MS# 4-636

# Rapid resumption of interrupted visual search: new insights into the interactions between vision and memory

Alejandro Lleras

University of Illinois at Urbana-Champaign

Ronald A. Rensink & James T. Enns

University of British Columbia

Word Count: 2500 (text + acknowledgements).

Number of references: 19.

Please direct correspondence to:

Alejandro Lleras

Department of Psychology

The University of Illinois at Urbana-Champaign

603 East Daniel St., Champaign, IL 61820

Telephone: (217) 265-6709

Fax: (217) 244-5876

Electronic mail: alleras@uiuc.edu

**Abstract**

A modified visual search task demonstrates that humans are very good at resuming a search after it has been momentarily interrupted. This is shown by exceptionally rapid response times to a display that reappears after a brief interruption, even when an entirely different visual display is seen during the interruption and when two different visual searches are performed simultaneously. This <u>rapid resumption</u> depends on the stability of the visual scene and is not due to display or response anticipations. These results are consistent with the existence of an iterative hypothesis-testing mechanism that compares information stored in short-term memory (the perceptual hypothesis) with information about the display (the sensory pattern). In this view, rapid resumption occurs because a hypothesis based on a previous glance of the scene can be tested very rapidly in a subsequent glance, given that the initial hypothesis-generation step has already been performed.

Although visual search has been studied extensively (e.g., Wolfe, 1998) many questions remain regarding the role played by memory. Some theorists have claimed memory plays no role; when participants search for a target among a set of distractor items, they shift their attention from one item to the next without any guidance from the items already encountered (Horowitz, & Wolfe, 1998, 2001, 2003). Others have argued for implicit memory of item location, since search can be facilitated by repeated display configurations (Chun & Jiang, 1998, 2003, Chun & Nakayama, 2000) and by information regarding the three previously scanned locations (McCarley et al., 2003, Peterson et al., 2001). Yet, when explicit memory tasks are performed concurrently with search, performance is unaffected, as if memory played no role (Woodman, Vogel & Luck, 2001, but see Oh & Kim, 2004). Consequently, the role of memory in visual search is still uncertain.

Our approach to this question begins with the observation that we rarely perform only one task at a time.  For example, while driving, we often perform visual searches, such as looking for a friend we have planned to meet. If memory plays a role in search, one should see benefits in returning to a search that has been momentarily interrupted.  We show here that such benefits are substantial.

Our results point to a hypothesis-testing mechanism in visual perception, one that forms an initial perceptual hypothesis based on a first glance at a scene and then tests this hypothesis in subsequent glances when the scene reappears. Note that this account of perception is not new: such iteration has been proposed for visual masking (e.g., Di Lollo, Enns, & Rensink, 2000). Here we show that the initial hypothesis-generation stage can improve performance. If the initial hypothesis is stored in memory for later use, when the display reappears, participants can test it directly against the current sensory information, skipping the initial hypothesis-generation stage, and thereby substantially reducing target-identification time. Below we present six experiments that provide strong evidence for this proposal.

## GENERAL METHOD

**Subjects**. A total of 110 undergraduate students at the University of British Columbia participated for extra-course credit. All had normal or corrected-to-normal vision and were naïve to the purpose of the experiments.

**Task, Equipment and Stimuli.** Participants were required to report the color of a target T-shape (either red or blue), presented among other L-shapes, by pressing the “z” key for a blue target and the “/” for a red target. Experiments were run on e-Mac computers, controlled by V-Scope software (Enns & Rensink, 1992). There were 16, 24, or 32 items in each display. Each item appeared in one of four randomly selected orientations and each line segment in the items subtended 0.5 degrees of visual angle (DVA). Items were arrayed inside an invisible 6x6 grid (cell size = 1.5 DVA), with a random amount of jitter (+/- 0.2 DVA) to avoid the collinear alignment of items. Letters could be either blue or red, and there was always an equal number of red and blue items in the display.

**Procedure.** The procedure is illustrated in Figure 1A. The search display was presented 100 milliseconds (ms), 500 ms in Experiment 3, and interrupted by blank displays of longer duration (900 ms in Experiments 1, 5 and 6, 950 ms in Experiment 2, 1600 and 2000 ms in Experiment 3, and 1500, 2500 and 3500 ms in Experiment 4). We will use the term epoch to refer to the time between the onset of a display and its reappearance (Rensink, 2000). Each session was about 45 minutes long, and was divided into 10 blocks of 60 trials each. Formal test trials were preceded by 30 trials of practice. The inter-trial interval was one second. During the first 500ms of a trial, participants viewed a fixation cross (0.5 DVA) in the center of the display before the search cycle began (search-display on followed by search-display off). Trials were terminated as soon as the participant responded or after 16 seconds, whichever occurred first.

## Experiment 1: Interrupting search with blank displays

We were initially interested in evaluating the participants' general ability at performing this modified version of a normal visual search task. Twelve participants (mean accuracy 95%) were tested. To evaluate the impact of the interruption on search performance, we looked at the distribution of their correct response times (RT). Figure 1B shows the RT distribution in Experiment 1 (display-on time = 100 ms; display-off time = 900 ms; set size = 16 items). Several features of the RT histogram are notable. First, with only a single glance, participants were able to identify the target correctly on 28% of the trials. Second, it took participants 500 ms to begin responding in the first epoch (only 4% of responses were faster than 500 ms); this can be interpreted as the time needed to initiate visual search. Third and most remarkable, this initial lag was absent in subsequent epochs. During the second epoch, 53% of responses occurred within the first 500 ms; during the third epoch 52% of responses did so. We refer to this phenomenon as <u>rapid resumption</u> (RR), since it indexes the benefit of having begun the search prior to its interruption.

To better illustrate RR, we normalized the RT distribution separately for epoch 1 (Figure 1D), and epochs 2 through 6 (Figure 1E). As is readily seen, participants responded in a fundamentally different way to the first display than to all subsequent displays, _$^2(9)=1588.69$, $p<.001$, Cramer's V=.45 (comparison across 10 100 ms bins). Specifically, they were able to resume their search much faster than they were able to start one.

As comparison, Figure 1F shows the RT distribution from a control experiment (n=12, accuracy=97%), identical in every way to Experiment 1, except for set size: only one T was present in the display (zero distractors). The peak of the RT distribution now occurred 400 ms after the onset of the display, comparable to the location of the first peak in the RT distribution when RR occurs (Figure 1E). This peak also occurs much earlier than the second peak in epochs 2-6 (Figure 1E) at 800 ms, which is comparable to the location of the peak in the RT distribution on Epoch 1 (Figure 1B).

Finally, Figure 1G shows the data from epochs 2-6 of a separate experiment in which displays contained either 16 or 32 items (n=12, accuracy=93%). Epoch time was 1050 ms (100 ms looks). The similarity in these two RT distributions indicates that RR does not depend on the number of items in the display, _$^2$(10)=14.21, p=.17, Cramer's V=.07. A larger number of items simply resulted in a longer search, with the correct response occurring in a later epoch, but it did not affect the shape of the RT distribution within an epoch. Taken together, Figures 1F and 1G suggest that when RR occurs, it is as if the target were the only item on the display.

**Experiment 2: Interleaving two searches**

As promising as the results from Experiment 1 are, it might be argued that search was never fully interrupted: the mental processes involved may have been continuously active, even during the blank display. To force participants to fully interrupt their search of a given display, a modified version was developed in which two different displays were interleaved (see Figure 2A): one containing red items, the second containing blue items in a different spatial layout. Participants again searched for the T and reported its color, but since they did not know in advance which display contained the target, they needed to search both displays. We included 20% of target-absent trials to minimize guessing based on the failure of finding a target in any given color. Displays containing items of one color were shown for 100 ms, followed by blank displays of 950 ms, followed by 100 ms displays containing items of the other color (epoch duration= 2100 ms).

Figures 2B-C show the RT distribution data from 12 participants (mean accuracy 95%) for each of the interleaved search displays. Several new features of RR are evident. First, the initial set-up time was found in search for targets of each color, indicating that searching for the target in displays of one color provided no benefit for searching for the target in displays of the other color. The initial search of each display resulted in the normal set-up time, meaning that participants interrupted their search of the first display in order to begin searching the second display. Second, RR was observed on the second appearance of each display, indicating that participants could benefit from their previous search of that display, even though search through a different set of items had intervened. In summary, starting a search through the red items is different than starting a search through the blue items: both searches incur their own set-up time. However, once each of the two searches has begun and has been interrupted, there is a large benefit to resuming the search as compared to starting it anew.

**Experiment 3: Effect of display duration**

Experiment 3 investigated the influence of display-presentation time on RR. Figures 2D-E show normalized RT distributions from twelve participants (mean accuracy 95%) from search tasks in which either 100 ms or 500 ms displays were presented followed by blank displays of either 2000 ms or 1600 ms, respectively (total epoch time = 2100 ms). Although search was very similar in the first epoch for both tasks (Figure 2D), RR was more pronounced for 500 ms “looks” than for 100 ms “looks” (44% and 29%, respectively, of responses in epochs 2-4 occurred in the first 500 ms of these epochs, see Figure 2E), _$^{2}$(1)=52.52, $p<0.001$. The two distributions were also significantly different from each other, _$^{2}$(20)=161.13, p<.001, Cramer's V=.26. This suggests that memory is stronger when there is more time to accumulate visual evidence.

**Experiment 4: Effect of blank duration**

Experiment 4 was designed to rule out the possibility that RR is caused by the participants' anticipation of the display reappearance. Figures 2F-G show normalized RT distributions from 20 participants performing a search task in which the blank intervals between the displays were randomly either 1500 ms, 2500 ms, or 3500 ms (mean accuracy 91%). Following the expected start up time in epoch 1 (Figure 2F), RR was equally strong regardless of the amount of time that elapsed before the reappearance of the display (Figure 2G). This indicates both that the effect does not depend on precise temporal predictability and that the benefits of this memory can survive longer than 3 seconds.

**Experiment 5: Ruling out a confirmation bias**

We next investigated whether participants might be using a "confirmation" strategy in which they would withhold a correct response while waiting to confirm their decision with an additional look at the following display. If so, it would be possible to present the display only once and to extract a correct response by forcing participants to respond. To test this, we ran an experiment where 80% of trials were alternating search/blank displays and on the remaining 20%, the search display appeared only once. On these latter trials, participants were forced to respond once they realized the display was not going to reappear. Data were collected from 18 participants.

The results were clear. The first epoch in both conditions led to the usual RT distribution in which responses began 500 ms after display onset. When this first epoch was followed by an alternating display the usual RR was observed (Figure 3A). However, following a single presentation, the RT distributions were quite similar for correct responses (Figure 3B) and incorrect responses (Figure 3C), indicating that participants were simply guessing the target's color: after 1000 ms 48% of responses were correct and 52% were incorrect, a non-significant difference as revealed by a Sign Test, n+=431, n-=461, p=.332 (bins between 1000 ms and 6000 ms). Clearly, participants were not merely withholding a correct response in anticipation of a second look.

**Experiment 6: Random reshuffling between views**

Finally, we tested whether RR requires the items in the scene to be stable. In this condition, the display configuration remained the same but the assignment of individual search items (including the target) to these locations was randomly reshuffled on each re-presentation. Under these conditions, RR was eliminated and the search task began anew in each epoch, see Figure 1C (n=12, mean accuracy 93%). Thus, the resulting RT distribution was significantly different from the RT distribution where RR was present (Figure 1B), _$^2$(55)=1351.95, $p < .001$, Cramer's V=.30 (tested bins between 500 ms and 6000 ms).

## GENERAL DISCUSSION

These experiments show that humans are able to resume an interrupted visual search much more quickly than they are able to begin a new search. The speed of resumption is comparable to the speed with which they can discriminate a target in the absence of any distracting items (Figure 1F). This is consistent with the proposal that visual perception consists of an iterative sequence of hypothesis generation and hypothesis testing, as we have proposed elsewhere (see Di Lollo, Enns & Rensink, 2000). Given a single glance at a scene, a hypothesis about it must first be generated before it can be tested (confirmed or rejected). Hypotheses based on an initial glance can be tested very rapidly in a second glance, simply because the initial generation step has already been accomplished. On this account only a limited portion of a scene — namely that involving the hypothesis — needs to be remembered during the interruption. Without further studies, it is difficult to say exactly what is represented in the hypothesis, but we anticipate that a perceptual hypothesis may include information about the shape of a few display items, their response relevance and their spatial location (see Lleras & Enns, 2004 for a related discussion).

Many details of the present study are consistent with iterative hypothesis testing. The fact that increases in the number of display items leads to target detection in a later epoch, but has no effect on the RT distribution within the epoch (Figure 1G), is consistent with a succession of hypotheses being tested about individual items (or small regions). The finding that a longer first look results in a greater likelihood of RR (Figure 2E) is consistent with greater success in hypothesis formation during the initial glance. The finding that permuting the display items between presentations eliminates RR (Figure 1C) is consistent with the need to reconnect a hypothesis stored in memory with actual sensory information. Future studies will be needed to fully uncover the rich interactions at play in RR, and more generally, when vision and memory operate under conditions that more closely resemble the world in which they evolved.

**Acknowledgements**

The authors would like to thank Taka Sunda, Lisa Vandenbeld and Mark Rempel for their feedback and help with the project. This work was supported by grants from NSERC and from Nissan Motor Corporation to Ronald Rensink and James Enns and by a minority postdoctoral research fellowship from the NSF to Alejandro Lleras, award #0309998.

**References**

Chun M. M., & Jiang, Y. (1998). Contextual Cueing: implicit learning and memory of visual context guides spatial attention. Cognitive Psychology, **36**, 28-71.

Chun, M. M., & Jiang, Y. (2003). Implicit, long-term spatial contextual memory. Journal of Experimental Psychology: Learning, Memory and Cognition, **29**, 224-234.

Chun, M. M., Nakayama, K. (2000). On the functional role of implicit visual memory for the adaptive deployment of attention across scenes. Visual Cognition, **7**, 65-81.

Di Lollo, V., Enns, J. T., & Rensink, R. A. (2000). Competition for consciousness among visual events: the psychophysics of reentrant visual processes. Journal of Experimental Psychology: General, **129**, 481-507.

Enns, J. T. & Di Lollo, V. (2000). What's new in visual masking? Trends In Cognitive Sciences, **4**, 345-352.

Enns, J.T., & Rensink, R.A. (1992). VScope(tm): Vision testing software for the Macintosh. Vancouver: Micropsych Software.

Horowitz, T. S., & Wolfe, J. M. (2003). Memory for rejected distractors in visual search? Visual Cognition, **10,** 257-298.

Horowitz, T. S., & Wolfe, J. M. (2001). Search for multiple targets: remember the targets, forget the search. Perception & Psychophysics, **63,** 272-285.

Horowitz, T. S., & Wolfe, J. M. (1998). Visual search has no memory. Nature, **394,** 575-577.

Lleras, A., & Enns, J. T. (2004). Negative compatibility or object updating? A cautionary tale of mask-dependent priming. Journal of Experimental Psychology: General, **133(4)**, 475-493.

Lleras, A., & Moore, C. M. (2003). When the target becomes the mask: using apparent motion to isolate the object-level component of object substitution masking. Journal of Experimental Psychology: Human Perception and Performance**, 29**, 106-120.

McCarley, J. S., Wang, R. F., Kramer, A. F., Irwin, D. E., & Peterson, M. S. (2003). How much memory does oculomotor search have? Psychological Science**, 14,** 422-426.

Mitroff, S. R., & Simons, D. J. (2002). Changes are not localized before they are explicitly detected. Visual Cognition, **9(8),** 937-968**.**

Moore, C. M., & Enns, J. T. (2004). Object updating and the flash-lag effect. Psychological Science, **15(12)**, 866-871**.**

Oh, S. H. & Kim, M. S. (2004). The role of spatial working memory in visual search efficiency. Psychonomic Bulletin and Review, **11(2)**, 275-281.

Peterson, M. S., Kramer, A. F., Wang, R. F., Irwin, D. E., & McCarley, J. S. (2001). Visual search has memory. Psychological Science**, 12,** 287-292.

Rensink, R.A. (2000). Visual search for change: A probe into the nature of attentional processing. Visual Cognition, **7**, 345-376.

Wolfe, J. M. (1998). What can 1 million trials tell us about visual search? Psychological Science**,9,** 33-39.

Woodman, G. F., Vogel, E. K., & Luck, S. J. (2001). Visual search remains efficient when visual working memory is full. Psychological Science**, 12,** 219-224.

**Figure Captions**

Figure 1. The interrupted search task. (A) Schematic depiction of an interrupted visual search task. (B) RT frequency distribution from this search (Experiment 1). Rapid resumption refers to the increased frequency of correct RT occurring within 500 ms of display onset in all but the first epoch. (C) RT frequency distribution from an interrupted search in which items randomly switched locations with other items between display presentations (Experiment 6). Rapid resumption is no longer present. (D) Normalized correct RT distribution for responses during Epoch 1 in Experiment 1. (E) Normalized correct RT distribution for responses during Epochs 2-6 in Experiment 1. (F) Normalized correct RT distribution from a control experiment in which all the Ls have been erased from the display; only the color of a single T was identified. (G) Normalized correct RT distribution for Epochs 2-6 from a similar experiment where set size was manipulated. Data are presented separately for trials on which the number of items was 16 (open symbols) or 32 (closed symbols).

Figure 2. (A) Visual search involving two temporally interleaved displays. The correct RT distribution from this search is shown separately for red (B) and blue (C) displays, on trials where the first display contained red items (identical results were observed on trials where the first display contained blue items). Rapid resumption occurs even when a different search display intervenes between repetitions of the display containing the target. (D) Experiment 3: normalized correct RT distribution for Epoch 1, separately for display durations of 100 ms (open symbols) and 500 ms (closed symbols). (E) Experiment 3: Normalized correct RT distribution for Epochs 2-6, separately for display durations of either 100 ms (open symbols) and 500 ms (closed symbols). (F) Experiment 4:

normalized correct RT in Epoch 1, for a visual search involving three unpredictable blank durations (1400, 2400 or 3400ms). (G) Experiment 4: normalized correct RT in Epochs 2-6, separately for epoch cycle times of 1500 ms (open symbols), 2500 ms (gray symbols), 3500 ms (black symbols).

Figure 3. RT distributions for Experiment 5. (A) RT distribution for trials in which the search display reappeared (80% of trials). Rapid resumption was observed. The remaining 20% of trials were single-look trials in which the display did not reappear. (B) Distribution of correct RTs for single-look trials. (C) Distribution for incorrect RTs for single-look trials. Eighteen participants each contributed 360 trials in total.