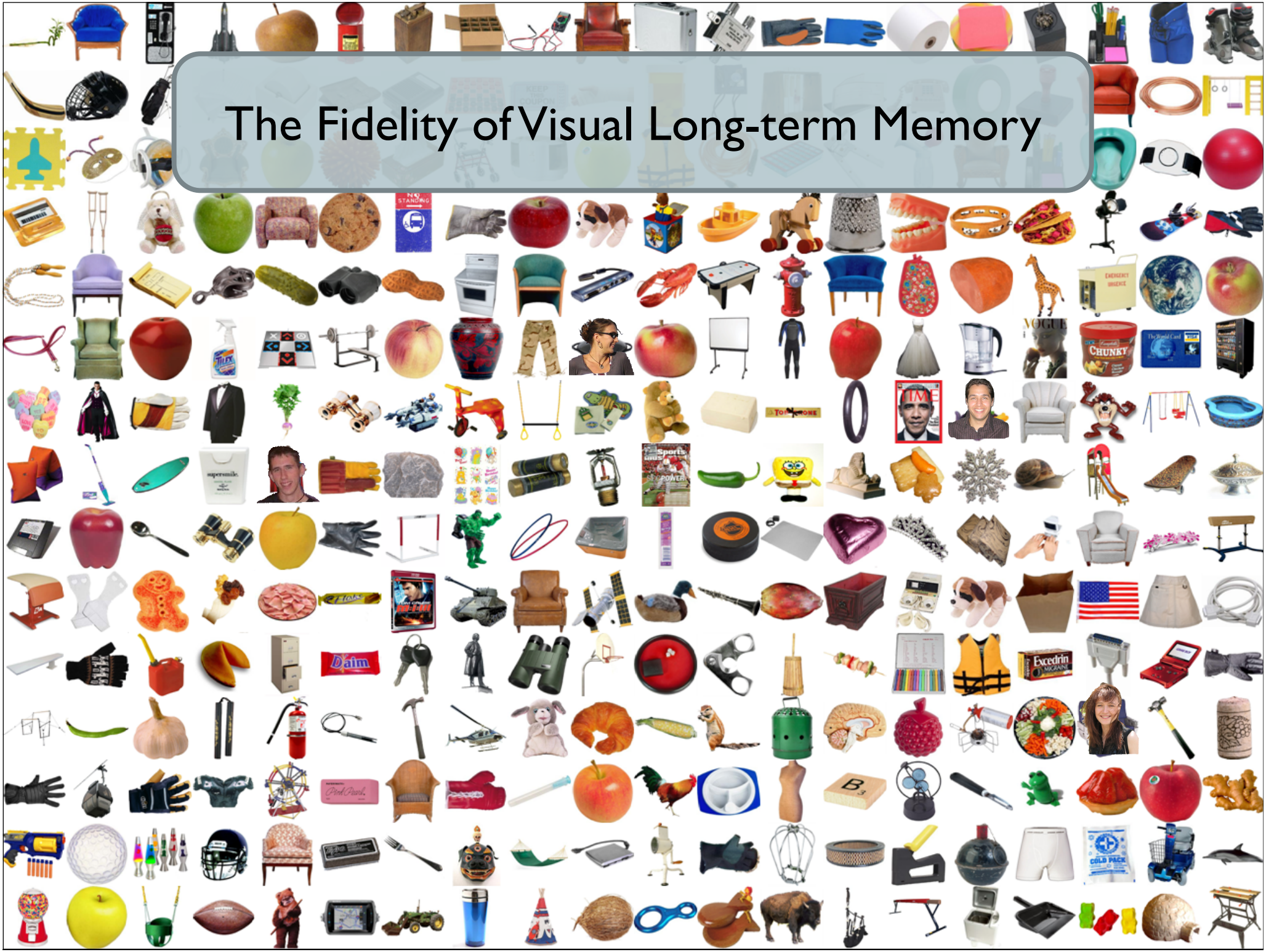
The Fidelity of Visual Long-term Memory

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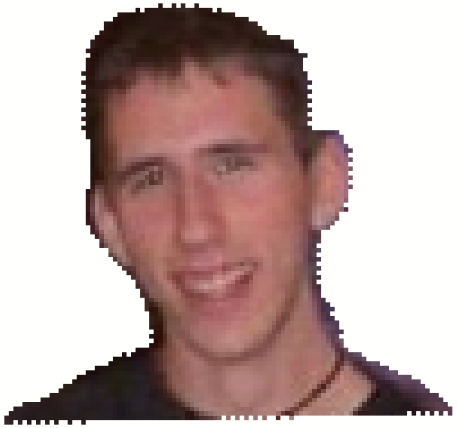


Tim Brady

Talia Konkle

George Alvarez

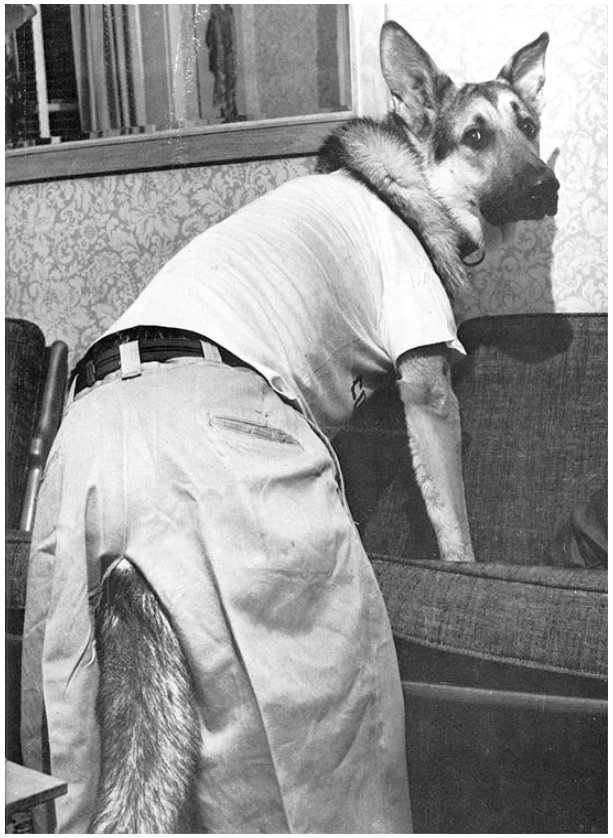
Aude Oliva

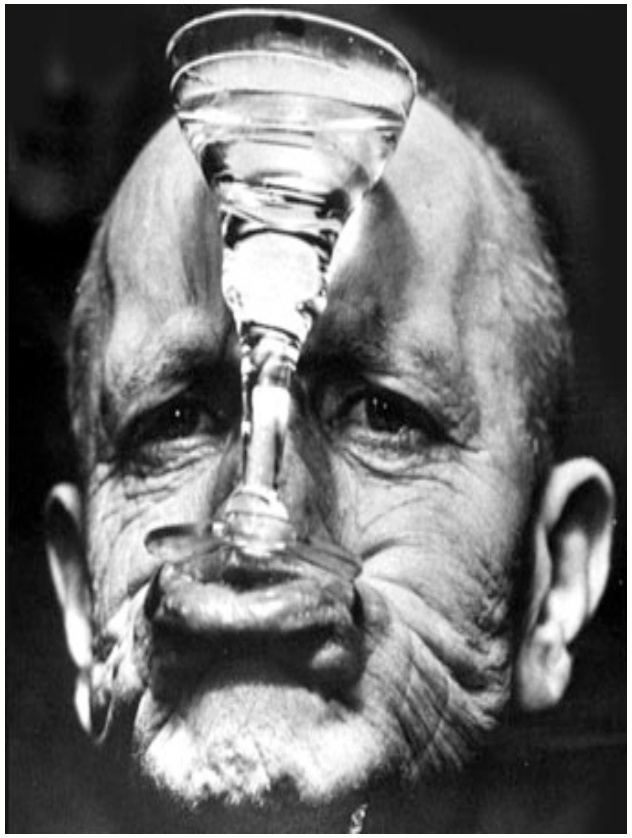
Vision Sciences Lab 2.0

Role of Memory in Vision

Role of Memory in Vision

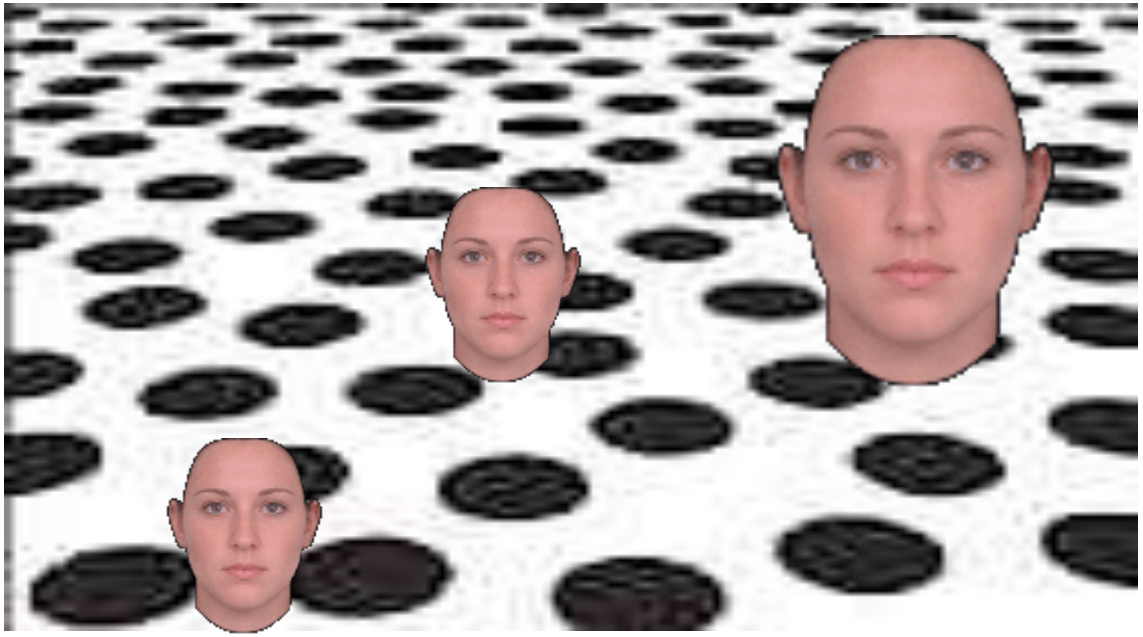
Determines What You See Things "As"





Role of Memory in Vision

Basis for Inference About the World



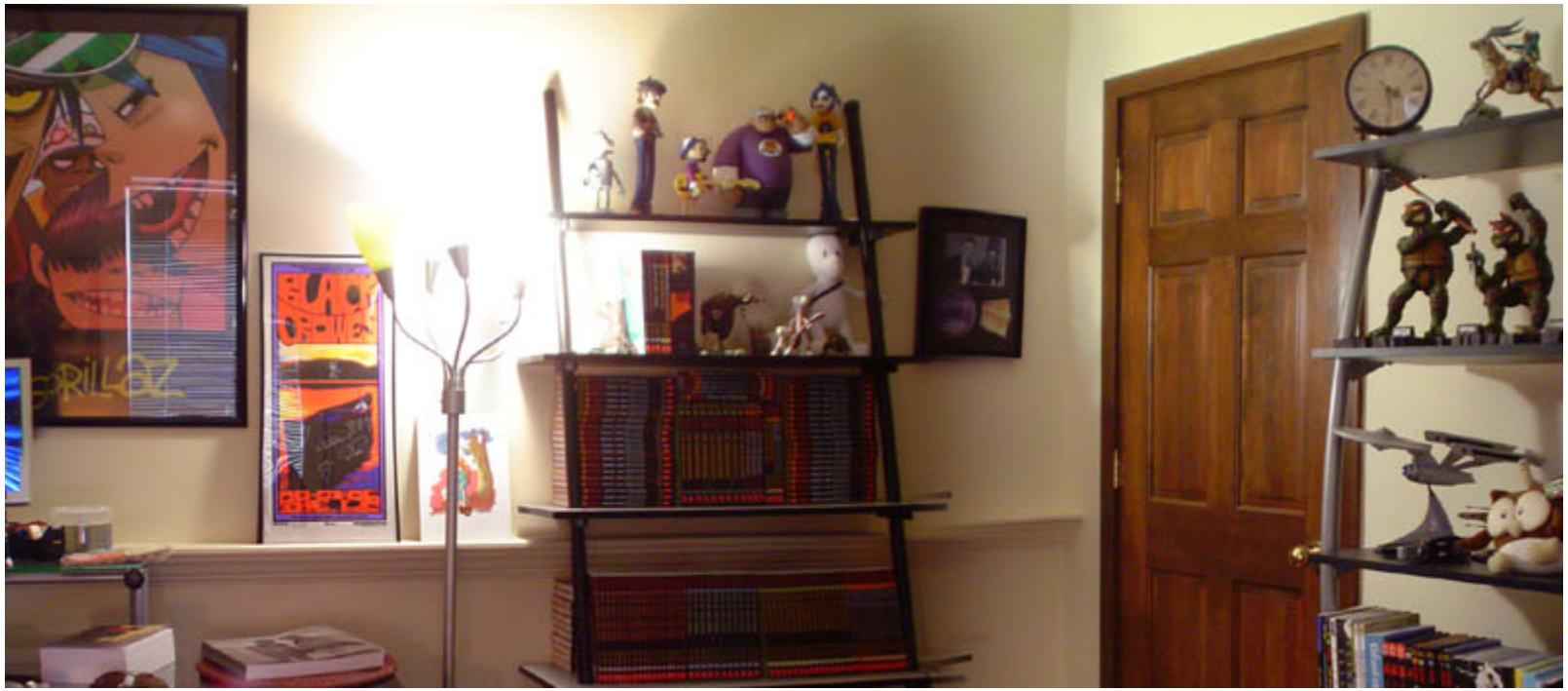
Role of Memory in Vision

Interacts With Perceptual Organization

Vision Provides Many Inputs to Potentially Remember

Vision Provides Many Inputs to Potentially Remember

2-3 Eye Movements Per Second



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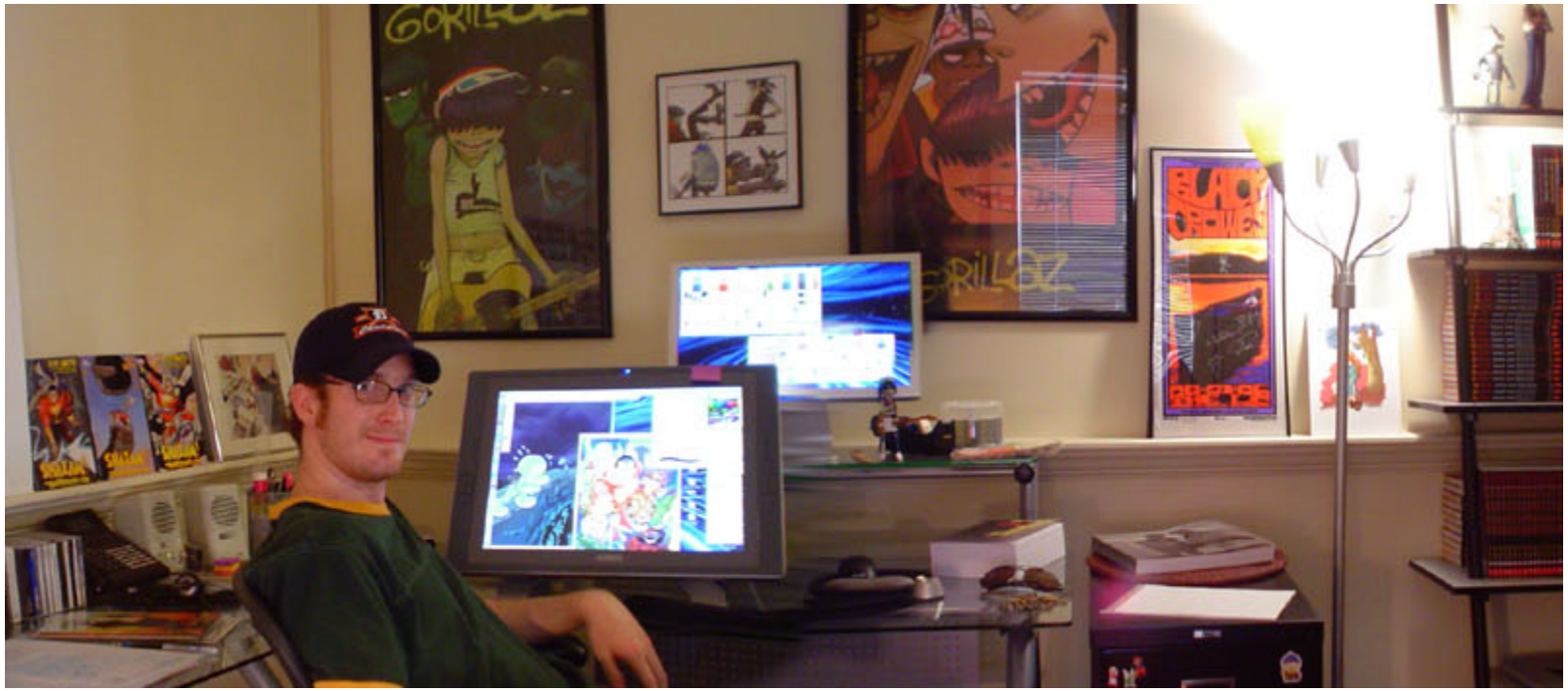

Vision Provides Many Inputs to Potentially Remember

Fixating Many Different Objects

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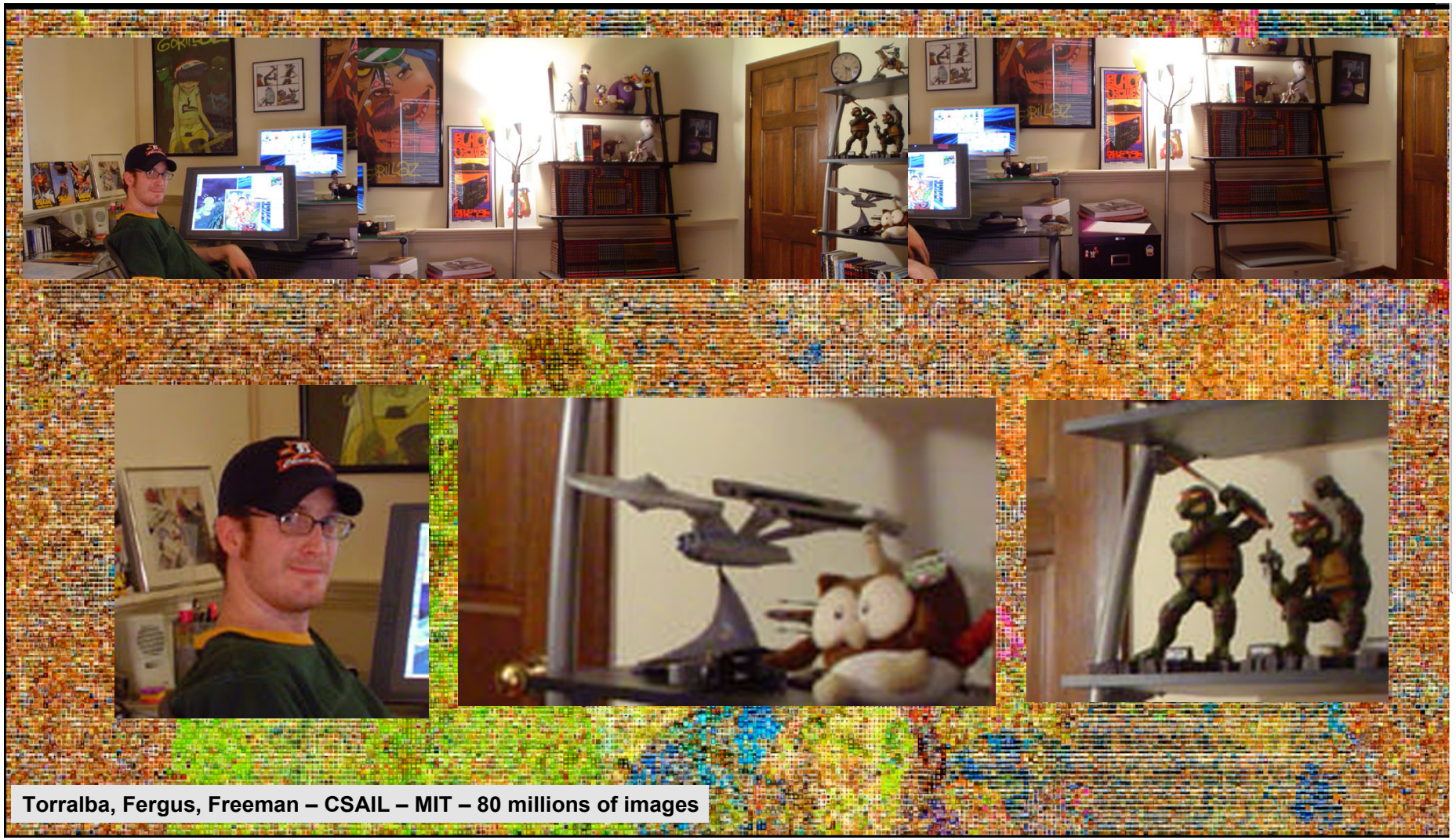
Fixating Many Different Objects

Vision Provides Many Inputs to Potentially Remember

~~165,000 Images Per Day~~



Torralba, Fergus, Freeman – CSAIL – MIT – 80 millions of images

What Should a Memory System do With This?

Remember them all sparsely?

Remember few with high detail?

Remember them ALL with high detail?

Remember them ALL with selective details? If so, which details?

The Broad Motivation

Understand Capacity and Fidelity of LTM

LTM informs "online" visual perception

Understanding these aspects of LTM is integral to understanding "online" visual processing

How visual perception interfaces with LTM

NOT going to answer these questions today

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LTM informs "online" visual perception

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How visual perception interfaces with LTM

NOT going to answer these questions today

Outline

1. Detailed Memory for Thousands of Objects
2. Comparing the Fidelity of Perception, Short-term Memory, & Long-term Memory
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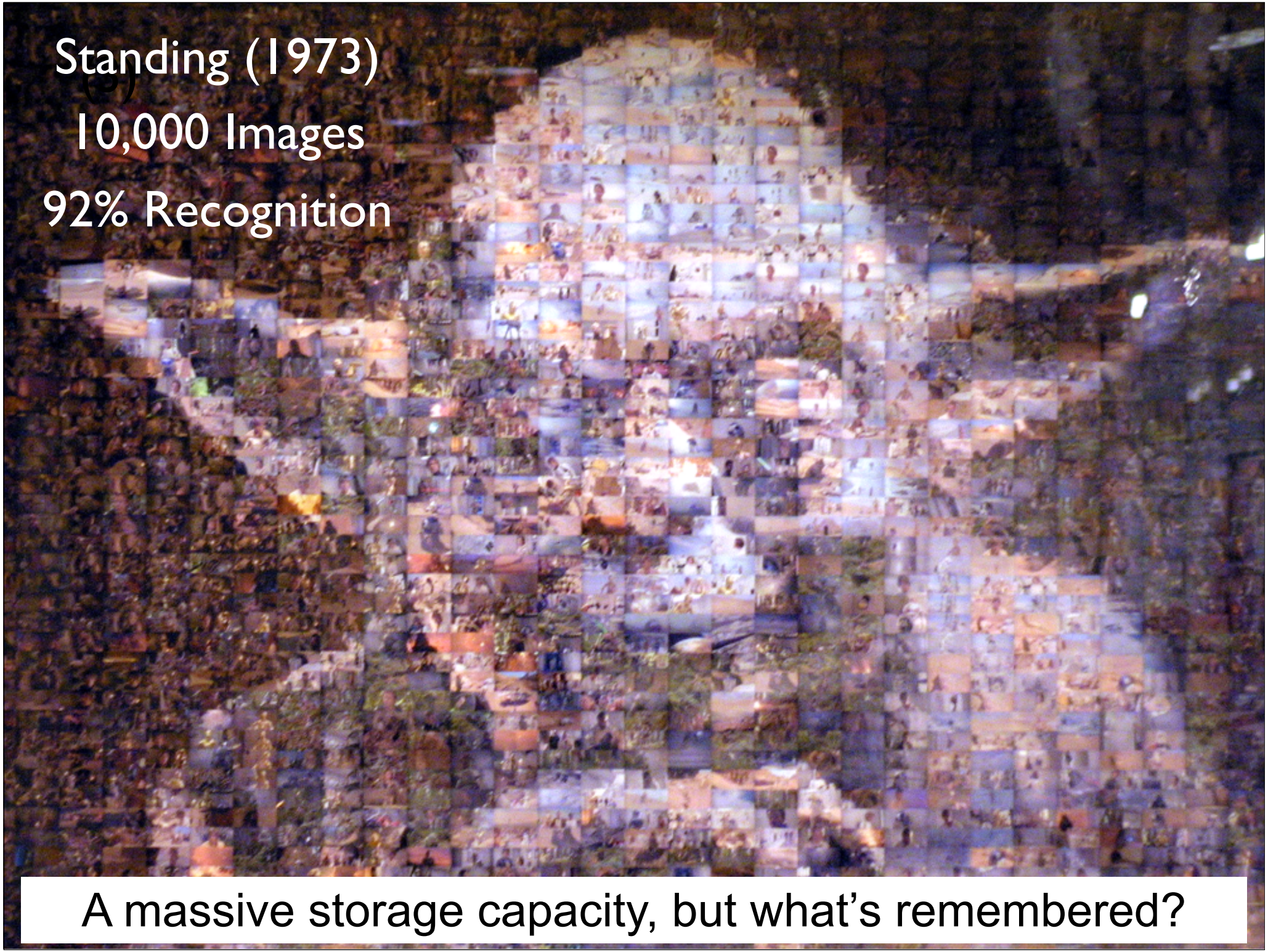
3 Preliminary Insights into the Temporal Dynamics of Encoding

How Much Can You Remember About What You See?

Thousands of Objects



A massive storage capacity, but what's remembered?

Standing's Image Set

According to Standing

"Basically, my recollection is that we just separated the pictures into distinct thematic categories: e.g. cars, animals, single-person, 2-people, plants, etc.) Only a few slides were selected which fell into each category, and they were visually distinct."

Standing's Image Set

According to Standing

"Basically, my recollection is that we just separated the pictures into distinct thematic categories: e.g. cars, animals, single-person, 2-people, plants, etc.) Only a few slides were selected which fell into each category, and they were visually distinct."

Could Span A Huge Range of Conceptual Space

“Old” or “New”?

“Old” or “New”?

But What Did You Remember?

Highly Detailed

Sparse Details

Dogs
Playing Cards

"Gist" Only

Vary Similarity to Probe Contents of Memory

Exactly which wedding did you see?

Experiment 1

Showed observers 2500 unique objects

1 at a time, 3 seconds each

800 ms blank between items

Study session lasted about 5.5 hours

N-back task to maintain focus

Followed by 300 2-alternative forced choice tests

Experiment 1 - Subject Instructions

Completely different objects...

Different instance of the same kind of object...

Different state of the same object...

Experiment 1 - Conditions Varying In Similarity

Completely different objects...

Different instance of the same kind of object...

Different state of the same object...

"Novel"
Requires "Gist"

<

"Exemplar"
More Details

<

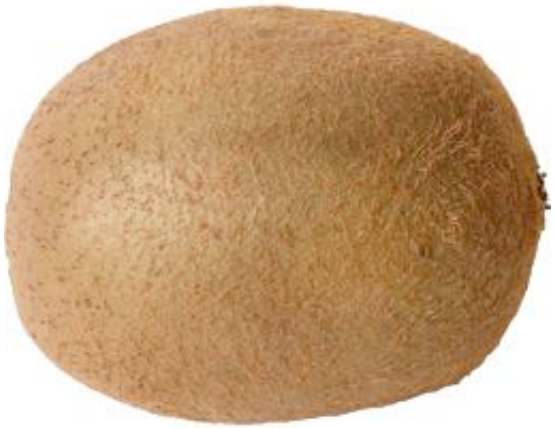
"State"
Even More Details

Experiment 1 - Demonstration

10 Minutes Later...

30 Minutes Later...

1 Hour Later...




POLICE

2 Hours Later...

4 Hours Later...


PURE
MAPLE SYRUP
540 mL

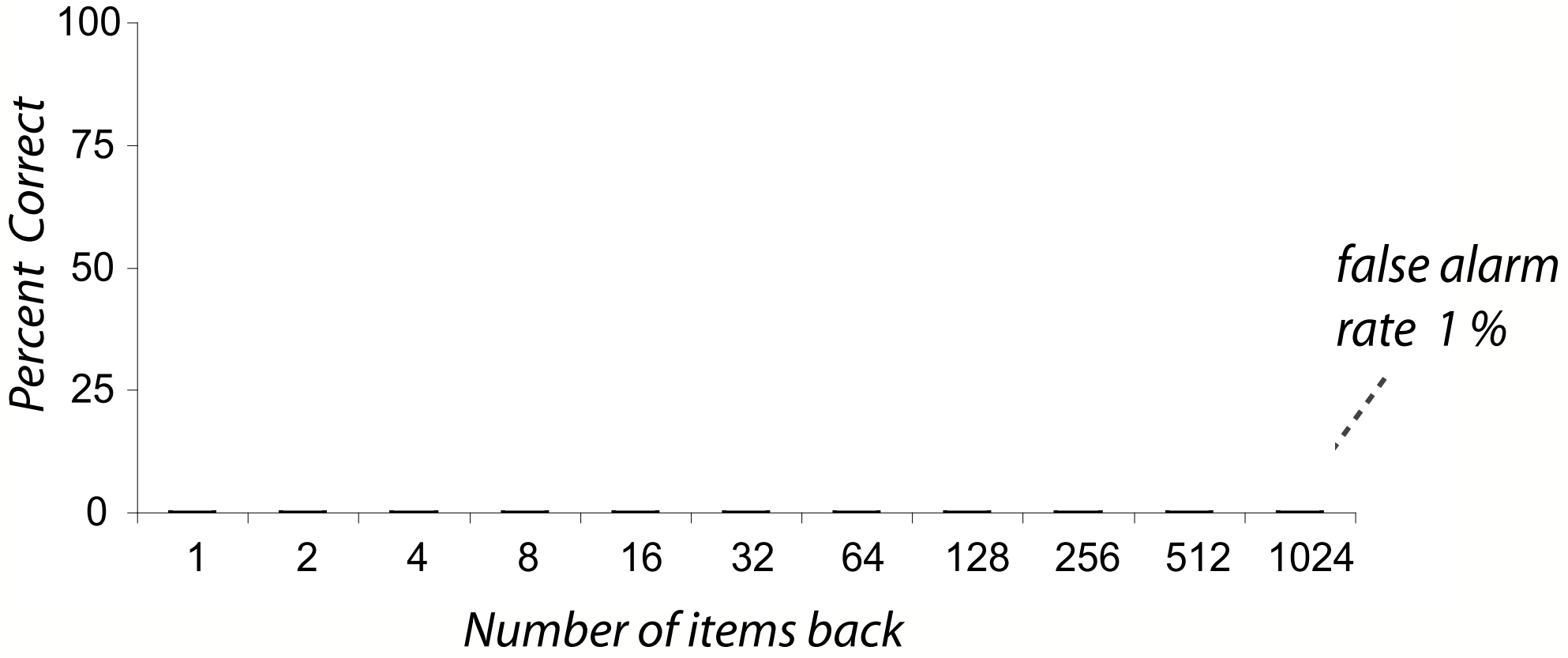

FM
SW
STANDARD
FM/AM

5:30 Hours Later...

Experiment 1 - Results

Experiment 1 - Results, Repetition Detection

High Detection Rate, Even at 1024-back!



Experiment 1 - Results, Recognition Performance

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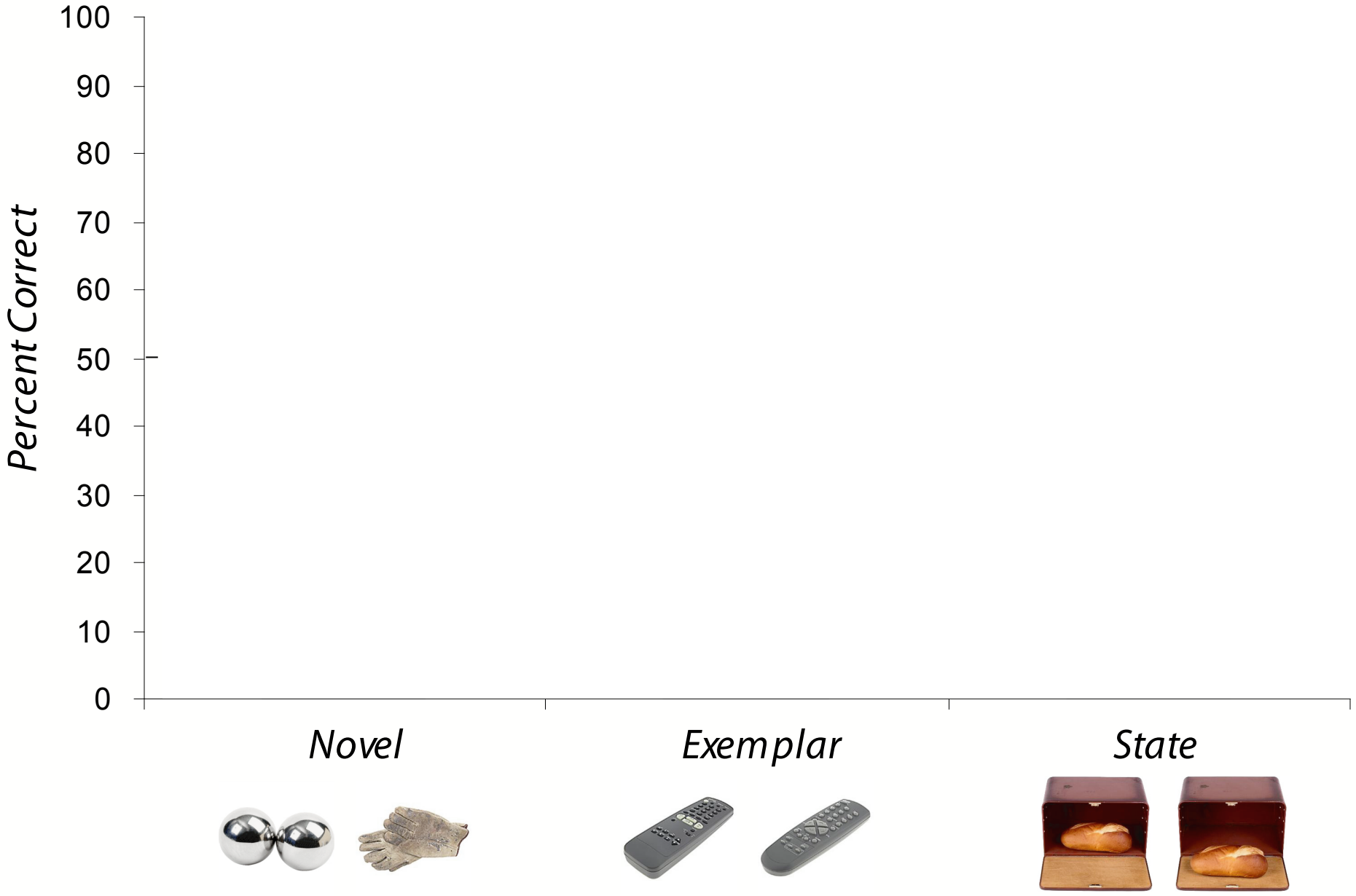
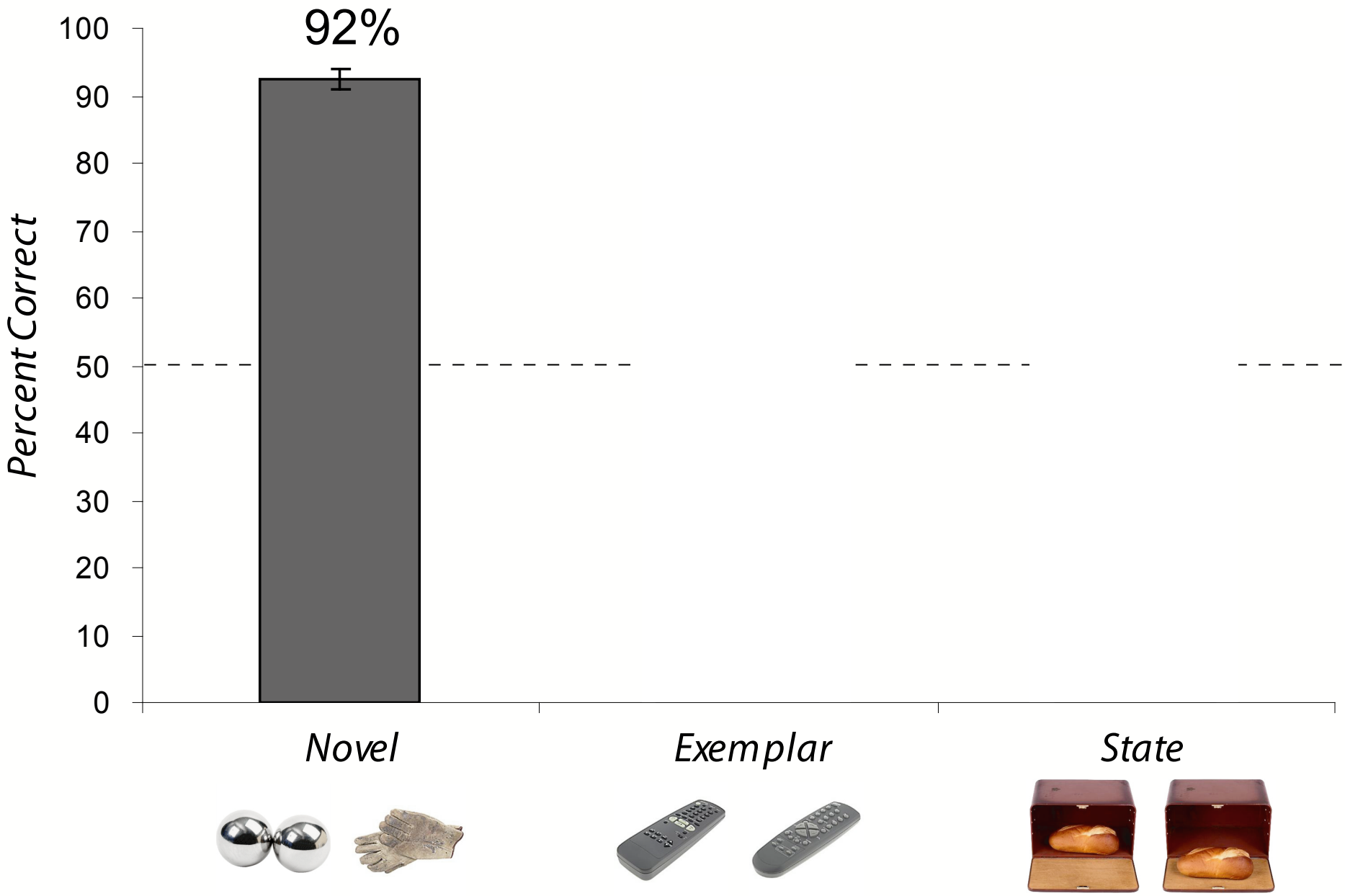
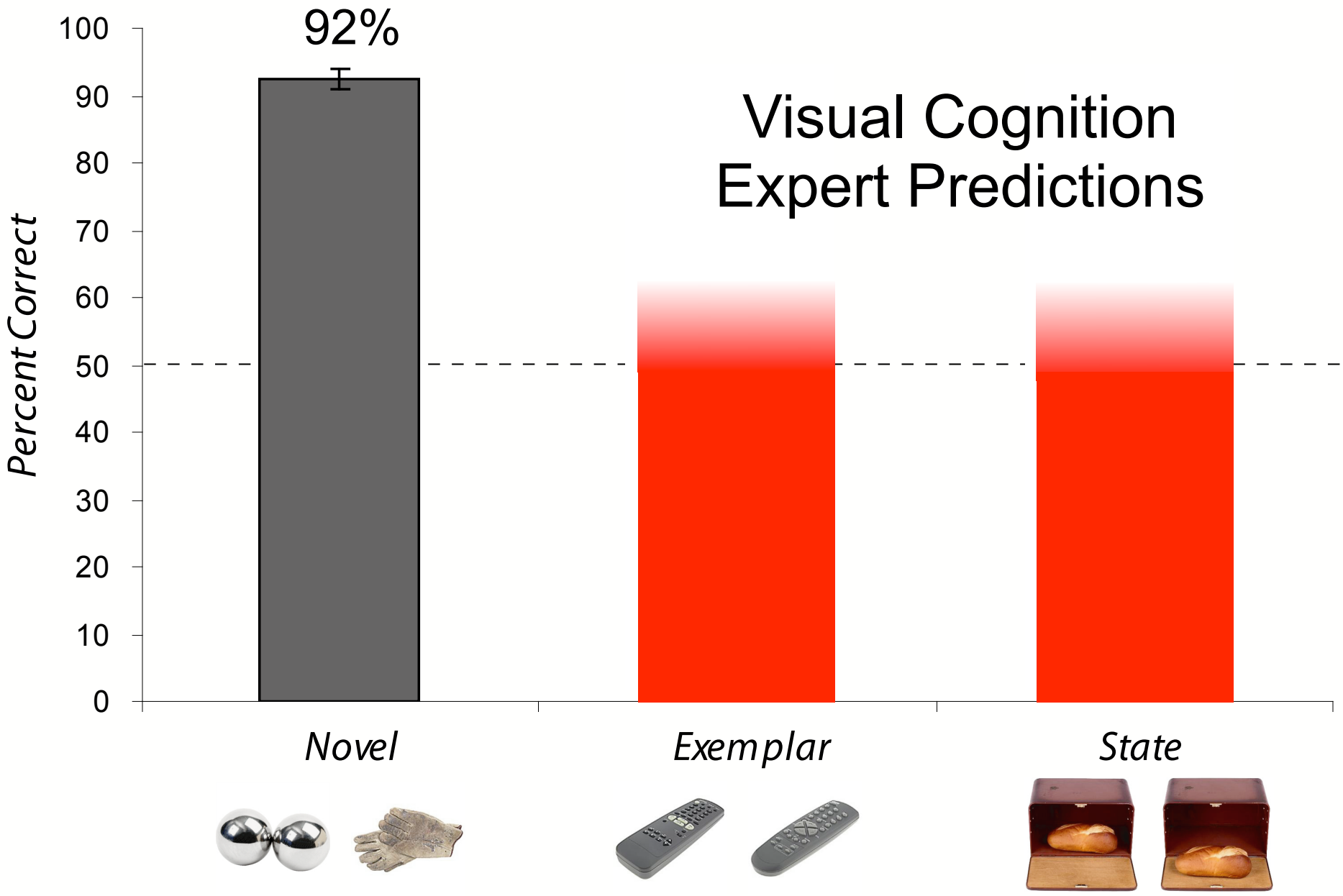


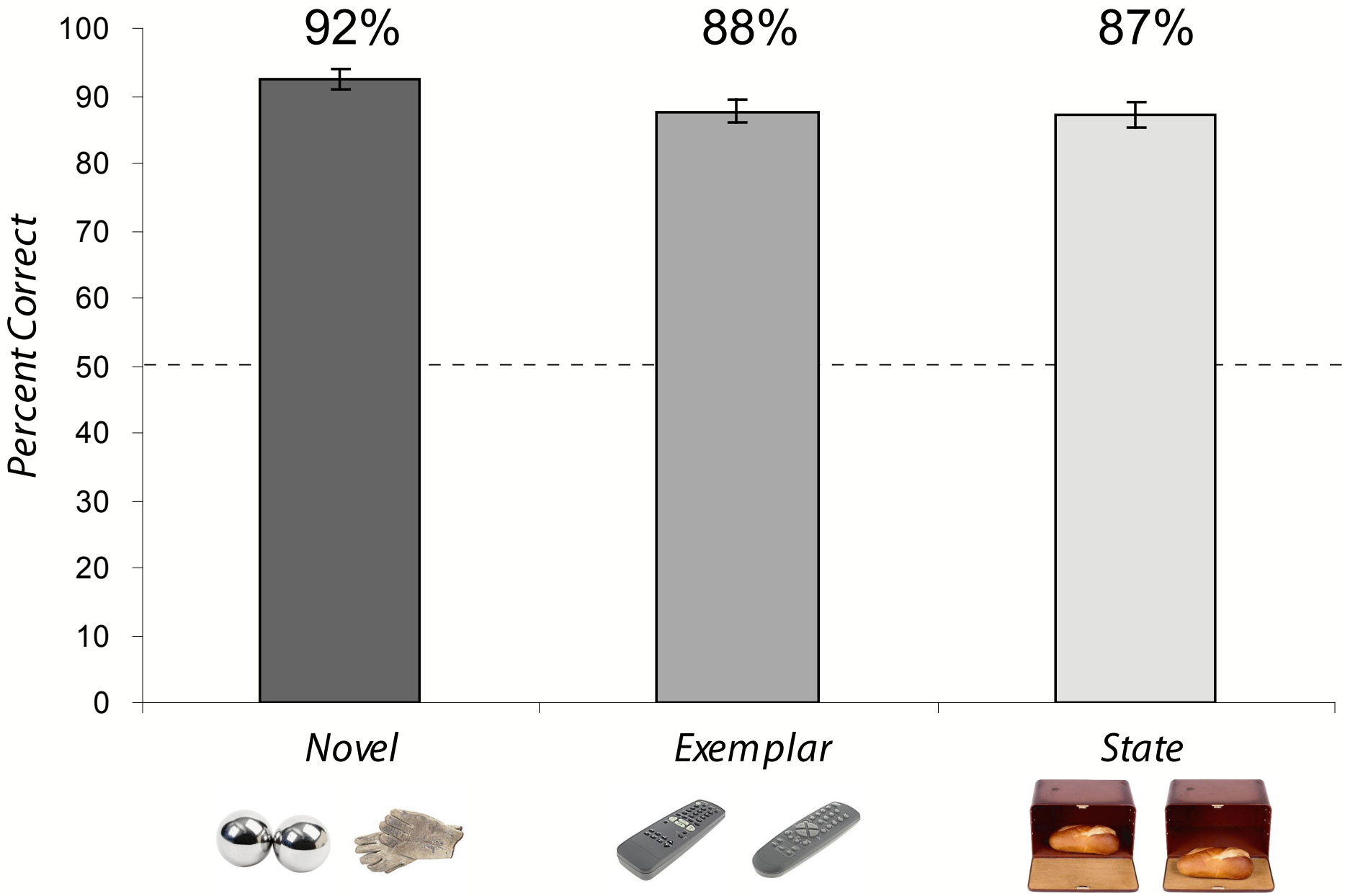
Experiment 1 - Results, Recognition Performance



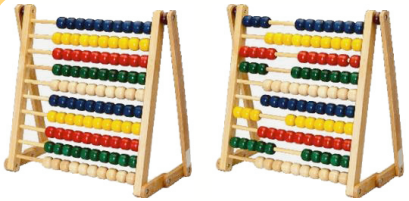
Experiment 1 - Results, Recognition Performance



Experiment 1 - Results, Recognition Performance



Experiment 1 - Results, Recognition Performance

Novel	*Exemplar*	*State*
 14 / 14	 13 / 14	 13 / 14
 13 / 14	 14 / 14	 12 / 14
 12 / 14	 12 / 14	 13 / 14
 14 / 14	 13 / 14	 12 / 14
 14 / 14	 14 / 14	 14 / 14

Experiment 1 - Results, Recognition Performance

Novel	*Exemplar*	*State*
  12 / 14	  13 / 14	  14 / 14
  12 / 14	  10 / 14	  11 / 14
  13 / 14	  12 / 14	  13 / 14
  14 / 14	  9 / 14	  12 / 14
  14 / 14	  11 / 14	  11 / 14

Summary & Interim Conclusions

LTM can hold a massive number of items

The fidelity of storage is high

Much higher than previously believed

But exactly how accurate are these representations?

How would it compare to the fidelity of perception (upper bound) or short-term memory (upper bound for memory)

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2. Comparing the Fidelity of Perception, Short-term Memory, & Long-term Memory

Qualitative Manipulation of "Required Fidelity"

Completely different objects...

Different instance of the same kind of object...

Different state of the same object...

"Novel"
Requires "Gist"

<

"Exemplar"
More Details

<

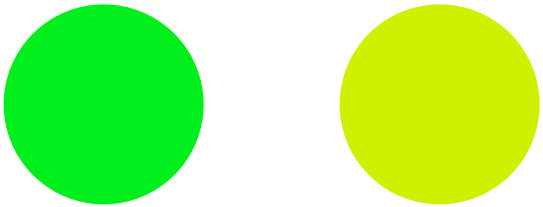
"State"
Even More Details

A Continuous Measure of Fidelity

How Well Can Observers Perceive and Remember the Color of Objects?

A Continuous Measure of Fidelity

Typically Assessed With Color Patches...



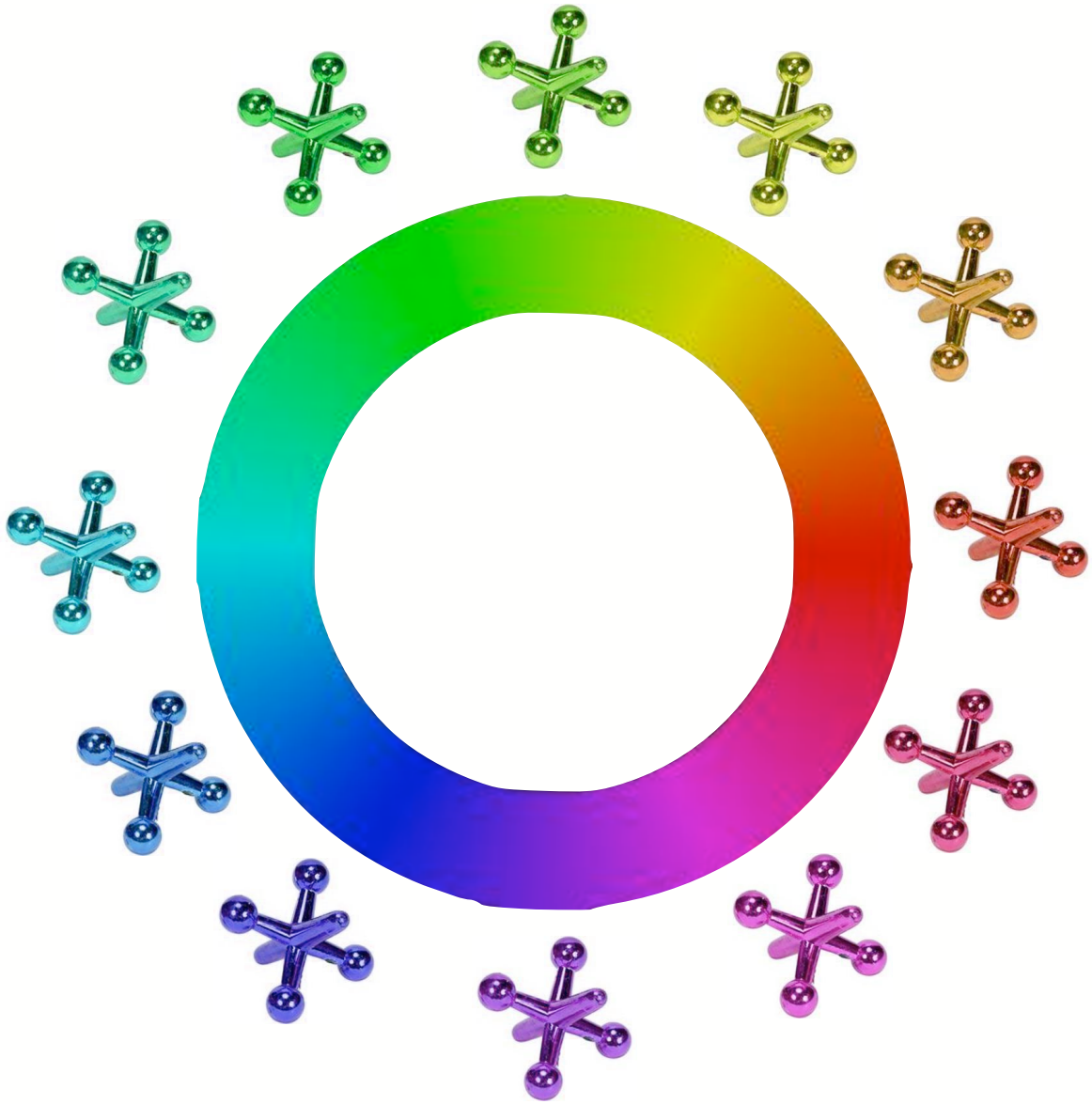
But you cannot do the long-term memory experiment with color patches

A Continuous Measure of Fidelity

So we're going to use real objects...

A Continuous Measure of Fidelity

A Continuous Measure of Fidelity

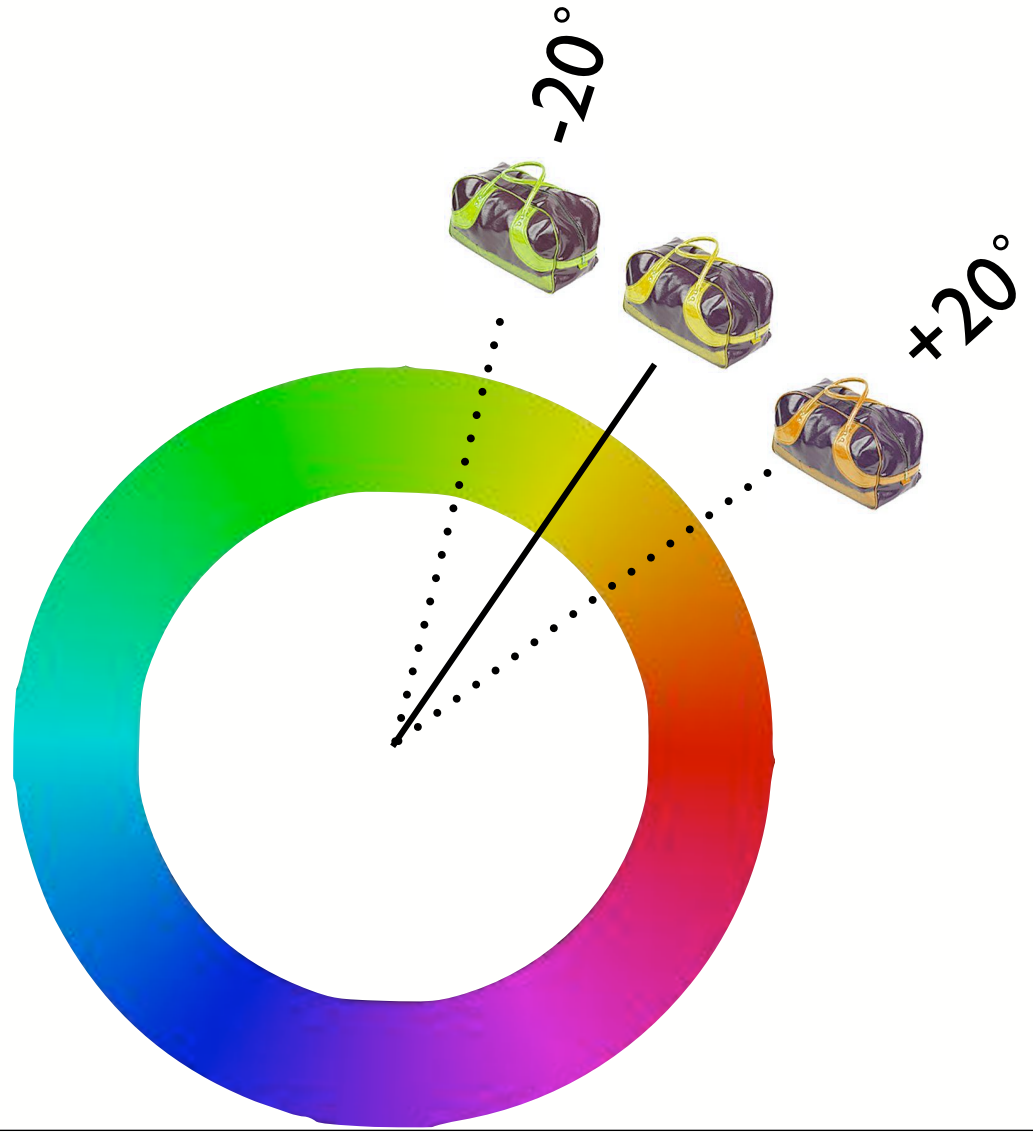


Perceptual Task

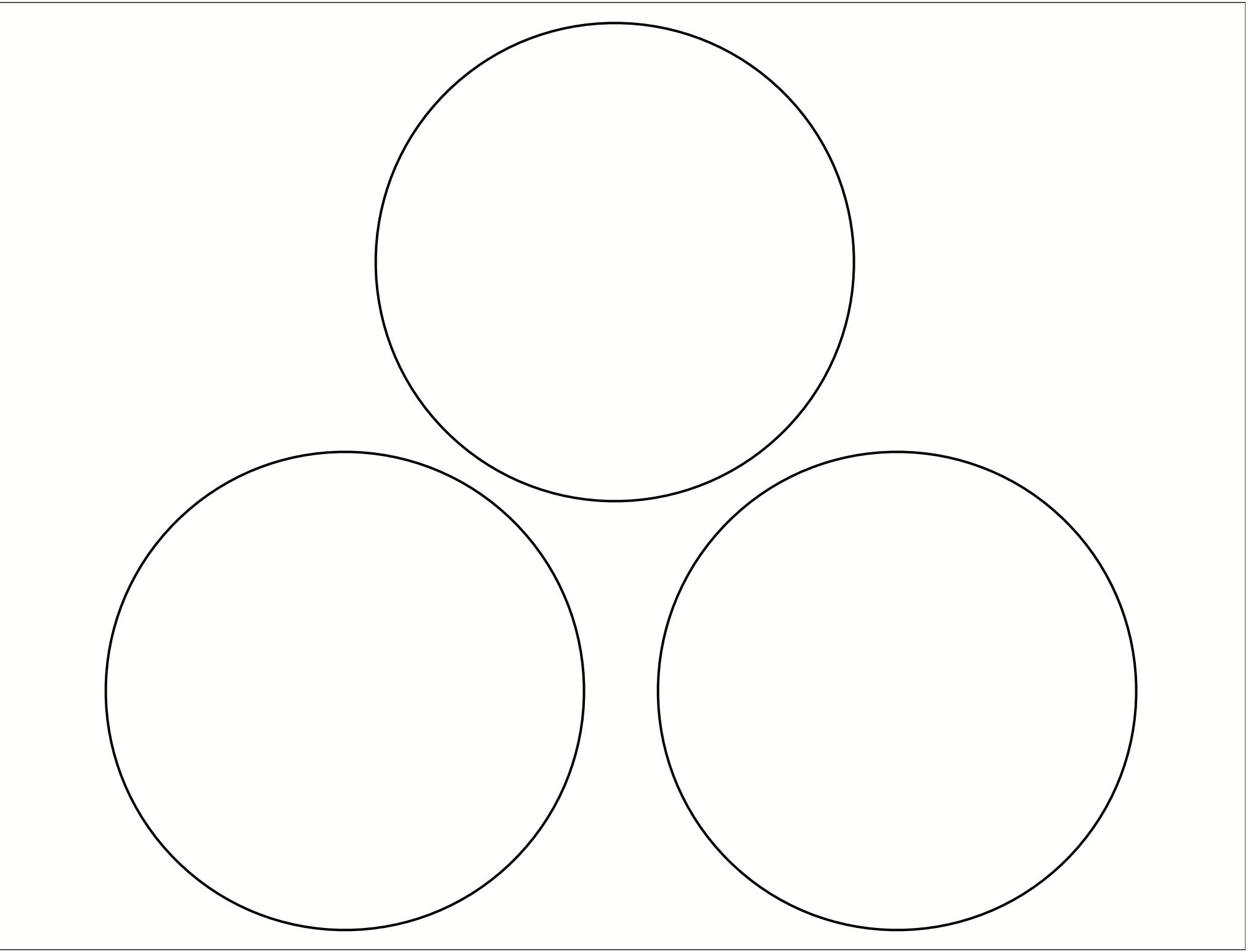
Perceptual Task

A Continuous Measure of Fidelity

Error = Angular Difference Between
Target Hue and Color Setting



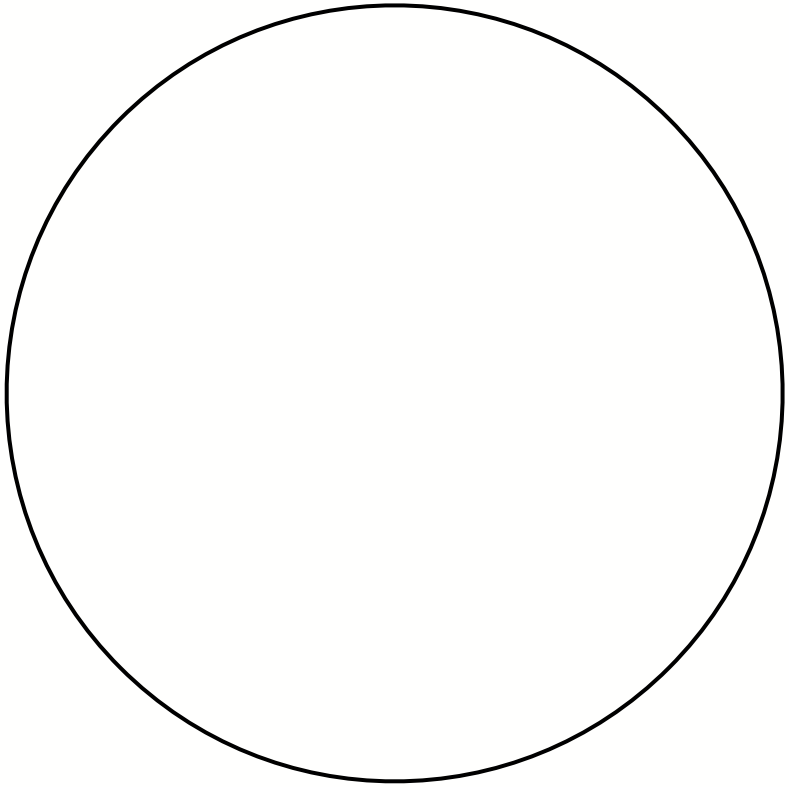
Short-term Memory Task, Remember 3 Items



Long-term Memory Task, Remember 180 Items

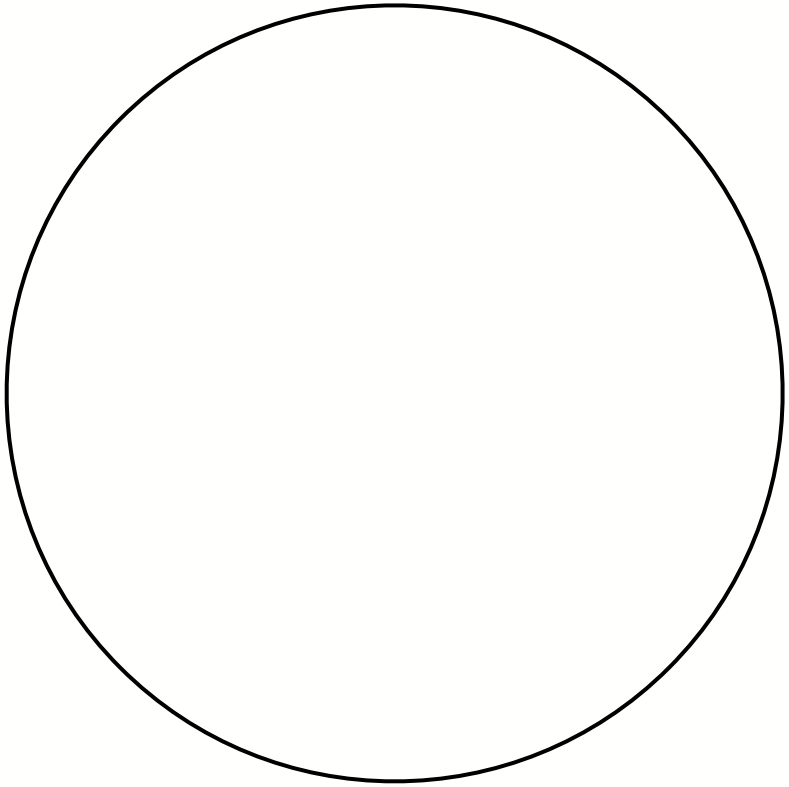
Long-term Memory Task, Remember 180 Items

Long-term Memory Task, Remember 180 Items



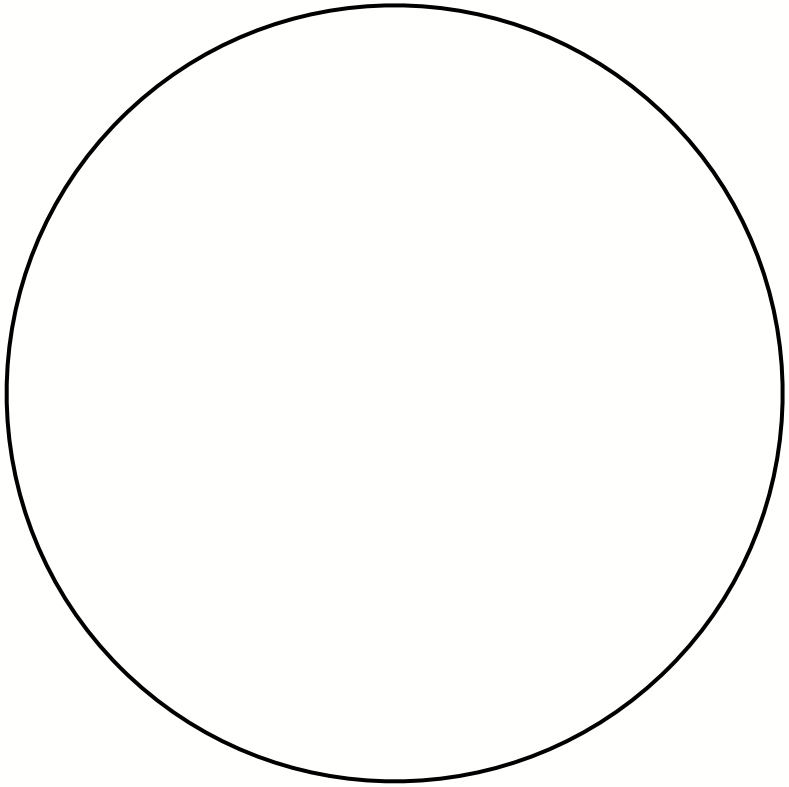
Long-term Memory Task, Remember 180 Items

Long-term Memory Task, Remember 180 Items



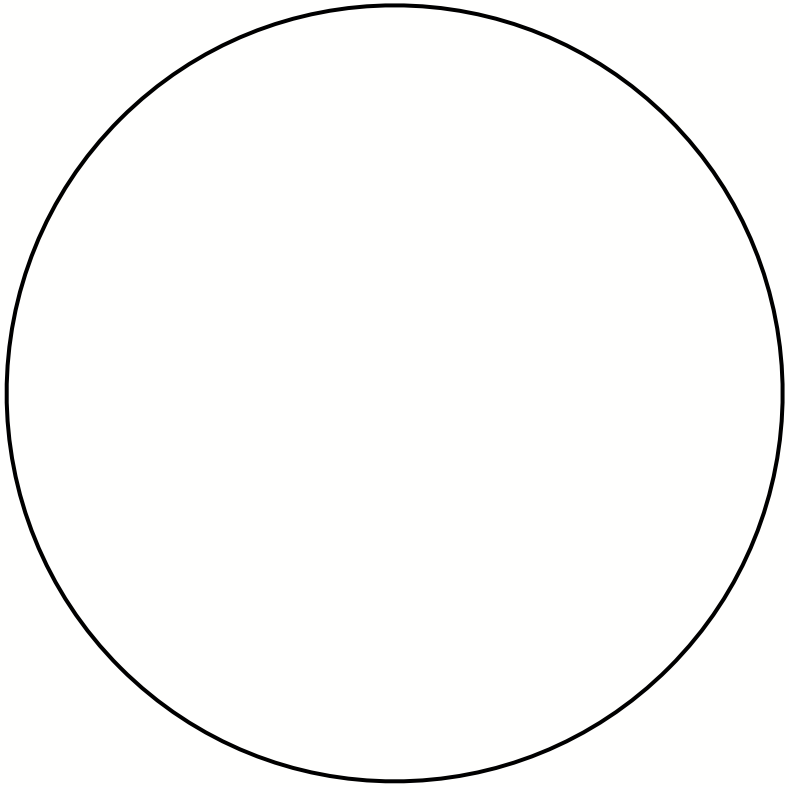
Long-term Memory Task, Remember 180 Items

Long-term Memory Task, Remember 180 Items



Long-term Memory Task, Remember 180 Items

Long-term Memory Task, Remember 180 Items



Long-term Memory Task, Remember 180 Items

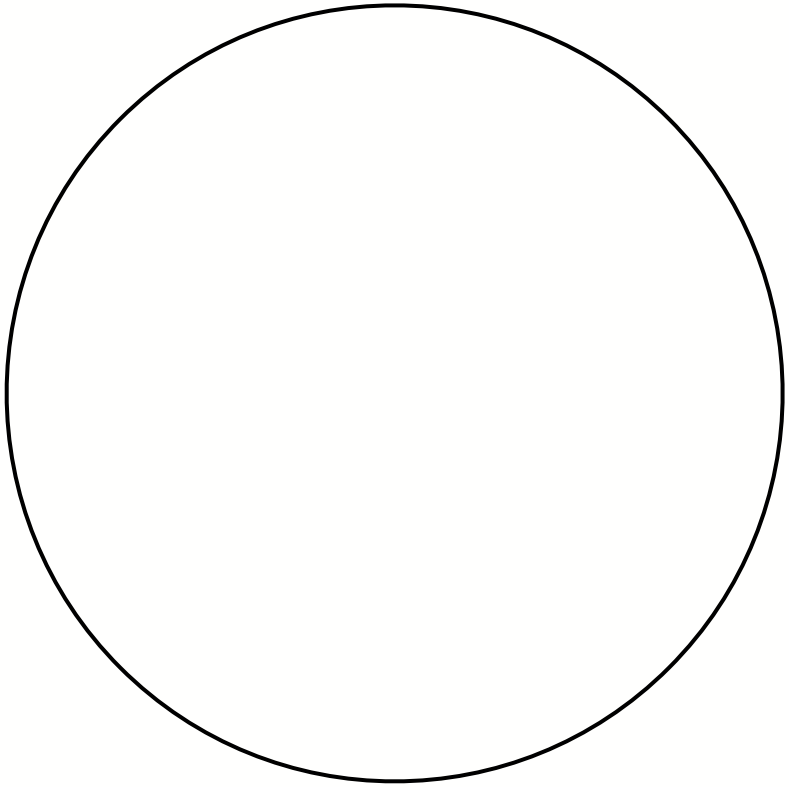
Long-term Memory Task, Remember 180 Items

...About 20 Minutes Later

Long-term Memory Task, Remember 180 Items

Long-term Memory Task, Remember 180 Items

Long-term Memory Task, Remember 180 Items



Long-term Memory Task, Remember 180 Items

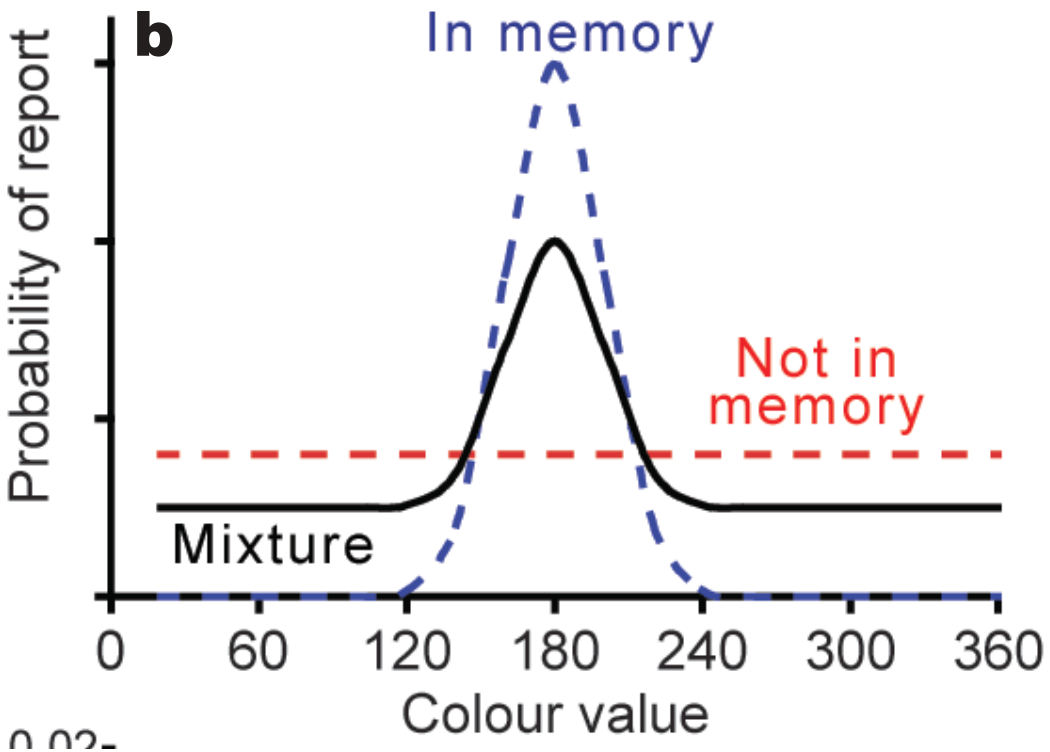
Long-term Memory Task, Remember 180 Items

Long-term Memory Task, Remember 180 Items

tested on all 180 objects

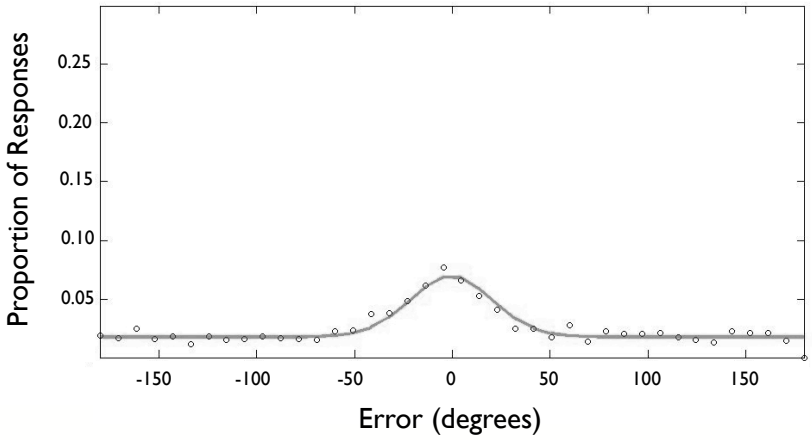
Mixture Modeling Analysis

Introduced by Zhang & Luck (2008)

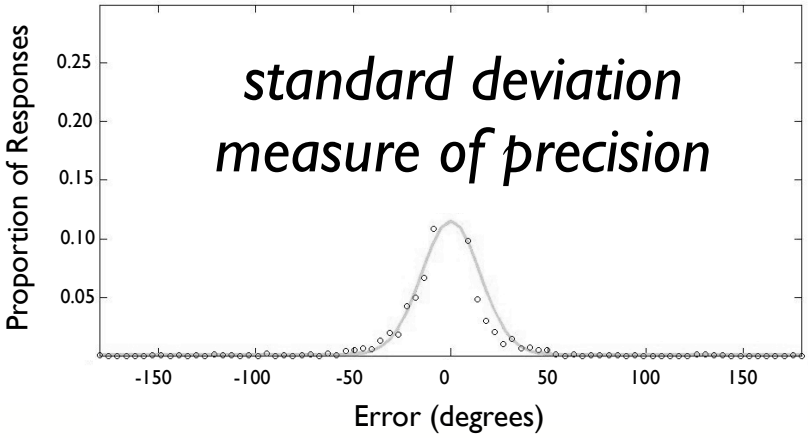


Mixture Modeling Analysis

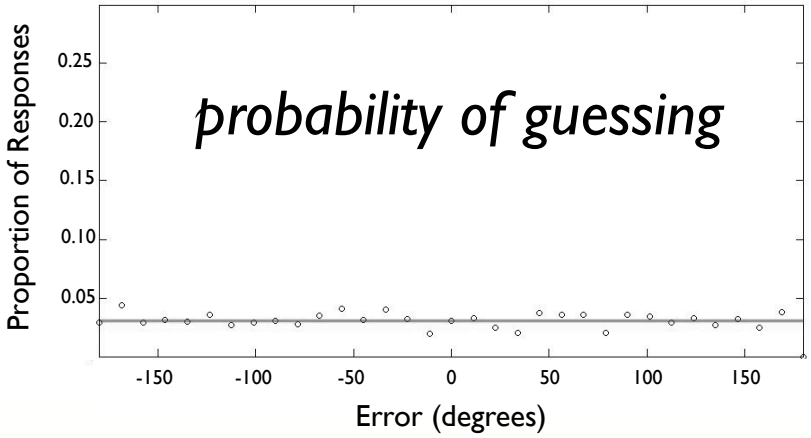
Observed Data



Gaussian (von mises)



Uniform



Experiment 2: A Continuous Measure of Fidelity

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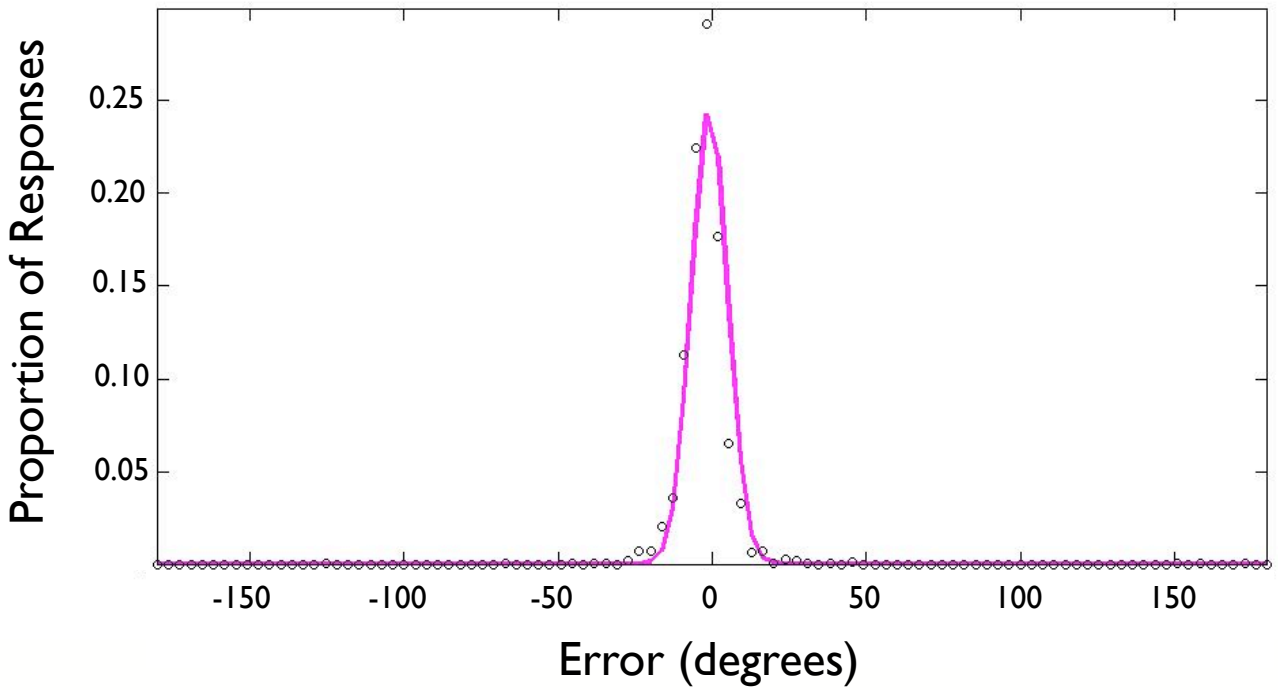
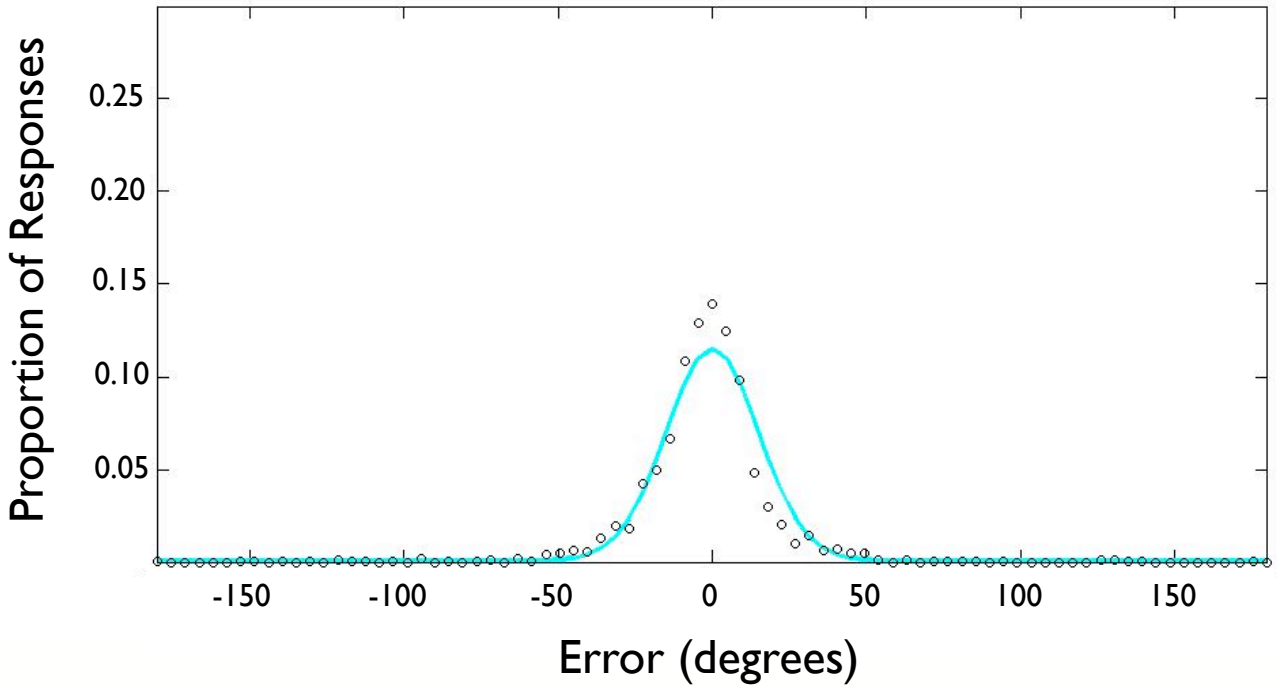
Perceptual Task: Group Model Fit



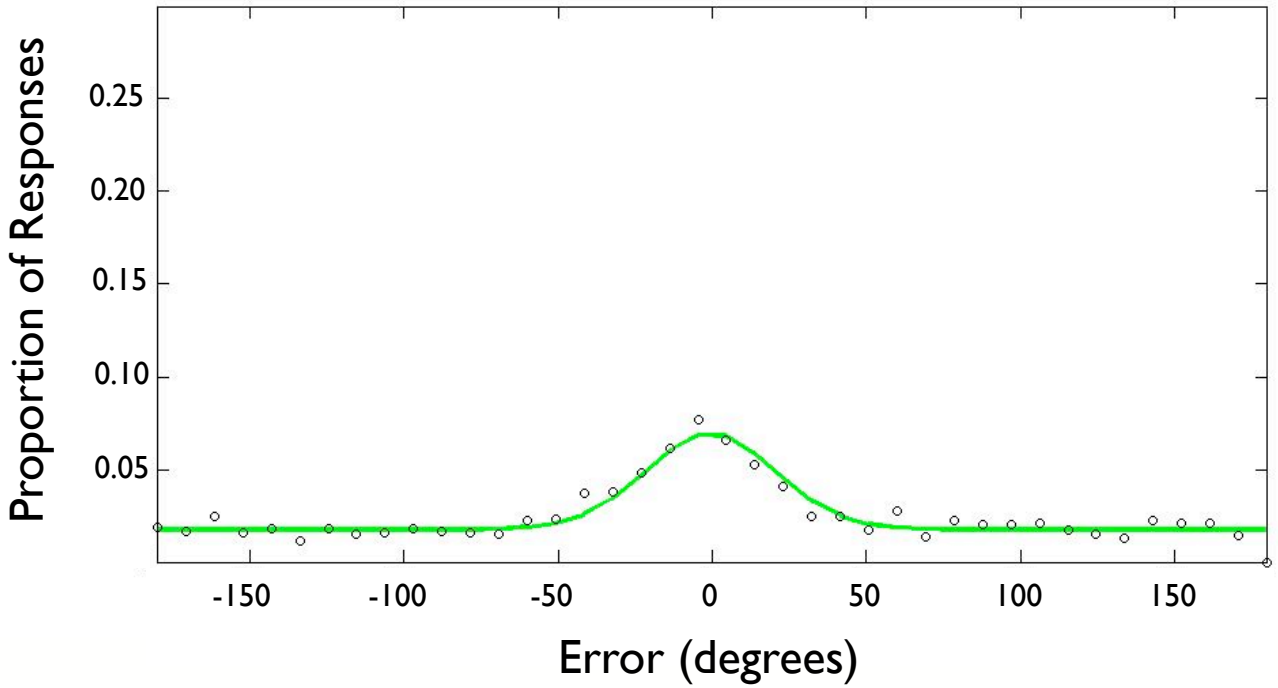
Experiment 2: A Continuous Measure of Fidelity

Short-term Memory Task: Group Model Fit



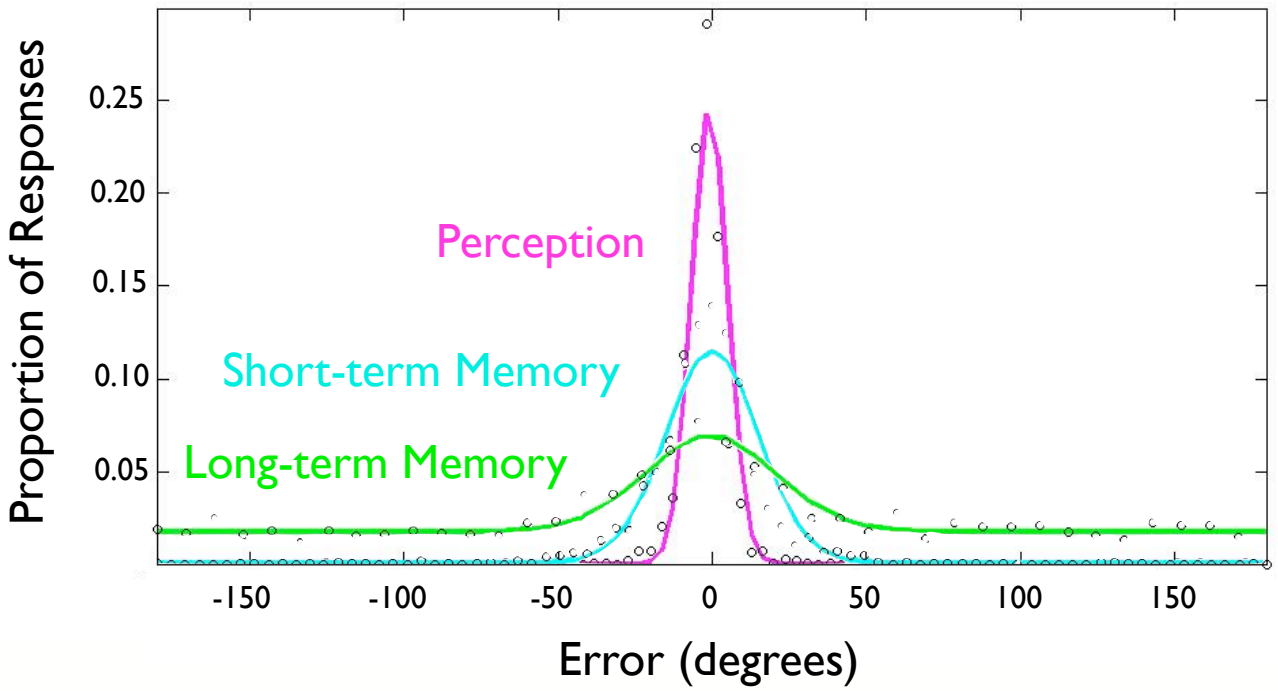
Experiment 2: A Continuous Measure of Fidelity

Long-term Memory Task: Group Model Fit



Experiment 2: A Continuous Measure of Fidelity

Summary Group Model Fits



Mixture Modeling Analysis

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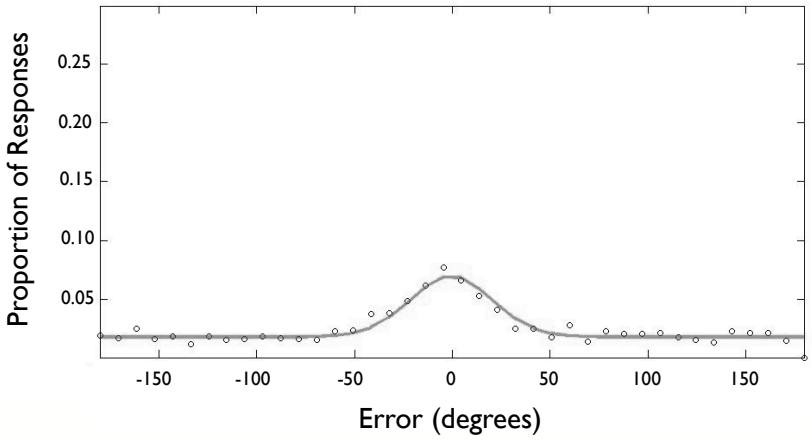

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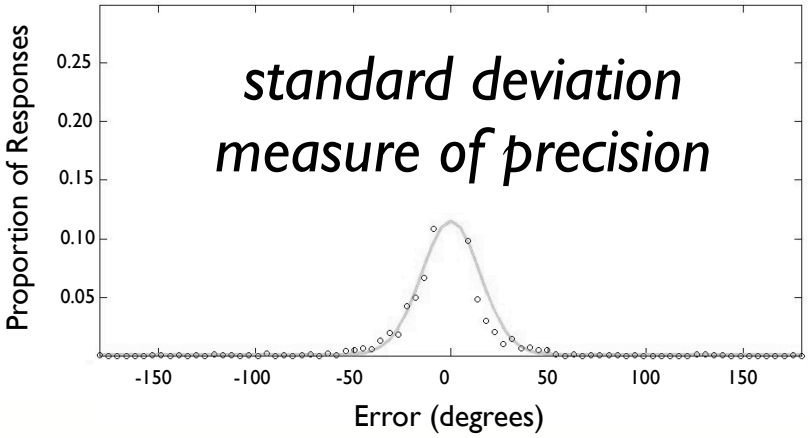
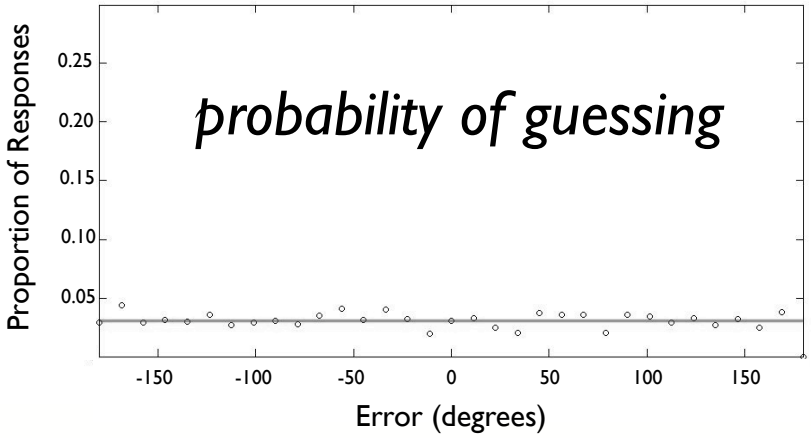


Uniform



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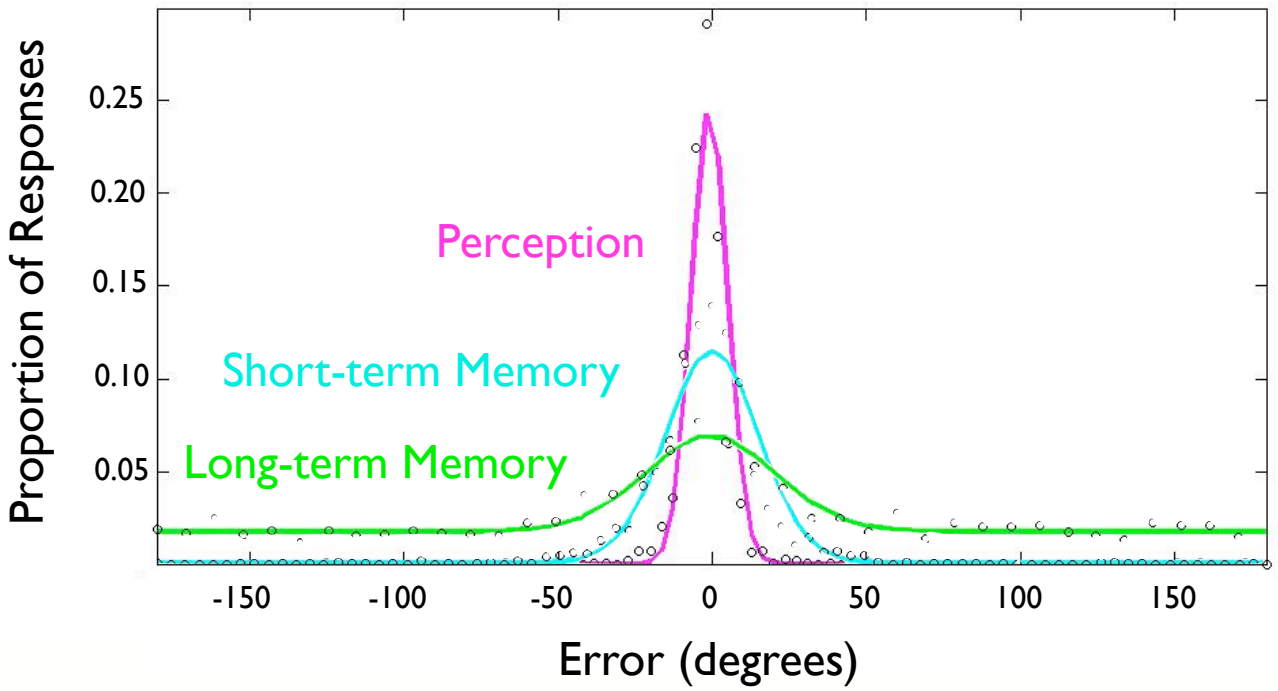
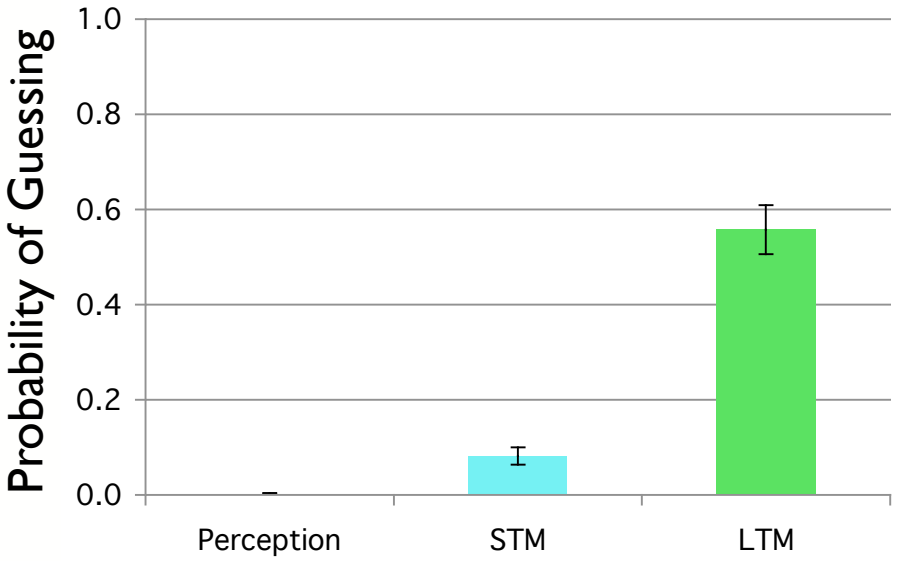


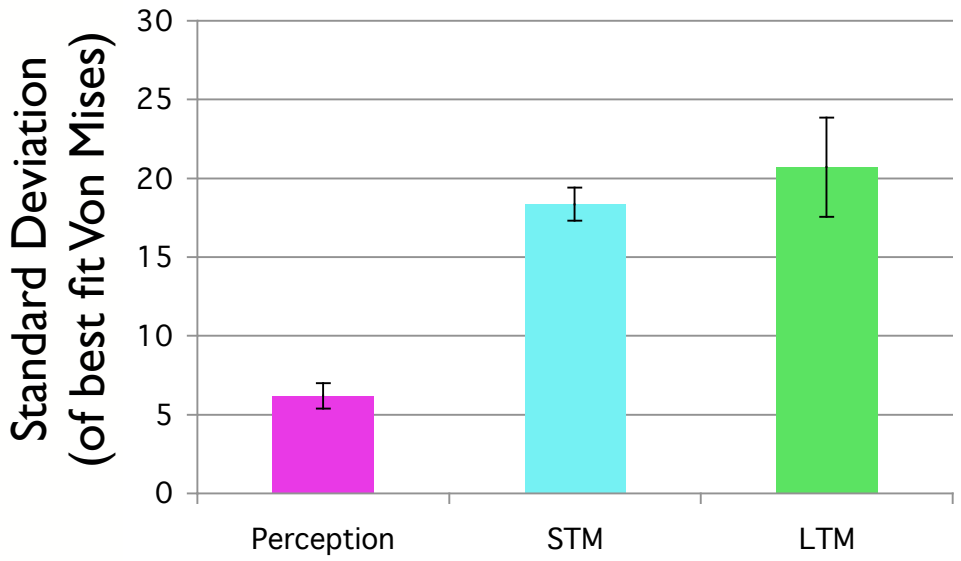
Likelihood Of Random Guessing

Much higher likelihood of random guessing in long-term memory condition



Estimate of Memory Precision

Short-term and Long-term Memory Have Comparable Fidelity!



Experiment 3: Continuous Report + Yes/No Response

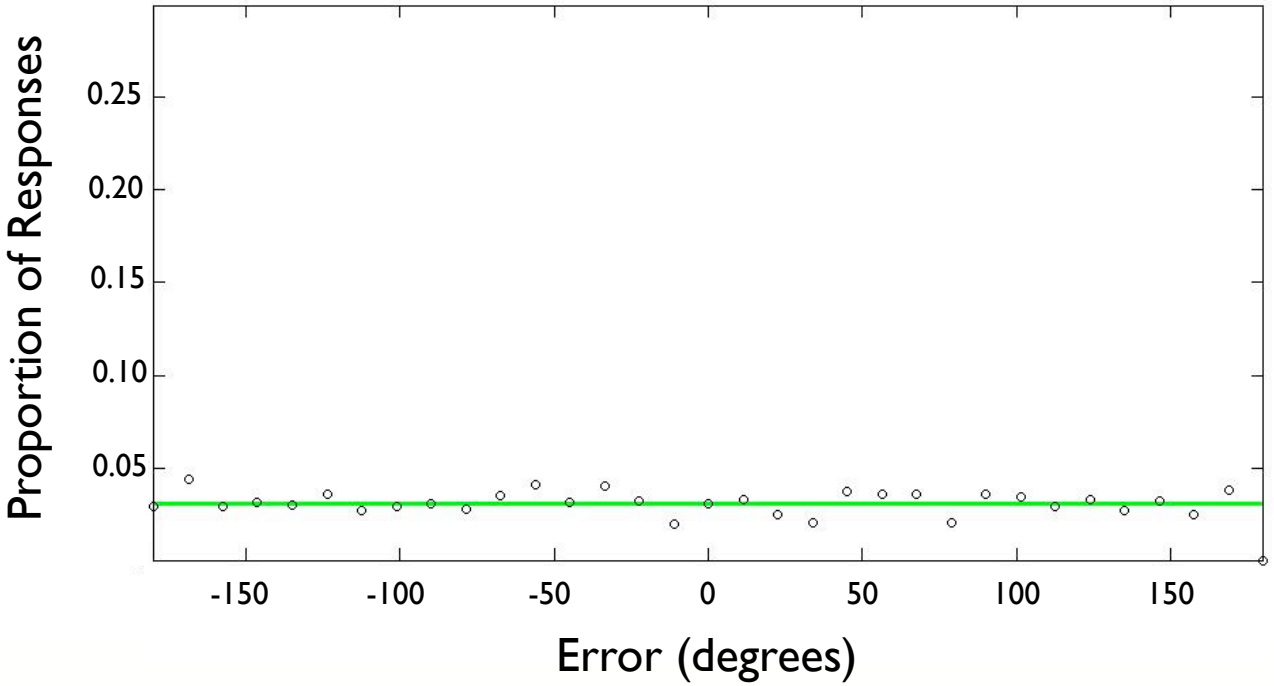
Long-term memory condition only. Same as E2, except half the test items are foils (items that were never seen).

For each test item, subjects report the remembered color, guessing if they haven't seen the item.

Then subjects report whether they remember seeing the test item ("Yes" or "No").

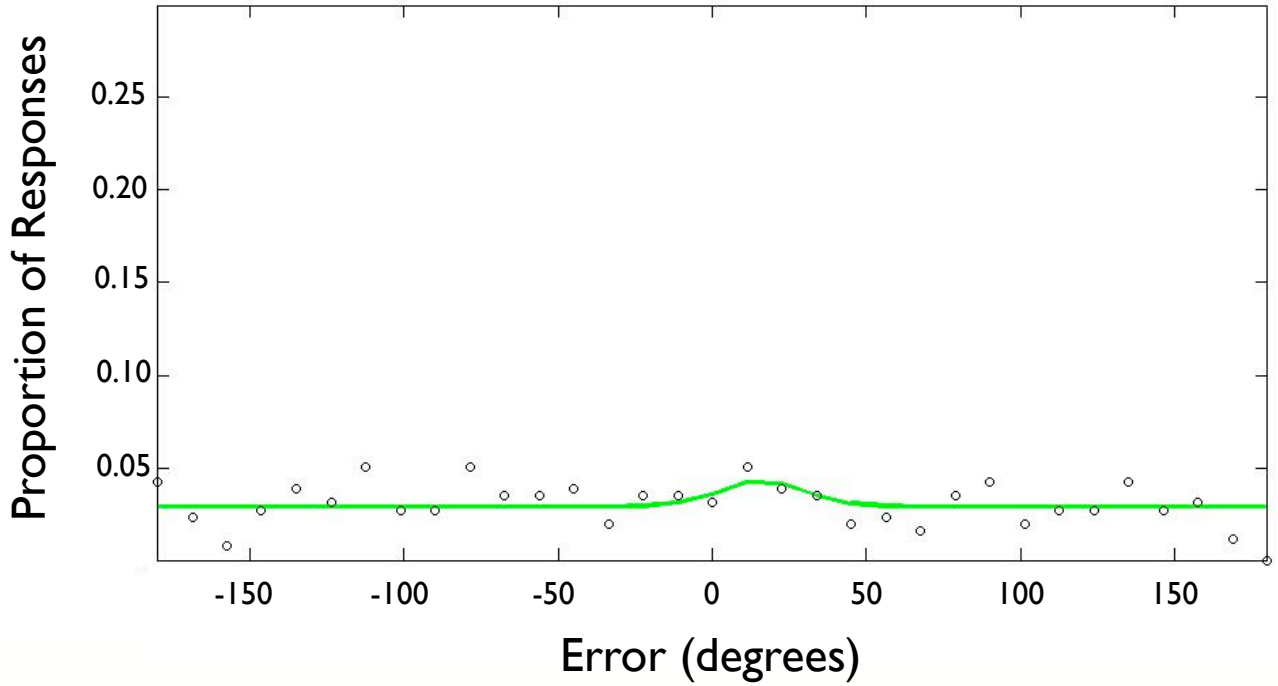
Experiment 3: Continuous Report + Yes/No Response

Sanity Check!: Model Fit Correct Rejections (82%)



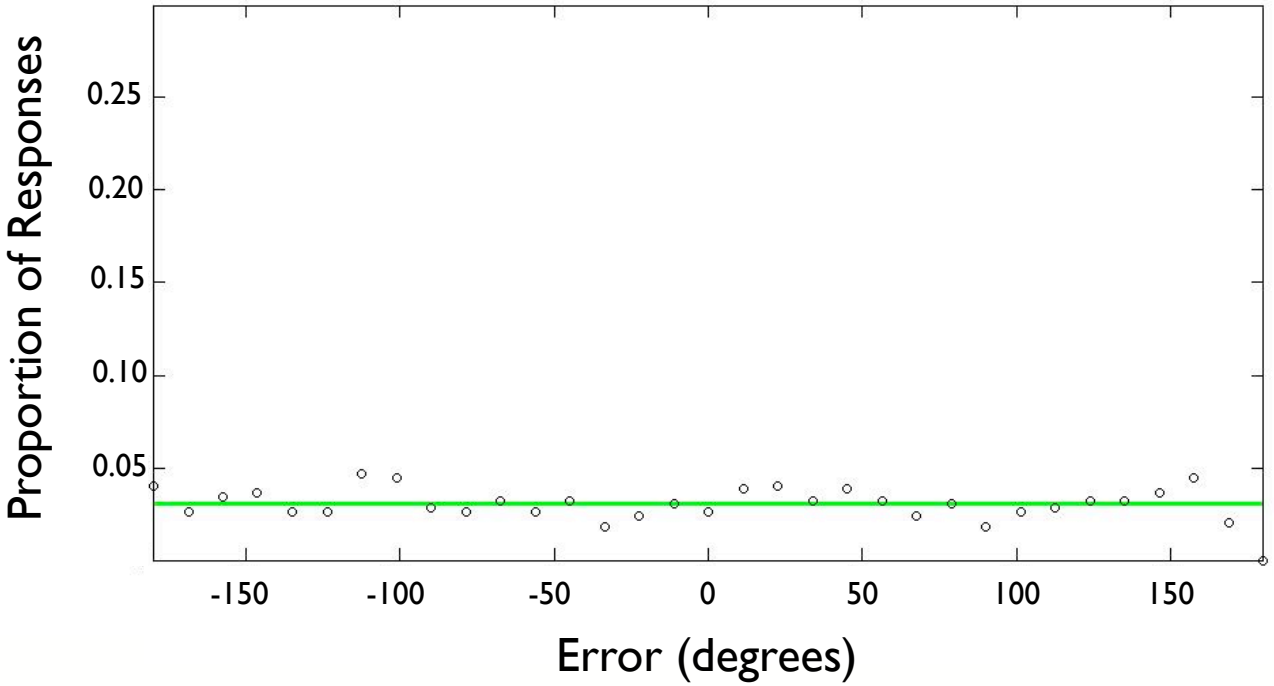
Experiment 3: Continuous Report + Yes/No Response

Sanity Check!: Model Fit False Alarms (18%)



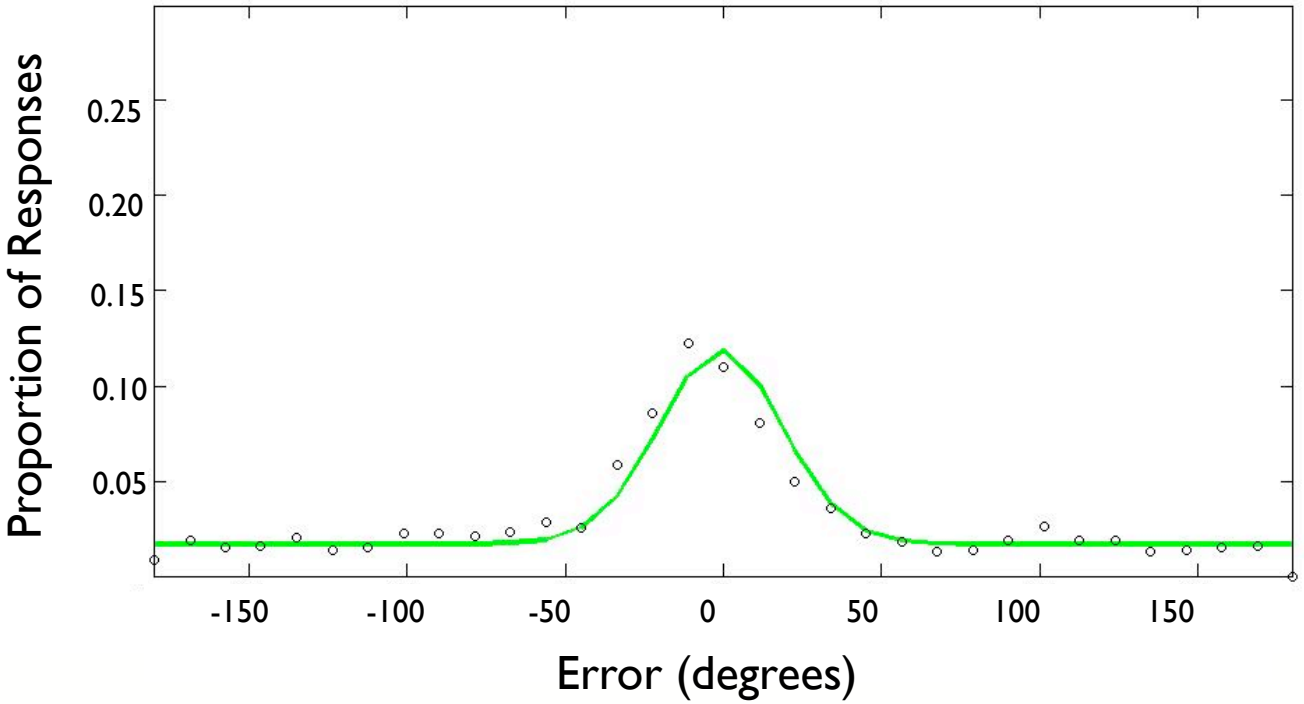
Experiment 3: Continuous Report + Yes/No Response

Model Fit Misses (34%)



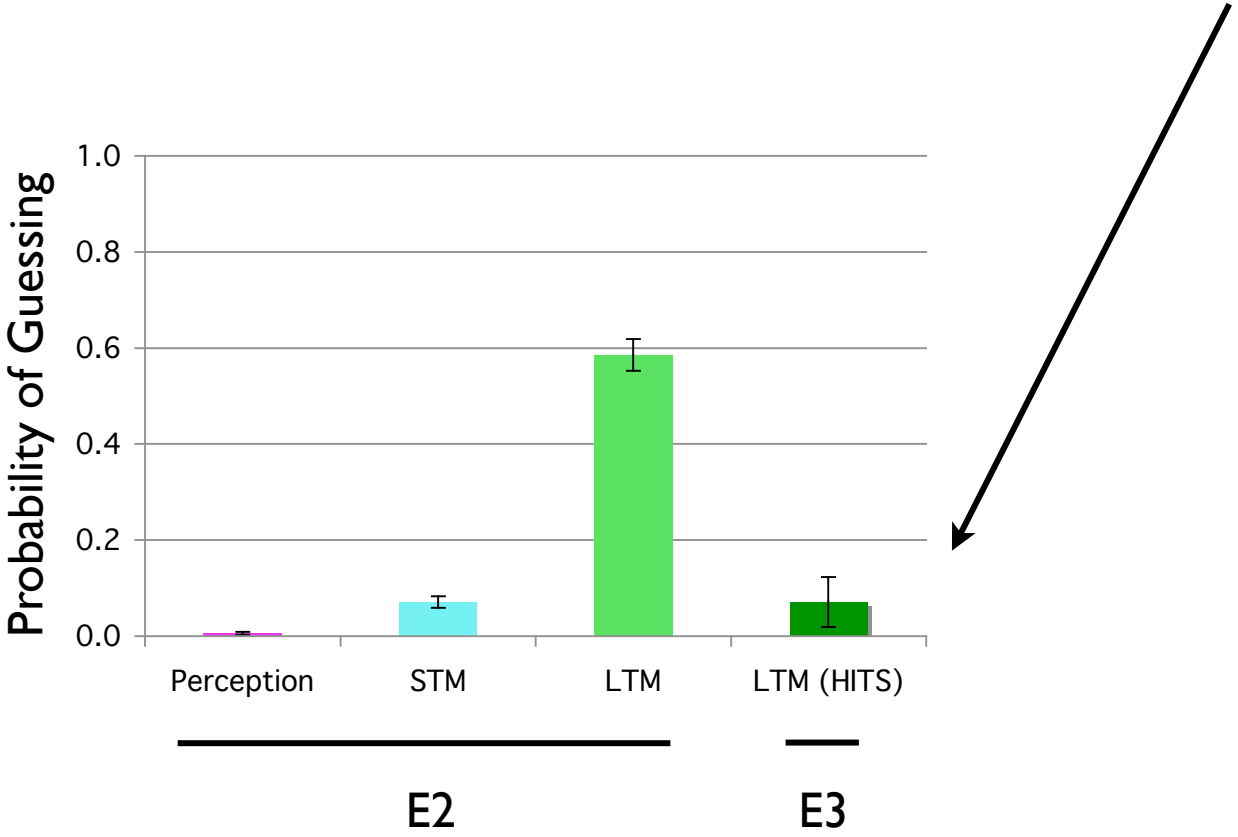
Experiment 3: Continuous Report + Yes/No Response

Model Fit Hits (66%)



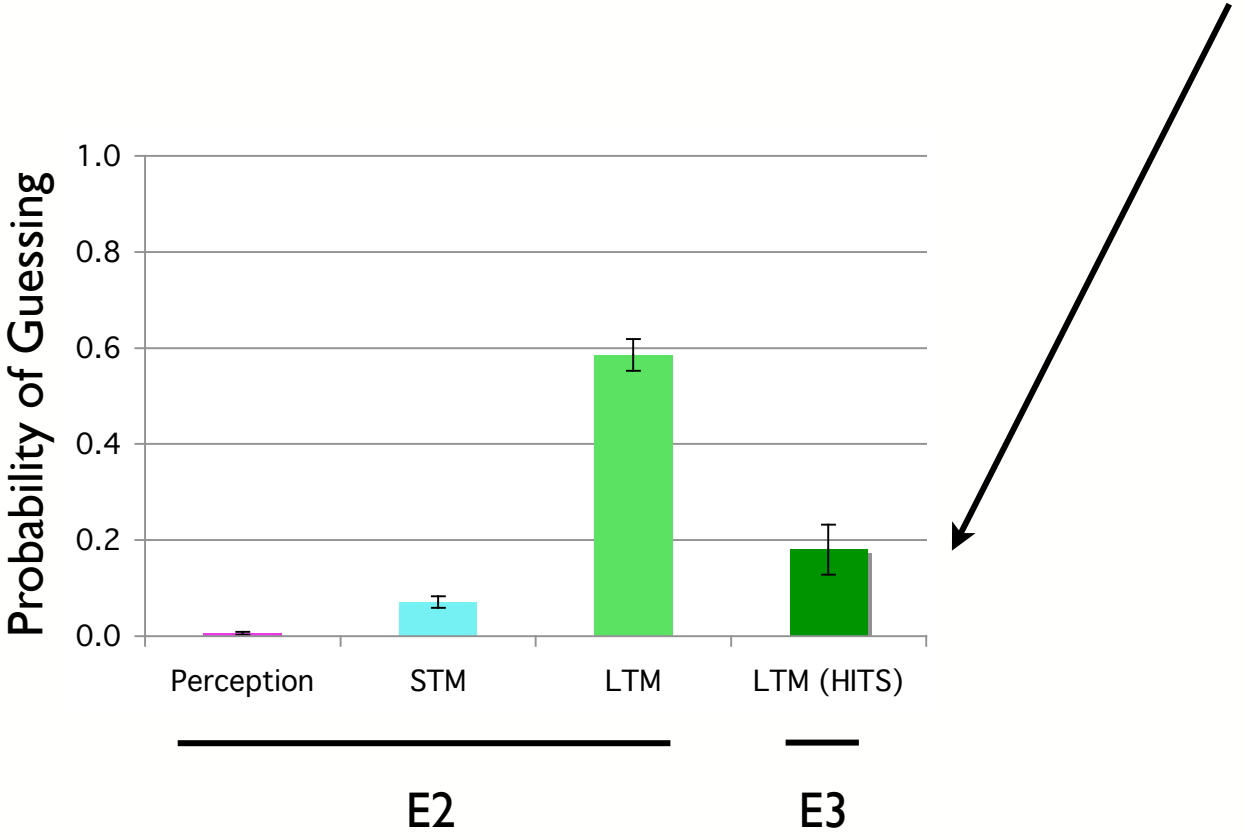
Likelihood of Random Guessing

If subjects only guess the color if they forget the item,
You would expect guessing rate to disappear for HITS



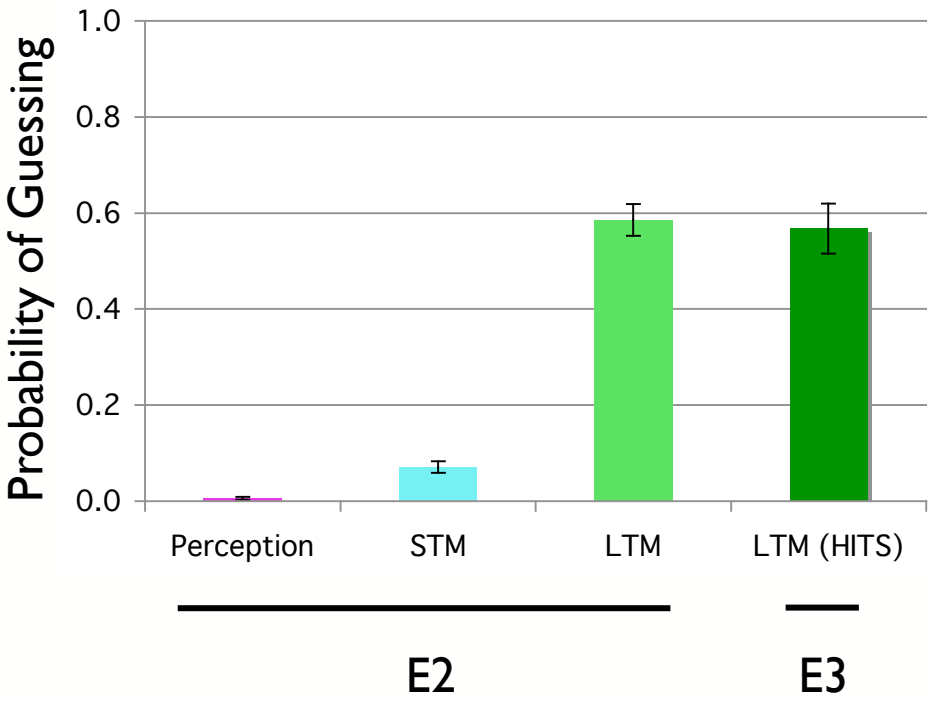
Likelihood of Random Guessing

or at least drop to the level of the false alarm rate...



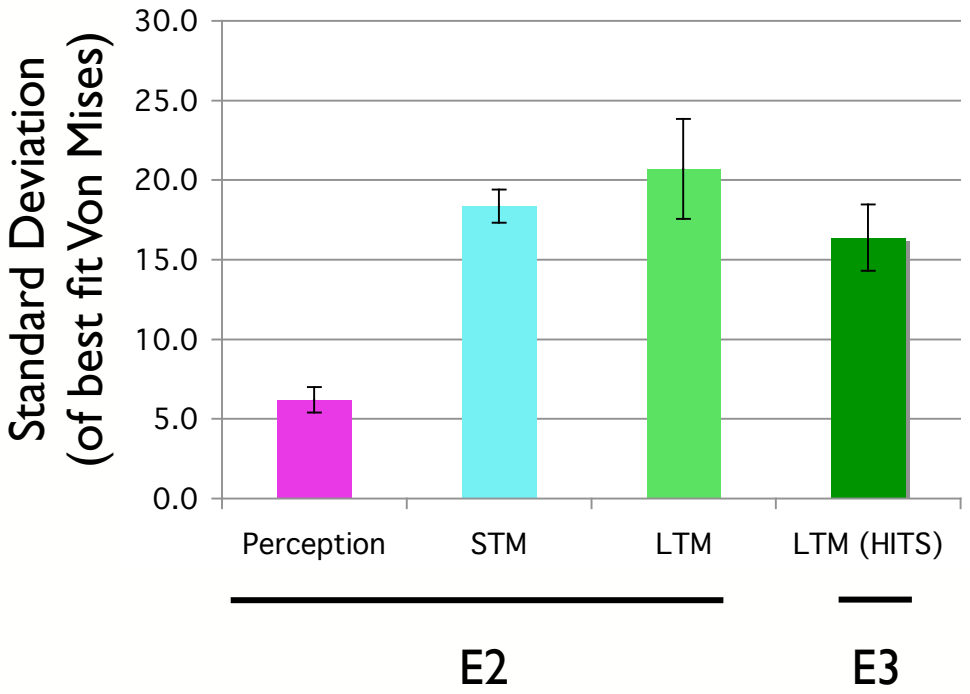
Likelihood of Random Guessing

Same Guessing Rate!
Observers remember the items, but forget the colors



Estimate of Memory Precision

Not much change in the precision, if anything better



Summary & Interim Conclusions

Combined continuous report & mixture modeling method enables estimation of

1. Standard deviation as a measure of memory precision
2. Probability of random guessing

Perception vs. STM, precipitous increase in standard deviation

STM vs. LTM: Relatively high probability of random guessing of color in LTM (even when the item is remembered)

However, when the color is remembered, it is comparable to the fidelity of short-term memory

Outline

1. Detailed Memory for Thousands of Objects

2. Comparing the Fidelity of Perception, Short-term Memory, & Long-term Memory

3. Preliminary Insights into the Temporal Dynamics of Encoding

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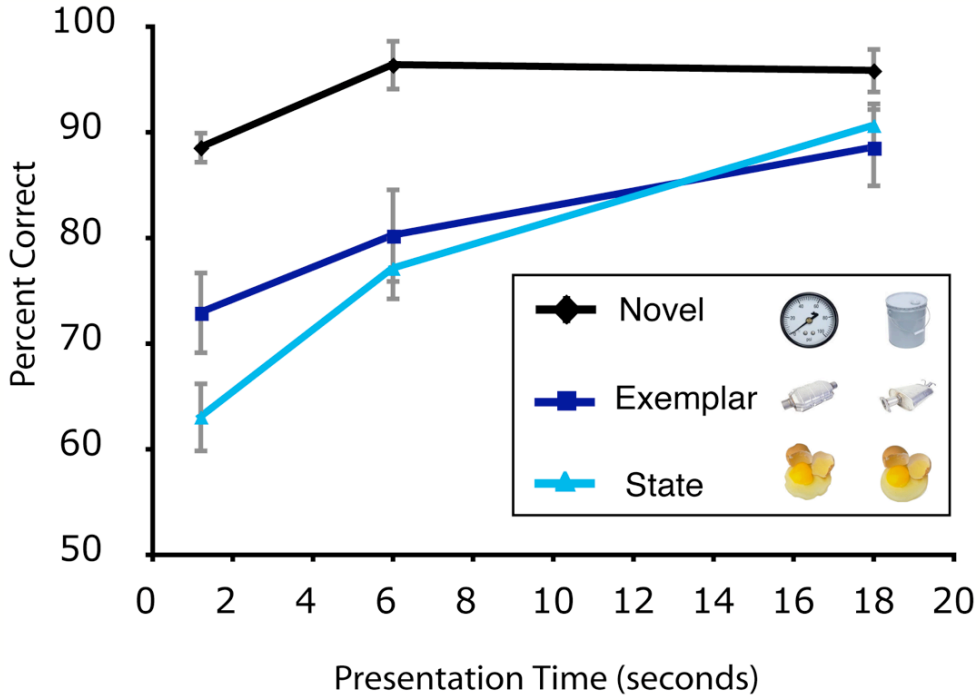
Experiment 4: Effect of Encoding Time on Detection of Changes at Category, Exemplar, and State Level

Short-term memory, change detection task
1.2, 6, or 18 second presentation of 6 objects
3 Conditions: *novel*, *exemplar*, *state*

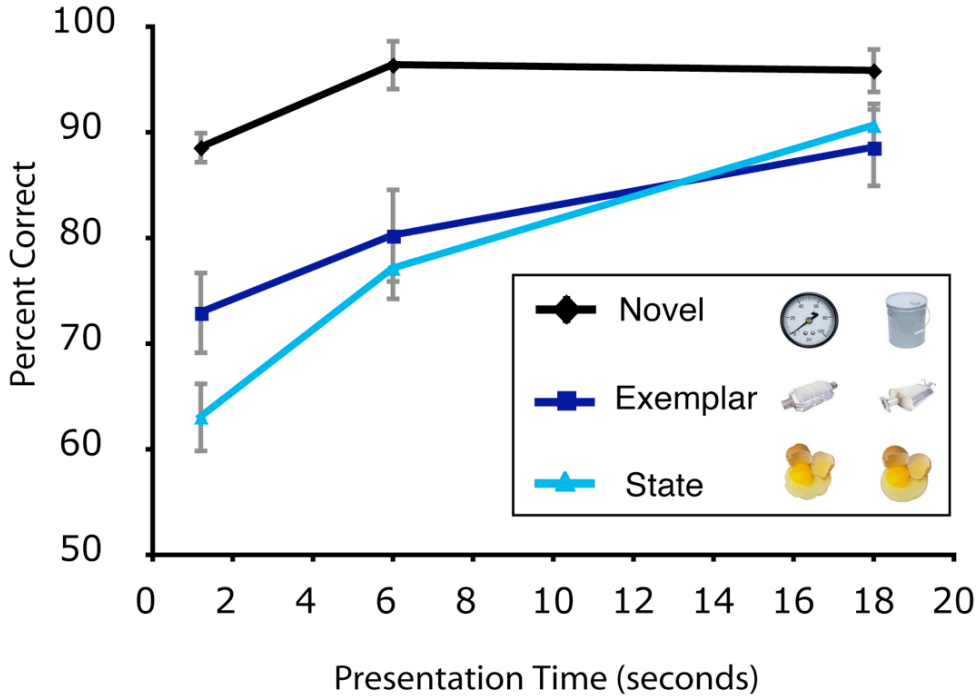
Experiment 4: Effect of Encoding Time on Detection of Changes at Category, Exemplar, and State Level

It takes time to get the details



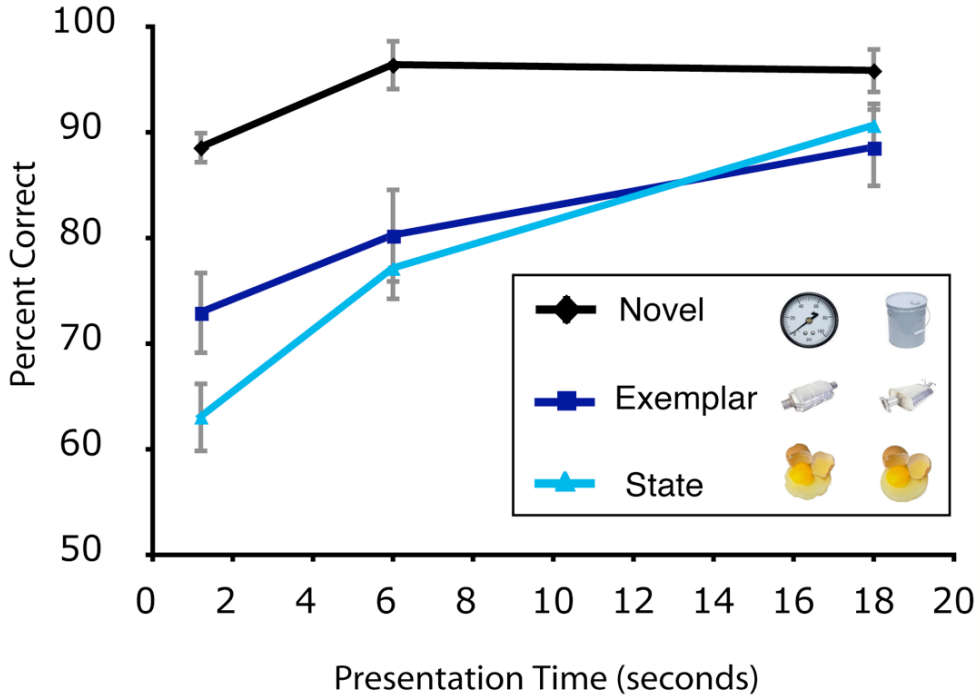
Experiment 4: Effect of Encoding Time on Detection of Changes at Category, Exemplar, and State Level

Maybe some changes require more precise representations, and precision increases with time



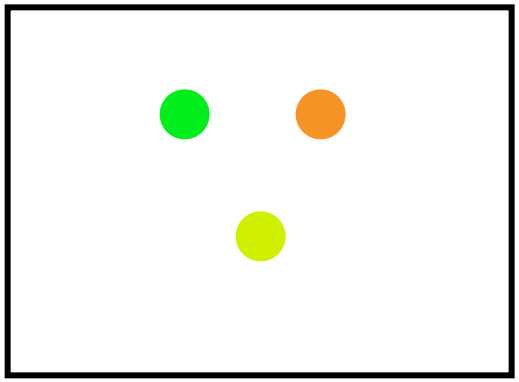
Experiment 4: Effect of Encoding Time on Detection of Changes at Category, Exemplar, and State Level

Or maybe this is about a hierarchical order of encoding, from category-level features, to exemplar-level features, to state-level features...

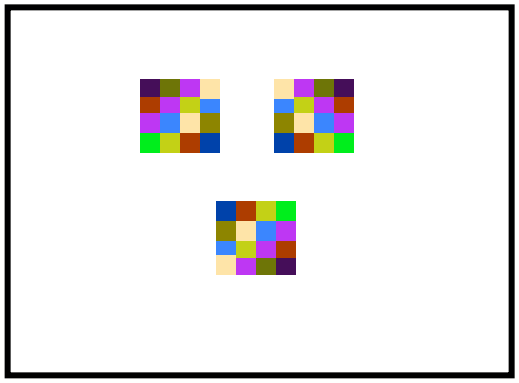


Experiment 5: Effect of Encoding Time on Encoding Color (Using Continuous Report)

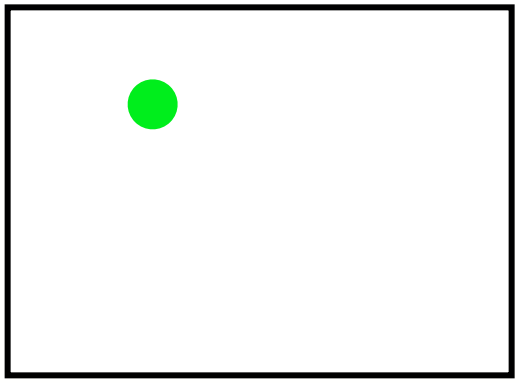
Short-term memory, continuous report
20, 40, 60, 80, 100, 120, 500 ms presentation
3 color patches, masked



Brief Presentation

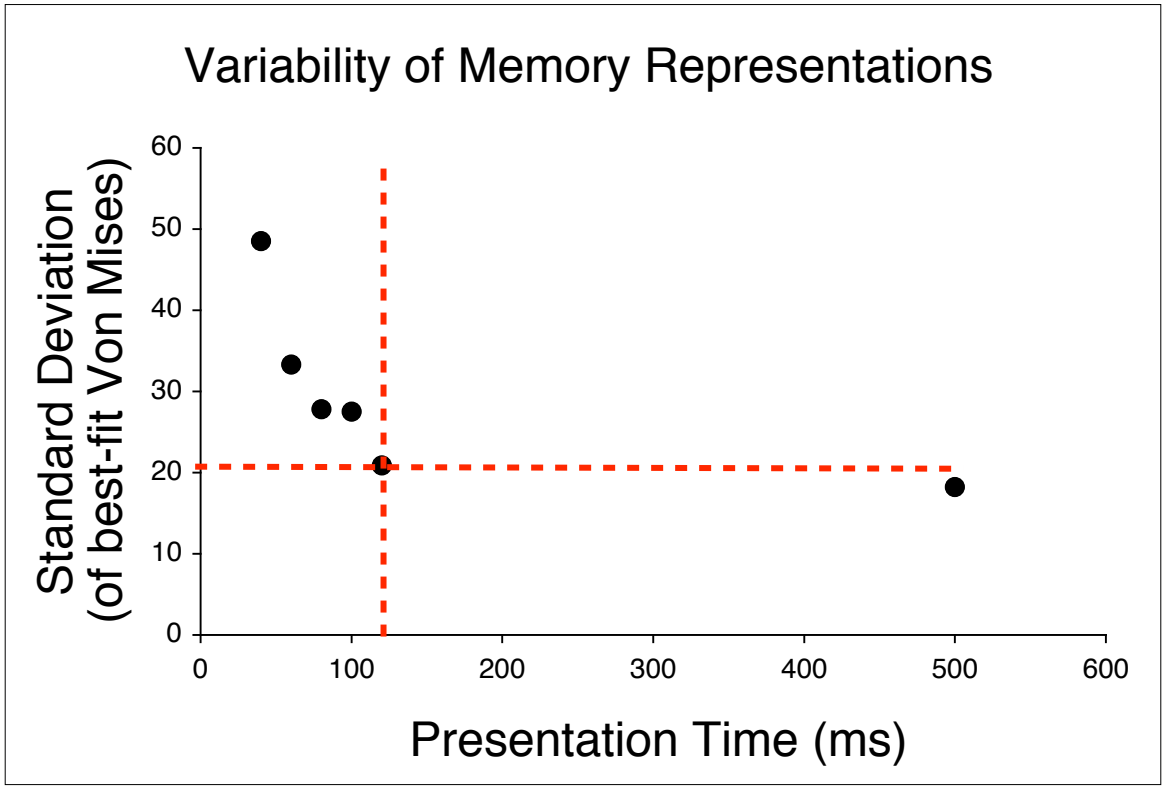


Mask

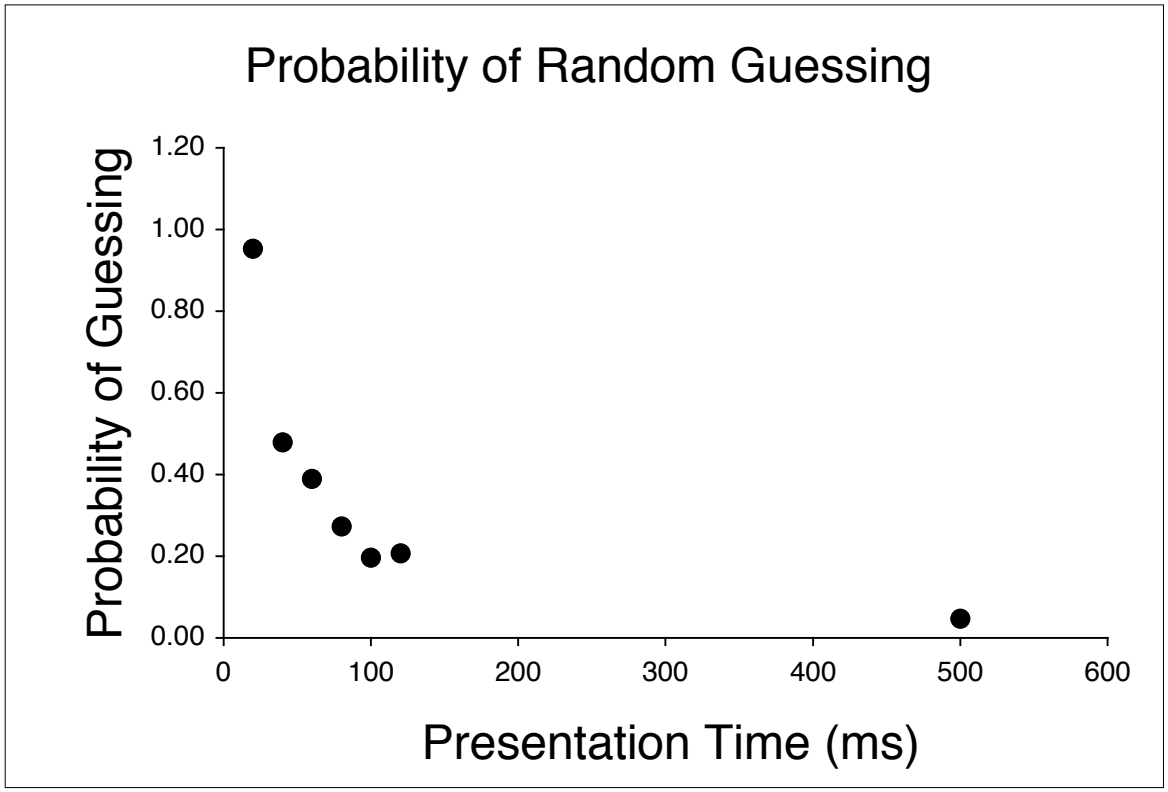


Color Setting

Experiment 5: Effect of Encoding Time on Encoding Color (Using Continuous Report)

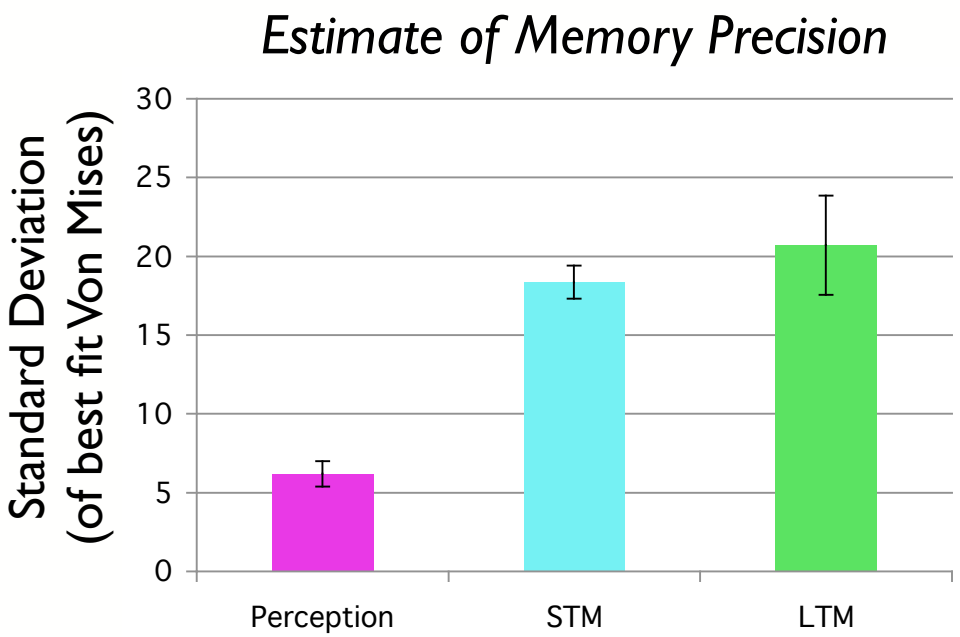


Experiment 5: Effect of Encoding Time on Encoding Color (Using Continuous Report)

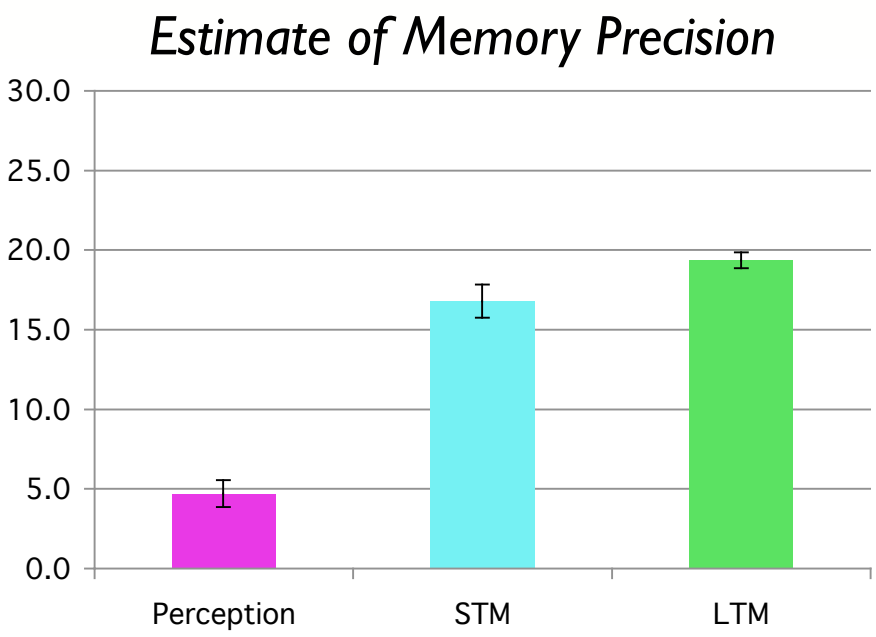


Effect of Encoding Time on Encoding Color In Long-term Memory

Experiment 2
3 Seconds/Item LTM

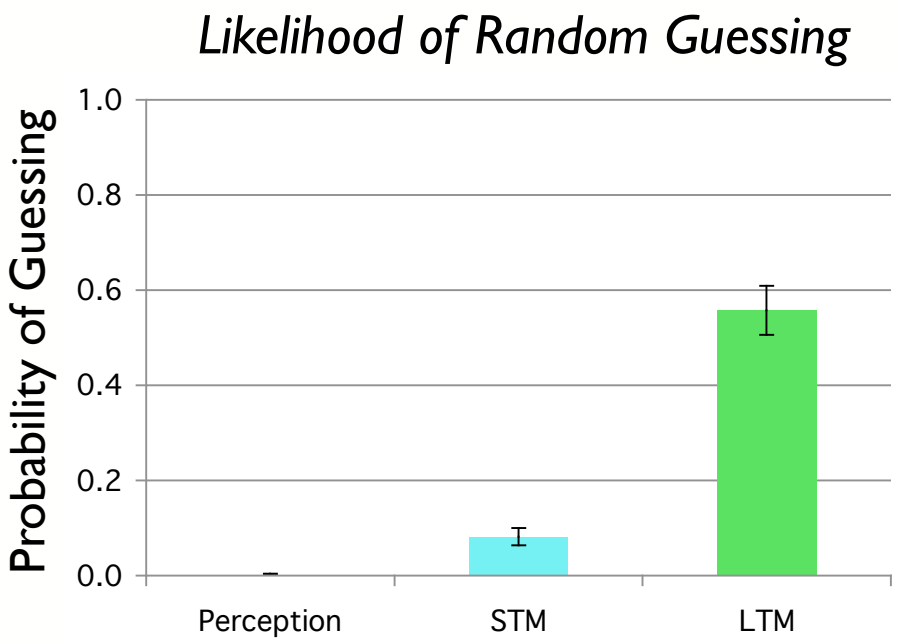


Experiment 6
1 Second/Item LTM



Effect of Encoding Time on Encoding Color In Long-term Memory

Experiment 2
3 Seconds/Item LTM



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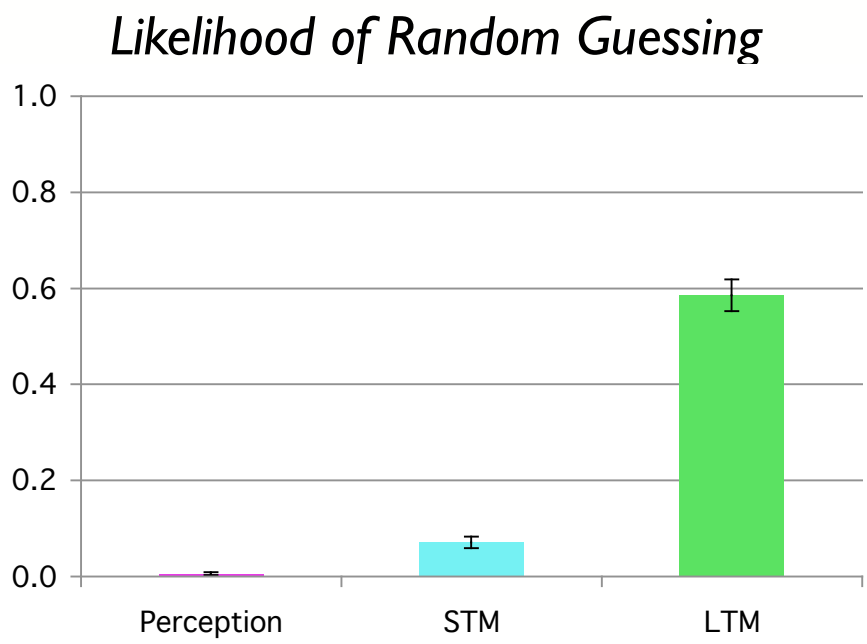


Summary & Interim Conclusions

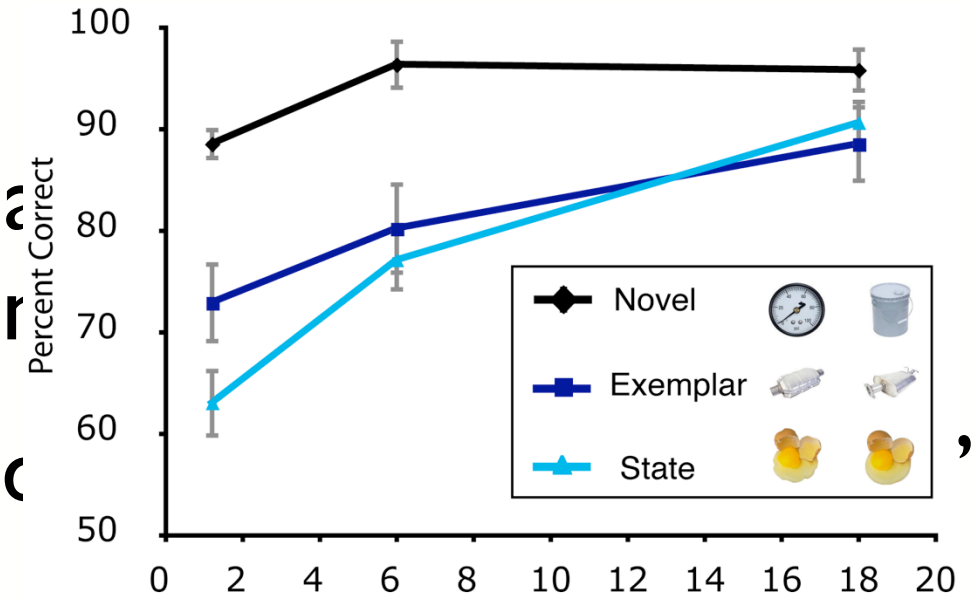
It takes time to encode the details

After the first 120ms, little benefit of additional time on encoding color

Suggests benefits of additional time after one second is not due to improved fidelity on any given feature dimension

Instead, additional time ma
knowledge-guided encodi

"Encoding of informative c



Take Home Points

Visual Long-term Memory has a much higher fidelity than previously demonstrated or believed, comparable to the fidelity of short-term memory.

There is a high rate of randomly guessing in LTM, suggesting either catastrophic retrieval failure, interference, or decay.

This is the case, even when observers appear to remember the items themselves. This "binding failure" in LTM may reflect the non-integral nature of color for these stimuli.

Precision increases rapidly over time, suggesting benefits of time beyond 500 ms are related to searching for/encoding additional features (possibly in a hierarchical progression).

Thank You.

tkonkle@mit.edu

oliva@mit.edu

alvarez@wjh.harvard.edu

tfbrady@mit.edu