Neural Differentiation: How Memory Retrieval Resolves Competition and Improves Learning

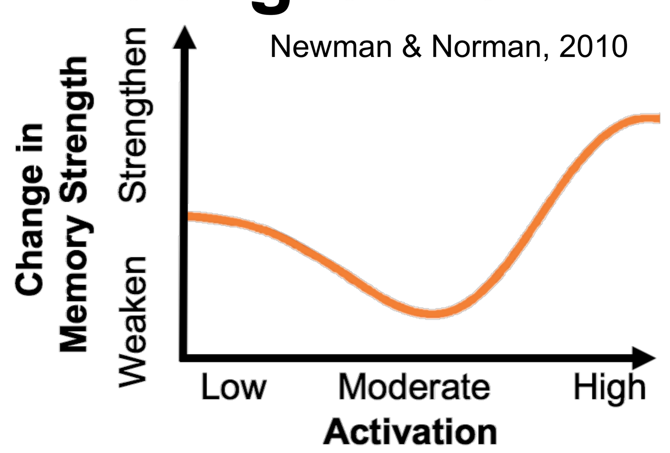
PRINCETON UNIVERSITY

Yechen Hu[1], Elizabeth A. McDevitt[1], James W. Antony[1], Kenneth A. Norman[1,2]

[1]Princeton Neuroscience Institute and [2]Department of Psychology, Princeton University

PRINCETON Neuroscience INSTITUTE

Background



Memories overlap and compete with each other. One way to resolve this competition is to decrease the neural overlap between competitors (i.e., **differentiation**), leading to better recall of more distinctive memories.

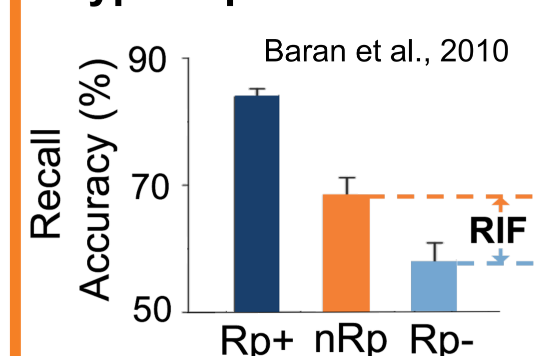
The **nonmonotonic plasticity hypothesis (NMPH)** posits that neural representations can be modified based on how strongly memories are activated during retrieval (see Figure). In one scenario, when a memory is strongly activated and competing memories are moderately activated at the same time, the connections between the strongly active memory and the moderately activated competitor(s) will be weakened, leading to differentiation. Here, we will explore how the NMPH differentiation mechanism and the resulting reduction in competition may account for **retrieval-induced forgetting (RIF)** and the **testing effect**.

Retrieval-Induced Forgetting Paradigm

Introduction

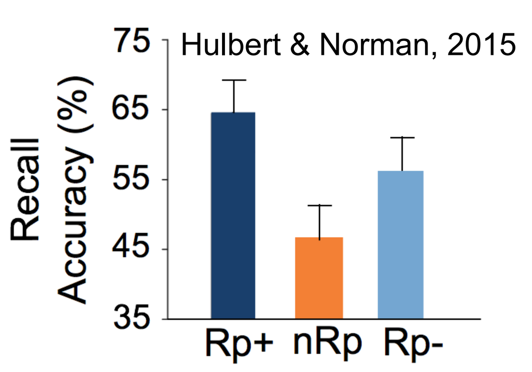
In RIF experiments, participants learn items that belong to different categories, and then practice half of the items from half of the categories. All items are tested at the end of the experiment. The general pattern of results is that while memory is improved for the retrieved items, memory is impaired for the related competitors.

Typical pattern of RIF results:



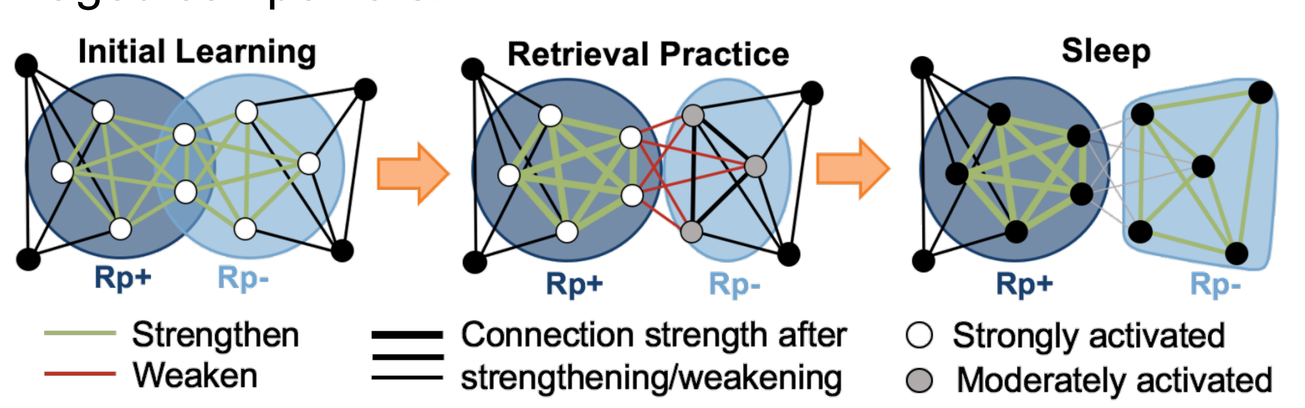
Rp+ (practiced items): studied items that undergo retrieval practice.
Rp- (unpracticed–related items): studied items that are not practiced, but related by category to the practiced ones.
Nrp (unpracticed–unrelated items): studied items in categories that are never practiced.

According to the NMPH, when the practiced items are retrieved, the related competitors are *moderately* activated. The competitors are both differentiated from the strongly activated targets, and weakened overall.



Subsequently restudying the damaged competitor will re-strengthen the memory while it remains differentiated from the target. Therefore, both the target memory and its competitor are better off than if they had not competed (Hulbert & Norman, 2015).

We **hypothesize** that memory consolidation processes during sleep (i.e., revisiting the damaged competitors via replay) may similarly reduce by promoting differentiation and re-strengthening the damaged competitors.



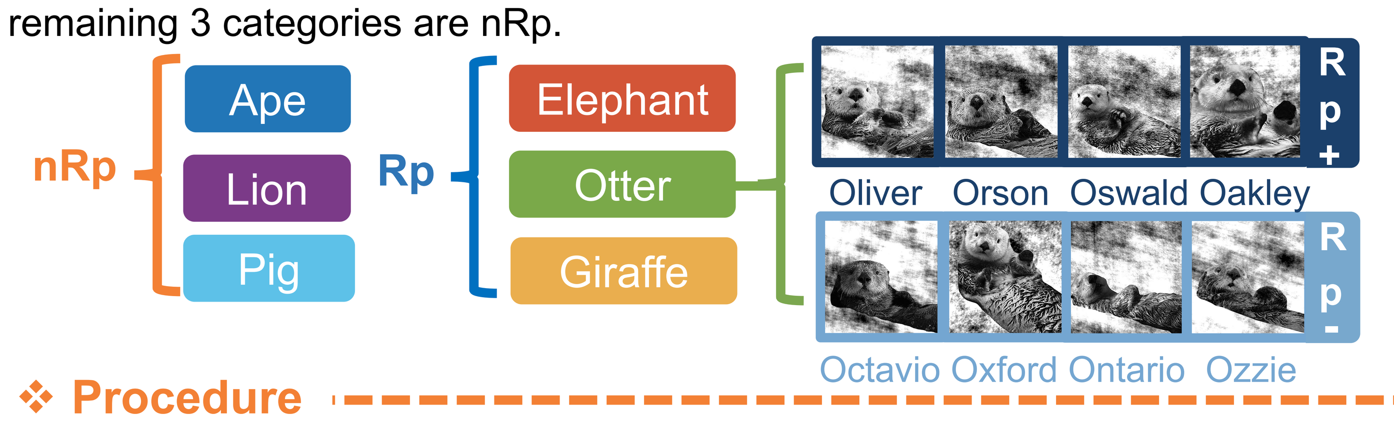
Aims:
1) Replicate traditional RIF effect with no delay and with 7-hour delay spent awake.
2) Test if sleep recovers memory for Rp- items.
3) Measure neural differentiation using fMRI and examine how it relates to behavioral memory.

Methods

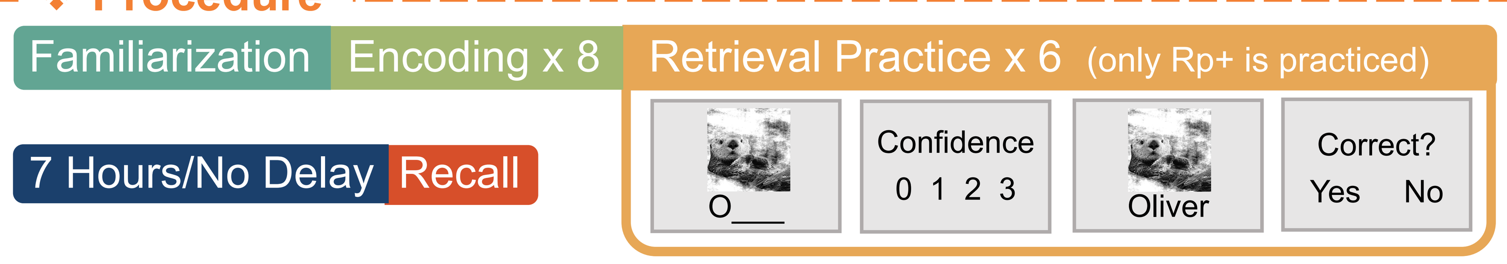
Based on Hulbert & Norman, 2015

❖ Material

Participants learn 48 animal-name pairs from six different mammalian categories. For 3 of 6 categories, half of the names are Rp+ and half are Rp-; all names in the remaining 3 categories are nRp.



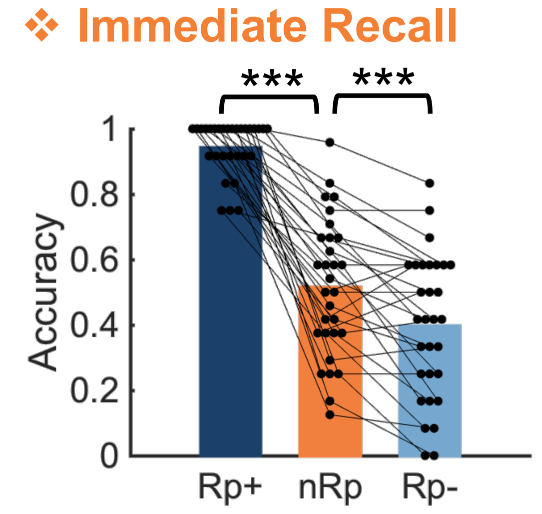
❖ Procedure



Behavioral Results

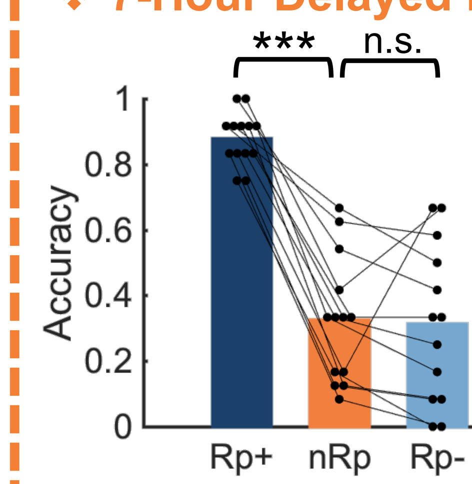
*** $p < 0.001$
* $p < 0.05$

❖ Immediate Recall



- ❖ On-campus behavioral pilot. N = 30.
- ❖ Rp+ performance is significantly better than nRp, and Rp- recall is significantly worse than nRp, replicating typical RIF effects.

❖ 7-Hour Delayed Recall



- ❖ On-campus behavioral pilot. N = 13.
- ❖ Although Rp+ performance is significantly better than nRp, Rp- performance is not significantly different from nRp ($p = 0.81$).
- ❖ Rp+ and nRp performance are both significantly worse than the immediate recall, but Rp- performance is not significantly different from the immediate recall ($p = 0.28$).

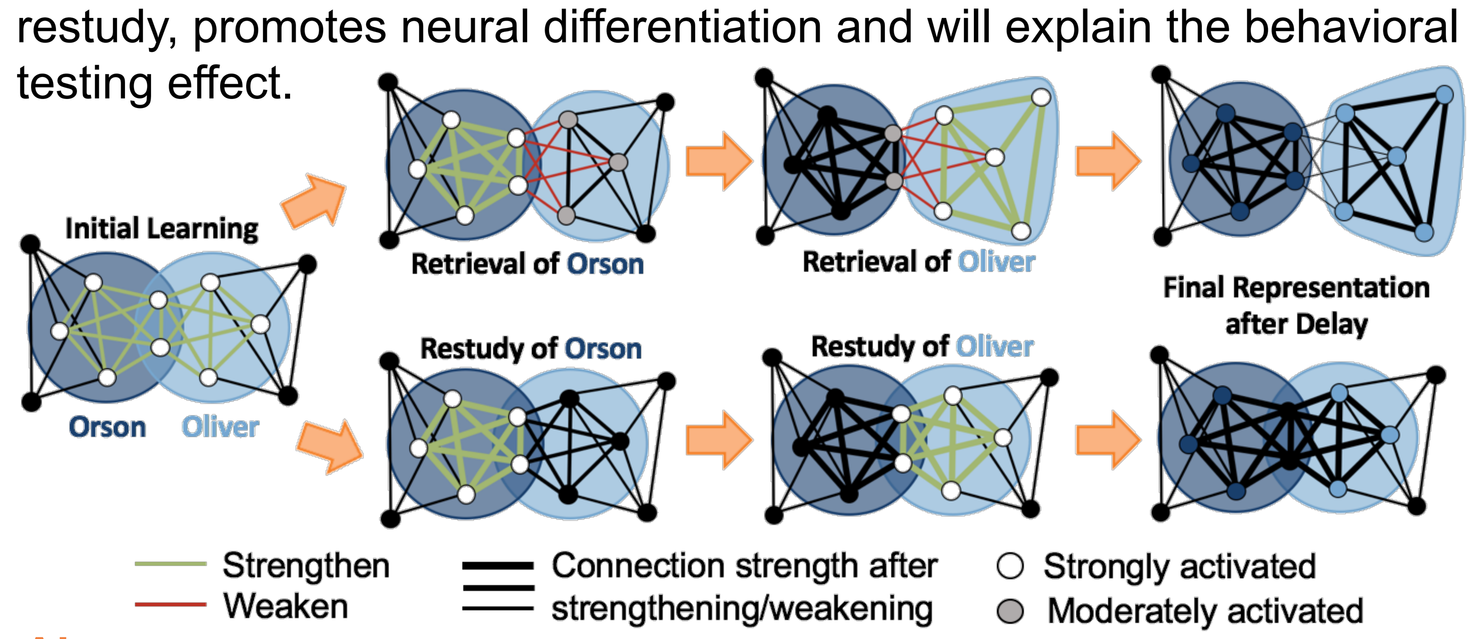
Testing Effect Paradigm

Introduction

The testing effect refers to the finding that retrieving a memory, compared to simply restudying the material, enhances long-term memory retention.

According to the NMPH, retrieving a memory *moderately* co-activates competitors, leading to differentiation. However, restudying limits activation to the restudied memory itself and does not co-activate competitors.

We **hypothesize** that competition during retrieval, compared to restudy, promotes neural differentiation and will explain the behavioral testing effect.



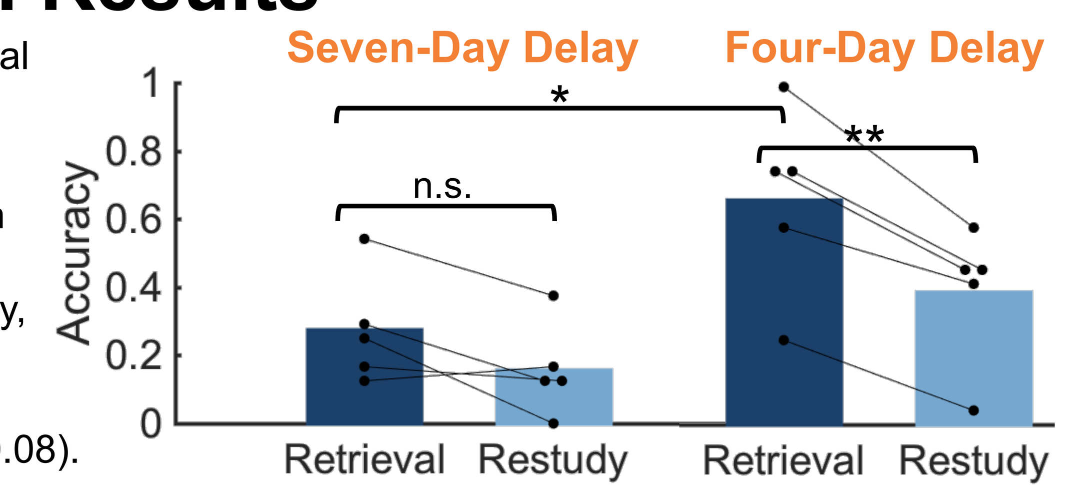
Aims:
1) Replicate behavioral testing effect.
2) Measure neural competition and differentiation as a function of retrieval and restudy using fMRI.
3) Examine how differentiation is related to the behavioral effect.

Methods

3 categories of animals are restudied, while the other 3 categories are retrieved (see RIF paradigm for retrieval trial design).

Based on Hulbert & Norman, 2015

Behavioral Results



- ❖ On-campus behavioral pilot. N = 5 for both conditions.
- ❖ 7-day delay condition shows substantial forgetting; numerically, the results are in the hypothesized testing effect direction ($p = 0.08$).
- ❖ The 4-day delay condition shows overall better memory retention and a strong testing effect.

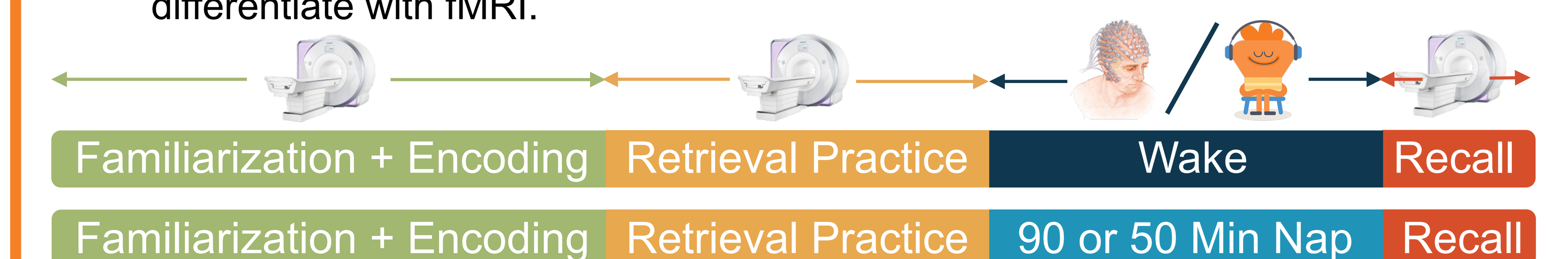
** $p < 0.01$ * $p < 0.05$

Conclusions

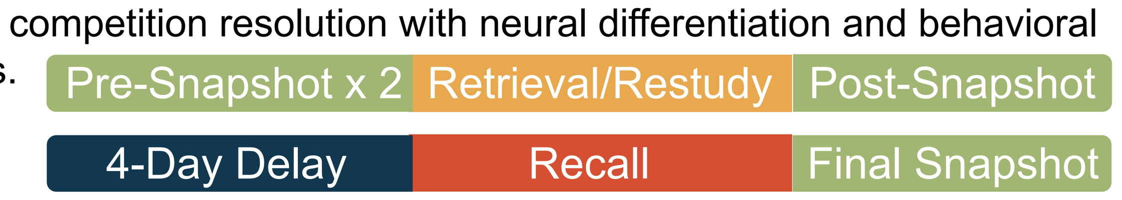
❖ Behavioral effects are observed in both paradigms.
- Although the immediate recall exhibits typical RIF, there is no evidence of RIF effect in the 7-hour delayed recall using current procedure, which contradicts our hypothesis that competitors should be weakened by the moderate activation during the retrieval of the target memory, and that revisiting the damaged competitors during sleep is critical to re-strengthening them.
- All participants in the 4-day delay condition show the testing effect.
- More behavioral data are being collected for the RIF paradigm delayed recall condition and the testing effect paradigm 4-day delay condition to confirm the effects.

Future Directions

❖ Retrieval-Induced Forgetting Paradigm
- Insert a period of sleep or wake between the retrieval practice and the final recall phase.
- Monitor sleep with EEG to examine whether and how different sleep stages recovers memory for Rp- items.
- Explore how neural representations of the competing memories change or differentiate with fMRI.



❖ Testing Effect Paradigm
- Use fMRI to track neural competition over repeated retrievals.
- Compare pre-, post-, and final snapshots to measure neural differentiation of the restudied and the retrieval practiced categories.
- Correlate competition resolution with neural differentiation and behavioral outcomes.



References & Acknowledgment

Baran, B., Wilson, J., & Spencer, R. M. C. (2010). REM-dependent repair of competitive memory suppression. *Experimental Brain Research*, 203(2), 471–477. doi:10.1007/s00221-010-2242-2

Hulbert, J. C., & Norman, K. A. (2015). Neural differentiation tracks improved recall of competing memories following interleaved study and retrieval practice. *Cerebral Cortex*, 25(10), 3994-4008. doi: 10.1093/cercor/bhu284

Newman, E.L., & Norman, K.A. (2010). Moderate excitation leads to weakening of perceptual representations. *Cerebral Cortex*, 20(11), 2760–2770. doi:10.1093/cercor/bhq021

This research is funded by NIH R01-MH069456 (K.A.N). This research was made possible by the generous support of the OURSIP program.

Contact: yechenh@princeton.edu