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Not All Features Are Created Equal: Processing Asymmetries between Location and
Object Features

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Abstract

Previous research has shown spontaneous location processing when location is not a task relevant feature and when a target is presented together with distractors. The present study investigates whether such processing can occur in the absence of distractor inhibition, and whether there is a processing asymmetry between location and an object feature. The results show that not all features are created equal. Whereas attending to an object's color or texture led to the involuntary processing of that object's location, attending to an object's location did not necessarily result in the encoding of its color or texture when these nonspatial properties were not task relevant. These results add to the body of evidence demonstrating the special role of location in attentional selection. They also provide a clearer picture of the interactions among location, object features, and participants' behavioral goals.

Precuing the location of a stimulus reduces the time to respond to that stimulus at the cued location relative to a different location (Jonides, 1981; Posner, Snyder, & Davidson, 1980). Knowing the color of a target beforehand in visual search enables observers to enhance search efficiency by limiting search to items of the target color (Carter, 1982; Egeth, Virzi, & Garbart, 1984). These findings suggest that attentional selection can be based on location as well as on nonspatial object features. However, although both can guide attention, these two types of selection are not equally effective (Bongartz & Scheerer, 1976; Sperling, 1960, 1963) or have the same perceptual consequences (Bashinski & Bacharach, 1980; Moore & Egeth, 1998). The present research investigates another difference between the two: the processing asymmetries between location and color, and location and texture.

Using stimulus displays that consisted of multiple items, previous studies have reported evidence for spontaneous location processing when attention is paid to an object feature such as color or form (Cave & Zimmerman, 1997; Cepeda, Cave, Bichot, & Kim, 1998; Kim & Cave, 1995, 1999a, 1999b; Tsal & Lavie, 1993). What is less clear is whether such processing can occur when there is no need for distractor inhibition, and whether attending to an object's location would also lead to the processing of an object feature. Knowing the relationship between the selection of location and object features is important because it helps to shed light on the mechanisms that underlie feature processing in visual selection. The experiments in this paper focus on two issues: (1) whether the processing of an object's color or texture entails the processing of that object's location regardless of task relevancy, and vice versa and (2) whether such processing interacts with participants' behavioral goals.

Attentional Guidance. Evidence for location-based attentional guidance has been reported in many studies. Participants are typically faster and/or more accurate to respond to a stimulus that appears at a location indicated by a precue relative to a different location (Henderson, 1996; Jonides, 1981; Posner et al., 1980). They are more likely to report a stimulus if it is near the location of a primary target than if it is farther away (Hoffman & Nelson, 1981; Tsal & Lavie, 1988, 1993). Furthermore, when a target is flanked by response incompatible distractors, interference decreases with increase in the spatial proximity between the target and the distractors (Eriksen & Hoffman, 1973; Eriksen & Eriksen, 1974; Gatti & Egeth, 1978). These results suggest that location plays an important role in attentional guidance.

In addition to location, attention can also be guided by object features such as color and form (Bacon & Egeth, 1994, 1997; Carter, 1982; Egeth et al., 1984; Kaptein, Theeuwes, & van der Heijden, 1995; but see Shih & Sperling, 1996; Theeuwes, 1993). Kaptein et al. (1995, Experiment 4) asked participants to search for a red target among red and green distractors. Search time on the target-present trials increased with the number of red distractors, but not with the number of green distractors. This result suggests that participants used color to guide attention to limit search to items of the target color. Similar results have been reported by Carter (1982), and Egeth and colleagues (Bacon & Egeth, 1997; Egeth et al., 1984).

Selection Efficiency and Perceptual Consequences. Although location and object features can both guide attention, several studies have shown that selection by location is more efficient than selection by an object feature (Bongartz & Scheerer, 1976; Sperling, 1960, 1963; von Wright, 1968, 1970, 1972; but see Nissen, 1985, Experiment 1). Using a partial report technique that required participants to respond to a subset of stimuli, Sperling (1960) assessed the amount of information participants

had at the time of selection before decay occurred. When he compared their performance with the performance obtained through a whole report technique that required responses to all stimuli, he found a partial report advantage, i.e., more stimuli could be reported in the partial than in the whole report when the response cue was based on location (e.g., to report stimuli in a specific row or column), but not when it was based on category (e.g., to report either letters or numbers). Related results were observed by von Wright (1968, 1970, 1972), who investigated selection by location, color, size, and orientation. Although a partial report advantage was found when the selection cue was location, color, or size (but not orientation), the magnitude of the effect was greater for location than for the other features. In addition, selection by location is faster than selection by color (Bongartz & Scheerer, 1976), and is the preferred mode of processing when several modes of selection are available (Tsal & Lavie, 1988, 1993; von Wright, 1968).

Selection by location also differs from selection by an object feature in perceptual consequences. There is evidence that location-based attention enhances the sensory quality of a stimulus. It has been shown that participants are more accurate in detecting a stimulus, and in performing discrimination tasks concerning brightness, orientation, and form, when the target stimulus occurs at or near a cued location relative to a location which is farther away (Bashinski & Bacharach, 1980; Downing, 1988). Cuing the location of a stimulus also increases the contrast sensitivity of that stimulus (Carrasco, Ling, & Read, 2004; Carrasco & Pestilli, 2005). These results suggest that location-based attention alters the appearance of a stimulus by enhancing its signal-to-noise ratio.

Contrary to location-based attention, feature-based attention appears to facilitate information processing through priority in visual search. Moore and Egeth

(1998) show that knowing a target's color improves visual search time when performance is under speed pressure and the target-distractor signal-to-noise ratio is high. However, the knowledge of color has no effect on performance when the signal-to-noise ratio between the target and distractors is low and accuracy rather than reaction time (RT) is emphasized. Given that performance is determined almost exclusively by the sensory quality of stimuli in the latter case (Norman & Bobrow, 1975), these results suggest that feature-based attentional effect arises from changes in search strategy so that stimuli that share the target feature are attended to first. This may explain, at least in part, why feature-based attentional effect is found in some experiments (Bacon & Egeth, 1994, 1997; Carter, 1982; Egeth et al., 1984; Kaptein et al., 1995) but not in others (Shih & Sperling, 1996; Theeuwes, 1993).

Does Location Have a Unique Role in Visual Attention? The question whether location has a unique role in visual attention is a complex one (see Lamy & Tsal, 2001, for a review). On the one hand, both location and object features can guide attention. Cuing an object's location in advance decreases the response latencies of detecting a target at the cued location relative to an uncued location (Eriksen & Hoffman, 1973; Eriksen & Eriksen, 1974). Informing participants the color of a target allows them to ignore distractors of a different color (Kaptein et al., 1995). On the other hand, location-based selection enables participants to report more items than feature-based selection (Bongartz & Scheerer, 1976). Moreover, whereas spatial attention enhances participants' sensory representation of a stimulus (Carrasco et al., 2004; Downing, 1988), feature-based attention facilitates processing by assigning higher priority to the relevant stimuli in visual search (Moore & Egeth, 1998). These results highlight the similarities and differences between location and object features in visual attention.

An important piece of evidence for the unique role of location is the finding of location processing even when location is not a task relevant attribute (Cepeda et al., 1998; Cave & Pashler, 1995; Cave & Zimmerman, 1997; Kim & Cave, 1995; Tsal & Lavie, 1993). In a series of experiments, Cave and colleagues (Cave & Zimmerman, 1997; Kim & Cave, 1995) showed participants stimulus displays that consisted of a target and several distractors. The primary task was to search for a target defined by a specific feature such as color or form. On most trials, the search display was followed by a delay, and participants withheld their responses during the delay until the appearance of a response prompt. On some trials, however, the target display was followed immediately by a small probe, and the task was to make a speeded response to the probe (a detection task) before doing the search task. Probe RT was faster when the probe was at a location previously occupied by a target than by a distractor. Because location was task irrelevant, this result suggests spontaneous location processing when an object's color or form is selected. Related findings have also been reported by Cave and Pashler (1995), and Tsal and Lavie (1993).

A common feature of the above studies is that the critical display consisted of both the relevant and irrelevant objects. Previous research has shown that the degree of attentional modulation differs as a function of the presence or absence of distractors (Chelazzi, Miller, Duncan, & Desimone, 2001; Moran & Desimone, 1985), suggesting that inhibition plays an important role in attentional selection (Desimone & Duncan, 1995). Given the role of inhibition, it is important to determine that location selection is an inherent part of visual attention and can therefore also occur without the presence of distractors. In the experiments reported here, all the displays consisted of a single stimulus. Because inhibition need not be evoked when a display contains no distractors (Chen & Treisman, 2008), evidence of location selection when

attention is focused on an object feature will provide strong support for spontaneous location processing regardless of behavioral goals.

A related question concerning the uniqueness of location in visual attention is whether the relationship between the selection of location and object features is a reciprocal one. In other words, whether attending to location would also lead to the processing of nonspatial visual properties such as color and form. Several researchers have examined this issue (Bloem & van der Heijden, 1995; Chen, 2005; Johnston & Pashler, 1990). Johnston and Pashler (1990) showed participants brief stimulus displays that consisted of multiple colored letters. Participants searched for a target defined by either color or form (the identity response), and then indicated the location of the target (the location response). Accuracy was the dependent measure. After correction for guessing, there was no evidence of identity perception without location. In contrast, location was correctly identified on about 10% of the trials while the identity responses were wrong. These results suggest that whereas identity perception is contingent upon location perception, location perception does not necessarily require identity perception. Similar findings were reported by Bloem and van der Heijden (1995). However, because participants were required to report both the target's identity and its location on each trial, the observed asymmetries could reflect differences in featural selection, in memory retrieval, or in both.

Chen (2005, Experiment 4) also reported a processing asymmetry between location and an object feature. Her participants saw a non-informative distractor followed by a target. When location was the irrelevant distractor feature and participants were reporting the form of a target, location affected responses. However, when form was the irrelevant distractor feature and participants were reporting the location of the target, form did not influence responses. These results indicate a

processing asymmetry between location and form. Unfortunately, because the main purpose of the study was to investigate the degree of processing of a non-target object, the participants were not required to encode the distractor. Given that the extent of processing of a task irrelevant feature can be influenced by the status of an attended object as being a target or a distractor (Remington & Folk, 2001; but see Chen & Cave, 2006), it is unclear whether similar processing asymmetries between location and object features would be generalized to task relevant stimuli.

The present experiments investigate whether in the absence of distractor inhibition the processing of an object's color or texture entails the processing of its spatial location and vice versa, and whether such processing interacts with participants' behavioral goals. In all experiments, participants saw stimulus displays that consisted of a fixation, a go/nogo response cue, and a letter target. The function of the go/nogo response cue was to ensure that participants attended to a specific feature of the cue. The task was to make a speeded response to the target on the basis of the cue (e.g., to judge whether the target was a T or a V when the response cue was red, but to refrain from responding when the response cue was green).

There were two principal independent variables in each experiment. The first independent variable (a within-block one) was the relationship between the irrelevant features of the cue and the target (e.g., their locations in successive displays). They were the same on half of the trials (the same condition) and different on the other half (the different condition). If one assumes that participants would process the relevant feature of the cue due to the go/nogo requirement (e.g., color), by computing the differences in participants' RTs between the same and different conditions, we could make inferences regarding the processing of the irrelevant feature of the cue (e.g., location) when attention was paid to its relevant feature (e.g., color). This is because

the only difference between the two conditions was the location of the cue relative to the target. Of course, participants would also attend to the relevant feature of the target (e.g., the form of the target if the task was to discriminate a T from a V). However, because all the processes that are involved in the encoding of, and responding to, the target are identical between the same and different conditions, the differences in participants' response latencies between the two conditions should reflect differences regarding the irrelevant feature of the cue only (see Donders, 1868/1969, for his discussion on the subtraction method). If RTs were faster in the same condition than in the different condition, that would suggest the processing of the irrelevant feature of the cue. Otherwise, there should be no difference between the two conditions.

The second independent variable (a between-block one) was the participants' task. In all the experiments, participants responded to one feature of the target in one block (e.g., form), and to a different feature of the target in the other block (e.g., location). The two tasks were chosen in such a way that the irrelevant dimension of the cue (e.g., location) was a response relevant feature in one task (e.g., a location judgment task), but a response irrelevant feature in the other task (e.g., a form judgment task). By varying the task, we could assess whether the processing of the irrelevant feature of the cue was a function of participants' behavioral goals.

Experiments 1A - 1C examined the relationship between location and color. Experiments 2A and 2B focused on location and texture. Experiments 3A and 3B sought to rule out the hypothesis that the results of Experiments 1A and 1B were caused by differential processing efficiencies between location and color. Together, these experiments provided a direct assessment of the roles of location, object features, and their interactions with behavioral goals.

Experiment 1A

Experiment 1A investigated location processing when color was attended. The go/nogo criterion was the color of the cue (red or green). The location of the cue relative to the target was manipulated so that they were the same on half of the trials (the same condition) and different on the other half (the different condition). The task was to determine the location of the target (left or right) in one block (the location task), and the form of the target (T or V) in the other block (the form task). Thus, whereas location was task relevant in the location task, it was task irrelevant in the form task. Because participants did not need to encode location in the form task, faster RTs in the same than the different condition would indicate spontaneous processing of location when color was attended. Furthermore, a comparison of participants' pattern of responses in the form and location tasks would reveal the extent to which location selection was modulated by behavioral goals.

Method

Participants. Ten University of Canterbury undergraduate students volunteered for the experiment.¹ Each was paid NZ\$10. All of them reported to have normal or corrected-to-normal vision.

Apparatus and stimuli. A Power Macintosh 6100/66 computer with a 13-in RGB monitor was used to display stimuli and to record responses. All stimuli were presented against a gray background. Participants were individually tested in a dimly lit room. The viewing distance was approximately 60 cm.

Each trial consisted of a fixation, a response cue, and a target (see Fig. 1²). The fixation was a small black cross of 0.76° at the center of the computer screen. The

response cue consisted of a pair of vertically aligned black or white bars at 6.3° left or right of fixation. Each bar was 1.24° in length and 0.29° in width, and the two bars were separated by 3.8° . The target, which was centered at 6.3° left or right of fixation, was a yellow capital letter T or V written in 60-point Geneva font.

Insert Figure 1 about here

Design and Procedure. The experiment was a 2x2 within-subjects design, with the principal manipulations being the cue-target location (same vs. different, a within-block manipulation) and the task (form vs. location, a between-block manipulation). Half of the participants responded to the target when the cue was white, and they refrained from responding when the cue was black. This was reversed for the other half of the participants. Three-fourths of the trials were “go” trials, with the rest of them “nogo” trials. All participants performed a form discrimination task (T vs. V) and a location discrimination task (left vs. right). The order of the tasks was counterbalanced across the participants.

Each trial started with a 1005 ms fixation at the center of the screen, followed by a 120 ms display of the response cue on the left or right side of the screen with equal probability. Upon the offset of the cue, the target was shown for 120 ms. The target was equally likely to be at the same location as the cue or at a corresponding location on the other side of fixation.

The experiment consisted of two blocks of 192 trials, with 24 practice trials before each block. On the “go” trials, participants pressed one of two labeled keys on the keyboard. In the form task, the keys were “.” for T and “/” for V. In the location task, the same keys were used, with “.” indicating left and “/” indicating right. On the

“nogo” trials, they pressed the space bar to proceed to the next trial. Both speed and accuracy were emphasized for the “go” trials, but only accuracy was stressed for the “nogo” trials. The importance of maintaining fixation throughout an entire trial was emphasized. While participants were doing the practice trials, the experimenter stood at a location where the participant’s eye movements could be observed. They were reminded of the “no eye movement” requirement whenever an overt eye movement was detected, and were given additional practice trials if it was deemed necessary.

Results and Discussion

The mean RT and accuracy data are shown in Table 1. Two repeated-measures analyses of variance (ANOVA), one on RT and the other on accuracy, were conducted. Participants were faster in the location discrimination task (425 ms) than in the form discrimination task (498 ms) [$F(1, 9) = 18.69$, $MS_e = 2890.26$, $p < .01$]. They were also faster and more accurate when the target occurred at the same location as the cue (448 ms with 3.3% error) than at a different location from the cue (474 ms with 7.0% error) [RT: $F(1, 9) = 58.37$, $MS_e = 116.68$, $p < .001$; Accuracy: $F(1, 9) = 5.47$, $MS_e = 24.89$, $p < .05$]. Furthermore, the magnitude of the location effect was larger when the task was location (43 ms) than when it was form (9 ms) [$F(1, 9) = 16.58$, $MS_e = 177.03$, $p < .01$]. Further analyses revealed that the location effect was significant in both the location and form tasks [$t(9) = 6.09$, $p < .001$ and $t(9) = 3.09$, $p < .05$, respectively]. No other results reached significance.

Insert Table 1 about here

Consistent with prior research (e.g., Kim & Cave, 1995; Tsal & Lavie, 1993), Experiment 1A indicates spontaneous processing of the location of a cue stimulus even when location was not task-relevant when participants attended to the color of the cue to determine whether to respond or not. Moreover, because none of the displays in the experiment contained any distractors, the location effect could not be attributed to a by-product of distractor inhibition. Interestingly, although location selection was spontaneous, its degree of processing was still influenced by participants' behavioral goals, as indicated by a larger effect when location was a task relevant rather than a task irrelevant attribute.

Experiment 1B

Experiment 1A found evidence for location processing when attention was paid to the color of the response cue. Experiment 1B examined whether attending to the cue's location would also lead to the processing of its color. To ensure that participants would encode the location of the cue, the "go/nogo" criterion was based on location. The color of the response cue relative to the target was varied so that they were the same on half of the trials (the same condition) and different on the other half (the different condition). As before, participants completed two blocks of trials. In one block, the task was to judge the color of the target (the color task). In the other block, it was to judge the identity of the target (the form task). Thus, whereas color was task relevant in the former condition, it was task irrelevant in the latter condition. If processing an object's location entails the processing of that object's color regardless of task relevancy, participants should be faster in the same condition than in the different condition in both the form and the color tasks. However, if color processing

is task dependent, the color effect would be found in only the color task, but not the form task.

Method

The method of Experiment 1B was the same as that of Experiment 1A except for the following changes (see Figure 2). First, the “go/nogo” decision was location-based: half the participants responded to the target when the response cue was on the left side of fixation, and vice versa for the other half of the participants. Second, the cue and the target could either be red or green. They had the same color on half the trials, and different colors on the other half. Third, whereas the cue could appear on the left or right of fixation as in Experiment 1A, the target always appeared at the center. Finally, the two tasks were letter discrimination (T vs. V) and color discrimination (red vs. green) in different blocks. Twelve new volunteers from the same participant pool took part in the experiment.

Insert Figure 2 about here

Results and Discussion

The results are illustrated in Table 2. ANOVA on RTs showed faster responses in the form task (515 ms) than in the color task (571 ms) [$F(1, 11) = 10.93$, $MS_e = 3398.75$, $p < .01$], and when the cue and the target had the same color (535 ms) than when they had different colors (551 ms) [$F(1, 11) = 9.47$, $MS_e = 330.61$, $p < .05$]. There was also a significant interaction between task and color [$F(1, 11) = 12.01$, $MS_e = 291.76$, $p < .01$]. Whereas the effect of color was reliable in the color task (33 ms)

[$t(11) = 3.43, p < .01$], it was negligible in the form task (-1 ms) [$t < 1$]. No significant effects were found in the accuracy data.

Insert Table 2 about here

The main finding of Experiment 1B was that color was processed only when it was a task relevant attribute. Taken together, the results of Experiments 1A and 1B showed a processing asymmetry between location and color. Whereas encoding the cue's color resulted in the selection of the cue's location regardless of task relevancy (even though the degree of location processing was still modulated by participants' behavioral goals), encoding the cue's location did not automatically lead to the processing of the cue's color. These results suggest that location selection is the default way of attentional selection in the visual system. In contrast, selection by color is employed only strategically when doing so benefits the behavioral goal.

Experiment 1C

Experiments 1A and 1B established the existence of a processing asymmetry between location and color. However, before we investigate its generality in the next two experiments, it would be prudent to determine whether the observed asymmetry was specific to the short cue-target stimulus onset asynchrony (SOA) used in the previous experiments. There is some evidence in prior research that the deployment of feature-based and location-based attention has different time courses, with feature-based attention rising later than location-based attention (Anllo-Vento & Hillyard, 1996; Liu, Stevens, & Carrasco, 2007; but see Hopf, Boelmans & Schoenfeld, 2004). In both Experiments 1A and 1B, the cue-target SOA was 120 ms. If location-based

attention developed within 120 ms but color-based attention did not unless color was a task relevant feature, participants would show evidence of location processing but not that of color processing in the form task.³ To address this issue, Experiment 1C was conducted with a much longer cue-target SOA than that in Experiment 1B.

Method

Experiment 1C was identical to Experiment 1B except for the cue-target SOA. A blank interval of 390 ms was inserted between the offset of the cue and the onset of the target, resulting in a cue-target SOA of 510 ms.⁴ As in Experiment 1B, the “go/nogo” decision was based on location; the cue and the target had the same color on half the trials (the same condition) and different colors on the other half (the different condition); and the two tasks were letter discrimination (T or V) and color discrimination (red or green) in separate blocks. If the null result observed in the form task of Experiment 1B was caused by the short cue-target SOA, we should find a significant color effect in the present experiment. However, if the null result was due to the nature of color selection when attention was paid to location, no difference in RTs should be observed between the same and different conditions. Thirteen new volunteers took part in the experiment.

Results and Discussion

Table 2 shows the results. One participant’s data were not included in the analyses because of high error rates that exceeded 50% in two conditions. An ANOVA on RTs indicated faster response latencies in the form task (479 ms) than in the color task (534 ms) [$F(1, 11) = 9.07$, $MS_e = 4060.48$, $p < .05$], and when the cue and the target had the same color (499 ms) than when they had different colors (514

ms) [$F(1, 11) = 6.00$, $MS_e = 422.42$, $p < .05$]. Although the interaction between task and color was not significant [$F(1, 11) = 1.54$, $MS_e = 590.19$, $p > .20$], two separate t tests were conducted to determine the degree of color processing in the two tasks. A significant effect was found in the color task (22 ms) [$t(11) = 1.93$, $p < .05$], but not in the form task (6 ms) [$t(11) = 1.18$, $p > .10$]. There were no reliable effects in the accuracy data.

The most important finding of Experiment 1C is the replication of the null result observed in the form task of Experiment 1B. In both experiments, participants showed no evidence of processing the color of the response cue when their attention was paid to the cue's location. Because the cue-target SOA was 510 ms in the present experiment, it seems unlikely that the processing asymmetry found in Experiments 1A and 1B was caused by a short SOA.

One may notice that Experiments 1B and 1C differed in one aspect of data. Whereas the task by color interaction was significant in Experiment 1B, it was not significant in Experiment 1C. To determine whether the pattern of data between the two experiments had qualitative differences, I conducted a combined analysis on RTs across the experiments. A mixed ANOVA revealed significant main effects of task [$F(1, 22) = 19.84$, $MS_e = 3729.62$, $p < .01$] and color [$F(1, 22) = 15.00$, $MS_e = 376.51$, $p < .01$], and a two-way interaction between task and color [$F(1, 22) = 9.06$, $MS_e = 440.98$, $p < .01$]. However, there was no significant effect involving experiment, suggesting that the pattern of data between Experiments 1B and 1C did not differ in a qualitative way. In light of these results, it seems safe to conclude that in the present paradigm spontaneous processing of color does not occur when attention is paid to an object's location.

Experiment 2A

Experiments 2A and 2B tested the generality of the processing asymmetry found in the previous experiments. Experiment 2A investigated location selection when attention was paid to texture (see Figure 3). Accordingly, the “go/nogo” criterion was based on the texture of the cue (dots or dashes). The cue and the target were equally likely to appear at the same location or different locations. The tasks were color discrimination in one block (where location was task irrelevant), and location discrimination in the other block (where location was task relevant). If the processing of the cue’s texture entails the processing of its location, RTs should be faster in the same condition than in the different condition regardless of whether the task was color or location.

Method

The method was the same as that of Experiment 1A with the following differences. First, the go/nogo criterion was based on the texture of the cue, which was made of white bars (the same as those in Experiment 1A) or white dots. Each dot subtended 0.29° in diameter, and the spatial separation between the dots was 1.24° within each pair, and 3.8° between the two pairs. As in the previous experiments, the center of the cue was situated at 6.3° left or right of fixation. Half of the participants responded to the target when the cue was made of dots, and the other half when the cue was made of bars. Second, the target, which was always the letter T, was equally likely to be yellow or green, and appeared at 6.3° left or right of fixation with equal probability. The cue and the target were at the same location on half of the trials (the same condition), and at different locations on the rest of the trials (the different condition). Participants performed a color discrimination task (yellow vs. green) in

one block and a location discrimination task (left vs. right) in the other block. All the other aspects of the method were the same as those in Experiment 1A. Twelve new people took part in the study.

Insert Figure 3 about here

Results and Discussion

Table 3 illustrates the results. RTs were faster when the task was location (500 ms) than when it was color (637 ms) [$F(1, 11) = 66.87$, $MS_e = 3348.40$, $p < .001$], and when the target appeared at the same location as the cue (557 ms) than at a different location from the cue (580 ms) [$F(1, 11) = 6.39$, $MS_e = 996.3$, $p < .05$]. Task and location did not interact [$F < 1$], suggesting that the degree of location processing was comparable in the two tasks. No significant effects were found in the accuracy data.

Insert Table 3 about here

As in Experiment 1A, location selection was found both when it was task relevant and irrelevant. However, unlike the result in Experiment 1A, the magnitude of the location effect was not modulated by the specific task of the participants. I discuss a possible account of this difference in the General Discussion.

Experiment 2B

Method

Experiment 2B tested texture selection when attention was paid to location (see Figure 4). The method was the same as Experiment 2A except for the following changes. The target was either a yellow or green capital letter T at the center of the screen, and it was equally likely to consist of dots or short bars. The “go/nogo” criterion was location (left vs. right). Half the participants responded to the target when the cue was on the left of fixation, and vice versa for the other half. In the same condition, the cue and the target had the same texture (both were made of dots or short bars). In the different condition, they had different textures (one was made of dots, and the other was made of short bars). The two tasks were color discrimination (yellow vs. green) and texture discrimination (dots or bars). If there is a processing asymmetry between location and texture, participants should demonstrate a texture effect in the texture task but not in the color task. Sixteen new participants volunteered for the study.

Insert Figure 4 about here

Results and Discussion

Table 4 shows the results. An ANOVA on RTs revealed a significant main effect of texture [$F(1, 15) = 13.10, MS_e = 163.16, p < .01$], with faster responses when the cue and target had the same texture (488 ms) than when they had different textures (500 ms). In addition, there was a significant task by texture interaction [$F(1, 15) = 5.05, MS_e = 248.39, p < .05$]. While the effect of texture was significant (20 ms) when the task was texture discrimination [$t(15) = 4.68, p < .001$], it was negligible (3 ms) when the task was color discrimination [$t < 1$]. These results suggest that the texture

of the cue was processed only when it was a task relevant attribute. The main effect of task was not significant [$F(1, 15) = 1.37, ns$]. No reliable effects were found in the accuracy data, either.

Insert Table 4 about here

The most important finding of the experiment was the selection of texture as a function of task relevancy. This processing asymmetry between location and texture mirrored the processing asymmetry between location and color in the previous experiments. In both cases, location accompanied the processing of an object feature, but not vice versa.

However, before any conclusions were drawn, it would be beneficial to address another possible alternative account, i.e., the observed processing asymmetries were not caused by inherent differences between location and an object feature, but by a difference in processing efficiency between the two. Inspection of participants' RTs showed that response latencies were generally faster when the task was location than when it was color. There is some evidence in prior research that the processing efficiency of a stimulus can influence the degree of processing of a task irrelevant dimension: the more efficient the processing of a relevant dimension, the less interference it receives from an irrelevant dimension (Chen, 2005; Chen & Cave, 2006). The next two experiments were designed to replicate Experiments 1A and 1B while controlling for differences in response latencies between location and color.

Experiments 3A and 3B

Several measures were taken to minimize the differences in processing efficiency between location and color in Experiments 3A and 3B. First, instead of two locations, the cue and the target could appear at one of four locations. Second, for the location task in Experiment 3A, participants were required to report whether the target was above or below the horizontal meridian instead of left or right of fixation. This change would minimize the possible influence of the Simon effect (Simon, Hinrichs, & Craft, 1970), which refers to faster RTs when there is spatial correspondence between the location of the response keys on the keyboard and the location of the stimuli in the display. Although the Simon effect should not influence the interpretation of the results in the previous experiments because it would have averaged out in the final results, its removal would increase participants' overall responses latencies in the location task. Finally, the color of the cue and the target were changed from red or green in Experiment 1B to black or white in both Experiments 3A and 3B.

The effect of these changes was then empirically verified in a baseline experiment. Ten participants saw stimulus displays that consisted of a 1000 ms fixation followed by a pair of white or black bar for 90 ms. The bars were the same as those used in Experiments 1A-1C except that they were equally likely to appear at one of four corners of an imaginary rectangle that subtended 9.36° in length and 6.88° in width, and that the gap between the two bars was 2.29° . The task was to make a speeded response to the location of the bar (above vs. below) in one block, and to the color of the bar (white vs. black) in a different block. The order of the blocks was counterbalanced across participants. No significant differences were found in RT or accuracy between the location task (402 ms with 4.8% error) and the color task [415 ms with 4.0% error; $t(9) < 1$, *ns*, for RT; and $t(9) = 1.29$, *ns*, for accuracy]. These

results confirmed that with the specific stimuli described above, comparable processing efficiency for color and location could be achieved.

Experiment 3A

Method

The method was the same as that in Experiment 1A except for the following differences. Both the response cue (the same as that used in the baseline experiment) and the target were equally likely to appear at one of four corners of an imaginary rectangle that centered at fixation and subtended 9.36° in length and 6.88° in width (see Figure 5). The target could occur, on an equal proportion of trials, at the same location as the cue (the SS condition), at a different horizontal location from the cue (the DH condition), at a different vertical location from the cue (the DV condition), and at a location diagonal to the cue (the DD condition). Thus, the target matched the location of the cue on 25% of the trials instead of on 50% of the trials as in the previous experiments. The presentation durations for the cue and the target were reduced from 120 ms to 90 ms to minimize overt eye movements within a trial (Alpern, 1972; Mayfrank, Kimmig, & Fischer, 1987). As in Experiment 1A, the go/nogo decision was based on color. Half the participants responded to the target when the cue was white, and the other half responded to the target when the cue was black. The tasks were form discrimination in one block (T or V), and location discrimination in the other block (target above or below the horizontal meridian). Of particular interest was whether RTs would be faster when the location of the target matched that of the cue in both tasks. Twelve new participants took part in the experiment.

Insert Figure 5 about here

Results

The results are shown in Table 5. A 2 x 4 repeated-measures ANOVA on RTs indicated faster RTs in the form task (513 ms) than in the location task (583 ms) [$F(1, 11) = 6.85, MS_e = 16887.3, p < .05$]. There was also a significant effect of location [$F(3, 33) = 10.62, MS_e = 665, p < .001$]. Although there was no significant location by task interaction [$F(3, 33) = 1.04, MS_e = 618.2, ns$], to understand the effect of location in each task, two separate one-way repeated-measures ANOVAs were conducted. A significant location effect was found for both the location task [$F(3, 33) = 6.07, MS_e = 284.5, p < .01$] and the form task [$F(3, 33) = 5.98, MS_e = 998.7, p < .01$]. Subsequent Neuman-Keuls tests indicated that for both tasks, RTs were faster in the SS condition than in the DH, DV, or DD conditions ($p < .05$), and no significant differences were found among the latter three conditions. Thus, the location effect found in Experiment 1A was replicated, although the magnitude of the effect did not vary as a function of task relevancy in the present experiment. (See Experiment 3B for discussion.)

Insert Table 5 about here

For the accuracy data, a similar 2 x 4 repeated-measures ANOVA was conducted. Consistent with the RT data, accuracy was higher in the form task (3.3% error rates) than in the location task (5.1% error rates) [$F(1, 11) = 11.1, MS_e = 6.44, p < .01$]. No other effects reached significance.

Experiment 3B

Method

Experiment 3B examined color selection while attention was paid to location. The method was the same as that in Experiment 1B except that the response cue could appear at one of four locations identical to those used in Experiment 3A, and that the target was equally likely to be white or black (see Figure 6). As in Experiment 1B, the go/nogo decision was based on the location of the cue, with half the participants responding to the target when the cue was above the horizontal meridian, and the other half when the cue was below the horizontal meridian. The two tasks were form discrimination (T vs. V) and color discrimination (black vs. white) in different blocks. The target, which always appeared at fixation, had the same color as the cue on half the trials (the same condition) and different color from the cue on the rest of the trials (the different condition). The question of interest was whether color selection was task dependent, i.e., whether it would occur only when color was the task relevant attribute. Fourteen new volunteers took part in the experiment.

Insert Figure 6 about here

Results and Discussion

Table 6 illustrates the results. RTs were faster in the form task (490 ms) than in the color task (583 ms) [$F(1, 13) = 45.87$, $MS_e = 2390.9$, $p < .001$], and faster when the cue and the target had the same color (526 ms) compared to when they had different colors (547 ms) [$F(1, 13) = 11.43$, $MS_e = 639.3$, $p < .01$]. More importantly, there was also a significant interaction between task and color [$F(1, 13) = 10.57$, $MS_e = 338.2$, $p < .01$]. Whereas a significant color effect was found in the color task (36

ms) [$t(13) = 3.78, p < .01$], it was negligible in the form task (6 ms) [$t(13) = 1.18, ns$].

No reliable effects were found in the accuracy data.

Insert Table 6 about here

Thus, the pattern of data in Experiments 3A and 3B mirrored that of Experiments 1A and 1B in general. In both sets of experiments, there was a processing asymmetry between location and color. Whereas location selection occurred when attention was directed to color regardless of participants' behavioral goals, there was no evidence of color processing when attention was directed to location unless color was task relevant. It is worth noting that the average response latency of the location task in Experiment 3A was remarkably similar to that of the color task in Experiment 3B (both were 583 ms). Given the results, it seems unlikely that the processing asymmetries between location and object features observed in the present experiments were caused primarily by the differential processing efficiency between the two types of features. Instead, the results suggest the existence of an inherent difference between the selection of location and nonspatial properties such as color and texture.

One may recall that the magnitude of the location effect was larger in the location than the form task in Experiment 1A, but not in Experiment 3A despite a numerical trend. To explore the differential location effect as a function of task in the two experiments, I performed a combined analysis of Experiments 1A and 3A.⁵ Not surprisingly, RTs were longer in Experiment 3A than in Experiment 1A [$F(1, 20) = 6.25, MS_e = 21,781, p < .05$], and when the cue and target were at different locations than when they were at the same location [$F(1, 20) = 59.13, MS_e = 312.4, p < .0001$].

In addition, there was a task by experiment interaction [$F(1, 20) = 21.12$, $MS_e = 5176.5$, $p < .001$], suggesting that the difference in RT between the location and form tasks was larger in Experiment 1A than in Experiment 3A. Importantly, there was also a significant location by task interaction [$F(1, 20) = 13.05$, $MS_e = 297.3$, $p < .01$], with a larger location effect in the location than the form task. However, there was no three-way interaction among task, location, and experiment [$F(1, 20) = 1.06$, ns], suggesting that the pattern of data regarding the magnitude of the location effect as a function of task relevancy did not differ in a statistically significant way between the two experiments. Taken together, these results indicate that although location selection was spontaneous regardless of task relevancy, its degree of processing could still be influenced by participants' behavioral goals.

General Discussion

The preceding experiments provide evidence for processing asymmetries between location and color, and location and texture. Whereas the processing of an object's color or texture is accompanied by the processing of that object's location, the processing of an object's location does not necessarily entail the processing of its color or texture. These experiments add to the body of evidence demonstrating the special role of location in attentional selection, and they provide a clearer picture of the interactions among location, object features, and participants' behavioral goals.

Location selection with or without a distractor. Prior research has established spontaneous location selection when a target is presented together with distractors (Cepeda et al., 1998; Cave & Pashler, 1995; Cave & Zimmerman, 1997; Kim & Cave, 1995, 1999a, 1999b; Tsal & Lavie, 1993). In the present experiments, each display contained a single stimulus. Yet, location selection was still observed

when attention was paid to an object's color (Experiments 1A and 3A) or to its texture (Experiment 2A). Because inhibition is not evoked when a display contains no distractors, these results suggest that task irrelevant location selection does not arise only when there is need for distractor inhibition. Instead, they suggest that location selection is obligatory: it occurs regardless of participants' behavioral goals.

Location processing in spatial vs. nonspatial tasks. Although location processing has been observed in both spatial and nonspatial tasks, its degree of processing can still be modulated by participants' behavioral goals. In Experiment 1A (and to a lesser degree also in Experiment 3A) when participants attended to the color of the response cue, they showed a larger location effect when location was a task relevant attribute relative to a task irrelevant attribute. However, the magnitude of the location effect was comparable in both the location and non-location tasks in Experiment 2A, where attention was directed to the texture of the response cue. The question is: what could cause this difference in results?

Although the exact nature of the difference is unclear, one possibility was the differential attentional focus required to perform the go/nogo tasks in the two experiments. When selection was based on texture (discriminating dots from short bars), participants needed to adopt a relatively narrow attentional focus. In contrast, when selection was based on color (discriminating black from white), a narrow attentional focus was not necessary. The extent of attentional focus, which is negatively correlated with the density of processing resources within an attended area (Eriksen & St. James, 1986), is known to influence performance in a variety of selective attention tasks (Chen, 2003; Chen & Chan, 2007; Eriksen & St. James, 1986; Goldsmith & Yeari, 2003; LaBerge, Brown, Carter, Bash, & Hartley, 1991). In the present experiments, because a narrow attentional focus was not needed to process

color in Experiment 1A, the encoding of the cue's location may be relatively coarse when it was not a task relevant attribute, and this may have contributed to the dilution of the location effect in the non-location task. In contrast, a narrow attentional focus, which was required for texture discrimination in Experiment 2A, may have induced participants to encode the cue's location more precisely and to a greater degree, perhaps because of the concentration of the attentional resources at the location of the cue. This in turn may have led to the comparable magnitude of the location effect between the location and non-location tasks.

Task dependent processing of color and texture. Whereas location accompanied the processing of an object's color or texture in the present study, the processing of color or texture was not a necessary condition for location processing. In other words, participants could successfully encode an object's location without having to encode the features of the object which occupied that location. Thus, unlike location selection, which is independent of task relevancy, the selection of an object's color and texture requires that they be the task relevant attributes.

Task dependent processing of an object feature has been reported in previous studies (Snyder, 1972; Hommel, 1998; Tsal & Lavie, 1988, 1993). Tsal and Lavie (1988; 1993) showed participants stimulus displays that consisted of multiple colored letters in different locations. In some experiments, the task was to report first a letter (the target) on the basis of a specified feature such as color or form, and then as many other letters as they could. Participants were more likely to report letters near the target rather than letters that had the same color or form. These results suggest that participants did not voluntarily select letters on the basis of color and form when they were not required to. Evidence for color selection was found only when color became a task relevant attribute (Lavie & Tsal, 1993, Experiment 4), i.e., when the decision to

respond or to refrain from responding to a target was based on the color of a cue that preceded the target. These results underlie the importance of behavioral goals in the selection of nonspatial features. Thus, the results of Experiments 1B, 1C, 2B, and 3B are generally consistent with the previous findings that an object feature is not automatically selected unless it is a task relevant attribute.

The special role of location in selective attention. Location holds an important place in many theories of attention (e.g., Broadbent, 1982; Cave, 1999; Downing & Pinker, 1985; Eriksen & St. James, 1986; Kubovy, 1981; Posner et al., 1980; Treisman, 1988; Treisman & Gelade, 1980; Wolfe, 1994). For example, according to the feature-integration theory (Treisman & Gelade, 1980), attention is location-based, and is required to bind different features into an object representation. Thus, successful performance in conjunction search, in which a target is defined by the conjoining of features, is contingent upon the correct localization of the target (Treisman, 1988). Consistent with the feature-integration theory, Nissen (1985) reported that correct identification of an object's shape depended on the correct identification of that object's location when participants were cued by color. Location-based selection is also central to the FeatureGate model of attention (Cave, 1999), which regards visual perception as the result of a hierarchy of space-based selections. These selections favor the locations of objects with unique or task relevant features while inhibiting the locations of objects with task irrelevant features. Similar emphasis on location can be found in the guided search theory (Wolfe, 1994) and in the theory of indispensable attributes (Kubovy, 1981).

Evidence for the special role of location has been reported in both single-unit recordings (Connor, Preddie, Gallant, & Van Essen, 1997) and electrophysiological studies (Luck, Fan, & Hillyard, 1993; Luck & Hillyard, 1995). Connor et al (1997)

measured neuronal responses in macaque area V4 to behaviorally irrelevant color bars while the monkeys were performing a form detection task concerning a nearby object (the target). Many V4 cells shifted their response profiles to the bars as a function of the spatial distance between the target and the bars: responses were stronger when the target was closer to the bars than when it was farther away. This result demonstrated space-based modulation of attentional enhancement at the neuronal level.

Similar findings have been reported by Luck et al. (1993), who measured participants' event-related brain potentials (ERPs) in a color by form conjunction search task. The critical manipulation was the location of a probe, which could appear at either the location of the target or the location of a critical distractor on the opposite side of fixation. The results show that when the probe appeared 250 ms after the onset of the search display, the P1, anterior N1, and posterior N1 components were significantly enlarged for probes presented at the target location than at the distractor location. Because conjunction search is known to require focal attention (Treisman & Gelade, 1980), these results indicate that sensory processing was enhanced at the location of attention even though location was not a task relevant attribute. Interestingly, evidence for location selection has also been reported in feature search tasks (Luck & Hillyard, 1995), suggesting that location selection can also occur in tasks that do not necessarily require focused attention.

Taken together, the available evidence suggests a special role of location in visual selective attention. Relative to selection by an object feature, location selection is faster (Bongartz & Scheerer, 1976), has a larger partial report advantage (Sperling, 1960, 1963; von Wright, 1968, 1970, 1972), and is the default way of selection when several options are available (Tsal & Lavie, 1988, 1993; von Wright, 1968).

Furthermore, whereas location accompanies the selection of an object feature (Cave &

Pashler, 1995; Cave & Zimmermann, 1997; Cepeda et al., 1998; Kim & Cave, 1995, 1999a, 1999b; and Experiments 1A, 2A, and 3A of the present study), the selection of an object's location does not necessarily require the encoding of nonspatial properties such as color, form, or orientation (Bloom & van der Heijden, 1995; Johnston & Pashler, 1990; and Experiments 1B, 1C, 2B, and 3B of the present study). If we consider the fact that all neurons in the visual cortex have receptive fields that are retinotopically organized, albeit the differences in the size of their receptive fields, it is perhaps not surprising that location should have a special status in visual selection relative to object features such as color and texture. Whereas all neurons are tuned to location, not all of them are tuned to color or texture (e.g., most V1 interblob neurons are not color sensitive). Thus, the processing asymmetries between location and object features may be a fundamental characteristic of the visual system. It may also reflect the relationship between space and object in general. Whereas an object has to exist at a specific location in space, space does not necessarily need to contain any objects.

References

- Alpern, M. (1972). Eye movements. In D. Jameson & L. M. Hurvich (Eds). *Handbook of sensory physiology*, 7 (pp. 303-330). Berlin: Springer-Verlag.
- Anllo-Vento, L., & Hillyard, S. A. (1996). Selective attention to the color and direction of moving stimuli: Electrophysiological correlates of hierarchical feature search. *Perception & Psychophysics*, 58, 191-206.
- Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception & Psychophysics*, 55, 485-496.
- Bacon, W. F., & Egeth, H. E. (1997). Goal-directed guidance of attention: Evidence from conjunctive visual search. *Journal of Experimental Psychology: Human Perception and Performance*, 23, 948-961.
- Bashinski, H. S., & Bacharach, V. R. (1980). Enhancement of perceptual sensitivity as the result of selectively attending to spatial locations. *Perception & Psychophysics*, 28, 241-248.
- Bloem, W., & van der Heijden, H. A. C. (1995). Complete dependence of color identification upon color localization in a single-item task. *Acta Psychologica*, 89, 101-120.
- Bongartz, W., & Scheerer, E. (1976). Two visual stores and two processing operations in tachistoscopic partial report. *Quarterly Journal of Experimental Psychology*, 28, 203-219.
- Broadbent, D. E. (1982). Task combination and selective intake of information. *Acta Psychologica*, 50, 253-290.
- Carrasco, M., Ling, S., & Read, S. (2004). Attention alters appearance. *Nature Neuroscience*, 7, 308-313.

- Carrasco, M., & Pestilli, F. (2005). Attention enhances contrast sensitivity at cued and impairs it at uncued locations. *Vision Research*, *45*, 1867-1875.
- Carter, R. C. (1982). Visual search with color. *Journal of Experimental Psychology: Human Perception and Performance*, *8*, 127-136.
- Cave, K. R. (1999). The FeatureGate model of visual selection. *Psychological Research*, *62*, 182-194.
- Cave, K. R., & Pashler, H. (1995). Visual selection mediated by location: Selecting successive visual objects. *Perception & Psychophysics*, *57*, 421-432.
- Cave, K. R., & Zimmerman, J. J. (1997). Flexibility in spatial attention before and after practice. *Psychological Science*, *8*, 399-403.
- Cepeda, N. J., Cave, K. R., Bichot, N. P., & Kim, M.-S. (1998). Spatial selection via feature-driven inhibition of distractor locations. *Perception & Psychophysics*, *60*, 727-746.
- Chelazzi, L., Miller, E. K., Duncan, J. & Desimone, R. (2001). Responses of neurons in macaque area V4 during memory-guided visual search. *Cerebral Cortex*, *11*, 761-772.
- Chen, Z. (2003). Attentional focus, processing load, and Stroop interference. *Perception & Psychophysics*, *65*, 888-900.
- Chen, Z. (2005). Selective attention and the perception of an attended nontarget object. *Journal of Experimental Psychology: Human Perception and Performance*, *31*, 1493-1509.
- Chen, Z., & Cave, K. R. (2006). When does visual attention select all features of a distractor? *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 1452-1464.

- Chen, Z., & Chan, C. C. (2007). Distractor interference stays constant despite variation in working memory load. *Psychonomic Bulletin & Review*, *14*, 306-312.
- Chen, Z., & Treisman, A. (2008). Distractor inhibition is more effective at a central than at a peripheral location. *Perception & Psychophysics*, *70*, 1081-1091.
- Conner, C. E., Preddie, D. C., Gallant, J. L., & Van Essen, D. C. (1997). Spatial attention effects in macaque area V4. *The Journal of Neuroscience*, *17*, 3201-3214.
- Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, *18*, 193-222.
- Donders, F. C. (1969). Over de snelheid van psychische processen [On the speed of mental processes]. (W. Koster, Trans.), In W. Koster (Ed.), *Attention and performance II*. Amsterdam: North-Holland. (Original work published in 1868)
- Downing, C. J. (1988). Expectancy and visual-spatial attention: Effects on perceptual quality. *Journal of Experimental Psychology: Human Perception and Performance*, *14*, 188-202.
- Downing, C. J., & Pinker, S. (1985). The spatial structure of visual attention. In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance XI: Mechanisms of attention* (pp. 171-187). Hillsdale, NJ: Lawrence Erlbaum.
- 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.

- Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16*, 143-149.
- Eriksen, C. W., & Hoffman, J. E. (1973). The extent of processing of noise elements during selective encoding from visual displays. *Perception & Psychophysics, 14*, 155-160.
- Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention. *Perception & Psychophysics, 40*, 225-250.
- Gatti, S. V., & Egeth. H. E. (1978). Failure of spatial selectivity in vision. *Bulletin of the Psychonomic Society, 11*, 181-184.
- Goldsmith, M., & Yeari, M. (2003). Modulation of object-based attention by spatial focus under endogenous and exogenous orienting. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 897-918.
- Henderson, J. M. (1996). Spatial precues affect target discrimination in the absence of visual noise. *Journal of Experimental Psychology: Human Perception and Performance, 22*, 780-787.
- Hoffman, J. E., & Nelson, B. (1981). Spatial selectivity in visual search. *Perception & Psychophysics, 30*, 283-290.
- Hommel, B. (1998). Event files: Evidence for automatic integration of stimulus response episodes. *Visual Cognition, 5*, 183-216.
- Hopf, J. M., Boelmans, K., Schoenfeld, M. A., Luck, S. J., & Heinze, H. J. (2004). Attention to features precedes attention to locations in visual search: Evidence from electromagnetic brain responses in human. *Journal of Neuroscience, 24*, 1822-1832.

- Johnston, J. C., & Pashler, H. (1990). Close binding of identity and location in visual feature perception. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 843-856.
- Jonides, J. (1981). Voluntary vs. automatic control over the mind's eye's movement. In J. Long & A. Baddeley (Eds.) *Attention and performance IX* (pp. 187-203). Hillsdale, NJ: Lawrence Erlbaum.
- Kaptein, N. A., Theeuwes, J., & van der Heijden, A. H. C. (1995). Search for a conjunctively defined target can be selectively limited to a color-defined subset of elements. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 1053-1069.
- Kim, M.-S., & Cave, K. R. (1995). Spatial attention in visual search for features and feature conjunctions. *Psychological Science*, *6*, 376-380.
- Kim, M.-S., & Cave, K. R. (1999a). Grouping effects on spatial attention in visual search. *Journal of General Psychology*, *126*, 326-352.
- Kim, M.-S., & Cave, K. R. (1999b). Top-down and bottom-up attentional control: On the nature of interference from a salient distractor. *Perception & Psychophysics*, *61*, 1009-1023.
- Kubovy, M. (1981). Concurrent-pitch segregation and the theory of indispensable attributes. In M. Kubovy & J. R. Pomerantz (Eds.). *Perceptual organization* (pp. 55-98). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.
- LaBerge, D., Brown, V., Carter, M., Bash, D., & Hartley, A. (1991). Reducing the effects of adjacent distractors by narrowing attention. *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 65-76.
- Lamy, D., & Tsal, Y. (2001). On the status of location in visual attention. *European Journal of Cognitive Psychology*, *13*, 305-342.

- Liu, T., Stevens, S. T., & Carrasco, M. (2007). Comparing the time course and efficacy of spatial and feature-based attention. *Vision Research*, *47*, 108-113.
- Luck, S. J., Fan, S., & Hillyard, S. A. (1993). Attention-related modulation of sensory-evoked brain activity in a visual search task. *Journal of Cognitive Neuroscience*, *5*, 188-195.
- Luck, S. J., & Hillyard, S. A. (1995). The role of attention in feature detection and conjunction discrimination: An electrophysiological analysis. *International Journal of Neuroscience*, *80*, 281-297.
- Mayfrank, L., Kimmig, H., & Fischer, B. (1987). The role of attention in the preparation of visually guided saccadic eye movements in man. In J. K. O'Regan & A. Levy-Schoen (Eds.), *Eye movements: From physiology to cognition* (pp. 37-45). New York: North-Holland.
- Moran, J., & Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. *Science*, *229*, 782-84.
- Moore, C. M., & Egeth, H. (1998). How does feature-based attention affect visual processing? *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1296-1310.
- Nissen, M. J. (1985). Accessing features and objects: Is location special? In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance XI* (pp. 205-219). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes. *Cognitive Psychology*, *7*, 44-64.
- Posner, M. I., Snyder, C. R. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General*, *109*, 160-174.

- Remington, R. W., & Folk, C. L. (2001). A dissociation between attention and selection. *Psychological Science, 12*, 511-515.
- Shih, S., & Sperling, G. (1996). Is there feature-based attentional selection in visual search? *Journal of Experimental Psychology: Human Perception and Performance, 22*, 758-779.
- Simon, J. R., Hinrichs, J. V., & Craft, J. L. (1970). Auditory S-R compatibility: Reaction time as a function of ear-hand correspondence and ear-response-location correspondence. *Journal of Experimental Psychology, 86*, 97-102.
- Snyder, C. R. R. (1972). Selection, inspection and naming in visual search. *Journal of Experimental Psychology, 92*, 428-431.
- Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs, 74*, 1-28.
- Sperling, G. (1963). A model for visual memory tasks. *Human Factors, 5*, 19-31.
- Treisman, A. (1988). Features and objects: The fourteenth Bartlett memorial lecture. *Quarterly Journal of Experimental Psychology, 40A*, 201-237.
- Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97-136.
- Theeuwes, J. (1993). Visual selective attention: A theoretical analysis. *Acta Psychologica, 83*, 93-154.
- Tsal, Y., & Lavie, N. (1988). Attending to color and shape: The special role of location in selective visual processing. *Perception & Psychophysics, 44*, 15-21.
- Tsal, Y., & Lavie, N. (1993). Location dominance in attending to color and shape. *Journal of Experimental Psychology: Human Perception and Performance, 19*, 131-139.

von Wright, J. M. (1968). Selection in visual immediate memory. *Quarterly Journal of Experimental Psychology*, 20, 62-68.

von Wright, J. M. (1970). On selection in visual immediate memory. *Acta Psychologica*, 33, 280-292.

von Wright, J. M. (1972). On the problem of selection in iconic memory. *Scandinavian Journal of Psychology*, 13, 159-171.

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

Notes:

1. In all the experiments reported here, none of the participants took part in more than one experiment, and none knew the purpose of the experiments.
2. For interpretation of color in Figs. 1-5, the reader is referred to the web version of the article.
3. I thank an anonymous reviewer for pointing that out.
4. The 510 ms SOA was chosen on the basis of prior research (e.g., Liu et al., 2007), which found evidence for feature-based attention at an SOA of 500 ms.
5. There were no significant differences among the three different-location conditions (i.e., the DH, DV, and DD conditions) of Experiment 3A. So their data were pooled.

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I thank David Whitney and two anonymous reviewers for their helpful comments.

Table 1

Mean Reaction Times (in Milliseconds) and Error Rates (Percent Incorrect), With Standard Errors, for Experiment 1A.

	<u>Location Task</u>				<u>Form Task</u>			
	<u>Location Same</u>		<u>Location Different</u>		<u>Location Same</u>		<u>Location Different</u>	
	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
RT	403	22.6	446	19.2	493	17.1	502	16.6
% Error	1.9	0.66	6.9	2.15	4.6	1.02	7.0	1.51

Table 2

Mean Reaction Times (in Milliseconds) and Error Rates (Percent Incorrect), With Standard Errors, for Experiments 1B and 1C

	<u>Color Task</u>				<u>Form Task</u>			
	<u>Color Same</u>		<u>Color Different</u>		<u>Color Same</u>		<u>Color Different</u>	
	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
Experiment 1B								
RT	554	42.1	587	36.9	515	34.6	514	32.9
% Error	5.1	1.56	5.7	1.18	4.2	0.69	3.6	0.77
Experiment 1C								
RT	523	41.1	546	38.5	476	26.6	482	26.6
% Error	4.7	1.24	4.0	0.97	2.9	0.47	3.3	0.73

Table 3

A. Mean Reaction Times (in Milliseconds) and Error Rates (Percent Incorrect), With Standard Errors, for Experiment 2A.

	<u>Location Task</u>				<u>Color Task</u>			
	<u>Location Same</u>		<u>Location Different</u>		<u>Location Same</u>		<u>Location Different</u>	
	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
RT	490	21.6	510	28.7	623	24.0	650	28.8
% Error	3.3	1.03	5.0	1.36	6.3	1.25	7.7	1.20

Table 4

Mean Reaction Times (in Milliseconds) and Error Rates (Percent Incorrect), With Standard Errors, for Experiment 2B.

	<u>Texture Task</u>				<u>Color Task</u>			
	<u>Texture Same</u>		<u>Texture Different</u>		<u>Texture Same</u>		<u>Texture Different</u>	
	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
RT	476	13.7	496	13.3	500	19.1	503	19.0
% Error	3.1	0.88	4.7	0.77	4.2	0.86	3.7	0.75

Table 5

Mean Reaction Times (in Milliseconds) and Error Rates (Percent Incorrect), With Standard Errors, for Experiment 3A.

		<u>Location Task</u>							
		<u>SS</u>		<u>DH</u>		<u>DV</u>		<u>DD</u>	
		<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
RT (ms)		551	33.2	582	34.3	601	39.3	596	46.3
% error		3.7	0.77	7.2	1.58	4.9	1.06	4.4	1.6
		<u>Form Task</u>							
		<u>SS</u>		<u>DH</u>		<u>DV</u>		<u>DD</u>	
		<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
RT (ms)		496	16.9	513	15.8	523	16.2	520	16.0
% error		4.0	1.39	3.3	1.29	2.3	1.01	3.7	0.82

Note: The notations for the conditions are: SS, target at the same location as the cue; DH, target at a different horizontal location from the cue; DV, target at a different vertical location from the cue; DD: target at a location diagonal to the cue.

Table 6

Mean Reaction Times (in Milliseconds) and Error Rates (Percent Incorrect), With Standard Errors, for Experiment 3B.

	<u>Color Task</u>				<u>Form Task</u>			
	<u>Color Same</u>		<u>Color Different</u>		<u>Color Same</u>		<u>Color Different</u>	
	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
RT	565	30.6	601	23.7	487	24.7	493	21.7
% Error	5.6	1.32	6.6	1.45	3.6	0.72	3.7	0.79

Figure Captions

Figure 1. Examples of stimulus displays from Experiment 1A. The experiment used a “go/nogo” paradigm on the basis of the color of the response cue, which could be black or white. The target was yellow. The cue and the target were equally likely to appear at the same location (the same condition) or at different locations (the different condition) in successive displays. The task was form discrimination (T vs. V) in one block, and location discrimination (left vs. right) in the other block. Thus, location was an irrelevant attribute in the form task, but a relevant attribute in the location task.

Figure 2. Examples of stimulus displays from Experiment 1B. The “go/nogo” criterion was based on the location of the response cue, which was on the left or right side of fixation. The cue and the target had either the same color (both red or both green; same condition) or different colors (one red and the other green; different condition). The task was color discrimination (red vs. green) in one block, and form discrimination (T vs. V) in the other block. Thus, color was an irrelevant attribute in the form task, but a relevant attribute in the color task.

Figure 3. Examples of stimulus displays from Experiment 2A. The “go/nogo” criterion was based on the texture of the response cue, which was made of white dots or white short bars. The target was either yellow or green. The cue and the target appeared at either the same location (same condition) or different locations (different condition). The task was color discrimination (yellow or green) in one block, and location discrimination (left vs. right) in the other block. Thus, location was an irrelevant attribute in the color task, but a relevant attribute in the location task.

Figure 4. Examples of stimulus displays from Experiment 2B. The “go/nogo” criterion was based on the location of the response cue, which was on the left or right of fixation. The cue was white, and the target was either yellow or green. The cue and the target had either the same texture (both were made of dots or bars; same condition) or different textures (one was made of dots and the other was made of bars; different condition). The task was color discrimination (yellow or green) in one block, and texture discrimination (dots or bars) in the other block. Thus, texture was an irrelevant attribute in the color task, but a relevant attribute in the texture task.

Figure 5. Examples of stimulus displays from Experiment 3A. The “go/nogo” criterion was based on the color of the response cue, which could be white or black. The target was yellow, and it could occur at the same location as the cue (the SS condition), at a different horizontal location from the cue (the DH condition), at a different vertical location from the cue (the DV condition), and at a location diagonal to the cue (the DD condition). The task was form discrimination (T vs. V) in one block, and location discrimination (target above or below the horizontal meridian) in the other block. Thus, location was an irrelevant attribute in the form task, but a relevant attribute in the location task.

Figure 6. Examples of stimulus displays from Experiment 3B. The “go/nogo” criterion was based on the location of the response cue, which was above or below the horizontal meridian. The cue and the target had either the same color (both black or both white; same condition) or different colors (one black and the other white; different condition). The task was color discrimination (black vs. white) in one block,

and form discrimination (T vs. V) in the other block. Thus, color was an irrelevant attribute in the form task, but a relevant attribute in the color task.

Figure 1

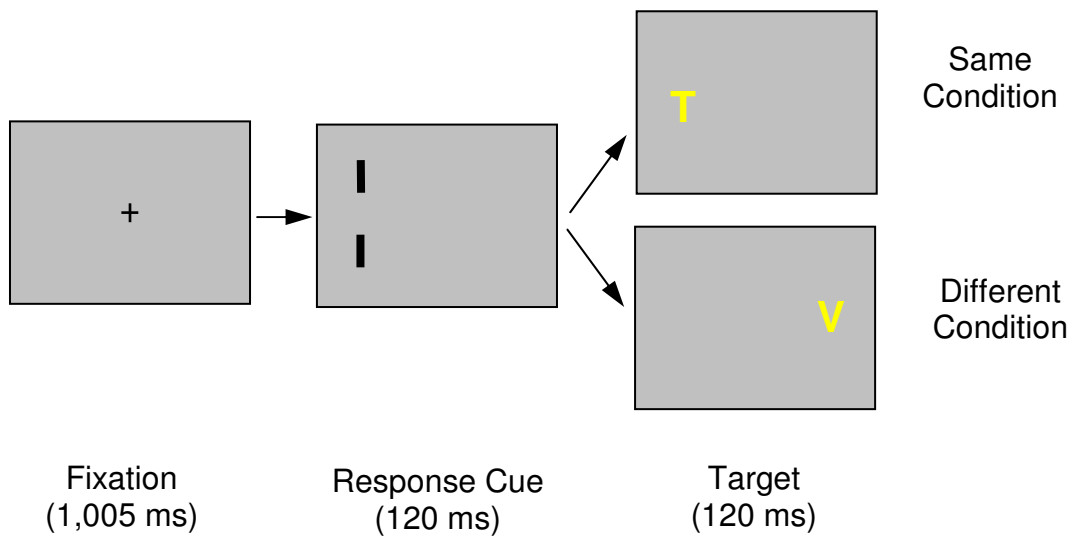


Figure 2

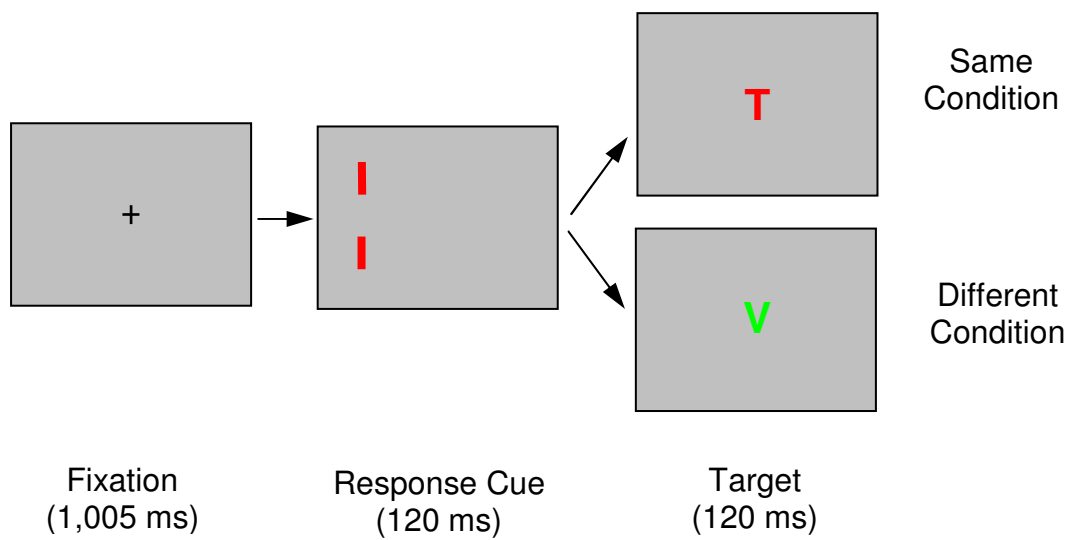


Figure 3

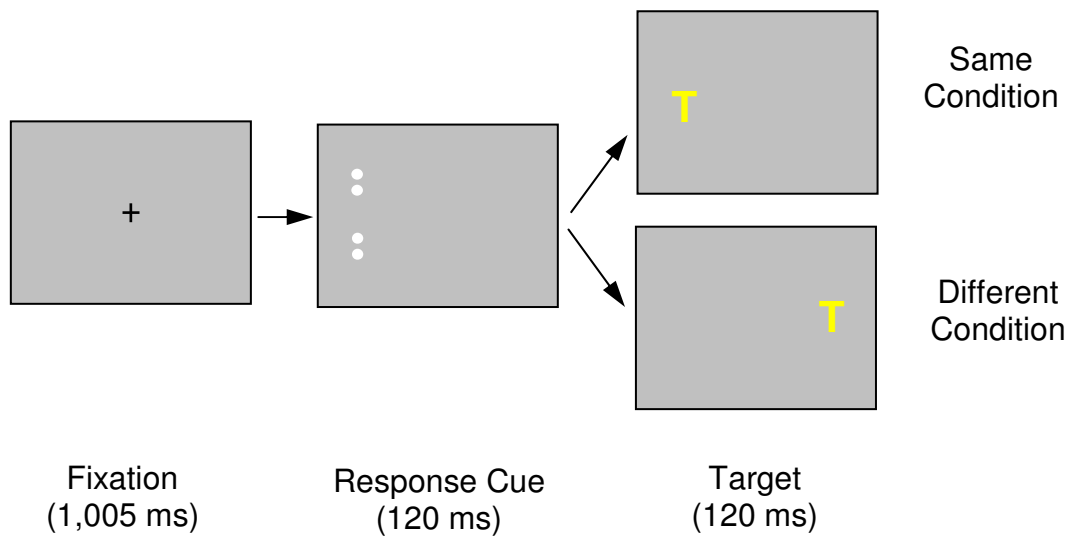


Figure 4

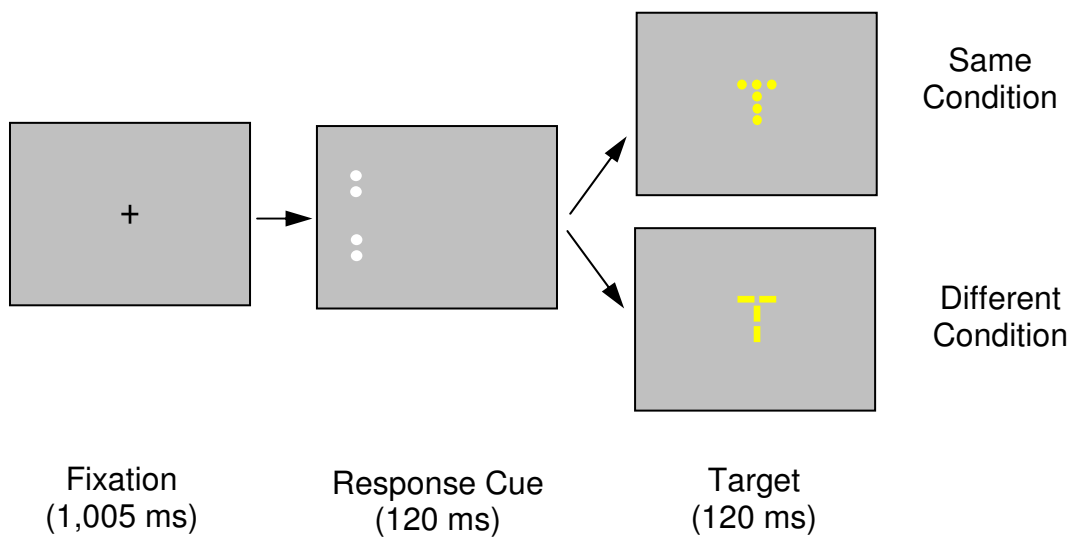


Figure 5

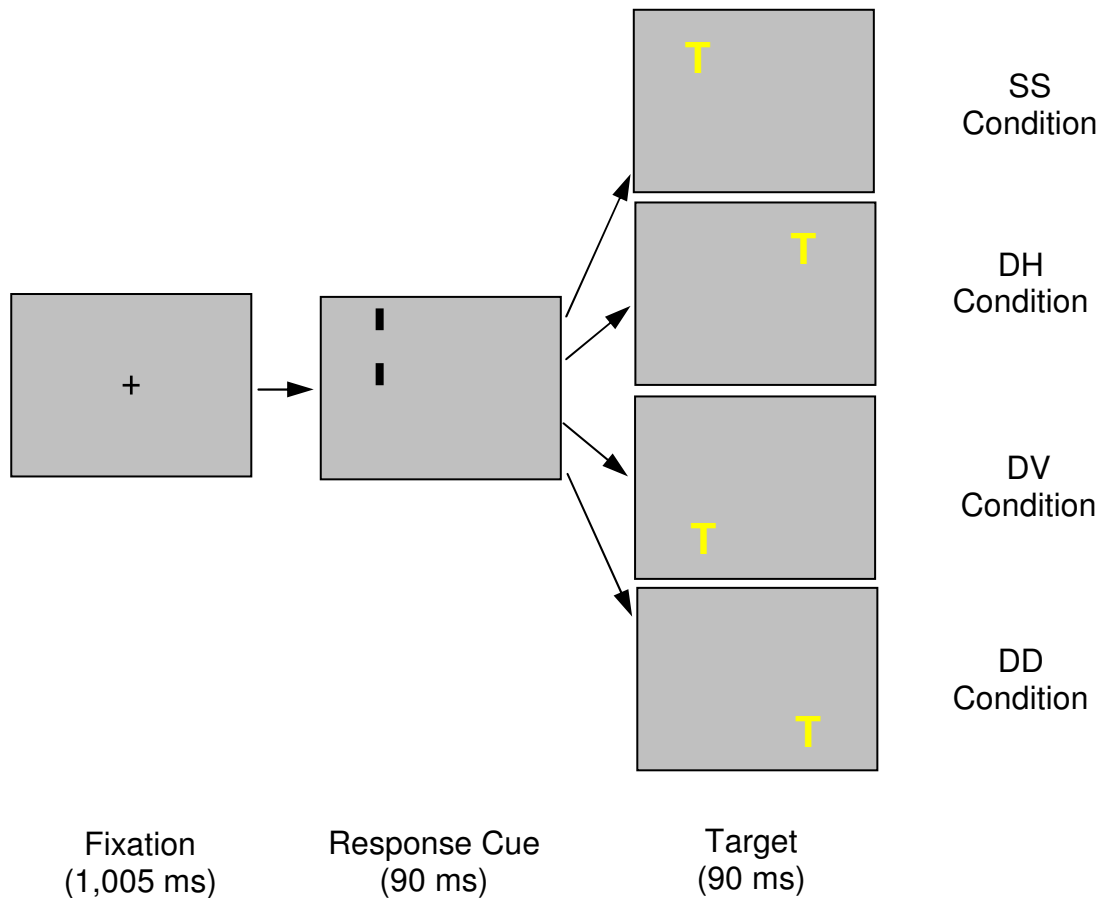


Figure 6

