Slides:

Object-based encoding in visual working memory

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University of Chicago

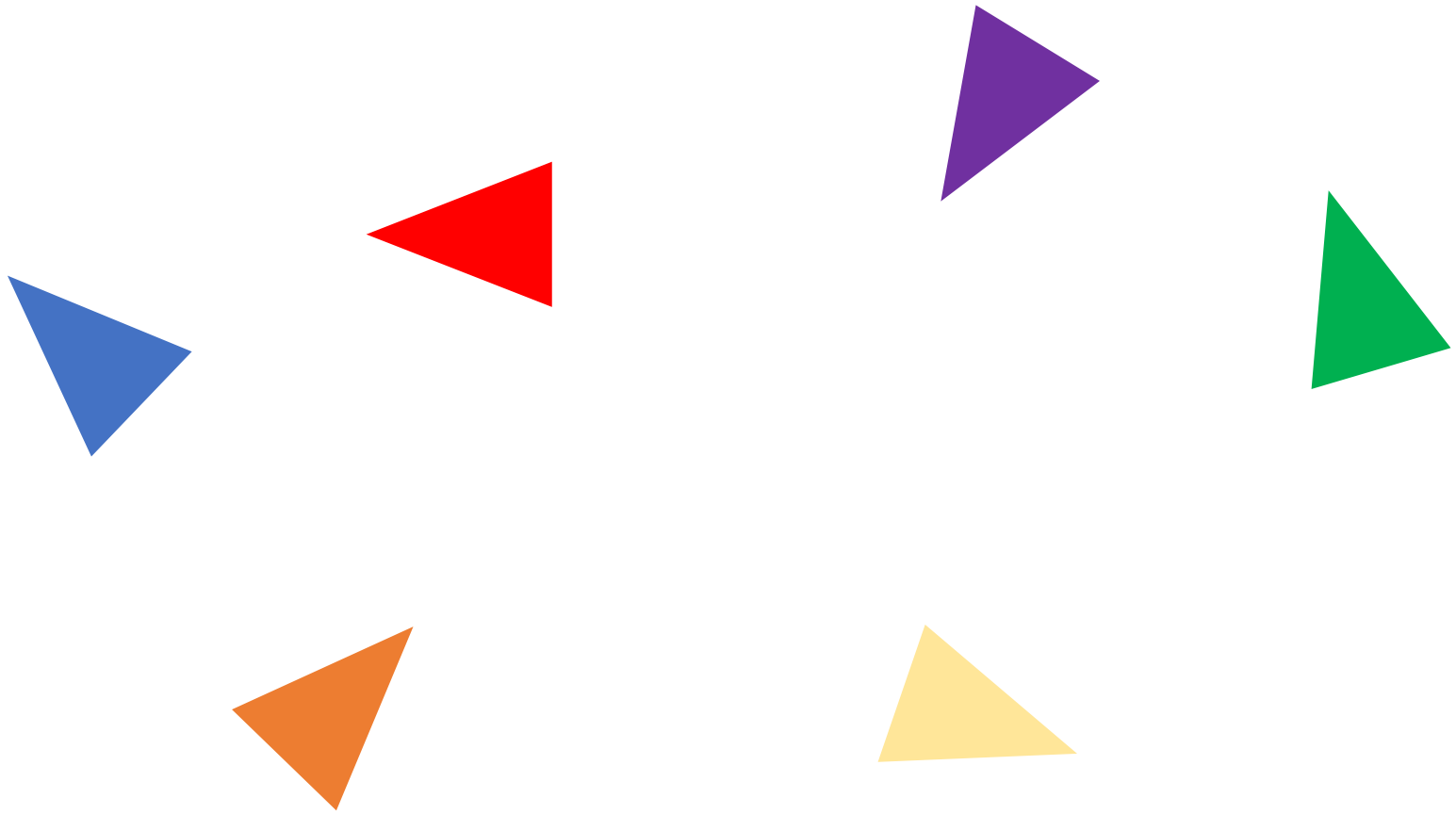
OPAM 30; Boston, Massachusetts; November 17, 2022

THE UNIVERSITY OF CHICAGO

I respectfully acknowledge we are gathered today on the unceded land of the Massachusett people, and their neighbors, the Wampanoag, and Nipmuc Peoples.

Acknowledgement of Land based on the Town Of Brookline's Indigenous People's Land Acknowledgement: https://www.brooklinema.gov/DocumentCenter/View/24507/Human-Services-Subcommittee-WA-11--Report-rev

What do you remember?



Visual working memory

- The sharply limited store for visual information that is actively being retained in mind for ongoing cognition and perception

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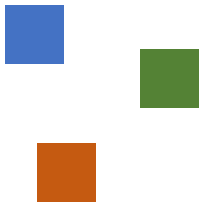
Object-based theory

"slot models"

(Luck and Vogel, 1997;
Zhang and Luck, 2008)



Feature-based theory

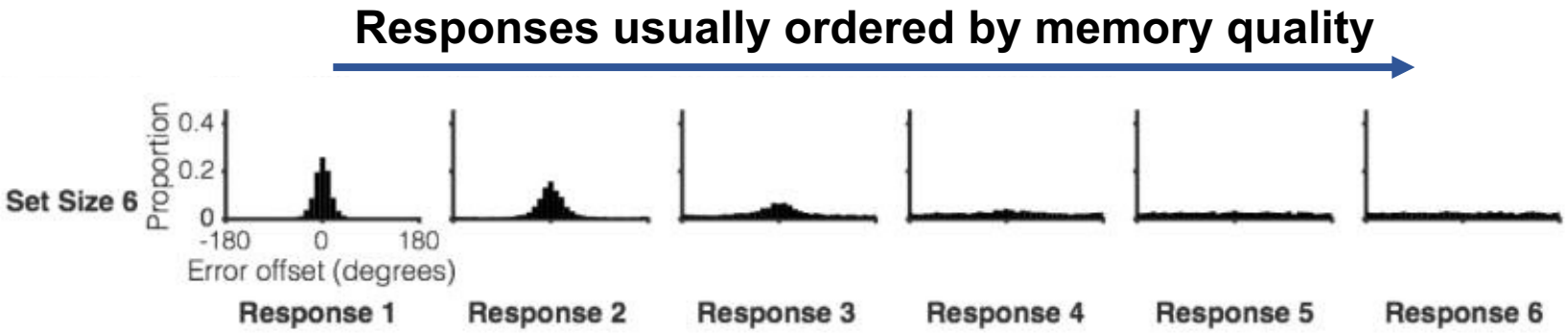
"resource models"

(Alvarez and Cavanagh, 2004;
Wilken and Ma, 2004)

Luck, S. J., & Vogel, E. K. (1997). https://doi.org/10.1038/36846
Zhang, W., & Luck, S. J. (2008). https://doi.org/10.1038/nature06860
Alvarez, G. A., & Cavanagh, P. (2004). https://doi.org/10.1111/j.0963-7214.2004.01502006.x
Wilken, P., & Ma, W. J. (2004). https://doi.org/10.1167/4.12.11

Introducing the whole-report paradigm

- Test recall for all items rather than just the one item (Adam et al., 2017)

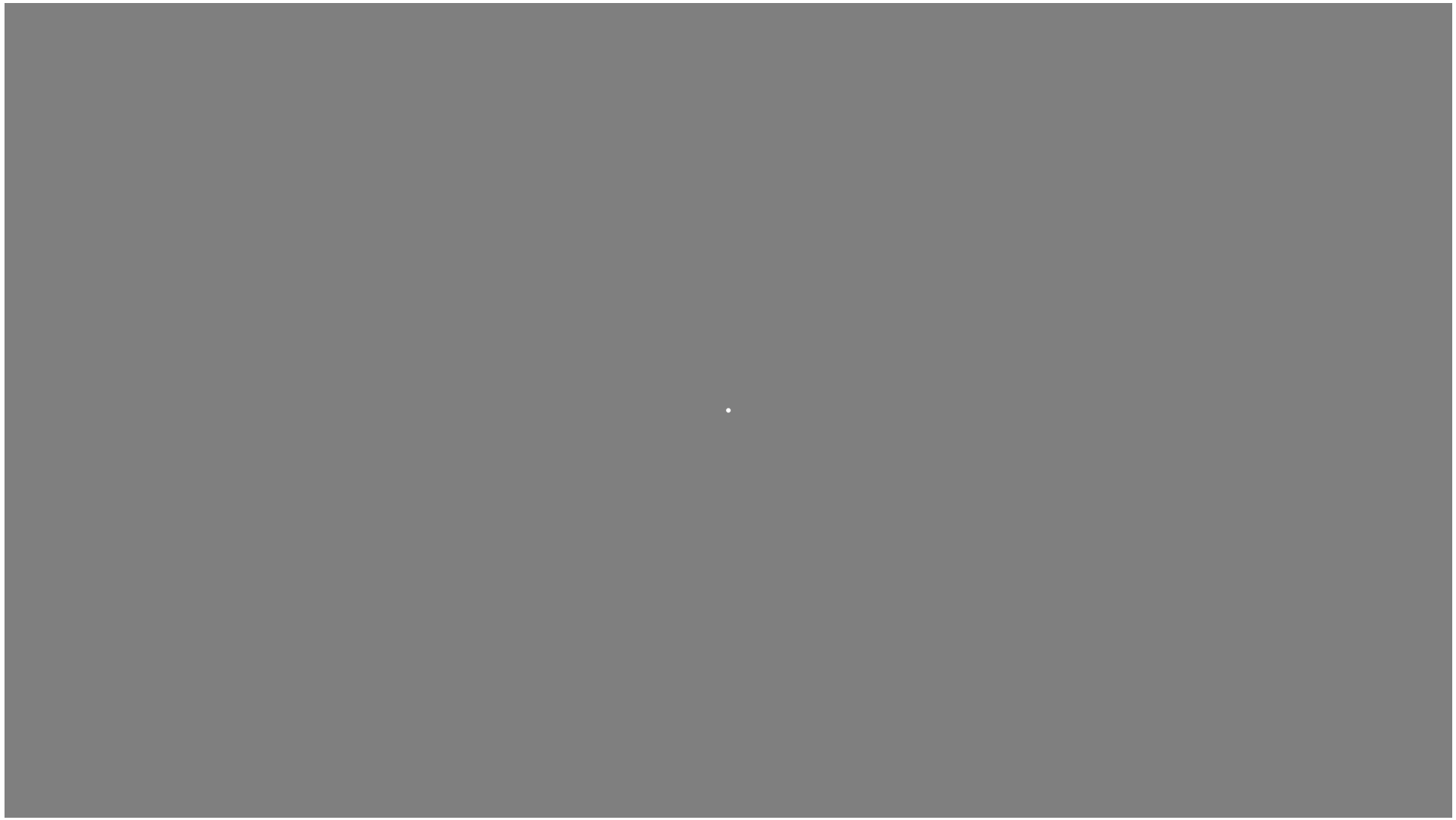


- The first whole-report experiments with conjunction stimuli

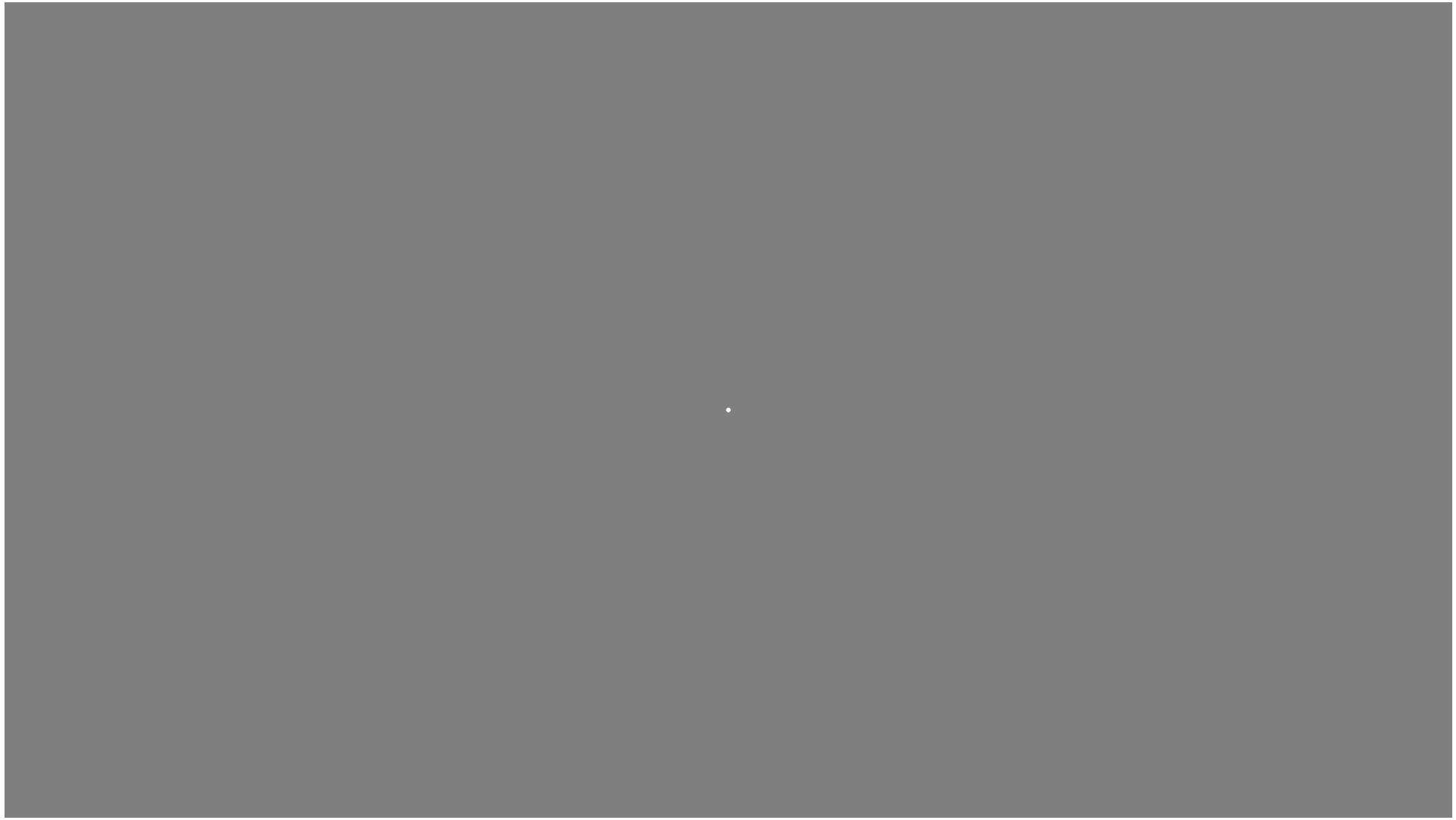
- Response interface that collects both features with one click (Sone et al., 2021)

Figure from Adam, K. C. S. et al. (2017) https://doi.org/10.1016/j.cogpsych.2017.07.001
Sone, H. et al. (2021) https://doi.org/10.1016/j.cognition.2020.104579

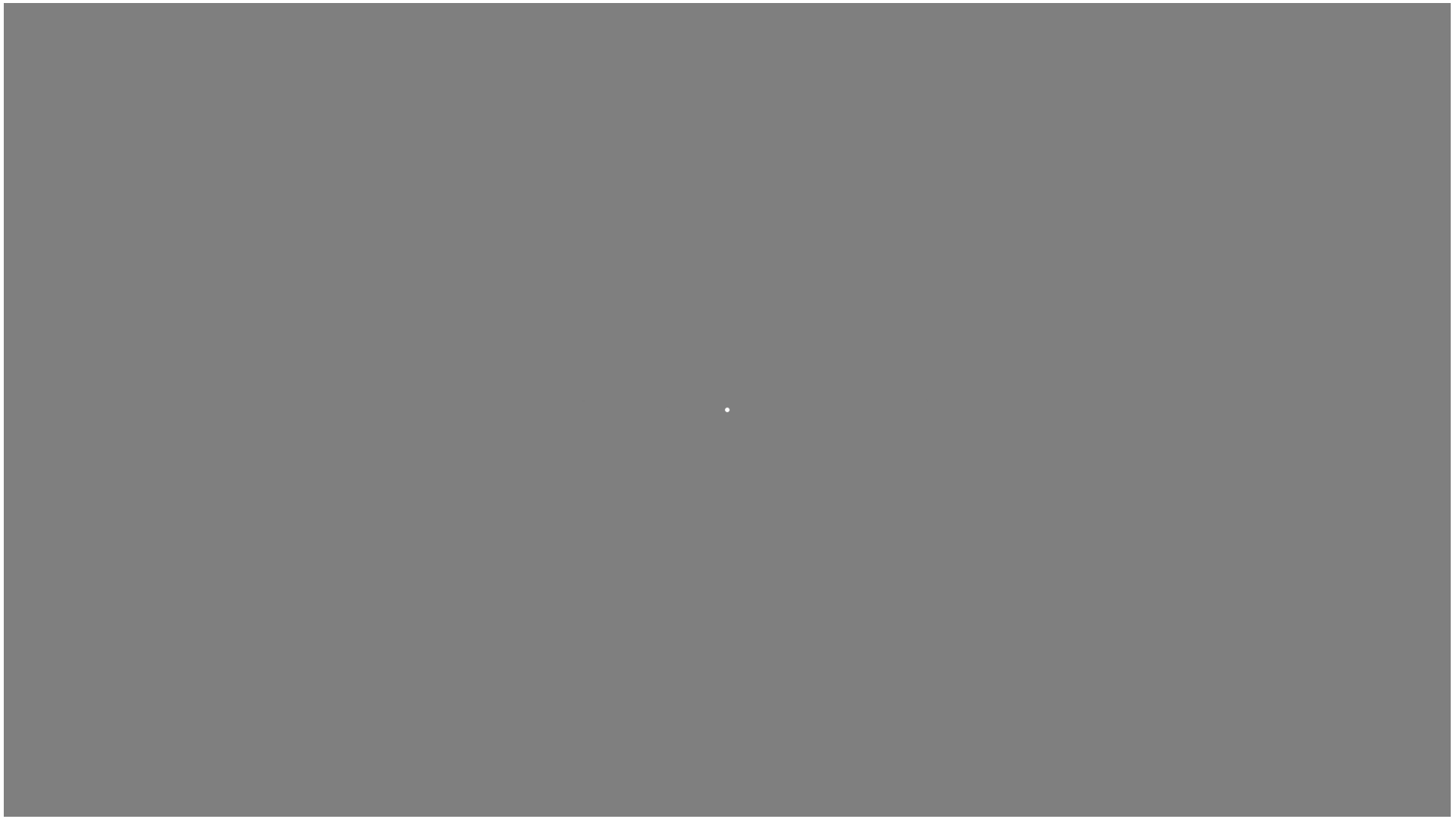
Orientation whole-report



Color whole-report

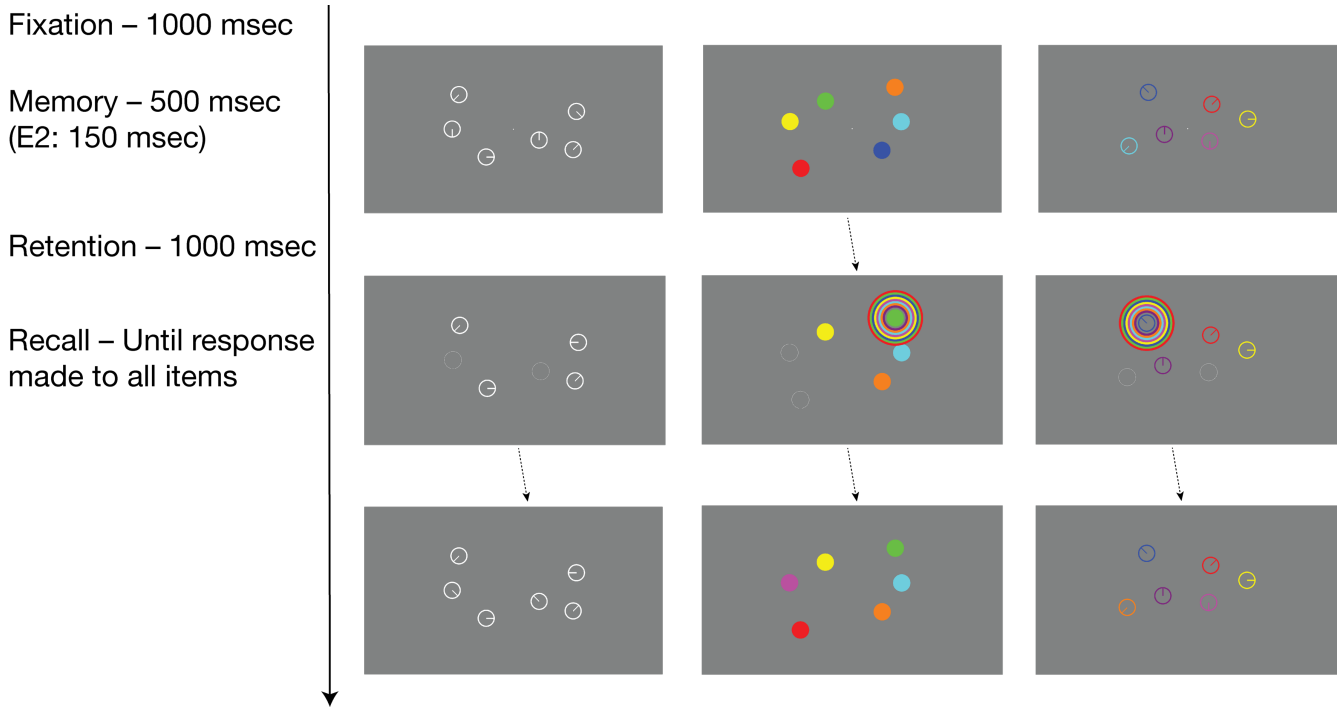


Conjunction whole-report

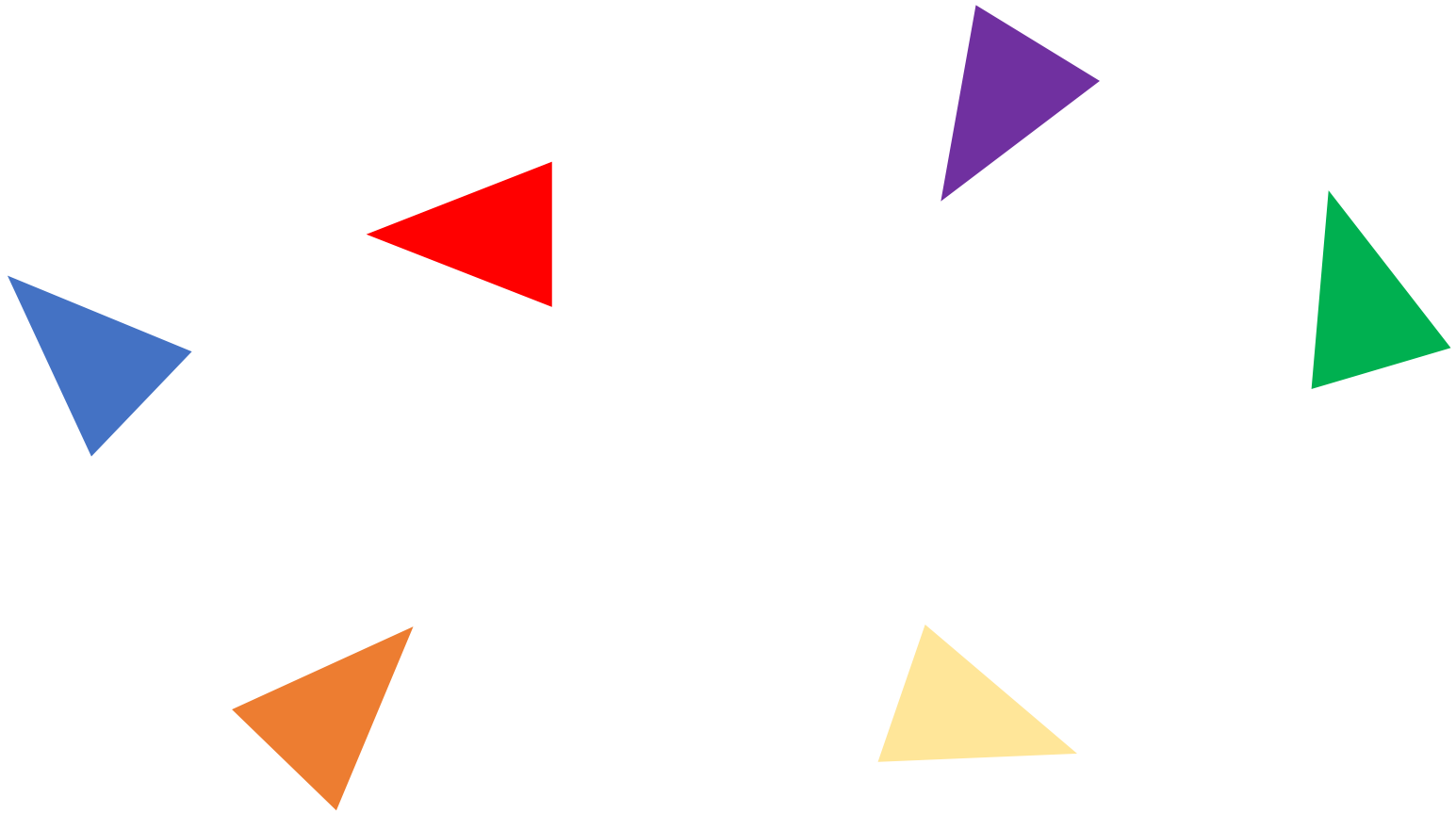


Our conjunction whole-report experiments

- Four experiments (30 subjects each)
  - E1: Colored clock faces
  - E2: Colored clock faces but rapid
  - E3: Colored triangles
  - E4: Colored shapes
- Three conditions (300 trials each)
  - Color only
  - Orientation only or Shape only
  - Conjunction
- Eight discrete colors, orientations, and shapes.

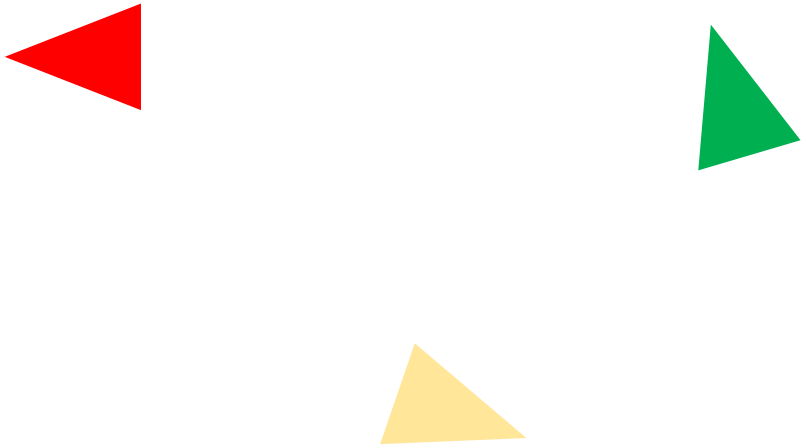


What is the unit of working memory?



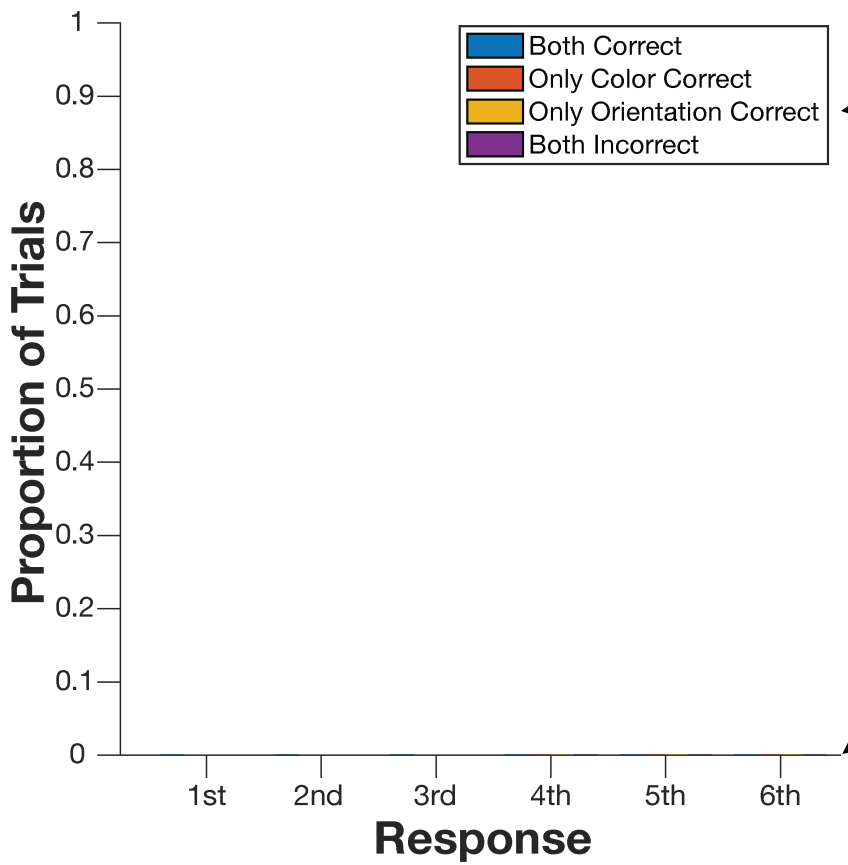
A *specific* object-based model – strong objects

- Fixed object capacity limit
- Lossless representations (“all-or-none”)
- No impact of complexity (additional features)



Has anyone ever truly believed this? Anyhow, an early rejection of this model: Olson, I. R. and Jiang, Y. (2002) https://doi.org/10.3758/BF03194756

A *specific* slot model – strong objects

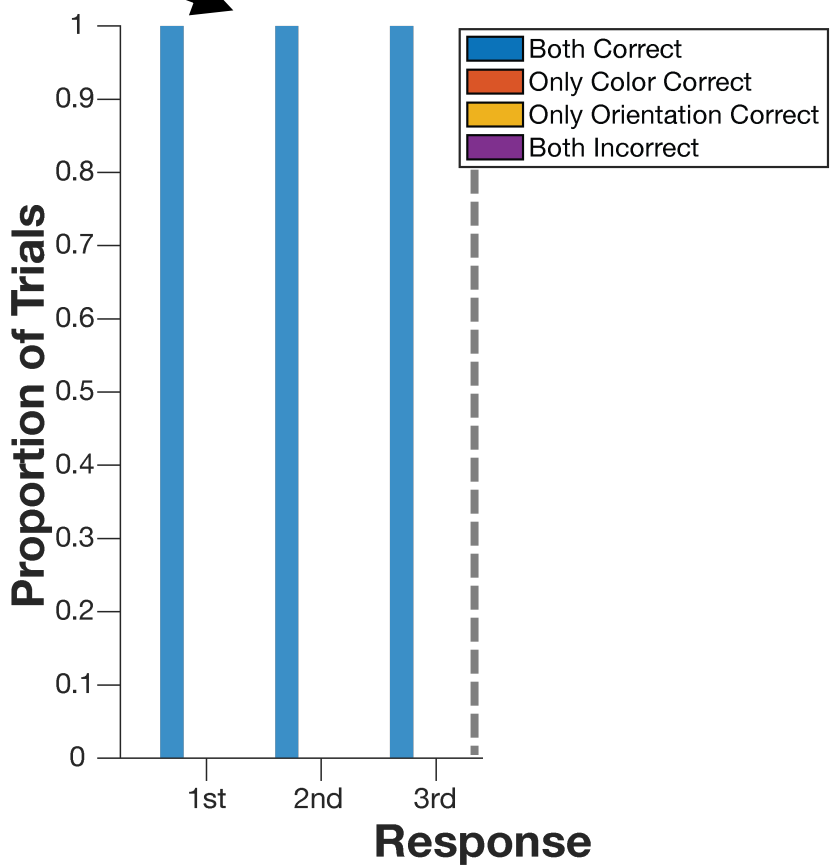


Possible types of recall

Ordered by responses

A *specific* slot model – strong objects

Perfect recall within item limit



A *specific* slot model – strong objects

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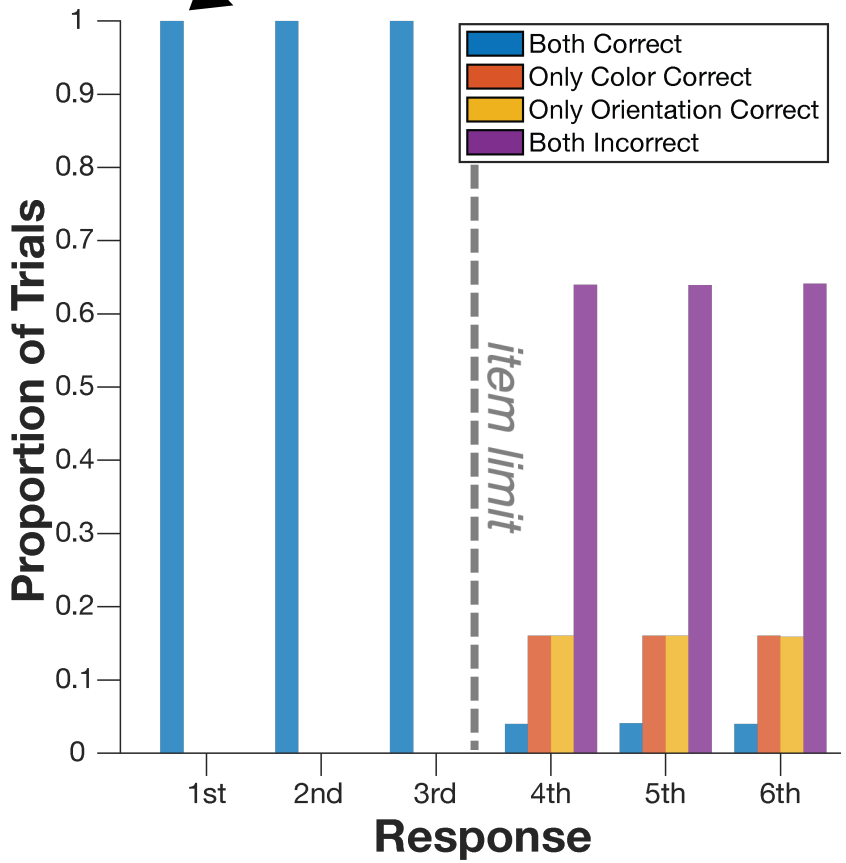
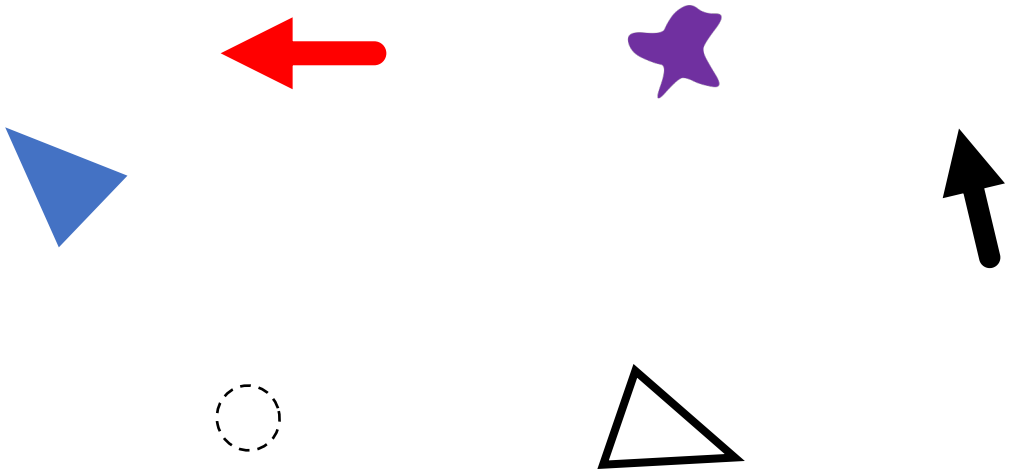


Guessing for remaining responses

A *specific* resource model – independent features

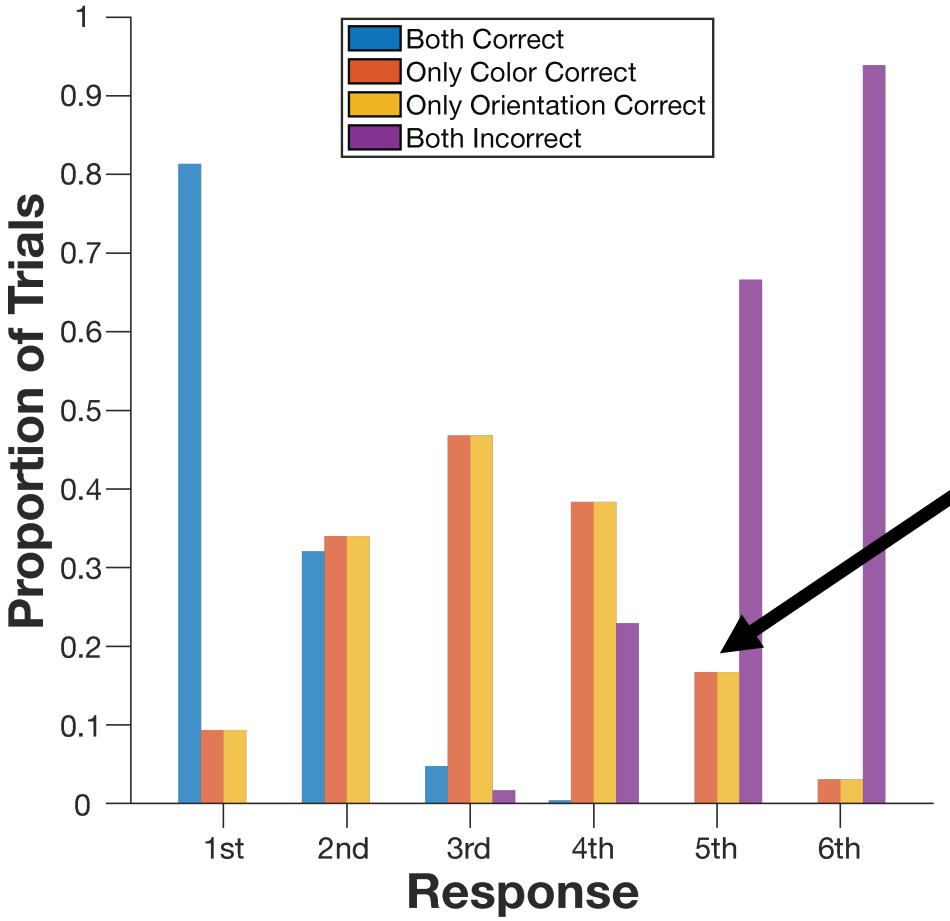
- Working memory resources are distributed to all items in the array
- Feature storage is not constrained by which objects contain the features
  - Probability of successful feature storage is independent of objecthood



Bundesen, C. (1990) https://doi.org/10.1037/0033-295X.97.4.523

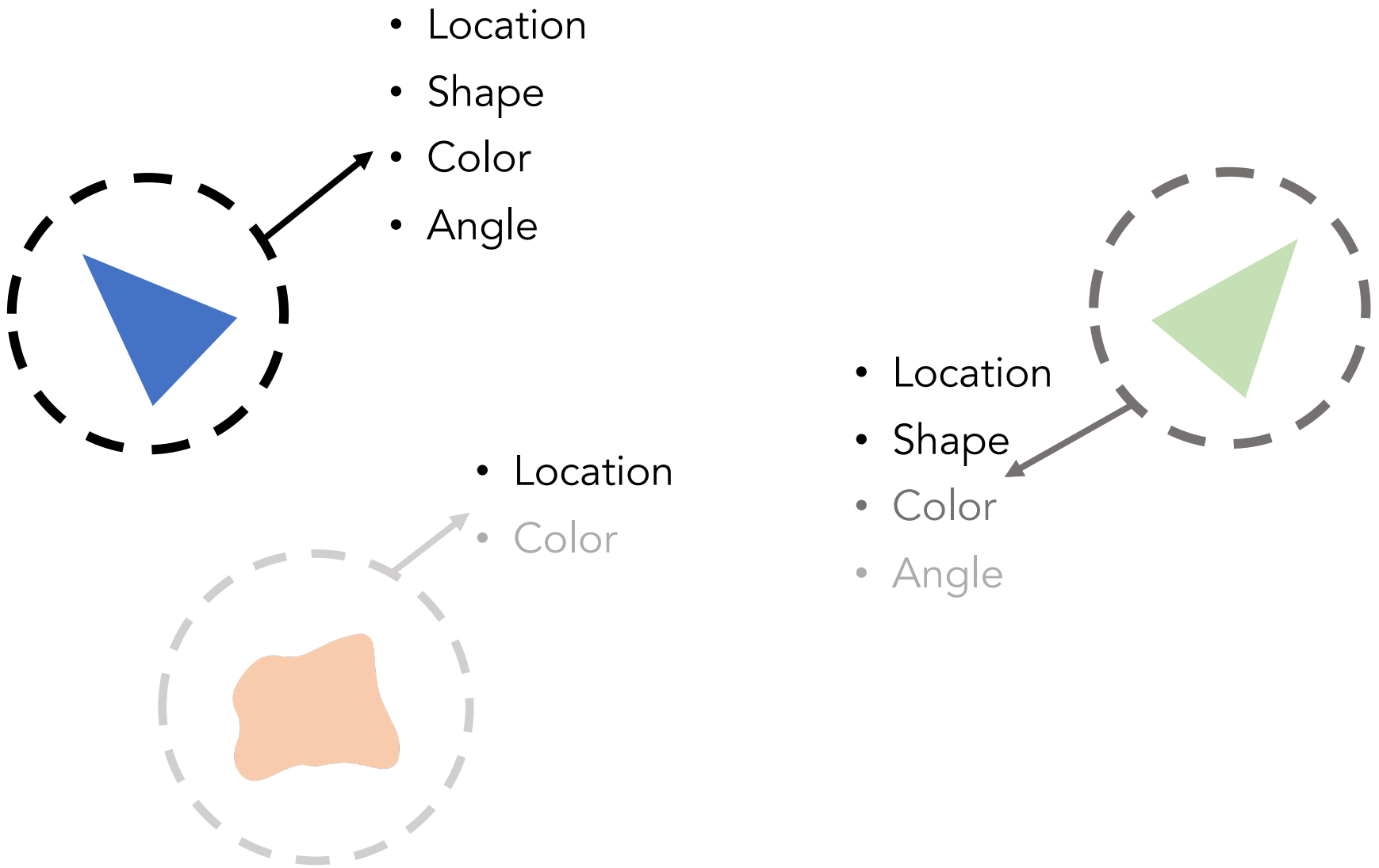
A *specific* resource model – independent features

Feature storage independent of objecthood



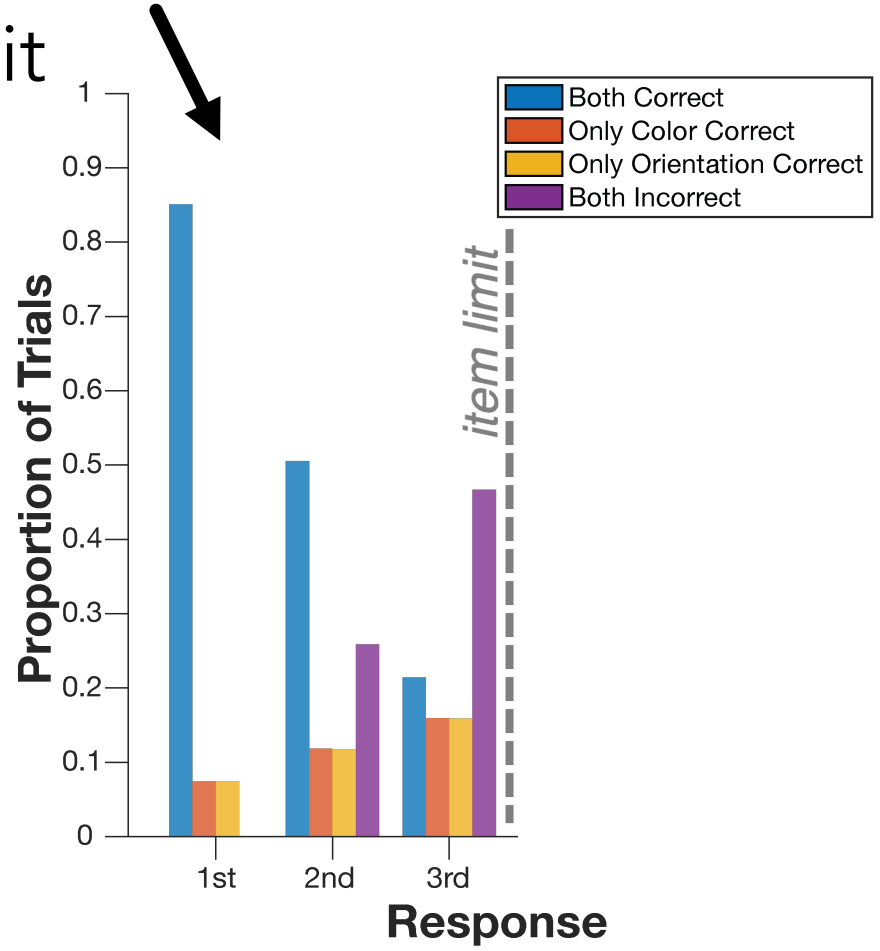
Accurate recall distributed across *all* responses

A new model characterization – pointers



A new model characterization – pointers

Accurate recall constrained within the item limit



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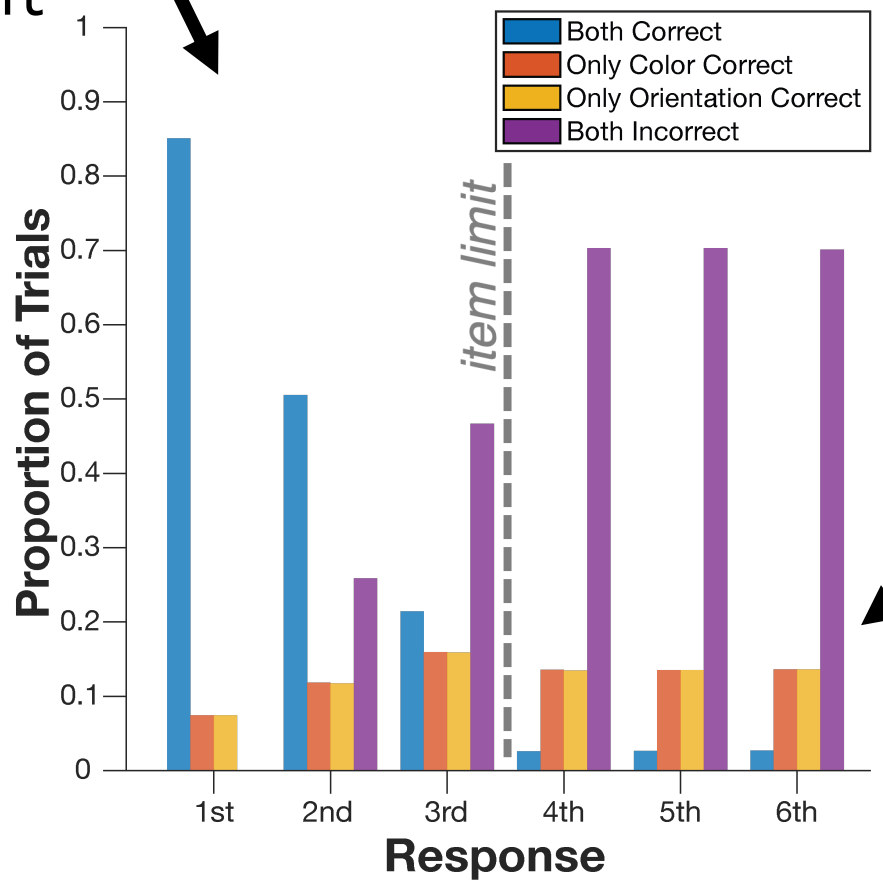

Guessing beyond the item limit

Recall accuracy

Mean Recall	Experiment 1	Experiment 2	Experiment 3	Experiment 4
Colors	3.21 ± 0.74	2.94 ± 0.64		3.61 ± 0.75
Orientations/Shapes	2.79 ± 0.44	2.45 ± 0.45		3.39 ± 0.64
Conjunctions	1.62 ± 0.38	1.38 ± 0.42	1.47 ± 0.44	1.92 ± 0.43

- Memory for conjunction stimuli is not lossless
  - Less conjunctions are fully recalled overall

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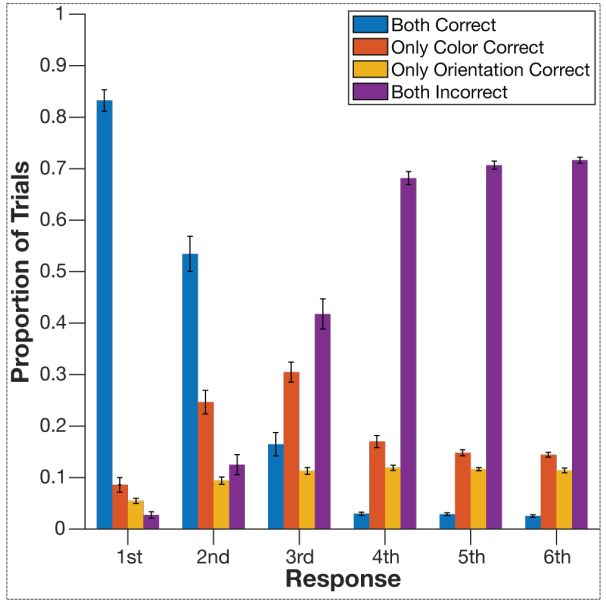
Features	4.94 ± 0.68	4.52 ± 0.83	5.11 ± 0.65	5.34 ± 0.85

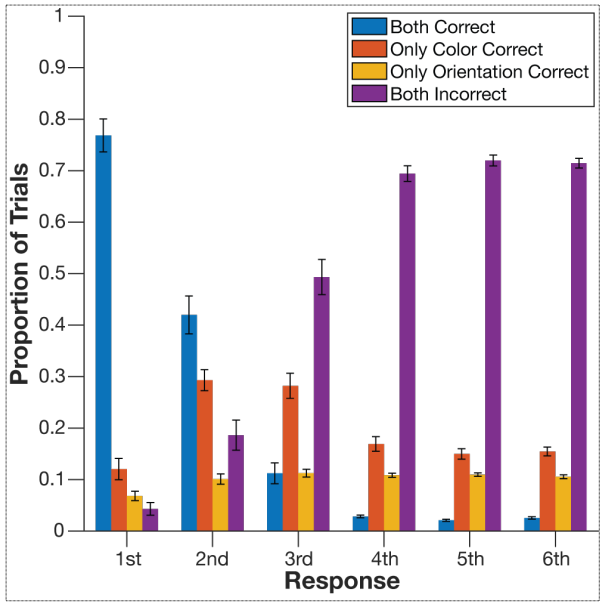
- Memory for conjunction stimuli is not lossless
  - Less conjunctions are fully recalled overall
- But we observe an object-based benefit
  - More features are recalled overall in the conjunction condition compared to the single-feature conditions (~5 features versus ~3 features)

Accuracy across responses

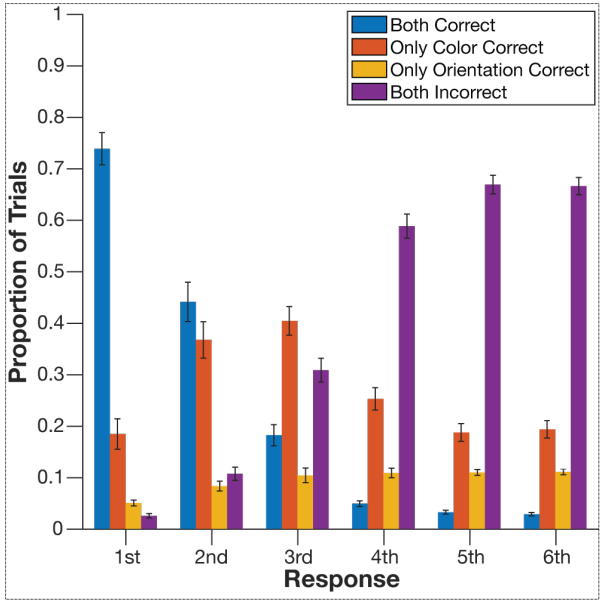
Experiment 1



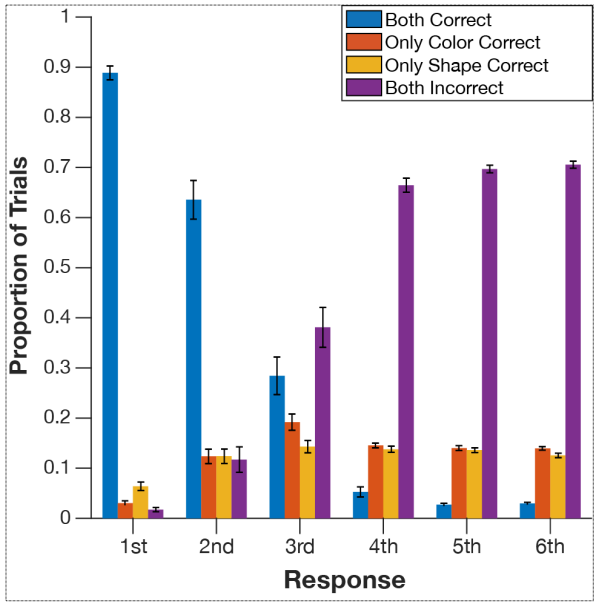
Experiment 2



Experiment 3



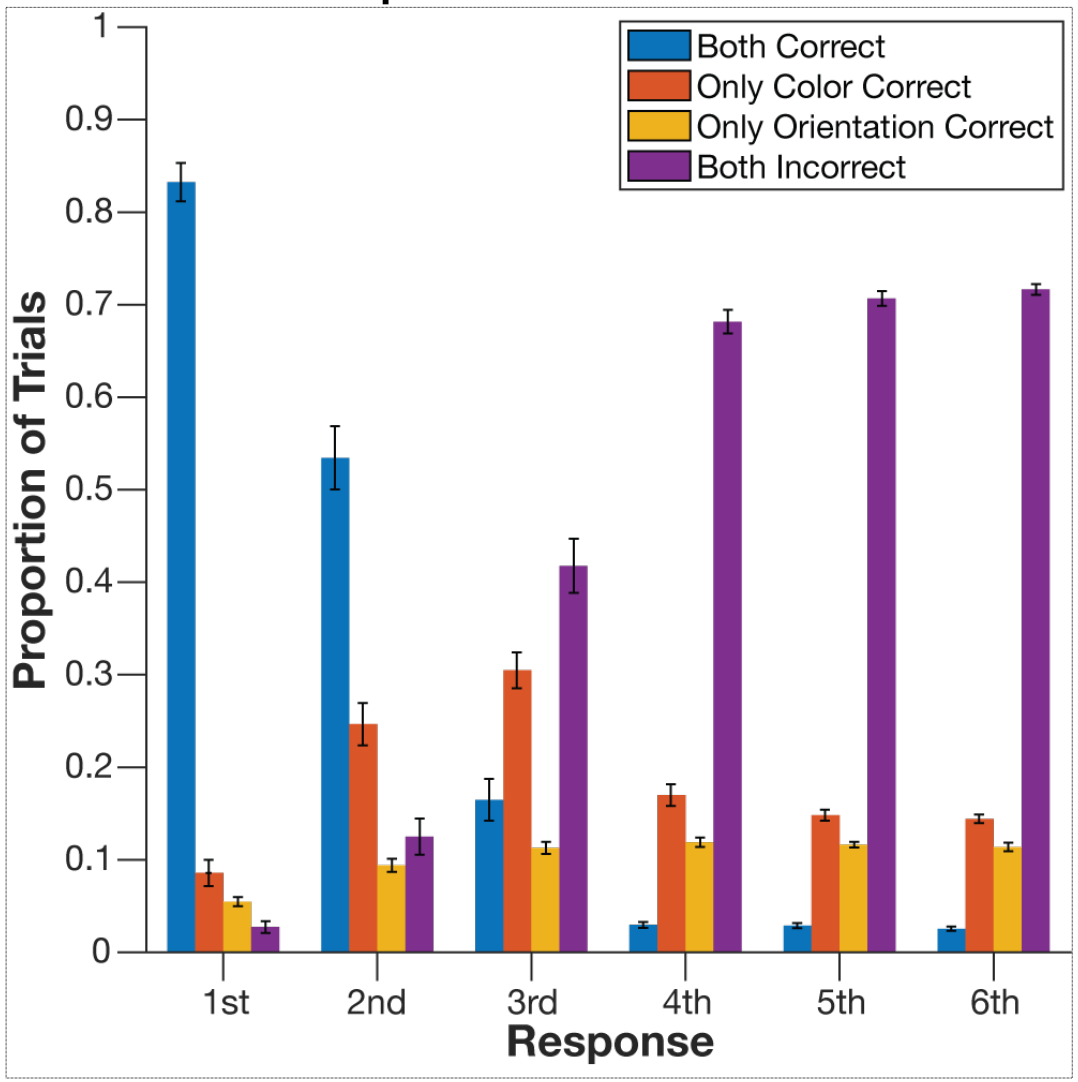
Experiment 4



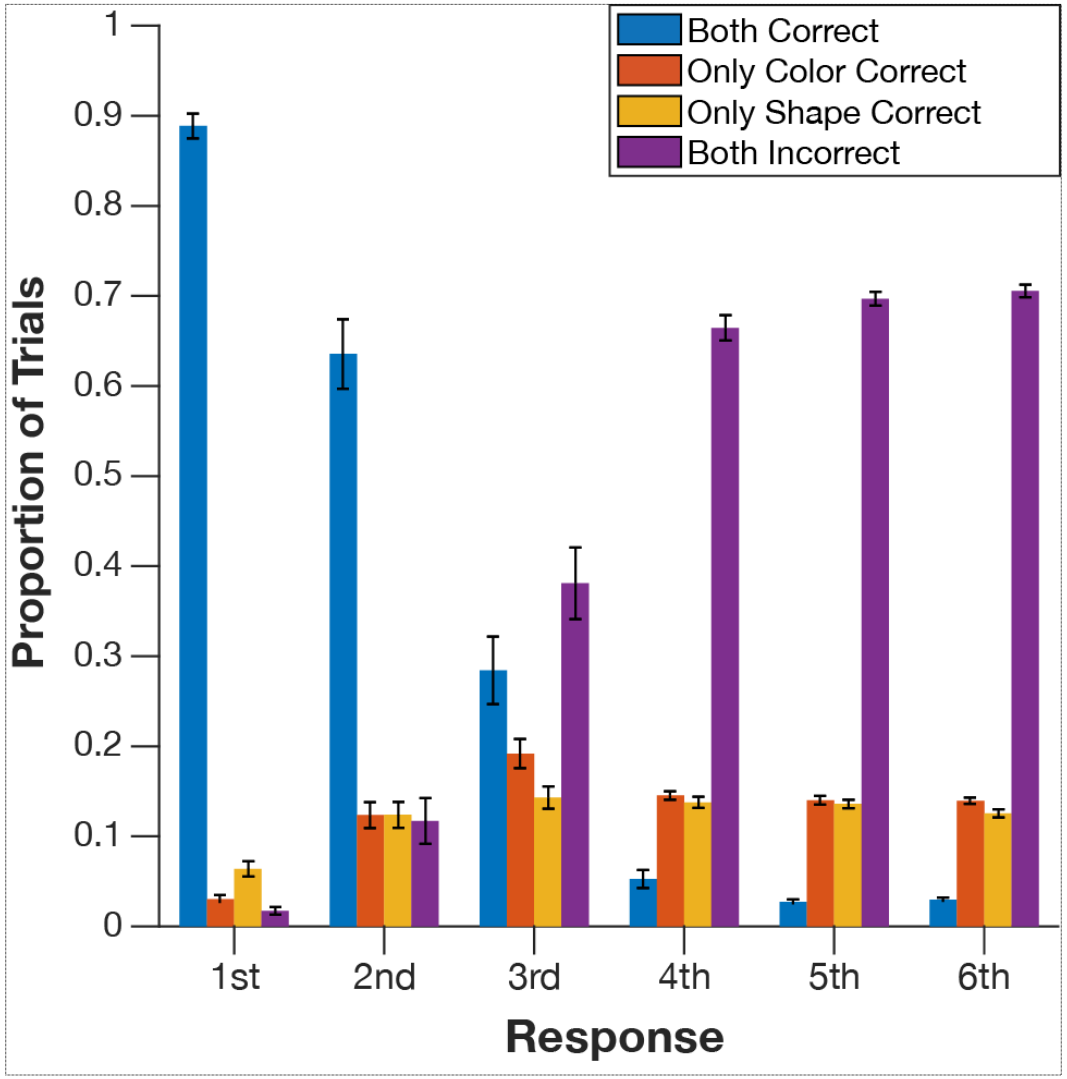
- The same empirical pattern was replicated across four experiments

Accuracy across responses

Experiment 1



Experiment 4



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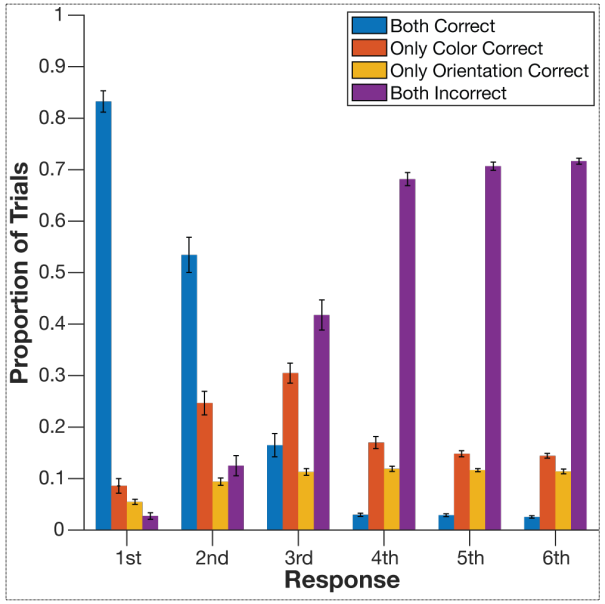
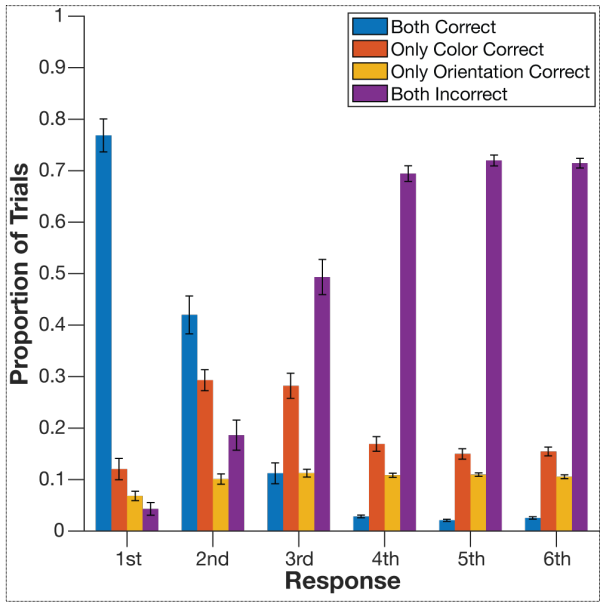
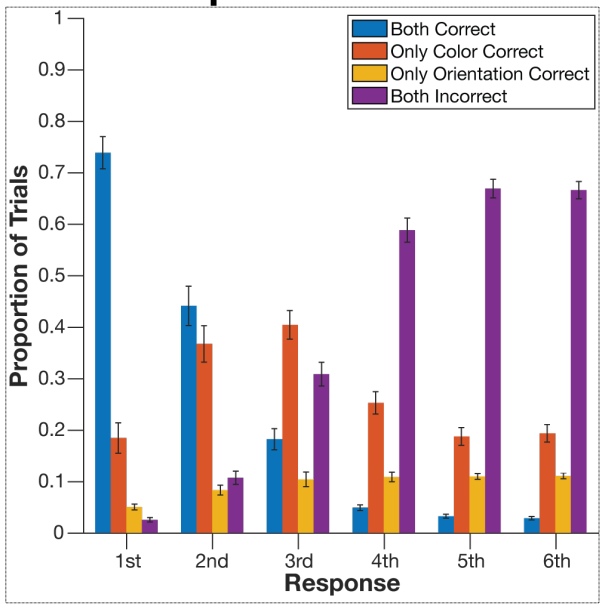


Experiment 2



Experiment 3



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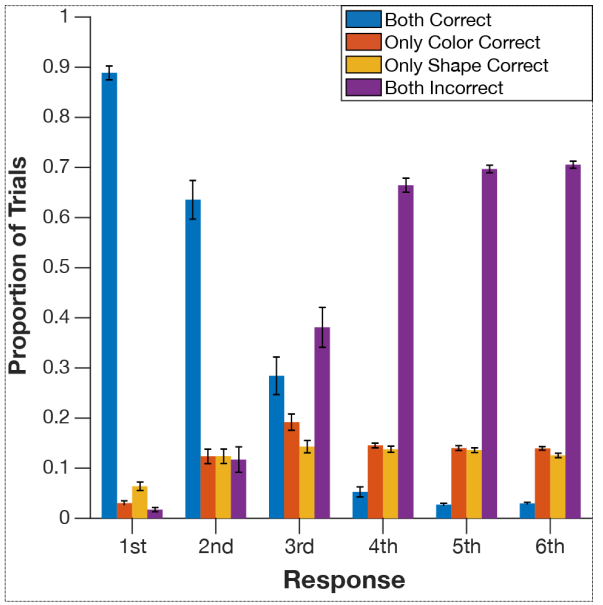
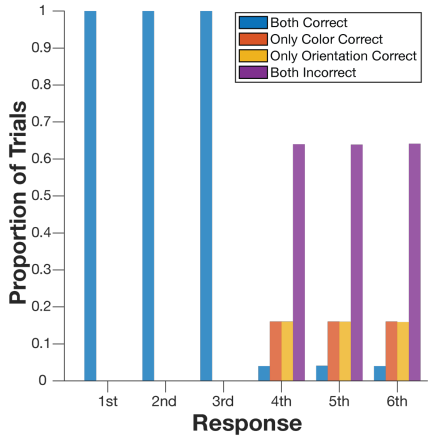


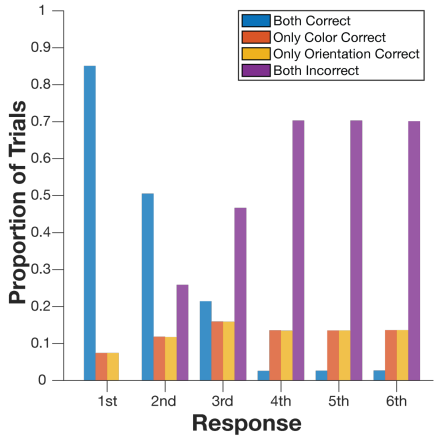
Strong Object Model

Accurate storage of three objects



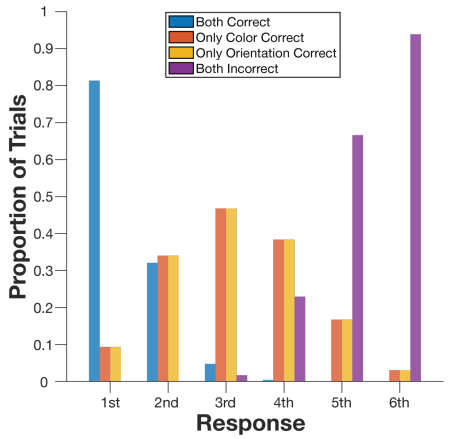
Pointer Model

Item-based storage with feature loss



Independent Feature Model

Feature storage independent of objecthood



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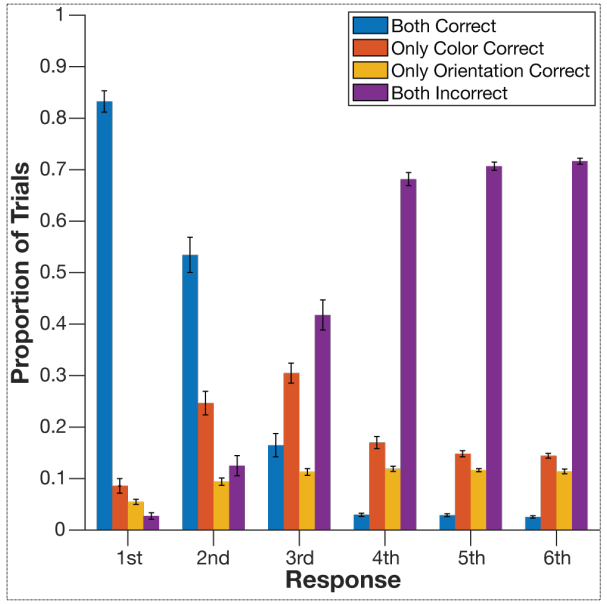
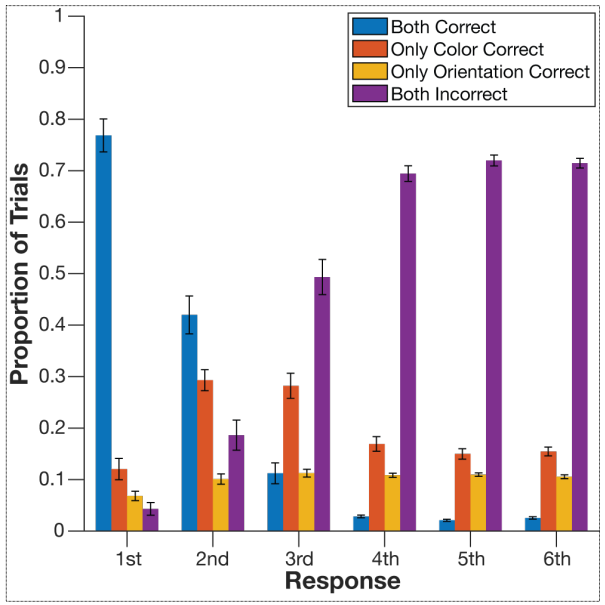
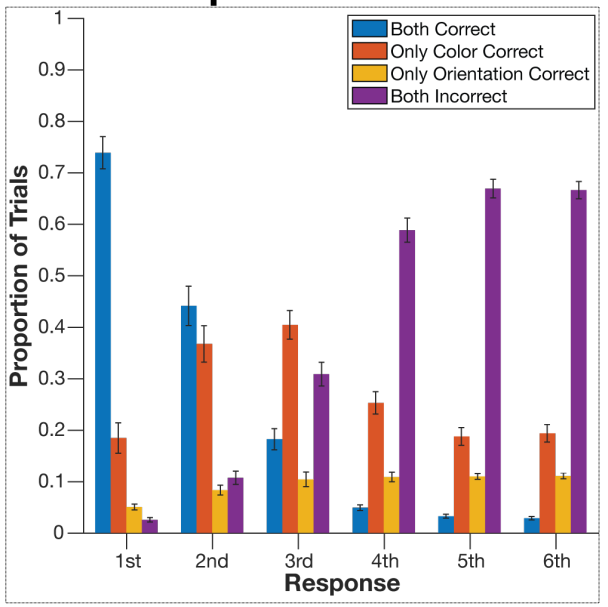


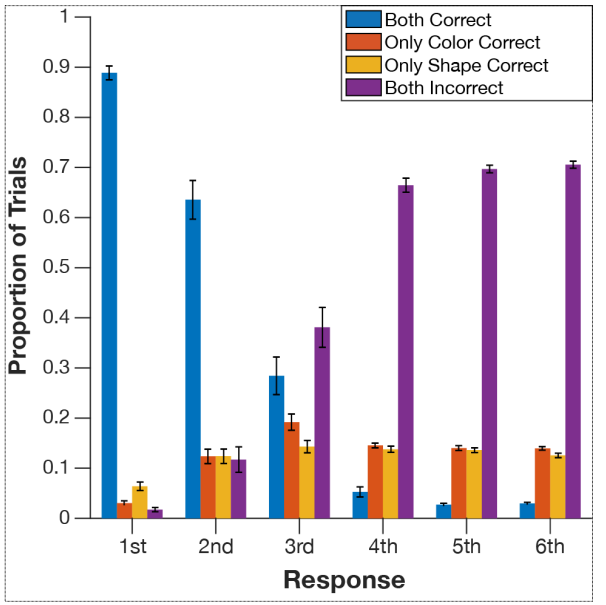
Experiment 2



Experiment 3



Experiment 4



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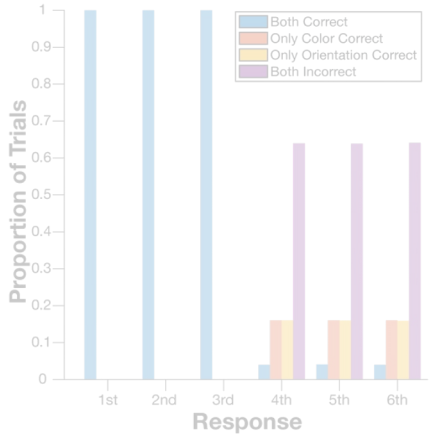
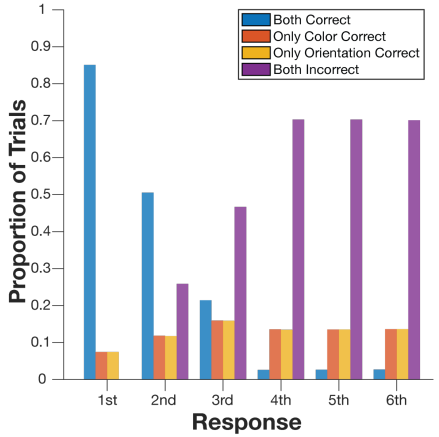


Pointer Model

Item-based storage with feature loss



Independent Feature Model

Feature storage independent of objecthood

Formal model comparison

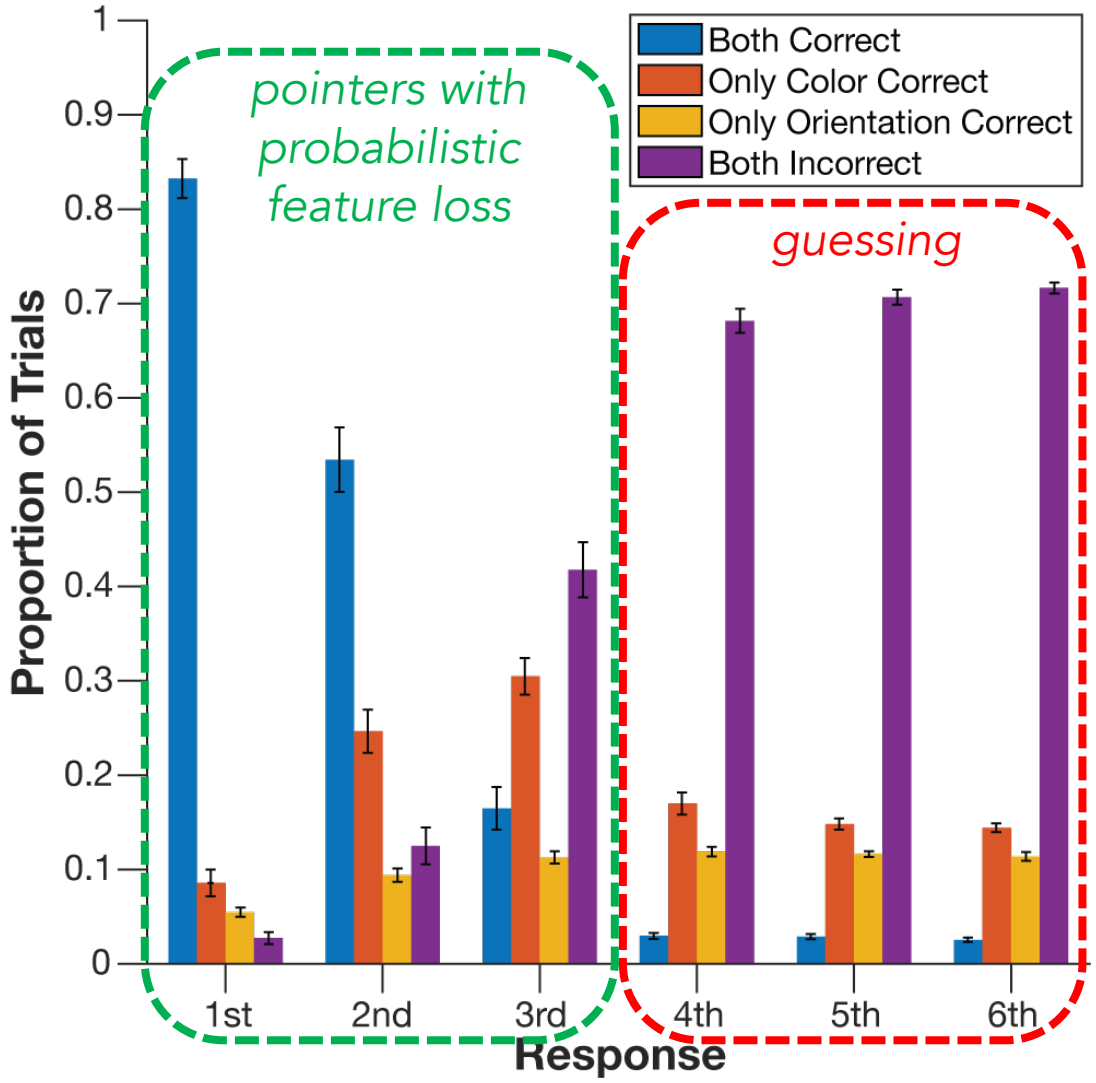
- The pointer model was best-fitting for all participants in all experiments

	✗	✓	✗
Model	Strong Object Model	Pointer Model	Independent Features Model
E1 AIC	4978.8	3326.2	4833.7
E1 BIC	4984.3	3337.2	4839.2
E2 AIC	4907.3	3310.2	4700.6
E2 BIC	4912.8	3321.2	4706.1
E3 AIC	5657.2	3497.4	4870.6
E3 BIC	5662.7	3508.4	4876.1
E4 AIC	4730.0	3211.5	4877.6
E4 BIC	4735.5	3222.5	4883.1

Our working hypothesis

- Pointers are required to maintain representations of objects through changes in its features
  - Like FINSTs or Object Files (Pylyshyn, 1989; Kahneman et al., 1992)

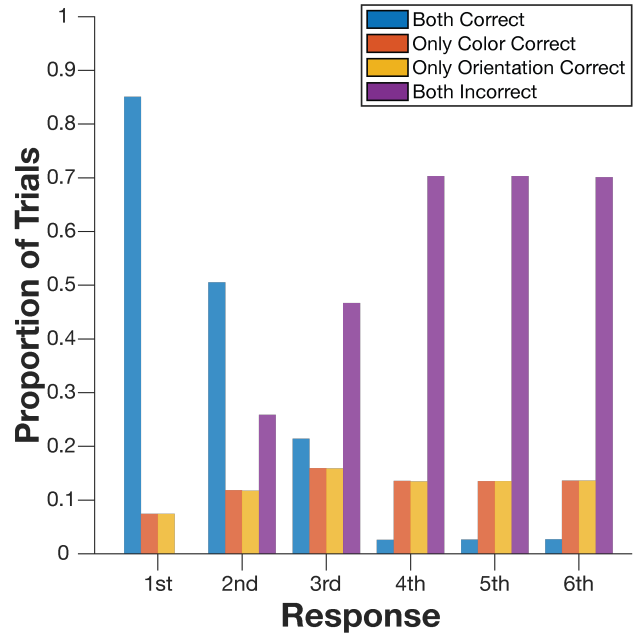
- Evidence for a neural signature that indexes load and generalizes across feature content (Thyer et al., 2022)

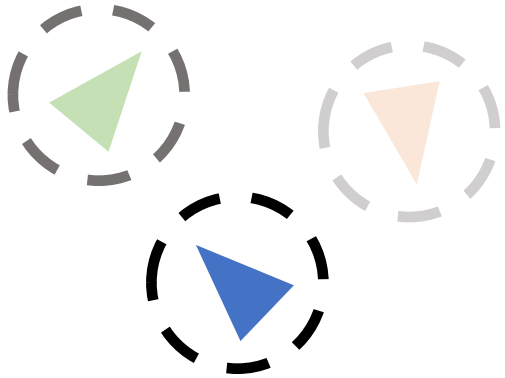


Pylyshyn, Z. (1989). https://doi.org/10.1016/0010-0277(89)90014-0
Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). https://doi.org/10.1016/0010-0285(92)90007-O
Thyer, W. et al. (2022). https://doi.org/10.1177/09567976221090923

Conclusions

- We observe an ***object-based benefit*** for memory recall
  - More features are recalled compared to the single-feature conditions
- Accurate recall is restricted to the first three responses regardless of number of features
  - Observers are ***guessing*** in the last three responses
  - But there is some ***feature loss*** in the memories
- Formal comparisons favored a model with an **object-based capacity limit** and probabilistic storage of each object's features
  - Outperformed a model with independent capacity limits for distinct features





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