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Bottom-Up Guidance in Visual Search for Conjunctions

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Understanding the relative role of top-down and bottom-up guidance is crucial for models of visual search. Previous studies have addressed the role of top-down and bottom-up processes in search for a conjunction of features but with inconsistent results. Here, the author used an attentional capture method to address the role of top-down and bottom-up processes in conjunction search. The role of bottom-up processing was assayed by inclusion of an irrelevant-size singleton in a search for a conjunction of color and orientation. One object was uniquely larger on each trial, with chance probability of coinciding with the target; thus, the irrelevant feature of size was not predictive of the target's location. Participants searched more efficiently for the target when it was also the size singleton, and they searched less efficiently for the target when a nontarget was the size singleton. Although a conjunction target cannot be detected on the basis of bottom-up processing alone, participants used search strategies that relied significantly on bottom-up guidance in finding the target, resulting in interference from the irrelevant-size singleton.

Keywords: attention, visual search, bottom-up, top-down, conjunction

Computational models of eye movements give bottom-up processing, the relative salience of objects in the stimulus, a prominent role in the guidance of attention (Koch & Ullman, 1985). Many models of visual search, however, suggest that when the target is defined as a conjunction of features, search is based primarily on top-down processing (e.g., Guided Search [GS]; Wolfe, 1994). The logic of the GS model is that if the target is defined by one color and one orientation (e.g., red and vertical) and the distractors are defined by a combination of one of these target features and another feature (e.g., red and horizontal or green and vertical), then the output of the bottom-up feature maps cannot be relied on for guiding attention to the target. A top-down search strategy is required presumably because each location contains at least one of the target's features and because no location is featurally unique.

In the present study, bottom-up and top-down processes are defined in terms of the two different types of input to the activation map in the GS architecture (Wolfe, 1994). An important additional concept is the idea of a participant's *search strategy*. A participant could strategically rely on bottom-up processing, top-down processing, or a combination of the two to perform a search task. Thus, a participant could search for a unique feature singleton (such as a vertical line among horizontal lines) by strategically relying on bottom-up processing to search for the unique object in the display or by strategically relying on top-down processing to search for the target-defining feature of "vertical" in the display (cf. singleton-detection mode versus feature-search mode, respectively; Bacon & Egeth, 1994). Note that the use of bottom-up processing versus top-down processing can be contingent on the strategy used by the participant, consistent with the contingent-capture hypothesis (Folk, Remington, & Johnston, 1992). Of course, the use of bottom-up processing might be involuntary (cf. Theeuwes, 2004); however, the main concern here is not whether bottom-up processing is automatic or contingent but, rather, whether bottom-up processing plays a key role in conjunction search.

Egeth, Virzi, & Garbart (1984) were the first to provide evidence for the top-down guidance of attention in conjunction search. A conjunction search task generally has two distractor types, with each type sharing one feature with the target. Egeth et al. kept the number of one distractor type constant and varied only the number of the other distractor items. They found that participants could restrict attention to one target feature and search for the target among those items that shared that feature. Zohary and Hochstein (1989) also reported evidence in favor of the top-down guidance of attention by modifying Egeth et al.'s procedure. They kept the total number of distractors constant and varied which distractor dominated the display. Response times were fastest when one distractor dominated and were slowest when equal numbers of each distractor were present. They concluded that participants selected the smaller subset in a top-down fashion and searched for the target among that grouping.

Bacon and Egeth (1997) noted, however, that a strategy of relying on the bottom-up guidance of attention could also explain Zohary and Hochstein's (1989) results. The smaller subset would be more salient because each item would more likely be surrounded by the other distractor type that outnumbers it. Therefore, Bacon and Egeth sought support for a top-down account by instructing participants to search one subset while also varying which subset dominated the display.

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Although Bacon and Egeth emphasized the result that participants could indeed restrict attention to the instructed subset, participants also abandoned the instructions when the other subset was the smaller one. Sobel and Cave (2002) noted that this action could be due to a reliance on either top-down or bottom-up processes, and they provided evidence from further experiments that was consistent with the bottom-up account.

Sobel and Cave (2002) concluded that because no smaller subset exists in standard conjunction search tasks, the "bottom-up system . . . is of little use in standard conjunction searches" (p. 1067). However, a participant can implement conjunction search in multiple ways, and the strategy of the participant must be known for clarification of the roles of the top-down and bottom-up guidance of attention for a conjunction target. It cannot be assumed that participants are necessarily following instructions and searching for a template of the target's defining features, as assumed by recent models such as GS (Wolfe, 1994).

In this study, I adapted an attentional capture paradigm to examine the reliance on bottom-up and top-down strategies in a conjunction search with the standard, equal number of each distractor type. Researchers in two studies used a variation of the attentional capture method, although with conflicting results. In one study, Lamy and Tsal (1999) used an additional singleton paradigm (cf. Theeuwes, 1991) to assess whether bottom-up processes are used in conjunction search. None of the additional singletons they used (defined by color, shape, or both) disrupted search on the target-present trials (although an effect was seen on the target-absent trials). Lamy and Tsal concluded that a salient singleton did not disrupt conjunction search.

In the other study, Friedman-Hill and Wolfe (1995; follow-up to Experiment 6) examined participants' ability to ignore an irrelevant distractor. They introduced an additional singleton to their task of having participants restrict search to a color subset and then search for an odd orientation within that subset. One of the distractor items (never the target) was oddly textured on each trial. The conclusion was mixed: Search suffered for some participants when the irrelevantly textured item was in the target color subset and for others when it was either color. Some participants' searches were not affected at all.

One drawback shared by these two studies, however, is that the tasks required participants to use the additional singleton paradigm. Because the nontarget singletons could never coincide with the target, the participants may have been implicitly encouraged to inhibit the output of a bottom-up process, to some extent; therefore, the role of bottom-up processing in standard conjunction search tasks may be underestimated by the modified tasks in these studies. To avoid this problem, I introduced an irrelevant feature that provided no information about the target location but coincided with the target on some trials.

Four Possible Strategies in a Conjunction Search Task

I designed this experiment to use attentional capture to differentiate four possible strategies that participants could use in a conjunction search task. A cartoon of the stimuli used and the trial types are shown in Figure 1. The predicted results, as a function of strategy, are shown in Figure 2. In the subsequent paragraphs, I provide a brief description of each strategy and explain how each strategy would be implemented through use of the bottom-up and top-down systems.

Strategy 1: Efficient Top-Down Selection

The top-down system can be relied on primarily for providing guidance to the target because no items are unique within either feature dimension (e.g., half are red, half are green, half are vertical, and half are horizontal; cf. Wolfe, 1994). There is no difference in the slope of the functions relating response time to display numerosity for the three types of target-present trials (which correspond to Figures 1A, 1B, and 1C).

Strategy 2: Inefficient Top-Down Selection

The top-down system can be relied on primarily for randomly selecting locations and for conjoining the features at each location until the target is found (cf. Treisman & Gelade, 1980). Strategy 2 might be differentiated from Strategy 1 by an examination of the target-present slopes. If this second strategy were operative, one would predict that the slopes would be steeper than those reported by Wolfe, Cave, and Franzel (1989), perhaps more like those reported by Treisman and Gelade. Most important, in either case the data would indicate that bottom-up processes have little or no role in standard conjunction search.

Strategy 3: Bottom-Up Selection Within a Subset

The observer can restrict search to one feature (red) and then search for the feature singleton in the other dimension among just that subset (the uniquely oriented bar; cf. Zohary & Hochstein, 1989). Note that for Strategy 3 (two panels), the slowest target-present response times

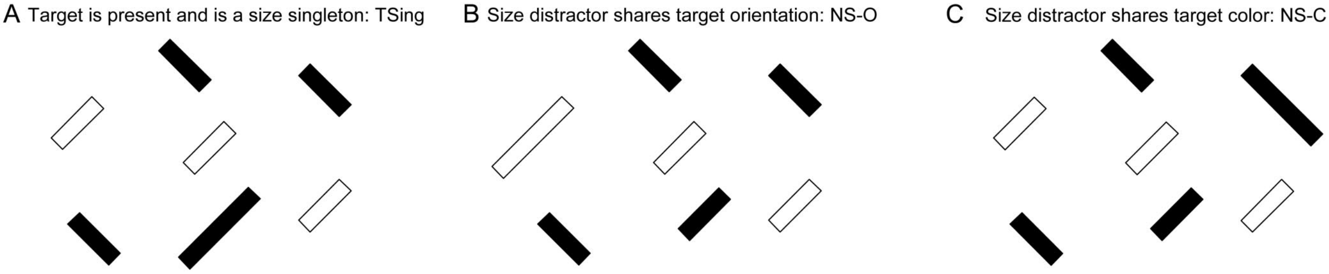


Figure 1. Examples of a conjunction search task with an irrelevant feature added to the display. The target is the right-tilted black bar. The irrelevant feature can coincide with the target or either nontarget type, as shown. TSing = target singleton; NS-O = nontarget singleton-orientation; NS-C = nontarget singleton-color.

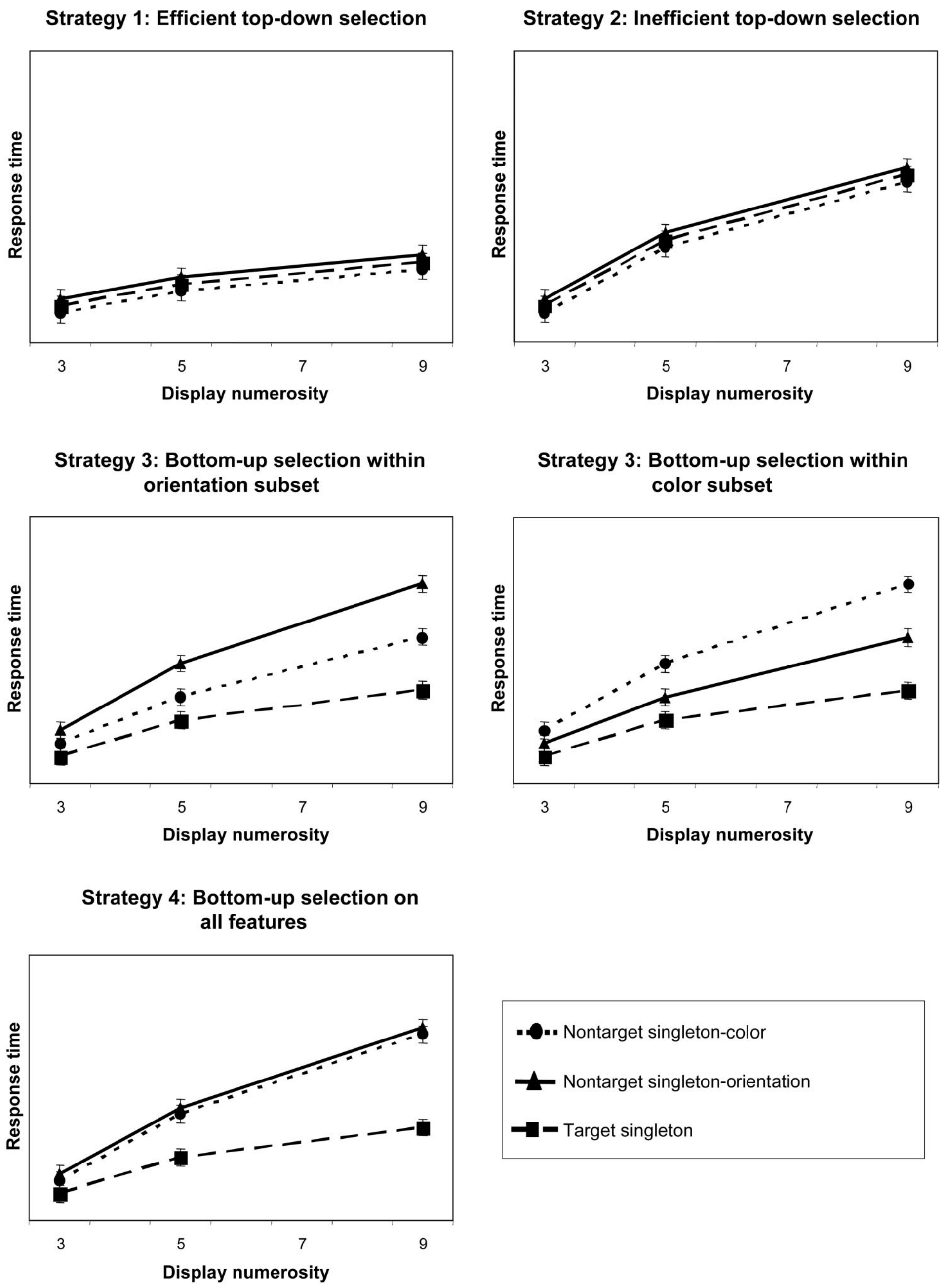


Figure 2. Predicted detection response times for the new conjunction experiments.

(RTs) are on those target-present trials in which the size singleton coincides with a distractor that is within the subset being searched through. For example, in Strategy 3 (orientation subset) the slopes indicate that responses to the target are slowed by the presence of the size singleton when it coincides with a distractor that shares the target's orientation (and are perhaps even speeded to the target when the target coincides with the size singleton).

Strategy 4: Bottom-Up Selection on All Features

Observers can search for the unique object in the display, as the target is the only item that is both red and vertical; therefore, if objects can be compared in their entirety as conjunctions of features, the distractors can be excluded in groups (cf. Duncan & Humphreys, 1989; Found, 1998). For Strategy 4, a prediction could be made that the irrelevant feature would influence visual search no matter with which object it coincides.

Method

Participants

Participants were 40 undergraduates reporting normal or corrected-to-normal vision. All gave informed consent and took part either for payment or for a course requirement.

Apparatus and Stimuli

Participants were 55 cm from the screen and used a chin rest in a dimly lit room. Stimuli were presented by a C++ and OpenGL program on an IBM-compatible computer. In the actual experiment, bars were either blue or green and either right tilted (45°) or left tilted (–45°). They were dispersed randomly in the cells of an invisible grid subtending 6°, 7°, or 8° of visual angle (with 7 × 7, 8 × 8, and 9 × 9 grid sizes, respectively) for a corresponding display numerosity (three, five, or nine bars, respectively). The bars were arranged within a subset of the cells of the grid, which were 1° apart, center to center, and the bar positions were each displaced by a random vertical and horizontal factor of ± 0.2°. The nonsingleton bar size subtended 0.6° of visual angle in length and 0.15° in width. The size singleton bar subtended 0.9° in length and 0.15° in width. There was no fixation point, and the background was black. A size singleton was present on every trial.

Participants were randomly assigned to one of four feature-assignment groups (10 per condition), each of which had a different set of features assigned to the target or the nontargets: (a) Group A target was blue and right tilted (and nontargets were either green and right tilted or blue and left tilted); (b) Group B target was blue and left tilted; (c) Group C target was green and right tilted; and (d) Group D target was green and left tilted.

The size singleton appeared on each trial and coincided with the target on 1/*d* of the trials, where *d* is the number of elements in the display. The size singleton coincided equally often with each nontarget type on the remainder of the trials. In a pilot experiment with 14 participants, I determined that the size singleton could capture attention in an orientation singleton detection task, thus demonstrating that the size singleton was sufficiently salient and conceptually replicated previous studies in this regard (Bacon & Egeth, 1994; Theeuwes, 1991).

Procedure

Participants were instructed to look for the particular features that defined the target for their condition and were informed of the 1/*d* relationship between the size singleton and the target. A display of bars appeared on each trial, and the participant responded "present" or "absent" with a keypress. Errors were signaled with auditory feedback. Each trial began after a 2-s intertrial interval. Each participant participated in two blocks of 270 trials per block. Each block included an equal number of target-absent and target-present trials and an equal number of trials for each display numerosity. Order of trial types was randomized. Participants began with a practice block of 20 trials.

Results

The error rates are shown in Table 1; they followed the same general pattern as the RT data (see Figure 3), indicating that a speed-accuracy tradeoff likely did not confound the comparisons of interest. RTs greater than 3.5 standard deviations from the mean for each participant were counted as errors, resulting in a loss of 0.88% of the trials. I conducted initial analyses of variance (ANOVAs) to find whether feature-assignment group (a between-subjects factor) had any interaction effects with the within-subjects variables. All interactions with feature-assignment group failed to reach significance. Thus, the following analyses collapse across group assignment.

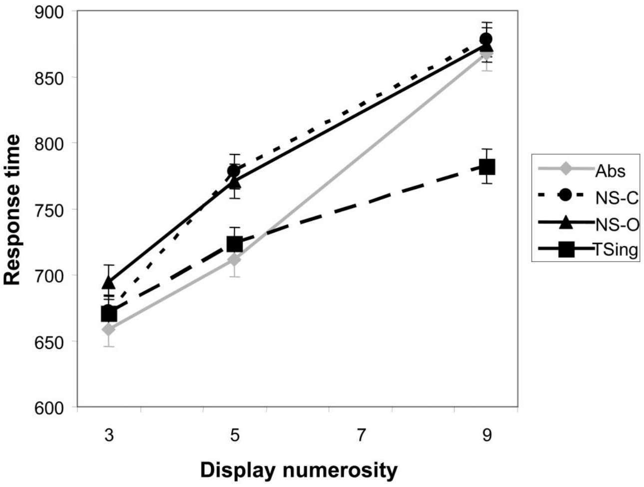


Figure 3. The response times for the main experiment are plotted as a function of display numerosity and trial type: target absent (Abs), nontarget singleton-color (NS-C), nontarget singleton-orientation (NS-O), and target singleton (TSing).

Analysis of Search Efficiency by Trial Type

A repeated-measures ANOVA that analyzed the target-present data revealed significant effects of trial type, $F(2, 78) = 59.0$, $p < .01$; display numerosity, $F(2, 78) = 223.8$, $p < .01$; and an interaction between these two factors, $F(4, 156) = 15.5$, $p < .01$. A separate ANOVA found a significant interaction between display numerosity (3, 5, 9) and nontarget-singleton trial type (nontarget singleton-color [NS-C] vs. nontarget singleton-orientation [NS-O]), $F(2, 78) = 4.2$, $p < .05$. The mean RTs are shown in Figure 3. As seen in Figure 3 and in Table 2, the search slope for the target-singleton trials (18 ms/item) was shallower than the search slopes for the nontarget-singleton trials (NS-C: 33 ms/item; NS-O: 29 ms/item); this observation is supported by the significant interaction between trial type and display numerosity. Although an obviously large difference was not seen between the slopes of the nontarget-singleton trial types, a significant interaction between nontarget-singleton trial type and display numerosity was found.

Table 1
Error Rates for Each Trial Type

	Display numerosity		
Trial type	3	5	9
Target present			
Target singleton	3.2	4.2	3.8
Nontarget singleton-color	3.6	6.5	10.9
Nontarget singleton-orientation	4.3	5.9	8.8
Target absent	3.0	3.1	3.8

Table 2
Search Slopes (in ms per Item) and Intercepts (in ms) by Trial Type

Trial type	Slope	Intercept
Target present		
Target singleton	18	624
Nontarget singleton-color	33	589
Nontarget singleton-orientation	29	613
Target absent	35	545

Intertrial Effects

In recent studies, researchers have noted that the introduction of a singleton could have its apparent prioritization effect as a result of intertrial priming rather than of reliance on bottom-up processing (Olivers & Humphreys, 2003; see also Maljkovic & Nakayama, 1994). Generally, this speeded response occurs because the target's defining features are the same from one trial to the other; RTs are slower if the target's features change. To ensure that priming does not account for the effect of the irrelevant-size singleton in the main experiment, the effects of the previous trial also were considered for this main experiment. If the size singleton was prioritized even on target-singleton trials that followed nontarget-singleton trials, which would not be predicted by the priming account, then the mean RT on those trials also should be significantly lower than the mean RT of the nontarget-singleton trials (which are shown in Figure 3). A t test revealed that the mean RT for the target-singleton trials that followed a nontarget-singleton trial (710 ms for NS-C as trial $n - 1$, and 705 ms for NS-O as trial $n - 1$) were faster than the mean RTs for the nontarget-singleton trials (783 ms for NS-C; 786 ms for NS-O) and all four t tests were significant, $p < .0125$ (Bonferroni-corrected for multiple comparisons). The mean RT effects of the singleton seen in Figure 3 were driven just as much by trials preceded by a different trial type, and it is hard to conceive how this could be attributed to priming.

Further Analysis and Discussion

The main result was that the irrelevant-size singleton influenced the prioritization of the objects in the display. The size singleton was more likely to be attended first. As evidenced by the significant interaction between display numerosity and trial type, the target was processed more efficiently if the size singleton coincided with it, but the target was processed less efficiently if the size singleton coincided with a nontarget. This result implies that bottom-up processing is used in search for a conjunction of features. The target-present data presented in Figure 3 are most similar to the predicted detection response times for Strategy 4 in Figure 2, in which participants rely on bottom-up processing of the display to find the target object. Furthermore, it appears that the participants in this main experiment were more likely to respond "absent" when a nontarget (vs. a target) coincided with the singleton (see Table 1). This also suggests that participants were more likely to attend to the size singleton because it resulted in their missing the target more often when the size singleton did not coincide with the target.

Strategic control: Bottom-up processing of the display or subset-selective search? The significant interaction between display numerosity and the nontarget-singleton trial types leads to an interesting question: Were the participants in this main experiment attending to the entire display and using the irrelevant-size singleton to prioritize items for further processing, or were they attending to a subset of the items (e.g., the target-defining color) and searching for a singleton within that subset (e.g., the unique orientation within the target-defining color subset)? The data were examined for split-half reliability because if the participants are engaging in a strategy in which they attend to the color subset and search for a singleton within that subset, then this strategy should be consistent between participants and within an individual's data set.

The scores are displayed in a scatterplot in Figure 4, in which

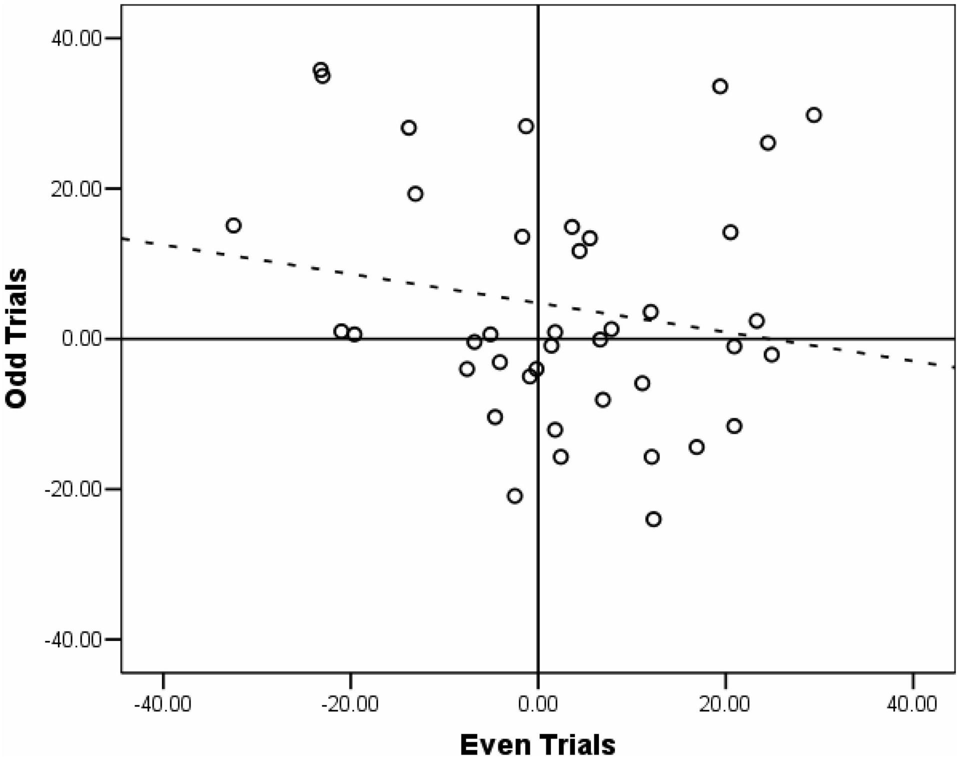


Figure 4. Scatterplot of the difference of the nontarget-color slope minus the nontarget-orientation slope for each participant.

the even trials are on the x-axis and the odd trials are on the y-axis. The slopes for the nontarget-trial types were compared to see whether the participants maintained the same strategy, which would be indicated by having one slope (e.g., the nontarget-color slope) greater than the other slope (e.g., the nontarget-orientation slope). The difference between the slopes (nontarget-color minus nontarget-orientation) resulted in two scores for each participant, one for the odd trials and one for the even trials. The dotted line is the linear best fit for the data. Participants used no reliable strategy; this observation was supported by a Pearson correlational analysis that did not reach significance, $r = -.18$, $p > .25$. As Figure 4 also makes clear, however, some participants were using a consistent strategy. This suggests that the apparent support for Strategy 4 (Figure 2) might actually arise from a mixture of both types of Strategy 3 and Strategy 4. In either case, the data support the notion that the participants relied on bottom-up guidance; the following experiments may provide some insight into which strategy is more prominent.

Explicit instructions for subset search. As a follow-up, I performed three experiments with a new set of participants for each. In the first experiment, I attempted to have all participants engage in a strategy of searching within the orientation subset ($n = 10$) or the color subset ($n = 10$) by giving them instructions to do so. All participants searched for a target that was green and right tilted (45°). Nontargets were green and left tilted (–45°) or blue and right tilted. Participants were randomly assigned to one of two conditions (10 per condition), with a different set of instructions for each condition: (a) Participants were instructed to search for the target among the color (green) subset; (b) participants were instructed to search for the target among the orientation (right-tilted) subset. Similar to the main experiment, separate ANOVAs for the data in Figures 5A and 5B exhibited a significant interaction of display numerosity by trial type: $F(6, 54) = 3.9, p < .01$ for the color-instructed group and $F(6, 54) = 3.1$, $p < .05$ for the orientation-instructed group. The main consideration here, however, was the effect of instructional condition. Taking the data in Figures 5A and 5B as a whole, there were main effects of display numerosity, $F(2, 36) = 155.6, p < .01$, and trial type, $F(3, 54) = 6.9, p < .01$, but the main effect of instructional condition failed to reach significance, $F(1, 18) = 2.4$, $p > .10$. The interactions of display numerosity by instructions, $F < 1$; trial type by instructions, $F = 1.3$, $p > .10$; and the three-way interaction, $F = 1.5$, $p > .10$, all failed to reach significance (keep in mind that fewer participants were used in the follow-up studies; the statistical power is reduced here compared with the main experiment). Because there was no reliable effect of the instructional manipulation, the conditions were combined for further analyses and are displayed in Panel 5C. There were significant effects of trial type, $F(2, 38) = 11.3$, $p < .01$; display numerosity, $F(2, 38) = 144.4$, $p < .01$; and Trial Type × Display Numerosity interaction, $F(4, 76) = 3.9, p < .01$. The results are shown in Figure 5. The data are surprisingly similar to the main experiment and, thus, indicate that participants did not adhere to one search strategy, as instructed.

Increased orientation heterogeneity: Implicit motivation for subset search? In the second experiment, I made an implicit attempt to affect the search strategies used by the participants ($n = 12$) by introducing additional orientation heterogeneity to the display. The stimuli and results are shown in Figure 6. All target-colored (green) nontargets were oriented 45° to the left, but the

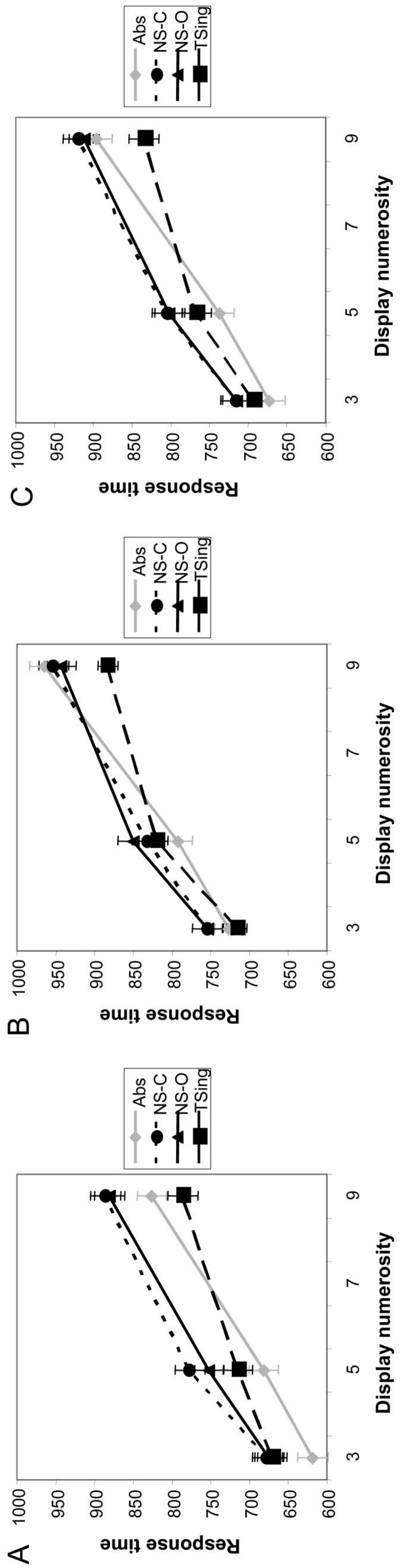
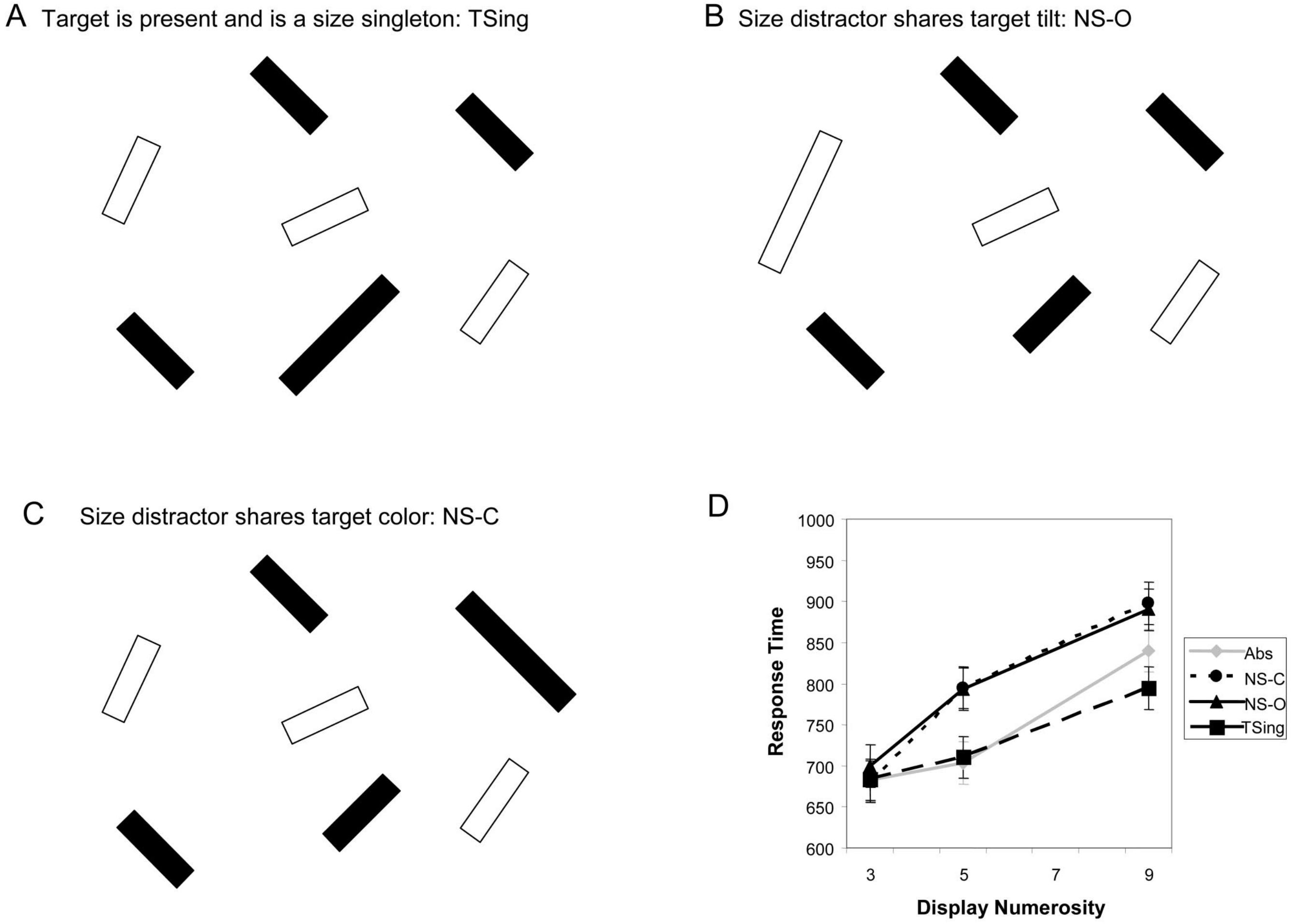


Figure 5. Response times plotted for the first follow-up experiment by instructional condition and with the data collapsed across instructional conditions. A: Color–subset instructional condition. B: Orientation–subset instructional condition. C: Collapsed across instructional conditions. The apparatus and stimuli were the same as those of the main experiment, except only one condition was used. Abs = target absent; NS-C = nontarget singleton-color; NS-O = nontarget singleton-orientation; TSing = target singleton.


A Target is present and is a size singleton: TSing

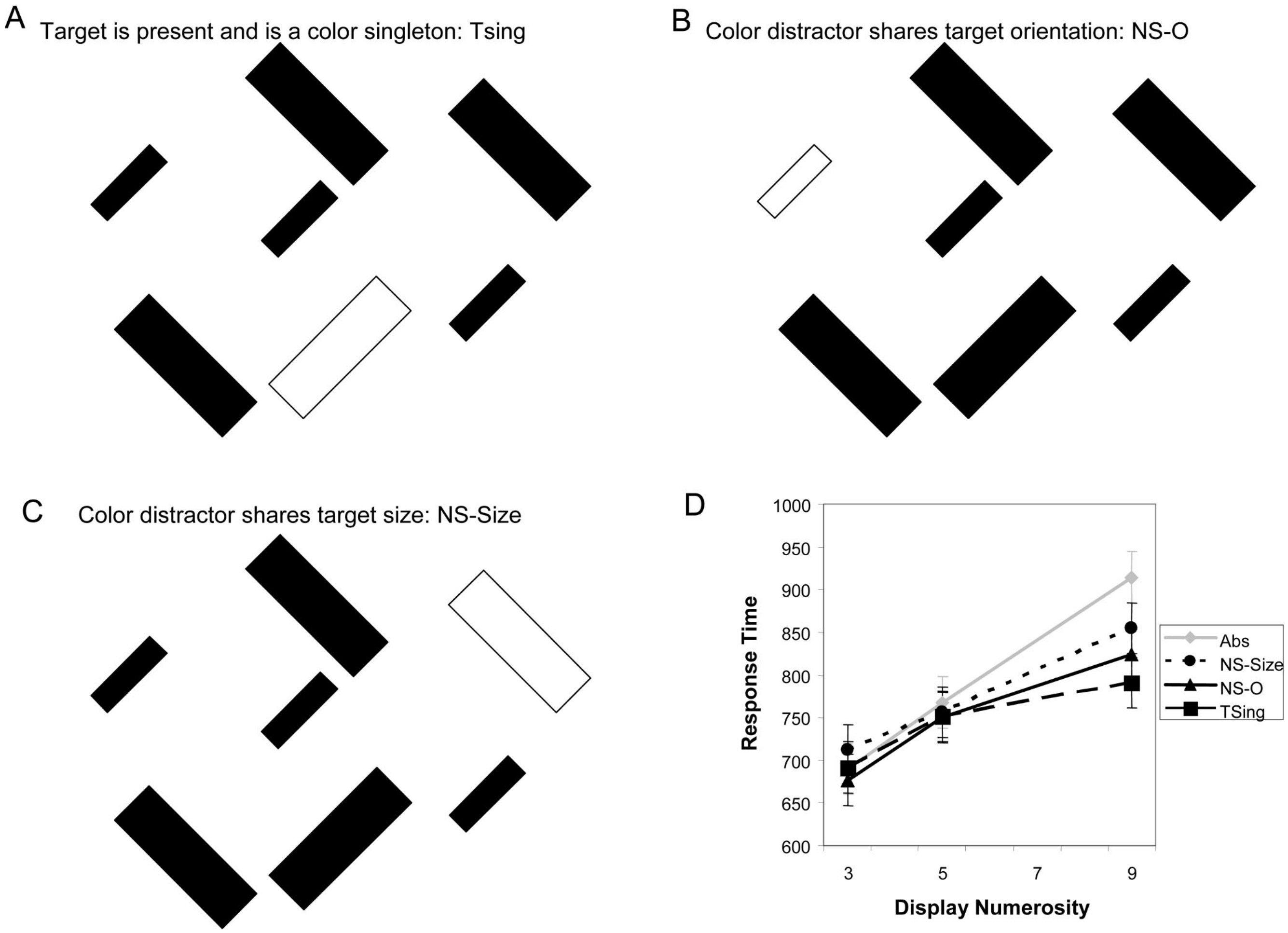
B Size distractor shares target tilt: NS-O

C Size distractor shares target color: NS-C

Figure 6. A: Example of the target-present trials in the second follow-up experiment. The target is shown as the right-tilted black bar. A target is present and also is the size singleton. B: A nontarget that does not share the target's color is the size singleton. C: A nontarget that shares the target color is the size singleton. D: The response times for the second follow-up experiment are plotted as a function of display numerosity and trial type: target absent (Abs), nontarget singleton-color (NS-C), nontarget singleton-orientation (NS-O), and target singleton (TSing).

right-tilted (blue) nontargets could be either 25°, 35°, 55°, or 65° to the right. There were significant effects of trial type, $F(2, 22) = 14.4$, $p < .01$; display numerosity, $F(2, 22) = 46.4$, $p < .01$; and Trial Type × Display Numerosity interaction, $F(4, 44) = 7.5$, $p < .01$. Search was most efficient on the target-singleton trials (19 ms/item) and less efficient for the nontarget-singleton trials (NS-C: 35 ms/item; NS-O: 31 ms/item). The additional clutter would make selecting the subgroup defined by the target's orientation extremely unlikely; however, selectively searching the items that matched the target's color would be simple. However, the results indicated, that, similar to the main experiment and the follow-up experiment just described, participants relied on bottom-up processing across all items in the display and apparently did not restrict processing to just a subset of the items (see Figure 6).

Importance of target versus distractor salience. I conducted a third and final follow-up experiment to examine the generality of the findings of the previous experiments to a new combination of features that define the target, the nontargets, and the irrelevant feature singleton. The target was now defined as a conjunction of size and orientation, and an irrelevant color singleton was presented at each trial (see Figure 7A). All participants ($n = 11$) searched for a target that was large and right tilted at 45°. Nontargets were large and left tilted at −45° or small and right-tilted. For this experiment, the irrelevant singleton was defined by color. Although most of the bars were blue, one bar was red on each trial. The small bars were the same size as those used in the prior experiments, subtending 0.6° of visual angle in length and 0.15° in width. In contrast, the large bars subtended 1.2° of visual angle in length and 0.3° in width. The results are shown in Figure 7D. The target-present data revealed significant effects of trial type, $F(2, 20) = 5.7$, $p < .05$, and display numerosity, $F(2, 20) = 58.2$, $p < .01$; however, the Trial Type × Display Numerosity interaction failed to reach significance, $F(4, 40) = 1.54$, $p > .20$. The results suggest that the relatively high salience of the large target (cf. Braun, 1994) was strong enough to overcome the relatively low



A Target is present and is a color singleton: Tsing

B Color distractor shares target orientation: NS-O

C Color distractor shares target size: NS-Size

D

Figure 7. A: Example of the target-present trials in the final follow-up experiment. The target is shown as the large, right-tilted bar. A: The target is present and also is the color singleton. B: A nontarget that shares the target's orientation is the color singleton. C: A nontarget that shares the target size is the color singleton. D: The response times for the final follow-up are plotted as a function of display numerosity and trial type: target absent (Abs), nontarget singleton-size (NS-Size), nontarget singleton-orientation (NS-O), and target singleton (TSing).

salience of the color singleton (cf. Yantis & Egeth, 1999). Note that I am not claiming that size singletons are more salient than color singletons but rather that the salience of the target versus that of the distractor is a key determinant of whether this method will be sensitive to the reliance on bottom-up guidance, as has been found in previous research (e.g., Proulx & Egeth, in press; Theeuwes, 1992).

General Discussion

The main finding of this study was that the irrelevant-size singleton influenced the prioritization of the objects in the display. An implication of this result is that participants were using bottom-up processing to guide attention across all objects in the display while engaged in visual search for a conjunction of features.

Duncan and Humphreys (1989) suggested that objects are analyzed not at the level of individual features, as proposed by the feature-integration theory of attention (Treisman & Gelade, 1980), but at the object level, where features or "structural units" are bound together as a coherent, whole, object. Because the target in the present conjunction search tasks was unique at the object level, it seems that participants might be engaging in a strategy to detect the unique item in the display, possibly consistent with Duncan and Humphreys.

One can use GS (Wolfe, 1994) to account for these results with a modification to how conjunction search is modeled. The current version of Wolfe's model has the activation map consider those features that are relevant to the task only when the participant searches for a conjunction of features. Other feature maps that are irrelevant, such as size, are effectively ignored. The experiments in this study reveal that participants are relying on bottom-up feature contrast in a conjunction-search task. This result suggests that bottom-up activation is indeed active and that irrelevant maps are not suppressed. To satisfy the current results, GS would have to account for participant strategies that use additional information from irrelevant feature maps.

There are two additional limitations to the models by Duncan and Humphreys (1989) and Wolfe (1994). Both include the use of a target template that is defined by the task instructions. In this study, the target template would not match the target when it coincides with the size singleton. Thus, the faster RTs that occurred when the target coincided with the size singleton would need explanation. A second limitation of these models is that they did not attempt to explain how irrelevant or additional singletons would affect search efficiency. Therefore, it is difficult to predict capture results from these models. These results would be consistent, however, with computational models of overt attention (e.g., Koch & Ullman, 1985).

The evidence for bottom-up processing in this study should not be taken as support for an automatic or involuntary mechanism. A participant's search strategy could entail relying on either bottom-up or top-down processing or on a combination of the two. Although top-down processing has been taken to imply strategic attentional control (cf. Folk et al., 1992; Theeuwes, 2004), there is substantial evidence that a participant can strategically rely on bottom-up processing (e.g., Bacon & Egeth, 1994). Thus, it is important, from a theoretical standpoint, that researchers distinguish the contribution of bottom-up and top-down inputs to an activation map for attentional prioritization, such as those described by Wolfe (1994), from the independent contribution of a participant's search strategy to selectively rely on one or both types of input to guide attention to the target.

In summary, the available strategies that participants can use to find the target in a search task can influence the role of top-down and bottom-up processing. The experiments presented in this study reveal that bottom-up processing plays a role in visual search for a conjunction of features. On a practical level, this study offers a method for probing the relative role of these processes through the use an irrelevant singleton, which is also important for understanding the neural correlates of visual search (e.g., Leonards, Sunaert, Van Hecke, & Orban, 2000). On a theoretical level, the surprising evidence that bottom-up processing guides attention in conjunction search will need to be addressed by models of visual search.

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