Visual Context

Dan O'Shea
Prof. Fei Fei Li, COS 598B

Cortical Analysis of Visual Context

Moshe Bar, Elissa Aminoff. 2003. *Neuron*, Volume 38, Issue 2, Pages 347-358.

Visual objects in context

Moshe Bar. 2004. *Nature Reviews Neuroscience*. 5: 617-629. 2004.

Visual Context

- Context serves as “glue” which ties together a visual scene
- Knowledge of context or scene identity improves *a priori* object identity distributions
- Certain scenes routinely feature particular objects at specific relative scales, orientations

Context Representations

- **Context-frame:**
  - Representation of context which integrates over expectations about which objects are most likely to appear
  - Occipital visual cortex: physical appearance
  - Anterior temporal cortex: basic level categories
  - Prefrontal cortex: semantic relations
  - Parahippocampal cortex (PHC): contextual relations

- **Biederman (1982):**
  - Perhaps defined along dimensions where violations degrade accuracy and reaction time
  - Support, interposition, probability, position, and size

Activation of Context Frames

- Activation of a context frame presumably sensitizes certain object representations
- Biasing of recognition may explain several behavioral phenomena:
  - **False memory:** reports of seeing object that was never there
  - **Boundary extension:** extrapolation beyond scene boundaries
  - **Change blindness:** inability to detect significant changes in a visual scene

Abstraction in Context Frames

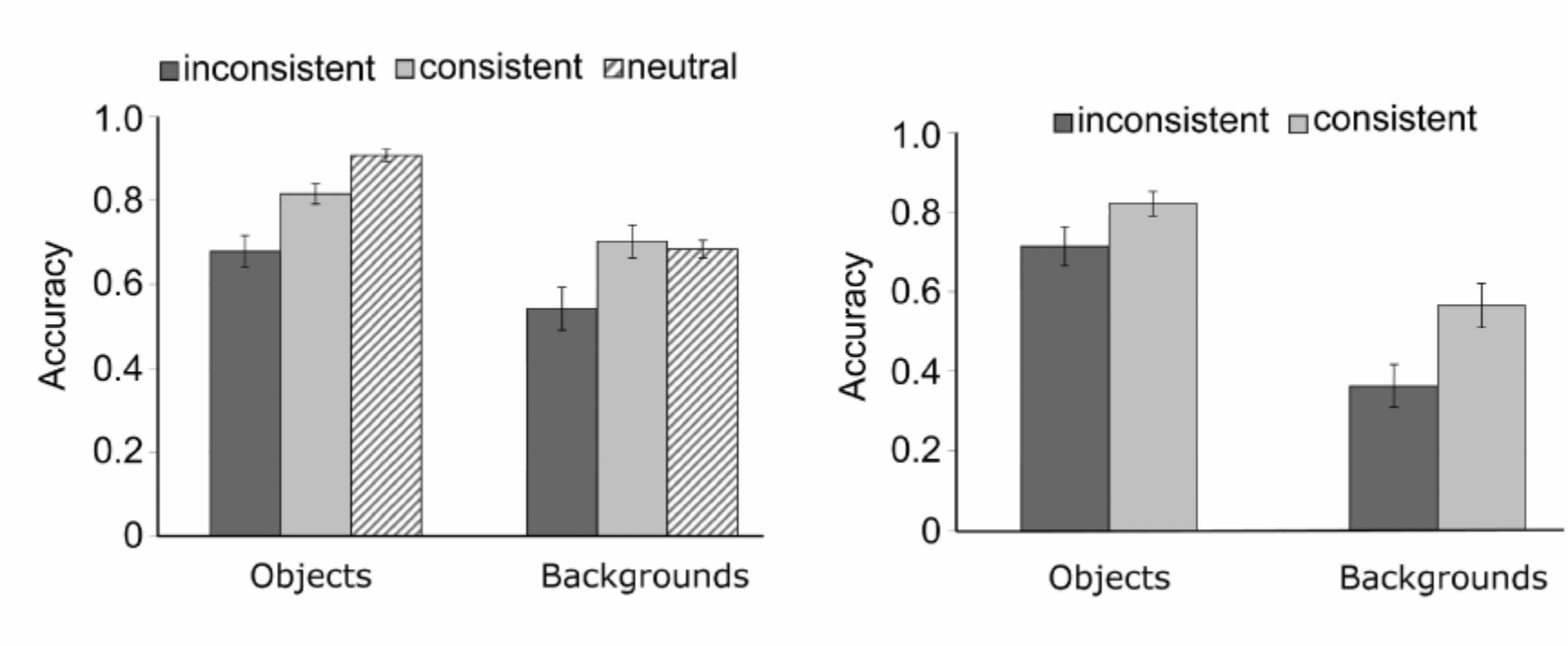
- Prototypical representation of unique contexts, guide formation of specific instantiations as episodic scenes
- **Basic-level concept:** level of abstraction which carries maximal information, at which objects are named most readily
- Derived from exposure to real world scenes

Context Facilitates Recognition

- Activation of a “context frame” facilitates object recognition for context exemplars
- Time of Recognition:
  - Object in context-coherent scene < object in meaningless background
  - Object in isolation < context coherent scene
  - Background segregation, attentional distractions, explained later

Bidirectional Facilitation

Conversely, recognition facilitates scene background understanding → processes interact



Source: Jodi L. Davenport, Mary C. Potter (2004). Scene Consistency in Object and Background Perception. *Psychological Science*. 15 (8), 559–564.

Difficulty of Interpretation

- Object recognition very efficient: 150 ms
- Benefit from many auxiliary processes:
  - Context identification
  - Familiarity
  - Non-contextual expectations
  - Top-down facilitation
  - Movement
- Manipulations of task difficulty may affect recruitment of these processes

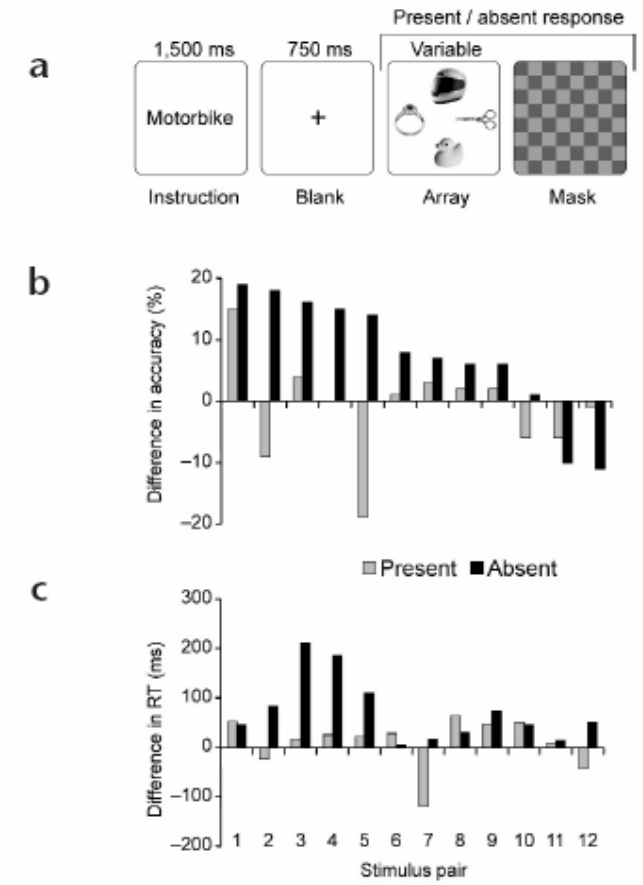
Recognition Facilitation Mechanism?

What role does context play?

- Context extracted rapidly, facilitates perceptual analysis of individual objects
- Context frame activated and sensitizes representation of all associated objects
- Object recognition and context analysis interact at late, semantic stage

Non-fixated Associated Objects

- Context facilitates identification of associated, non-fixated objects in scene
- Helps the direct attention and saccades towards associated objects



Source: Elisabeth Moores, Liana Laiti, Leonardo Chelazzi. Associative knowledge controls deployment of visual selective attention. Nature Neuroscience 6, 182 - 189 (2003).

.

Speed of Extraction

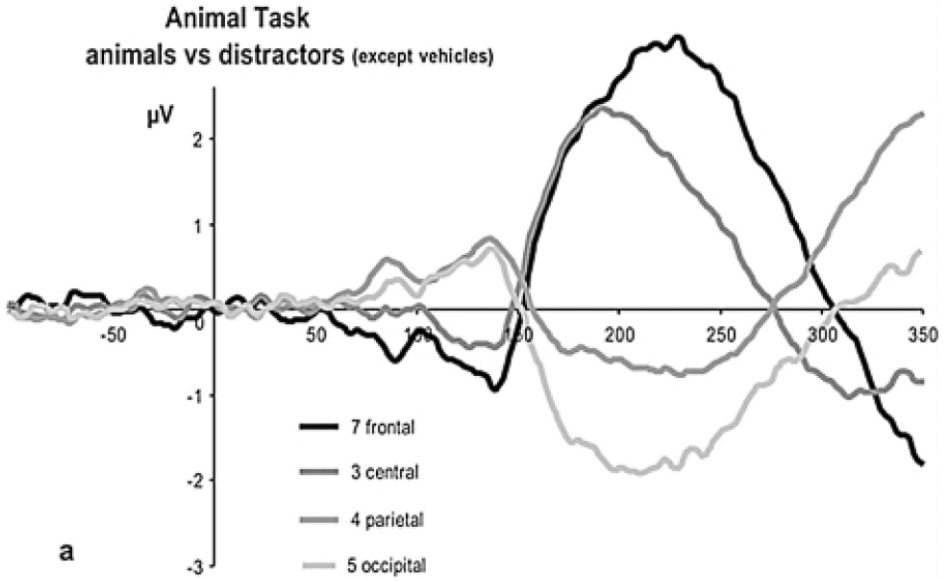
- Context must be extracted rapidly to aid recognition process
- Semantic information extracted by 80 ms
- Before perceptual processing is completed (priming effects seen before primes identified)
- Before saccades to most informative regions may be made
- Before individual object identification

Neural Signature of Context Extraction

ERP: visual category discrimination by 75-80 ms

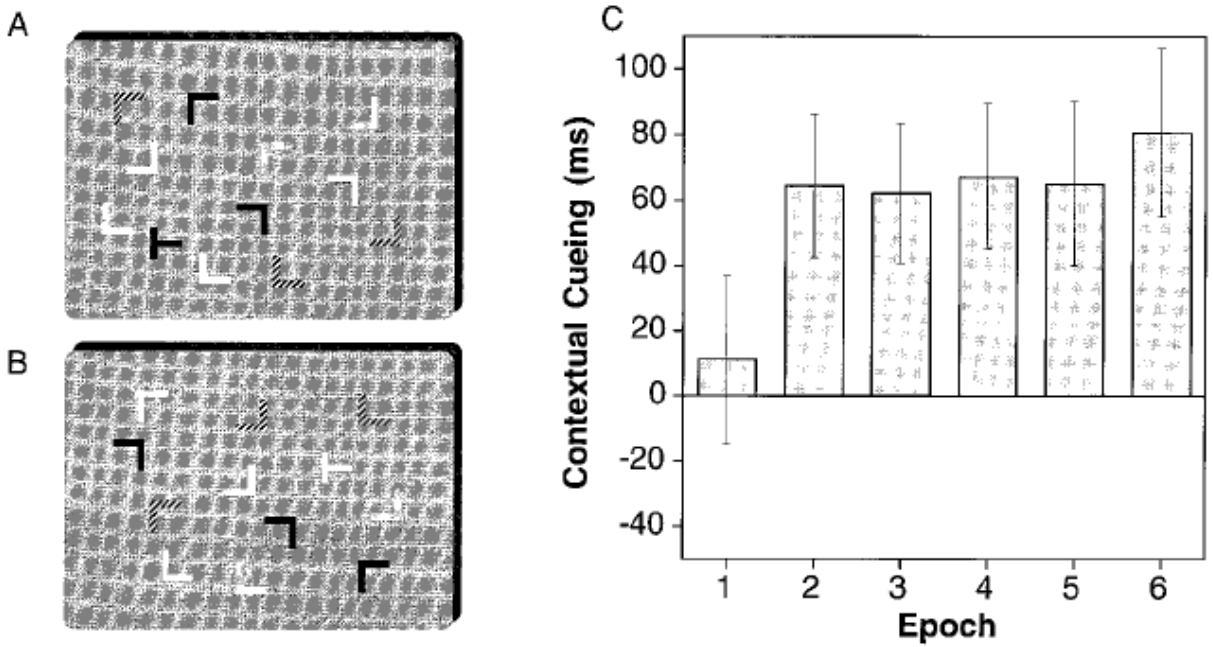
fMRI and MEG: PHC and fusiform gyrus: waves at 130, 230 ms

- Initially coarse, then richer representation?



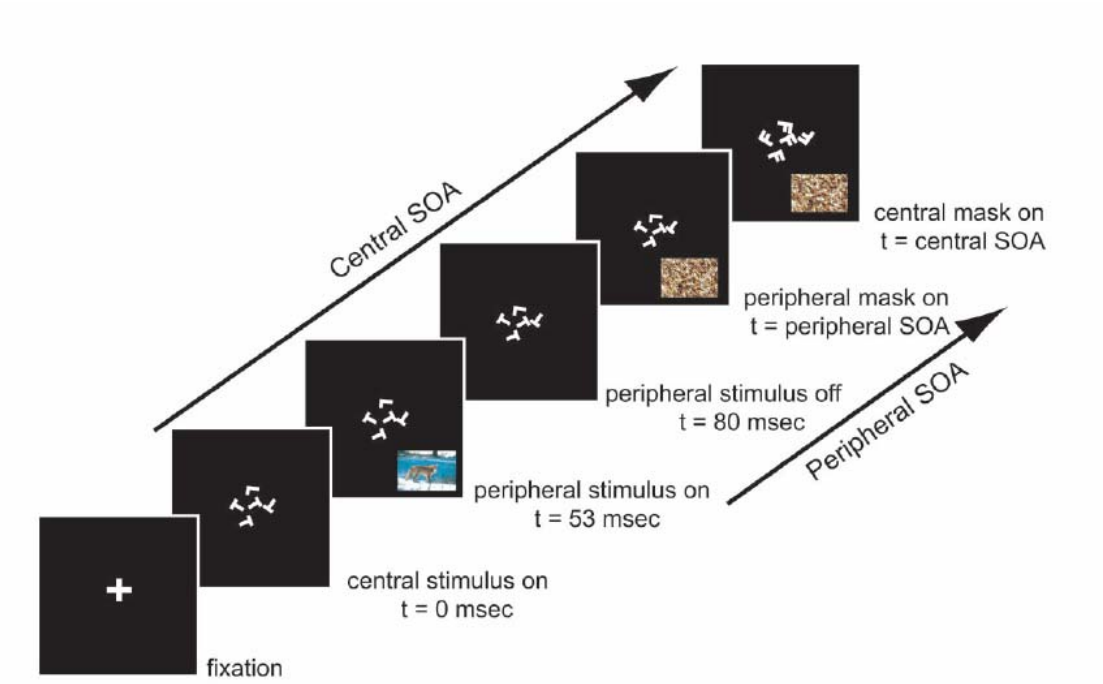
Source: VanRullen, R. & Thorpe, S. J. The time course of visual processing: from early perception to decision-making. *J. Cogn. Neurosci.* 13, 454-461 (2001).

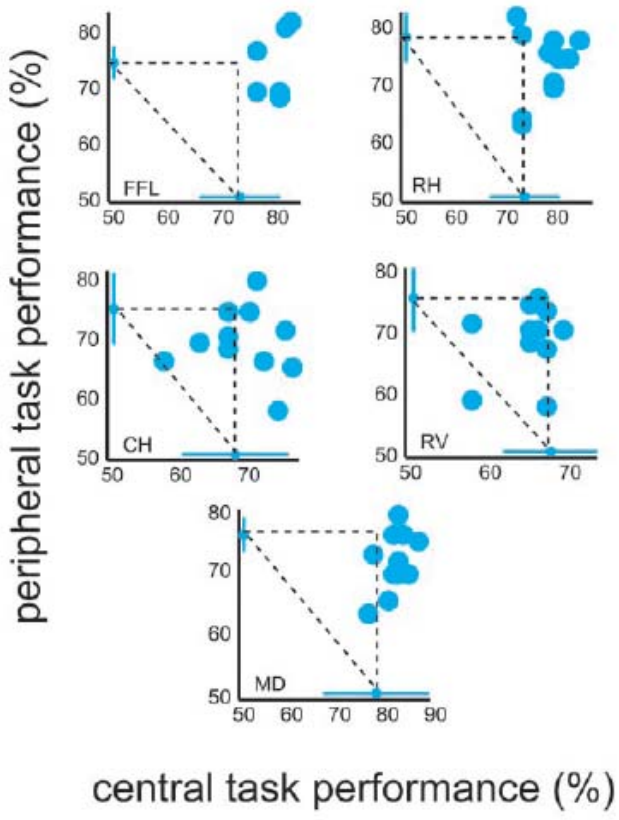
Context Learning without Awareness



Source: Chun, M. M. & Jiang, Y. Contextual cueing: implicit learning and memory of visual context guides spatial attention. *Cogn. Psychol.* **36**, 28–71 (1998).

Categorization Without Attention





Source: Li FF, VanRullen R, Koch C, Perona P. Rapid natural scene categorization in the near absence of attention. *Proc Natl Acad Sci U S A*. 2002 Jul 9;99(14):9596-601. Epub 2002 Jun 20.

Neural Mechanisms

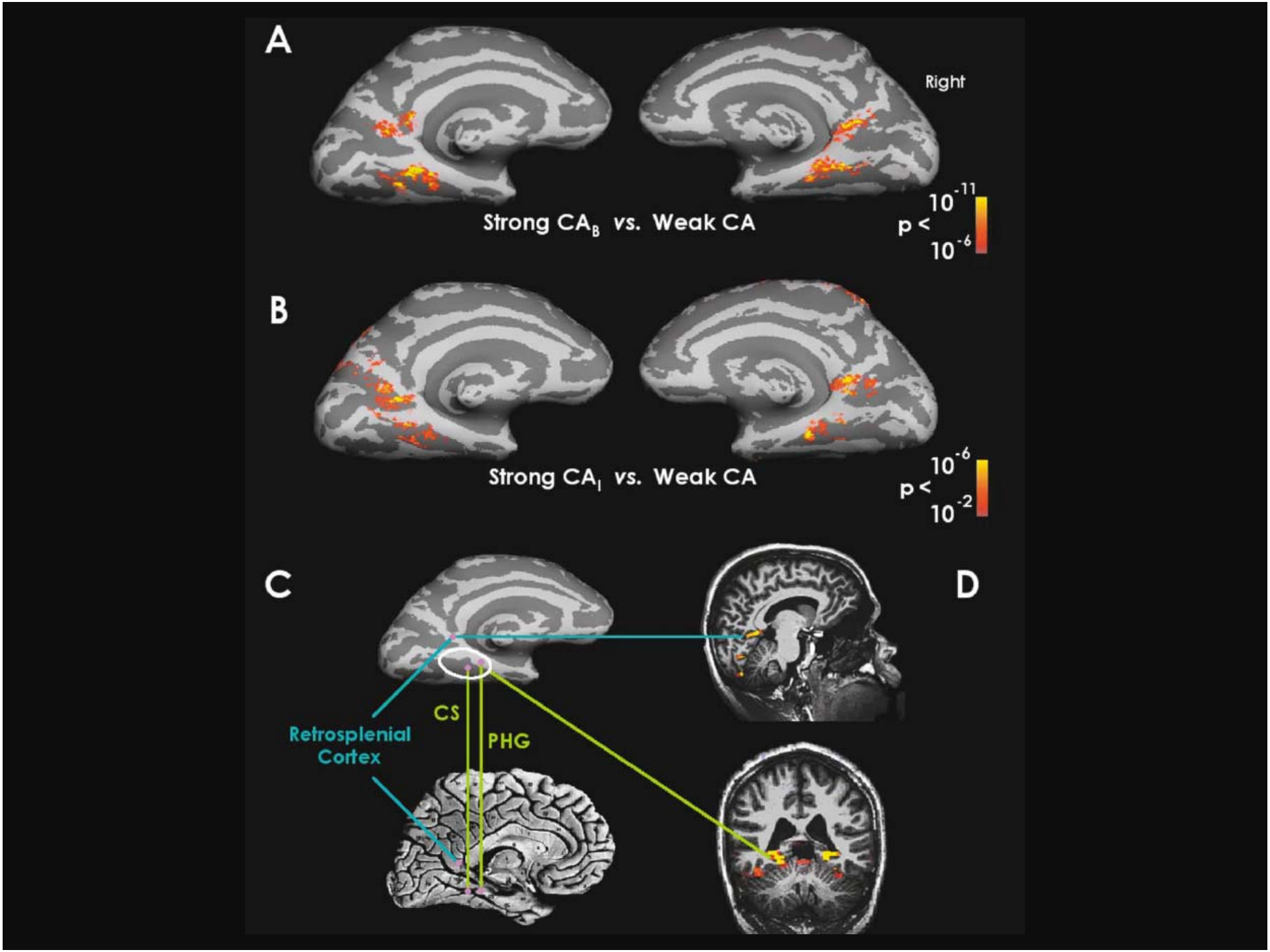
- Can we identify the locus of context frames?
- Use fMRI to identify regions that are activated by objects strongly associated with a certain context

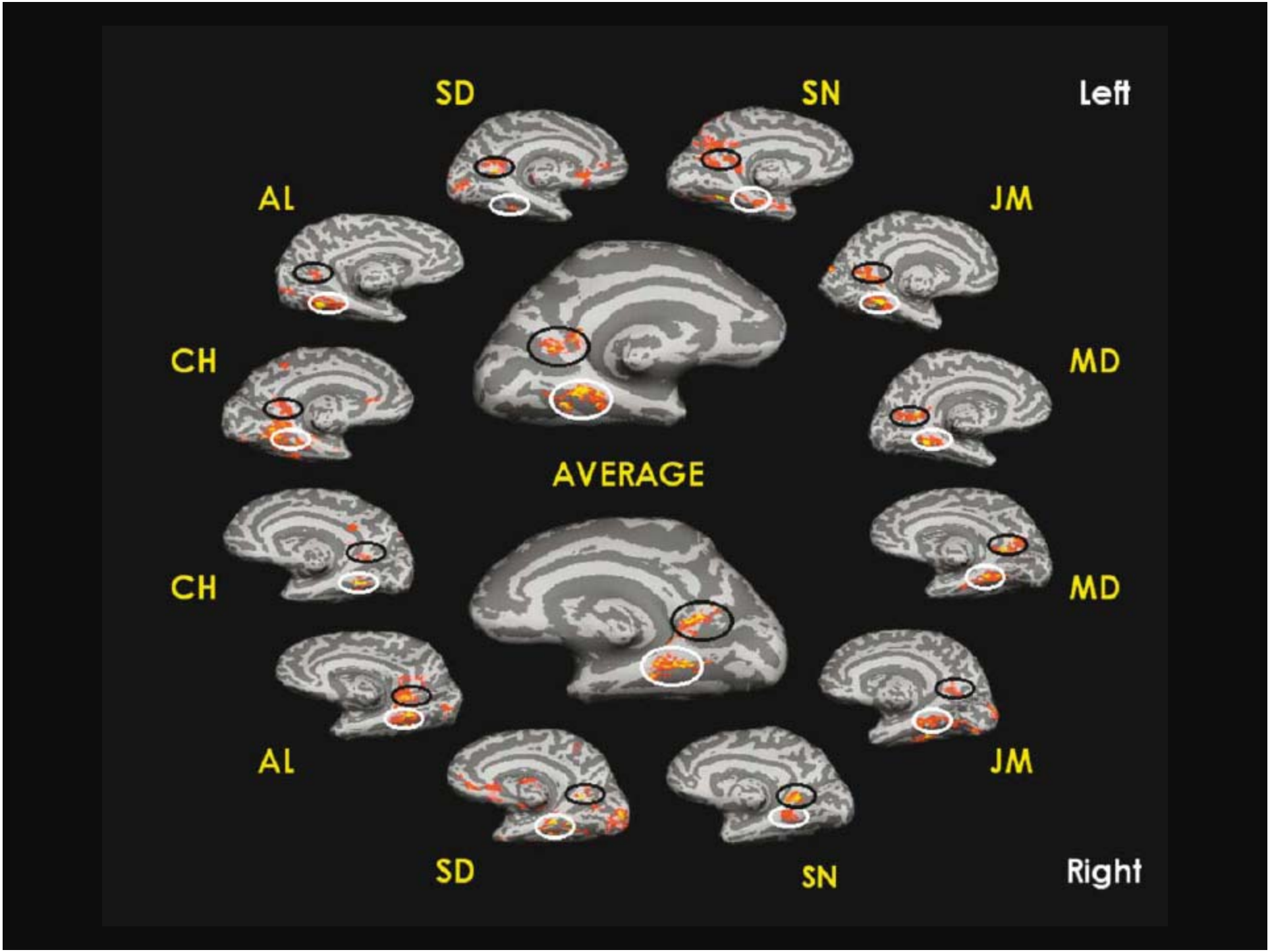
Visual Stimuli Types

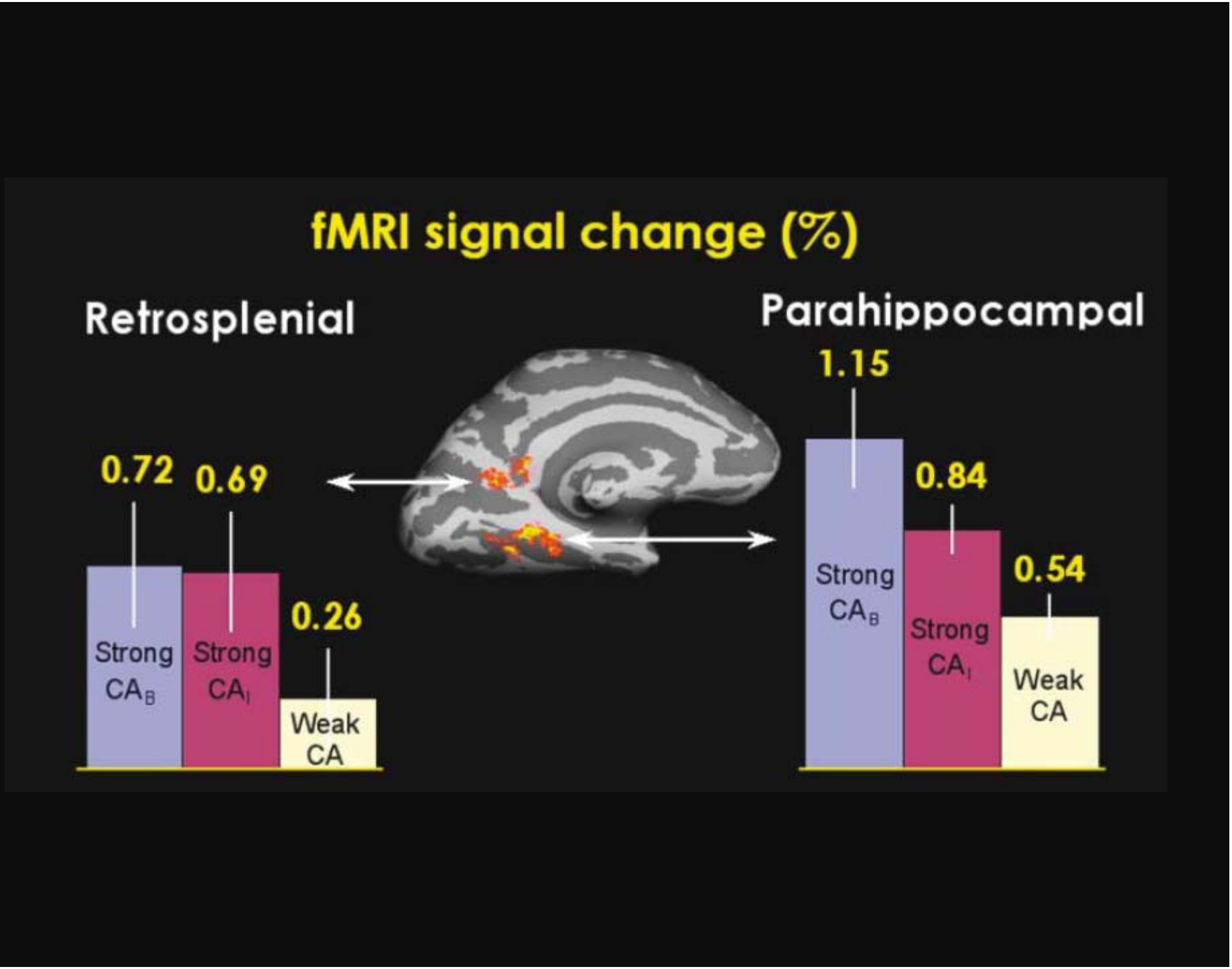
- Weak CA: objects with no strong association with any specific context, in isolation
- Strong CA_I: objects with a strong association with a particular context, in isolation
- Strong CA_B: objects with a strong association with a particular context, in that context

Exp 1: Strong $CA_{B,I}$ vs Weak CA

- **Task:** Press response key upon recognizing presented objects
- **Compare:**
  - Strong CA_B vs. Weak CA
  - Strong CA_I vs. Weak CA
- **Results:** Bilateral activation of:
  - Posterior part of parahippocampal cortex (PHC)
    - Less pronounced for CA_I, sensitive to visual apperance?
  - Retrosplenial cortex (RSC)


A
Right
Strong CA_B vs. Weak CA
$p < 10^{-11}$
10^{-6}
B
Strong CA_I vs. Weak CA
$p < 10^{-6}$
10^{-2}
C
D
CS
PHG
Retrosplenial Cortex


SD
SN
Left
AL
JM
CH
MD
AVERAGE
CH
MD
AL
JM
SD
SN
Right

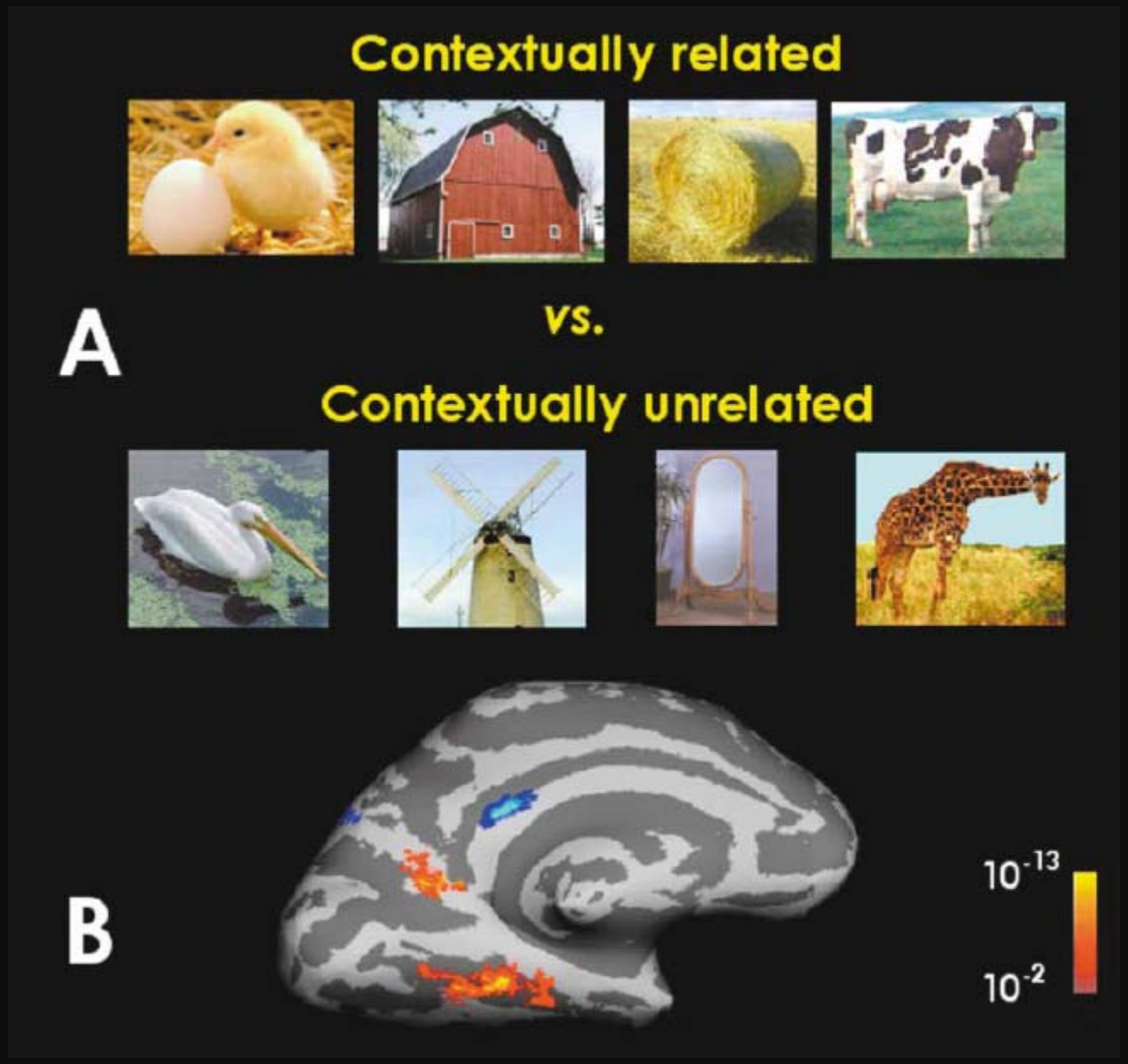

fMRI signal change (%)
Retrosplenial
0.72
0.69
0.26
Strong CA$_B$
Strong CA$_I$
Weak CA
Parahippocampal
1.15
0.84
0.54
Strong CA$_B$
Strong CA$_I$
Weak CA

Implicated Areas

- **PHC:** Previously termed parahippocampal place area (PPA) because it responds to houses and environmental landmarks
  - Consists of parahippocampal gyrus (PHG) and collateral sulcus (CS)
- **RSC:** implicated in aspects of memory and spatial information, occasionally in PPA studies

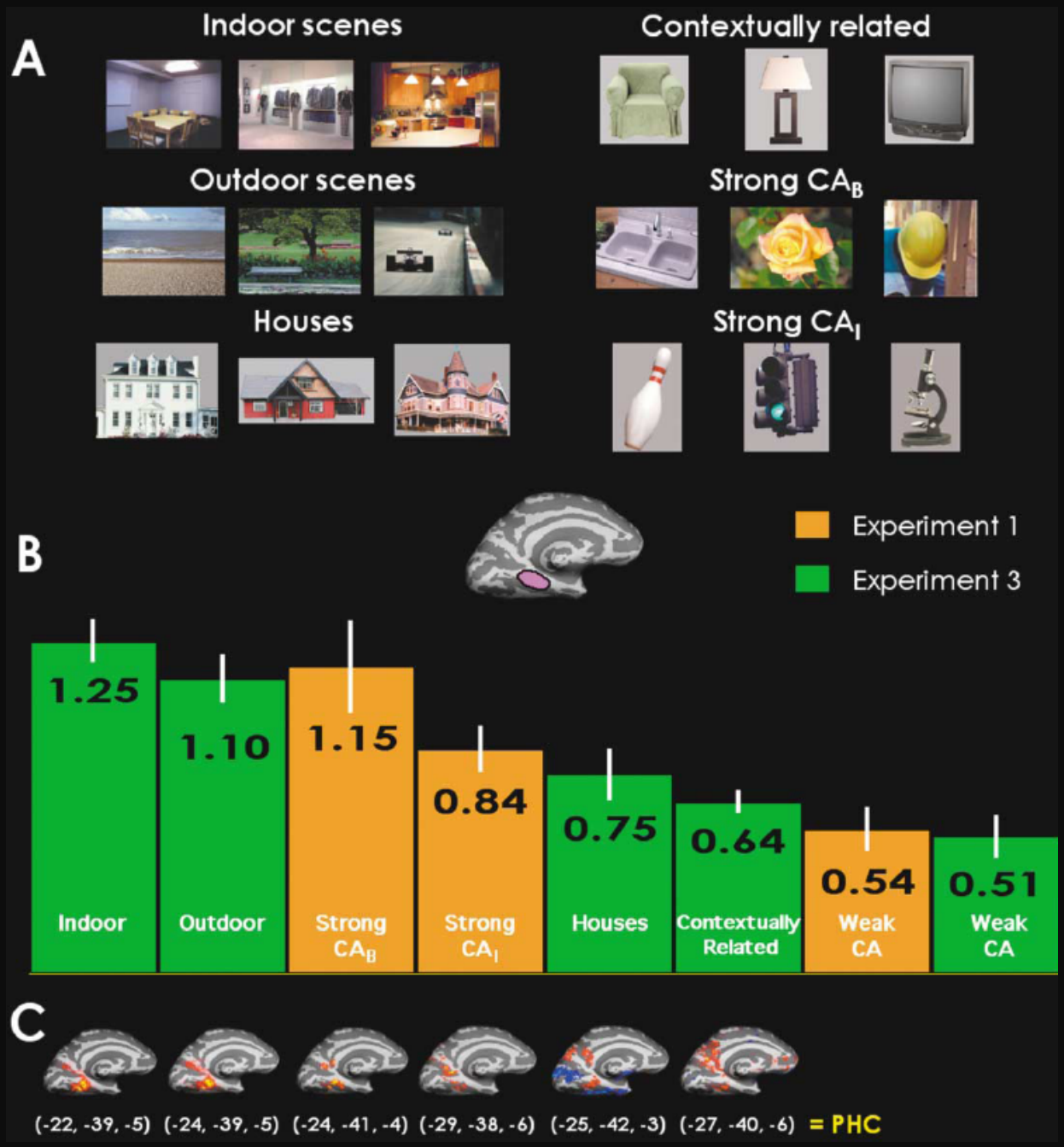
Exp 2: Contextually Related Objects

- **Task:** Observe blocks of object images
- **Compare:**
  - Blocks of contextually related vs. unrelated images
- **Results:**
  - Increased activation at same loci (PHC and RSC) as Experiment 1


Contextually related
A
vs.
Contextually unrelated
B
10^{-13}
10^{-2}

Exp. 3: Relative Activation

- **Task:** press button indicating recognition
- **Five Conditions:**
  - Weak CA
  - Contextually related objects in isolation
  - Houses
  - Indoor Scenes
  - Outdoor Scenes
- **Results:**
  - Activation due to contextual objects in isolation equivalent to pictures of individual houses


A
Indoor scenes
Contextually related
Outdoor scenes
Strong CA_B
Houses
Strong CA_I
B
Experiment 1
Experiment 3
1.25
1.10
1.15
0.84
0.75
0.64
0.54
0.51
Indoor
Outdoor
Strong CA_B
Strong CA_I
Houses
Contextually Related
Weak CA
Weak CA
C
(-22, -39, -5)
(-24, -39, -5)
(-24, -41, -4)
(-29, -38, -6)
(-25, -42, -3)
(-27, -40, -6)
= PHC

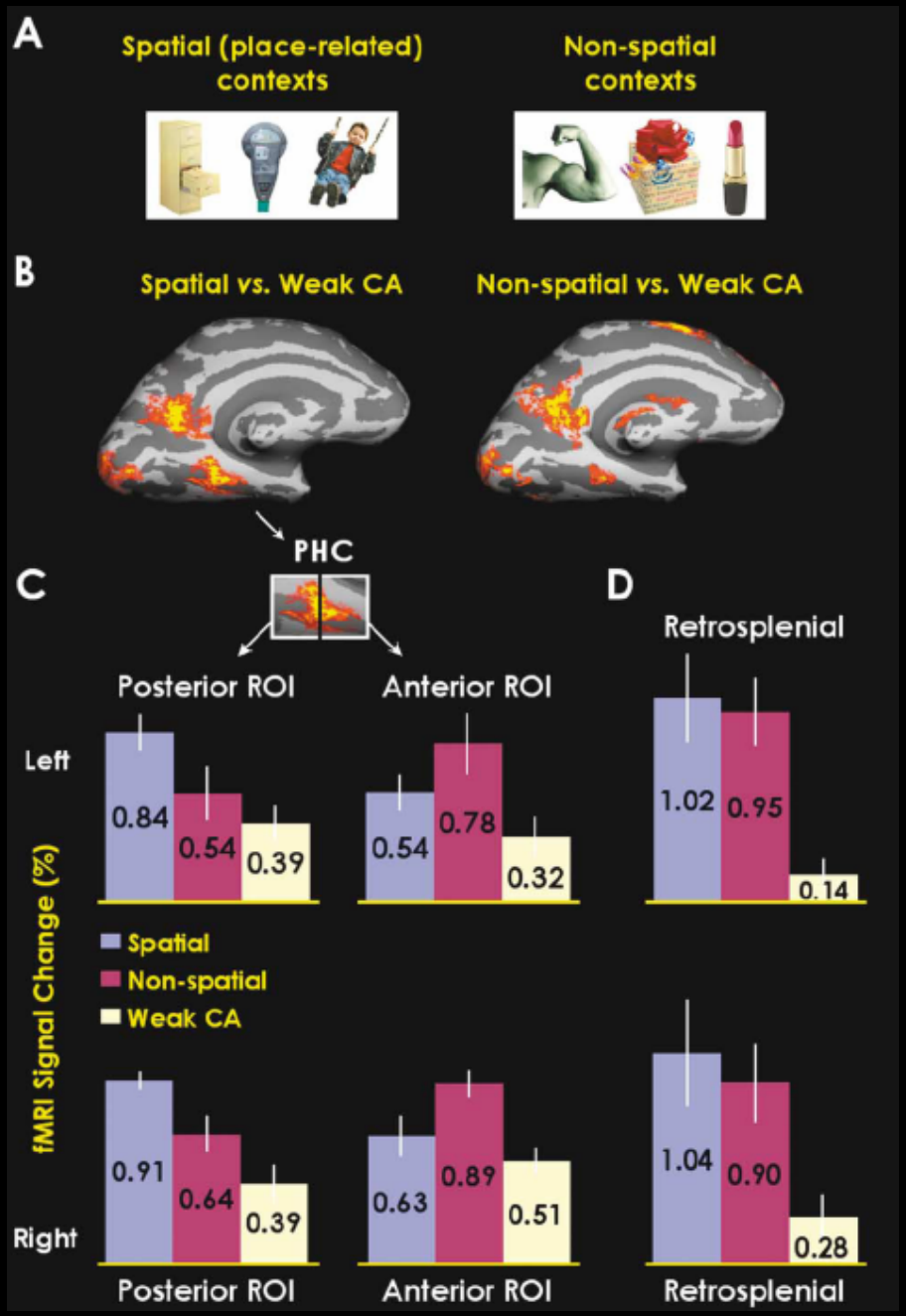
Exp. 4a: Contexts or Places?

- **Task:** Recognize object
- **Compare:**
  - Objects with strong spatial context vs. Weak CA
  - Objects with strong non-spatial context vs. Weak CA
- **Results:**
  - Significant differential activation in PHC and RSC only for spatial condition

Conclusion: Spatial contexts automatically activated during object recognition. Change task to activate explicitly non-spatial contexts.

Exp. 4b: Contexts or Places?

- **Task:** Recognize *context*
- **Compare:**
  - Objects with strong spatial context vs. Weak CA
  - Objects with strong non-spatial context vs. Weak CA
- **Results:**
  - Significant differential activation in PHC and RSC for both spatial and non-spatial
  - Spatial contexts activate more posterior PHC focus, non-spatial contexts activate more anterior PHC focus


A
Spatial (place-related) contexts
Non-spatial contexts
B
Spatial vs. Weak CA
Non-spatial vs. Weak CA
PHC
C
D
Retrosplenial
Posterior ROI
Anterior ROI
Left
0.84
0.54
0.39
0.54
0.78
0.32
1.02
0.95
0.14
fMRI Signal Change (%)
Spatial
Non-spatial
Weak CA
0.91
0.64
0.39
0.63
0.89
0.51
1.04
0.90
0.28
Right
Posterior ROI
Anterior ROI
Retrosplenial

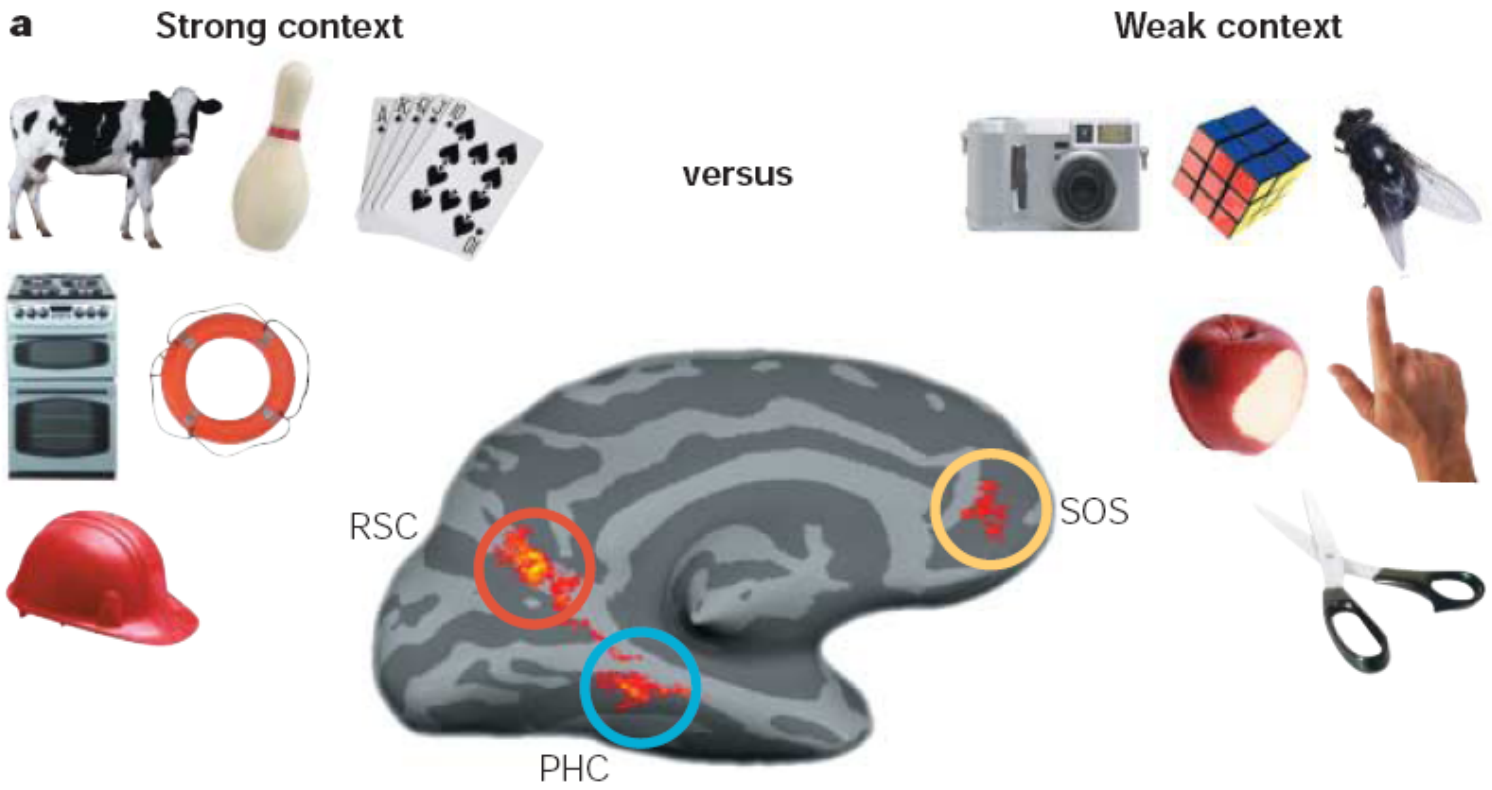
PHC and RSC

- Both involved in episodic memory and place-related information
- PHC and RSC mediate general analysis of contextual associations, bridging these two well-established roles

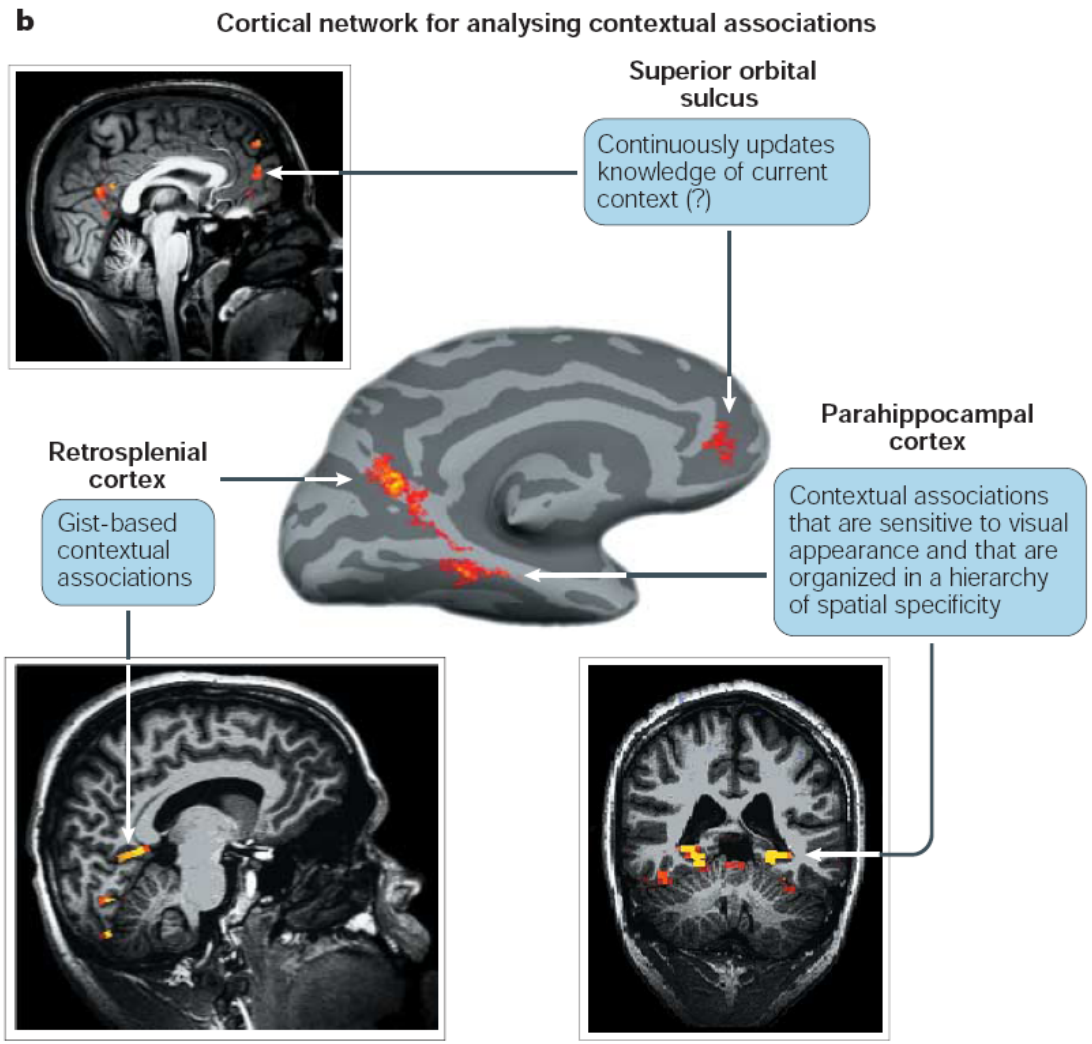
Interaction with Hippocampus

- PHC implicated in associative processing, represents associative, experiential knowledge
- Hippocampus represents episodic instances of PHC knowledge at a later stage
- Hippocampus activated equally above baseline for Strong CA and Weak CA

Cortical Context Association Network



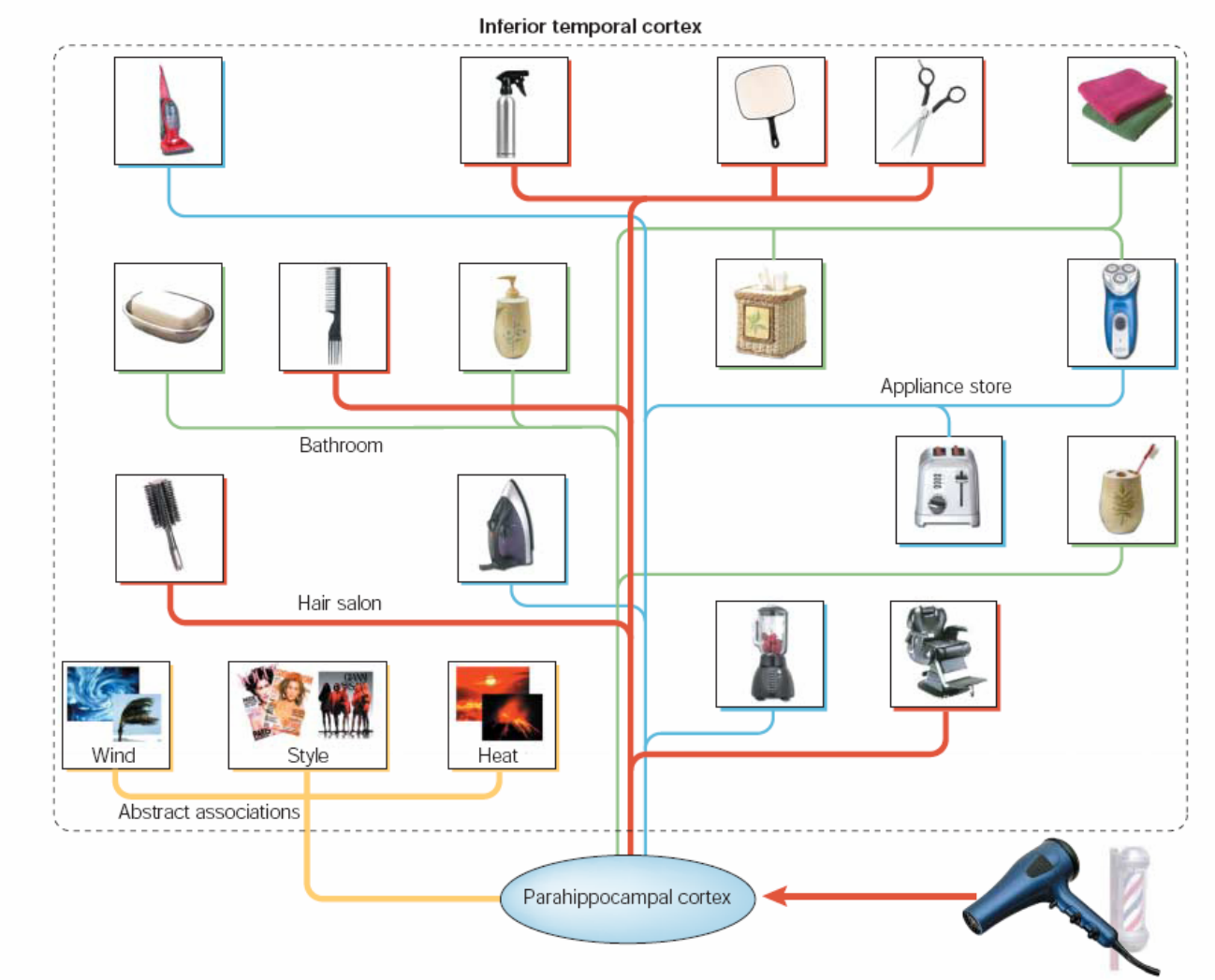
Cortical Context Association Network



Representation of Associations in PHC

- PHC as Switchboard:
  - PHC acts as multiplexer of contextual associations between detailed entity representations elsewhere
  - IT represents visual objects in detail, connective associations gated by PHC
  - PHC associations could be trained using Hebbian learning according to Bayesian inference methods

PHC as Contextual Switchboard



Beyond Visual Coherency

- Scenes may be bound along several domains
- Association could encompass:
  - Context frames, feature conjunctions, different exemplars of same object
  - Other sensory modalities
- Circuitry involves more than visual perception
  - Only 8% of PHC's input is visual
  - Polysensory input from: RSC, cingulate gyrus, posterior parietal cortex, STS, insula, TE/TEO, perirhinal cortex

PHC as Associative Gateway

- Associative Representations:
  - Perceptual response in TE before PHC
  - Association elicits response in PHC before TE
  - Lesioning MTL disrupts paired visual associations
- PHC shows N400 ERP for semantically incongruent stimuli

Words vs. Pictures

- Contextual information in words and pictures:
  - Dual-code view: multiple semantic systems
  - Single-code view: unified system
- ERP evidence:
  - N400 more frontal for pictures, more occipital for words
- Behavioral evidence:
  - Words read faster, pictures categorized faster

Conclusion:

- Similar but not completely overlapping areas
- Use same area but utilize different circuits?
- **Initiated by modal regions, elaborated in amodal regions**

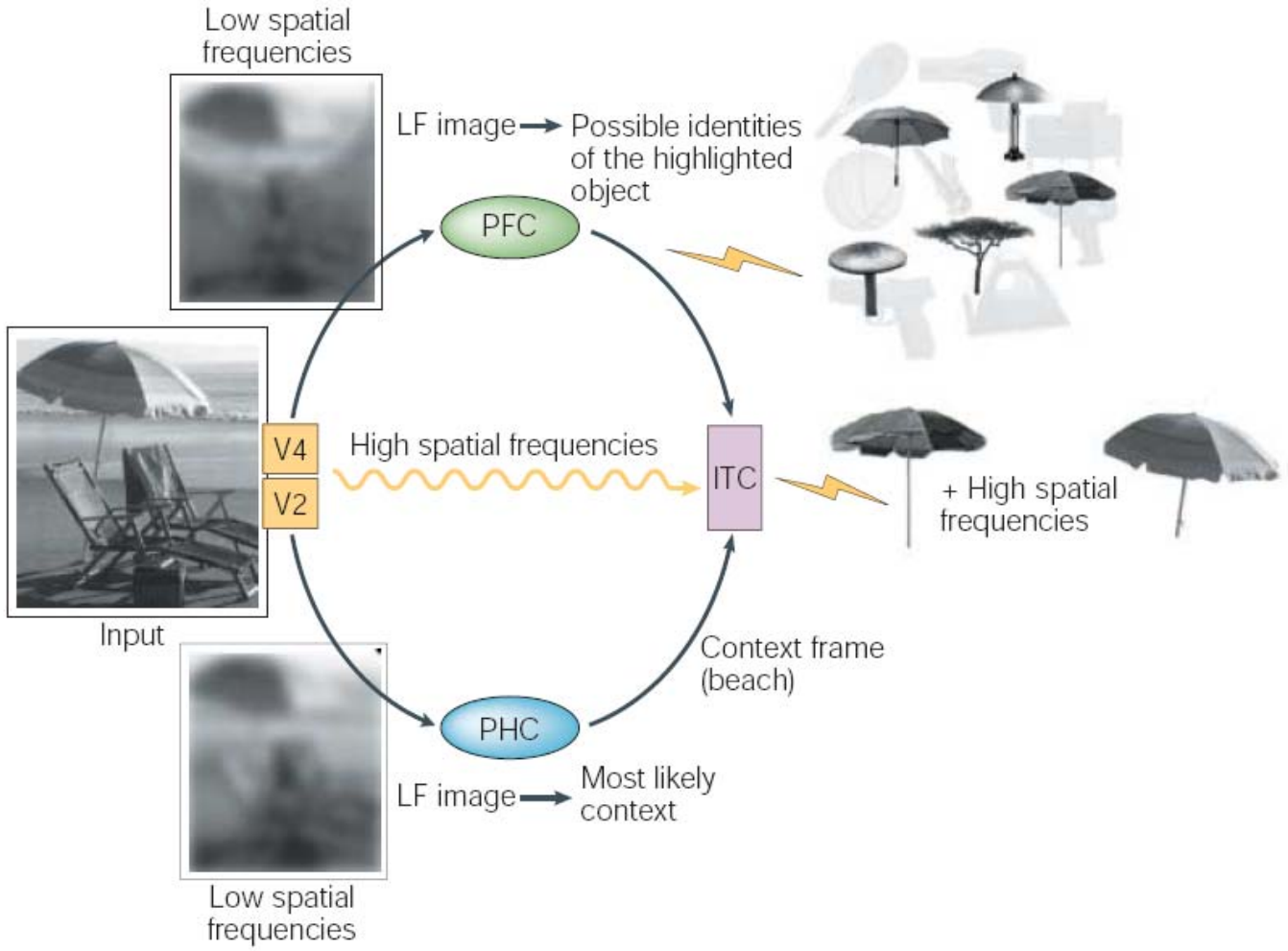
Role of PFC

- Prefrontal cortex implicated in contextual processing
  - fMRI activation during face-name associations
  - Demonstrates N400 effect
- Activity often coupled with MTL, regions interact?

Model of Contextual Facilitation

- Low frequency input processed very quickly
- PHC selects context frame guess, connecting associations in IT
- PFC sensitizes the most likely candidate interpretation of the target object (selected via foveal vision and bottom-up attention)
- Higher frequency input refines selected object

Model of Contextual Facilitation



Evidence for Model

- **PFC:**
  - PFC receives fast input from magnocellular pathway
  - Differential “Recognition Activity” appears earlier in orbital PFC than in IT
  - fMRI signal for low spatial frequencies stronger in PFC
- **IT:**
  - IT activity initially broadly tuned to coarser features, then become fine tuned 51 ms later
  - Single-unit recordings show low-frequencies

Conclusions & Future Directions

- Context is an important element of visual processing which facilitates object recognition and sensitizes likely candidates based on experiential history
- Extraction occurs extremely quickly (80 ms), utilized before perceptual processing and recognition completed
- Relationship to top-down or bottom-up attention?
- Division of labor among perceptual areas, PFC, and MTL?
- Gating or rewiring mechanisms of PHC network?