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Repetition Blindness for Locations: Evidence for Automatic Spatial Coding in an RSVP Task

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The authors report a new phenomenon called *repetition blindness (RB) for locations*: When 3 or 4 letters are presented rapidly and sequentially at random locations within a spatial array, experimental participants have difficulty reporting pairs of letters appearing in the same location within 250 ms of each other. This deficit occurs both during report of letter identities and during report of the locations in which the letters appear; it can also be found using a partial report task. During letter report, the deficit is found for 4-location arrays but not for 8-location arrays. In contrast, letter RB is not found during location report even when the letters are always chosen from a set of 4. These results indicate that a small number of locations—but not letters—can be encoded automatically even when they are not explicitly reported. The authors argue that RB for locations results from a difficulty individuating 2 tokens at the same spatial location.

Although much of early visual processing is performed rapidly and in parallel, the capacity of visual awareness is quite restricted. Experiments on object tracking (Intriligator, Nakayama, & Cavanagh, 1991; Pylyshyn & Storm, 1988), object file review (Kahneman, Treisman, & Gibbs, 1992), scene change detection (Luck & Vogel, 1997; McConkie & Currie, 1996; Rensink, O'Regan & Clark, 1997; Simons, 1996), and inattentional blindness (Mack & Rock, 1998) suggest that only a small number of distinct objects can be simultaneously monitored within a visual scene. Similarly, rapid serial visual presentation (RSVP) experiments on conceptual masking (Potter, 1975, 1976), repetition blindness (Kanwisher, 1987, 1991; Park & Kanwisher, 1994), and the attentional blink (Chun & Potter, 1995; Duncan, Ward, & Shapiro, 1994; Raymond, Shapiro, & Arnell, 1992; Shapiro, Raymond, & Arnell, 1994) suggest that there are strict limits to the rate at which rapidly presented stimuli can be resolved into distinctly experienced, reportable events. Though it would be parsimonious to assume that these limits are related or even equivalent, there is presently little direct evidence for a connection between the mechanisms used to organize visual input into distinctly experienced objects in space and those used to organize visual input into distinctly experienced events in time. (Chun & Cavanagh, 1997, is a notable exception; see below.) The experiments reported here were designed to address this issue by investigating the role of spatial location in *repetition blindness* (RB).

Repetition blindness (Kanwisher, 1987) occurs when people view briefly presented sequences or arrays of visual stimuli: When two of the items in the display are identical, they often fail to report both occurrences. For example, if the sentence "It was work time so work had to be done" is presented at a rate of 8 words/s, it is often reported as "It was work time so had to be done," even though this is ungrammatical. Kanwisher (1987, 1991) has characterized this deficit as a failure to assign a distinct episodic token to both occurrences of the same visual type. In other words, RB results not from an inability to recognize the second occurrence of the repeated item but from a failure to individuate it as a distinct event. RB has been demonstrated for words in lists and sentences (Kanwisher, 1987), letters in words and spatial arrays (Kanwisher, 1991), colors (Kanwisher, 1991), homophones (Bavelier & Potter, 1992), rebus sentences consisting of words and pictures (Bavelier, 1994), pictures of familiar objects (Kanwisher, Yin, & Wojciulik, 1999), and pseudoobject pictures (Arnell & Jolicoeur, 1997).

What is the role of spatial location in the individuation of visual tokens? Given that spatial location is often considered to play a privileged role in the organization of visual information (Nissen, 1985; Treisman & Gelade, 1980; Tsal & Lavie, 1988), one might assume that spatially separating two stimuli will ensure that both are individuated. In fact, this is not the case. Kanwisher and Potter (1989) found no reduction in RB when the stimulus was a sentence with each word presented slightly to the right of the previous one and only slight reduction when the second half of the sentence containing the second instance of the repeated word was presented in a different location from the first half. Furthermore, a number of studies (Bjork & Murray, 1977; Egeth & Santee, 1981; Kanwisher, 1991; Kanwisher, Driver, & Machado, 1995; Luo & Caramazza, 1996; Mozer, 1989) have found an impairment in reporting identical letters presented simultaneously in spatial arrays. These experiments demonstrate that RB cannot be entirely overcome simply by presenting items in different locations. However, they do not preclude the possibility that location may in some circumstances provide a useful (if not infallible)

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disambiguating cue that can be used by the visual system to reduce RB.

Chun and Cavanagh (1997) addressed a related issue by presenting people with RSVP displays of two apparent motion streams passing each other in opposite directions. When two letters were presented within these apparent motion streams, RB was significantly greater when they were presented within the same stream than when they were presented within different streams. Chun and Cavanagh concluded that it is harder to individuate two identical letters within the same object file (Kahneman et al., 1992) than within different object files. (In this case, the object files correspond to the apparent motion streams.) This finding provides evidence that perceptual grouping can provide a disambiguating cue that can significantly reduce RB.[1]

If location cues behave like grouping cues, then presenting two identical items in different locations should help individuate them as distinct events. However, it is also possible that location is not just a factor that can reduce RB for other stimulus dimensions but a stimulus dimension that can itself cause RB. In other words, one might observe repetition blindness when two different letters appear in the same location, just as one observes repetition blindness when two identical letters appear in different locations. The experiments we report here were designed to test this possibility.

We presented RSVP sequences of three or four letters in which the individual letters appeared at different locations within a visual array. Participants either reported the letters of the sequence (letter-report task) or reported the locations where the letters appeared (location-report task). Stimulus sequences contained repetitions in presentation location or letter identity or both. Thus, we were able to examine the effect of location repetition on perception of an RSVP sequence while simultaneously noting any interaction between this effect and standard letter RB. To anticipate, we found that participants had difficulty reporting two letters appearing in the same location within a quarter second of each other. This deficit, which we term *repetition blindness for locations,* occurs even when the letters in question are not identical. We argue that this deficit results from a difficulty in individuating two separate events at the same location and hence is closely related to standard RB.

Experiment 1

This experiment tested participants' ability to report RSVP letter sequences containing repetitions in letter presentation location. Participants viewed RSVP sequences of three or four letters appearing one at a time at random locations within an eight-location spatial array. We compared performance in location-repeat trials (in which two of the letters were presented in the same array position) with performance in location-repeat trials (in which each of the letters was presented in a unique array position). In one block of trials, participants reported the positions in which the letters appeared (location-report task); in another block of trials, they reported the identities of the letters (letter-report task). This design allowed us to measure the effect of location repetition both when location was explicitly reported and when it was not.

We were also interested in whether RB for letters would be obtained in this paradigm and if so, how it would interact with location repetition. To this end, half of the four-letter trials contained a repetition in letter identity (i.e., two of the four letters were the same). Thus, we produced four basic types of stimulus sequences by crossing letter repetition with location repetition: sequences with a repetition in both letter identity and presentation location, sequences with a repetition in letter identity alone, sequences with a repetition in presentation location alone, and sequences with no repetitions at all.

Method

Participants. Twelve members of the Harvard University community participated in this experiment. Participants had no experience with any other RB study: they were naive about the purpose of the experiment and were paid for their participation. All had normal or corrected-to-normal vision.

Procedure. Participants were presented with a display consisting of eight pound signs arrayed in a square configuration, with a fixation cross in the center (see Figure 1). The sides of the square on which the pound signs were centered were 1.8 cm from the fixation point. Each pound sign was 1.1 cm wide and 1.3 cm high, and the fixation cross was 0.5 × 0.5 cm. Thus, from a typical viewing distance of 50 cm, the pound signs subtended an angle of about 1.4° and were centered at a distance of either 1.8° (for the four pound signs at the sides of the square) or 2.6° (for the four pound signs in the corners of the square) from fixation. This array remained on the screen between trials.

Participants were instructed to look at the fixation cross and press the mouse key to begin a trial. After a short delay, the fixation cross became a circle for 75 ms before reverting to a cross, signaling that letters were about to appear. Participants then saw an RSVP sequence of three or four letters chosen from the set *M, R, X, O, G, L, V, Z.* The first letter appeared 375 ms after the fixation cross reappeared, replacing one of the pound signs. Each letter was presented for 135 ms in the report-letter task and 120 ms in the report-position task, with no ISI between successive letters. (Different presentation durations were used to roughly equate the overall performance in the two tasks.) The four-letter trials consisted of the presentation of five distinct visual arrays, of which each of the first four contained a single letter and seven pound-sign distractors, and the fifth contained only distractors. In each successive display, the pound sign distractors flipped orientation, ensuring that visual transients occurred at all locations and not just the locations where letters appeared or disappeared. Thus, the distractors were pound signs in the second and fourth arrays, and flipped pound signs in the first, third, and fifth arrays. The same number of arrays were presented in three-letter trials, though only the first three contained letters in this case. These trials were included in the experiment to discourage participants from reporting a fourth item when only three items were seen.

In different blocks, participants either reported the identities of the letters (without concern for the locations in which the letters appeared) or the locations in which the letters appeared (without

[1] Interestingly, when the two letters were different, performance was the same for both conditions. Thus, even though the object file differences reduced RB, they did not aid the individuation of unrepeated letters.

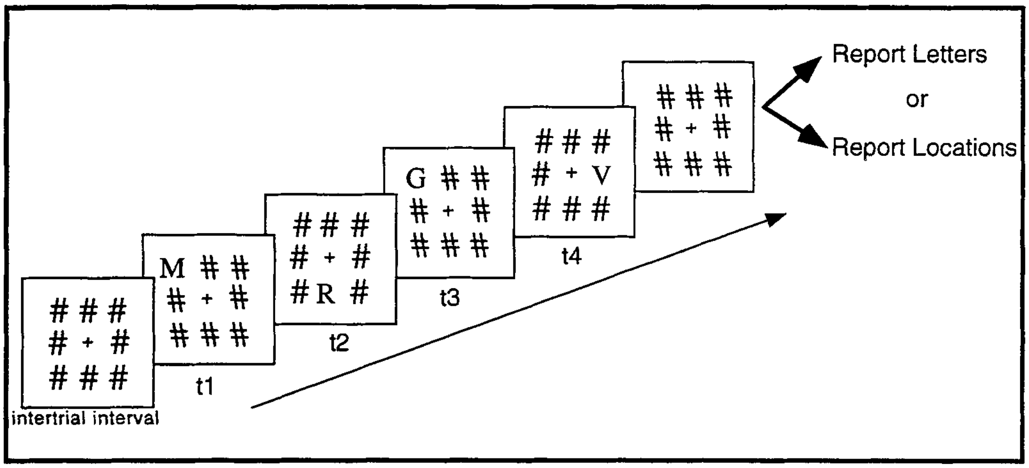

Figure 1. Procedure for Experiment 1. Participants viewed 3 or 4 letters presented in randomly chosen array locations then reported either the identities of the letters (report-letter task) or the locations in which the letters appeared (report-location task). Each letter was presented for 120 ms (in the report-location task) or 135 ms (in the report-location task). Pound signs flipped back and forth to ensure that visual transients occurred at all array locations. The trial shown here contains a repetition in presentation location. Procedures for Experiments 2 and 3 were similar (see text). t1, t2, t3, and t4 = Time 1, Time 2, Time 3, and Time 4, respectively.

concern for their identities). In both cases, it was emphasized that repetitions could occur and should be reported as two separate events. As an aid to recall, participants were encouraged to report the sequence in the order in which it appeared, though it was emphasized that reporting items correctly was more important than reporting them in the right order. In the report-letter task, participants reported the letters by clicking with a mouse on a row of letters at the bottom of the screen. This row contained the eight possible response letters and was present on the screen at all times when participants were doing the report-letter task. When a letter was clicked, it appeared on the screen beneath the stimulus array. In the report-location task, participants reported locations by clicking with the mouse on the appropriate array positions, which were marked by pound signs in the intertrial interval. As they did so, a sequence of letters representing the compass directions corresponding to the chosen locations (*N, S, E, W, NE, NW, SE, SW*) appeared on the screen beneath the stimulus array. In both tasks, participants had to enter four items. If the sequence only contained three items, they could enter a space instead of a fourth item by clicking on the screen outside the array; it appeared as an ampersand in the on-screen response sequence. Participants could also enter a space if an item appeared that they absolutely could not identify/localize; however, they were encouraged to guess in these cases. In case of errors in entering the response sequence, it could be erased by pressing the delete key after which a new response sequence could be entered. No feedback was given during the experiment.

Each block was preceded by 10 training trials. In these trials, the letters were presented at a rate that was gradually increased from half the normal rate in the first two trials up to the normal rate in the tenth trial. Every stimulus condition was shown in these practice trials. In addition, the participants performed a few warm-up trials at the very beginning of the experiment to acquaint them with the procedure. Most participants felt comfortable with the procedure after two or three trials. The entire experiment took approximately 50 min.

Design. This experiment used a $2 \times 2 \times 2 \times 2$ mixed factorial design. There were three independent variables crossed within subjects. The first was the reported dimension (report-letter task vs. report-location task). The second was letter repetition (i.e., whether the trial contained a repetition in letter identity or not). The third was location repetition (i.e., whether the trial contained a repetition in presentation location or not). There was also one between-subjects variable: block order (letter-report task first vs. location-report task first).

The experiment consisted of two blocks of 100 trials each. In one block, participants performed the report-letter task, and in the other block, participants performed the report-location task. Half of the participants did the report-letter block first, and half did the report-location block first. Of 100 trials in each block, 80 were four-letter trials and 20 were three-letter trials. In the 80 four-letter trials in each block, letter repetition was crossed with location repetition to produce 20 trials with no repetition in either location or letter identity, 20 with a repetition in location only, 20 with a repetition in letter identity only, and 20 with repetitions in both letter identity and location. In half of the trials with repetitions, the first and third items were the repeated items, and in the other half, the second and fourth items were the repeated items. Of the 20 trials with both location and identity repetition, 10 trials had both location and identity repeated in the same pair of items (for example, letter sequence *M R X R,* where both *R*s appear in the same location), whereas 10 trials had location and identity repetition in different pairs of items (e.g., *M R X R,* where the *M* and the *X* appear in the same location but the *R*s appear in different locations). Though both configurations were included to ensure that information about a repetition in one dimension did not give information about a repetition in the other dimension, only the trials with letter and location repetition in the same pair of items were scored. (Note that this meant that this condition had half as many scored trials as the other three four-letter conditions.) Three-letter trials never contained a repetition of either letter identity or letter location. Subject to these constraints, the particular letters and the particular locations in which they appeared were determined randomly at the beginning of each trial. The order in which these various types of trials were presented was determined randomly at the beginning of each block.

Apparatus. This experiment was run on a Macintosh Quadra computer with an AppleColor high-resolution RGB monitor. The software used for creating and running the experiments was MacProbe, written by Hunt (1993). The experiment was carried out in a normally illuminated room.

Results

Trials were scored as correct if both critical items were reported correctly, irrespective of the order in which they were reported. Critical items were the two letters that were identical in letter identity, presentation location, or both. Trials that contained no repetitions in either dimension were scored by averaging the score obtained by assigning the first and third items as critical with the score obtained by assigning the second and fourth item as critical.

Results are shown in Table 1. The data were analyzed in a $2 \times 2 \times 2 \times 2$ analysis of variance (ANOVA), which revealed a main effect of lower performance for critical items in repeated-location trials compared with unrepeated-location trials, $F(1, 11) = 23.4$, $MSE = 0.0251$, $p < 0.001$, and a main effect of lower performance for critical items in repeated-letter trials compared with unrepeated-letter trials, $F(1, 11) = 69.4$, $MSE = 0.0056$, $p < 0.001$. There was a significant interaction between location repetition and task, $F(1, 11) = 103.5$, $MSE = 0.0110$, $p < 0.001$, reflecting the fact that there was significant location RB in the report-location task, $F(1, 11) = 73.1$, $MSE = 0.0230$, $p < 0.001$, and a nonsignificant trend toward priming for repeated locations in the report-letter task, $F(1, 11) = 3.5$, $MSE = 0.0131$, $p = 0.09$. There was also an interaction between letter repetition and task, $F(1, 11) = 27.7$, $MSE = 0.0116$, $p < 0.001$, reflecting the fact that letter RB was found in the report-letter task, $F(1, 11) = 85.4$, $MSE = 0.0083$, $p < 0.001$, but not in the report-location task ($F < 1$).

There was no significant difference in overall performance between the two tasks ($F < 1$), nor did the order in which the participants did the two tasks make any difference in performance ($F < 1$). No interaction between letter RB and location RB was found ($F < 1$).

Table 1
Experiment 1: Proportion of Trials in Which Both Critical Items Were Reported Correctly

Letter	Location: Repeated	Location: Unrepeated	*M*
	Report letter task		
Repeated	0.53	0.43	0.48
Unrepeated	0.72	0.71	0.72
M	0.63	0.57	
	Report location task		
Repeated	0.42	0.80	0.61
Unrepeated	0.43	0.78	0.61
M	0.42	0.79	

Discussion

These results clearly demonstrate a deficit in the report of pairs of items appearing in the same array location, an effect we call RB for locations. In this experiment, this deficit was only observed in the report-location task. This might indicate that repetition in location only leads to RB when participants attend explicitly to location. Analogous claims have been made about color and shape: Repetitions in these dimensions do not lead to RB if the dimension is unattended (Kanwisher et al., 1995). However, it is also possible that locations were not coded in the report-letter task in this experiment simply because it was too difficult to discriminate between eight different array locations while simultaneously attending to the identities of the letters. If so, then location RB might be found in a report-letter task with fewer array locations, a possibility we explore in the next experiment. Finally, we note that the present results are consistent with a response bias explanation of location RB (Fagot & Pashler, 1995). Despite our assurances to the participants that more than one letter could appear in the same location and our instructions that they should report both such occurrences, they might still have been reluctant to report the same location twice.

We also found repetition blindness for letters in the report-letter task. This result was expected, given that letter RB has been demonstrated for letters presented simultaneously in spatial arrays (Bjork & Murray, 1977; Egeth & Santee, 1981; Kanwisher, 1991; Kanwisher et al., 1995; Mozer, 1989) and words presented sequentially in different locations (Kanwisher & Potter, 1989). In contrast, no letter RB was found in the report-location task.

Experiment 2

In Experiment 1, RB for locations was found in the location-report task but not in the letter-report task. However, other experiments (Epstein & Kanwisher, 1996) suggested that a strong location RB effect could be found in a report-letter task if a simpler visual array was used. In Experiment 2a, we compared performance in the letter-report task when letters were presented in a four-location array to performance when letters were presented in an eight-location array (as in the letter-report task in Experiment 1). We hypothesized that location would be automatically encoded and lead to RB with the simpler four-item arrays but not with the eight-item arrays.

In contrast, we hypothesized that letter identity would not be automatically encoded in the location-report task even when the letters were always chosen from the same very small set. To test this, in Experiment 2b we compared performance in the location-report task when the presented letters were always selected from the same set of four letters with performance when the letters presented were selected from a set of eight letters (as in the location-report task in Experiment 1). We predicted that no letter RB would be found in either case.

Experiment 2a

Method

Participants. Twenty-eight new participants from the pool described in Experiment 1 took part in this experiment and were paid for their participation.

Procedure and design. The basic procedure was the same as in Experiment 1. The experiment was divided into two blocks. Participants performed the report-letter task in both blocks. In one block, there were four possible array locations in which letters could appear, and in the other block, there were eight possible array locations in which letters could appear (as in Experiment 1). Letters were chosen from the set *M, R, X, O, G, L, V, Z*. Letter presentation rate was the same as in the report-letter task in Experiment 1.

There were two nested between-subjects independent variables. The first was block order: Half of the participants did the four-location block first, and the other half did the eight-location block first. The second independent variable was arrangement of array locations in the four-location arrays (see Figure 2): For half of the participants, the array locations in the four-location array corresponded to the corners of the eight-location array (square arrangement); for the other half of the participants, the locations in the four-location array corresponded to the sides of the eight-location array (diamond arrangement).

Within each block, there were three crossed within-subject independent variables: array size (four vs. eight), location repetition (repeated vs. unrepeated), and letter repetition (repeated vs. unrepeated).

Results

The data were scored as described in Experiment 1; results are shown in Table 2. An omnibus ANOVA revealed that the location RB effect was significant overall (i.e., accuracy was lower for report of critical items in trials containing location repetitions), $F(1, 24) = 23.4$, $MSE = 0.0183$, $p < 0.001$, as was letter RB, $F(1, 24) = 74.1$, $MSE = 0.0413$, $p < 0.001$. There was a significant interaction between location repetition and array size, $F(1, 24) = 18.4$, $MSE = 0.0110$, $p < 0.001$, reflecting the fact that location RB was significant for four-location arrays, $F(1, 24) = 28.2$, $MSE = 0.0215$, $p < 0.001$, but not for eight-location arrays, $F(1, 24) = 2.68$, $MSE = 0.0077$, $p > 0.1$. Though letter RB was found for both four-location arrays, $F(1, 24) = 33.0$, $MSE = 0.0284$, $p < 0.001$, and eight-location arrays, $F(1, 24) = 101.2$, $MSE = 0.0224$, $p < 0.001$, it was stronger for eight-location arrays than for four-location arrays, which was reflected in a significant interaction between letter repetition and array size, $F(1, 24) = 15.1$, $MSE = 0.0095$, $p < 0.001$.

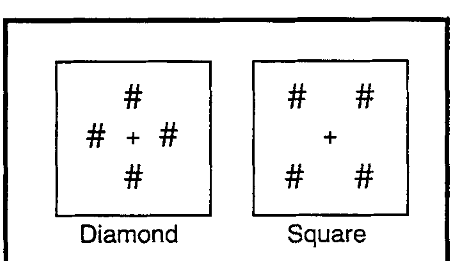

Figure 2. The two varieties of four-location arrays used in Experiment 2. (Diagram is schematic; see text for stimulus sizes and distances.)

Table 2
Experiment 2a (Report-Letter Task): Proportion of Trials in Which Both Critical Items Were Reported Correctly

Letter	Location: Repeated	Location: Unrepeated	*M*
	Four array locations		
Repeated	0.38	0.58	0.48
Unrepeated	0.61	0.71	0.66
M	0.50	0.64	
	Eight array locations		
Repeated	0.41	0.47	0.44
Unrepeated	0.73	0.72	0.72
M	0.57	0.59	

In addition, there was a significant interaction between letter repetition and location repetition, $F(1, 24) = 8.5$, $MSE = 0.0108$, $p < 0.01$, reflecting the fact that RB for either dimension was more severe when there was a repetition in the other dimension than when there was not. However, this interaction was found only for participants who performed the four-location block first, $F(1, 12) = 19.4$, $MSE = 0.0098$, $p < 0.001$, but not for participants who performed the eight-location block first ($F < 1$), and this difference was reflected in the significant triple interaction between block order, letter repetition, and location repetition, $F(1, 24) = 9.23$, $MSE = 0.0108$, $p < 0.01$. This result may reflect the use of different response strategies: Participants performing the four-location block first might be tempted to use location information to verify their recollection of the letter sequence, a strategy that would result in confusion when both letter and location are repeated in the same item. Participants performing the eight-location block first would be less tempted to adopt such a strategy. Finally, there was no main effect of configuration (diamond vs. square) of the four-location arrays ($F < 1$), nor did configuration interact with any other variable (all Fs < 1).

In sum, location RB was found for four-location arrays but not for eight-location arrays in a letter-report task, whereas letter RB was found for both four- and eight-location arrays.

Experiment 2b

Method

Participants. Participants were twenty-eight members of the MIT community who had no experience with any other RB Experiment (including Experiment 2a) and were naive about the purpose of the experiment. They were paid for their participation. All had normal or corrected-to-normal vision.

Procedure and design. The basic procedure was similar to that in Experiment 2a. The experiment was divided into two blocks. Participants performed the report-location task in both blocks. In one block, letters were chosen from the set *M, R, X, O,* and in the other block, letters were chosen from the set *M, R, X, O, G, L, V* (as in Experiment 1). There were eight possible locations in which letters could appear. Letter presentation rate was the same as in the report-location task of Experiment 1.

Half of the participants did the four-letter block first, and the other half did the eight-letter block first. Thus, in addition to the three crossed within-subject independent variables of letter-set size (four vs. eight), location repetition (repeated vs. unrepeated), and letter repetition (repeated vs. unrepeated), there was one between-subjects independent variable (block order).

Results

The data were scored as described in Experiment 1; results are shown in Table 3. An omnibus ANOVA found significant location RB, $F(1, 26) = 160.3$, $MSE = 0.049$, $p < 0.001$, but no letter RB ($F < 1$). Letter-set size did not interact with location repetition ($F < 1$), but there was a marginally significant interaction between letter-set size and letter repetition, $F(1, 26) = 3.74$, $MSE = 0.0094$, $p = 0.064$, reflecting the fact that priming for repeated letters was found when letters were chosen from a set of size eight, $F(1, 26) = 4.76$, $MSE = 0.0081$, $p < 0.05$, but not when they were chosen from a set of size four ($F < 1$). This repeated-letter priming occurred only when location was also repeated, resulting in a significant interaction between letter repetition and location repetition, $F(1, 26) = 4.94$, $MSE = 0.0079$, $p < 0.05$, which was significant when there were eight possible letters, $F(1, 26) = 6.70$, $MSE = 0.0106$, $p < 0.05$, but not when there were only four letters ($F < 1$). The triple interaction between letter repetition, location repetition, and letter-set size was marginally significant, $F(1, 26) = 3.49$, $MSE = 0.0093$, $p = 0.07$. No other significant effects were observed.

Discussion (Experiments 2a and 2b)

Experiment 2a demonstrates that RB for locations can be obtained even when participants do not have to explicitly attend to locations to do the task. This result provides evidence for automatic encoding of locations: Even though participants did not report locations, this information must have been processed to some degree. This result is particularly interesting when contrasted with the failure to find letter RB in the report-location task in Experiment 2b.[2] Previous experiments have found RB for letter identity and color only when these dimensions are specifically attended (Kanwisher, 1991). The current finding of a repetition deficit for the unreported stimulus dimension of location indicates that RB for locations behaves differently from RB for other stimulus attributes such as letter identity or color. The question of whether or not this reflects a difference in the mechanisms underlying RB for letters and RB for locations is taken up in the General Discussion.

The critical factor determining whether location RB was observed in the report-letter task was the number of possible locations where letters could appear. A deficit for repeated locations was found in Experiment 2a when there were only four array locations but not when there were eight array locations (replicating the result of Experiment 1). In contrast, no letter RB was found in the report-location task in Experiment 2b, even when the letters were also chosen from a set of four. This pattern of results indicates that a limited amount of location coding—but not letter coding—can occur automatically. The fact that no difference was found between square and diamond configurations of four-location arrays in Experiment 2a suggests that it is the number of discrete locations in the array and not the angular distance between the array locations that determines whether locations are automatically encoded. However, we cannot at this point definitely exclude the possibility that it is the higher density of the eight-location arrays that prevents location encoding in this condition (He, Cavanagh, & Intriligator, 1996). The finding of RB for locations with eight-location arrays in the report-location task suggests that more locations (or, alternatively, finer-grained distinctions between locations) *can* be encoded when participants explicitly attend to location.

In most RB experiments, RB is found only for the reported dimension (Kanwisher, 1991). In contrast, in the present experiment, RB was found in one dimension (location) when reporting another (letter identity). This allows us to draw certain conclusions that cannot normally be made conclusively in RB experiments. For example, the repeated-location deficit observed in this experiment cannot be due to any standard kind of report bias because participants were not reporting location. Furthermore, by looking at trials in which two different letters were presented in the same location, we can determine which critical item was lost. This is an issue of considerable theoretical importance, yet previous efforts to distinguish reports of the first critical item from reports of the second critical item have not been convincing (Fagot & Pashler, 1995). As can be seen in Table 4, the location-repetition deficit found for four-location arrays in this experiment is entirely due to a failure to correctly report the second item appearing in the same

Table 3
Experiment 2b (Report-Location Task): Proportion of Trials in Which Both Critical Items Were Reported Correctly

Letter	Location: Repeated	Location: Unrepeated	*M*
	Four possible letters		
Repeated	0.45	0.83	0.64
Unrepeated	0.46	0.85	0.65
M	0.46	0.84	
	Eight possible letters		
Repeated	0.51	0.82	0.67
Unrepeated	0.42	0.84	0.63
M	0.46	0.83	

[2] In fact, a small amount of repetition priming was found when letters were chosen from a set of eight but not when they were chosen from a set of four. Although this effect was not observed consistently (i.e., it was not found in the report-location task in Experiment 1 even though the parameters of the experiment were the same), it may reflect the previously reported tendency for repetition priming effects to increase as cross-trial item repetition decreases (Kahneman et al., 1992).

Table 4
Experiment 2a: Proportion of Letter-Unrepeated Trials in Which the First (C1) and Second (C2) Critical Items Were Reported Correctly

Critical item	Location repeated	Location unrepeated	Unrepeated–repeated
C1	0.89	0.89	0.00
C2	0.70	0.79	0.09
M	0.78	0.84	

Note. These results are for the four-location block only.

location (at least in the letter-unrepeated trials). This result argues against any account of the effect in terms of backward masking of the first critical item by the second critical item appearing in the same location because such an account could not explain a deficit for the second critical item.

Finally, it is interesting to note that letter RB was greater for eight-location arrays than for four-location arrays in Experiment 2a. Chun and Cavanagh (1997) found that letter RB was smaller when letters appeared within different objects (in their case, different apparent motion streams) than when letters appeared within the same object. If locations are encoded in the four-location arrays but not in the eight-location arrays, then one would expect letter RB to be smaller for the four-location arrays because location differences can be used to disambiguate repeated letters in this case. This is exactly what is found: Letter RB when location is unrepeated is smaller for the four-location arrays (unrepeated − repeated performance = 0.14) than for the eight-location arrays (unrepeated − repeated performance = 0.25).

Experiment 3

We have described location RB as a perceptual deficit. However, it is conceivable that it results from a particular report strategy in which participants mentally query each location to retrieve the identity of the letter that appeared there. If participants adopt this strategy, then retrieval of the first letter presented in a given location might disrupt retrieval of the second letter presented at that location. Thus, it is possible that location RB, at least in the letter-report task, might result from a memory or retrieval failure (Armstrong & Mewhort, 1995).

To test this hypothesis, we devised a partial-report variant of the letter-report task. Participants viewed an RSVP sequence of four different letters presented within a four-location spatial array, with half of the presentation sequences containing a repetition in location. Afterward, they reported what they had seen in two possible ways. Either they reported all four letters (as in Experiments 1 and 2), or they responded *yes* or *no* to a query about the presence of a single letter. This partial-report task thus allowed us to measure accuracy of report for a single letter in the case where participants did not have to report any other letters. Any interference at the retrieval stage should be eliminated by this report method.

Participants did not know which type of report they would be required to make until the end of the trial. Thus, any difference in performance between the partial-report trials and the full-report trials must be attributed to events in the retrieval and report stage and not to events in the perceptual stage. If RB for locations is due to interference in the retrieval stage, then it should not be found in the partial-report task. On the other hand, if RB for locations is due to difficulties in the perceptual stage then it should be unaffected by the method of report and should be found in both tasks.

Method

Participants. Eleven new participants from the same pool as Experiment 1 participated in this experiment. One participant was eliminated because her overall accuracy in the partial report task was more than two standard deviations below the mean.

Procedure. The basic procedure was the same as in Experiment 2 except as noted. In all trials, participants viewed an RSVP sequence of four different letters from the set *M, R, X, O, G, L, V, Z*. There were four possible array locations where letters could appear, corresponding to the diamond locations in Experiment 2. Presentation time was 135 ms/letter. At the end of the trial, there was a 675 ms delay, after which one of two possible queries appeared on the screen. In the partial-report task, the query *X*? (where *X* was one of the eight possible stimulus letters) appeared on the screen beneath the array. Participants responded by clicking with the mouse on one of the letters *Y* (for yes) or *N* (for no), which appeared on the screen beneath the query and simultaneously with it. Once the participants clicked on either *Y* or *N*, the query and these letters disappeared. In the full-report task, the letters *M, R, X, O, G, L, V, Z* appeared on the screen beneath the array; as in previous experiments, participants reported the full stimulus sequence by clicking on four of these letters, clicking a letter twice if they saw it twice.

Eighteen reduced-rate practice trials were performed at the beginning of the experiment to familiarize participants with the procedure. All conditions were presented in these practice trials, in roughly equal proportion to their proportions in the recorded trials. The entire experiment took about 50 min, and participants were prompted by the computer to take a break halfway through.

Design. There were a total of 288 trials in this experiment. Participants performed the full-report task in half the trials (144 trials) and the partial-report task in the other half. Within the 144 trials of each task, one quarter (36) contained a repetition in location in the first and third letter, one quarter (36) contained a repetition in location in the second and fourth letter, and one half (72) contained no location repetitions. (Note that letter identity was never repeated in any trial in this experiment.) For each of these three conditions in the partial-report task, the correct answer to the yes/no query was yes in two-thirds of the trials and no in one-third of the trials. When the correct answer was yes, the queried letter was equally likely to be any of the four presented letters, so participants could not predict the queried letter from the stimulus sequence.

This experiment thus had a 2 × 2 × 2 within-subjects design. The three independent crossed variables were task (full report vs. partial report), location repetition (repeated vs. unrepeated), and serial position of queried item (C1 vs. C2). In the repeated-location condition, C1 was the first letter presented at a location, whereas C2 was the second letter presented at that location. In the unrepeated condition, the first and second letters were counted as C1, whereas the third and fourth letters were counted as C2. This allowed comparison between equivalent items in the two repetition conditions.

Results

The results are shown in Table 5. The results for the partial-report task were calculated using the standard guessing-correction formula, in which the rate of *yes* responses in trials in which the queried letter did not appear is used to obtain corrected hit rates for the trials in which the queried letter did appear (i.e., high-threshold alpha). For the full-report task, we recorded accuracy for each item in this task. Note that this measure is different from the one used in the preceding experiments, where we measured the proportion of trials in which *both* critical items were reported correctly. Thus, the fact that overall performance appears to be slightly better and differences between conditions slightly smaller when compared with previous experiments can be attributed to the use of a less stringent performance criterion in the present experiment.

Separate ANOVAs were performed on the data for each task. In the partial-report task, a significant deficit for repeated locations was found, $F(1, 9) = 14.24$, $MSE = 0.0101$, $p < 0.01$. Though performance on C1 was slightly higher than performance on C2 in this task, this difference was not significant ($F = 1.05$), nor was there an interaction between critical item (C1 vs. C2) and location repetition ($F < 1.1$). There was also a significant deficit for repeated locations in the full-report task, $F(1, 9) = 8.21$, $MSE = 0.0044$, $p < 0.05$. In this task, C2 performance was significantly lower than C1 performance, $F(1, 9) = 14.95$, $MSE = 0.0023$, $p < 0.01$; however, there was no interaction between critical item and location repetition ($F < 1$).

Discussion

In this experiment, a deficit for repeated locations was found in a partial-report task, demonstrating that RB for locations is not merely an artifact of the strategies adopted in the full-report task. Thus, RB for locations occurs on-line during perceptual encoding, not at a response stage.

Table 5
Experiment 3: Proportion of Trials in Which the First (C1) and Second (C2) Critical Items Were Reported Correctly

	Location		
Critical item	Repeated	Unrepeated	Unrepeated–repeated
	Partial-report trials		
C1	0.76	0.90	0.14
C2	0.73	0.82	0.09
M	0.74	0.86	0.12
	Full-report trials		
C1	0.84	0.89	0.05
C2	0.77	0.84	0.07
M	0.80	0.86	0.06

Note. Partial-report trials were corrected for guessing.

One surprising result was a failure to find a difference in the size of the RB effect between C1 and C2 in either the partial-report or full-report trials. These results contrast with the results of Experiment 2a, in which the entire RB effect was found on C2, not on C1. It is possible that this failure to replicate the pattern found in Experiment 2 is simply due to the small number of participants in the current experiment. However, it is also possible that participants in Experiment 3 adopted a different encoding strategy because they were not required to give a full report of the sequence in all trials. In particular, knowing that they would not always have to report every item, participants in Experiment 3 might have devoted less attention to the individual letters as they appeared. Consequently, RB in this case might sometimes be due to a failure to stabilize a C1 token by the time C2 comes along (Bavelier, 1994), rather than due to a disruption of C2 encoding by a fully tokenized C1. Which of these effects predominates may depend on the temporal contour of attentional deployment, which may be spread more evenly over the entire sequence when partial report is sometimes required, but focused more strongly on the beginning of the list when full report is required on each trial.

General Discussion

Our main finding in this study is that participants are impaired at reporting letters appearing in repeated locations in an RSVP sequence (RB for Locations or Location RB). We have demonstrated several key facts about this effect. First, location RB occurs both when participants explicitly report the locations in which the letters appear (the report-location task) and when they merely report the identities of the letters (the report-letter task). Second, whereas location RB is found for both four- and eight-location arrays in the report-location task, it is only found for four-location arrays (i.e., not eight-location arrays) in the report-letter task. In contrast, letter RB is not found in the report-location task even when the number of possible letters is similarly reduced. Third, location RB can be found in both full-report and partial-report tasks and is therefore unlikely to be a result of interference at the response stage.

We propose that location RB results from a tokenization difficulty similar to the one that underlies RB for letters, words, and other visual attributes. According to the type/token theory (Kanwisher, 1987, 1991), RB results from a failure to bind a visual type to two distinct episodic tokens. A visual type is a predefined category in long-term visual memory (such as a word, letter, object, or perceptual feature) or a novel category generated on the fly (Arnell & Jolicoeur, 1997). A token is a place-holder in time, or space, or both that is equivalent to an object file; it is a marker that says something happened at this time/place. Exactly what happened is defined by the type, so perception of a visual event requires type and token to be bound together. Types are activated quickly and automatically, but the visual system is limited in the rate at which it can create new tokens. When stimuli are shown in an RSVP sequence at a rate of 7–10 items/s, the capacity of the visual system to create new tokens is taxed to the limit, and errors are made when the same type must be bound to two different tokens. In situations in which more than one stimulus dimension is varied (e.g., if the stimuli are colored letters), RB occurs if any attended stimulus dimension is repeated, even if the events are distinguishable in another stimulus dimension (Bavelier, 1994; Bavelier & Potter, 1992; Kanwisher et al., 1995). Our experiments indicate that location (when coded) acts much like any other stimulus dimension in this respect. When a letter is presented in the same location as a previous letter, this provides evidence against counting this new letter as a new event, even if the letters are theoretically distinguishable on the basis of identity. Just as participants have difficulty individuating two events in an RSVP sequence when they repeat visual features, so they have difficulty individuating two events in an RSVP sequence when they occur in a repeated location.

However, there are important differences between the two effects, indicating that location RB may be more than just a new form of standard RB. Most prominently, standard RB does not occur if participants do not attend to the stimulus dimension in which the repetition occurs (Bavelier, 1994; Bavelier & Potter, 1992; Kanwisher, 1991; Kanwisher et al., 1995). In contrast, location RB occurs even in the letter-report task in which location is unreported. There are two possible ways to account for this difference between location RB and letter RB. One possibility is that there are two tokenization processes in the brain: one that tokenizes events on the basis of their attributes and another that tokenizes events on the basis of their locations. Another possibility is that there is only one tokenization process, but because locations are coded automatically and letter identities are not, only location repetitions lead to RB when task irrelevant. We do not at present have enough evidence to decide between these two accounts, though parsimony suggests that the second one is more likely. In either case, location plays a privileged role in the creation and stabilization of tokens.[3]

Another question that remains concerns the nature of the codes underlying location RB. Although we have described the effect in terms of location repetition, the critical factor might actually be repetition of events within the same "object files" (Baylis & Driver, 1993; Kahneman et al., 1992; Kanwisher & Driver, 1992; Tipper, Driver, & Weaver, 1991). In all our experiments, an array of pound signs was present on the screen both during and between trials. Because of the consistency of the array configuration, it is possible that object files were set up for the array locations even before the sequence began. If so, it would be natural for the sequence to be encoded by associating each letter with a particular preexisting object file, a strategy that could lead to confusion when two letters were presented in the same object file.[4] Thus, location RB might result from the efforts of the visual system to create a coherent percept in which events (letter presentations) are experienced as occurring within specific objects (elements of the array).

If the location RB reported here were in fact based on object files instead of pure location codes, this would suggest two possible accounts for the occurrence of location RB for four-item arrays but not eight-item arrays in the report-letter task. First, it may simply not be possible to support eight different object files while simultaneously processing letter identity. Such a limit would be consistent with those proposed for the number of instantiation fingers (FINSTS; Pylyshyn & Storm, 1988) or object files (Kahneman et al., 1992; Luck & Vogel, 1997) that can be simultaneously supported by the visual system. Alternatively, the visual system might group the separate locations together into a single object when there are eight adjacent items but not when there are four arrayed in a more dispersed fashion. In either case, the system would fail to set up eight distinct object files to which letter presentations could be assigned, and RB would not occur. In contrast, when participants explicitly report location, more attentional resources would be available for discriminating locations, so RB would occur even for eight-location arrays in this task.

Relationship to Other Phenomena

Inhibition of Return

Both location RB and inhibition of return (IOR) involve a diminished ability to report stimuli appearing at previously stimulated locations. IOR occurs when participants must detect a stimulus in one of several (usually two) possible locations: Reaction time is found to be slower at locations that have previously been cued, even if that cue gives no information about the subsequent target (Maylor & Hockey, 1985; Posner & Cohen, 1984). IOR is usually found for stimulus onset asynchronies (SOAs) of 500 ms or more; however, Tassinari and Berlucchi (1993) have observed fast IOR at SOAs of 200 ms in a detection task. IOR has also been measured using an accuracy paradigm (Cheal, Chastain, & Lyon, 1998). It is not inconceivable that location RB, letter RB, and fast IOR could all reflect a general tendency of the nervous system to be more sensitive to novel sensory information than repeated sensory information (Johnston, Hawley, & Farnham, 1993) on the quarter-second time scale. However, a recent result of Lupianez, Milan, Tornay, Madrid, and Tudela (1997) argues against this possibility.[5] On detection of a target, participants in their experiment pressed a button corresponding to the target color. At SOAs comparable to the ones used in the present experiment, Lupianez et al. (1997) found *facilitation* of return in this discrimination task (see also Danziger, Kingstone, & Snyder, 1998). This task is the closest analogue to the present experimental paradigm in the IOR literature. We conclude that RB for locations cannot be due to IOR: If the two phenomena were linked, one would expect to find higher performance (facilitation of return) for items appearing in repeated locations in our experiments.

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[3] This conclusion is consistent with Baylis, Driver, and Rafal's (1993) proposal that tokens are processed in the dorsal visual stream (Ungerleider & Mishkin, 1982) along with spatial information.

[4] If it is the predictability of array locations over trials that leads to this encoding strategy, then the RB effect should be greatly reduced if the array configuration is varied over trials and/or if the pound signs are not present before the letters appear.

[5] We thank Bob Rafal for suggesting this argument to us.

Iconic Memory

A number of researchers have proposed dual-buffer accounts of iconic memory (Coltheart, 1983; Mewhort, Campbell, Marchetti, & Campbell, 1981; Mewhort & Leppman, 1985) that include both a precategorical sensory store and a postcategorical store. These models postulate a limit to the rate at which information can be transferred out of the postcategorical store into a more permanent reportable store that includes a durable link between stimulus identity and location. Thus, both these accounts of iconic memory and the type/token account of RB postulate a bottleneck in the transfer from postcategorical representations (types) to representations that include location and episodic information (types linked with tokens). Given this similarity, it is possible to describe RB for locations in terms of interference in iconic memory: When two letters appear in the same location, interference in the postcategorical iconic memory representations of the letters may make it difficult to move both letters into the report (token) stage.[6] With this plausible mapping of postcategorical representations onto types and report stage representations onto tokens, the iconic memory interpretation of RB for locations does not differ substantially from the account we have offered above.

Object Substitution Masking

The present results also bear some similarity to the recently reported phenomenon of object substitution masking (Enns & Di Lollo, 1997), in which performance at reporting geometric shapes at parafoveal (but not foveal) locations is reduced when a four-dot metacontrast mask appears in the same location. Enns and Di Lollo hypothesized that the absence of focused attention at parafoveal locations allows the representation of the mask to interrupt and overwrite the representation of the target. Thus, as with location RB, interference is found when two stimuli are presented in the same location within a small amount of time. However, the location RB paradigm differs from the object-substitution-masking paradigm in that masks occur at every location in location RB. The pound-sign masks used in the present experiment are more salient than the four-dot masks used in Enns and Di Lollo's experiment. If object substitution masking occurred in this paradigm, one would expect it to occur at every location; thus, object substitution masking cannot account for RB for locations. At present, we must consider location RB and object substitution masking to be distinct phenomena, though future research may reveal a connection between the two.

Attentional Blink

When participants are required to detect two targets embedded within an RSVP stream of nontargets, they often fail to report the second target if it occurs 200–400 ms after the first target. This phenomenon, known as the attentional blink (AB; Raymond et al., 1992) has a similar time course to repetition blindness for locations, which suggests that two phenomena may be related. In particular, Chun and Potter (1995) found that AB for letter targets was much stronger when the distractors were digits than when they were more easily discriminable symbols such as the pound signs used in the current experiment, and Seiffert and Di Lollo (1997) found that AB depended critically on whether or not the first target was masked by subsequent distractors. If the second letter presented at a location in repeated-location trials acts as a more effective mask than the pound sign that appears in that location during unrepeated-location trials, then one might conceivably observe an attentional blink for the second letter in the repeated-location condition that does not occur in the unrepeated-location condition. However, a recent study by Breitmeyer et al. (1999) allows us to reject this possibility. In their experiment, subjects viewed letter targets embedded within a stream of digit distractors that appeared in random locations within a four- or nine-element array very similar to the one used in our experiments. Critically, AB was found to be no greater when the two targets appeared in the same array location than when they appeared in different array locations, demonstrating that RB for locations cannot be interpreted as a case of location-dependent AB. Interestingly, AB was greater when each target and distractor was followed by an ampersand mask in the same location. Taken together, Breitmeyer et al.'s results are consistent with Chun's (1997) claim that RB and AB are dissociable phenomena that have different etiologies: RB resulting from interference between reported targets and AB resulting from interference between targets and nonreported distractors.

Conclusion

We have described a new phenomenon, which we term repetition blindness for locations. This phenomenon demonstrates that the spatial organization of the visual field influences the way in which the visual stream is parsed into distinctly experienced events in time—even in situations in which participants are not explicitly asked to report or attend to this spatial information. Location codes are set up automatically by the visual system, and these location codes play a key role in stabilizing perceptual representations in awareness (Marcel, 1983). RB for locations provides a promising tool for future research into the nature of the location codes that are set up on-line during the perception of complex visual sequences.

[6] The interference could not arise at the precategorical feature stage: Because every letter in our experiments is followed by a pound sign that could cause interference at the feature level, any interference at this stage should be equal for all letters.

References

Armstrong, I. T., & Mewhort, D. J. K. (1995). Repetition deficit in rapid-serial-visual-presentation displays: Encoding failure or retrieval failure? *Journal of Experimental Psychology: Human Perception and Performance, 21,* 1044–1052.

Arnell, K. M., & Jolicoeur, P. (1997). Repetition blindness for pseudoobject pictures. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 999–1013.

Bavelier, D. (1994). Repetition blindness between visually different items: The case of pictures and words. *Cognition, 51,* 199–236.

Bavelier, D., & Potter, M. (1992). Visual and phonological codes in repetition blindness. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 134–147.

Baylis, G. C., & Driver, J. (1993). Visual attention and objects: Evidence for hierarchical coding of location. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 451–470.

Baylis, G. C., Driver, J., & Rafal, R. D. (1993). Visual extinction and stimulus repetition. *Journal of Cognitive Neuroscience, 5,* 453–466.

Bjork, E. L., & Murray, J. T. (1977). On the nature of input channels in visual processing. *Psychological Review, 84,* 472–484.

Breitmeyer, B. G., Ehrenstein, A., Pritchard, K., Hiscock, M., & Crisan, J. (1999). The roles of location specificity and masking mechanisms in the attentional blink. *Perception & Psychophysics, 61,* 798–809.

Cheal, M. L., Chastain, G., & Lyon, D. R. (1998). Inhibition of return in visual identification tasks. *Visual Cognition, 5,* 365–388.

Chun, M. M. (1997). Types and tokens in visual processing: A double dissociation between the attentional blink and repetition blindness. Journal of Experimental Psychology: *Human Perception and Performance, 23,* 738–755.

Chun, M. M., & Cavanagh, P. (1997). Seeing two as one: Linking apparent motion and repetition blindness. *Psychological Science, 8,* 74–79.

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 109–127.

Coltheart, M. (1983). Iconic memory. *Philosophical Transactions of the Royal Society of London, B, 302,* 283–294.

Danziger, S., Kingstone, A., & Snyder, J. J. (1998). Inhibition of return to successively stimulated locations in a sequential visual search paradigm. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 1467–1475.

Duncan, J., Ward, R., & Shapiro, K. (1994). Direct measurement of attentional dwell time in human vision. *Nature, 369,* 313–315.

Egeth, H. E., & Santee, J. L. (1981). Conceptual and perceptual components of interletter inhibition. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 506–517.

Enns, J. T., & Di Lollo, V. (1997). Object substitution: A new form of masking in unattended visual locations. *Psychological Science, 8,* 135–139.

Epstein, R., & Kanwisher, N. (1996). *Repetition blindness for locations.* Poster session presented at the 37th annual meeting of the Psychonomics Society, Chicago, IL.

Fagot, C., & Pashler, H. (1995). Repetition blindness: Perception or memory failure? *Journal of Experimental Psychology: Human Perception and Performance, 21,* 275–292.

He, S., Cavanagh, P., & Intriligator, J. (1996). Attentional resolution and the locus of visual awareness. *Nature, 383,* 334–337.

Hunt, S. M. J. (1993). MacProbe (Version 1.6) [Computer software]. Woodland Hills, CA: Aristometrics.

Intriligator, J., Nakayama, K., & Cavanagh, P. (1991). Attentive tracking of multiple moving objects at different time scales. *Investigative Ophthalmology and Visual Science, 32,* 1040.

Johnston, W. A., Hawley, K. J., & Farnham, M. (1993). Novel popout: Empirical boundaries and tentative theory. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 140–153.

Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: Object specific integration of information. *Cognitive Psychology, 24,* 175–219.

Kanwisher, N. (1987). Repetition blindness: Type recognition without token individuation. *Cognition, 27,* 117–143.

Kanwisher, N. (1991). Repetition blindness and illusory conjunctions: Errors in binding visual types with visual tokens. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 404–421.

Kanwisher, N., & Driver, J. (1992). Objects, attributes, and visual attention: Which, what, and where. *Current Directions in Psychological Science, 1,* 26–31.

Kanwisher, N., Driver, J., & Machado, L. (1995). Spatial repetition blindness is modulated by selective attention to color and shape. *Cognitive Psychology, 29,* 303–337.

Kanwisher, N., & Potter, M. C. (1989). Repetition blindness: The effects of stimulus modality and spatial displacement. *Memory & Cognition, 17,* 117–124.

Kanwisher, N., Yin, C., & Wojciulik, E. (1999). Repetition blindness for pictures: Evidence for the rapid computation of abstract visual descriptions. In V. Coltheart (Ed.), *Fleeting memories* (pp. 119–150). Cambridge, MA: MIT Press.

Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature, 390,* 279–281.

Luo, C. R., & Caramazza, A. (1996). Temporal and spatial repetition blindness: Effects of presentation mode and repetition lag on the perception of repeated items. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 95–113.

Lupianez, J., Milan, E. G., Tornay, F. J., Madrid, E., & Tudela, P. (1997). Does IOR occur in discrimination tasks? Yes, it does, but later. *Perception & Psychophysics, 59,* 1241–1254.

Mack, A., & Rock, I. (1998). *Inattentional blindness.* Cambridge, MA: MIT Press.

Marcel, A. J. (1983). Conscious and unconscious perception: An approach to the relations between phenomenal experience and perceptual processes. *Cognitive Psychology, 15,* 238–300.

Maylor, E. A., & Hockey, R. (1985). Inhibitory component of externally controlled covert orienting in visual space. *Journal of Experimental Psychology: Human Perception and Performance, 11,* 777–787.

McConkie, G., & Currie, C. (1996). Visual stability across saccades while viewing complex pictures. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 563–581.

Mewhort, D. J. K., Campbell, A. J., Marchetti, F. M., & Campbell, J. I. D. (1981). Identification, localization, and "iconic memory": An evaluation of the bar-probe task. *Memory & Cognition, 9,* 50–67.

Mewhort, D. J. K., & Leppman, K. P. (1985). Information persistence: Testing spatial and identity information with a voice probe. *Psychological Research, 47,* 51–58.

Mozer, M. (1989). Types and tokens in visual letter perception. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 287–303.

Nissen, M. J. (1985). Accessing features and objects: Is location special? In M. I. Posner & O. S. Marin (Eds.), *Attention and performance XI* (pp. 205–219). Hillsdale, NJ: Erlbaum.

Park, J., & Kanwisher, N. (1994). Determinants of repetition blindness. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 500–519.

Posner, M. I., & Cohen, Y. A. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X* (pp. 531–556). Hillsdale, NJ: Erlbaum.

Potter, M. C. (1975). Meaning in visual search. *Science, 187,* 965–966.

Potter, M. C. (1976). Short term conceptual memory for pictures. *Journal of Experimental Psychology: Human Learning and Memory, 2,* 509–522.

Pylyshyn, Z. W., & Storm, R. W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spatial Vision, 3,* 179–197.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18,* 849–860.

Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science, 8,* 368–373.

Seiffert, A. E., & Di Lollo, V. (1997). Low-level masking in the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 1061–1073.

Shapiro, K. L., Raymond, J. E., & Arnell, K. M. (1994). Attention to visual pattern information produces the attentional blink in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 357–371.

Simons, D. J. (1996). In sight, out of mind: When object representations fail. *Psychological Science, 7,* 301–305.

Tassinari, G., & Berlucchi, G. (1993). Sensory and attentional components of slowing of manual reaction time to non-fixated visual targets by ipsilateral primes. *Vision Research, 33,* 1525–1534.

Tipper, S. P., Driver, J., & Weaver, B. (1991). Short report: Object-centered inhibition of return of visual attention. *Quarterly Journal of Experimental Psychology, 43A,* 289–298.

Treisman, A. M., & Gelade, G. (1980). A feature integration theory of attention. *Cognitive Psychology, 12,* 97–136.

Tsal, Y., & Lavie, N. (1988). Attending to color and shape: The special role of location in selective visual processing. *Perception & Psychophysics, 44,* 15–21.

Ungerleider, L. G., & Mishkin, M. (1982). Two cortical visual systems. In D. J. Ingle, M. A. Goodale, & R. J. W. Mansfield (Eds.), *Analysis of visual behavior* (pp. 549–585). Cambridge, MA: MIT Press.

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