RSVPupillometry: Incidental memory and psychophysiology in rapid-serial multiple-target search.

Michael C. Hout [1], Megan H. Papesh [2], & Stephen D. Goldinger [1]

[1] Arizona State University; [2] Louisiana State University

12th Annual Meeting of the Vision Sciences Society

ABSTRACT – # 56.329

Typically, visual search experiments involve single-target (ST), template-guided search: Observers are shown a picture and look for it embedded among distractors. But real-world search is more difficult. Multiple-target (MT) search is ubiquitous; consider collecting your keys, wallet and phone before departing from home. Also, we rarely have a picture from which to generate a target representation. Rather, we search categorically, by compiling target features from long-term memory. Importantly, MT search incurs speed and accuracy costs, relative to ST search: Observers' RTs are slowed, they make more (and longer) fixations, and they are more likely to miss and false-alarm (Hout & Goldinger, 2012). Paradoxically, this increased workload creates more robust incidental memory for distractors encountered while viewing (Hout & Goldinger, 2010). In the current investigation, we contrasted template- (picture cues) and categorical-search (word cues), using a rapid-serial visual presentation task (Williams, 2010), wherein participants maintained a varying number of targets in working memory (WM) while passively viewing streams of 24 briefly presented images (centrally displayed, one at a time). This task allowed us to ensure equal encoding opportunities across conditions. The target appeared in each quartile of the stream (early, mid-early, mid-late, late) equally often. After search, we administered a surprise, 2AFC recognition memory test for items previously seen; foils were semantically matched. Search accuracy was better under ST conditions, relative to MT, and was better in template- relative to categorical-search. People also located the target more accurately when it appeared late in the stream, relative to earlier. Recognition memory performance, however, was better for items encountered while searching for multiple targets (and tended to be better for items that appear after the target, relative to before it). The results are discussed with respect to our preliminary model of learning in visual search (SQuEaL; Hout & Goldinger, 2011), which suggests that MT template-guided search may involve a strategy shift, wherein cognitive resources are transferred from maintaining target representations in WM to the faithful encoding of search items. In categorical search, a similar mechanism may come into play, whereby the maintenance of guiding features is less stable in MT search. Finally, we explored pupil diameters in order to examine attentional vigilance and its relation to search performance (e.g., Papesh, Goldinger & Hout, 2012). Pupil dilation was a reliable marker of task difficulty, as well as target identification. Moreover, pupils elucidated existing shortcomings of the SQuEal model; future modeling efforts are revised in keeping with the attentional signatures indicated by pupil dilation.

The difficulties of real-world search.

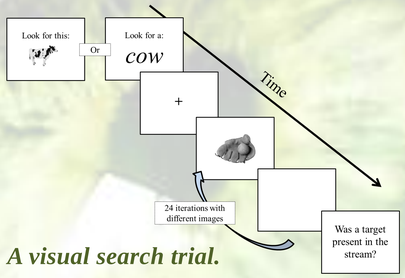
- Many laboratory search tasks involve looking for a single target; and cues are often a veridical representation of what the observer will find.
- By contrast, in real-world searches, we often look for several targets simultaneously. Moreover, we are seldom given picture cues from which to guide search, but must instead generate a target representation by compiling features stored in long-term memory.
- The current experiments examined template-guided (picture cues) and categorically-guided (word cues) search, for single-targets (ST) and multiple targets (MT). We explored search behavior and incidental memory (and constructed a computational model to simulate both), and the physiological markers of cognitive effort (pupil dilation).
- We are interested in 1) search performance under varying conditions of difficulty, 2) the factors that lead to incidental acquisition of information during search, and 3) the physiological signatures of template creation and maintenance, and target detection (cf. Papesh, Goldinger & Hout, 2012).

The SQuEaL model.

- Prior work has shown that MT search increases task demands, slowing search and resulting in more (and longer) fixations, and poorer search accuracy, relative to ST search (Hout & Goldinger, 2012).
- Paradoxically, incidental memory for items encountered while searching for several targets is better than memory for those seen while looking for a single target. This is true even when stimulus exposure is equated by using a rapid-serial visual-presentation task (RSVP; Hout & Goldinger, 2010).
- It's possible that under MT conditions, cognitive resources are diverted away from maintaining the targets in memory. Instead more effort may be devoted to the service of faithfully encoding incoming (i.e., shown) items, in hopes that the target will "pop out" to the viewer. This would lead to poorer search accuracy through visual working memory (VWM) decay, and better incidental memory through strengthened item encoding.
- We developed a multiple-trace memory model – Scanning Quiet Echoes and Learning (Hout & Goldinger, 2011) -- derived from Hintzman's (1988) *MINERVA2*, in order to simulate these findings, and corroborate our hypothesis. Objects are represented by randomly generated feature loadings (-1s, 0s, +1s), and each "event" is represented by its own memory trace.
- By varying only two parameters – (1) the amount of decay from VWM (features are set to zero), and (2) the strength of encoding of search items (features are probabilistically encoded) – we successfully replicated these patterns (i.e., search and recognition accuracy in ST and MT search).
- In the model, for ST search, the target is faithfully maintained, but incoming items are weakly encoded; in MT search, the targets quickly decay, but item encoding is strengthened.
- The new version of the model simulates categorical-search via similar mechanisms. Here, features may be called upon incorrectly, and target elements become unstable over time (to simulate the difficulty of creating and maintaining a target representation from memory). This process is hindered in MT search.

The current investigation.

- People searched for one or three targets (only one ever appeared) in streams of 24 rapidly presented (250 ms each) real-world objects. They indicated target absence or presence after the stream. Images were gray-scaled.
- Targets were new on each trial and were cued with either pictures (template-guided) or words (categorically-guided). The target, when present, appeared equally often in each quadrant of the stream (early, mid-early, mid-late, late).
- Distractors were seen several times each, but only in a single condition (making recognition memory directly comparable across search conditions).
- Following search, we administered a surprise 2AFC memory test, with semantically-matched foils. Participants indicated which item was old, and the confidence of their response ("Sure this one is old," "I think this one is old").
- Pupil diameter was recorded by an SR-Systems Eyelink 1000 eyetracker at 1000hz. All responses were made using the keyboard. E-Prime software was used.

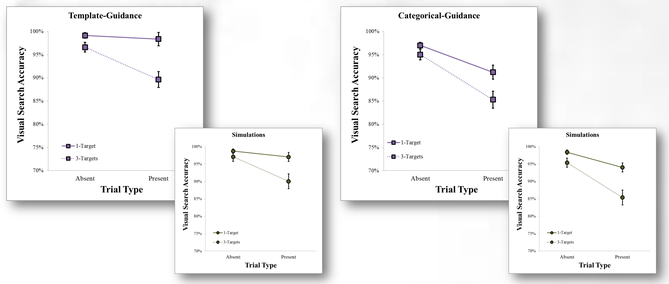


A visual search trial.

Recognition memory.

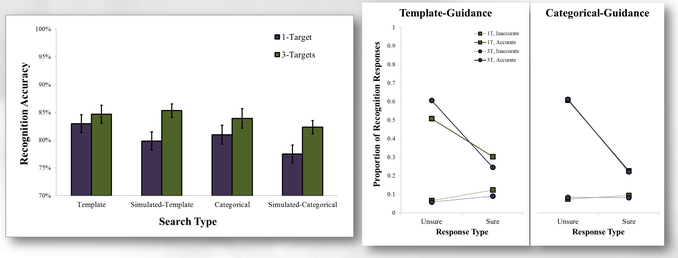
Results: Visual search.

- Participants were 60 Arizona State University students; 32 completed template-guided search, 28 completed categorically-guided search. All other manipulations were within-subjects.
- Main effect of Search Type ($p < .01$, $\eta_p^2 = .13$): Better accuracy for template-guided (96%), relative to categorically-guided (92%) search.
- Main effect of Load ($p < .001$, $\eta_p^2 = .45$): Better accuracy for ST (96%), relative to MT search (92%).
- Main effect of Trial Type ($p < .001$, $\eta_p^2 = .51$): Better accuracy on target-absent trials (97%), relative to target-present (91%).
- Interactions of Search Type x Trial Type ($p < .05$, $\eta_p^2 = .10$), and Load x Trial Type ($p < .01$, $\eta_p^2 = .14$).
- The SQuEaL model is probabilistic; we simulated 50 statistical subjects (25 each for template- and categorical-search). The simulations were a perfect replication of the empirical findings.
- Only two model parameters varied by Load. In template-search, VWM decay was higher for MT search; in categorical-search, feature stability was lower in MT search. For both Search Types, item encoding rates were higher in MT search.



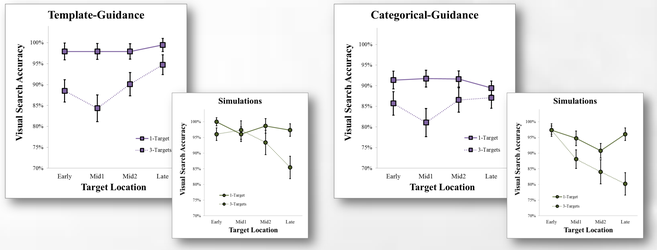
Results: Recognition memory.

- Main effect of Load ($p < .05$, $\eta_p^2 = .08$): Better memory for items encoded while searching for multiple targets (85%), relative to searching for a single target (82%).
- No effect of Search Type ($p = .52$), and no interaction.
- Again, the model replicated the findings, including the relative frequency of "unsure" responses (not shown).
- Confident responses were more frequent for accurately recognized items (relative to inaccurate responses), but were not more frequent for either Search Type or Load group. Surprisingly, when responses were accurate, unconfident ("unsure") responses were more frequent than confident ("sure") responses.



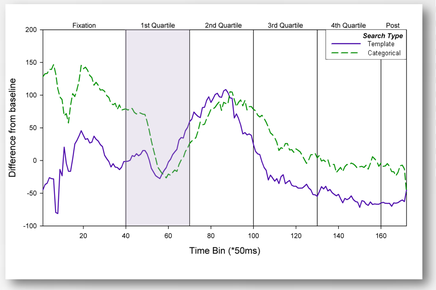
A closer look: Where the model fails.

- Considering the target-present trials alone, there was an interaction of Load x Target Location (early, mid-early, mid-late, late), such that in MT search, accuracy was better when the target appeared late in the stream ($p < .05$, $\eta_p^2 = .14$).
- The model, however, cannot reproduce this result. In template-guided search, target representations decay over time. Similarly, in categorical-search, target representations become unstable over time. Thus, the model predicts that performance will suffer when targets are late arriving, rather than improve.



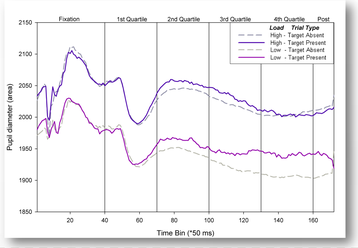
Pupil dilation: Setting up the target representation.

- Pupil dilation was assessed (as a function of condition) based on various trial "events", such as the fixation cross, or quartiles of the search stream.
- During the fixation cross, dilation (indexed as a change from baseline) was increased for categorical-, relative to template-guided search ($p < .01$, $\eta_p^2 = .14$), indicating greater cognitive effort in the creation of the search template.

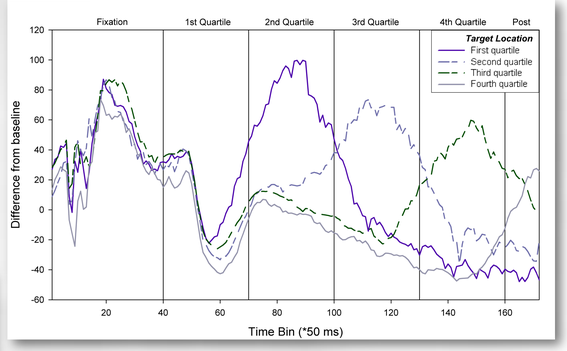


Pupil dilation: Task difficulty and target identification.

- When searching for multiple targets, pupils were larger, relative to searching for one target. This pattern was consistent during the second, third, and fourth quartiles of the stream (all $ps < .05$, η_p^2s $> .08$), indicating greater cognitive effort under load.
- Pupils were also larger on target-present trials, relative to target-absent trials, reflecting identification of the target.. (All interest periods: $ps < .01$, η_p^2s $> .19$).



- On target-present trials, pupil dilation was a reliable indicator of target identification. For instance, when the target appeared in the first-quartile of the stream, pupil dilations sharply rose, peaking shortly after presentation of the target (in quartile 2).



Conclusions.

- Our model faithfully recreated key findings in RSVP search, including search performance, and subsequent memory formation. However, it is imperfect with respect to performance over time.
- We assume that in template-search, targets decay over time, and that in categorical-search, representations do not fade (cf., Malcolm & Henderson, 2009) but may instead become unstable. These assumptions should be revised.
- Pupil dilation was a reliable index of the difficulties of creating a categorical representation and of searching for multiple targets. Furthermore, they clearly indicated target identification, reaching peak dilation after the target was shown, and dwindling thereafter (cf. Goldinger & Papesh, 2012; Privatera et al., 2010).

References

Goldinger, S. D., & Papesh, M. H. (2012). Pupil dilation reflects the creation and retrieval of memories. *Current Directions in Psychological Science, 21*, 90-95.

Hintzman, D. L. (1988). Judgements of frequency and recognition memory in a multiple-trace memory model. *Psychological Review, 95*, 528-551.

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

Hout, M. C., & Goldinger, S. D. (2011). Multiple target search increases workload but enhances incidental learning: A computational modeling approach to a memory paradox. *In* Object Perception, Attention & Memory 2011 Conference Report, *Visual Cognition*, 18-21.

Hout, M. C., & Goldinger, S. D. (2012). Incidental learning speeds visual search by lowering response thresholds, not by improving efficiency. *Journal of Experimental Psychology: Human Perception and Performance, 38*, 90-112.

Malcolm, G. L., & Henderson, J. M. (2009). The effects of target template specifity on visual search in real-world scenes: Evidence from eye movements. *Journal of Vision, 9*, 1-13.

Papesh, M. H., Goldinger, S. D., & Hout, M. C. (2012). Memory strength and specificity revealed by pupillometry. *International Journal of Psychophysiology, 83*, 56-64.

Privatera, M., Bennieger, L. W., Carney, T., Klein, S., & Aguilar, M. (2010). Pupil dilation during visual target detection. *Journal of Vision, 10*, 1-14.

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

Support from NIH grant R01 DC 004535-10 to Stephen D. Goldinger

Email: michael.hout@asu.edu Website: www.michaelhout.com