On the (un)importance of foveal vision during visual search in real-world scenes

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Introduction

- When searching for a target letter in an alphanumeric display, foveal vision was found to be necessary in order to achieve normal search performance (Bertera & Rayner, 2000).
- In contrast, foveal vision was not necessary to correctly locate and identify medium-sized target objects in natural scenes (Nuthmann, 2014).
- In an attempt to reconcile these findings, we combined a scene search paradigm (Nuthmann, 2014) with a letter search task (Bertera & Rayner, 2000).
- In Exp. 1, observers searched for the letter "T" embedded in greyscale pictures of real-world scenes.
- In Exp. 2 we added a letter recognition component to the task (is the target a "T" or an "L"?), thereby increasing similarity to the task requirements in Bertera & Rayner (2000).
- The ability to locate a target based on extrafoveal vision alone may depend on the size and visual salience of the target. In both experiments, we manipulated the size of the target and controlled for salience.

Methods

Stimuli: 120 greyscale images of real-world scenes (25° × 19°) in which a target letter was embedded.
Apparatus: SR Research EyeLink 1000/2K Desktop mount, 21-inch CRT monitor at 140 Hz.
Design: Four target sizes were crossed with the presence vs. absence of foveal vision.
Target size (letter width): Exp. 1: 0.25° (S - small), 0.66° (M - medium), 1.08° (L - large), 1.5° (XL - extra large); Exp. 2: 0.25° (S), 0.41° (I - intermediate), 0.66° (M), 1.08° (L).
Foveal vision: A gaze-contingent moving mask (Rayner & Bertera, 1979) was used to simulate the absence of foveal vision. The grey mask was circular with a radius of 1° with its perimeter smoothed.
Instruction: In Exp. 1, observers pressed a button once they found the letter "T". In Exp. 2, upon identifying the target observers pressed one of two buttons corresponding to either "T" or "L".
Target location: location for which there was a *medium* change in local contrast when inserting the letter.
Algorithmic approach to target insertion:

$$\text{CriteriaMap} = \sum_{\text{letter, size}} \left| ContrastDifferenceMap_{\text{letter}}^{[\text{size}]}(r,c) - t_{\text{letter}, size} \right|$$

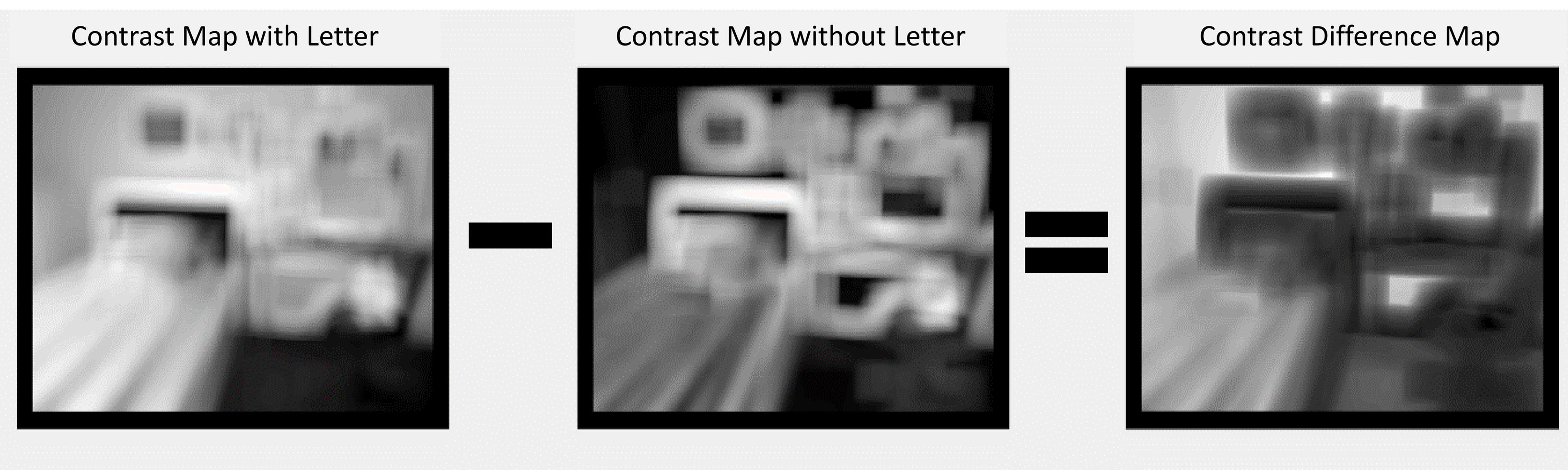


Figure 1. Creation of the Contrast Difference Map: $\Delta C = M_w - M_0$

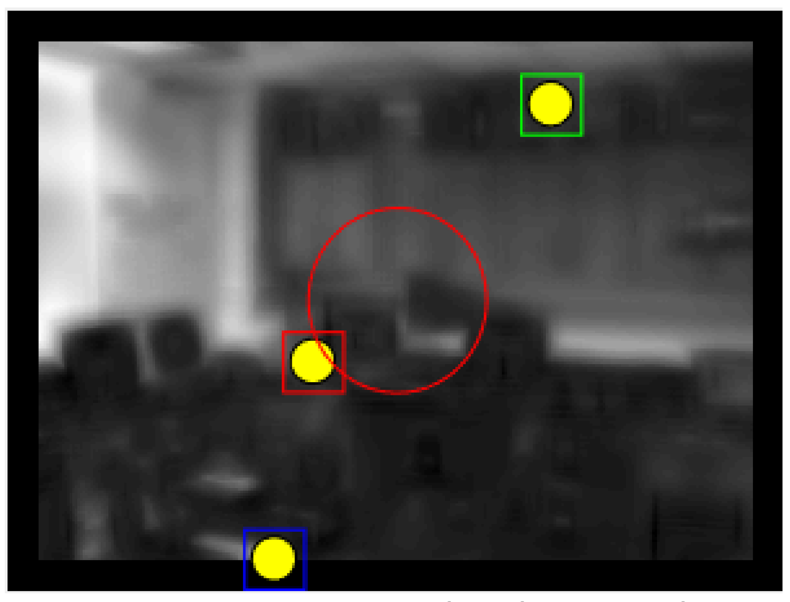


Figure 2. Criteria checking with central exclusion (red) and edge exclusion (blue)

Figure 3. Example scene with simulated scotoma and T size 1.08°

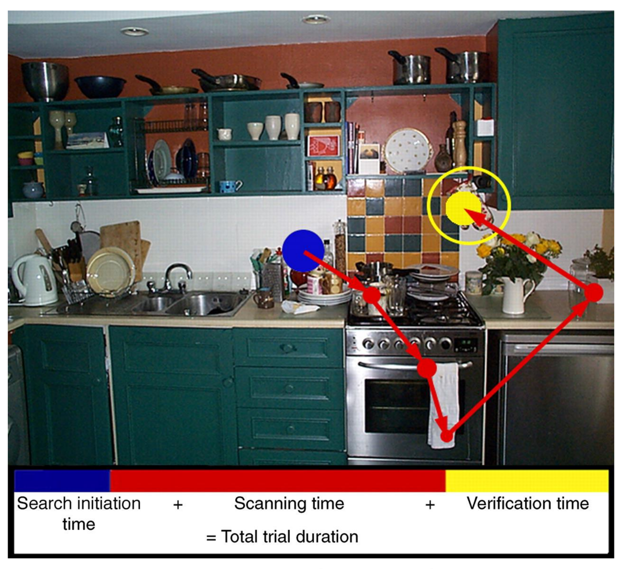


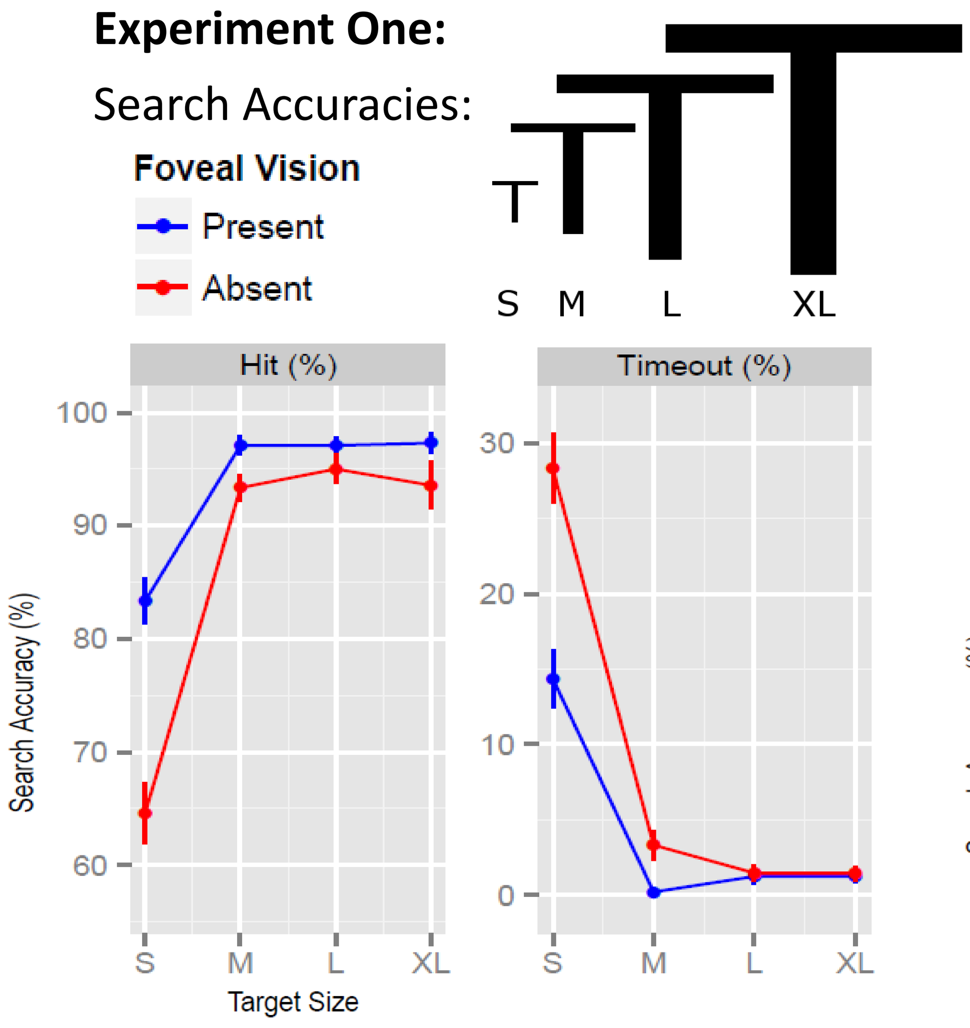
Figure 4. Gaze-based decomposition of search time (Malcolm & Henderson, 2009)

Initiation Time: Initial saccade latency. Scene onset to initiation of first saccade.
Scanning Time: From the first eye movement until gaze lands within target interest area (actual time searching for the target).
Verification Time: The gaze duration on the target. Time taken from first gaze into interest area until the button was pressed.

Results

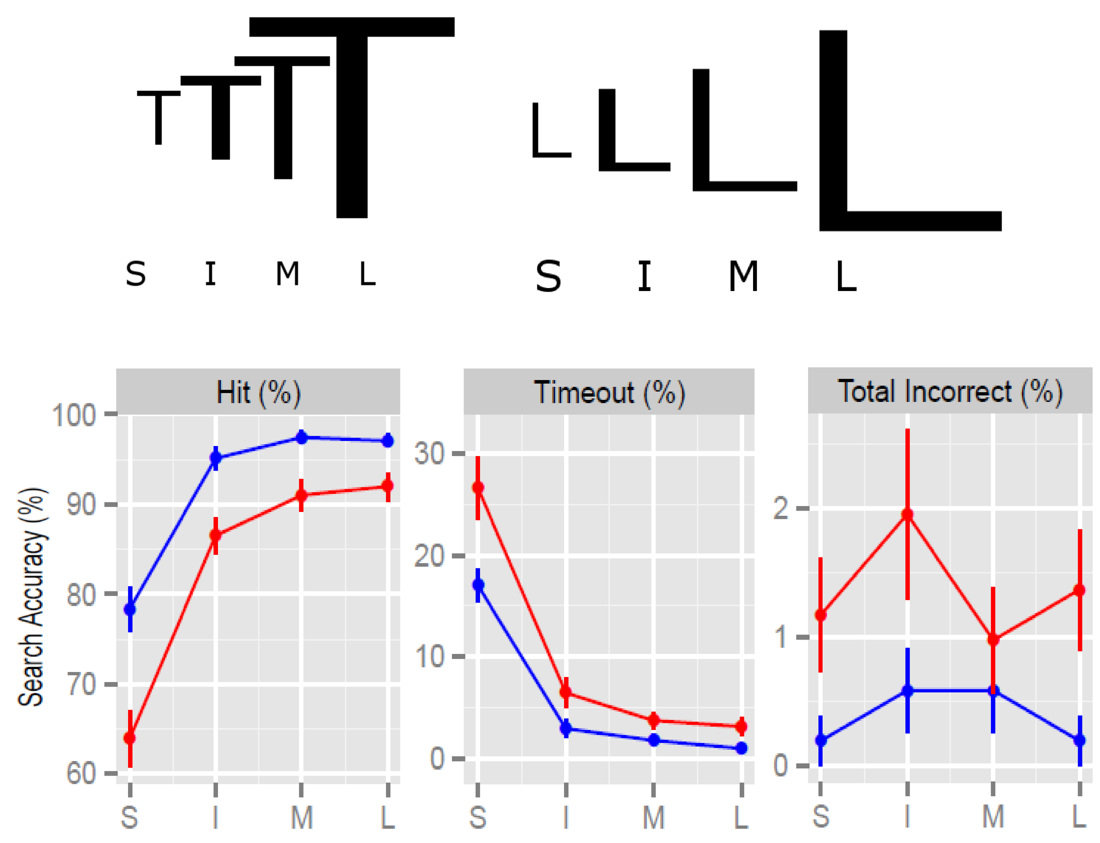
Experiment One:

Search Accuracies:

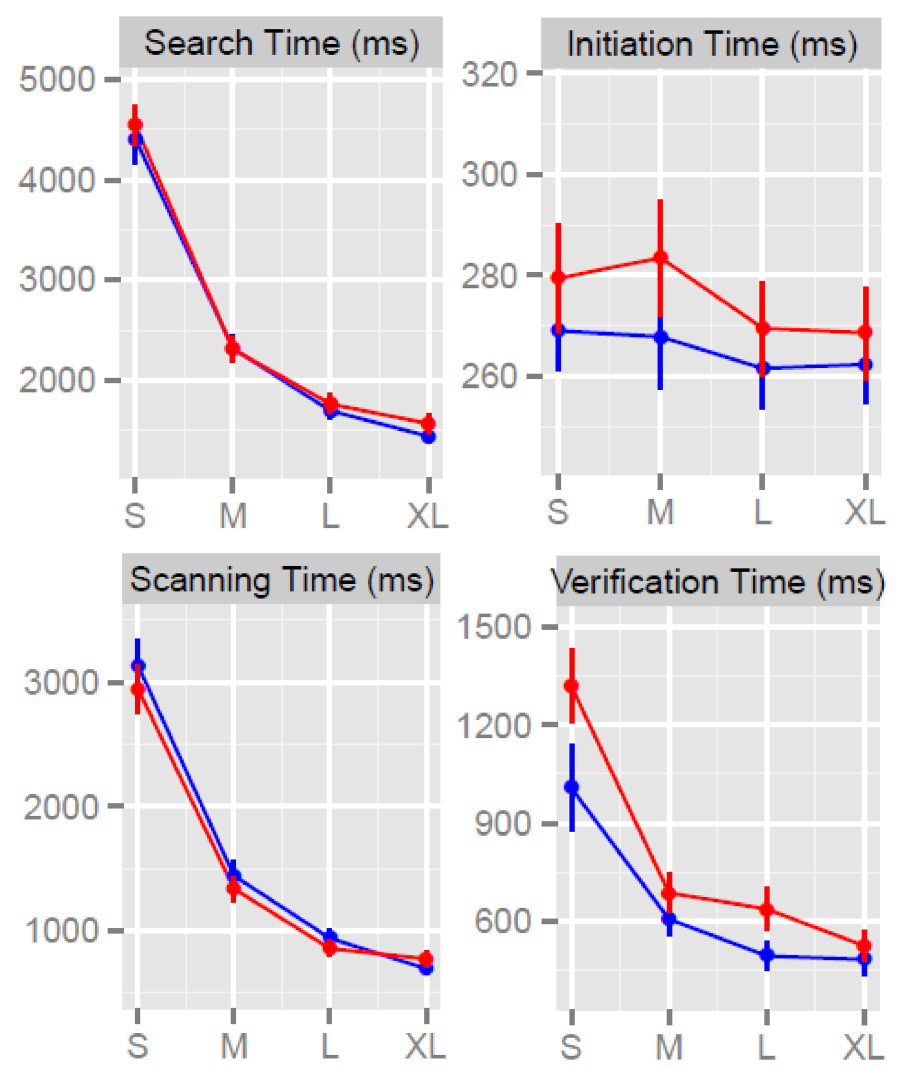


Experiment Two:

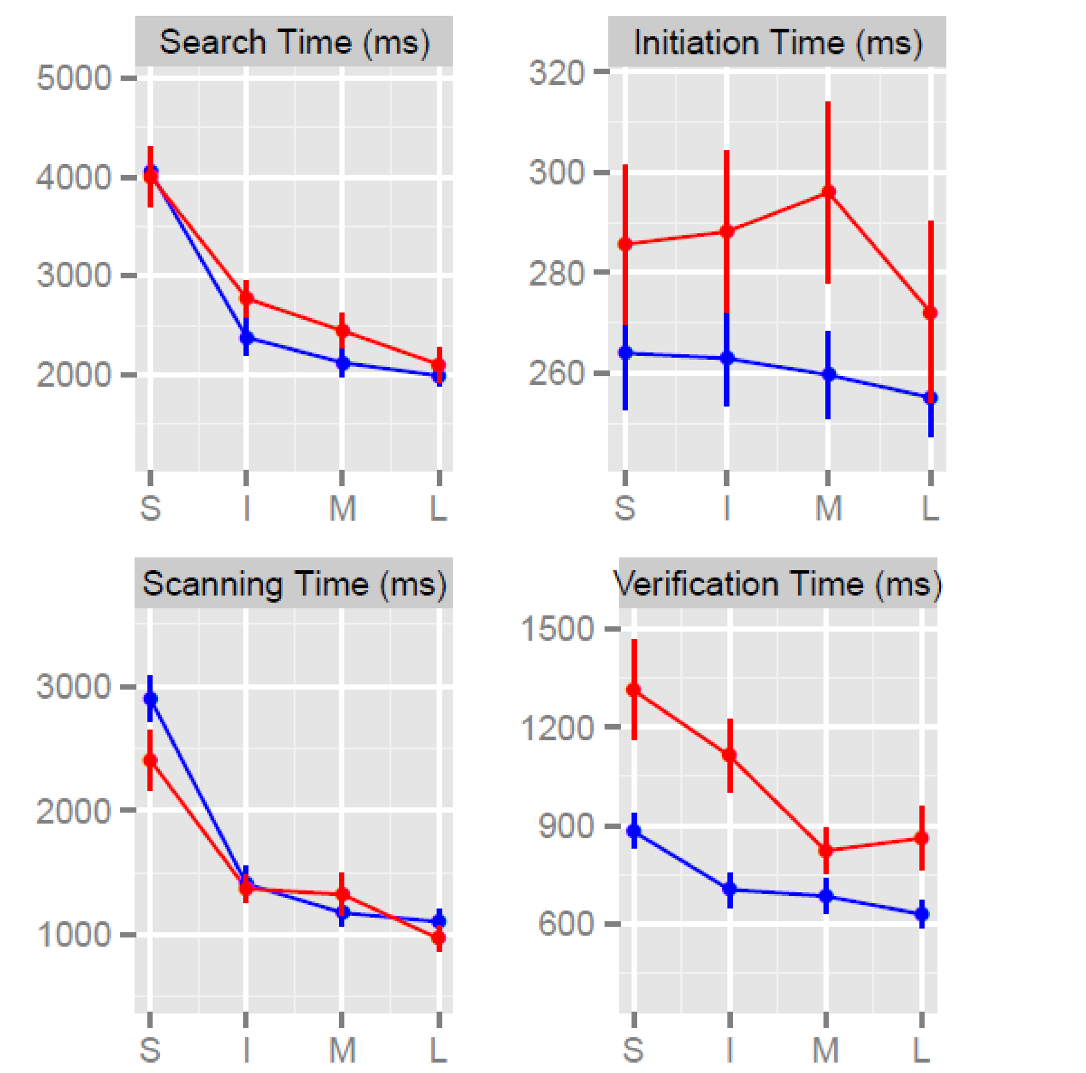
Search Accuracies:



Eye Movement Behaviours:



Eye Movement Behaviours:



Key findings and discussion

Target size:
- For S-targets, observers were less likely to find the letter within 15 sec (timeout). When search was successful (hit), search times were shorter for larger targets.

Importance of foveal vision:
- Without foveal vision, timeout probabilities were somewhat increased, in particular for S-targets.
- Importantly, blocking out foveal vison did not prolong search times.
- Gaze-data based segmentation of search time (Malcolm & Henderson, 2009): Search initiation and target localisation (scanning time) were unaffected. The process of verifying the identity of the target took longer to complete. This increase in verification time was stronger in Exp. 2 (is it a "T" or an "L"?) than in Exp. 1. However, this small-scale effect did not affect overall search times.

Take-home message: The present data show that foveal vision was not necessary for localising target letters within naturalistic scenes but was beneficial for target verification and identification.
Impact: We simulated the loss of foveal vision experienced by patients suffering from age-related macular degeneration (AMD). The data suggest that foveal vision is less important for visual search than it is for reading and may help to develop visual aids for AMD patients.

References

Bertera, J. H., & Rayner, K. (2000). Eye movements and the span of the effective stimulus in visual search. *Perception & Psychophysics, 62*(3), 576-585.
Malcolm, G. L., & Henderson, J. M. (2009). The effects of target template specificity on visual search in real-world scenes: Evidence from eye movements. *Journal of Vision, 9*(11):8, 1-13.
Nuthmann, A. (2014). How do the regions of the visual field contribute to object search in real-world scenes? Evidence from eye movements. *Journal of Experimental Psychology: Human Perception and Performance, 40*(1), 342-360.
Rayner, K., & Bertera, J. H. (1979). Reading without a fovea. *Science, 206*, 468-469.