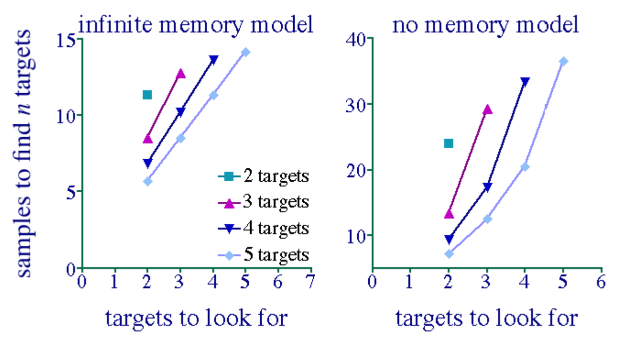
Search for multiple targets: Search rate depends on what is being remembered.

Todd S. Horowitz[1,2], Jeremy M. Wolfe[1,2], Randall S. Birnkrant[1] (1) Visual Attention Laboratory, Brigham & Women's Hospital; (2) Department of Ophthalmology, Harvard Medical School

how much memory does visual search have?

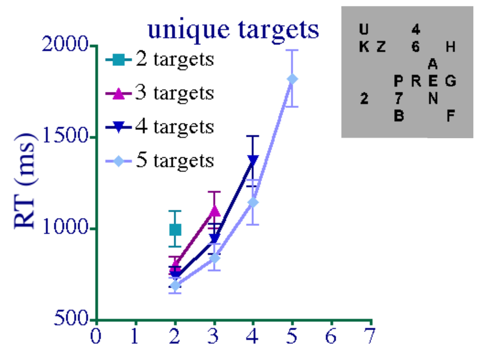
multiple target search method

Different memory assumptions make different predictions about how long it should take to find the n^{th} target in a multiple-target display



With infinite memory, time to find each target is constant, yielding linear functions.

With no memory, time to find each target increases, yielding accelerating functions.



We found that RTs were highly accelerated, favoring low memory models (Horowitz & Wolfe, 2001, Experiment 1)

the math (if you really want to know)

A is the zero memory model, M is the infinite memory model, and L_c is the limited capacity model.

These equations determine the number of samples needed to find n targets. RT predictions were generated by multiplying by a rate parameter and adding an intercept. RMS error to individual observer data was minimized.

$$A = \sum_{i=1}^{n} 1 + \left(\frac{t-i+1}{d+i-1}\right)$$

$$M = \frac{n(t+d+1)}{t+1}$$

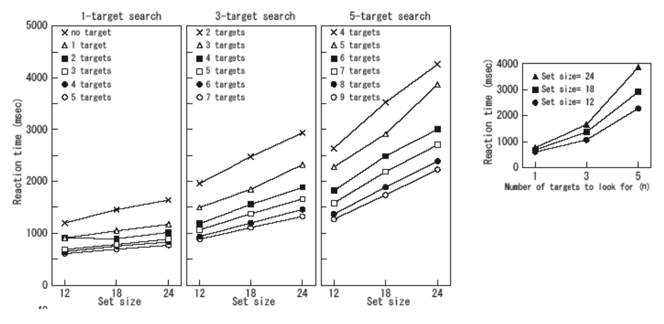
$$L_c = \sum_{i=1}^{t} \left(M_{i,c} + A_{t-i,s-c}\right)$$

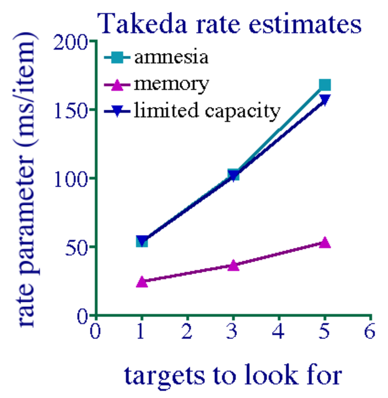
t = number of targets present
d = number of distractors
n = number of targets to look for
c = memory capacity

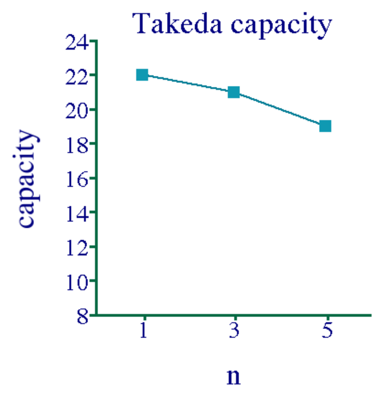
Challenge: is search rate constant across *n*?

We had assumed that search rate was constant across conditions. If search became slower as the number of targets to look for increased, then the RT curves would accelerate even with infinite memory.

Yuji Takeda (in press) argued that search rate did increase with *n*. He ran three groups of observers with three different values of n, and varied set size. He found that search rates increased with n. Furthermore, his data favored high memory models.







... but, Takeda's search task is different from ours

Importantly, the search task was different: Takeda's observers looked for O targets among Landolt C distractors (see Figure for Experiment 1).

The critical difference might be the nature of memory for targets, not for rejected distractors.

With unique targets, you can remember names (I found a "7"). With identical targets you must remember spatial location ("There was a target in the upper left."). While verbal or visual memory loads do not slow search rate (Woodman, Vogel, & Luck, 2001), spatial memory loads do (Oh & Kim, 2002).

We replicated Takeda's experiment with his stimuli and then with ours:

We theorized that:

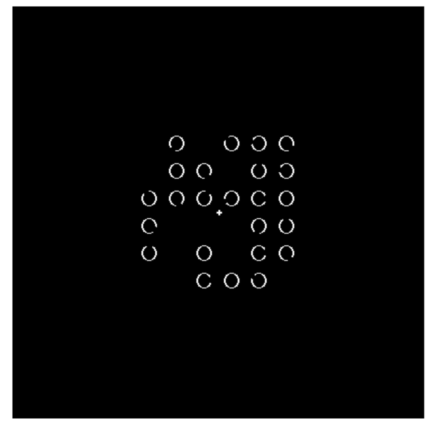
1. Spatial memory for *targets* can add to the apparent memory capacity for multiple target searches.
2. Spatial memory comes with an RT cost (More memory leads to slower search rate).

Therefore:

Testable Hypothesis 1: Search rate will be slower for tasks where observers must use spatial memory to keep track of targets.

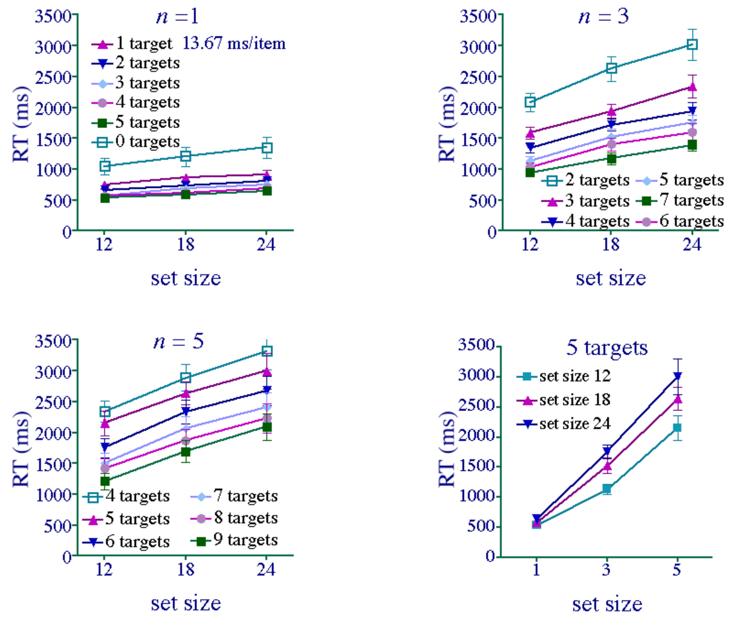
Testable Hypothesis 2: Use of spatial memory for targets will increase the estimated memory capacity in a visual search task.

Experiment 1: Takeda replication

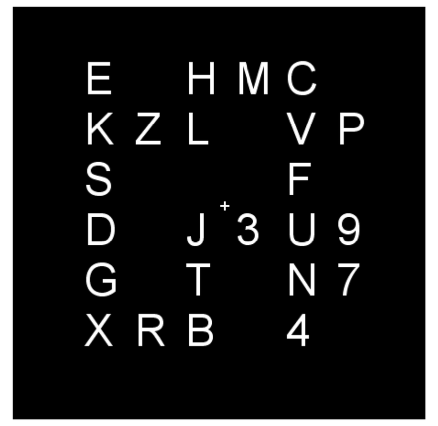


Task: are there at least *n* targets (Os)? *N* was varied between-subjects, with 12 observers in each condition. There were 18 blocks of 60 trials.

Here are the raw data but the real action is in the modeling results at the top of the final column.

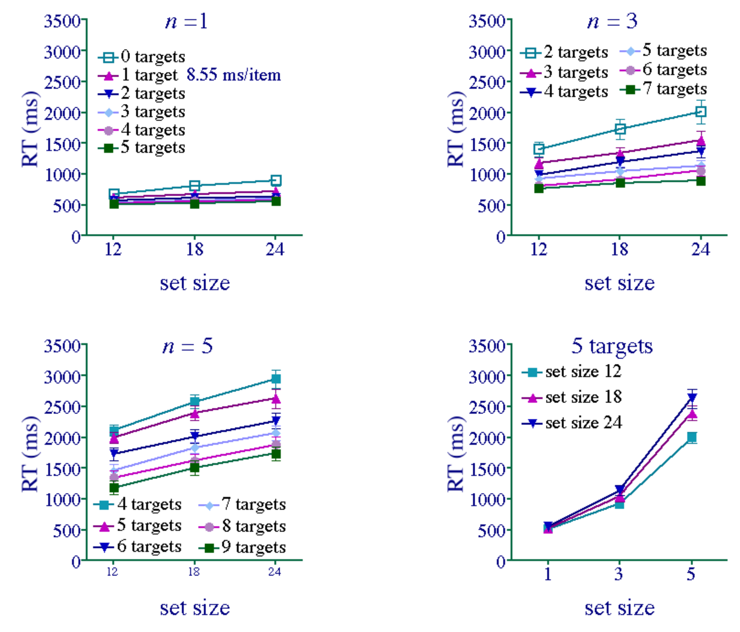


Experiment 2: Horowitz & Wolfe stimuli with Takeda design



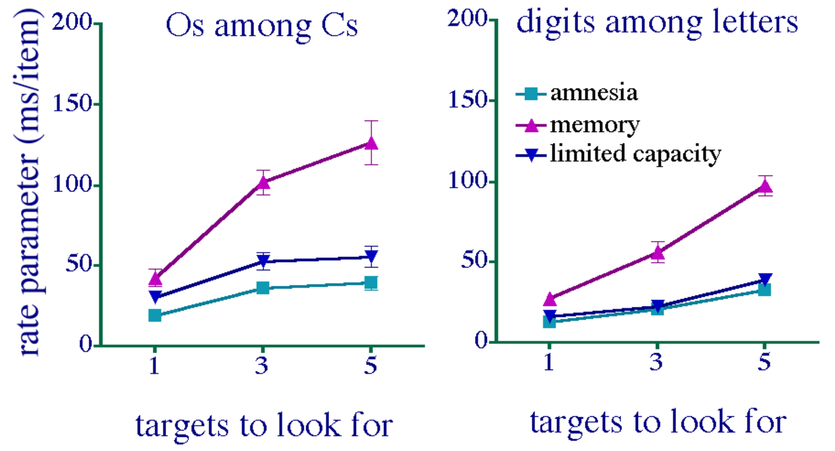
Task: are there at least n targets (digits)? Stimuli were larger. Procedure was otherwise identical to Experiment 1.

Again, these are raw data but the real action is in the modeling results at the top of the final column.



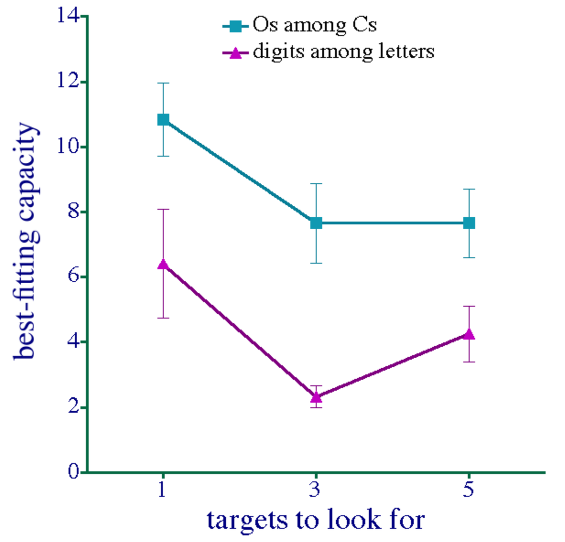
The Real Action: modeling results

1) We replicate Takeda: Estimated search rate slows as number of targets to look for increases in both experiments.



2) Hypothesis 1 confirmed: Search rate was slower in Experiment 1 (required spatial memory).

3) Hypothesis 2 confirmed: Estimated limited memory capacity was higher in Experiment 1, perhaps reflecting the contribution of spatial memory for targets.



conclusions

1) Spatial memory for targets can add to the apparent memory capacity of visual search.

2) But spatial memory for targets slows search.

3) So, if not necessary, spatial memory may not be used. Estimates of memory for distractors in visual search may be inflated by memory for found targets.

references

Horowitz, T. S., & Wolfe, J. M. (2001). Search for multiple targets: remember the targets, forget the search. Perception & Psychophysics, 63(2), 272-285.
Oh, S.-H., & Kim, M. S. (2002, July 22-24). Visual search efficiency is affected by spatial working memory. Paper presented at the Second Asian Conference on Vision.
Takeda, Y. (in press). Search for multiple targets: Evidence for memory-based control of attention. Psychonomic Bulletin & Review.
Woodman, G. F., Vogel, E. K., & Luck, S. J. (2001). Visual search remains efficient when working memory is full. Psychological Science, 12(3), 219-224.

acknowledgements

This research was supported by a grant from AFOSR. We are grateful to Yuji Takeda for allowing us to discuss and reprint his data here.

comments/requests