Category Learning is Modulated by Visual Similarity

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Introduction

How does the brain acquire information about categories and concepts as a result of encounters with specific exemplars? Two views have been suggested:

• Category knowledge is based on abstraction of information about prototypes (implicit learning).

• Category learning emerges from item memory, based on similarity between an old prototype and a new exemplar (explicit learning).

Intact category learning in amnesic patients indicates that this form of non-declarative memory is implicit and independent of MTL structures (Knowlton & Squire, 1993).

Pablo Picasso: The Blue Period prototypes

***Self portrait*, 1901**

***The tragedy*, 1903**

***Blue nude*, 1902**

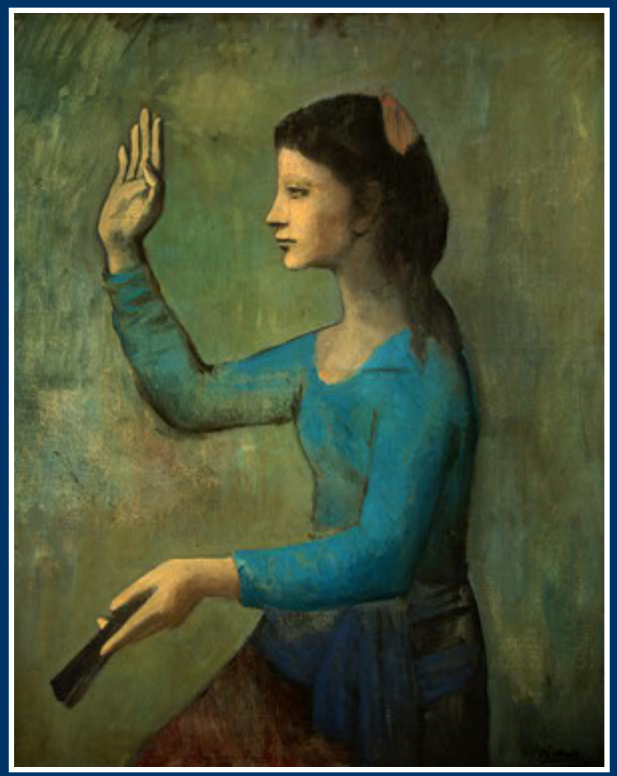
***The old guitar player*, 1903**

New Exemplars: Visually Similar

***La celestina*, 1904**

New Exemplars:
Visually Ambiguous

***Le Gourmet*, 1901**



***Lady with a Fan*, 1905**

New Exemplars:
Visually Dissimilar

***Girl in a Chemise*, 1905**

Hypothesis

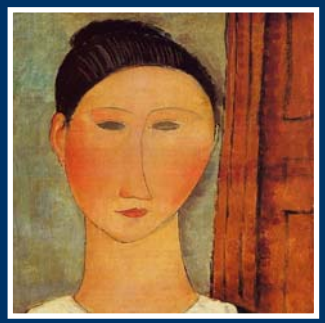
Categorical knowledge depends on both implicit abstraction of information from prototypes and explicit item memory, two processes that require matching novel items with familiar ones.

This matching is likely modulated by the visual similarity between new and familiar exemplars.

If so, then category learning of objects would result in activation in the visual cortex and the ‘memory network’ that is modulated by the degree of visual similarity (e.g., decreased activity with decreased similarity).

Experimental Design: Memory Encoding

Portraits



Modigliani

Renoir

Landscapes

Van Gogh

Pissaro

Abstract Paintings

Miro

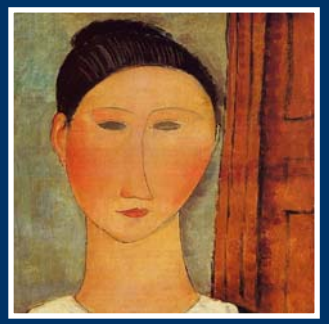
Kandinsky

Subjects memorized 15 prototypes from each painter (total of 60 pictures).
Each picture was presented for 5 sec and was randomly repeated 4 times to enable deep encoding.

Experimental Design: Memory Retrieval

Categorization or Recognition

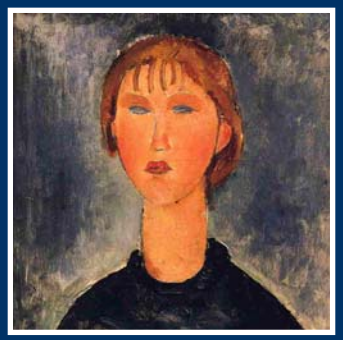
old prototype



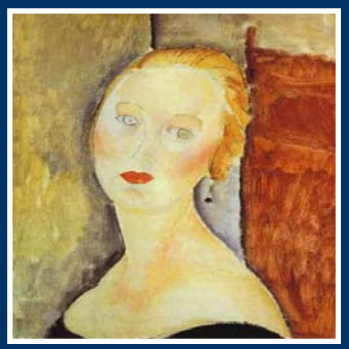
Modigliani

New Exemplars

similar



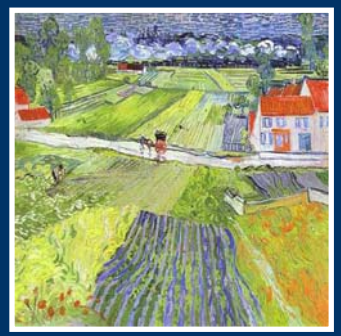
ambiguous



dissimilar

Matisse

old prototype

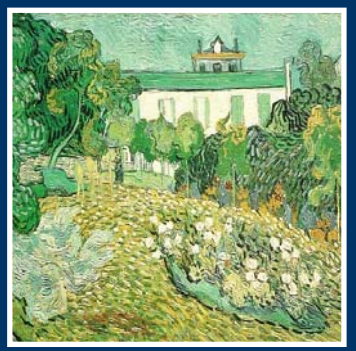


Van Gogh

New Exemplars

similar

ambiguous



dissimilar

Gauguin

old prototype

Miro

New Exemplars

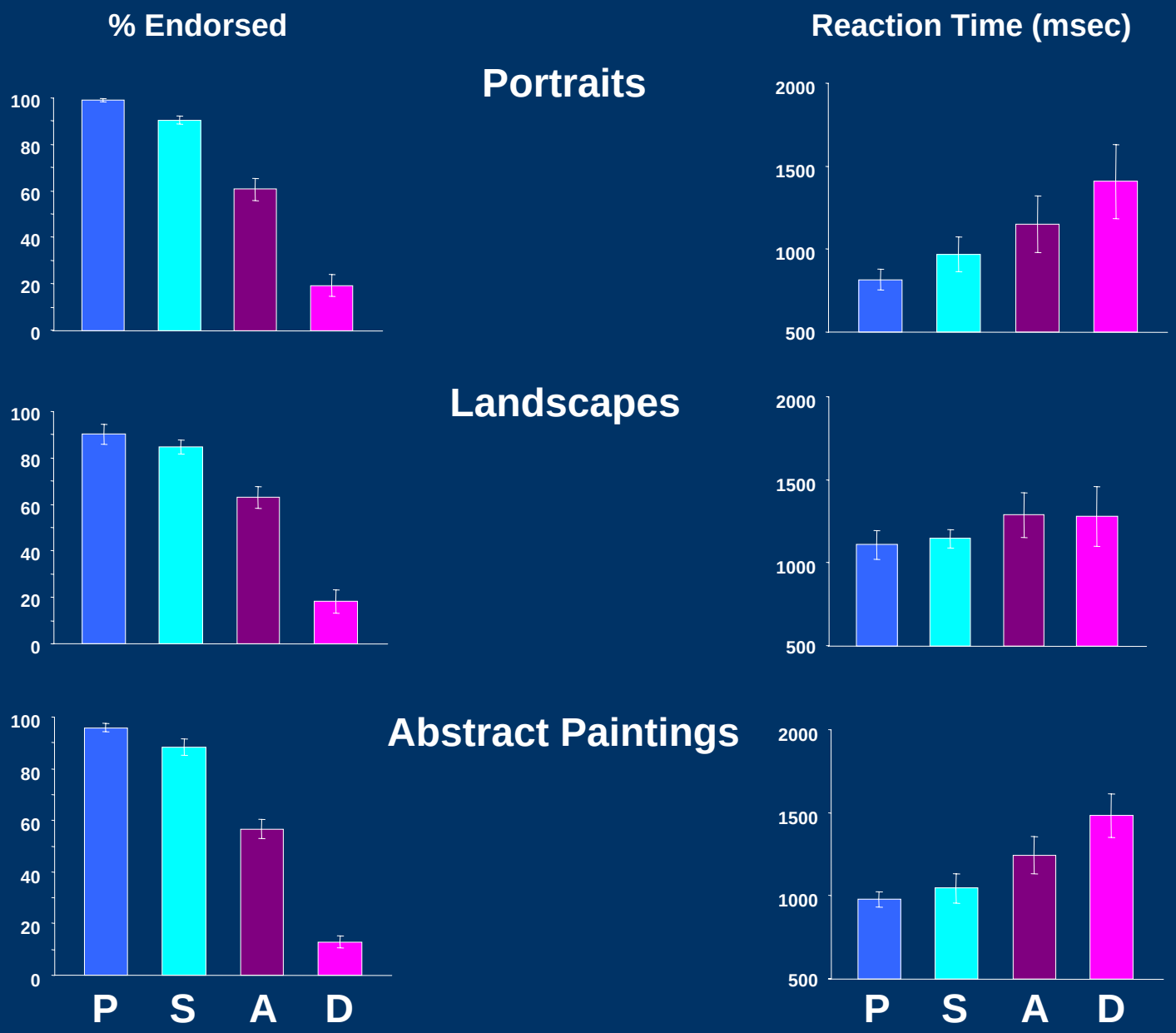
similar

ambiguous

dissimilar

Mitchel

Behavioral Pilot: Categorization (N=4)

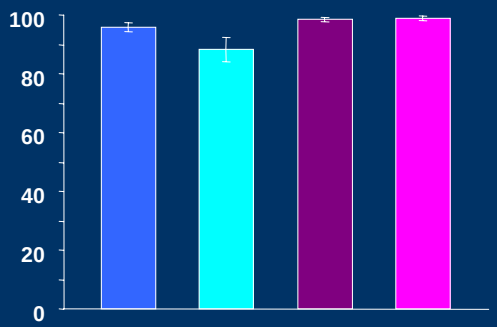


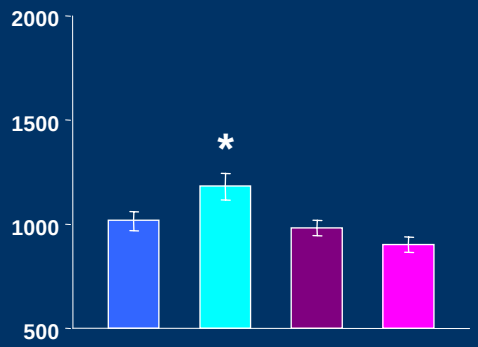
Behavioral Pilot: Recognition (N=12)
Correct Trials

Accuracy (%)

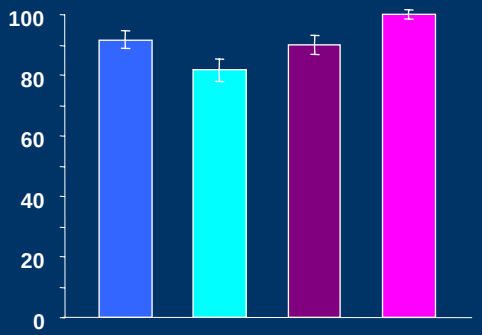
Reaction Time (msec)

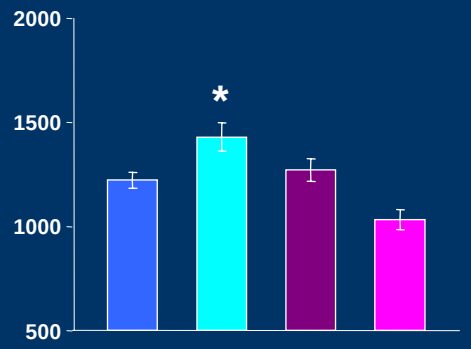
Portraits



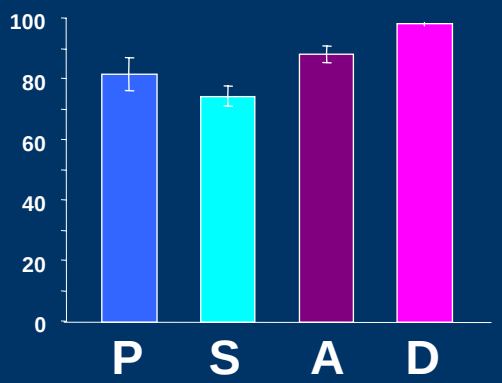


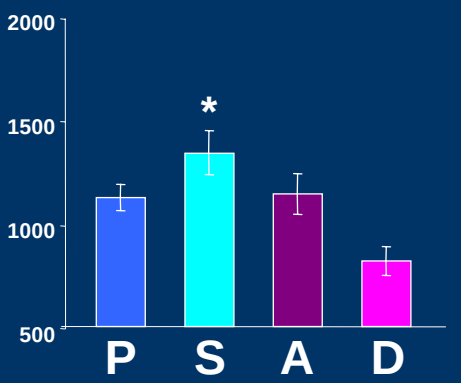
Landscapes





Abstract Paintings





fMRI Experiment: Visual Baseline

Helleu

Monet

Pollock

Imaging

Data acquisition: 3T Philips Scanner

Anatomy: Whole-head image acquisition
180 slices
Slice-thickness: 0.75 mm

Functional MR images:
RT: 3 sec (=stimulus duration)
35 slices
Slice-thickness: 4 mm

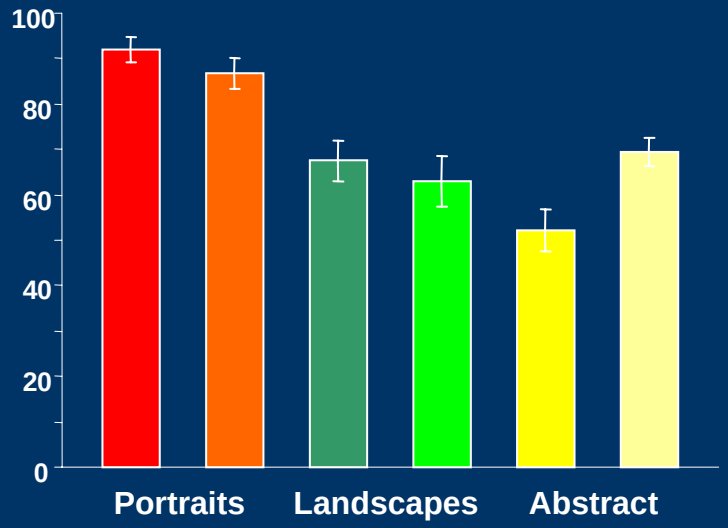
Data Analysis: BrainVoyager QX 1.3.
Motion correction, temporal filtering, spatial smoothing (5mm).

Statistics: GLM

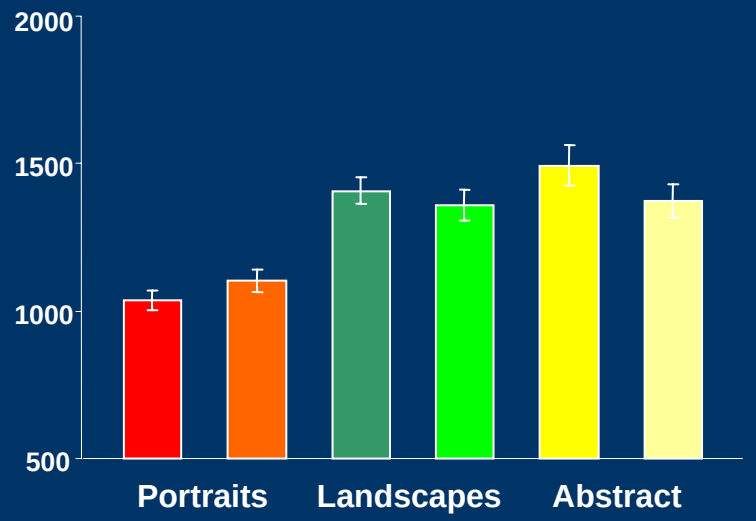
ROI Analysis:
$p<0.01$ uncorrected on individual statistical maps.
Beta Weights (P, S, A, D) for correct trials only.

Behavioural Data
Recognition of learned Prototypes (N=14)

Accuracy (%)



Reaction Time (msec)



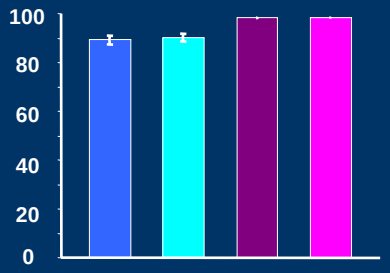
Modigliani Renoir Pissarro Van Gogh Kandinksy Miro

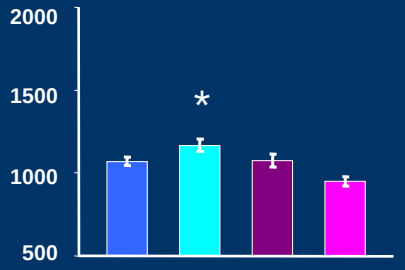
Prototypes & New Exemplars
Correct Trials

Accuracy (%)

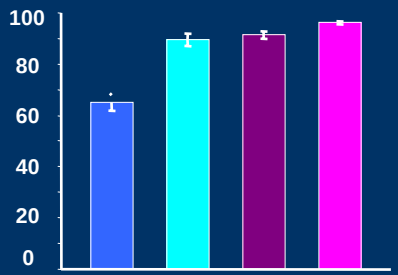
Reaction Time (msec)

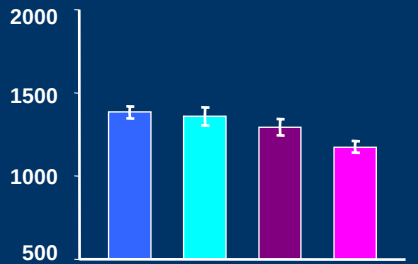
Portraits



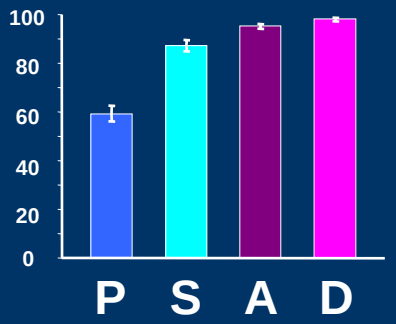


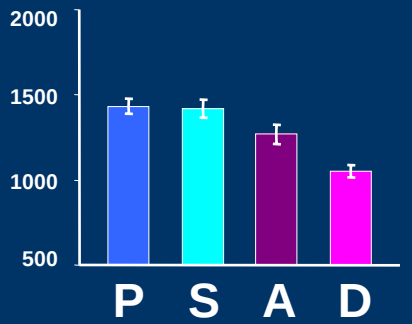
Landscapes





Abstract Paintings

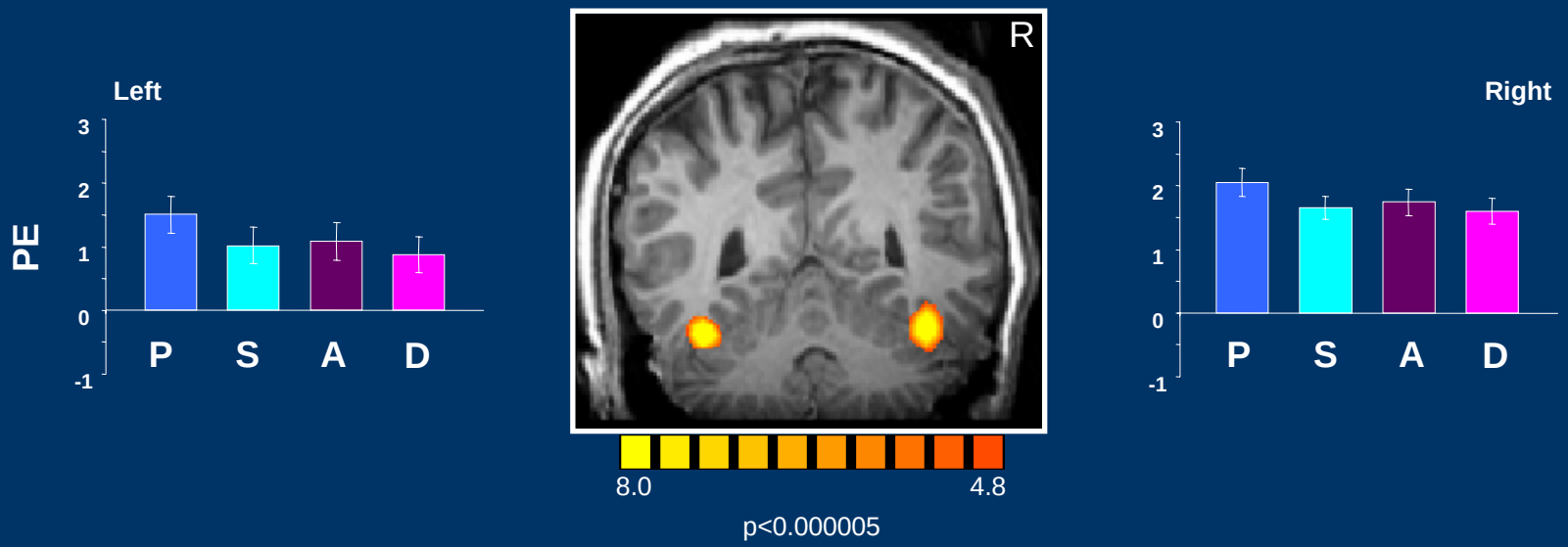




fMRI Results:
Category-selective activation in the visual cortex

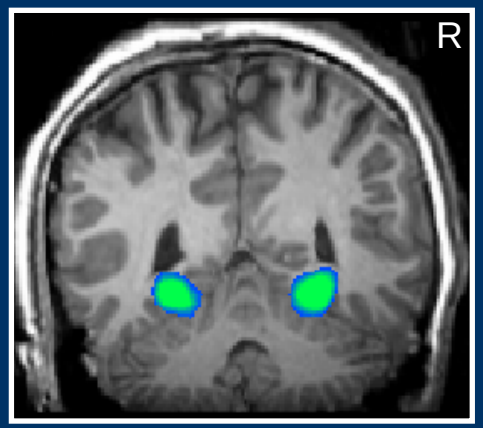
Faces* vs. *Landscapes

FFA, y=-46



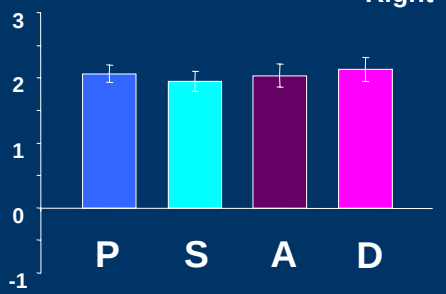
Faces vs. Landscapes

MFG, y=-45

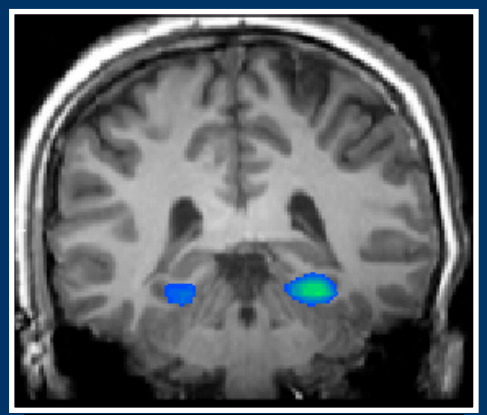


Left

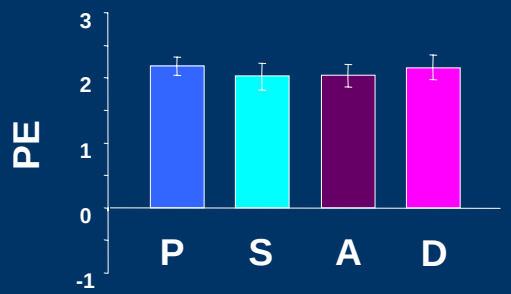
Right

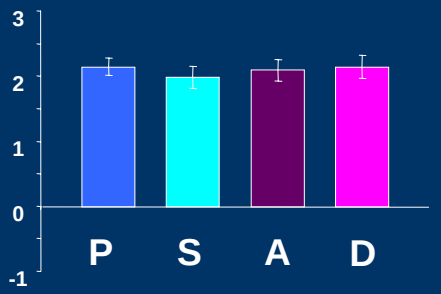


PPA, y=-35

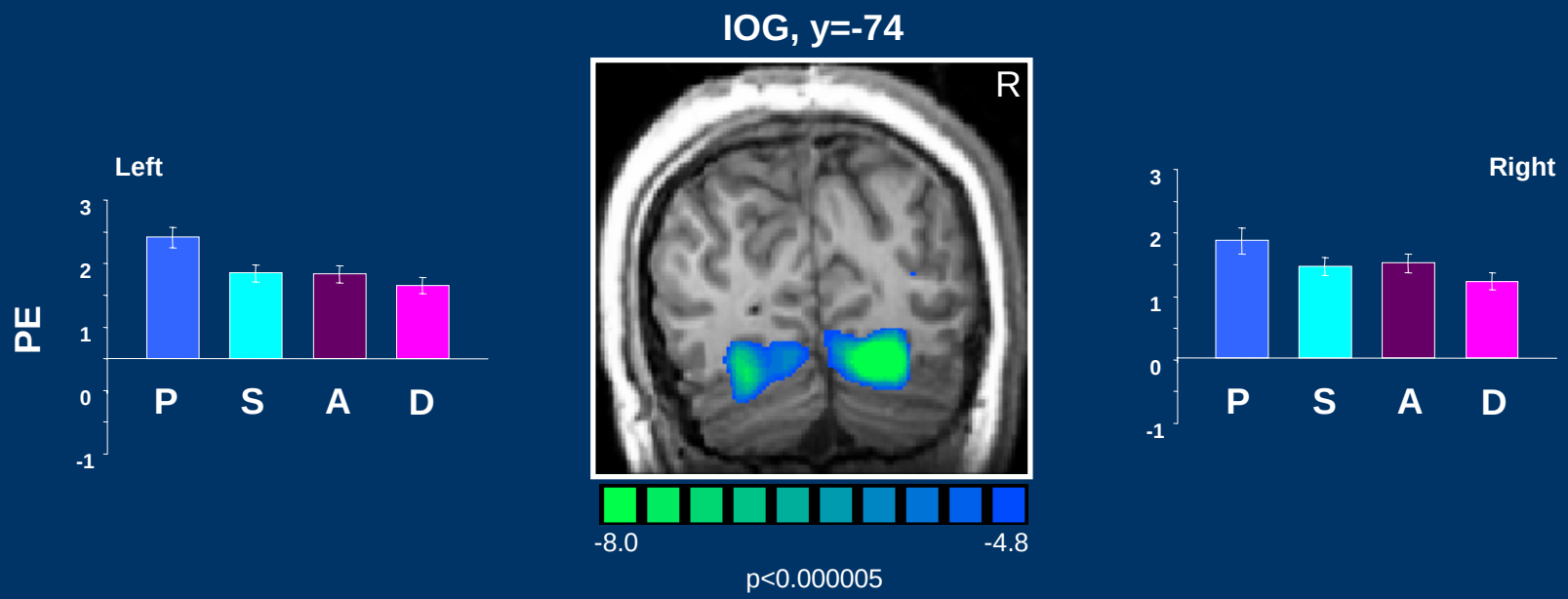


p<0.000005



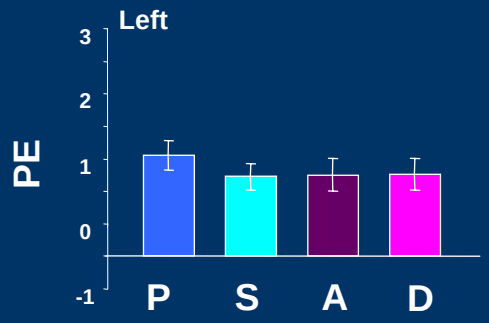


Faces vs. Abstract paintings

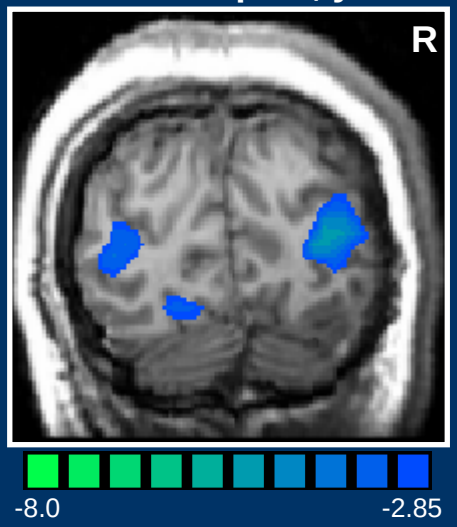


Landscapes vs. Abstract paintings: PPA

Faces vs. Landscapes

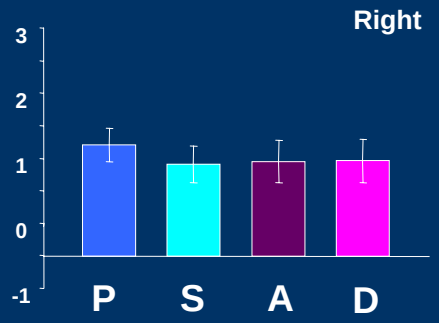


Dorsal Occipital, y=-81

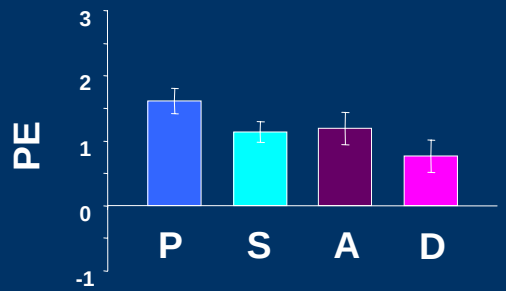


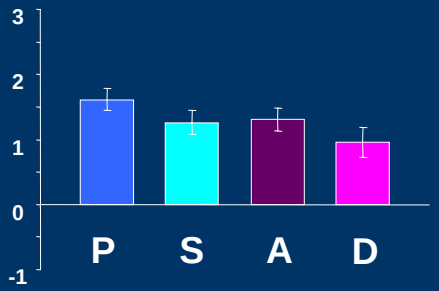
-8.0 -2.85

Subject JA, p<0.01



Faces vs. Abstract paintings

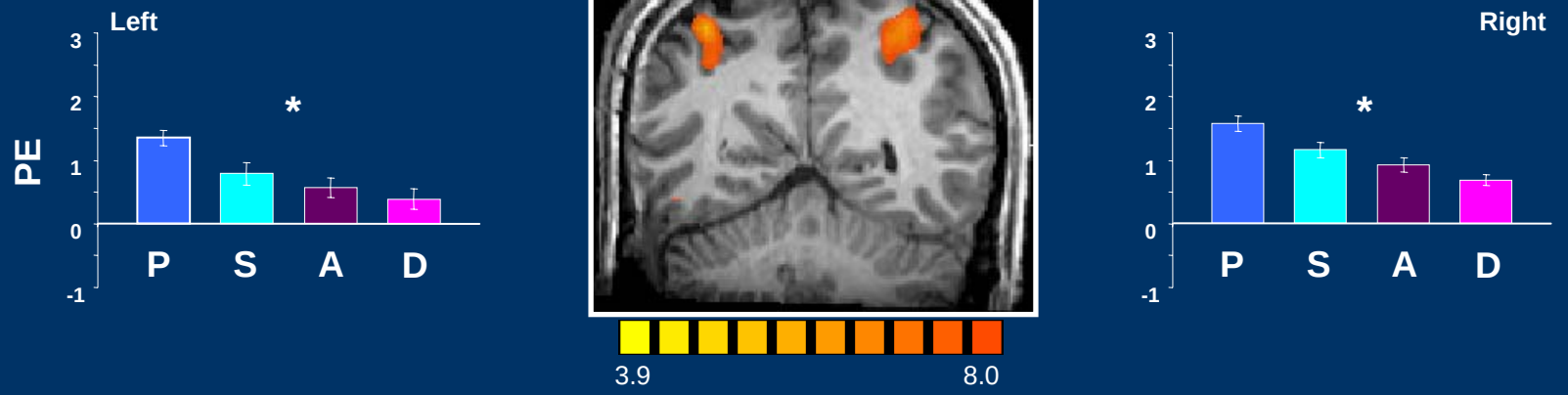




Activation in attention-related areas

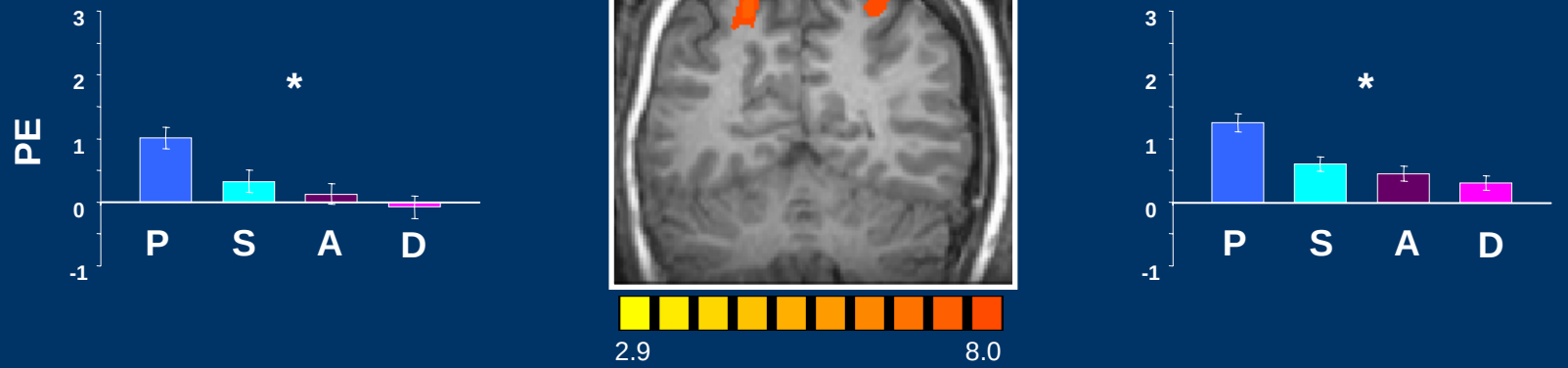
P/S* vs. *A/D

IPS, y=-51



Subject CS, p<0.0001

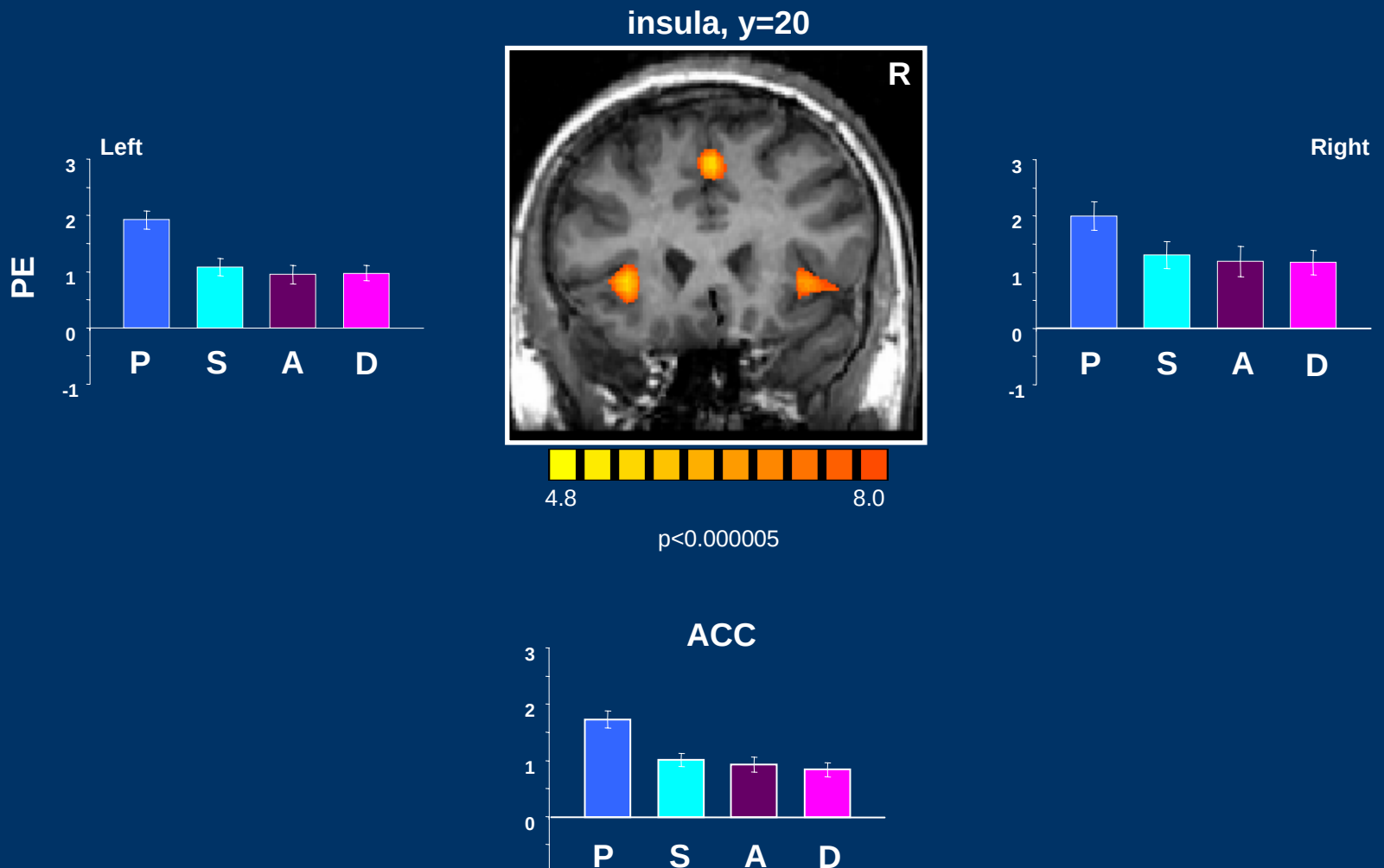
SPL, y=-59



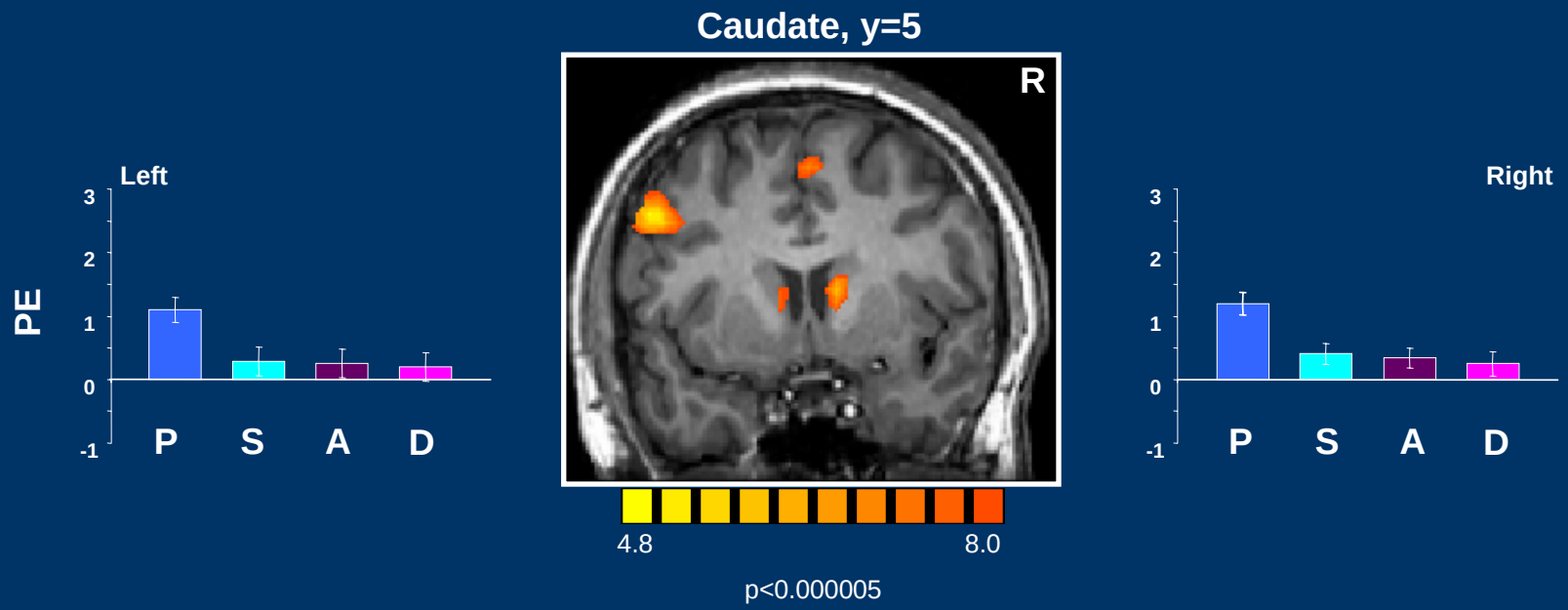
Subject YS, p<0.005

Activation in memory-related areas

P/S* vs. *A/D



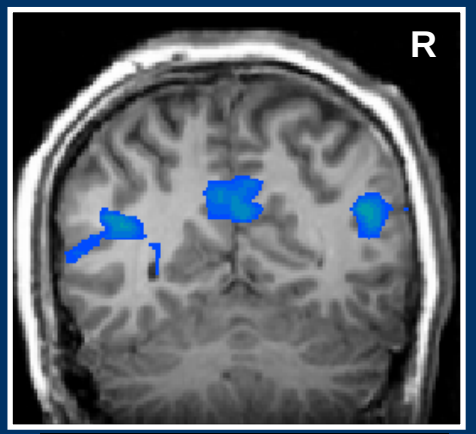
P/S* vs. *A/D



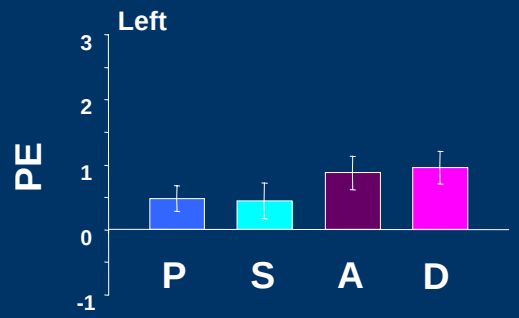
Monkey brain: learning involves corticostriatal circuit: modulation of IT (Middelton & Strick 1996) and PFC (Pasupathy & Miller 2005)
Human brain: The caudate nucleus is active in classification learning (Seger & Cincotta 2002, 2005)

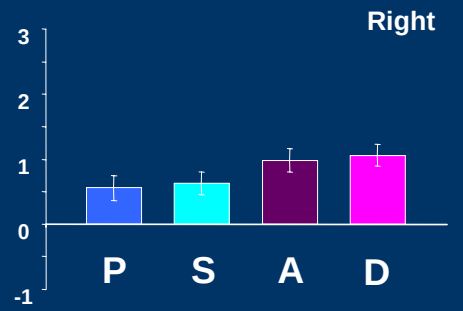
P/S vs. A/D

precuneus / STS, y=-55

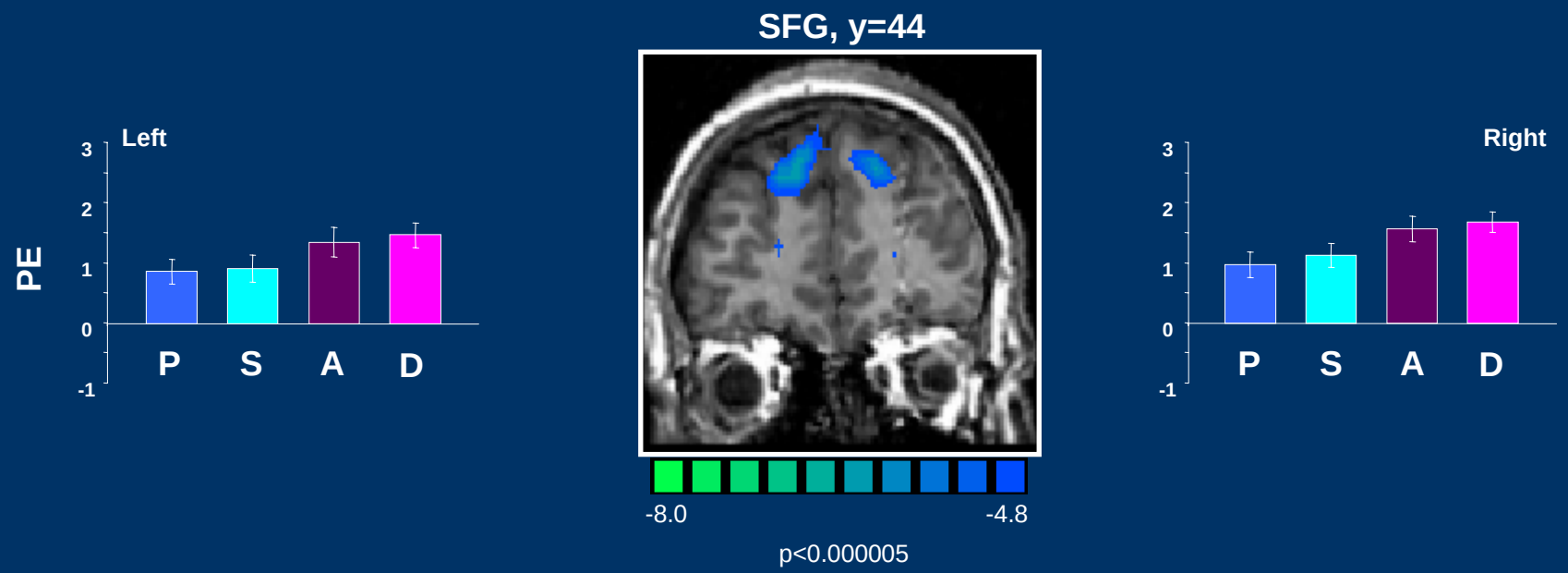


p<0.000005



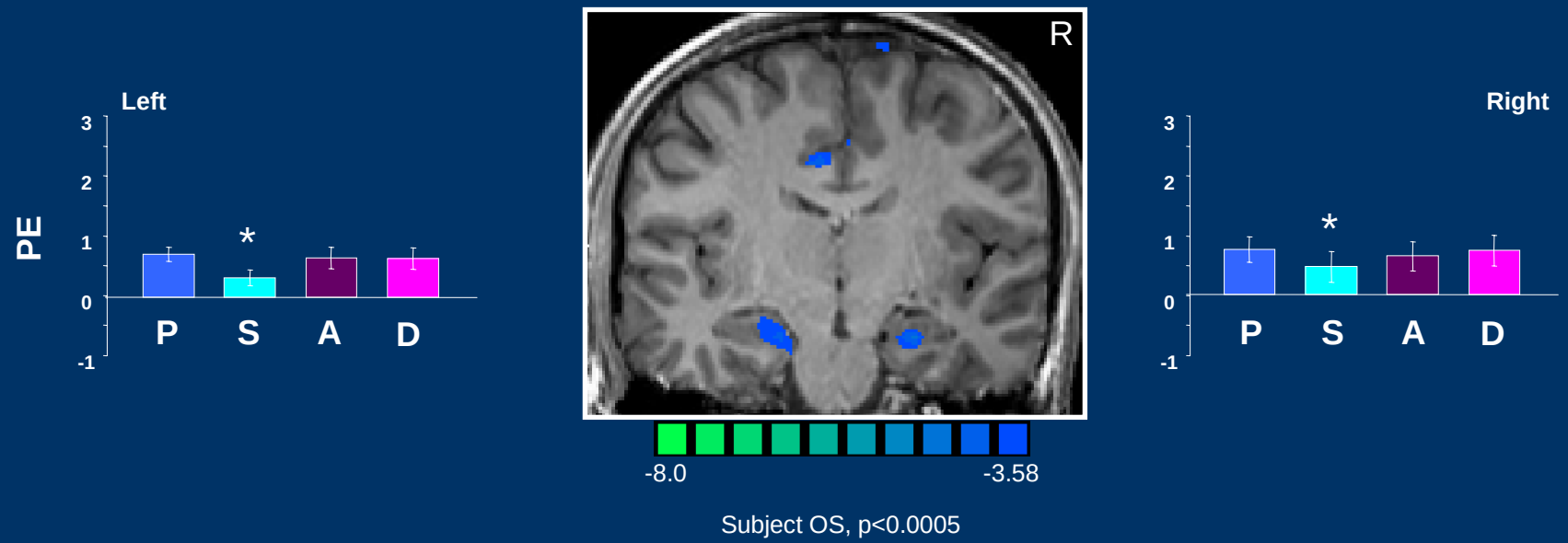


P/S* vs. *A/D



S vs. D

hippocampus, y=-13



Subject OS, p<0.0005

Summary

- **Behavioral Data:** Subjects recognized 90% of the familar faces but only ~60% of the familiar landscapes & abstract paintings.

- **fMRI Data:** activation was found in **a distributed cortical network** that includes:

Face- and object-selective regions in the **visual cortex**, where the prototypes evoked stronger activation than the new exemplars.

Attention-related areas (IPS and SPL), where the response to new exemplars was reduced with decreasing similarity to the prototypes.

Memory-related areas, where two patterns of activation were observed:

1) Caudate/insula/ACC, where the learned prototypes elicited stronger activation than the new items.

2) Precuneus/SFG/STG/hippocampus, where visually different exemplars evoked stronger activation.

Conclusion

Our findings suggest that category learning is mediated by stimulus-specific representations stored in the visual cortex, activation in attention-related areas where visual similarity to familiar prototypes is detected, and activation in memory-related areas where new exemplars are classified as a match or a mismatch, based on their similarity to familiar prototypes.