Multiple-target search increases workload but enhances incidental learning:

A computational modeling approach to a memory paradox

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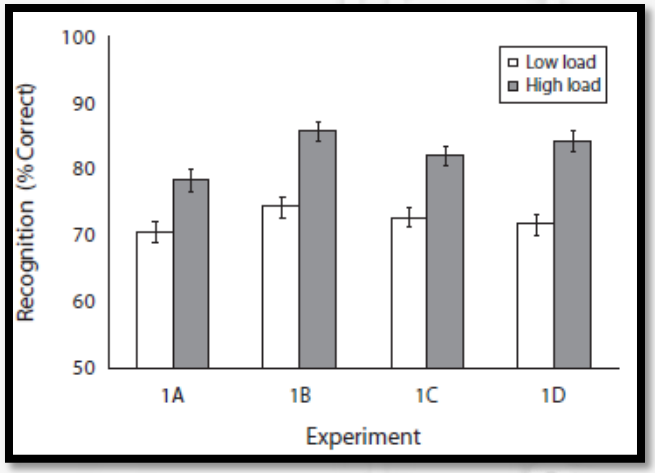
Object memory; Visual search

- Intentional object / picture memory is outstanding! [1-3]
- Substantial memory is also generated incidentally during visual search. [4-5]
- Typically, search is conducted for a single target (ST)… but multiple-target (MT) search is a ubiquitous behavior.
- MT search incurs a cost. [6]

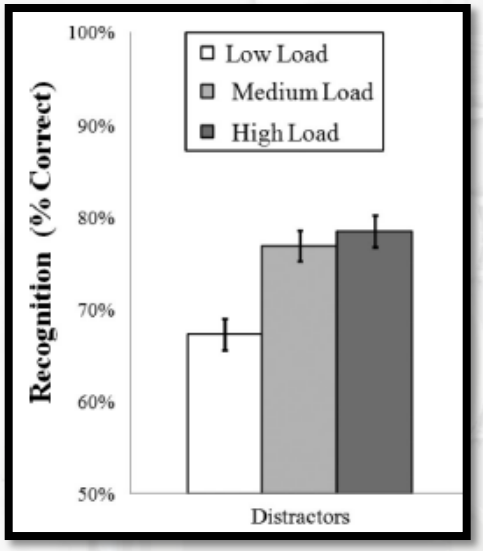
1 – Brady, T. F., Konkle, T., Alvarez, G. A., & Oliva, A. (2008). Visual long-term memory has a massive storage capacity for object details. *Proceedings of the National Academy of Sciences, 105,* 14325-14329.
2 – Wolfe, J. M., Horowitz, T. S., & Michod, K. O. (2007). Is visual attention required for robust picture memory? *Vision Research, 47,* 955-964.
3 – Evans, K. K., Cohen, M. A., Tambouret, R., Horowitz, T., Kreindel, E., & Wolfe, J. M. (2011). Does visual expertise improve visual recognition memory? *Attention, Perception, & Psychophysics, 73,* 30-35.
4 - Hollingworth, A., & Henderson, J. M. (2002). Accurate visual memory for previously attended objects in natural scenes. Journal of Experimental Psychology: Human Perception and Performance, 28, 113-136.
5 – Williams, C. C., Henderson, J. M., & Zacks, R. T. (2005). Incidental visual memory for targets and distractors in visual search. *Perception & Psychophysics, 67,* 816-827.
6 - Menneer, T., Cave, K. R., & Donnelly, N. (2009). The cost of search for multiple targets: Effects of practice and target similarity. *Journal of Experimental Psychology: Applied, 15,* 125-139.

- MT (or "loaded") search is slower and more error-prone than search for one target. [1]
- Incidental memory for "background" distractors is greater for items encountered under MT conditions (relative to ST).
  - Suggests increased scrutiny during search.
- But, number of targets is confounded with stimulus exposure!
  - In MT search, RTs are longer; items are fixated longer and more frequently. [2]

1 vs. 3 targets



1, 2 or 3 targets



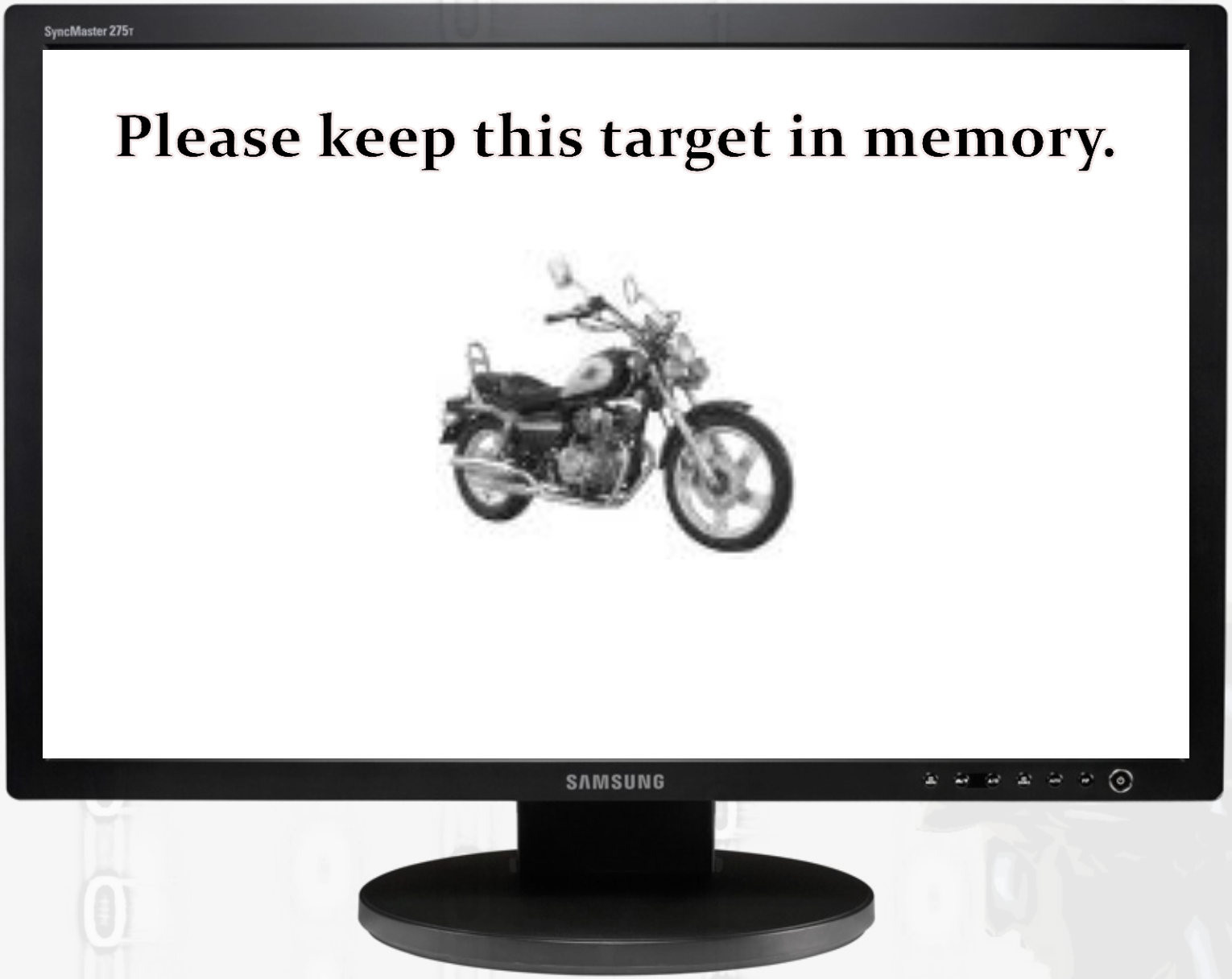
1 – Hout, M. C., & Goldinger, S. D. (2010). Learning in repeated visual search. *Attention, Perception, & Psychophysics, 72,* 1267-1282.
2 – Hout, M. C., & Goldinger, S. D. (2011). Incidental learning speeds visual search by lowering response thresholds, not by improving efficiency: Evidence from eye movements. *Journal of Experimental Psychology: Human Perception and Performance,* advanced online publication.

RSVP search

- Equal encoding opportunities, via rapid-serial visual presentation (RSVP) search. [1]
  - Ps maintained a variable number of targets in working memory (WM).
  - Search "streams" were centrally presented, one item at a time, for 250 ms.

1 – Williams, C. C. (2010). Incidental and intentional visual memory: What memories are and are not affected by encoding tasks? *Visual Cognition, 18,* 1348-1367.

Single-target RSVP search



Was the target present or absent??

Three-target RSVP search

Was a target present or were they all absent??

- Exp 1 IVs:
  - Stream Length: 5, 10, or 15 items.
  - Load: 1, 3, or 5 potential targets.

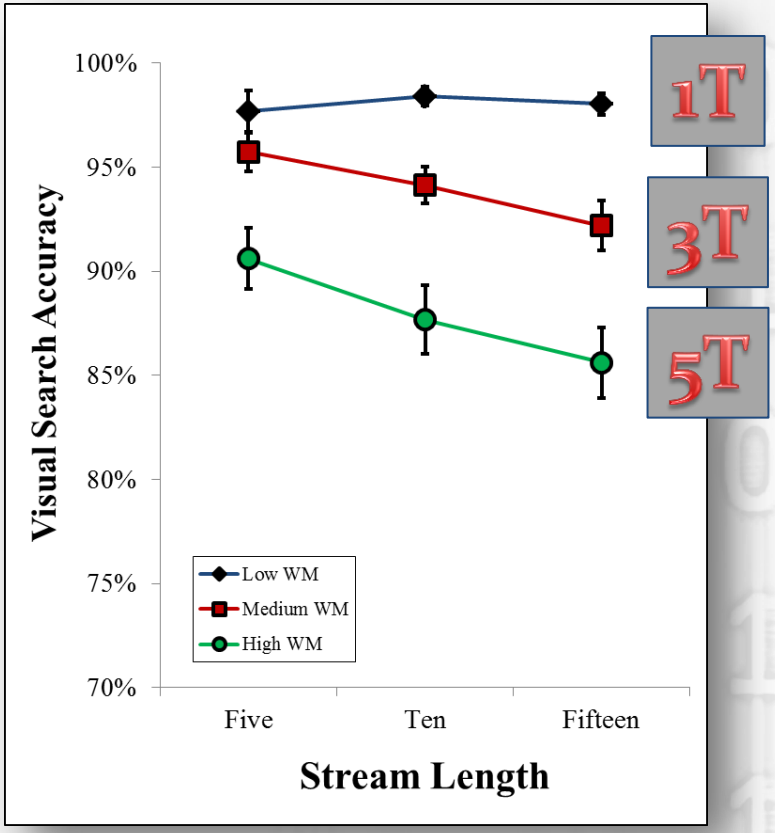
- 9 blocks of 20 trials.
- Stream order was randomized; 50% target presence.
- Distractor sets were discretely grouped for each block.

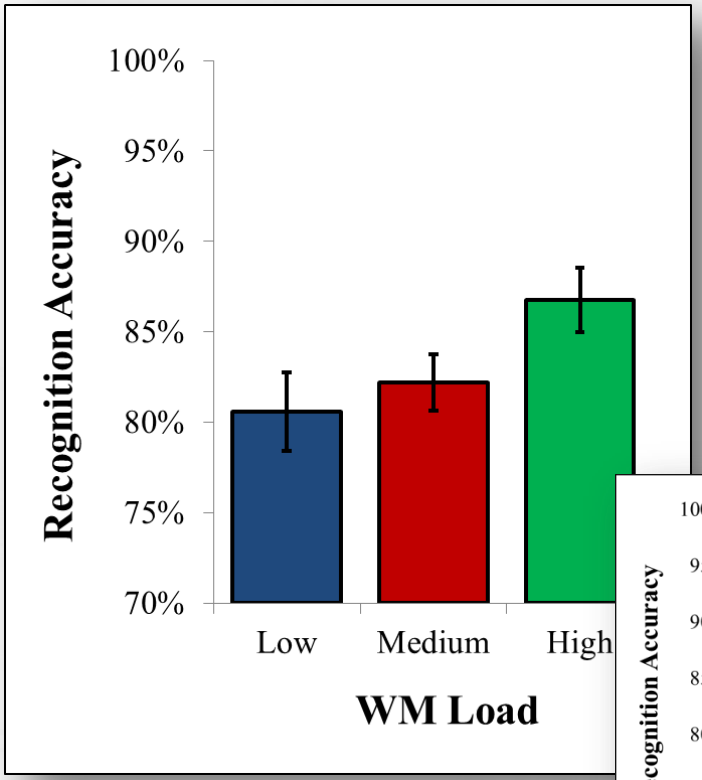
- Surprise recognition memory test:
  - 2AFC with semantically matched foils.
  - Tested all distractors.

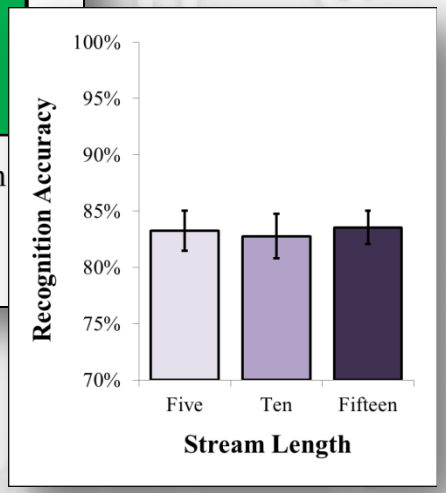
- Stimuli: gray-scaled photos.

Is item memory dependent on the amount of info in the stream?

Results – Exp 1







- Search accuracy
  - More targets → More errors
  - Longer stream → More errors
  - Significant interaction
- Recognition memory
  - More targets → Better memory
  - Longer stream → No effect
  - No interaction

Exp 1 summary; Exp 2

- Looking for MTs incurs an accuracy cost, exacerbated by prolonged search.
- Controlling for stimulus exposure, MT search still enhances incidental memory. [1]
- No evidence that item memory is dependent on total information exposure.

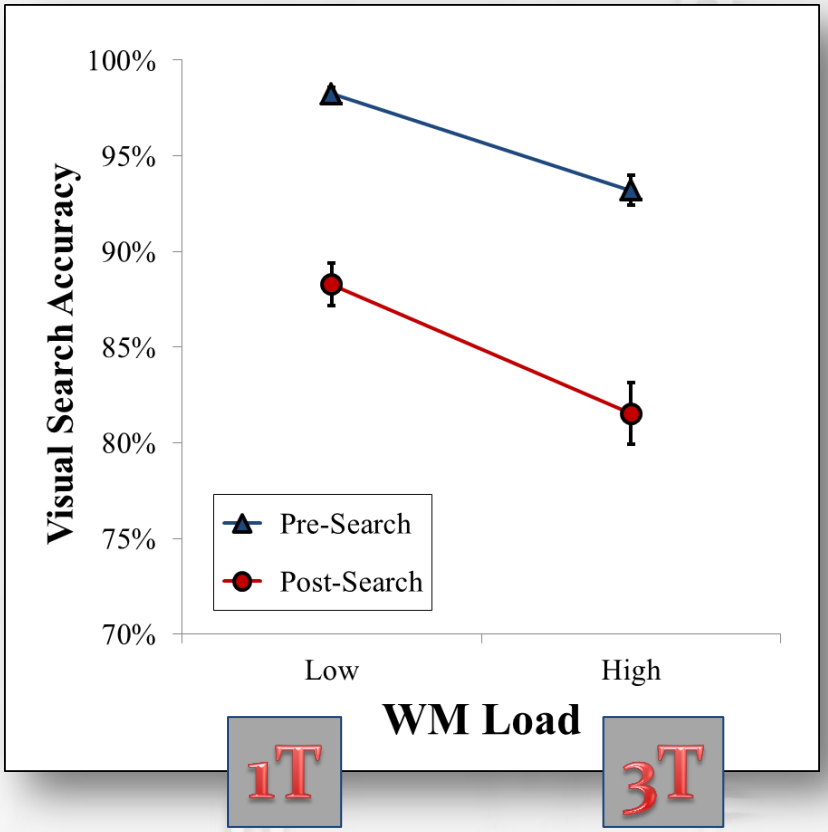
Can people adjust their strength of encoding without knowing the targets?

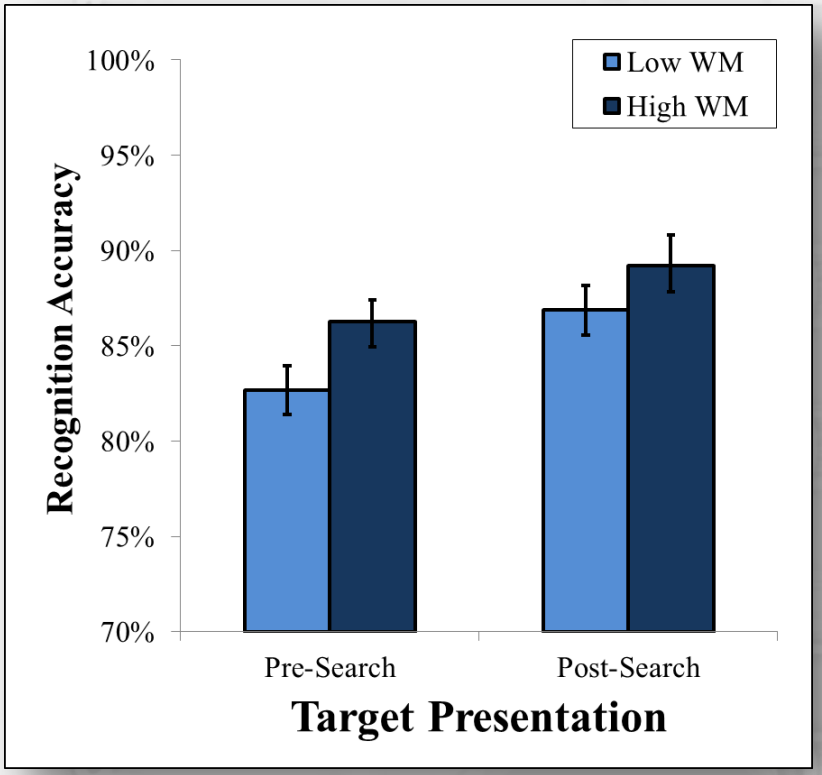
- Consequence of comparing items to multiple targets in WM or possible strategy shift?
- Exp 2 IVs:
  - Load: 1 or 3 potential targets.
  - Target Presentation: pre-search vs. post-search.
  - 4 blocks of 30 trials.

1 – Hout, M. C., & Goldinger, S. D. (2010). Learning in repeated visual search. *Attention, Perception, & Psychophysics, 72,* 1267-1282.

Post-presentation RSVP search

Results – Exp 2





- Search accuracy
  - More targets → More errors
  - Post-search → More errors
  - No interaction
- Recognition memory
  - More targets → Better memory
  - Post-search → Better memory
  - No interaction

Exp2 summary; Strategy shift?

- MT search increases workload, but enhances incidental item memory.
- Ps are capable of tuning their level of scrutiny for incoming items.

- **If search "strength" is ramped up in MT, why is search accuracy not on par with ST search?**

- Perhaps Ps shift to external focus:
  - Resources reallocated from WM maintenance (internal) to search strength (external).
  - One target: high WM maintenance, low search strength.
  - Multiple targets: low WM maintenance, high search strength.

SQuEaL

(Scanning QUiet Echoes And Learning)

- Multiple-trace model, derived from *Minerva2*. [1-2]
- Objects: vector of feature loadings:
  - e.g., {-1 0 +1 +1 -1 … 0}

- Incoming probes "shown" to model's WM buffer, returns "echo".
  - Distractors: low intensity echo.
  - Targets: high intensity echo.

- Imperfect encoding!
  - Elements can be lost over time (from WM).
  - Elements can be missed.

- Also weakly stored in long-term memory.
  - Accumulated memory used for 2AFC.
  - Old item and foil vectors sent to LTM.

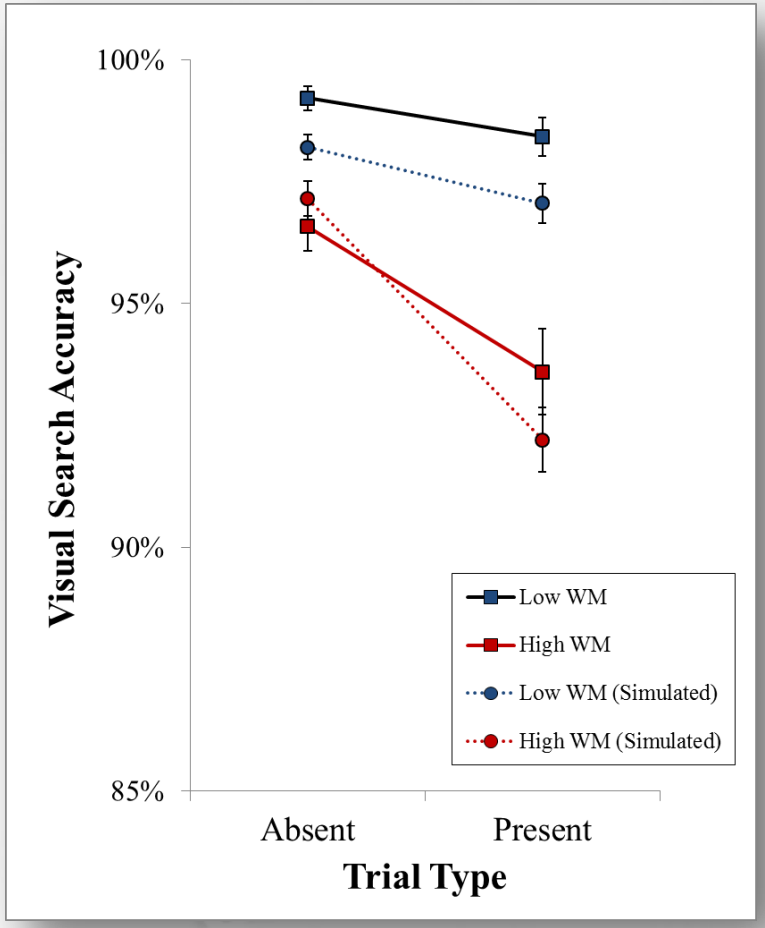
- ST: low decay, low strength
- MT: high decay, high strength

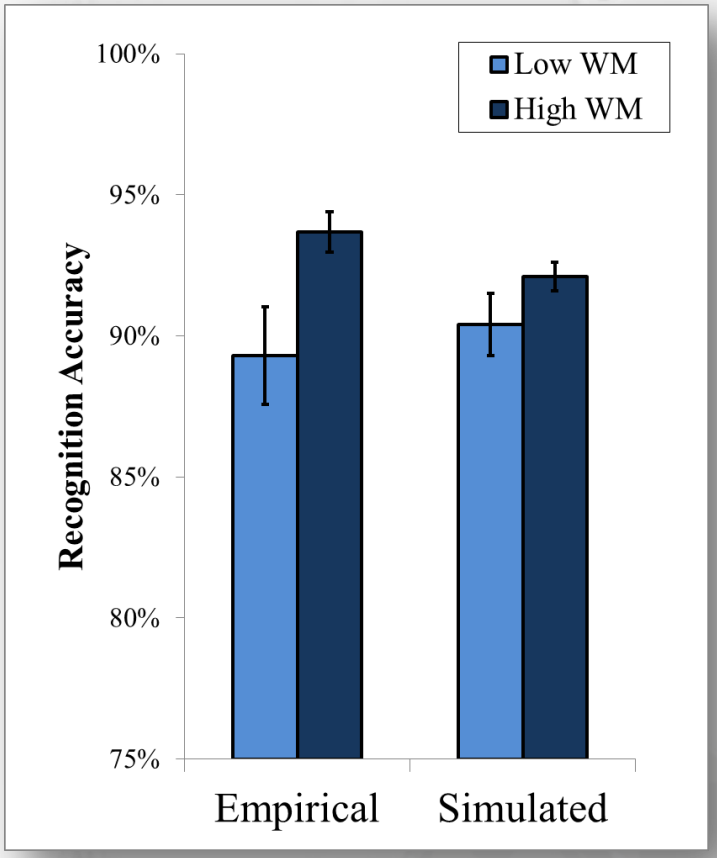
Target decay: loss of elements from WM

Search strength: probability of faithful encoding

1 – Hintzman, D. L. (1988). Judgments of frequency and recognition memory in a multiple-trace memory model. *Psychological Review, 95*, 528-551.
2 – Clark, S. E., & Gronlund, S. D. (1996). Global matching models of recognition memory: How the models match the data. *Psychonomic Bulletin & Review, 3*, 37-60.

Data from Hout & Goldinger, 2010



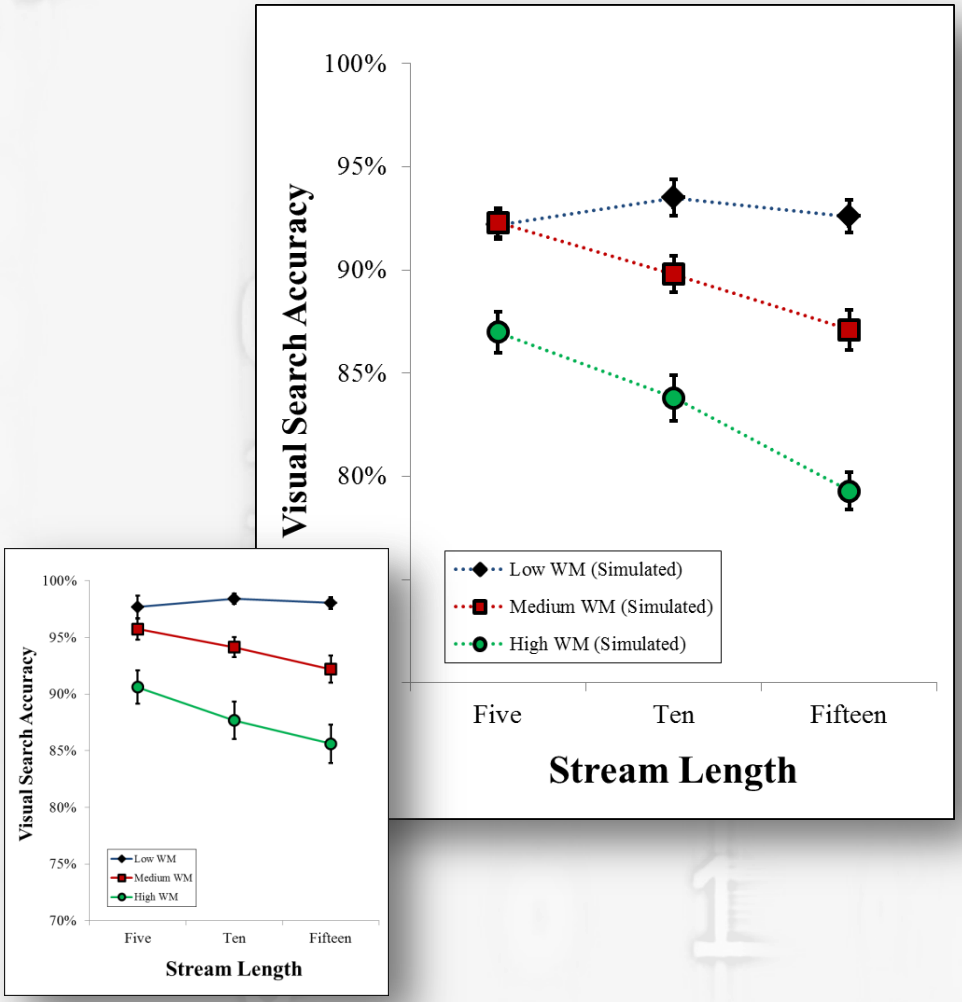


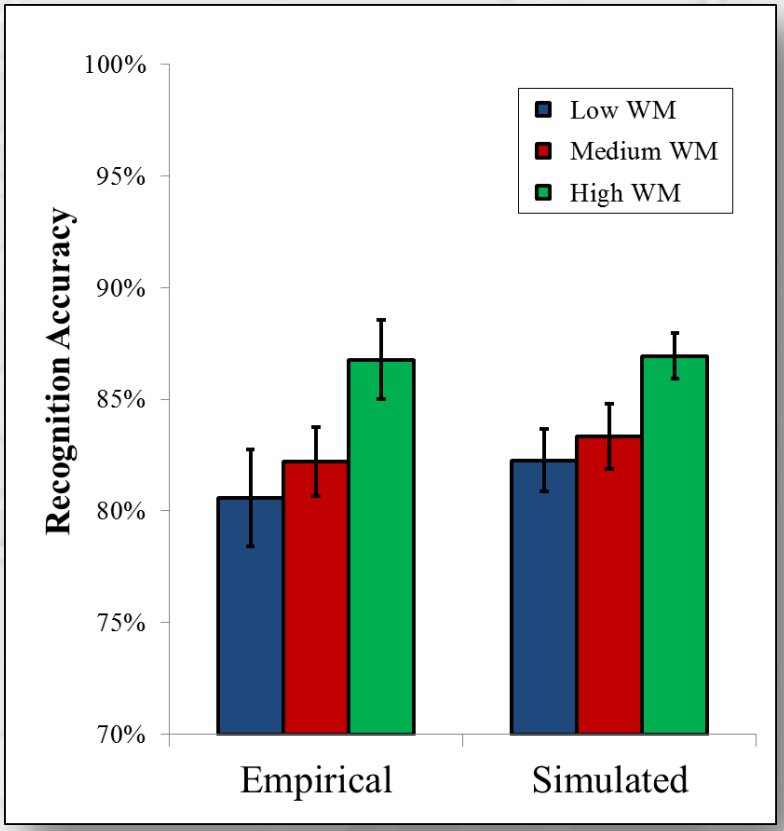
ST: low decay, low strength

MT: high decay, high strength

- 57 empirical subjects; 50 statistical subjects.
- All main effects and interactions replicated.

Data from Exp 1





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- 45 empirical subjects; 50 statistical subjects.
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General discussion

- MT search incurs cost arising from conflict between top-down requirements. [1-2]
  - Paradoxical increase in item retention.
- Item memory is independent (Exp 1), and searchers can voluntarily "tune" their search strength (Exp 2).
- Ps switch focus in MT search: targets fade, so incoming items can be encoded more faithfully.
- Multiple-trace model gives credence to hypothesized strategy shift. [3]
  - Varied only two parameters: target decay and search strength.

1 – Menneer, T., Barrett, D. J. K., Phillips, L., Donnelly, N., & Cave, K. R. (2007). Costs in searching for two targets: Dividing search across target types could improve airport security screening. *Applied Cognitive Psychology, 21,* 915-932.
2 – Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: An alternative to the feature integration model for visual search. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 419-433.
3 – Roberts, S., & Pashler, H. (2000). How persuasive is a good fit? A comment on theory testing. *Psychological Review, 107,* 358-367.

Future directions

- Implications for baggage / medical screening.

- How else might strategy-changes affect search behavior? [1]

1 – Watson, M. R., Brennan, A. A., Kingstone, A., & Enns, J. T. (2010). Looking versus seeing: Strategies alter eye movements during visual search. *Psychonomic Bulletin & Review, 17,* 543-549.

Thank you for your attention!

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Memory & Language Laboratory

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