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Second-Order Parallel Processing: Visual Search for the Odd Item in a Subset

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Visual search tasks in which participants searched for an odd element in a subset of items were investigated. Participants searched for an item of odd orientation in the red subset. The target was a red line of $X°$, distractors were green lines of $X°$ and red lines of $Y°$. The orientations, X and Y, changed on every trial. In this task, orientation information was useful only after color had been used to select the relevant subset. Results show that response time (RT) and error data were different from standard color X orientation conjunction searches (Experiment 1). RT × Set Size functions had slopes near 0 ms per item (Experiment 2). The selection of the subset appeared to take 200–300 ms (Experiments 2 and 3). Subset selection was based on properties of the relevant subset, not the irrelevant subset (Experiment 4). It was more difficult (perhaps impossible) to select a subset defined by 2 colors (Experiment 5). Random variation in an irrelevant dimension did not disrupt subset search (Experiment 6).

Following Neisser (1967), many vision researchers have divided visual processing into two stages: preattentive and attentive. In the preattentive stage, information about basic features can be extracted from many or all items in parallel (Julesz, 1984; Treisman & Gormican, 1988). These parallel processes can be used in visual search tasks to guide attention to a target item among a variable number of distractor items. When unlimited capacity parallel processes can reliably guide attention to the target, search response times (RTs) are independent of the number of items in a visual display (set size). In these "parallel" searches, RTs on target-absent trials are also independent or nearly independent of set size. The architecture envisioned for the parallel stage is a modular system, where individual feature modules are dedicated to extracting information about a single feature (color, orientation, size, etc.). It is tacitly assumed that parallel processing for all features occurs at about the same time and that the modules operate in isolation from each other. This spatially unlimited preattentive stage is capable of fast, seemingly effortless, detection of items of unique feature in a field of homogeneous distractors. For instance, a red square will "pop out" of a field of green squares (e.g., Nagy & Sanchez, 1990); an oblique line will pop out of a display of vertical lines (e.g., Foster & Ward, 1991); and a large item will be immediately apparent in a display of smaller items (e.g., Treisman & Gormican, 1988). Popout is a bottom-up, stimulus-driven process because it is based on the physical difference between a target stimulus and the neighboring distractor stimuli (Nothdurft, 1992). The parallel stage is also capable of finding items of unique category in a heterogeneous display if participants are aware of the defining characteristics of the target. For example, search functions with slopes near 0 ms per item are possible when participants search for the red item in a field of other distinctively hued items such as yellow, green, and purple (Duncan, 1989). Similarly, participants are able to detect the "steeply" tilted line in a display of "shallow" lines (Wolfe, Friedman-Hill, Stewart, & O'Connell, 1992). In contrast to bottom-up popout, parallel search with heterogeneous distractors is a "top-down" process in which the participant's knowledge of the target features guides visual search.

In simple conceptions of this two-stage processing scheme, preattentive and attentive processes are independent and sequential. If initial parallel processing cannot guide attention to the target, focal attention moves serially through the display, processing one item at a time until the target item is detected or until all items in the display have been visited by attention. Focal attention is a limited capacity process that can operate only over a restricted region of the visual field at any one time. The serial deployment of attention results in RTs that increase linearly as the number

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of distractors increases. The slopes of these RT × Set Size functions are roughly twice as great for target-absent (blank) trials as for target-present trials (Treisman & Gelade, 1980). Serial self-terminating searches are characteristic of tasks in which no simple feature information distinguishes targets from distractors (e.g., a search for a *T* among *L*s when the *T*s and *L*s can appear in any one of four orientations; Wolfe, Cave, & Franzel, 1989; see also Humphreys, Quinlan, & Riddoch, 1989, for a discussion of the importance of using mixed orientations in this task). It was originally thought that serial self-terminating search was required for targets defined by conjunctions of two features (e.g., a blue vertical line among blue horizontal and brown vertical lines). However, subsequent research has shown that much more efficient conjunction search is possible in many cases (Egeth, Virzi, & Garbart, 1984; Nakayama & Silverman, 1986; Quinlan & Humphreys, 1987; Treisman & Sato, 1990; Wolfe, 1992; Wolfe et al., 1989).

How do participants execute efficient conjunction searches? Consider a search for a red vertical target among red horizontal and green vertical distractors. A common intuition of participants performing such tasks is that they somehow "group" or "select" the red items and then perform a subsequent search operation (parallel or serial) for a vertical item in the red subset. This intuition has received some experimental support and theoretical development. Egeth et al. (1984) had their participants search for a red *O* in a display of red *N*s and black *O*s. The displays used by Egeth et al. used varying ratios of red and black items (and consequently of *O*s and *N*s). Participants were explicitly instructed to search through the red items. If the number of black items was varied while the number of red items was held constant, search functions had flat slopes, suggesting that participants were able to confine their search to the red items.

Although Egeth et al. (1984) explicitly instructed their participants to search through the subset of red items or *O*s, it is not clear whether participants would have spontaneously adopted the strategy of selecting the smaller subset of items sharing one of the target characteristics. In the absence of instruction, the selection could be a bottom-up, stimulus-driven selection of the more unusual subset or a top-down, user-driven selection of a particular attribute (red or *O*). Evidence that unequal distractor ratios do produce bottom-up selection of a subset can be found in Zohary and Hochstein's (1989) experiment. Using briefly presented displays rather than analyzing RT as a dependent variable, Zohary and Hochstein examined the minimum stimulus onset asynchrony (SOA) required for 70% correct responses in a conjunction search task. The shortest SOAs occurred with displays having the most extreme distractor ratios. Because participants were able to select the smaller subset even when the displays were flashed and even when different distractor ratios were mixed in the same block of trials, it would appear that selection in these experiments is a stimulus-driven automatic process.

Poisson and Wilkinson (1992) questioned whether unequal distractor ratios completely explain fast RTs in these conjunction searches. Their target-present RTs changed only a little as a function of distractor ratios, with the longest RTs occurring when the distractor ratio was about 1:1. Blank trials were different: RTs increased substantially until 17 of 25 items were the target color (red) and then subsequently declined. Poisson and Wilkinson suggested that participants do not switch subset from trial to trial but that large distractor ratios lead to clumps of homogeneous distractors out of which the target can pop out when it is present. In the absence of a target, participants perform a serial search, but search is more efficient with grouped distractors than with randomly placed distractors. With large set sizes, there will be local concentrations of homogeneous distractors that are processed in clumps. Thus, although Egeth et al. (1984) and Zohary and Hochstein (1989) emphasized stimulus grouping as a means of limiting serial search for a target to just a few items, Poisson and Wilkinson posited that stimulus grouping enables the parallel detection of targets and the serial rejection of aggregates of homogeneous distractors. Some time earlier, Treisman (1982) made a similar point, showing in a series of experiments that conjunction search was much easier when the distractor items were grouped by kind. Humphreys et al. (1989) showed significant effects of spatial grouping in searches for *T*s of one orientation among *T*s of a distracting orientation.

Humphreys and Müller's (1993) model, SEarch via Recursive Rejection (SERR), relies on this principle of grouping and discarding clumps of similar distractors to explain conjunction search performance. The model of Ross, Grossberg, and Mingolla (1993) relies on a similar principle (Grossberg, Mingolla, & Ross, 1994). By contrast, the Guided Search (GS) model (Wolfe, 1993, 1994; Wolfe et al., 1989) proposes a different mechanism of conjunction search. Returning to the example of a search for a red vertical target, the GS model holds that participants select red items in a parallel color processor and at the same time they select vertical items in a parallel orientation processor. If the combination of these two selections is used to guide attention, it is likely that attention will be guided toward loci containing red vertical items even though no parallel processor could, by itself, select such items.

When there are equal ratios of distractor types, conjunction search data do not seem to adhere to the model that holds that participants select one feature and then perform a serial search through the resulting subset of the items. Such a search should produce slopes of RT × Set Size functions that are proportional to the size of the subset. That is, if a serial search through all items yields a target-present slope of 20–30 ms per item, a serial search through the 50% of items that are red should produce slopes of 10–15 ms per item. There are numerous cases of conjunction search tasks that yield much shallower slopes (see Treisman & Sato, 1990, or Wolfe et al., 1992, for examples), falsifying this prediction. However, selection of all red items followed by parallel orientation processing of those items remains a plausible mechanism of efficient conjunction search (Ross et al., 1993, proposed a model of this sort).

In an effort to distinguish this model of sequential parallel operations from the GS model of simultaneous parallel operations, we used a task that required participants to select the red items before proceeding to orientation processing. They searched for a red item of orientation *X* among red items of orientation *Y* and green items of orientation *X*. *X* and *Y* varied from trial to trial and were unknown to the participant. "Colorblind" orientation processing of the entire display was not helpful because half of the items shared the target orientation. However, if participants could select or group the red items, subsequent orientation processing should have been useful. The target, if present, was the only item of odd orientation in the red subset. In this article, we show that participants can indeed perform such "subset searches." However, the pattern of the RT data suggests that this strategy is different from participants' performance of standard conjunction searches.

In six experiments we examined the more general question of grouping in visual search. As noted earlier, Treisman (1982) found that grouping of spatially contiguous, similarly featured items in a visual display had a large effect on conjunction searches. She varied the number of groups of distractors and the number of items within groups and reported that between-groups processing reflected the serial movement of attention but that within-group processing was parallel. Because the groups in Treisman's (1982) displays were formed by neighboring stimuli, she speculated that "attention cannot be distributed over a subset of items (e.g., the red ones or the curved ones) when these are spatially scattered among other items in a randomly mixed display" (p. 199). She subsequently concluded that attentional selection of randomly placed items is possible in some cases (Treisman & Sato, 1990). The subsequent work by Humphreys and Müller (1993), Poisson and Wilkinson (1992), and Grossberg et al. (1994) also gave an important role to spatial proximity.

Working with a different experimental design, Yantis (1992) documented participants' ability to select distributed items by attending to complex "virtual" objects in a top-down fashion. Yantis asked his participants to track a subset of moving plus signs and to indicate after some time interval whether a particular plus sign was part of the designated group. Yantis interpreted his results as indicating that humans are able to attend to the constantly shifting subset as a single object. "The experiments demonstrate that perceptual organization need not be entirely stimulus-driven, but can be imposed on a display by virtue of the perceptual demands of a task" (Yantis, 1992, p. 300; also see the finger of instantiation [FINST] model of Pylyshyn & Storm, 1988). In our subset search experiments, the virtual object was not a set of moving dots but was a complex irregular figure created by a goal-directed selection of color.

Using the subset search paradigm, we found that a subset of items with shared features could be selected for preferential processing even when the similar stimuli were not spatially proximate. Participants were able to select items of a specific color in a top-down fashion, and this spatially scattered subset could be processed in parallel. It appears that the subset of items can be treated as a single complex object or group with ragged edges and interior holes, formed by the irrelevantly colored items that are interspersed with the selected items. There are many real-world examples in which complex shapes emerge from individual components and are processed as a group. For example, anyone who has had the experience of driving on a busy interstate highway knows that constantly shifting configurations of moving cars can be monitored by attending to the pack of cars as a whole.

In Experiment 1, we found that subset search was not a serial self-terminating search through the designated subset. In Experiment 2, we demonstrated that subset search proceeded completely independent of set size. Experiment 3 showed that subset search became increasingly independent of set size as set size increased. We hypothesized that this would be the product of a hybrid strategy, with subset selection occurring only with larger set sizes. It took time to select the subset. Prior to the completion of selection, participants searched items serially. If the set size was small, the entire search was completed prior to subset selection. With larger set sizes, participants could search in parallel after subset selection. Experiment 4 demonstrated that participants selected a subset on the basis of the featural properties of the subset, not on the properties of items outside the subset. That is, they could select the red items, but they could not select the items that were "not green." In Experiment 5, selection of a subset was hampered if the subset was defined by two colors rather than just one. Subset search also was slowed when participants were uncertain of the relevant color on which to base their grouping of the subset. Finally, Experiment 6 showed that variation in an irrelevant feature did not disrupt subset search.

Experiment 1: Search Through a Spatially Scattered Subset

We investigated whether participants could search for an oddly oriented red item when the red stimuli were intermixed with green stimuli. Can participants produce shallow RT × Set Size functions in this task? Such functions would suggest that they can efficiently select the spatially scattered red subset and can then perform a parallel search for the odd orientation in that subset. We compared this subset search condition with feature searches for an odd orientation in an otherwise homogeneous display and to a standard conjunction search for a red vertical target.

Method

Apparatus and procedure. Stimuli were presented on a CRT monitor (640 × 480 pixels) that was part of a modified SUB-ROC-3D video game controlled by an IBM PC-XT with IBM Yoda graphics boards. Stimuli were red (luminance = 0.65 cd/m^2; International Commission on Illumination [CIE] coordinates, $x = 0.63$, $y = 0.35$) and green (luminance = 1.5 cd/m^2; CIE coordinates, $x = 0.33$, $y = 0.58$) lines that were 2.0° long and 0.3° wide.

Anti-aliasing techniques were used to eliminate the jaggedness of oblique lines. Stimuli were presented on a black 11.3° × 11.3° field. Each stimulus fit within a 2° × 2° square that could be placed at any of 16 locations in a slightly irregular 4 × 4 array. Participants were asked to maintain fixation on a small central fixation point, but eye movements were not monitored. Participants initiated each trial by keypress with the thumb of their left hand. Subsequently, stimuli were presented at 4, 8, 12, or 16 randomly chosen loci. All stimuli were presented virtually simultaneously by adjusting a color look-up table, although items at the top of the display could appear up to 17 ms before items at the bottom because of video refresh. The target item, present in 50% of the displays, always replaced one of the distractors. Set size, locations of targets and distractors, and presence or absence of target were random across trials. Each display was presented until the participants terminated the trial by pressing the thumb of their right hand to a key that designated an "odd" target was present or an alternative key that designated the absence of the target. Feedback was given after each trial. RTs were measured from stimulus onset to response keypress. All experiments were variations of this visual search paradigm.

The four experimental conditions were a vertical feature search, a randomly oriented feature search, a standard conjunction search, and a subset search. In each condition, participants completed 330 trials. The first 30 trials were discarded as practice. The four conditions were run in a pseudorandom order across participants. Sample displays for each experimental condition are illustrated in Figure 1. The first three conditions were control conditions, run for purposes of comparison with the subset search condition. In the vertical feature condition, participants searched for a red vertical line among equal numbers of green and red horizontal lines. This is a simple feature search. Color information was completely irrelevant; the target received strong bottom-up activation because of its unique orientation. Participants also had access to top-down information because they were told that the target would be vertical. In the randomly oriented feature condition, the target was a red line of orientation *X*°, and distractors were red and green lines of orientation *Y*°. The orientations of target and distractors were randomly chosen from a list of orientations that included vertical (0°), horizontal (90°), and lines tilted 10°, 20°, 30°, 40°, 50°, 60°, 70°, or 80° to the left and right of vertical. On any given trial, the target and distractor orientations were constrained to be at least 30°

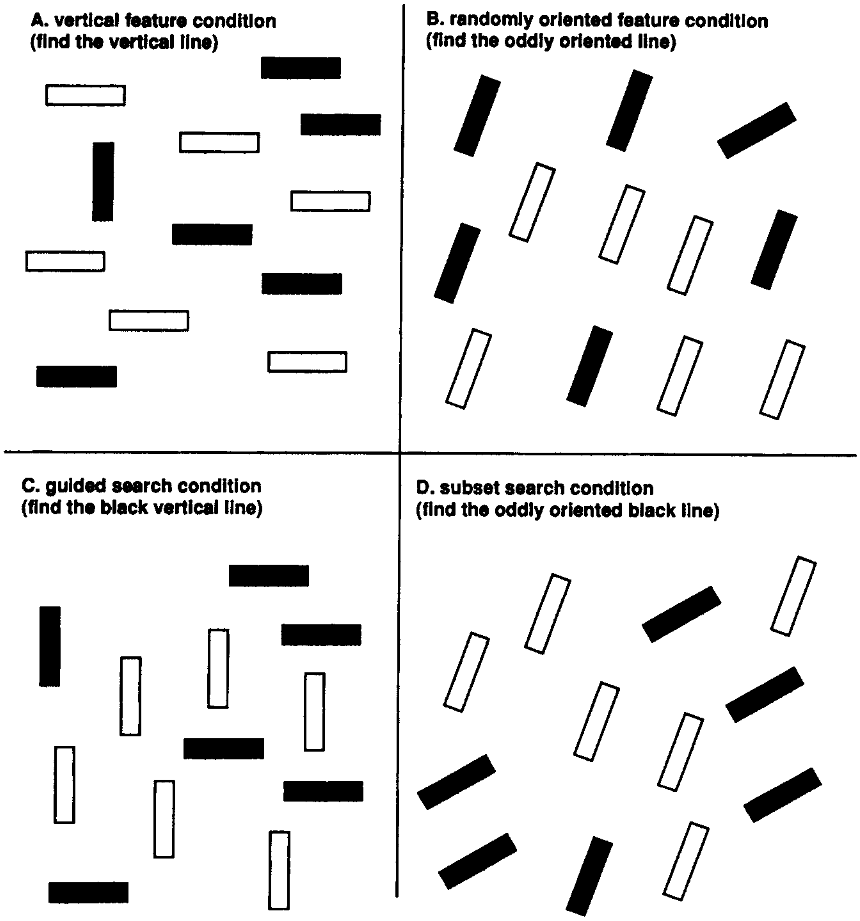

Figure 1. Sample target trials for four conditions of Experiment 1. In all cases, the task can be described as a search for the oddly oriented black line. In the vertical feature condition, that line is the only vertical line. In the randomly oriented feature condition, it is a feature singleton. In the conjunction condition, it is the only black vertical line. In the critical subset search condition, it is *just* the oddly oriented black line. In this and subsequent figures, stimuli are represented as black or white line segments. The actual stimuli were red and green.

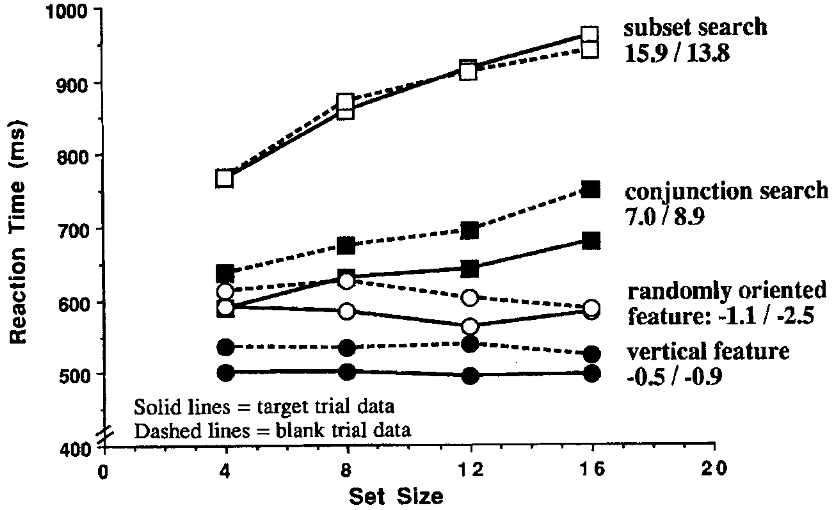

Figure 2. Results for Experiment 1. Note three properties of the subset search: (a) It is slower than other searches, (b) the slope ratio is about 1:1, and (c) blank trial reaction times (RTs) are the same as target trial RTs. The second and third observations are not consistent with serial, self-terminating search. Solid symbols = constant target orientation; open symbols = variable target orientation; circles = feature search; squares = conjunction search. Target trial slopes are listed first, followed by a slash and blank trial slopes.

apart. Color was once again irrelevant for this task. Because participants needed only to search for the odd orientation in the display, this condition was also a simple feature search. It was different from the vertical feature condition because the random changes in target and distractor orientation eliminated top-down information. However, the target would still receive strong bottom-up activation from a parallel orientation processor. In the conjunction search, participants searched for a red vertical target among red horizontal and green vertical distractors. Bottom-up feature information was useless because half the items were red and half were green; half were vertical and half were horizontal. Top-down information about color and orientation was available, making it possible either to select red and subsequently search the red items for a vertical item or, as the GS model predicts, to simultaneously select red in the color map and vertical in the orientation map and to use these two sources of information to guide attention to red vertical targets.

The critical condition was the subset search condition. Here, the target was a red line of orientation $X°$ among green lines of orientation $X°$ and red lines of orientation $Y°$. As in the conjunction condition, the target could not receive bottom-up activation because there were equal numbers of red and green lines and equal numbers of lines of orientation $X°$ and $Y°$. Initial top-down guidance was available, but only for color, not for orientation. Participants were told that the target would be a red line of odd orientation, so they could direct their attention to the red items in the display. The task could be done efficiently if bottom-up, parallel orientation processing could be performed on a subset of items defined by top-down color processing and less efficiently if participants performed a serial search through the red subset.

Participants. Eleven students, drawn from the Massachusetts Institute of Technology (MIT) undergraduate subject pool, were tested. All gave informed consent and were paid for their participation. All participants had normal color vision and an acuity of at least 20/25 when wearing their best optical correction.

Results

Figure 2 shows average RT × Set Size functions for target and blank trials for data from 10 participants. One participant was excluded from data analysis because of a high error rate.[1] Two general conclusions emerged from these results: (a) Participants could perform the subset search without relying on a serial, self-terminating search strategy and (b) the pattern of results for subset search is different from that for the feature or standard conjunction searches. Turning to the specific results and beginning with the two feature search conditions, we found that the slopes for the vertical feature and the randomly oriented feature conditions did not differ significantly from zero, $t(9) < 1.7$, $p > .1$ (one-group t tests on target and blank trial slopes).

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[1] For several of the experiments reported in this article, we excluded 1 or 2 participants from data analysis. There were two criteria we used in deciding whether to include or exclude participants. First, all participants were instructed to respond "as quickly and as accurately as possible." Although most participants were able to limit their errors to an acceptable level, we occasionally had to exclude those with average error rates, within an experimental condition, that exceeded 10%. The second principle for exclusion was an inability to perform efficient feature searches. In many experiments, we ran feature searches as a control condition to ensure that the stimuli used in the critical experimental condition were easily discriminable and would pop out of a field of homogeneous distractors. When the great majority of participants produced Response Time × Set Size functions with flat slopes for these control feature searches, the inability to do so became an exclusion criterion. There may be interesting information in these individual differences (O'Neill, Wolfe, & Bilsky, 1993), but they are beyond the scope of this article.

Thus, the participants were able to perform parallel search for the odd orientation regardless of whether they knew the specific orientation of the target. The effect of experimental condition on RT was assessed by using an analysis of variance (ANOVA). The randomly oriented feature condition yielded significantly slower RTs than the vertical feature condition: target trials, $F(1, 9) = 8.7, p < .02$; blank trials, $F(1, 9) = 9.0, p < .02$.

The conjunction search condition replicates other conjunction search data of recent years. Slopes were significantly greater than zero, $ts(9) > 4.9, p < .001$ (one-group t tests on target and blank trial slopes), but they were shallower than would be expected from a serial, self-terminating search through all items (Egeth et al., 1984; Nakayama & Silverman, 1986; Quinlan & Humphreys, 1987; Treisman & Sato, 1990; Wolfe, 1992; Wolfe et al., 1989). In the subset search condition, the target and blank trial slopes were significantly greater than zero $ts(9) > 4.9, p < .001$ (one-group t tests on target and blank trial slopes). In this experiment, the target trial slopes for the subset search condition were roughly consistent with a serial, self-terminating search through the subset. Standard serial slopes are around 20–30 ms per item. A serial search through half of the items would yield slopes between 10 and 15 ms per item. However, two aspects of the data suggest that this is not an adequate explanation of the subset search results. First, in a serial, self-terminating search, the ratio of blank trial slopes to target trial slopes should be approximately 2:1. It is obvious from Figure 2 that this was not the case for the average data. Figure 3 indicates that this is not a fluke of averaging across participants. The graph shows a scatterplot of blank to target trial slopes for each participant in the subset search condition. Clearly, the subset search data fit the 1:1 slope ratio line better than the 2:1 ratio line. Indeed, one-group t tests on slope ratios revealed that the slopes of the subset search condition did not differ significantly from a 1:1 slope ratio and were significantly less than 2:1, $t(9) = -11.3, p = .0001$. The second unusual aspect of the subset search data is that the blank trial RTs were not longer than the target trial RTs, $F(1, 9) = 0.029, p > .8$. This would not be predicted in a serial search through the red subset.

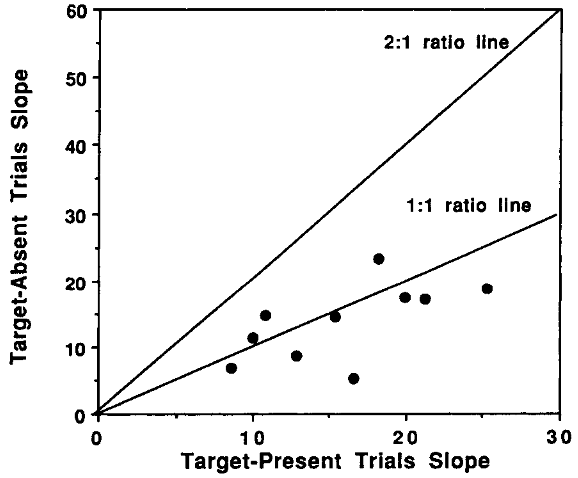

Figure 3. Scatterplot of target-present and target-absent slopes for the subset search condition of Experiment 1. Note that slope ratios lie closer to the 1:1 line than to the 2:1 line.

The pattern of subset search results was different from the pattern of results for the standard conjunction search. An ANOVA of the two conditions revealed that subset search yielded slower RTs and steeper slopes than did conjunction search (target and blank trials were separated), $Fs(1, 9) > 16.7, p < .004$; paired one-tailed t tests on slopes, $ts(9) > 3.5, p < .005$.

Error rates for the vertical feature condition were as follows: For Set Size 4, false alarms = 2.5%, misses = 3.2%; for Set Size 8, false alarms = 2.2%, misses = 2.0%; for Set Size 12, false alarms = 1.3%, misses = 1.9%; and for Set Size 16, false alarms = 1.6%, misses = 1.3%. Error rates for the randomly oriented feature condition were as follows: For Set Size 4, false alarms = 4.0%, misses = 2.9%; for Set Size 8, false alarms = 3.9%, misses = 4.2%; for Set Size 12, false alarms = 3.2%, misses = 2.1%; and for Set Size 16, false alarms = 1.8%, misses = 1.9%. Error rates for the conjunction condition were as follows: For Set Size 4, false alarms = 3.8%, misses = 2.6%; for Set Size 8, false alarms = 4.0%, misses = 2.2%; for Set Size 12, false alarms = 1.8%, misses = 3.0%; and for Set Size 16, false alarms = 2.4%, misses = 2.5%. Error rates for the subset condition were as follows: For Set Size 4, false alarms = 7.7%, misses = 3.1%; for Set Size 8, false alarms = 4.1%, misses = 3.8%; for Set Size 12, false alarms = 4.6%, misses = 7.4%; and for Set Size 16, false alarms = 4.0%, misses = 10.2%. Note that here and elsewhere, false-alarm percentages are given as percentage of target-absent trials and miss percentages as percentages of target-present trials. Total percentage error was the average of the false alarms and miss values, not the sum.

Discussion

The results of Experiment 1 show that it is possible to search for an odd element of a subset even if that element does not "pop out" of the display as a whole. The results are not definitive on the nature of the search through the subset, but they do suggest that people do not perform a serial, self-terminating search through the red items when looking for the odd man out in a subset of spatially scattered items. Serial, self-terminating search is unlikely because the slope ratio was significantly less than 2:1 and because blank trial RTs were the same as target trial RTs. However, target and blank trial slopes of 13–15 ms per item are not consistent with a simple model of unlimited capacity parallel processing of the orientation of those red items. Such a model would predict slopes close to 0 ms per item.

The lack of RT or slope difference between blank and target trials is a diagnostic for a serial, exhaustive search. In this case, that would be search through the red subset. One would have to assume an unusually fast rate of serial processing (13–15 ms per item), and one would have to assume that participants would continue to search exhaustively after they have located the odd target in the subset. Thus, serial exhaustive search is possible, if not likely.

As Townsend (1990) pointed out, there are many routes to a given pattern of RTs. The data from a single experiment are too narrow a base for much theorizing. To broaden the base, we repeated the subset search experiment with a few modifications. RTs in the subset condition of Experiment 1 were slow, much slower than the feature search conditions and about 200–300 ms slower than RTs for the standard conjunction search. These longer RTs suggest that selection of a subset for subsequent processing takes time.[2] If it takes time to process a subset, what determines that time: the number of items included in the subset, the number of items excluded from the subset, or the total number of items in the display? In Experiment 2, we independently manipulated the numbers of red and green items in an effort to address this question. In addition, the range of set sizes was increased.

Experiment 2: Subset Search With Varying Ratios of Red and Green Items

Method

Experiment 2 was a variant of the subset search condition of Experiment 1. The target was a red line of orientation $X°$ among distractors that were green lines of orientation $X°$ and red lines of orientation $Y°$. Both the display set size and the ratio of red to green items varied randomly across trials. Figure 4 shows the nine combinations of red and green items that were tested and the mean RTs that were obtained for target-present and target-absent trials. Each participant completed 30 practice and 900 data trials. In all other respects, the conditions of this experiment were the same as those in the previous experiment. Nine new students from the MIT subject pool and 1 student from the previous experiment were tested.

Number of Red Items

Number of Green Items	**4**	**6**	**8**	**10**	**12**
4	848 / 845	871 / 853			864 / 947
6	867 / 869	905 / 882		910 / 918	
8			887 / 929		
10		924 / 926			
12	867 / 858				

Figure 4. Average response times for Experiment 2 as a function of number of red items and number of green items. Target trial response times are shown in the upper left portion of each cell; blank trial response times are shown in the lower right portion of each cell.

Results

One participant was excluded from data analysis because of high error rates. As noted earlier, average RTs for the remaining 9 participants are presented in Figure 4. The data were uninformative on the question of the relative importance of the numbers of red and green items, because there was no significant effect of set size, number of red items, or number of green items on target trial RTs. One may look at the effect of holding the number of red items constant and varying the number of green items by reading down the first 2 columns of Figure 4. There was no significant effect of the number of green items on RT for target-present trials. ANOVA results on the effect of number of green items on RT showed that for displays with four red items present, target trials, $F(2, 16) = 1.1, p = .4$, blank trials, $F(2, 16) = 0.4, p = .7$; for displays with six red items present, target trials, $F(2, 16) = 2.0, p = .2$, blank trials, $F(2, 16) = 5.5, p = .02$. The regression of RT on number of green items yielded a slope of 3.2 ms per green item. The correlation was not significant. One can look at the effect of varying the number of red items while holding the number of green items constant by reading across the first 2 columns. This effect was also insignificant for target-present trials, such

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[2] There are other possible explanations of the slow response times (RTs) in the subset search condition. In the subset search, participants did not know the precise target identity because they did not know its orientation. Perhaps this requires a comparison step in which participants find a candidate target and compare it with neighboring items. If it is the same orientation as a green item or a different orientation from a red item, then there is a target present. The time required for execution of this comparison step would result in larger RTs for subset searches than for standard conjunction searches. If one argued that such comparisons would not be needed for blank trials, one could explain why the usual difference between blank trial and target trial RTs is reduced or eliminated in subset searches.

At first glance, such a model is appealing, but it generates inconsistencies that are hard to explain. If checking is required whenever target identity is not known, then checking should be required for the randomly oriented feature search. If the checking step takes 200+ ms, why was the difference between the two feature search conditions of Experiment 1 much less than 200 ms? One way around this problem is to propose that there is more checking in the subset search. In the feature search, the target draws attention to itself effectively. In the subset search, perhaps there will be candidate targets that must be checked. However, if the target trials of a subset search include checking of some incorrect items, then the blank trials should also involve such checking. Otherwise, participants would have an infallible clue to use: "If you don't need to check, the target is not present." (Note that this clue makes checking in the randomly oriented feature search unlikely to start with.) If there is checking of false candidate targets on the blank trials, then it becomes hard to imagine why there would be less such checking on a blank trial than on a target trial. Therefore, if there is the same or more checking on the blank trials, we can no longer explain why target and blank trial RTs do not differ. In summary, the checking idea, although appealing, seems less consistent with the results than the hypothesis of a 200- to 300-ms cost associated with selection of the red group of items.

that the effect of number of red items on RT showed that for displays with four green items present, target trials, $F(2, 16) = 0.5, p = .6$, blank trials, $F(2, 16) = 5.7, p = .01$; for displays with six green items present, target trials, $F(2, 16) = 1.5, p = .3$, blank trials, $F(2, 16) = 1.4, p = .3$. The regression of RT on number of red items yielded a slope of 2.1 ms per red item. The correlation was not significant. Finally, reading the main diagonal of Figure 4, one can see that there was no significant effect of overall display set size for target-present trials when the numbers of red and green items were equivalent: target trials, $F(2, 16) = 2.0, p = .2$; blank trials, $F(2, 16) = 4.4, p = .03$. The regression of RT on total number of items yielded a slope of 4.0 ms per item. The correlation was not significant.

For the blank trials, there were significant correlations between RT and number of red items (slope = 12.0, $r^2 = .49, p < .05$) and total number of items (slope = 10.1, $r^2 = .48, p < .05$), but not for number of green items (slope = 1.9, $r^2 = .01$, *ns*). These results suggest that, in the absence of a target, participants took an extra look at the red items before terminating the search.

A direct comparison with Experiment 1 was done by looking at the slope of the RT × Set Size function for set sizes 8, 12, and 16 and a red:green ratio of 1:1. In Experiment 2, the slopes were 4.9 ms per item for target-present trials and 10.5 ms per item for target-absent trials. At first glance, these average slopes appear to be much shallower than the average slopes obtained in the subset search condition of Experiment 1. Inspection of Figure 2, however, suggests that the RT × Set Size function is somewhat curvilinear and rises more steeply between Set Sizes 4 and 8. If we exclude the data from Set Size 4 of Experiment 1, a regression on the mean RTs for the remaining set sizes yields a target-present slope of 12.6 ms per item and a target-absent slope of 8.7 ms per item. This manipulation rendered insignificant the differences between Experiment 1's slopes and the slopes obtained from the comparable cells of Experiment 2, $t(17) < 2.1, p > .06$ (unpaired two-tailed). We pursued this set size effect further in Experiment 3.

For all nine experimental conditions in Experiment 2, we found, as we did for the subset search of Experiment 1, that target-absent trial RTs were not significantly slower than target-present RTs, $Fs(1, 8) < 5.2, ps > .05$. Error rates for all nine experimental conditions were less than 4.8%.

Discussion

These results provide good evidence for rejecting the hypothesis that participants would perform a serial, self-terminating search through the red items in subset searches. When the number of green items was held constant, increasing the number of red items did not increase the RT. Moreover, target-absent RTs were the same as target-present RTs, a pattern of results never seen (to our knowledge) in a serial self-terminating search. The results are consistent with the hypothesis that participants first select the red items and then perform a parallel, odd-man-out orientation operation on that red subset. Because there was no systematic effect of varying either the number of red or green items, this experiment could not be used to determine whether participants select the subset by activating the red items or by suppressing the green items. We took a different approach to this question in Experiment 4.

These data provide another reason to think that the processes underlying subset search are different from those supporting efficient search for standard conjunctions of color and orientation. Zohary and Hochstein (1989) and Poisson and Wilkinson (1992) found effects of distractor ratios in standard conjunction search. Roughly speaking, search is easier when one color (or orientation) is comparatively rare. There was no systematic effect of distractor ratio on either target or blank trials in the data from Experiment 2.

The important conclusion to be drawn from Experiment 2 is that subset search can be virtually independent of set size, supporting the hypothesis that it is possible to perform a parallel search through a subset of items. Because the absence of significant slopes was surprising in light of Experiment 1, we repeated Experiment 2 with a new set of participants and obtained virtually identical results to those reported here. It appears that the set size effect gets smaller as the set size gets larger. In Experiment 3, we tested additional larger set sizes and confirmed this observation. Practice effects could be another variable contributing to the shallower slopes found in Experiment 2 because participants completed 900 trials in Experiment 2, compared with only 300 trials in Experiment 1. Results of Experiment 3 also confirmed that practice effects could reduce slopes for this odd-man-out task.

Experiment 3: Subset Search With Large Set Sizes

Method

Ten new students from the MIT subject pool were tested. The target was once again a red line of orientation $X°$ among green distractors of orientation $X°$ and red distractors of orientation $Y°$. The display set sizes used were 4, 8, 16, 24, and 32. To accommodate the large set sizes, the field was expanded to 15° × 15°. Participants completed three blocks of 330 trials, and the first 30 trials of each block were discarded as practice. In all other respects, the experimental conditions were the same as those used in Experiment 1.

Results

Figure 5 shows the RT × Set Size functions for all three experimental blocks. The graph represents data from 9 participants; 1 participant was excluded because of high error rates. The target trial functions are clearly nonlinear. To illustrate this point, Figure 5A shows the overall slope for each block and the slopes for the segments between Set Sizes 4 and 8 and between Set Sizes 8 and 32. Larger set sizes produced shallower slopes for target trials. The RT × Set Size function for target trials rose sharply between Set Sizes 4 and 8, with slopes ranging from 31 to 45 ms per

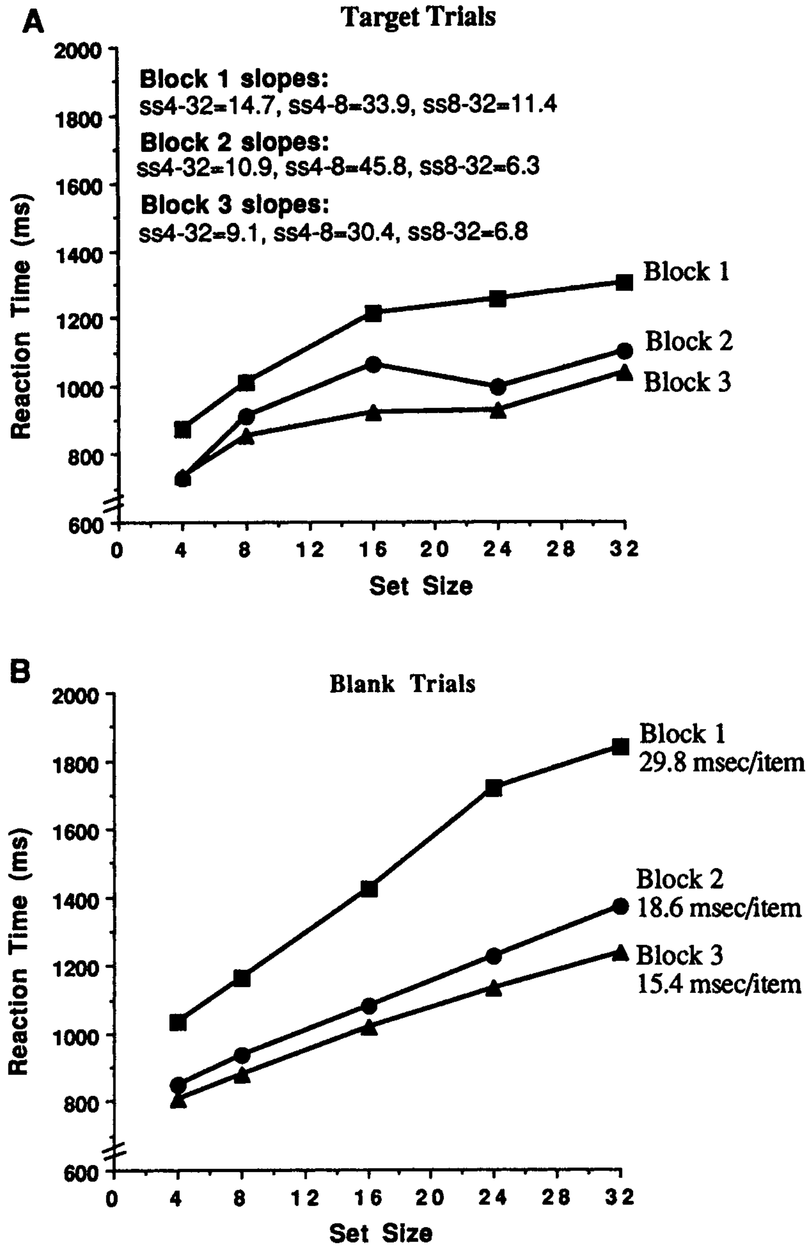

Figure 5. Average reaction times (RTs) for Experiment 3, subset search for the odd orientation in the red subset. Note that target trial functions are curvilinear, with shallow slopes for larger set sizes. This effect was accentuated by one block (330 trials) of practice. The reduction in slope with increasing set size can be seen in the three slopes that are given for each target trial function: One for the entire function, a second for the increase in RT between Set Sizes 4 and 8, and a third for the increase in RT between Set Sizes 8 and 32.

item. After Set Size 8, the function flattened out with slopes of 5–10 ms per item. On the other hand, blank trial slopes increased linearly across all set sizes. The difference in slope between these small and large set size slope estimates was significant for target trials, $t(8) = 2.2$, $p < .03$ (paired one-tailed), but not for blank trials, $t(8) = 0.07$, $p > .2$ (paired one-tailed).

Practice improved participants' performance from Block 1 to Block 2, as reflected by significantly faster RTs (target-present and target-absent trials were analyzed separately), $F(1, 8) > 12.2$, $p < .01$, and smaller RT × Set Size slopes, $t(8) > 3.0$, $p < .01$ (paired one-tailed t tests for target and blank trials). However, further practice did not significantly improve performance from Block 2 to Block 3, $F(1, 8) < 1.3$, $p > .2$, $t(8) < 1.0$, $p > .1$ (paired).

For the first experimental block, blank trial RTs and slopes were significantly greater than target trial RTs and slopes, $F(1, 8) = 6.0, p = .04, t(8) = 2.9, p = .01$ (paired t test of slopes). Blank trial RTs were not significantly different from target trial RTs for the second and third blocks, $F(1, 8) < 5.0, p > .05$, and blank trial slopes were not significantly different from target trial slopes for the third block, $t(8) = 1.5, p = .08$ (paired).

Error rates for Block 1 were as follows: For Set Size 4, false alarms = 6.1%, misses = 1.6%; for Set Size 8, false alarms = 3.3%, misses = 1.6%; for Set Size 16, false alarms = 2.1%, misses = 4.4%; for Set Size 24, false alarms = 0.9%, misses = 6.9%; and for Set Size 32, false alarms = 0.4%, misses = 10.2%. Error rates for Block 2 were as follows: For Set Size 4, false alarms = 4.1%, misses = 2.4%; for Set Size 8, false alarms = 2.1%, misses = 2.9%; for Set Size 16, false alarms = 1.6%, misses = 5.8%; for Set Size 24, false alarms = 1.6%, misses = 7.3%; and for Set Size 32, false alarms = 0%, misses = 5.7%. Error rates for Block 3 were as follows: For Set Size 4, false alarms = 4.2%, misses = 2.8%; for Set Size 8, false alarms = 3.0%, misses = 1.3%; for Set Size 16, false alarms = 2.4%, misses = 5.6%; for Set Size 24, false alarms = 1.1%, misses = 6.1%; and for Set Size 32, false alarms = 0.4%, misses = 12.1%.

Discussion

In subset search, RT × Set Size functions for target trials were not linear. They rose rapidly and then appeared to level off. This pattern suggests that participants might have used a hybrid search strategy: serial self-terminating search for small set sizes and parallel processing of the subset for larger set sizes. It is incorrect to think of parallel and serial processes in visual search as strictly sequential. Rather, they should be seen as concurrent (e.g., Braun & Sagi, 1990). When a trial begins, attention is deployed somewhere. In terms of the GS model, it would be directed toward the locus of highest activation. Initially, the activation represents random noise or perhaps an underlying bias in favor of the central part of the field. Over time, activation builds with unusual items receiving strong bottom-up activation and items that are categorically equivalent to the target's known features receiving top-down activation. As this parallel activation rises, it can begin to guide attention in a more efficient search through the items. In standard feature or guided searches, useful information from parallel processes becomes available relatively quickly. In a truly serial search, useful information never materializes. In the subset searches that are the subject of this article, we propose that useful parallel information can be developed, but over a relatively long time. What is happening during those 200 ms? Participants are not blind during that time and could examine four or five items in a strictly serial manner. If there are only four or five red items, a serial search would find the target before the parallel, subset information became available. In subset search, this serial task is more *difficult than* usual because the orientation of the target is unknown. A serial search would require a comparison between items to determine whether an attended red item is a red item of odd orientation. Thus, small set sizes show relatively steep "serial" RT × Set Size functions. Once the subset has been extracted, it becomes much more efficient to perform a parallel operation on the subset and, thus, all searches beyond a certain duration show about the same RT regardless of set size.

We can speculate about the processing step that requires this additional 200–300 ms. It cannot be the mere activation of red items because that is presumed to take place in standard conjunction searches as well as in subset searches. The new requirement in subset searches is the restriction of parallel processing in one module (orientation) to items selected in another (color). This communication between parallel feature modules (either laterally or via feedback from the activation map) is a likely candidate for the slow step in subset search. Alternatively, the 200 ms could reflect a cost for confirming that the target is a true target in these tasks where absolute target identity is not known (see Footnote 2).

If introspection is any guide (which, of course, it may not be), communication between parallel feature modules might involve a type of figure–ground segregation as the red items become the figure and the green items are relegated to background status. After subset experiments, participants routinely describe the task in figure–ground terms and will often insist that the task was made easier because the red items were brighter. They are, in fact, less than half the luminance of the green items. Moreover, participants report that the green items appear brighter if green becomes the relevant subset and thus the figure. Variables that influence grouping will influence subset search. In Treisman's (1982) work, spatial contiguity aided grouping and search. In Experiment 3, the increased density of items at larger set sizes might have improved grouping and facilitated search. The constraints on grouping or subset selection were examined further in Experiments 4 and 5.

Experiment 4: Selection by Target Feature Activation, not Distractor Inhibition

In Experiments 1–3, the subset of items to be selected for further processing was always homogeneously colored (i.e., red) as was the "background" of distractor items (i.e., green). Because participants knew that the target would always be red and could never be green, there were three plausible strategies that they could use to select the subset: (a) specifically activate all items with the relevant feature (i.e., all red lines); (b) specifically inhibit items of an irrelevant feature (i.e., the green lines); or (c) generally inhibit items that lacked the relevant feature (i.e., all nonred lines). In the previous experiments, all nonred lines happened to be green, but it is possible to disentangle these hypotheses with different groups of heterogeneously colored distractors. Results of Experiment 4 show that selection was based on knowledge of the relevant, target attribute, not the irrelevant, distractor attributes.

Method

All conditions of Experiment 4 were variations of a search for an oddly oriented line in a subset defined by color. Participants had advance knowledge about color but not about target orientation. The four experimental conditions, illustrated in Figure 6 were as follows.

1. The red target condition was the basic subset search used in previous experiments. Participants searched for the oddly oriented red line in a display in which 50% of the distractors were red lines of a second orientation and 50% were green lines of the target orientation. This condition served as a baseline against which to compare the other experimental conditions.

2. In the many irrelevant colors condition, the target was a red line (0.3 cd/m^2; CIE, $x = 0.61, y = 0.36$) of orientation $X°$ among red distractors of orientation $Y°$ and variously colored nonred lines of orientation $X°$. The nonred lines were green (0.8 cd/m^2; CIE, $x = 0.33, y = 0.58$), yellow (0.8 cd/m^2; CIE, $x = 0.44, y = 0.50$), purple (0.3 cd/m^2; CIE, $x = 0.33, y = 0.16$), and blue (1.3 cd/m^2; CIE, $x = 0.23, y = 0.30$). Some or all of these colors were present in the distractor set, depending on the display set size. The colors present for a particular trial were randomly chosen. As in the red target condition, the target was the oddly oriented red line, but now the nonred lines were heterogeneously colored. If participants specifically activated (or "grouped") all red lines, then the search task could be transformed into a simple feature search for an odd orientation. Likewise, if participants could generally inhibit all nonred items, the oddly oriented target would pop out. However, because the lines of orientation $X°$ were heterogeneous in color, participants could not select the appropriate subset by inhibiting one specific color.

3. In the many relevant colors condition, the target was a colored line of orientation $X°$ among variously colored distractors of orientation $Y°$ and green lines of orientation $X°$. The nongreen hues that could be present in a display were red, yellow, purple, and blue. If participants could specifically inhibit all green items in the display, then the oddly oriented target should pop out of the remaining nongreen items. Because participants had no top-down knowledge of the target orientation, they could not perform this task by selecting the subset of lines oriented $X°$ and then looking for an odd color.

4. The feature search condition was a control condition de-

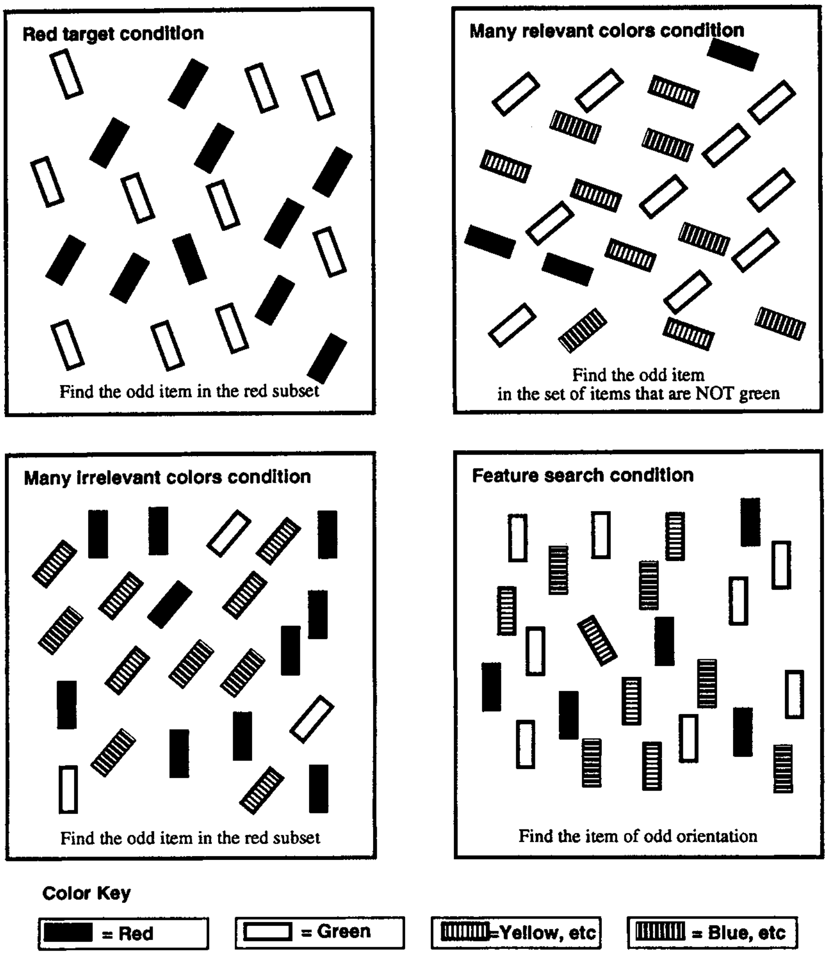

Figure 6. Stimuli for Experiment 4. In the first three conditions, respondents searched for an odd orientation in a designated subset. Designation of the subset changed over conditions. The fourth condition was a control to show that irrelevant color variation did not disrupt orientation feature search.

signed to ensure that heterogeneity of stimulus color did not disrupt the search for an oddly oriented line. The target was a line of orientation $X°$ among distractors of orientation $Y°$ (as in Experiment 1). All stimuli were randomly colored red, yellow, green, blue, or purple. Color was an irrelevant dimension because participants needed to consider only the orientations of the stimuli.

Two groups, each containing 10 participants, were run in Experiment 4. One group completed the first 3 conditions. The other group performed the feature search control task. The participants were chosen from a pool of students recruited at Harvard Medical School, Northeastern University, Boston University, Emmanuel College, Simmons College, and Massachusetts College of Art. For each of the three subset search conditions, participants completed one block of 400 trials, with the first 100 trials discarded as practice. For the feature search, participants completed 30 practice and 300 data trials. Display set sizes were 4, 8, 12, and 16. In all other respects, the methods were the same as those used in previous experiments.

Results

Mean RT as a function of set size is plotted in Figure 7. It is readily apparent from this graph that the many relevant colors condition was more difficult than the red target condition or many irrelevant colors condition and that the latter two conditions were equivalent. It is also evident that the feature search was efficient. These conclusions were confirmed by statistical analyses. The RT × Set Size slopes for target and blank trials of the many relevant colors condition were significantly greater than slopes for either the many irrelevant colors condition or the red target condition, $ts(9) > 4.6, p < .001$ (paired one-tailed). RTs for that condition were significantly longer than RTs for the other conditions (effect of experimental condition on target and blank trial RTs), $Fs(1, 9) > 52.0, p < .0001$. Target and

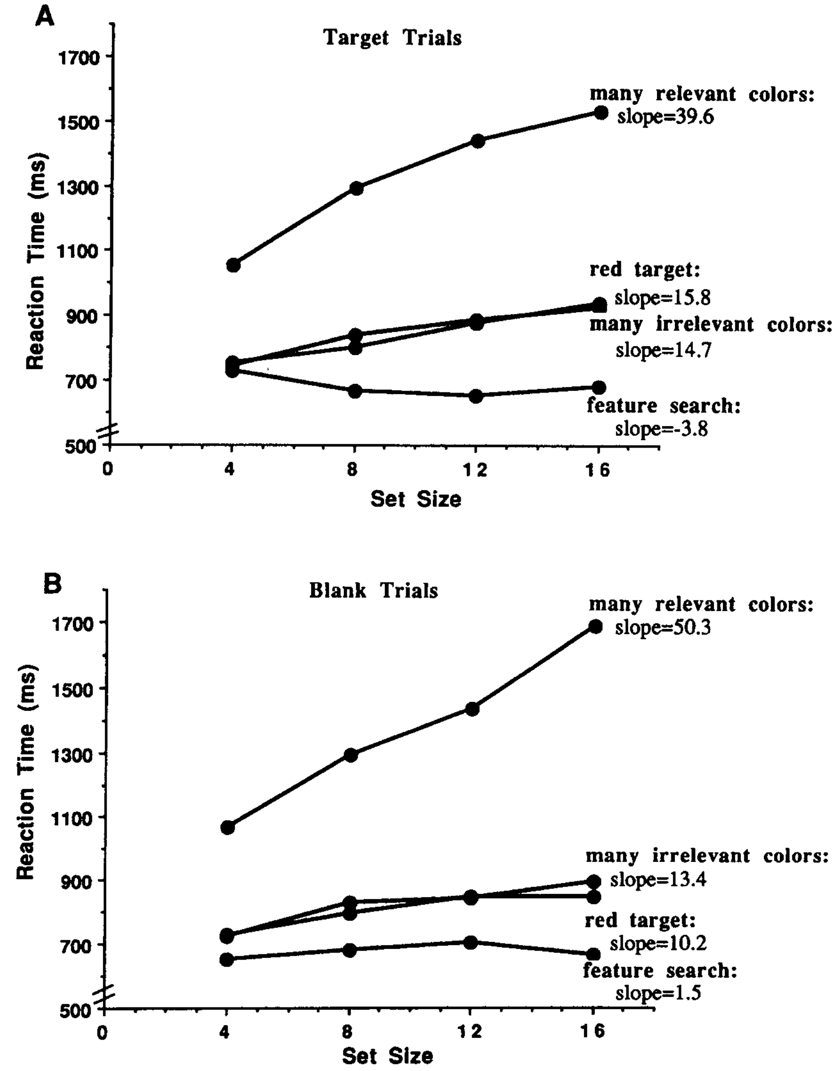

Figure 7. Results of Experiment 4. Standard subset search results were obtained when the color of the subset was known. However, if only the color of the irrelevant items was known (many relevant colors condition), efficient subset search was not possible.

blank trial slopes for the red target condition did not differ significantly from slopes for the many irrelevant colors condition, *t*s(9) < 0.8, $p > .2$ (paired one-tailed). RTs for target and blank trials did not differ between conditions (ANOVAs with target and blank trials analyzed separately), *F*s(1, 9) < 0.2, $p > .6$.

For all three subset search conditions, within-condition comparisons revealed that there was no effect of target presence versus target absence on RTs, *F*s(1, 9) < 2.7, $p > .1$. For the many relevant colors and many irrelevant colors conditions, target presence or absence also had no effect on slopes, $t(9) < 1.7$, $p > .05$ (paired one-tailed). Blank trial slopes for the red target condition were actually significantly shallower than target trial slopes, $t(9) = 3.0$, $p < .01$ (paired one-tailed).

As expected, the feature search produced fast RTs and flat slopes. Both target-present and target-absent trial slopes were not significantly different from zero, *t*s(9) < 1.5, $p > .1$ (two-tailed, one-group *t* tests).

Error rates for the red target condition were as follows: For Set Size 4, false alarms = 5.2%, misses = 5.3%; for Set Size 8, false alarms = 3.1%, misses = 3.3%; for Set Size 12, false alarms = 2.5%, misses = 6.0%; and for Set Size 16, false alarms = 3.1%, misses = 7.2%. Error rates for the many relevant colors condition were as follows: For Set Size 4, false alarms = 6.1%, misses = 4.4%; for Set Size 8, false alarms = 6.9%, misses = 7.4%; for Set Size 12, false alarms = 5.0%, misses = 14.5%; and for Set Size 16, false alarms = 5.5%, misses = 12.6%. Error rates for the many irrelevant colors condition were as follows: For Set Size 4, false alarms = 4.2%, misses = 4.3%; for Set Size 8, false alarms = 6.3%, misses = 4.8%; for Set Size 12, false alarms = 3.7%, misses = 5.1%; and for Set Size 16, false alarms = 3.4%, misses = 11.2%. Error rates for the feature search condition were as follows: For Set Size 4, false alarms = 2.9%, misses = 4.9%; for Set Size 8, false alarms = 1.4%, misses = 2.5%; for Set Size 12, false alarms = 1.9%, misses = 2.0%; and for Set Size 16, false alarms = 2.7%, misses = 2.4%.

Discussion

There are several interesting aspects to the results of this experiment. First, the lack of significant differences between the red target and the many irrelevant colors conditions suggests that heterogeneity of the irrelevant items does not alter subset search performance. Participants were just as efficient at selecting the red subset when the background was heterogeneous as when it was homogeneous. Second, in contrast to the insignificant effect of varying the nonred hues, heterogeneity of color in the relevant subset strongly degraded performance. Whatever strategy participants used to select the red subset in the red target condition was foiled when they had to select a heterogeneously colored subset in the many relevant colors condition. If they were able to select a subset by somehow "killing" the green items in the red target condition, then they also should have been able to kill the green items in the many relevant colors condition. The data imply that participants cannot, in fact, inhibit items possessing a specific irrelevant feature. Because the feature search condition with heterogeneous color stimuli yielded fast RTs and flat slopes, participants' difficulty in finding an odd nongreen item in the many relevant colors condition must lie in the selection of the heterogeneous subset. Once the subset is selected, there should be no problem finding the uniquely oriented target.

A third interesting finding is that blank trial slopes can actually be significantly shallower than target trial slopes in subset searches, something that is not usually seen in standard conjunctions of two basic features.[3] Finally, these results make it harder to explain the results of the previous experiments in terms of any strategy that does not involve selection of the red subset of items. If participants were not selecting a subset, it is hard to understand why manipulating the nature of that subset should have made such a difference in RTs.

To summarize, we found that participants could divide a set of items into relevant and irrelevant subsets and could perform visual search operations that were limited to the relevant subset. Selection of the relevant subset was based on the attributes of the relevant subset, not on the attributes of the irrelevant subset. That is, in a search for an odd orientation in the red items, participants were selecting the red items. They were not suppressing the green items. In terms of the three hypotheses with which we began this experiment, we ruled out the possibility that participants perform subset searches by specifically inhibiting irrelevant hues. However, selection of the relevant items could be accomplished either by activation of items possessing the relevant attribute or general inhibition of items lacking that attribute. In this experimental paradigm, inhibiting nonreds and activating reds are logically equivalent, although they could result from distinct neurophysiological mechanisms. Although this is an interesting topic for future research, further investigation of this matter is beyond the scope of this article.

Experiment 5: Selection Is Hampered by Heterogeneity of Relevant Features

In Experiment 4, we demonstrated that participants have difficulty selecting a subset that is heterogeneously colored and whose constituent colors may change from trial to trial. The many relevant colors condition of Experiment 4 did not allow separate analysis of whether search was retarded by

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[3] Target-absent response times (RTs) that are faster than target-present RTs have been reported (Humphreys, Quinlan, & Riddoch, 1989; discussed and modeled in Humphreys & Müller, 1993). This seems to occur when a "no" response can be based on the impression that all items are the same. Humphreys and his colleagues used forms such as *T*s and *L*s. In the subset searches, the comparable impression is that it may be faster to respond "All red items are the same" than to respond "One red item is different." As Treisman (1993) put it, "there may be something special about the coding of identical objects" (p. 26).

the heterogeneity of the subset per se or by the participants' lack of top-down knowledge of the relevant colors. In Experiment 5, we investigated this question using two experimental conditions. In one condition, the relevant subset contained two colors, but the colors remained constant so the participant always knew which hues were relevant. In the other condition, the relevant "figure" was one homogeneous hue, and the irrelevant background was a different homogeneous hue, but the participant did not know which of the two colors would be relevant on any given trial.

Method

Including two control conditions, there were four experimental conditions in Experiment 5. All were variations of the "odd-man-out in a colored subset" task. These are illustrated in Figure 8. In the yellow subset condition, participants searched for a yellow line of orientation $Y°$ among purple, red, and green lines of orientation $Y°$ and yellow lines of orientation $X°$. In the purple subset condition, participants searched for a purple line of orientation $X°$ among yellow, red, and green lines of orientation $X°$ and purple lines of orientation $Y°$. In the yellow-and-purple subset condition, the target was a yellow or purple line of orientation $X°$ among red and green lines of orientation $X°$ and yellow and purple lines of orientation $Y°$. Thus, the target was the oddly oriented line in the group of yellow and purple lines. If the inefficiency of the many relevant colors condition of the previous experiment was attributable to the heterogeneity of the subset, then this should be a hard task. If that task was hard because participants did not know the specific colors of the subset, then the yellow-and-purple task should be easy. For all three of these conditions, each of the four stimulus colors was present on 25% of the items in the display. In the fourth condition, there were only two colors present in the display, and each color was present on 50% of the stimuli. For this yellow-or-purple subset condition, the target was a yellow line of orientation $X°$ or a purple line of orientation $Y°$ among yellow lines of orientation $Y°$ and purple lines of orientation $X°$. Here, participants looked for the odd orientation in the yellow subset or the odd orientation in the purple subset without knowing the relevant subset in advance. If the "pop-out" of orientation in local clumps of like-colored items makes subset searches reasonably efficient, then this task should be about as efficient.

Ten students were chosen from the subject pool described in Experiment 4. The participants completed 330 trials of each experimental condition, with the first 30 trials discarded as practice. Each display could contain 15, 18, 21, or 24 items.

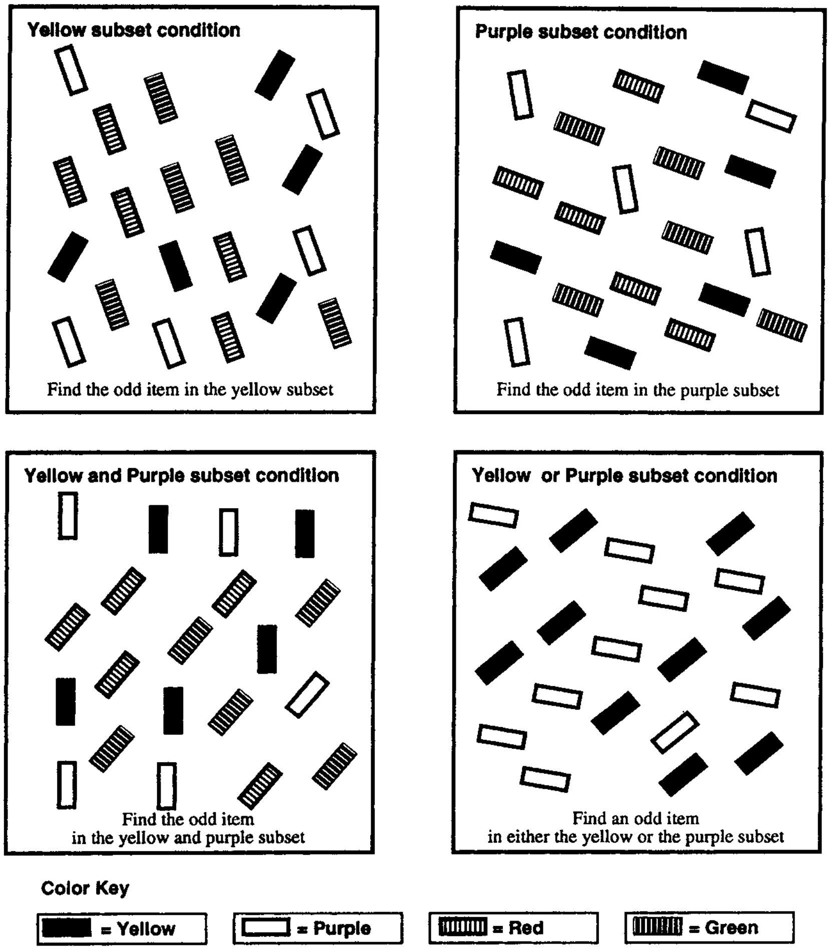

Figure 8. Samples of the four conditions of Experiment 5. In each case, respondents searched for an item of odd orientation in a subset defined by the color of the lines.

Results

A quick glance at the mean RTs plotted in Figure 9 reveals that participants performed less efficient searches in the yellow-or-purple subset and the yellow-and-purple subset conditions than they did for the two simple subset conditions. Target and blank slopes for both the conjunctive (yellow-and-purple) and disjunctive (yellow-or-purple) subset searches were significantly steeper than slopes for the yellow subset and purple subset conditions, *t*s(9) > 1.9, *p* < .05 (paired one-tailed). RTs for the conjunctive and disjunctive subset searches were significantly longer than RTs for the two simple subset conditions (target and blank trials were analyzed separately), *F*s(1, 9) > 29.1, *p* < .0001. The two simple subset searches were equivalent: There were no significant differences in RT or slope between the yellow subset and the purple subset conditions, *F*s(1, 9) < 0.8, *p* > .3 (ANOVAs of RTs), *t*s(9) < 0.2, *p* > .8 (paired two-tailed *t* tests on slopes). For the conjunctive and disjunctive subset conditions, there was no significant difference in slopes between the yellow-or-purple subset and the yellow-and-purple subset conditions, *t*s(9) < 1.8, *p* > .1 (paired two-tailed). The yellow-and-purple subset condition did yield significantly faster RTs for target-present trials than did the yellow-or-purple subset condition, *F*(1, 9) = 7.0, *p* = .03; however, target-absent trial RTs were not significantly different, *F*(1, 9) = 3.9, *p* = .08.

Turning to the within-condition comparisons of target and blank trials, target presence versus absence had no significant effect on slopes or RTs for the yellow subset and the purple subset conditions *F*s(1, 9) < 0.4, *p* > .5 (ANOVAs of RTs), *t*s(9) < 1.7, *p* > .1 (paired two-tailed). By contrast, for both the yellow-or-purple subset and the yellow-and-

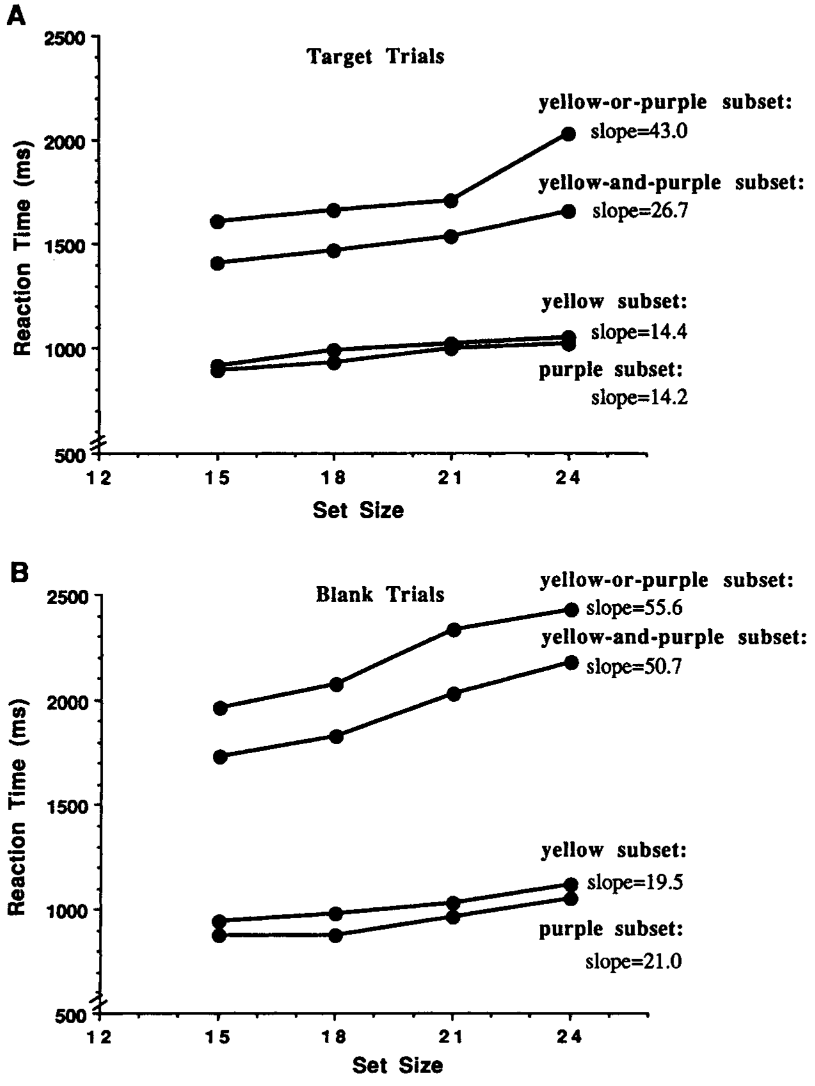

Figure 9. Results for Experiment 5. If the subset was defined by two colors, subset search was much slower, yielding results consistent with the hypothesis that respondents are performing two searches, first through items of one color, then through the other.

purple subset conditions, target-absent trial slopes and RTs were significantly greater than target-present slopes and RTs, $Fs(1, 9) > 35.0, p < .001, ts(9) > 2.0, p < .04$ (paired one-tailed).

Error rates for the purple-and-yellow subset condition were as follows: For Set Size 15, false alarms = 2.2%, misses = 12.2%; for Set Size 18, false alarms = 1.1%, misses = 19.2%; for Set Size 21, false alarms = 2.4%, misses = 17.4%; and for Set Size 24, false alarms = 1.9%, misses = 17.7%. Error rates for the yellow subset condition were as follows: For Set Size 15, false alarms = 4.4%, misses = 6.1%; for Set Size 18, false alarms = 3.8%, misses = 3.8%; for Set Size 21, false alarms = 1.1%, misses = 10.0%; and for Set Size 24, false alarms = 1.9%, misses = 9.4%. Error rates for the purple subset condition were as follows: For Set Size 15, false alarms = 1.9%, misses = 5.2%; for Set Size 18, false alarms = 3.3%, misses = 8.5%; for Set Size 21, false alarms = 1.6%, misses = 7.3%; and for Set Size 24, false alarms = 2.1%, misses = 10.8%. Error rates for the purple-or-yellow subset condition were as follows: For Set Size 15, false alarms = 3.1%, misses = 18.0%; for Set Size 18, false alarms = 3.4%, misses = 15.0%; for Set Size 21, false alarms = 3.3%, misses = 17.8%; and for Set Size 24, false alarms = 3.0%, misses = 17.4%.

Discussion

The main finding of Experiment 5 was that subset search was easy to disrupt with fairly minimal changes in the definition of the subset. Search was hindered when the relevant subset contained two colors even when those colors were predictable (as in the yellow-and-purple subset condition). Therefore, we may conclude that it was not the lack of specific color information that made the many relevant colors condition of Experiment 4 difficult. Subset search was impaired even when the subset contained only one color if that color was unpredictable (as in the yellow-or-purple subset condition). Apparently, either heterogeneity of the subset within trials or a lack of top-down information across trials can have a deleterious effect on search efficiency. The difficulty of the yellow-or-purple condition is fairly easy to explain. Participants had only a 50% chance of guessing the correct color for the subset. If they guessed wrong, the other subset had to be selected at considerable additional cost. The difficulty of the yellow-or-purple condition makes it less likely that the relative efficiency of the standard subset search can be explained by lines of odd orientation "popping out" of clumps of homogeneous items.

There are at least two plausible explanations for participants' difficulty with the yellow-*and*-purple condition. It could be that they used a strategy similar to that just described for the yellow-*or*-purple condition. Participants selected one color first. If that failed to turn up a target, they tried the other color. Alternatively, the greater processing demands could reflect increased difficulty in selecting a two-color subset. This experiment did not differentiate between these alternatives, but it did demonstrate that there was a substantial cost to be paid if a subset was defined by two colors rather than one.

Experiment 6: Subset Search With Noise in an Irrelevant Dimension

To summarize the findings from the first 5 experiments, when participants were asked to indicate the presence of an oddly oriented line in a subset of display items, they did not perform a serial search. Instead, they were able to use their top-down knowledge of the target's color to select the relevant subset of items. Selection of the subset was based on knowledge of the properties of the subset (e.g., its color), not on the properties of the irrelevant items. The selection process appeared to be a relatively slow, perhaps limited capacity, parallel process. For small set sizes, participants might have been performing a serial search through the red items in the manner described by Egeth et al. (1984). Selection of the subset was sufficiently slow to make second-order parallel processing worthwhile only for larger set sizes.

In Experiment 6, we examined the nature of that second-order processing. Specifically, we investigated whether second-order parallel processing would be limited to one relevant feature or whether it would be disrupted by irrelevant variation in another featural dimension.

Method

The conditions are illustrated in Figure 10. In all conditions, stimuli were red and green lines that were associated with small or large circles. In all four experimental conditions, the target could be described as the oddly sized (or oddly shaped) red item, but in two of the conditions, knowledge of the target color was not necessary for successful search. The upper left panel of Figure 10 shows a simple size feature search. The target was the big circle. It happened to be red in all cases, but that information was not needed. In this condition, all lines were the same orientation (20° to the right of vertical). In the noisy size feature search, the orientation of lines was random but still irrelevant. In the basic subset search condition, participants searched for a red line with a circle of size *A* among green lines with circles of size *A* and red lines with circles of size *B*. On any given trial, *A* could be either small or big and *B* was whichever size *A* was not. For example, in the lower left Figure 10, the target item is the small item in the black subset. All lines in the display were oriented 20° to the right of vertical. In the noisy subset search condition, the orientation of the lines was random. In the lower right panel of Figure 10, the target is still the small item in the black subset.

Thus, the two size feature conditions served as controls; they were needed to show that the size feature supported "parallel" search. The two subset search conditions served to test whether it was possible to search for an item of odd size in the red subset and to determine whether that subset search would be disrupted by irrelevant variation in another dimension (orientation).

Ten new students from the MIT subject pool completed 30 practice and 300 data trials for each of the four experimental conditions. Displays contained 4, 8, 12, or 16 items. In all other respects, experimental methods were the same as those used in the previous experiments.

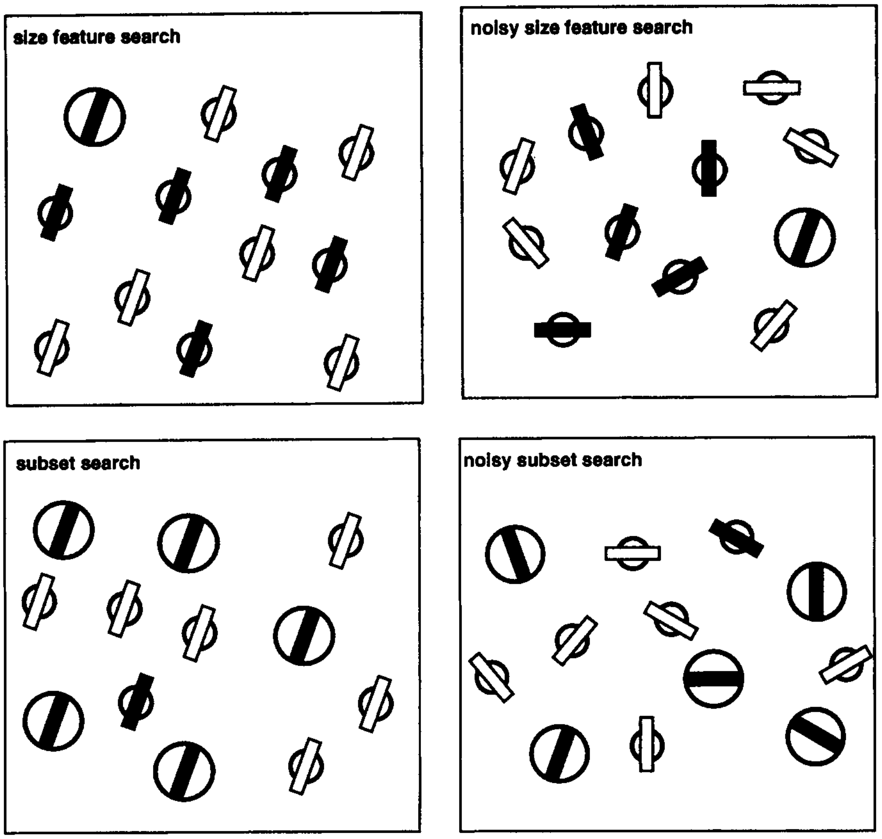

Figure 10. Stimuli for Experiment 6. Search for an item of odd size either in a feature search or in a subset search. Experiment 6 examines the effects of irrelevant variation of orientation.

Results

Data from 2 participants were discarded from analysis. One participant had large error rates; the other participant had steep RT × Set Size slopes for the feature search conditions (see Footnote 1). Mean RTs for the 8 remaining participants are plotted as a function of set size for all four experimental conditions in Figure 11. There are no significant differences in RT or slope between the subset search and the noisy subset search conditions (target and blank trials were analyzed separately), $F\text{s}(1, 7) < 0.4$, $p > .5$, $t\text{s}(7) < 0.4$, $p > .6$ (paired two-tailed t tests on target and blank slopes). There were no significant RT or slope differences between the size feature search and noisy size feature search conditions, $F\text{s}(1, 7) < 0.7$, $p > .4$, $t\text{s}(7) < 0.5$, $p > .6$ (paired two-tailed). For all four experimental conditions, target presence versus absence had no effect on slope, $t\text{s}(7) < 1.6$, $p > .1$ (paired two-tailed), nor on RTs, $F\text{s}(1, 7) < 4.1$, $p > .05$.

Error rates for the subset search condition were as follows: For Set Size 4, false alarms = 3.7%, misses = 2.2%; for Set Size 8, false alarms = 3.4%, misses = 3.9%; for Set Size 12, false alarms = 2.7%, misses = 3.2%; and for Set Size 16, false alarms = 2.5%, misses = 8.3%. Error rates for the noisy subset search condition were as follows: For Set Size 4, false alarms = 4.0%, misses = 2.9%; for Set Size 8, false alarms = 3.4%, misses = 2.5%; for Set Size 12, false alarms = 3.5%, misses = 1.7%; and for Set Size 16, false alarms = 1.8%, misses = 4.6%. Error rates for the size feature search condition were as follows: For Set Size 4, false alarms = 3.9%, misses = 1.3%; for Set Size 8, false alarms = 2.5%, misses = 2.3%; for Set Size 12, false alarms = 3.1%, misses = 1.0%; and for Set Size 16, false alarms = 0.6%, misses = 3.8%. Error rates for the noisy size feature search condition were as follows: For Set Size 4, false alarms = 3.8%, misses = 3.0%; for Set Size 8, false alarms = 9.8%, misses = 1.4%; for Set Size 12, false alarms = 3.1%, misses = 3.9%; and for Set Size 16, false alarms = 0.7%, misses = 2.4%.

Discussion

Adding noise in an irrelevant dimension had no adverse effects on these feature or subset searches. Whether participants searched for the oddly sized item in the entire display or in the red subset, they were able to ignore noise in the form of irrelevant orientations. This finding is consistent with previous work in other search tasks in which there is evidence that the contributions of different feature activations can be modulated by knowledge of the specific task demands (e.g., Francolini & Egeth, 1979).

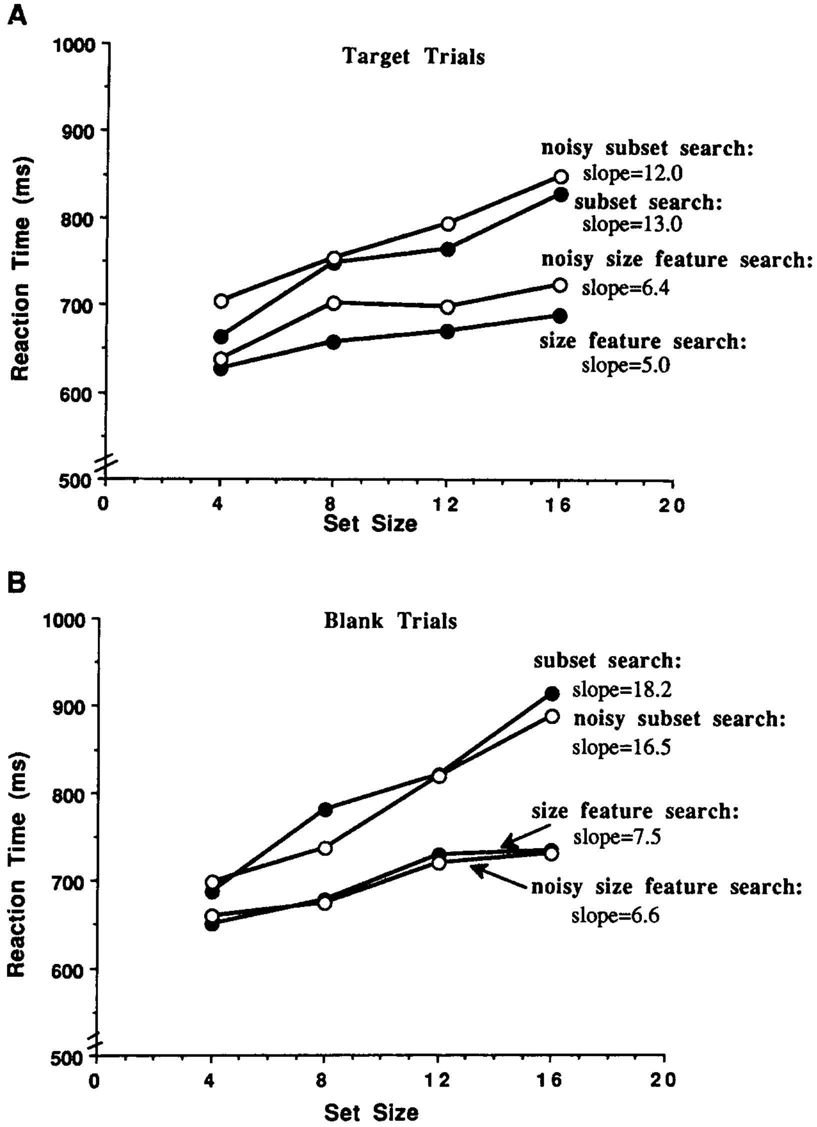

Figure 11. Results for Experiment 6. There was little or no effect of irrelevant variation in orientation in the search for an item of odd size.

One could interpret this finding to imply that once participants select the subset of red items, they do not merely search for an unusual item in that subset. Instead, given information that the target is oddly sized or oddly oriented, they specifically reprocess the subset for the relevant feature. Irrelevant information did not intrude on the second-order processing. There could be an alternative interpretation. Perhaps variation in an irrelevant feature did not affect the feature search or subset search because the signal from the odd item is strong enough to stand out against the noise from the irrelevant feature. After all, the target is unique in its size, whereas the irrelevant variation in orientation includes many different orientations. It could be that the most unusual item exerts the strongest pull on attention. A stronger test of participants' ability to ignore signals in other feature modules would be to include an irrelevant distractor as unique as the relevant target but in another feature dimension (e.g., a red subset with one odd orientation and one odd size).

To test this hypothesis, we repeated the basic subset search for an odd orientation in the red items. We added a single oddly textured item to either the red or the green subset. Some participants seemed to pay a cost only when the irrelevant singleton was in the red subset. Others paid a cost regardless of whether the singleton was red or green, whereas still others seemed to pay no cost. This range of results may not be surprising if one considers the range of findings on the effects of singletons. Jonides and Yantis showed that, all else being equal, irrelevant transients will capture attention (Jonides & Yantis, 1988; Yantis & Johnson, 1990; Yantis & Jonides, 1990). However, Yantis and colleagues found that this effect is not observed if the transient is known not to mark the target. Similarly, we have found that a "snowstorm" of irrelevant dots, appearing at a rate of one every 40 ms, need not interfere with serial search tasks (Wolfe & Friedman-Hill, 1990). Pashler (1988) showed that singletons in an irrelevant dimension need not disrupt search (but see Remington, Johnston, & Yantis, 1992, and Theeuwes, 1991, 1992). Clearly, a more complete account of the fate of irrelevant signals awaits further experimentation.

General Discussion

The results of the six experiments presented here paint a dynamic picture of parallel processing. At the instant that the stimulus appears, there is no parallel guidance of attention. Attention is deployed at some location, and limited-capacity processes can check the identity of any item at that location. Shortly after stimulus onset, bottom-up parallel processing produces activation at loci of local change, whereas top-down parallel processing activates loci with the target attributes. Attention is deployed to loci in order of decreasing activation. When attention arrives at a location, its contents are checked and attention redeployed elsewhere if a target is not found. Given enough time (200–300 ms), the parallel processes can group or otherwise select noncontiguous items on the basis of their similarity in some feature (e.g., color). Once a group of items has been selected, parallel processing can be restricted to that group with minimal interference from the items outside the group.

Returning to the basic subset search task described in this article, a standard display would contain equal numbers of red and green items and equal numbers of lines of two different but initially unknown orientations. Because the target is known to be "red," all red items should receive top-down activation, and the initial deployment of attention should be from item to item in the red subset. After 200–300 ms, the red items are grouped into a subset, and information about membership in the subset is shared with other parallel feature processors. This might be implemented via lateral connections between feature processors, as advocated, for example, by Green (1991). With processing restricted to the subset, a parallel processor for orientation will now generate bottom-up activation of a unique target item if it is present.

The selection of the subset is based on positive rather than negative attributes of the subset (selection of items that are "red" rather than of items that are "not green"; Experiment 4). Furthermore, the subset becomes more difficult to select if it is defined by two colors (Experiment 5). Finally, Experiment 6 showed that once a subset has been selected for further processing, it is possible to ignore at least some variation in an irrelevant feature dimension.

The recursive processing that seems to be involved in subset search tasks suggests that visual information processing is not a simple two-tier hierarchy. Feature modules need not operate as passive one-shot filters, and all parallel processing need not be complete prior to serial, attentional processing. In the subset search tasks, the information needed by parallel processes takes so long to distill from the visual display that attentional processes begin to operate at random before the parallel information can influence the course of the search. It is probable that parallel and serial processes are occurring at the same time, but in most laboratory tasks, the parallel processes have done all of their useful work long before the serial processes can finish the trial. In cases of protracted parallel processing, our results show that information that has passed through basic feature modules once can be reprocessed by these same modules. For instance, in a standard subset search, orientation is processed once (uselessly) over the set of all items and then, when the red subset has been selected, orientation is processed again for that subset alone, revealing the presence or absence of a target.

Our data suggest that second-order parallel processing can be feature specific. Once participants select a subset, instead of reprocessing the subset in all feature modules, the second-order processing can be limited to a second relevant feature dimension. This finding further suggests that feature modules are not constrained to operate over the set of all items. Information from one parallel feature detector can be used to direct the subsequent processing by a different feature detector, without an intervening serial process. Parallel processes do not just feed-forward information to later serial operations; they also "talk" to each other.

The processes underlying the selection of the subset are certainly worthy of further investigation. In particular, the relationship between subset selection and other grouping tasks should be examined more closely. The experiments reported here put the putative grouping mechanism to a harsh test by randomly intermixing relevant and irrelevant colors. This requires "population segregation," to use Beck's (1993) terminology. If there is some organization to the items, that information can be used to support search. For instance, grouping and subsequent search is easier with contiguous clumps of same-color items (Treisman, 1982). It would be interesting to relate the efficiency of grouping in subset search with known rules of grouping such as those developed by the gestalt school (see Palmer, 1992, for a quick review and an addition to the classic list; see also Beck, 1993).

Finally, returning to standard conjunction searches, it is possible to maintain that a search for a conjunction of, say, color and orientation is performed by first selecting all items of one color and then checking that subset for items of the target orientation. In light of our data, however, adherents of such a model would need to explain why the pattern of RT results is different from the pattern in subset search. It seems more likely that, in standard conjunction tasks, selection by both color and orientation occurs simultaneously. Color does provide a compelling segmentation of an array of items, more compelling than that generated by most other items. This grouping may explain participants' introspective impression that they are selecting by color first. However, in a standard conjunction search, this introspection would seem to be misleading. In subset search, when participants must group by color first, the results are much different.

In summary, our experiments add more detail to the understanding of the role of parallel processing in visual search. Preattentive vision is not a static collection of modules that get one chance to find simple stimuli and then must defer to serial, attentive processing. Rather, under top-down control, preattentive vision is a flexible tool that works throughout the course of a visual search to develop information with which to guide spatially limited processes to promising loci in the visual field. Within the parallel processes there will be implicit information about the location of items with relatively complex properties (conjunction, odd man out in subset, etc.). The role of attention seems to be to make that information explicitly available.

References

Beck, J. (1993). The British Aerospace Lecture: Visual processing in texture segregation. In D. Brogan, A. Gale, & K. Carr (Eds.), *Visual search 2* (pp. 37–58). London: Taylor & Francis.

Braun, J., & Sagi, D. (1990). Vision outside the focus of attention. *Perception & Psychophysics, 48,* 45–58.

Duncan, J. (1989). Boundary conditions on parallel processing in human vision. *Perception, 18,* 457–469.

Egeth, H. E., Virzi, R. A., & Garbart, H. (1984). Searching for conjunctively defined targets. *Journal of Experimental Psychology: Human Perception and Performance, 10,* 32–39.

Foster, D. H., & Ward, P. A. (1991). Asymmetries in oriented-line detection indicate two orthogonal filters in early vision. *Proceedings of the Royal Society (London B), 243,* 75–81.

Francolini, C. M., & Egeth, H. (1979). Perceptual selectivity is task dependent: The pop-out effect poops out. *Perception & Psychophysics, 25,* 99–110.

Green, M. (1991). Visual search, visual streams, and visual architectures. *Perception & Psychophysics, 50,* 388–403.

Grossberg, S., Mingolla, E., & Ross, W. D. (1994). A neural theory of attentive visual search: Interactions of boundary, surface, spatial, and object representations. *Psychological Review, 101,* 470–489.

Humphreys, G. W., & Müller, H. J. (1993). SEarch via Recursive Rejection (SERR): A connectionist model of visual search. *Cognitive Psychology, 25,* 43–110.

Humphreys, G. W., Quinlan, P. T., & Riddoch, M. J. (1989). Grouping processes in visual search: Effects with single and combined-feature targets. *Journal of Experimental Psychology: General, 118,* 258–279.

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception & Psychophysics, 43,* 346–354.

Julesz, B. (1984). A brief outline of the texton theory of human vision. *Trends in Neuroscience, 7,* 41–45.

Nagy, A. L., & Sanchez, R. R. (1990). Critical color differences determined with a visual search task. *Journal of the Optical Society of America A, 7,* 1209–1217.

Nakayama, K., & Silverman, G. H. (1986). Serial and parallel processing of visual feature conjunctions. *Nature, 320,* 264–265.

Neisser, U. (1967). *Cognitive psychology.* New York: Appleton-Century-Crofts.

Nothdurft, H. C. (1992). Feature analysis and the role of similarity in pre-attentive vision. *Perception & Psychophysics, 52,* 355–375.

O'Neill, P., Wolfe, J. M., & Bilsky, A. B. (1993). Individual differences in visual search. *Investigative Ophthalmology and Visual Science, 34,* 1236.

Palmer, S. E. (1992). Common region: A new principle of perceptual grouping. *Cognitive Psychology, 24,* 436–447.

Pashler, H. (1988). Cross-dimensional interaction and texture segregation. *Perception & Psychophysics, 43,* 307–318.

Poisson, M. E., & Wilkinson, F. (1992). Distractor ratio and grouping processes in visual conjunction search. *Perception, 21,* 21–38.

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

Quinlan, P. T., & Humphreys, G. W. (1987). Visual search for targets defined by combinations of color, shape, and size: An examination of the task constraints on feature and conjunction searches. *Perception & Psychophysics, 41,* 455–472.

Remington, R. W., Johnston, J. C., & Yantis, S. (1992). Involuntary attentional capture by abrupt onsets. *Perception & Psychophysics, 51,* 279–290.

Ross, W. D., Grossberg, S., & Mingolla, E. (1993). A neural model of visual search. *Investigative Ophthalmology and Visual Science, 34,* 1235.

Theeuwes, J. (1991). Cross-dimensional perceptual selectivity. *Perception & Psychophysics, 50,* 184–193.

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception & Psychophysics, 51,* 599–606.

Townsend, J. T. (1990). Serial and parallel processing: Sometimes they look like Tweedledum and Tweedledee but they can (and should) be distinguished. *Psychological Science, 1,* 46–54.

Treisman, A. (1982). Perceptual grouping and attention in visual search for features and for objects. *Journal of Experimental Psychology: Human Perception and Performance, 8,* 194–214.

Treisman, A. (1993). The perception of features and objects. In A. Baddeley & L. Weiskrantz (Eds.), *Attention: Selection, awareness, and control* (pp. 5–35). Oxford, England: Clarendon Press.

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

Treisman, A., & Gormican, S. (1988). Feature analysis in early vision: Evidence from search asymmetries. *Psychological Review, 95,* 15–48.

Treisman, A., & Sato, S. (1990). Conjunction search revisited. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 459–478.

Wolfe, J. M. (1992). "Effortless" texture segmentation and "parallel" visual search are not the same thing. *Vision Research, 32,* 757–763.

Wolfe, J. M. (1993). Guided search 2.0: The upgrade. *Proceedings of the Human Factors and Ergonomics Society, 37,* 1295–1299.

Wolfe, J. M. (1994). Guided search 2.0: A revised model of visual search. *Psychonomic Bulletin and Review, 1,* 202–238.

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: An alternative to the feature integration model for visual search. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 419–433.

Wolfe, J. M., & Friedman-Hill, S. R. (1990, November). *Must we attend to every abrupt onset?* Paper presented at the annual meeting of the Psychonomic Society, New Orleans, LA.

Wolfe, J. M., Friedman-Hill, S. R., Stewart, M. I., & O'Connell, K. M. (1992). The role of categorization in visual search for orientation. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 34–49.

Yantis, S. (1992). Multielement visual tracking: Attention and perceptual organization. *Cognitive Psychology, 24,* 295–340.

Yantis, S., & Johnson, D. N. (1990). Mechanisms of attentional priority. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 812–825.

Yantis, S., & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 121–134.

Zohary, E., & Hochstein, S. (1989). How serial is serial processing in vision? *Perception, 18,* 191–200.

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