Pupil Size as a Measure of Working Memory Load During a Complex Visual Search Task

Nada Attar[1,2], Matthew Schneps[2], Marc Pomplun[1]

[1] Department of Computer Science, University of Massachusetts at Boston, [2] Harvard-Smithsonian Center for Astrophysics

Introduction

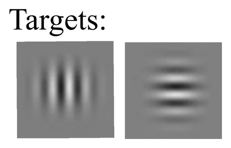
- An observer's pupil dilates and constricts in response to changes in variables such as ambient luminance, emotional stimulus content, and working memory load
- Porter, Troscianko, and Gilchrist (QJEP 2007) found that pupil size statistically increased over the course of the search, and they attributed this finding to accumulating working memory load. However, other factors, e.g., arousal and effort, likely affected pupil size as well and added noise to the data and some uncertainty to the conclusions
- In contrast to their study, our experiment estimated working memory load by measuring pupil size during the presentation of intermittent fixation screens showing only a central fixation marker, thought to induce a low, stable level of arousal and cognitive effort to minimize the influence of these variables on the estimation of working memory load
- Our experiments interspersed a complex visual search/counting task (Experiment 1) and simple search task (Experiment 2) with the intermittent blank screens

Experiment 1: Visual Search/Counting Task

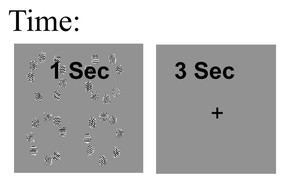
Method

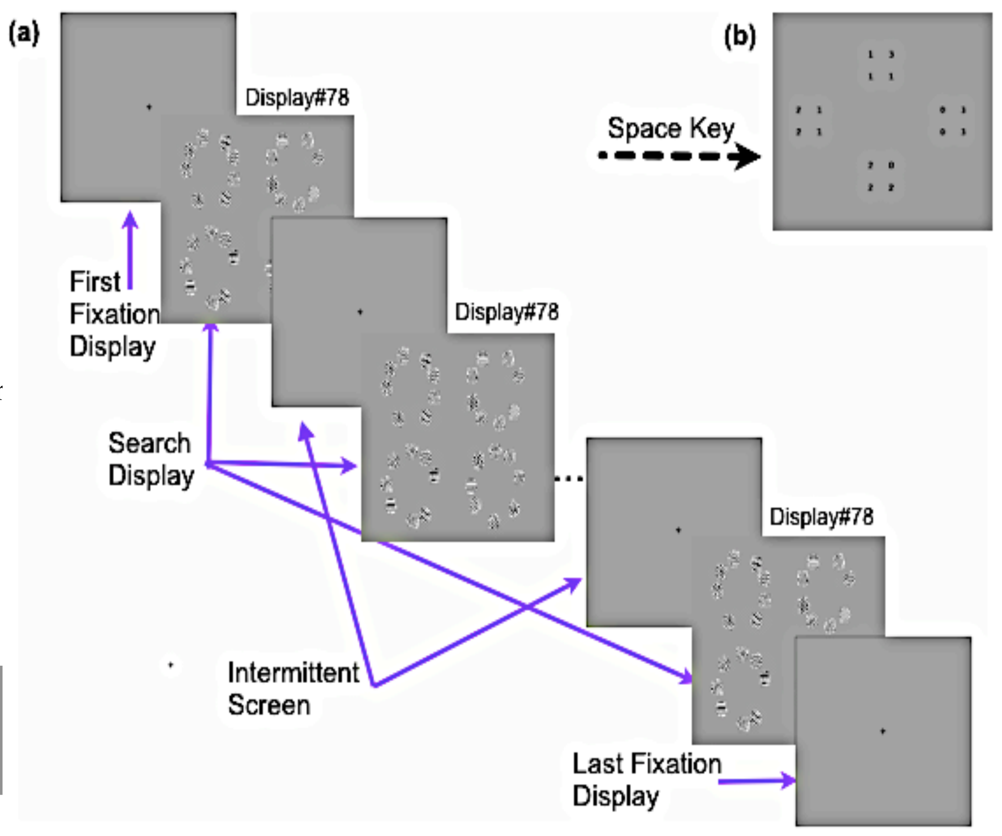
The targets and distractors were arranged randomly around the circumference of four circles in the search displays. Subjects reported in a multiple-choice test the number of targets contained in each circle. The task was designed to progressively increase WML during task completion. This allowed us to collect baseline data for studying working memory use in a "regular" visual search task in Experiment 2.

- SR Research EyeLink 1000 desktop
- 32 items (3-5 targets)
- 6 Blocks
- 10 Trials per block
- 10 Search displays per trial
- 13 Subjects
- Targets:



Time:





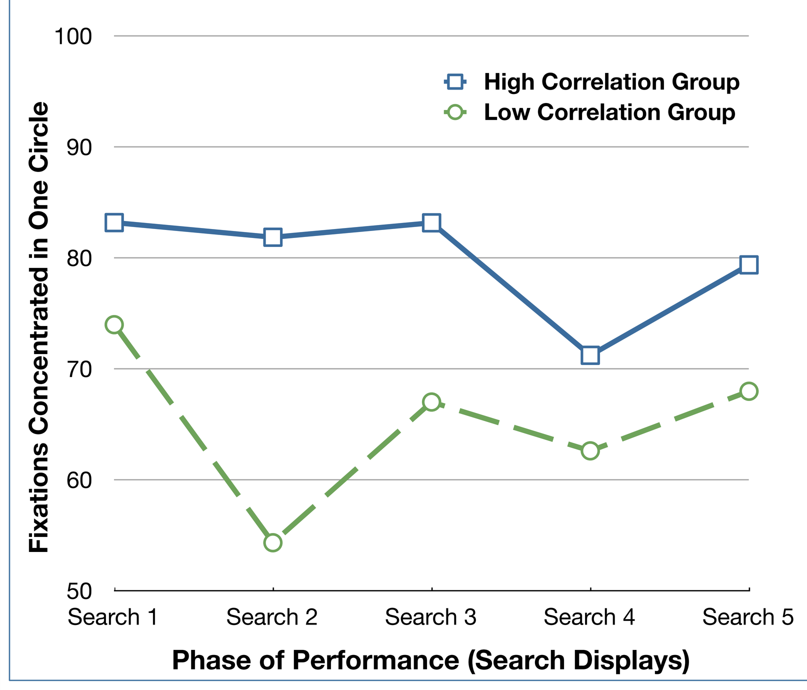
Analysis and Results

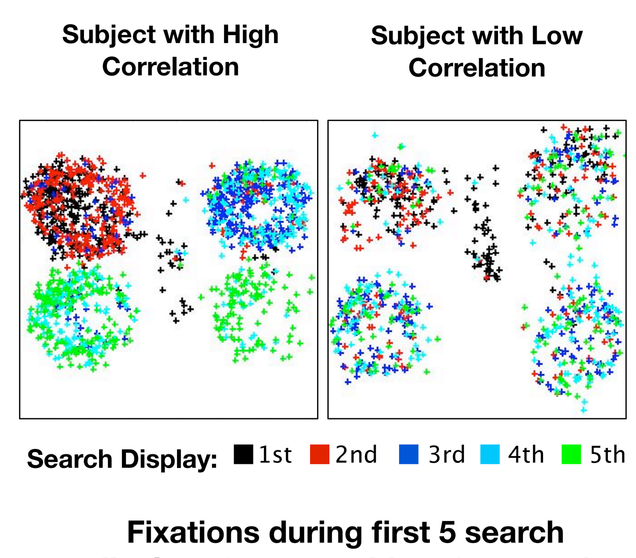
- We computed the correlation between the difference in mean pupil size between the first two intermittent screens and RT (same for search displays). Our hypothesis was a negative correlation, indicating that greater working memory load increase led to faster searches
- Pupil size increase during intermittent screens showed a slightly negative correlation with RT (r = -0.085), whereas measurement during search displays revealed a positive correlation (r = 0.124). This difference in correlation between the two methods of measurement was significant, t(12) = 2.61, p < 0.05

To extend the analysis, we compared the gaze patterns in the search displays by dividing the participants into two groups depending on the r = -0.085

- **High-Correlation Group** had correlations with r < -0.085 (matching our hypothesis) and **Low-Correlation Group** had a correlation with r > -0.085

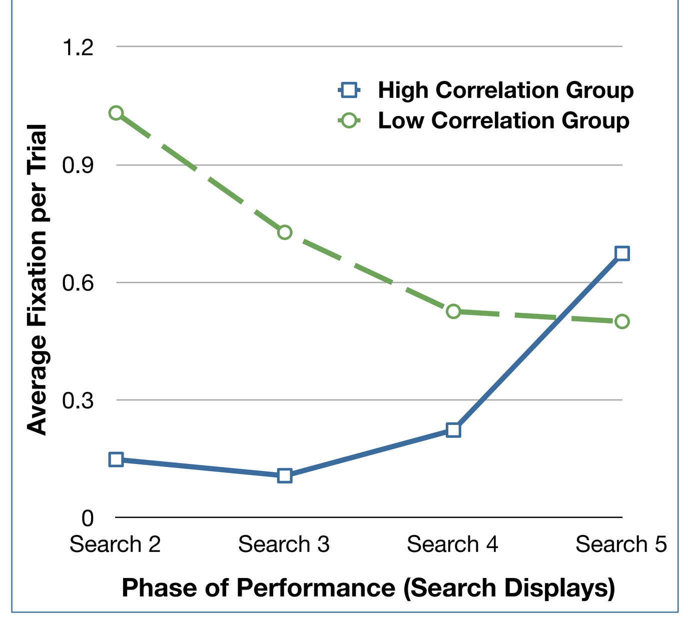
1. *Proportion of fixations on same circle during search interval:*
   - High-correlation group tended to fixate on one circle at each search display while low-correlation group tended to have less systematic search, distributed fixations among more than one circle





Fixations during first 5 search displays for one subject from each correlation group

2. *Number of circles revisited*
   - Inefficient search behavior of low-correlation group was indicated by many fixations revisiting previously inspected circles



Discussion

- For efficiently and systematically searching subjects, greater pupil size increase led to faster searches
- Negative correlation of the increase in working memory load during the early search stages and the time taken to find the target is stronger when measuring pupil size during the fixation phases than during the search phases

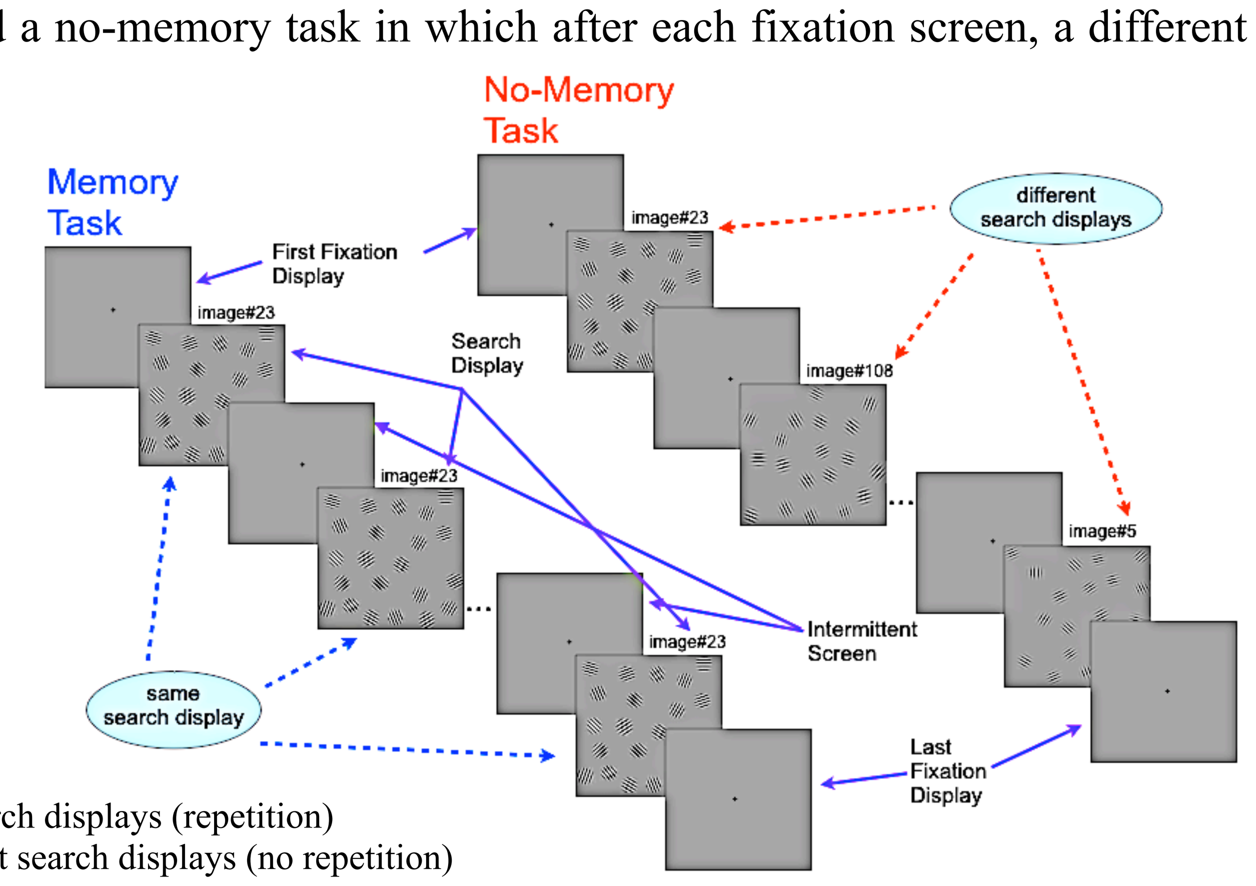
Experiment 2: Simple Visual Search Task

Method

To test our hypotheses that **(1)** increasing working memory load during search can best be measured by comparing pupil size between successive fixation screens and **(2)** loading working memory is an integral part of performing "regular" search tasks efficiently, we included two controls: **First**, we introduced a no-memory task in which after each fixation screen, a different search display was shown. **Second**, we computed the difference in mean pupil size in first two successive search displays and first two intermittent screens as a measure of working memory load increase.

- SR Research EyeLink 1000 desktop
- 32 items (1 target)
- 8 Blocks
- 10 Trials per block
- 10 Search displays per trial
- 13 Subjects

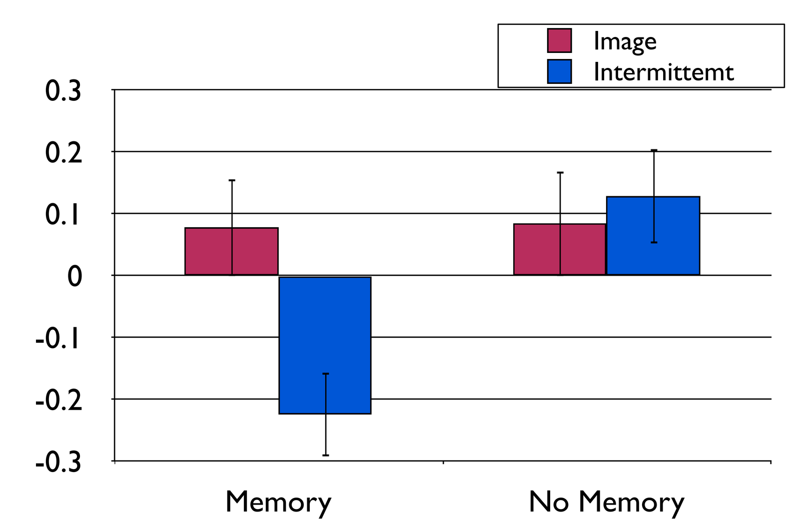
4 Memory blocks = 40 different search displays (repetition)
4 No-Memory blocks = 400 different search displays (no repetition)



Analysis and Results

Correlation Between Mean Pupil Size and RT Measured by 2x2 Within-Subject ANOVA:

Tests of Within-Subjects Contrasts	
Effect of Task	F(1;12) = 4.05, P = 0.067
Effect of Phase(Image, Intermittent)	F(1;12) = 5.08, P = 0.044
Effect of Task*Phase(Image, Intermittent)	F(1;12) = 8.4, P = 0.013



- A within-subject analysis showed that the mean pupil size difference between the first two fixation screens in the memory blocks was a significant predictor of RT in the same trial, with an inverse correlation of approximately r = -0.23. There were clearly weaker correlations for the no-memory blocks and for mean pupil measurement during search phases
- The results are indicating that during the memory blocks, the greater pupil size increase in the intermittent blank screens tended to be followed by shorter search time. Furthermore, the difference in mean pupil size between the first two search display presentations did not predict RT in both memory and no-memory blocks

Discussion

- In a "regular" visual search task (Experiment 2), memory load increase during task performance is even more clearly reflected in pupil size changes than it is in a specifically designed task with explicit memory encoding component (Experiment 1)
- Our new paradigm is effective at reducing the interference of other cognitive processes from the measurement of working memory load

Conclusions

1. Working memory load increases during efficient visual search
2. Greater load increase tends to be associated with faster search
3. Intermittent fixation screens are more reliable than search displays to measure pupil size as an indicator of working memory load during the early search stages
4. The advantage of this visual paradigm we introduced is that memory load can be measured without introducing an additional memory task that could interfere with the search process for simple and complex tasks

References

- Peterson, M. S., Beck, M. R., & Wong, J. H. (2008). Were you paying attention to where you looked? The role of executive working memory in visual search. Psychonomic Bulletin and Review, 15 (2), 372-377.
- Porter, G., Troscianko, T. & Gilchrist, I.,D. (2007). Effort during visual search and counting: Insights from pupillometry, The Quarterly Journal of Experimental Psychology, 60:2, 211 - 229
- Han, S-H. & Kim, M-S. (2004). Visual search does not remain efficient when executive working memory is working. Psychological Science, 15 (9), 623-628.