Category learning drives neural repulsion initially but integration at a delay

Marlie C. Tandoc, Sarah H. Solomon, Ashley B. Williams, Alex Gordienko, Jacob A. Parker, Anna C. Schapiro

Penn Computational Cognitive Neuroscience Lab

Introduction

Flexible behavior relies on our ability to learn and retrieve both **general** patterns and **specific** details (most dogs bark, your friend's dog bites)

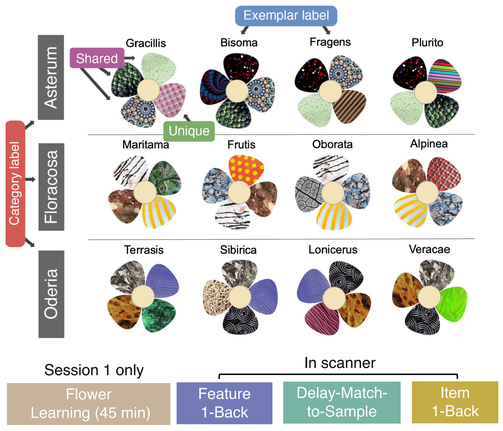
Memory for specific details often fade with time, but general patterns persist[1,2]

How does the brain flexibly **represent** and **retrieve** general vs. specific knowledge, and how does this change with **time**?

Design

n = 32, two-session 3T fMRI (1-2 weeks apart)

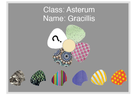
Categories with **general** (shared petals, category labels) and **specific** (unique petals, exemplar labels) properties



Session 1 only | In scanner

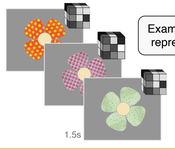
Flower Learning (45 min) | Feature 1-Back | Delay-Match-to-Sample | Item 1-Back

Flower Learning



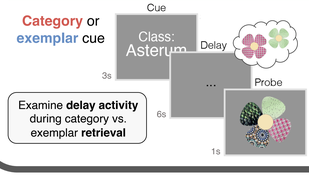
Property inference with corrective feedback
1. Shared features
2. Unique features
3. Category labels (class)
4. Exemplar labels (name)

Feature 1-back



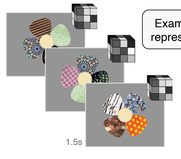
Examine **feature** representations

Delay-Match-to-Sample



Examine **delay activity** during category vs. exemplar **retrieval**

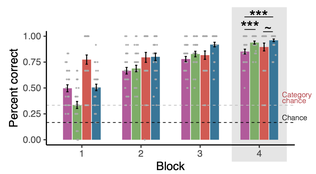
Item 1-Back



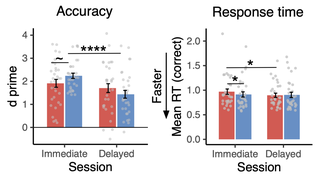
Examine **item** representations

Behavior

Flower Learning



Delay-Match-to-Sample

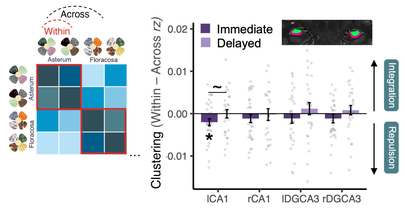


Strong memory for **exemplars** fades after 1-2 weeks, **category** knowledge is preserved

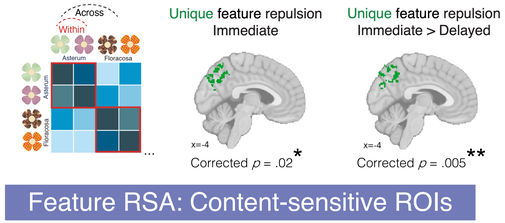
Shared feature | Unique feature | Category label | Exemplar label

Initial repulsion for items and unique features in hippocampus and cortex

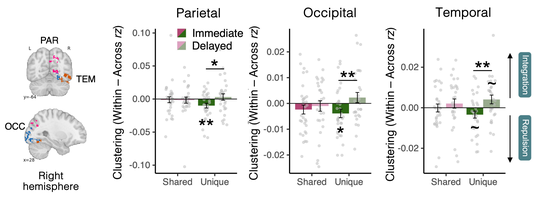
Item RSA: Hippocampus



Feature RSA: Whole-brain Searchlight



Feature RSA: Content-sensitive ROIs



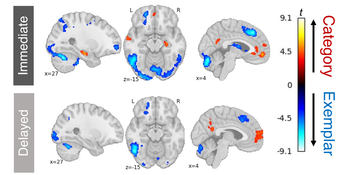
Repulsion for items in CA1 and **unique features** in precuneus and in content-sensitive cortex

Repulsion disappears after 1-2 weeks

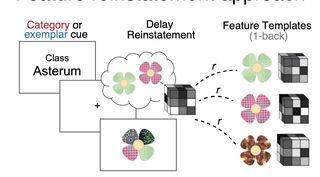
Content-sensitive ROIs: Regions from a whole-brain searchlight which showed that a petal is more correlated to itself across repeats than to other petals

Flexible reinstatement in hippocampus and parietal cortex

Delay-Match-to-Sample

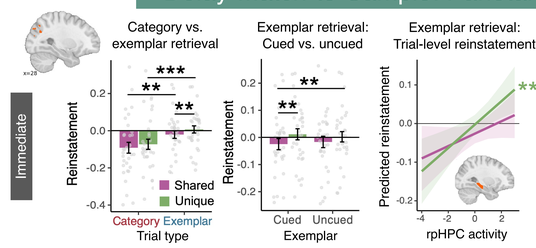


Distinct regions for **category** vs. **exemplar** retrieval, consistent with these regions representing categories at different abstraction levels[3]



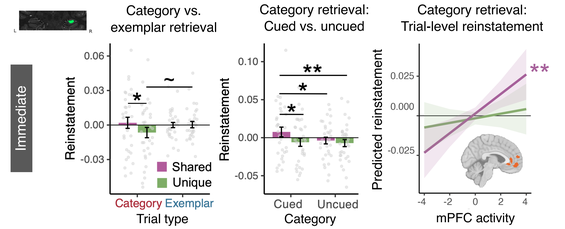
Corrected for multiple comparisons with non-parametric permutation testing at $p < .05$

Delay-Match-to-Sample: Parietal reinstatement



Exemplar retrieval: Parietal reinstatement of **unique features** tracks posterior hippocampus activity

Delay-Match-to-Sample: DG-CA3 reinstatement

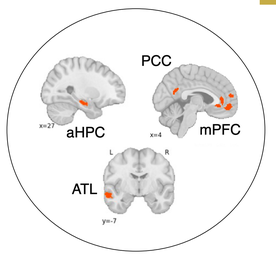


Category retrieval: DG-CA3 reinstatement of **shared features** tracks mPFC activity

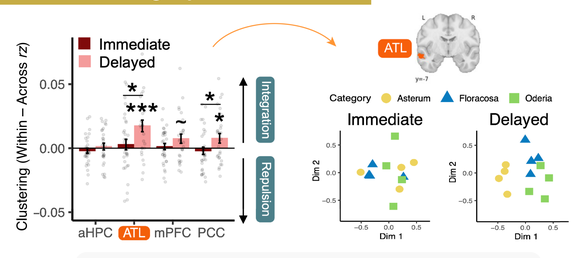
Flexible reinstatement effects went away after a 1-2 week delay

Time-dependent cortical integration

Item RSA: Category retrieval ROIs



Category retrieval ROIs from univariate delay-match-to-sample analysis



Category clustering emerges in cortex (especially in ATL), but only after 1-2 weeks

Conclusions

Items and **unique features** from the same category are initially differentiated in hippocampus and neocortex, with integration emerging in other cortical regions (ATL) only after consolidation

General and specific knowledge are reinstated according to task demands, with posterior hippocampal-parietal circuits for **exemplar retrieval** and mPFC-hippocampal interactions for **categorization**

Repulsion and reinstatement of specific details may support our initial ability to resolve competition between similar memories, giving way to integration at a delay

References

1. Sekeres, M. J., Winocur, G., & Moscovitch, M. (2018). The hippocampus and related neocortical structures in memory transformation. *Neuroscience Letters*, 680, 39-53.
2. Richards, B. A., Xia, F., Santoro, A., Husse, J., Woodin, M. A., Josselyn, S. A., & Frankland, P. W. (2014). Patterns across multiple memories are identified over time. *Nature Neuroscience*, *17*(7), 981-986.
3. Bowman, C. R., Iwashita, T., & Zeithamova, D. (2020). Tracking prototype and exemplar representations in the brain across learning. *eLife*, *9*, e59360.