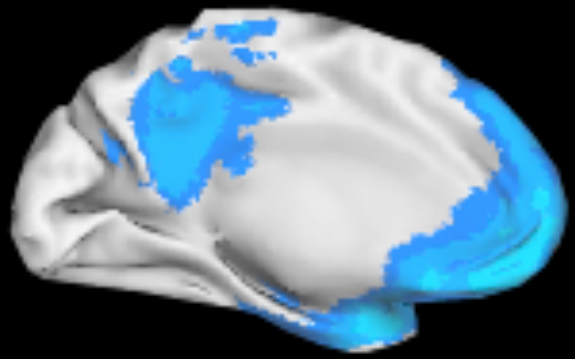


PHC/MTL

mPFC

"Rest" > Task





Fox et al., 2005 Moshe Bar 2009 Buckner et al., 2005

Default network

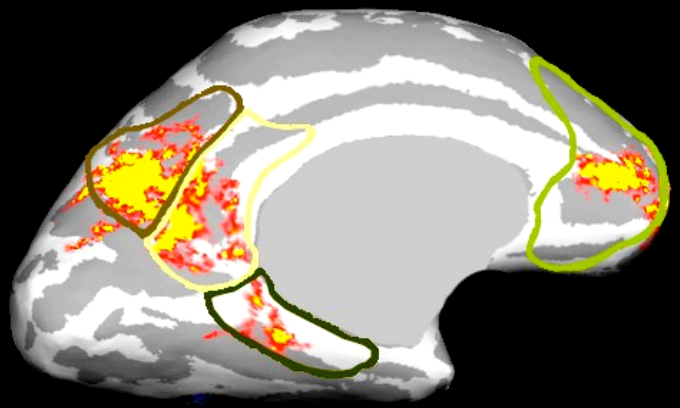
Precuneus

RSC/PCC



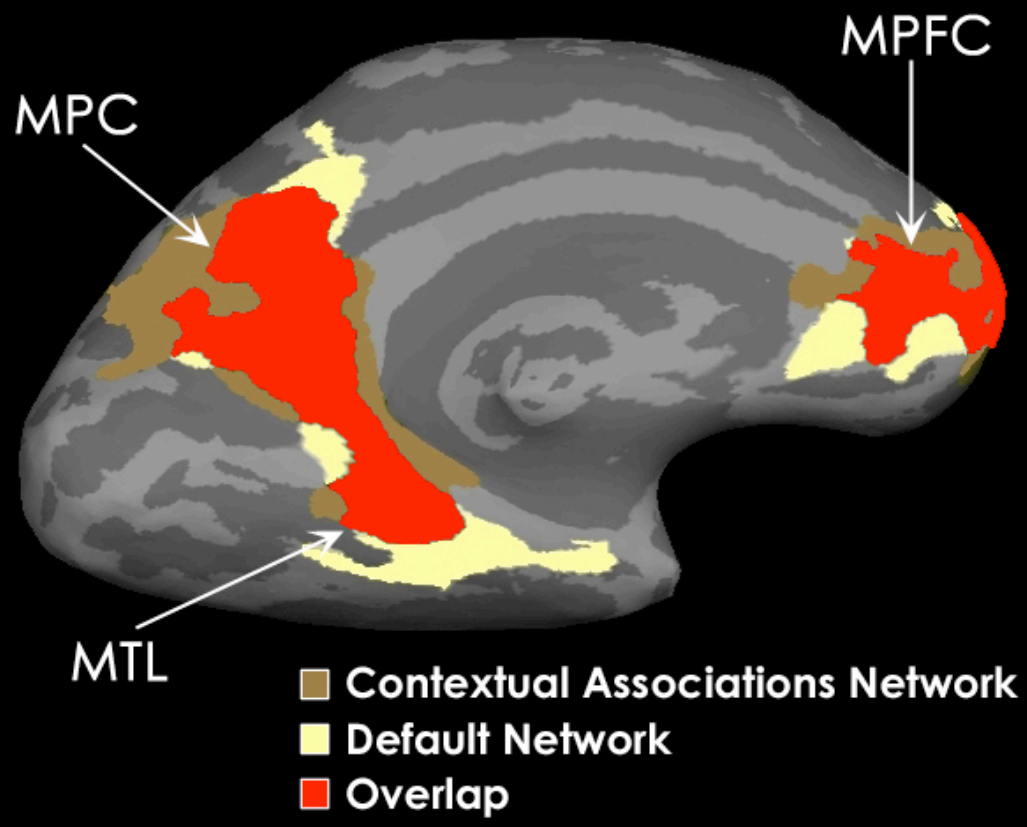
PHC/MTL

mPFC



Contextual associations

context-default overlap



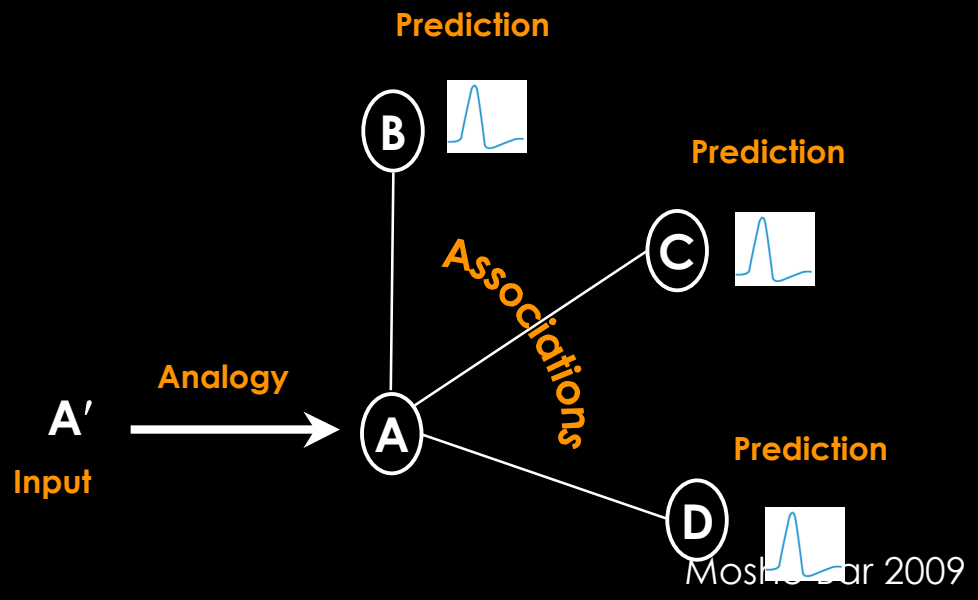
Bar et al., Hippocampus, 2007

Associative processing is an integral process of default activity in the proactive brain

Moshe Bar 2009

Predictions are triggered by analogies

Analogy is typically seen as a sophisticated cognitive tool used in types of problem-solving and reasoning.



What is this **like**?





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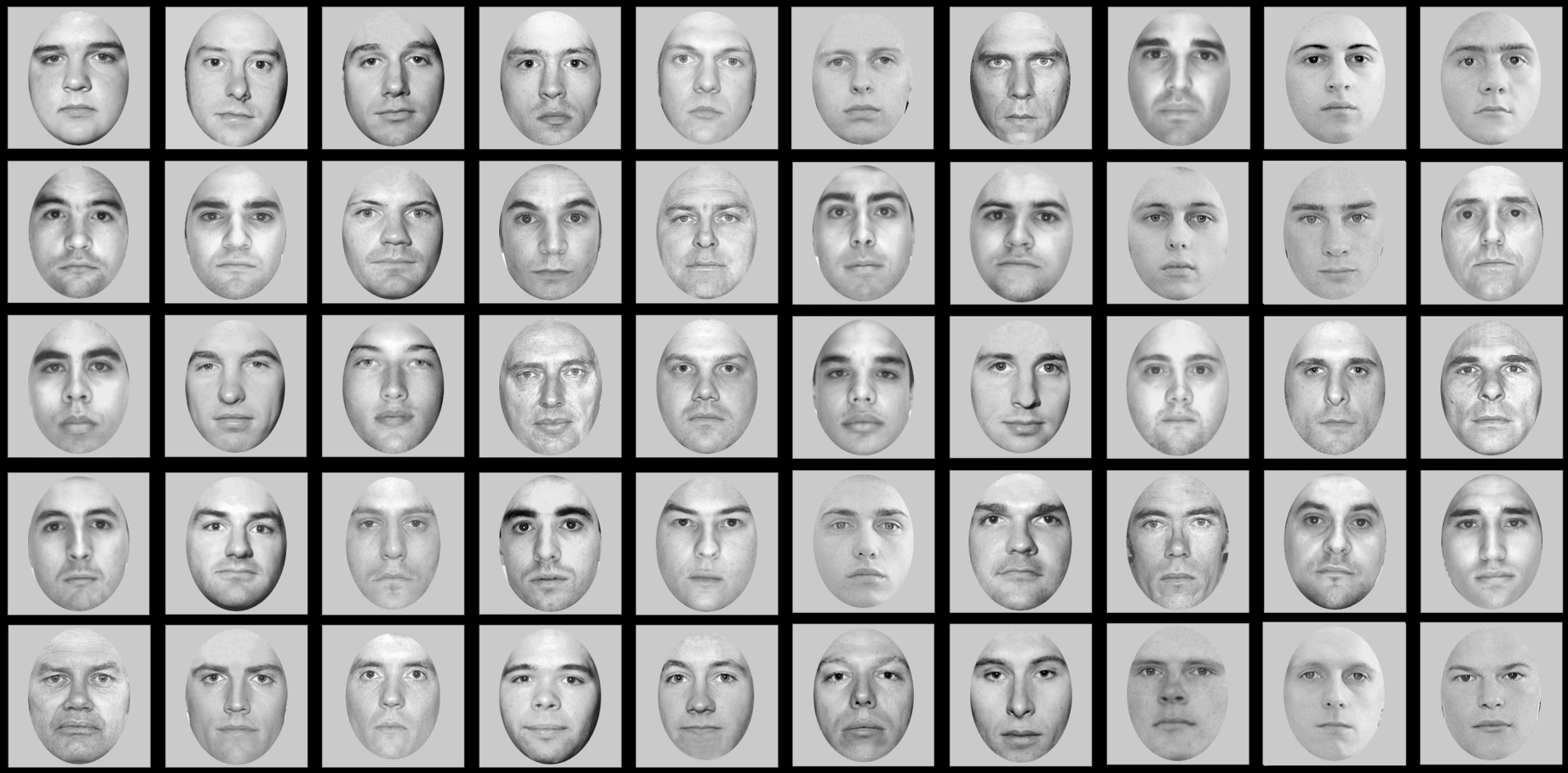
Visual features that drive first impressions



Bar, Neta and Linz, *Emotion*, 2006

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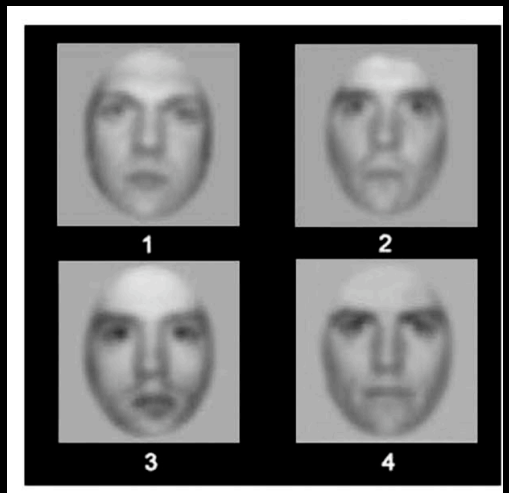
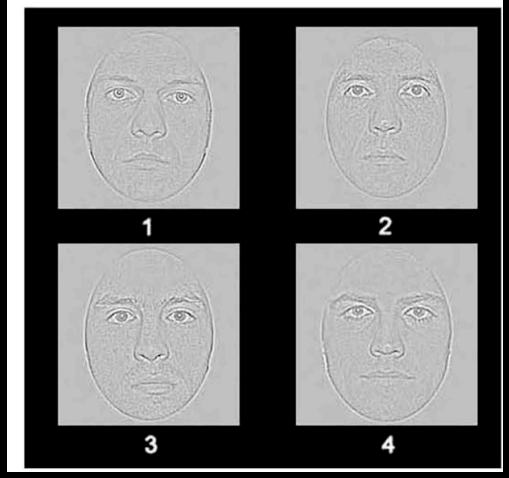
Rapid first impressions

Faces that were judged as most threatening in 39 ms and 1700 ms









Maital Neta

Bar, Neta and Linz, *Emotion*, 2006

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First impressions as a platform for predictions



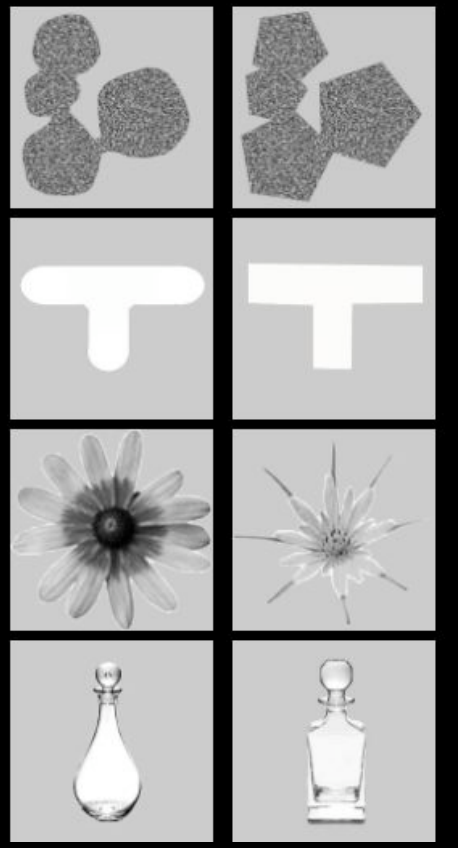
Analogies can be based on similarity in various levels: perceptual, conceptual, semantic, functional.



The visual features that mediate preference formation

Do people like sharp-angled objects less than objects with curved contours?





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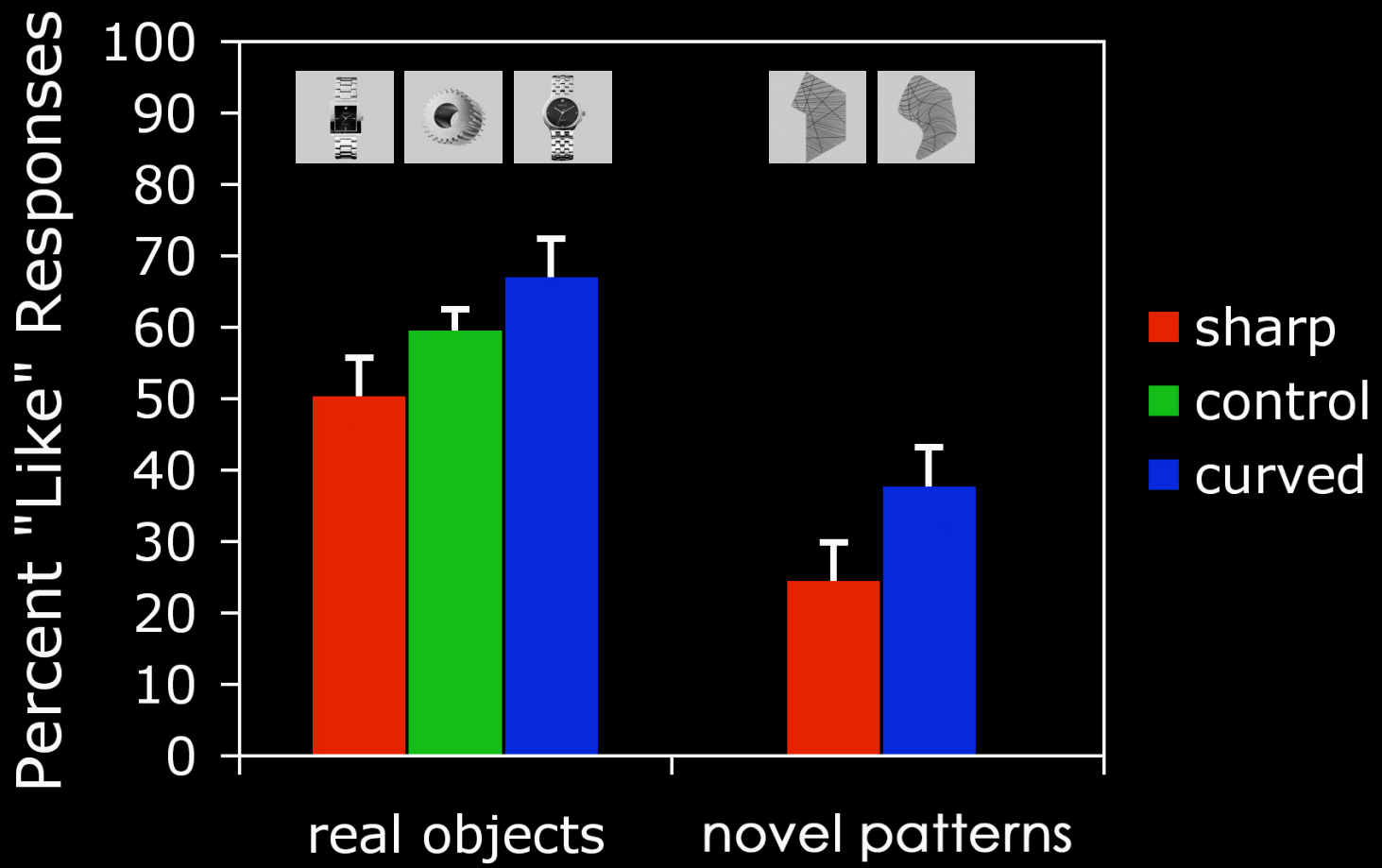
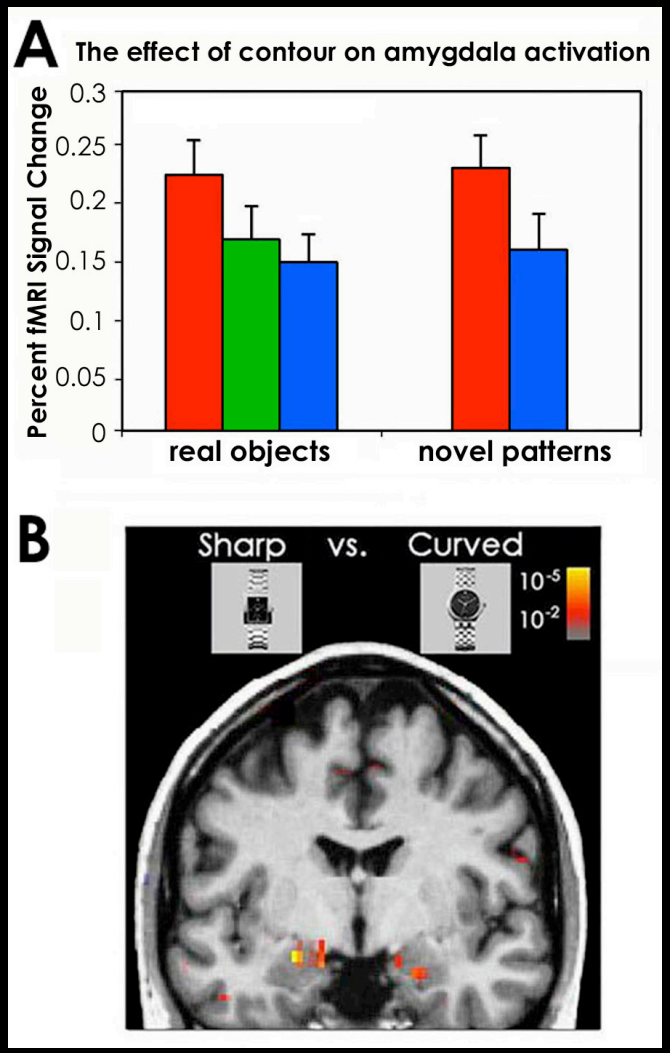


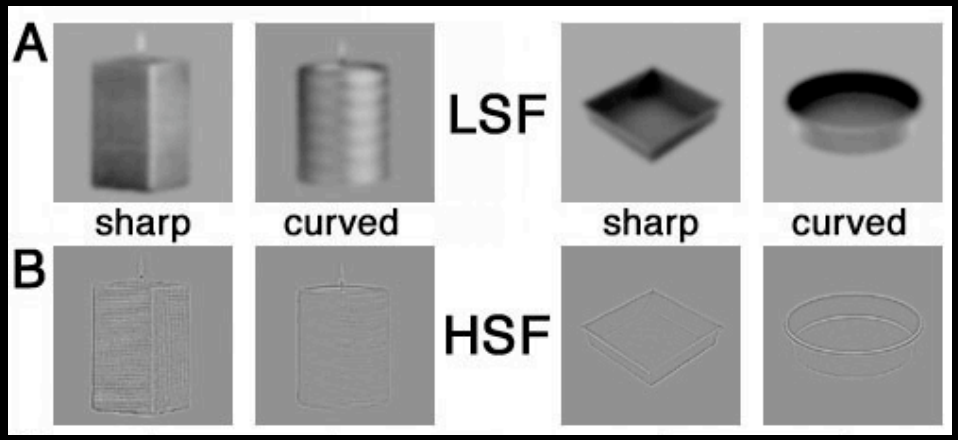
Bar and Neta, 2006

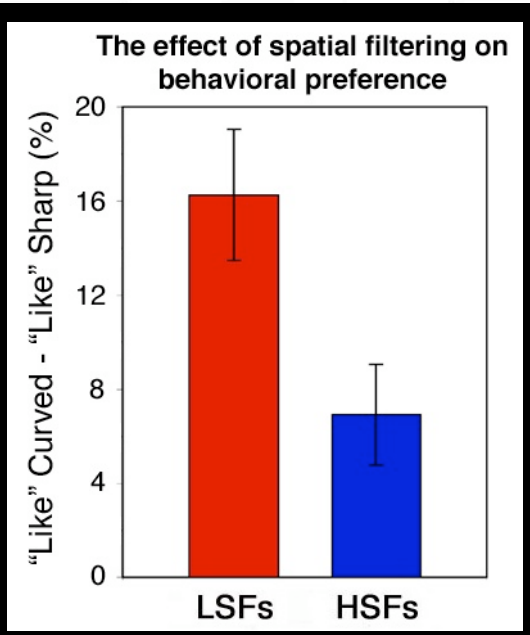
This difference in preference stems from a sense of threat conveyed by the sharp transitions in contour.

Moshe Bar 2009

Vision-based preference formation







Bar and Neta, *Neuropsychologia*, 2007

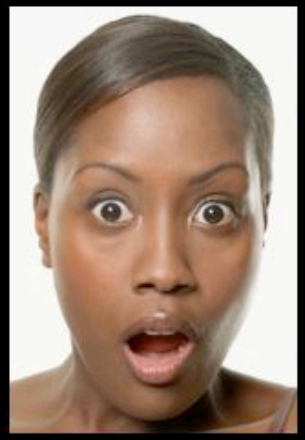
Moshe Bar 2008

Based on LSF information

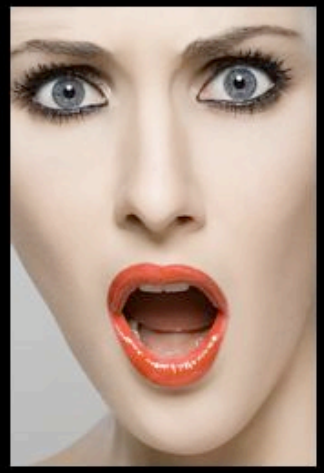
Applied predictions

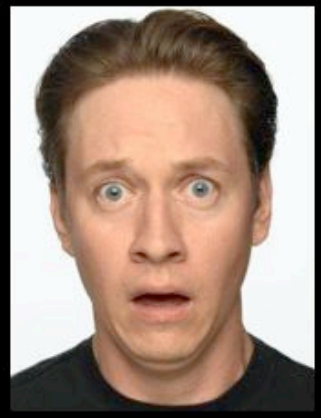
- Span a wide spectrum of complexity and function (Hebb to simulations)
- Perception, language, interactions
- "Chance favors the prepared mind"
- Clinical implications: Depression, PTSD, pain
- Filling-in also helps memory reconstruction
- Future memory and "memory"
- Help perceiving a stable environment











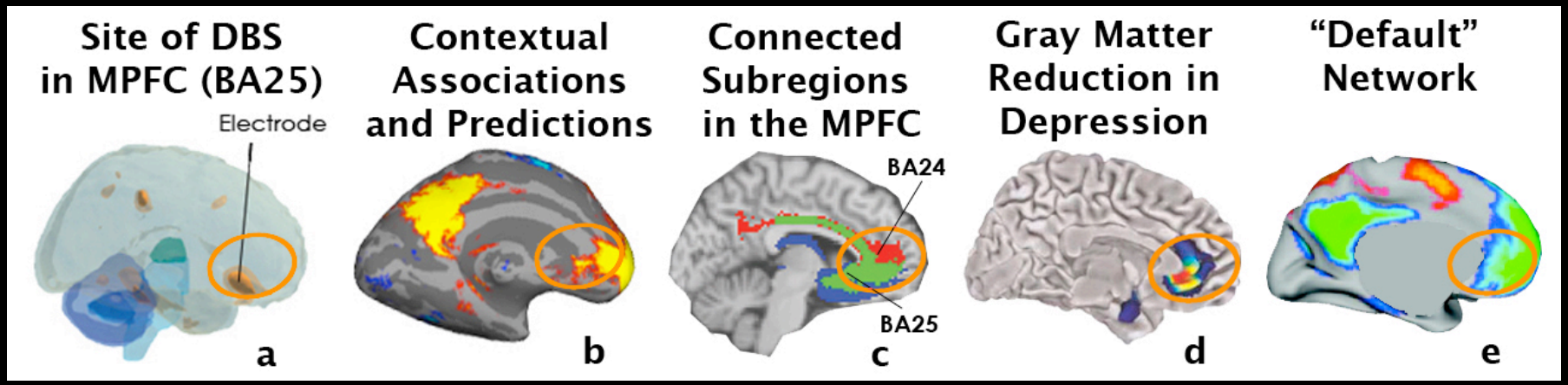
Moshe Bar 2009

What happens to people who have consistent problems in generating predictions?

Clinical implications in mood disorders:
Anxiety, Depression, PTSD, pain, placebo.

Associative predictions and depression

Context, rumination, uncertainty, hippocampal neurogenesis, PFC-MTL interactions, inhibition.



Dr. Cibu Thomas Kathrine Shepherd



Conclusions

- Perception relies on exiting knowledge as much as it does on incoming information. (lessons to artificial systems)
- A rapid "first pass" (e.g. LSF), via analogies, answers "what is this like?" (lessons to artificial systems)
- By answering this question, our proactive brain generates predictions that facilitate perception, cognition and action. Moshe Bar 2009

past



present





future

http://barlab.mgh.harvard.edu

Moshe Bar 2009