Chen, Z., & Cave, K. R. (2006). When does visual attention select all features of a distractor? *Journal of Experimental Psychology: Human Perception & Performance, 32*, 1452-1464.

When Does Visual Attention Select All Features of a Distractor?

Zhe Chen

University of Canterbury

Kyle R. Cave

University of Massachusetts

Send correspondence to:

Zhe Chen
Department of Psychology
University of Canterbury
Private Bag 4800
Christchurch, New Zealand
e-mail: zhe.chen@canterbury.ac.nz
phone: 3-3642987 ext. 7987
fax: 3-3642181

Abstract

What happens after visual attention is allocated to an object? Although many theories of attention assume that all of its features are selected and processed, there has been little direct evidence that an irrelevant feature dimension of an attended non-target is processed. In 5 experiments presented here, we employed a singleton paradigm to investigate the effect of attention on non-target objects. Participants made a speeded feature discrimination of a target for which the response was either compatible or incompatible with an irrelevant feature dimension of a distractor. The results show that the irrelevant distractor features were processed to the point that they interfered with the response to the target. The response compatibility effect was observed even when the location of the target or of the distractor was invariant, although it was much weaker when both locations were invariant. These results demonstrate that in many circumstances an attended distractor is completely selected and fully processed, and the complete processing of distractors depends on a number of factors, many of which are related to the strength of attention to the distractor.

Keywords: attention, selection, distractor, interference

One set of questions in visual attention research concerns how targets are found so that information about them can be separated from information about distractors. Many recent experiments have been designed to answer these questions by measuring attention to locations and to objects. (For reviews, see Cave and Bichot, 1999; Lamy & Tsal, 2001; Scholl, 2001.) Another set of questions concerns how visual information is processed after a location or object is attended. Many current theories include an assumption that once an object is attended, it will be "selected" such that all of the features belonging to that object will be processed and identified regardless of whether they are task relevant or irrelevant (Kahneman & Henik, 1981; Kahneman & Chajczyk, 1983). These claims are based mainly on the fact that responses to one dimension of an object are often subject to interference from other dimensions, as in the Stroop effect (see MacLeod, 1991, for a review). In some theories of attention, the purpose of attention to an object is to create an object file representation that contains information about all the features in different dimensions belonging to the object (Kahneman & Treisman, 1984). In this view, attending to an object is synonymous with forming a complete object representation.

However, Remington and Folk (2001; Folk & Remington, 2004) have demonstrated that a visual distractor object can be attended as a result of a spatial cue, and yet its feature on a dimension irrelevant to the current task will not interfere with the response. For example, in one experiment, the participants were required to respond to either the identity or the orientation of a red target letter among three white distractor letters. The stimuli were displayed inside four individual rectangles that were visible during an entire trial. The presentation of the target was preceded by a precue consisting

of a set of dots positioned around each of the four rectangles. Three sets were white and the remaining set was red. The status of the object inside the rectangle cued by the red dots was manipulated. It could be the target, the critical distractor, or one of two neutral items. Remington and Folk (2001; Folk & Remington, 2004) found that when the attended object was a target, its irrelevant dimension showed interference when it was inconsistent with the target response. In contrast, when it was a distractor, the interference effect was obtained with the relevant dimension, but not with the irrelevant dimension. On the basis of these results and comparable findings from subsequent experiments, Remington and Folk (2001) make a distinction between attention and selection, and propose that an item can be attended without its task irrelevant dimensions being selected.

The Results of Attention

Previous research has established that attention facilitates the processing efficiency of an attended location or object. There is extensive evidence that attention increases the speed and/or accuracy of processing stimuli at the attended location relative to elsewhere (Posner, Snyder, & Davidson, 1980; Shaw & Shaw, 1977). It reduces response variability (Prinzmetal, Amiri, Allen, & Edwards, 1998; Prinzmetal & Wilson, 1997) and enhances signal-to-noise ratio of a briefly displayed stimulus (Bashinski & Bacharach, 1980; Downing, 1988). Attending to a stimulus on one part of an object also facilitates the processing of other stimuli that pertain to the same object (Chen, 1998; Chen & Cave, in press; Duncan, 1984; Egly, Driver, & Rafal, 1994; see Scholl, 2001, for a review). Furthermore, attention binds features into integrated objects, prevents illusory

conjunctions of features that belong to different objects, and sets up object files that store information about the various relationships between the individual features of an object (Kahneman, Treisman, & Gibbs, 1992; Treisman, 1988).

However, recent studies also suggest that the effects of attention may be more complex than was previously understood. Attention can not only facilitate performance, but also impair performance under certain circumstances. For example, attention impairs texture segregation at central locations, even though it enhances texture segregation at peripheral locations (Yeshurun & Carrasco, 1998). Attention also increases distractor interference when the relevant and irrelevant information are parts of a same object (Chen, 2003). The effects of attention on perception seem to be rather short-lived, too (Wolfe, 1999). Wolfe, Klempen, & Dahlen (2000) demonstrated that observers did not improve the efficiency of visual information processing even after they had been repeatedly exposed to the same stimulus pattern. They showed that search slope, an index of information processing efficiency in visual search tasks, did not change as a function of the number of times a stimulus display had been repeated. These results suggest that although attention may bind the various features of an object to create a coherent perceptual representation when attention is being directed to that object, once attention has moved on to other stimuli, the features of the previously attended object will no longer be bound. As a result, there is little difference between the postattentive and the preattentive visual representation of an object.

The results from Remington and Folk (2001) and the questions that they raise further underscore the limited knowledge that we have regarding the effects of attention on perception. To what degree is the entire object processed as a unit? Is it possible to

select some features of an object without selecting others, and if so, what factors determine how the object is processed? Two recent studies suggest that processing load and timing may be important factors in how an object is processed once it is attended. Yang and Kim (2003) used an experimental paradigm similar to Remington and Folk's and found that interference from a distractor varied according to the level of perceptual load. Chen (2005) measured interference from the irrelevant feature dimension of a distractor object, as Remington and Folk did, but she ensured that the distractor was attended by presenting it before the target, rather than cuing its location. She found that interference from an irrelevant distractor feature depended on the time over which the stimulus was processed. Together these two studies suggest that irrelevant features may be processed after relevant features, if the time and resources are available.

Chen (2005) also found that the processing of an irrelevant distractor feature depended on the nature of the visual task being performed. The irrelevant distractor features affected responses when participants were reporting the identity of a target, but not when they were reporting its location. The role of location in Chen's experiments raises an interesting possibility regarding the lack of irrelevant feature processing in Remington and Folk's (2001) experiments. In those experiments, attention is allocated to the distractor as a function of its location within a cued region. Attention is directed first to a cue consisting of a set of dots because of their unique color or motion. This cue pattern causes the region that it surrounds to be attended. When a distractor appears within that region, it does not share the color or motion of the cue dots, but is attended solely because of its location near the cue dots. As a result, the irrelevant distractor feature produces no interference in target identification. In Chen's experiment, on the

other hand, when participants reported location, there was no interference, but when they reported nonspatial properties, the interference appeared. Perhaps the distractor is more likely to be fully processed in tasks involving nonspatial features than in tasks involving location.

The Special Role of Location

Location holds a unique place in many theories of attention (e.g., Broadbent, 1982; Cave, 1999; Cave & Wolfe, 1990; Downing & Pinker, 1985; C. W. Eriksen & St. James, 1986; Posner et al., 1980; Treisman & Gelade, 1980; Wolfe, 1994). Various metaphors of attention, such as “spotlight” (B. A. Eriksen & C. W. Eriksen, 1974; Posner et al., 1980), “zoom-lens” (C. W. Erisksen & St. James, 1986; LaBerge, 1983), and “gradients” (Downing & Pinker, 1985), have been proposed to emphasize the spatial properties of attention. In these models, attention selects a contiguous region of space, and the processing of a stimulus property is accompanied by the mandatory processing of its location.

Location also plays a central role in Treisman’s Feature Integration Theory (Treisman, 1988; Treisman & Gelade, 1980). According to the theory, when attention is required to bind features into an object representation as in the case of a conjunction search, selection is based on location. Thus, correct identification of an object is dependent on correct localization. Attending to an object defined by a conjunction of features entails the selection of its spatial location.

The importance of location and its unique status in perception are reflected in Kubovy’s theory of indispensable attributes, too. Kubovy (1981) compared spatial

location in vision to frequency in audition. He proposed that both location and frequency were indispensable attributes in their respective modality. Like frequency in hearing, variation in spatial location is a necessary condition for stimuli that are presented simultaneously to be perceived as separate entities. For example, if two objects which differ only in color (e.g., a red circle and a yellow circle) are displayed at the same spatial location, they will be seen as a single object, i.e., an orange circle. In contrast, if two objects have the same color, as long as they appear in different locations, they will still be seen as separate entities. Hence, spatial location is an indispensable attribute, and has a unique status in visual perception.

Many studies have provided evidence that the role of location in visual attention is different from the role of nonspatial visual properties such as color or orientation. C. W. Eriksen and Hoffman (1972) showed that flanking distractors only interfered with a target if they were nearby. Hoffman and Nelson (1981; Hoffman, Nelson, & Houck, 1983) found that performance was better in dual task experiments if the stimuli for both tasks were near one another. Participants in experiments by Cave and Pashler (1995) were better able to identify a succession of digits when they all appeared at the same location than when they appeared at different locations. Responses to spatial probes (Kim & Cave, 1995, 1999a, 1999b) reveal that in the process of searching for and identifying a target defined by color or shape, the location occupied by the target is selected. The special role of location can also be seen in error patterns, with participants more likely to mistakenly select distractors near a target than those farther away, even when the targets are defined by some property other than location (Snyder, 1972; Tsal & Lavie, 1988; 1993). Further evidence for the special role of location comes from studies using ERP’s

(Luck, Fan & Hillyard, 1993; Luck & Hillyard, 1995) and single-unit recordings (Connor, Preddie, Gallant and Van Essen, 1997). The conclusion that location plays a special role in selection is consistent with the special role that location plays in the organization of the early stages of the visual system, in which different brain areas devoted to vision are organized into spatial maps.

Available evidence suggests that attending to an object's location does not necessarily lead to the processing of an object's color, form, or texture. Chen (2004) performed one of the few studies to examine the involuntary selection of an object feature when the task is to report its location. Her participants performed a go/nogo task in which they saw a response cue followed by a target. When the cue was based on an object feature such as color or texture, the location of the object was encoded despite its irrelevance to the task. In contrast, when the cue was based on location, there was no evidence that the participants processed the color or texture of the object. These results add to the evidence that location plays a special role in visual selection.

Overview of the Present Study

The experiments reported here were designed to (1) provide converging evidence that the irrelevant distractor features of an attended non-target object influence target processing when attention is paid to an object feature and (2) investigate the relationship between attention and selection when the positions of the target and the distractor are known in advance versus unknown. Unlike Remington and Folk's (2001) experiment, attention will not be directed to the target and distractor by a spatial cue. Instead, the target and disctractor will be embedded in a regular array of line segments that have the

same color and orientation. The target and distractor will each have a feature that differs from the surrounding elements in this field. Thus, they will receive attention as a result of their status as feature singletons, rather than by being at a cued location. Whereas Remington and Folk (2001) demonstrated that attention could be allocated to a spatial cue without causing all features being selected, these experiments will test whether attention without selection is possible when attention is drawn by a color or orientation singleton directly.

The present study also tests whether the effect of attention on selection depends on the synchrony between targets and distractors. In Remington and Folk (2001), the critical distractor was displayed simultaneously with the target and two other irrelevant stimuli, and there was no evidence that the irrelevant distractor dimension was processed. In contrast, in Chen's (2005) study, the distractor was presented alone before the onset of the target, and interference from the irrelevant distractor dimension was found. Although the distractors in Remington and Folk were not marked by any specific features, prior research suggests that the mere presence of an irrelevant object may compete for attentional resources (Chen, 2000; B. A. Eriksen & C. W. Eriksen, 1974; Kahneman, Treisman, & Burkell, 1983; Treisman, Kahneman, & Burkell, 1983). Treisman and colleagues (Kahneman et al., 1983; Treisman et al., 1983) used the term *filtering cost* to refer to the positive association between observers' reaction times to a target (or targets) and the number of distractors to be filtered out. With regard to letter identification tasks, filtering costs have been found even when the distractors were from a completely different category such as black disks (C. W. Eriksen & Hoffman, 1972), colored shapes (C. W. Eriksen & Schultz, 1978), or a dot patch (Kahneman et al., 1983).

Given that the mere presence of a distractor can compete for attentional resources, when a distractor was in the same display as the target in Remington and Folk's (2001) experiments, the presence of the target would likely limit the amount of attention that the distractor could receive, resulting in fewer attentional resources for the processing of the distractor. If the degree of processing a distractor depends on the availability of resources (Lavie, 1995; Lavie & Tsal, 1994), fewer attentional resources would reduce the effect of attention on selection, leading to the failure of processing the task irrelevant dimension.

One might wonder that in light of Kahneman et al.'s (1983, Experiment 4) finding that filtering costs could be eliminated when the location of the target was pre-cued, why it was still likely for the filtering costs to play a role in the results of Remington and Folk (2001), who also employed an effective pre-cue in their experiments. Despite the fact that both studies used pre-cues, there was an important methodological difference between the two studies. Whereas the cue was 100% valid in Kahneman et al., it was uninformative in Remington and Folk. In other words, while the participants in Kahneman et al.'s experiment would be motivated to inhibit all the non-cued locations, thereby adopting a narrow attentional focus, the participants in Remington and Folk's study were more likely to adopt a relatively wide attentional focus so that the target could be perceived. Previous research has shown that filtering cost arise when an object is inside one's attentional focus (Chen, 2000).

So far, evidence for a direct link between attention and selection has been found only when the distractor preceded the target. This raises the possibility that an attended non-target object can be fully selected only under very special conditions in which it has

full access to attentional resources. That possibility was tested in the experiments presented here, in which target and distractor always appeared simultaneously.

Understanding the factors that influence the effect of attention on selection is important because it can shed light on the role of attention in visual information processing as well as in response selection. In five experiments, participants made a speeded response to either the color or orientation of a target on the basis of a response cue at the beginning of each trial. The target was presented together with an array of neutral items and a critical distractor whose task irrelevant feature was compatible or incompatible with the target response. Experiment 1 required participants to respond to a target whose location was unpredictable. Experiments 2 to 4 examined whether the processing of the irrelevant dimension of the distractor found in Experiment 1 could be eliminated when the location of the target, the distractor, or the locations of both the target and the distractor, was known in advance. Experiment 5 provided converging evidence to the findings of Experiments 1 through 4 by using a feature unrelated to the response to define the target. Together, the results suggest that there is a tight link between attention and selection.

Experiment 1

In Experiment 1, participants viewed a response cue, followed by a multi-element array that consisted of a target, a distractor whose irrelevant dimension was consistent or inconsistent with the target, and forty other irrelevant foils that were not associated with any specific responses. The foils were employed to form a uniform background in order to make the target and the distractor appear as feature singletons. Singletons are known to

capture attention under most circumstances (Theeuwes, 1992; 1994; 2004; for a review, see Theeuwes & Godijn, 2001), especially when the target is a singleton and thus induces participants to rely on "singleton detection mode" (Bacon & Egeth, 1994).[1] To induce our participants to adopt a singleton detection mode, we constructed the stimulus displays so that on any given trial there was one colored stimulus and one uniquely oriented stimulus in an otherwise homogenous background made of many identical elements. The target was defined by the specific response cue that was shown at the beginning of each trial. The task was to respond to the color or the orientation of the target, depending on the cue. Of particular interest is whether reaction time to the target varies as a function of the response compatibility between the target and the irrelevant distractor dimension. If attention results in full selection of all distractor dimensions, then participants should take longer to respond to the target when it is inconsistent with the distractor compared to when the two are consistent. If the attended distractor is not selected as a complete object, then no difference should be found between the two conditions.

Method

Participants. Sixteen University of Canterbury undergraduate students participated in the experiment as paid volunteers. They received NZ$10 (USD$6.23) for their participation. All of them reported to have normal or corrected-to-normal vision.

Apparatus and Stimuli. Stimuli were shown on a Power Macintosh 6100/66 computer with a 13-inch RGB monitor. MacProbe (Version 1.6.9, Hunt, 1994) was used to display and to record responses. Participants were individually tested in a dimly lit

room. The viewing distance between the participants and the computer monitor was approximately 60 cm.

Figure 1 shows a sample display. All stimuli were presented against a homogenous gray background. Each trial started with the display of a response cue. It was either a black letter C or O presented in 36-point Geneva font at the center of the computer screen. The target display, which subtended 5.7° x 6.2° in length and width, respectively, consisted of a 6 x 7 element array with equal distance among the individual items. All the elements except for two were vertical black bars, each subtending .67° in length and 0.095° in width. The two exceptional stimuli were located at the central column, either next to each other or at the 2nd and 5th positions. One of these elements was a red or green vertical bar, and the other one was a white oriented bar tilted 45° left or right from the center. The target was defined by the specific response cue on each trial. When it was a C, the colored vertical bar was the target, and the white oriented bar was the critical distractor. When the response cue was an O, the white orientated bar was the target, and the colored vertical bar was the distractor. It is important to note that regardless of the response cue on a given trial, both the target and the distractor were feature singletons. They differed not only from each other but also from the rest of the elements in the display.

Insert Figure 1 about here

Design and Procedure. The experiment used a 2 x 2 x 2 within-subjects design, with the principal manipulations being the task (color vs. orientation), the response

compatibility between the target and the distractor (consistent vs. inconsistent), and the spatial separation between the two (near vs. far). There were as many color trials as orientation ones, and the response associated with the distractor was equally likely to be consistent or inconsistent with the response of the target. On half of the trials, the target and distractor were close to each other, and on the rest of the trials, they were relatively far apart. The target was equally likely to be above or below the distractor.

Each trial started with the presentation of the response cue for 1,005 ms. After 510 ms of blank screen, the target display was displayed for 120 ms. The task was to make a speeded response to the color or orientation of the target on the basis of the response cue, with a C indicating color and O orientation. The participants pressed the “>” key if the response was “red” or “left”, and to press the “/” key if the response was “green” or “right”. Thus, each response key was mapped with two feature dimensions on any given trial, a task relevant dimension and a task irrelevant one.

Fixation at the center of the screen throughout the duration of an entire trial was emphasized, and the target display was presented too briefly to allow for the planning and execution of a saccade while it was visible. Both speed and accuracy were stressed. After 64 practice trials, each participant performed 4 blocks of 128 trials. The experiment lasted about 40 minutes including short breaks between the blocks.

Results and Discussion

Table 1 shows the mean reaction times and accuracy data. A repeated measures analysis of variance (ANOVA) was conducted on the mean reaction time of 15 participants. One person’s data were not included in the analysis due to her high error

rates, which exceeded 30 percent in four of the eight conditions. There was a main effect of compatibility [$F(1, 14) = 11.88$, $MS_e = 405.99$, $p < .01$], indicating faster reaction times when the target and distractor were consistent (503 ms) than when they were inconsistent (516 ms). In addition, there was a significant effect of spatial separation [$F(1, 14) = 11.37$, $MS_e = 280.94$, $p < .01$]. Responses were faster in the near condition (504 ms) than in the far one (515 ms). Both of these main effects are illustrated in Figure 2. There was also a task by distance interaction [$F(1, 14) = 5.08$, $MS_e = 213.30$, $p < .05$]. The difference between the near and far conditions was smaller on color trials (5 ms) than on orientation trials (17 ms). No other effects were significant.

Insert Figure 2 about here

A similar ANOVA was conducted on the error rates. Consistent with the reaction time data, there were fewer errors on the consistent than inconsistent trials [2.9% vs. 6.3% error, $F(1, 14) = 26.51$, $MS_e = 13.13$, $p < .001$], and in the orientation than in the color task [3.4% vs. 5.8% error, $F(1, 14) = 15.42$, $MS_e = 11.83$, $p < .01$]. Moreover, there was a task by condition interaction [$F(1, 14) = 8.43$, $MS_e = 19.59$, $p < .05$]. Further analyses revealed a significant compatibility effect in the color task [5.8 %, $t(14) = 4.19$, $p < .001$], but not in the orientation task [1.1%, $t(14) = 2.10$, *ns*] . No other effects were reliable.

Insert Table 1 about here

The most important finding is that responses to the target were influenced by the response compatibility between the target and the distractor. The fact that they were both faster and more accurate on the consistent than inconsistent trials indicates that the irrelevant distractor dimension was processed. This result provides converging evidence to the finding of Chen (2005) that attention leads to full selection when the attended dimension is a non-location object feature such as color or orientation. In addition, it generalized the effect of attention on selection from a paradigm in which the target and distractor were presented sequentially to a paradigm when they were shown simultaneously. This generalization is important because it suggests that the processing of an irrelevant dimension does not require full attentional resources. In the present experiment, we can reasonably assume that the target gets at least as much attention as the distractor due to their simultaneous onset. The finding of the compatibility effect demonstrates that selection of an attended distractor is not limited to very special circumstances.

Recall that the target and distractor were situated at the center of the display in the near condition, but at the 2^{nd} and 5^{th} rows in the far condition. This means that whereas the target was always right next to the fixation in the former, it was more than 1^{0} away in the latter. Furthermore, there were two intervening elements between the fixation and the target in the far condition. Thus, the increase in reaction time in the far condition could be caused by an increase in eccentricity (Hughes & Zimba, 1985; Payne, 1966; Zimba & Hughes, 1987). However, if the target and distractor are more likely to be interpreted as a single group in the near condition and two separate objects in the far condition, there may

have been an extra cost to filter out the separate object. Previous research has shown that filtering irrelevant objects costs attentional resources, which in turn increases response latencies (Chen, 2000; B. A. Eriksen & C. W. Eriksen, 1974; Kahneman et al., 1983; Treisman, et al., 1983).

Another interesting aspect of the data is the absence of a significant interaction between distance and compatibility, even though the overall reaction time was faster in the near than in the far condition. The statistically comparable compatibility effects between the two conditions could be due to the fact that the distractor in our experiment was a feature singleton. The distractors in classical flanker paradigms (B. A. Eriksen & C. W. Eriksen, 1974; C. W. Eriksen & Hoffman, 1972) are different in that the target and distractors differ in only the relevant dimension. With that type of distractors, the distance between target and distractors strongly affects interference. The distractor in the present experiment differs from the distractors in the earlier experiments in that its location was inter-changeable with that of the target, and that it was shown against a largely homogenous background. All this would increase the salience of the distractor, causing it to attract more attention, which in turn could lead to its selection regardless of its distance from the target. Of course, it is entirely possible that a further increase in the spatial separation between the target and distractor would lead to a significant reduction in distractor processing, as was indicated by a downward trend in the magnitude of the compatibility effect.

With regard to the accuracy data, error rates were higher in the color than in the orientation task. Different colors may have been harder to distinguish than different orientations in these displays, but several other factors might have contributed to the

higher accuracy in the orientation task. Whereas the colored bar differed from the foils only in color, the oriented bar differed from the foils in color and orientation. Furthermore, the response key that was designated for the "left" response was situated on the left of the key that was designated for the "right" response. The consistency between the orientation of the bar and the position of the response keys could also facilitate responses on the orientation trials (Simon, Hinrichs, & Craft, 1970).

Regardless of the exact causes, the oriented bar was likely to have been more salient than the colored bar in this stimulus array, as suggested by the larger compatibility effect on the color trials than on the orientation ones. If there is a positive relationship between the salience of a feature and its effect on the processing of another feature, then an incompatible oriented bar will influence color discrimination more than the other way round, leading to a greater compatibility effect on the color trials than on the orientation trials. Because the effect was found in accuracy, simple tests were warranted in reaction time even though the interaction between task and condition was not statistically significant. Consistent with the accuracy data, there was a significant compatibility effect in the color task [$t(14) = 2.80$, $p < .05$], but not in the orientation task [$t(14) = 1.31$, *ns*]. We will come back to this issue in the general discussion section.

Experiment 2

In Experiment 1, the target and distractor had interchangeable locations, and this produced strong interference from the irrelevant distractor dimension. In Experiment 2, the distractor could still appear in one of two possible locations, but the target always occurred at the center. On the one hand, knowing the location of the target should

encourage participants to focus attention on the target location, which could reduce or eliminate the effect of the distractor. On the other hand, inhibiting the distractor may still be difficult, because the location of the distractor is unknown in advance. To prevent distractor interference, both locations would have to be inhibited, and inhibition would have to be applied to noncontiguous locations. Should the compatibility effect still be observed, this would indicate that the link between attention and selection is quite tight, so that features from an attended distractor will interfere with target processing even when the target benefits from highly focused attention.

Method

Experiment 2 was the same as Experiment 1 with the following changes. First, a row of seven vertical bars was inserted into the target display so that it had seven instead of six rows. The addition of the new row allowed the target to be presented at the center. Second, the target location was fixed at the center of the display. Finally, the distractor was always placed next to the target, either above or below the target at the 3^{rd} or 5^{th} row in the middle column. The experiment consisted of 4 blocks of 128 trials. Twelve new participants took part in the experiment.

Results and Discussion

The data are shown in Table 2. A 2 x 2 repeated-measures ANOVA on reaction time found faster responses in the orientation than color task [508 ms vs. 546 ms, $F(1, 11) = 13.42$, $MS_e = 1284.06$, $p < .01$] and faster responses on the consistent than inconsistent trials [519 ms vs. 535 ms, $F(1, 11) = 7.27$, $MS_e = 453.52$, $p < .05$]. A similar

analysis on the accuracy data showed a similar pattern of data, with fewer errors in the orientation than the color task [3.4% vs. 7.0%, $F(1, 11) = 8.61$, $MS_e = 18.48$, $p < .05$], and fewer errors on the consistent than inconsistent trials [4.0% vs. 6.3%, $F(1, 11) = 19.14$, $MS_e = 3.23$, $p < .01$]. As in the reaction time data, the task by compatibility interaction did not reach significance.

Insert Table 2 about here

Knowing the location of the target did not prevent the participants from processing the irrelevant distractor dimension. Moreover, combined analyses of Experiments 1 and 2 (without including the data in the far condition of Experiment 1) indicated a comparable degree of distractor interference in the two experiments. There was no experiment by compatibility interaction in either reaction time [$F(1, 25) = .02$, $MS_e = 413.00$, *ns*] or accuracy [$F(1, 25) = 3.32$, $MS_e = 6.92$, *ns*]. If attention works by facilitating processing at a selected location in the present paradigm, we would have expected less distractor interference in Experiment 2 than in Experiment 1, because fixing the target location at the center would make it easier to attend to the target. Instead, the participants were unable or unwilling to prevent interference from a feature singleton distractor.

The distractor location on each trial was unknown before the stimulus appeared, but it was always limited to one of two locations. Thus, interference could have been prevented by inhibiting both distractor locations. Evidence for distractor inhibition comes from a study by Cepeda, Cave, Bichot, & Kim (1998). Cepeda et al. measured the

distribution of attention at various locations within a stimulus display with a spatial probe that appeared on some of the trials during a delay period while participants withheld their responses to a primary search task. They found that reaction time to the probe was faster when the probe occurred at a blank location between distractors rather than at a location previously occupied by a distractor. Furthermore, the delay in the latter condition could not be attributed to masking, but to attentional inhibition at the distractor location. These results suggest that inhibition can be allocated to noncontiguous regions of space, suggesting that a similar pattern of inhibition should have been possible here.

If distractor inhibition is possible in Cepeda et al.'s (1998) experiments, why does it not prevent interference here? There are several important methodological differences between Cepeda et al.'s study and Experiment 2. First, whereas none of the distractors had distinctive features in Cepeda et al.'s study, the distractor was a feature singleton in the present experiment. Second, the onset of the distractors preceded the display of the probe in Cepeda et al's study, allowing time for inhibition to develop (Humphreys et al., 2004). In contrast, in Experiment 2 the target appeared simultaneously with the distractor, and target identification may have been affected by distractor features before the inhibition could develop. In the current experiment, inhibition could be applied before the onset of the distractor, but participants would have to rely on their memory of the distractor locations. Such a strategy might be risky because the target was positioned between the two distractor locations. A small error in location memory would easily end up inhibiting the location of the target. Allocating attention was easier in the Cepeda et al. experiment, because the display elements were much farther apart. In the current experiment, it might be safer and easier to withhold inhibition until the onset of the

stimulus display. However, assuming that the visual system requires time to evoke inhibition effectively, some degree of distractor processing would be inevitable when the target and distractor had simultaneous onsets.

Experiment 3

Experiment 2 showed that knowing the location of the target could not eliminate interference from irrelevant distractor features. In Experiment 3, we investigated the effect of the foreknowledge of the distractor. Instead of placing the target at the center while varying the location of the distractor, we displayed the distractor at the center and presented the target either above or below the distractor. There is some evidence that inhibition at fixation may be more efficient than inhibition elsewhere. Mack and Rock (1998) have shown that when participants are required to perform an attentionally demanding task, they often fail to detect a superthreshold, unexpected stimulus: a phenomenon they termed “inattentional blindness”. Interestingly, inattentional blindness is greater when the unexpected stimulus appears at fixation than when it occurs at other locations. Placing the distractor at fixation in Experiment 3 might allow participants to inhibit it more efficiently.

Method

Other than switching the locations of the target and the distractor, Experiment 3 was identical to Experiment 2. Fourteen new participants from the same subject pool as before took part in the experiment.

Results and Discussion

The data are shown in Table 3. The most important finding was the existence of the compatibility effect, both in reaction time and accuracy, with 599 ms and 2.7% error for consistent trials, and 617 ms and 5.7% error for inconsistent trials [$F(1, 13) = 6.81$, $MS_e = 655.00$, $p < .05$ and $F(1, 13) = 14.92$, $MS_e = 7.98$, $p < .01$, for reaction time and accuracy, respectively]. Furthermore, consistent with the previous experiments, the accuracy data showed a significant main effect of task. Error rates were lower on the orientation trials (2.8%) than on the color ones (5.6%). No other effects were significant.

Insert Table 3 about here

Placing the distractor at fixation did not prevent it from being processed. When the distractor location is known, there is still a strong association between attention and selection. One factor making it difficult to block interference may have been the spatial proximity between the target and distractor. Previous research has shown that attentional spotlight has a minimal size of 1^0 (B. A. Eriksen & C. W. Eriksen, 1974) so that distractors within the spotlight are processed together with the target regardless of task relevancy. Perhaps there also exists a minimal size for an inhibitory zone. When a distractor is flanked by targets, if distractor suppression carries with it the risk of inhibiting the target together with the distractor, it may be more cost-effective not to apply strict inhibition. This would lead to the compatibility effect observed in Experiment 3.

Experiment 4

So far, we had been unable to eliminate the compatibility effect. The irrelevant distractor dimension was processed regardless of whether the location of the target or the distractor was known in advance. In Experiment 4, we created a more favorable environment for distractor inhibition by making both the target and distractor appear at fixed locations on every trial within a single block. The target would always occur at the center, with the distractor above the target in one block and below the target in another block. We reasoned that the knowledge of the exact locations of the target and the distractor would facilitate both the processing of the target and the suppression of the distractor. Because the foils were not strong competitors for attention, if the distractor was above the target in a given block, participants could simply focus attention to the target location while inhibiting the entire upper visual field.

Method

Except for distractor location, Experiment 4 was identical to Experiment 2. The distractor appeared above the target in one block, and below it in the other block. The order of the blocks was counterbalanced across participants. Twelve undergraduate students from the same subject pool took part in the experiment.

Results and Discussion

The data are shown in Table 4. As in the previous experiments, two 2 x 2 repeated ANOVAs were conducted. The participants were faster and more accurate in the orientation task (457 ms with 2.1% error) than in the color task (531 ms with 5.8% error)

[$F(1, 11) = 23.69$, $MS_e = 2790.13$, $p < .001$, and $F(1, 11) = 12.43$, $MS_e = 13.13$, $p < .01$ for reaction time and accuracy, respectively]. No compatibility effect was found in reaction time [$F(1, 11) = .04$, $MS_e = 186.48$, *ns*]. However, error rates were still higher on the inconsistent trials (4.6%) than on the consistent ones (3.3%) [$F(1, 11) = 6.06$, $MS_e = 3.06$, $p < .05$]. Furthermore, there was a task by compatibility interaction [2.1% vs. 0.4%, for color and orientation, respectively, $F(1, 11) = 8.35$, $MS_e = 1.03$, $p < .05$]. Further analyses indicated a significant compatibility effect in the color task [$t(11) = 2.95$, $p<.05$)], but not in the orientation task [$t(11) = .93$, *ns*]. There were no other reliable effects.

Insert Table 4 about here

To compare the magnitude of the compatibility effect between Experiments 2 and 4, a combined analysis was conducted on the reaction time data of the two experiments. As expected, there were main effects of task [$F(1, 22) = 37.02$, $MS_e = 2037.10$, $p < .001$] and compatibility [$F(1, 22) = 5.65$, $MS_e = 320.00$, $p < .05$]. More importantly, there was also a significant compatibility by experiment interaction [$F(1, 22) = 4.67$, $MS_e = 320.00$, $p < .05$], confirming that there was a significant reduction in the magnitude of the compatibility effect from Experiment 2 to Experiment 4. A similar analysis on accuracy showed no speed-accuracy tradeoff. Consistent with the reaction time data, accuracy was higher in the orientation than the color task [$F(1, 22) = 20.39$, $MS_e = 15.81$, $p < .001$], and on the consistent than inconsistent trials [$F(1, 22) = 23.55$, $MS_e = 3.15$, $p < .001$].

Moreover, the compatibility effect was larger in the color task than in the orientation task [$F(1, 22) = 10.25$, $MS_e = 2.04$, $p < .01$].

Remarkably, the compatibility effect was still found in accuracy, even though the effect was negligible in reaction time. The comparison with Experiment 2 shows that inhibition was more effective when the distractor location was invariant across trials. As we noted earlier, this could be due to the fact that inhibition could now be applied to a single location or an entire region above or below the target because the target was no longer positioned between two potential distractor locations. Thus, the results from Experiment 4 are consistent with those from Cepeda et al. (1998) in that a target is defined by a feature such as color or orientation, and spatial attention takes the form of inhibition of the locations occupied by distractors.

Despite the help from attention, the compatibility effect did not disappear completely. Amazingly, even with the locations of the target and distractor both known in advance, some processing of the irrelevant dimension of the distractor occurred, at least on the color trials. This is likely due to the fact that the distractor was a feature singleton in our paradigm, so that it attracted attention involuntarily when it appeared on the screen. The tight link between attention and selection in turn led to the processing of its irrelevant dimension.

Experiment 5

The results of Experiments 1 to 4 provided strong evidence that attention leads to selection when attention is directed to an object feature of a stimulus. However, there is a potentially important difference between these experiments and those by Remington and

Folk (2001) who found no evidence of selection of irrelevant features in distractors. In these experiments, the feature dimension that the participants responded to was also the dimension on which attention was drawn. If participants know that they should attend to items with a particular feature, this might be enough to prompt them to fully select items with that feature.[2] There also exists the possibility that the participants might confuse the target with the distractor. This in turn might cause attention to linger over the distractor, resulting in its selection. Although the high accuracy of our data, with error rates averaging 4.5% across Experiments 1 to 4, argues against such an account, it would still be beneficial if the possibility of target distractor confusion can be minimized.

In Experiment 5, we separated the feature defining the target from the feature to be reported by changing the target into the letter T while keeping the distractor the same as in the previous experiments. The results will test the link between attention and selection in circumstances closer to those used by Remington and Folk (2001), in which the target can be identified with a feature unrelated to responses.

Method

The method was the same as that in Experiment 1 with two changes. First, the far condition was excluded from the new experiment. Meanwhile, as in Experiments 2 through 4, the number of trials in the remaining near condition was doubled so that the total number of trials were identical to that in Experiment 1. Second, instead of using the same stimulus as a target on one trial and a distractor on a different trial, we created two independent stimuli. Whereas the distractor was either a colored bar or a tilted bar as in the previous experiments, the target became the letter T. Specifically, on color relevant

trials it was a red or a green T. On orientation relevant trials, it was a white T tilted 45^0 left or right. The participants were informed in the instructions that the target was always the letter T. This change in the target should minimize the possibility that participants would mistake the distractor for the target on a given trial, or that the irrelevant distractor feature was selected because it was a target defining feature on some of the trials. Fifteen new volunteers from the same participant pool took part in the experiment.

Results and Discussion

Table 5 shows the results. A repeated-measures ANOVA on reaction time showed that the participants were faster on consistent trials (520 ms) than on inconsistent trials (531 ms) [$F(1, 14) = 13.15$, $MS_e = 144.00$, $p < .01$]. They were also faster when the task was orientation (496 ms) than when it was color (556 ms) [$F(1, 14) = 22.85$, $MS_e = 2387.00$, $p < .001$]. The task by compatibility interaction did not reach significance [$F(1, 14) = 3.69$, $MS_e = 154.00$, *ns*]. A similar analysis on accuracy revealed a significant main effect of task and a task by compatibility interaction. Consistent with the reaction time data, accuracy was higher on the orientation trials (1.2% error) than on the color trials (5.4% error) [$F(1, 14) = 16.89$, $MS_e = 15.70$, $p < .001$]. Furthermore, interference from incompatible distractors was larger in the color (2.8% error) than in the orientation task (0.2% error) [$F(1, 14) = 5.50$, $MS_e = 4.78$, $p < .05$]. The main effect of compatibility was not significant [$F(1, 14) = 3.65$, $MS_e = 9.65$, *ns*].

Insert Table 5 about here

The most important finding of the experiment is the observation of the compatibility effect, showing that even with the changes in Experiment 5, the irrelevant distractor feature is still attended and affecting the response. This result was important because it suggests that the findings of our previous experiments were unlikely to be the results of prolonged attention on the distractor because of confusion between the target and the distractor. It also eliminated a potentially important methodological difference between our experiments and those of Remington and Folk (2001). The current experiment is similar to theirs in that the target was defined by a feature dimension that was independent of participants' responses. Furthermore, the target was presented together with the distractors. Whereas object-based selection for an attended non-target stimulus was observed in our experiments, similar results were not found in Remington and Folk. Recall that Remington and Folk used a spatial cue to guide attention to the cued location, which was subsequently occupied by an object. We used feature singletons to direct attention to object features such as color and orientation. Although the issue of location versus an object feature was not examined directly in the present experiments, our finding of distractor processing when attention was governed by an object feature is consistent with the results of Chen (2005, Experiments 2 & 4), which showed differential processing of an attended non-target object as a function of attention to an object feature versus to an object's location.

General Discussion

These experiments provide a more complete picture of the factors that determine when a distractor object that is attended will be fully selected and processed, and when it

will not. In Experiment 1, the locations of the target and distractor varied across trials, and there was clear evidence that the irrelevant feature of the distractor interfered with a response to the target. Evidence of response compatibility effects was found even when the location of the target or of the distractor was invariant (Experiments 2 and 3, respectively), or when the target was defined by an independent feature dimension unrelated to the task (Experiment 5). Only when both the locations of the target and distractor were known in advance was the interference from the irrelevant dimension reduced (Experiment 4). Taken together, these results converge with evidence from previous experiments that attention and selection are closely linked when the attended attribute is an object feature (Chen, 2005). They also support object-based theories of attention, which predict the processing of all the features of an attended object regardless of task relevancy (Duncan, 1984; Kahneman & Treisman, 1984).

Knowledge of Distractor and Target Locations

Experiment 4 shows that when the target and distractor locations are consistent from trial to trial so that participants can anticipate where they will appear, the interference from the irrelevant distractor dimension is curtailed. Note that knowledge of the target location by itself will not limit distractor interference, because in Experiment 2 the target location is known, yet the interference from the irrelevant distractor dimension is still strong. Likewise, knowledge of the distractor location by itself will not reduce distractor interference, as can be seen in Experiment 3.

Knowledge of the distractor location probably allows participants to inhibit the distractor location before or soon after the distractor appears. There is evidence from

spatial probe studies (Cepeda et al., 1998; Cave & Zimmerman, 1997) that attentional inhibition can be focused selectively at distractor locations. In both of these probe studies, the target was distinguished from distractors by shape or color. Therefore it is not surprising that the same sort of distractor inhibition would be used in the current experiments, in which the target is distinguished from distractors by either color or orientation. Likewise, knowledge of the target location may allow an attentional facilitation of that location, as predicted by spotlight theories of attention (Posner et al., 1980). However, the specific methodology used in our experiments, which includes the close spatial proximity between the target and distractor, their simultaneous onset, and the fact that both of them were feature singletons, may have prevented effective distractor inhibition, resulting in significant compatibility effects.

Evidence of processing the irrelevant feature of the distractor can be found even when participants had foreknowledge of the locations of both the target and the distractor, as shown in Experiment 4. Although the interference is too weak to be detected in the response times, the orientation singleton distractors did exert a measurable effect on the accuracy in reporting the color targets. Because similar asymmetries between reaction time and accuracy were observed in two other experiments that were not reported here (Chen & Cave, 2005), the results of Experiment 4 were unlikely to be accidental. Accuracy may be a more sensitive measure than reaction time in our paradigm. Further experiments are required to explore this issue.

The Role of Featural Salience

In many of these experiments, there is some difference in the level of interference depending on which feature defines the target and which defines the distractor. In these experiments, there is generally more interference with the color target. In other words, irrelevant orientation interferes more with a color response than irrelevant color interferes with an orientation response. We assume that these differences are due to the relative salience of the particular color and orientation values used here. The differences between the colors and the differences between the orientations were chosen arbitrarily, and it is to be expected that one feature difference would be more salient and thus more effective at drawing attention than the other. Recall that in the present experiments, whereas the colored stimulus differed from the rest of the items in one dimension (i.e., color), the oriented stimulus differed in two dimensions (i.e., color and orientation). This stimulus difference, as well as the consistency between the orientation of the bar and the position of the response keys, may have led to the oriented stimulus being more salient than the colored one. The fact that participants were generally faster and more accurate on the orientation trials than on the color ones is consistent with this view.

The relative featural salience between the color and orientation dimensions can affect the level of interference in at least two different ways. First, a stimulus with higher salience will probably receive more attention, or receive attention sooner and for a longer time, which will lead to a stronger representation of its features. Second, a distractor with weaker salience and less attention may be processed more slowly. By the time its features are identified and represented, a response to the target may already have been triggered, before the distractor features had an opportunity to interfere. If the orientation distractor

was indeed more salient than the color distractor, there should be greater interference from the former than from the latter. This is indeed what we found.

The overall pattern of results, especially the processing asymmetry between the color and orientation trials, is consistent with Chen's (2005) proposal of a three-stage processing of an irrelevant distractor feature. Based on the assumptions that perception proceeds from target to distractor (Lavie & Tsal, 1994), relevant to irrelevant dimensions, and that it self-terminates as soon as target presentation occurs (Treisman & Gelade, 1980), Chen proposed that the selection of an irrelevant distractor feature may consist of three stages: precategorization, categorization, and identification. Thus, when target processing is efficient so that its representation becomes available while the processing of the irrelevant distractor feature is still in its precategorization stage, there should be no behavioral manifestation of the distractor interference effect. Conversely, when target processing is inefficient and therefore does not complete until the irrelevant dimension has been fully processed, the irrelevant distractor dimension will be identified and response interference should occur. With respect to the present experiments, the difference in the processing time between color and orientation may have influenced the degree of processing of the irrelevant distractor dimension, which in turn resulted in the differential magnitude of the compatibility effects in the color and orientation tasks.

Comparison with Remington and Folk (2001)

Just as the timing of the processing of target and distractor may be important in explaining differences between color and orientation, it may also be important in explaining differences between these results, showing interference from irrelevant

distractor dimensions, and the results from Remington and Folk (2001) showing no such interference. Remington and Folk directed attention via a spatial cue, whereas the distractors in these experiments draw attention because they possess a singleton feature. Part of the original motivation for these experiments was to avoid a spatial cue, and thus limit the role of location in transferring attention from cue to distractor. Nonetheless, in both experiments a distractor is attended because of the appearance of a featural singleton. Why do the irrelevant features of that attended distractor interfere in these experiments, but not in Remington and Folk's?

There are three differences in procedure that could be relevant. The first is the role of location in transferring attention from cue to distractor. Attention is drawn to the distractor object itself in these experiments, while in Remington and Folk (2001), attention is drawn to a cue, and the distractor appears in the cued region 100 msec or 170 msec later. There is, of course, plenty of evidence that attention to the cue will transfer to the later stimulus at that location, but the role of location may change the nature of attention, or the delay and the stimulus change at that location may simply weaken the attentional activation. There are two other differences not directly related to the role of location. When Remington and Folk's (Experiment 1) distractor appears, it appears in a color that is never a target color, and participants may use this color to guide inhibition. As noted above, Cepeda et al. (1998) have demonstrated that color can be used effectively to inhibit distractor locations. Finally, in Remington and Folk's displays, there is only one element in each quadrant, while in the current experiments there are many more display elements and they are closer together, boosting the salience of the singletons. All three of these factors could make attention to the distractor stronger in

these experiments than in Remington and Folk's. That extra attentional strength could speed distractor processing so that the irrelevant features are identified early enough to interfere with target processing. Currently, the exact relationship between the strength of attentional activation and selection is still unclear. Further experiments are needed to understand how the amount of attention influences the degree of processing of an attended, non-target object, and to identify the exact reasons why selection and attention are linked in the present experiments, but are dissociated in Remington and Folk.

Cohen's DA Model

The effect of irrelevant feature dimensions has been the focus of earlier studies by Cohen and colleagues (Cohen & Shoup, 1997; Feintuch & Cohen, 2002). In a series of elegant studies that used a modified version of the flanker paradigm (B. A. Eriksen & C. W. Erisken, 1974), Cohen and Shoup varied the flankers in two dimensions so that on any given trial the target and flankers were compatible on either the same dimension or two different dimensions. Therefore, on some trials a target defined by color could be presented with flankers whose color was compatible or incompatible with the target's response (the same dimension condition). On other trials, the same target could be shown with flankers whose orientation was compatible or incompatible with the target's response (the different dimension condition). The researchers found that the flankers produced interference only when they were from the same dimension as the target. Similar results were also reported by Maruff and his associates (Maruff, Danckert, Camplin, & Currie, 1999; but see Mordkoff, 1998).

Based on their results, Cohen and Shoup (1997) proposed a dimensional-action (DA) model to explain when relevant and irrelevant features from targets and distractors will affect responses, and when they will not. In the DA model, there is a separate decision mechanism for each feature dimension. The outputs of these decision mechanisms are transmitted to a central executive only when the relevant stimulus is attended. The central claim underlying the model is that when a distractor is not attended, its irrelevant dimensions will not be able to influence responses.

In Cohen and Shoup's (1997) study, target and distractor locations were known in advance. Given the results from Experiment 4 above, we would expect this foreknowledge to limit interference from the distractors. Also, unlike Cohen and Shoup's experiments, the distractors in our experiments were attended because they were feature singletons. According to the DA model, both target and distractor should be able to influence the central executive and affect the final response. The results of our experiments are generally consistent with the DA model. However, in order to account for all the results presented here, which includes the asymmetry between color and orientation and the elimination of the compatibility effect in the reaction time data of Experiment 4, the attentional system in the DA model needs to take into account the featural salience of the attended object and the knowledge of stimulus locations for effective inhibition.

Conclusion

Remington and Folk (2001) demonstrated that attention to a distractor does not necessarily result in full selection and processing of all its features. With this

demonstration, it became important to determine what factors determine the processing of irrelevant dimensions in an attended distractor. An important step in answering this question is to determine how distractors are processed when they are attended because of their own salient features rather than a spatial cue. The experiments presented here show that when the distractor is a feature singleton embedded in a homogenous field of densely packed foils, its irrelevant features will generally be processed. This finding fits with the result from Chen (2005) that irrelevant features of a distractor appearing by itself could also interfere with the target response. The current experiments further demonstrate that knowing the location of only the target or only the distractor cannot reduce distractor interference. Only when both their locations are invariant can distractor processing be substantially reduced.

These experiments illustrate that feature singleton distractors are often fully selected, but that full knowledge of target and distractor locations can sharply limit the processing of their irrelevant dimensions. Comparison with previous experiments suggests that the strength of attention to the distractor may influence how fully the irrelevant distractors are processed. Other studies have shown that processing of irrelevant dimensions also depends on the level of processing load (Yang and Kim, 2003), the ability of a stimulus to capture attention (Chen & Simmonds, in press), the status of the attended object (Remington & Folk, 2001), the processing efficiency of the target, and the feature dimension attention is directed to (Chen, 2005). Together, these studies show that within a specific task and a specific set of attentional factors, the degree to which a distractor is processed will vary depending on fairly subtle differences in a number of factors.

References

Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus attention-driven capture. *Perception & Psychophysics*, *55*, 485-496.

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.

Broadbent, D. E. (1982). Task combination and selective intake of information. *Acta Psychologica*, *50*, 253-290.

Cave, K. R. (1999). The FeatureGate model of visual selection. *Psychological Research, 62*, 182-194.

Cave, K. R., & Bichot, N. P. (1999). Visuospatial attention: Beyond a spotlight model. *Psychonomic Bulletin & Review, 6*, 204-223.

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. M. (1997). Flexibility in spatial attention before and after practice. *Psychological Science, 8*, 399-403.

Cave, K. R., & Wolfe, J. M. (1990). Modeling the role of parallel processing in visual search. *Cognitive Psychology*, *22*, 225-271.

Cepeda, N. J., Cave, K. R., Bichot, N. P., & Kim, M-S. (1998). Spatial selection via feature-driven inhibition. *Perception & Psychophysics*, *60*, 727-746.

Chen, Z. (1998). Switching attention within and between objects: The role of subjective organization. *Canadian Journal of Experimental Psychology*, *52*, 7-16.

Chen, Z. (2000). An object-based cost of visual filtering. *Perception & Psychophysics, 62*, 482-495.

Chen, Z. (2003). Attentional focus, processing load, and Stroop interference. *Perception & Psychophysics*, *65,* 888-900.

Chen, Z. (2004). Not all features are created equal: The encoding of location versus an object feature. Poster presented at the 45th Annual Meeting of the Psychonomic Society, Minneapolis, November, 2004.

Chen, Z. (2005). Selective attention and the perception of an attended non-target object. *Journal of Experimental Psychology: Human Perception & Performance, 31,* 1493-1509.

Chen, Z., & Simmonds, M. (in press). Visual attention and the selection of non-target objects. In C. M. Fletcher-Flinn, & G. M. Haberman (Eds.), *Cognition and language: Perspectives from New Zealand* (pp. xxx-xxx). Bowen Hill: Australian Academic Press.

Chen, Z., & Cave, K. R. (in press). Reinstating object-based attention under positional certainty: The importance of subjective parsing. *Perception & Psychophysics*.

Chen, Z., & Cave, K. R (2005). To see or not to see: attention leads to selection. Poster presented at Psychonomic Society 46th Annual Meeting, Toronto, Ontario, Canada. November, 2005.

Cohen, A., & Shoup, R. (1997). Perceptual dimensional constraints in response selection processes. *Cognitive Psychology*, *32*, 128-181.

Connor, C. E., Preddie, D. C., Gallant, J. L., & Van Essen, D. C. (1997). Spatial attention effects in macaque area V4. *Journal of Neuroscience*, *17,* 3201-3214.

Downing, C. J. (1988). Expectancy and visual –spatial attention: effects of 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: Erlbaum.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: Gerneral*, *113*, 501-517.

Egly, R., Driver, J., & Rafal, R. D. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion participants. *Journal of Experimental Psychology: Gerneral*, *123*, 161-177.

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. (1972). Some characteristics of selective attention in visual perception determined by vocal reaction time. *Perception & Psychophysics*, *11*, 169-171.

Eriksen, C. W., & Schultz, D. W. (1978). Temporal factors in visual information processing: A tutorial review. In J. Requin (Ed.), *Attention and performance VII* (pp. 3-23). Hillsdale, HJ: Erlbaum.

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention. *Perception & Psychophysics, 40*, 225-250.

Feintuch, U., & Cohen, A. (2002). Visual attention and coactivation of response decisions for features from different dimension. *Psychological Science, 13*, 361-369.

Folk, C. L. & Remington, R. W. (2004). Attention is not selection: Dimensional gating in object- and space-based attention tasks. Paper presented at Psychonomic Society 45th Annual Meeting, Minneapolis, MN, November, 2004.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attention control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 1030-1044.

Gibson, B. S., & Jiang, Y. (1998). Surprise! An unexpected color singleton does not capture attention in visual search. *Psychological Science*, *9*, 176-182.

Gibson, B. S., & Kelsey, E. M. (1998). Stimulus-driven attentional capture is contingent on attentional set for displaywide visual features. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 699-706.

Hoffman, J. E., & Nelson, B. (1981). Spatial selectivity in visual search. *Perception & Psychophysics, 30*, 283-290.

Hoffman, J. E., Nelson, B., & Houck, M. R. (1983). The role of attentional resources in automatic detection. *Cognitive Psychology*, *51*, 379-410.

Hughes, H. C., & Zimba, L. D. (1985). Spatial maps of directed visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, *11*, 409-430.

Hunt, S. M. J. (1994). MacProbe: A Macintosh-based experimenter's workstation for the cognitive sciences. *Behavior Research Methods, Instruments, & Computers, 26*, 345-351

Humphreys, G. W., Kyllingsbaek, S., Watson, D. G., Olivers, C N. L., Law, I., & Paulson, O. B. (2004). Parieto-occipital areas involved in efficient filtering in search: A time course analysis of visual marking using behavioral and functional

imaging procedures. *Quarterly Journal of Experimental Psychology*, *57*A, 610-635.

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

Kahneman, D., & Chajczyk, D. (1983). Tests of the automaticity of reading: Dilution of Stroop effects by color-irrelevant stimuli. *Journal of Experimental Psychology: Human Perception and Performance*, *9*, 497-509.

Kahneman, D., & Henik, A. (1981). Perceptual organization and attention. In M. Kubovy & J. R. Pomerantz (Eds.), *Perceptual organization* (pp. 181-211). Hillsdale, NJ: Erlbaum.

Kahneman, D., & Treisman, A. (1984). Changing views of attention and automaticity. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of attention* (pp. 29-61). Orlando, FL: Academic Press.

Kahneman, D., Treisman, A., & Burkell, J. (1983). The cost of visual filtering. *Journal of Experimental Psychology: Human Perception and Performance*, *9*, 510-522.

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

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: Erlbaum.

LaBerge, D. (1983). Spatial extent of attention to letters in words. *Journal of experimental Psychology: Human Perception and Performance*, *9*, 371-379.

Lamy, D., & Tsal, Y. (2001). On the status of location in visual attention. *European Journal of Cognitive Psychology*, *13*, 305-342.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 451-468.

Lavie, N. & Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. *Perception & Psychophysics*, *56*, 183-197.

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.

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

MacLeod, C. M. (1991). Half a century of researchont he Stroop effect: An integrative review. *Psychological Bulletin*, *109*, 163-203.

Maruff, P., Danckert, J., Camplin, G., & Currie, J. (1999). Behavioral goals constrain the selection of visual information. *Psychological Science*, *10*, 522-525.

Mordkoff, J. T. (1998). Between-dimension flanker effects: A clarification with encouraging implications. *Psychonomic Bulletin & Review*, *5*, 670-675.

Payne, W. H. (1966). Reaction time as a function of retinal location. *Vision Research*, *6*, 729-732.

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.

Prinzmetal, W., Amiri, H., Allen, K., & Edwards, T. (1998). Phenomenology of attention: 1. Color, location, orientation, and spatial frequency. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 261-282.

Prinzmetal, W., & Wilson, A. (1997). The effect of attention on phenomenal length. *Perception*, *26*, 193-205.

Remington, R. W., & Folk, C. L. (2001). A dissociation between attention and selection. *Psychological Science*, *12*, 511-515.

Scholl, B. J. (2001). Objects and attention: the state of the art. *Cognition, 80*, 1-46.

Shaw, M. L., & Shaw., P. (1977). Optimal allocation of cognitive resources to spatial locations.

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.

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

Theeuwes, J. (1994). Stimulus-driven capture and attentional set: Selective search for color and visual abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 799-806.

Theeuwes, J. (2004). Top-down search strategies cannot override attentional capture. *Psychonomic Bulletin & Review, 11*, 65-70.

Theeuwes, J., & Godijn, R. (2001). Attention and oculomotor capture. In C. L. Folk & B. S. Gibson (Eds.), *Attraction, distraction, and action: Multiple perspectives on attentional capture* (pp. 121-150). Amsterdam: Elsevier.

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.

Treisman, A., Kahneman, D., & Burkell, J. (1983). Perceptual objects and the cost of filtering. *Perception & Psychophysics, 33*, 527-532.

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.

Wolfe, J. M. (1999). Inattentional amnesia. In V. Coltheart (Ed.), *Fleeting memories* (pp.71-94). Cambridge, MA: MIT.

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

Wolfe, J. M., Klempen, N., & Dahlen, K. (2000). Postattentive vision. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 693-716.

Yang, H. J., & Kim, M.-S. (2003). What affects the dissociation between attention and selection. Poster presented at the 4th International Conference on Cognitive Science, Sydney, July, 2003.

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

Yeshurun, Y., & Carrasco, M. (1998). Attention improves or impairs visual performance by enhancing spatial resolution. *Nature*, *396*, 72-75.

Zimba, L. D., & Hughes, H. C. (1987). Distractor-target interactions during directed visual attention. *Spatial Vision*, *2*, 117-149.

Acknowledgments

This research was supported by Grant U6498 from the University of Canterbury to ZC, and by a University of Canterbury Visiting Erskine Fellowship to KRC. We thank Yuhong Jiang, Roger Remington, Charles Folk, Asher Cohen, and an anonymous reviewer for helpful comments, and Celestien Chan for help in conducting experiments.

Table 1

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

	Near				Far			
	Consistent		Inconsistent		Consistent		Inconsistent	
	M	SE	M	SE	M	SE	M	SE
Color								
RT	493	21.3	515	21.5	501	21.2	516	23.0
% Error	2.5	0.56	9.8	1.74	3.4	0.84	7.6	1.49
Orientation								
RT	500	20.2	508	19.4	518	23.2	523	20.0
% Error	2.4	0.61	3.4	0.69	3.3	0.93	4.4	0.99

Table 2

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

	Color				Orientation			
	Consistent		Inconsistent		Consistent		Inconsistent	
	M	SE	M	SE	M	SE	M	SE
RT	534	19.9	557	22.2	503	18.9	513	19.4
% Error	5.3	1.66	8.6	1.85	2.7	0.61	4.0	0.58

Table 3

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

	Color				Orientation			
	Consistent		Inconsistent		Consistent		Inconsistent	
	M	SE	M	SE	M	SE	M	SE
RT	602	43.6	623	44.0	595	44.9	610	46.2
% Error	3.7	0.89	7.5	1.75	1.7	0.48	3.8	0.86

Table 4

Mean Reaction Times (in Milliseconds) and Error Rates (Percent Incorrect), With Standard Errors, for Experiment 4.

	Color				Orientation			
	Consistent		Inconsistent		Consistent		Inconsistent	
	M	SE	M	SE	M	SE	M	SE
RT	530	17.4	532	17.4	457	12.8	457	11.9
% Error	4.7	0.98	6.8	1.40	1.9	0.70	2.3	0.76

Table 5

Mean Reaction Times (in Milliseconds) and Error Rates (Percent Incorrect), With Standard Errors, for Experiment 5.

	Color				Orientation			
	Consistent		Inconsistent		Consistent		Inconsistent	
	M	SE	M	SE	M	SE	M	SE
RT	547	25.0	564	26.6	493	12.6	498	19.4
% Error	4.0	1.1	6.8	1.84	1.1	0.35	1.3	0.48

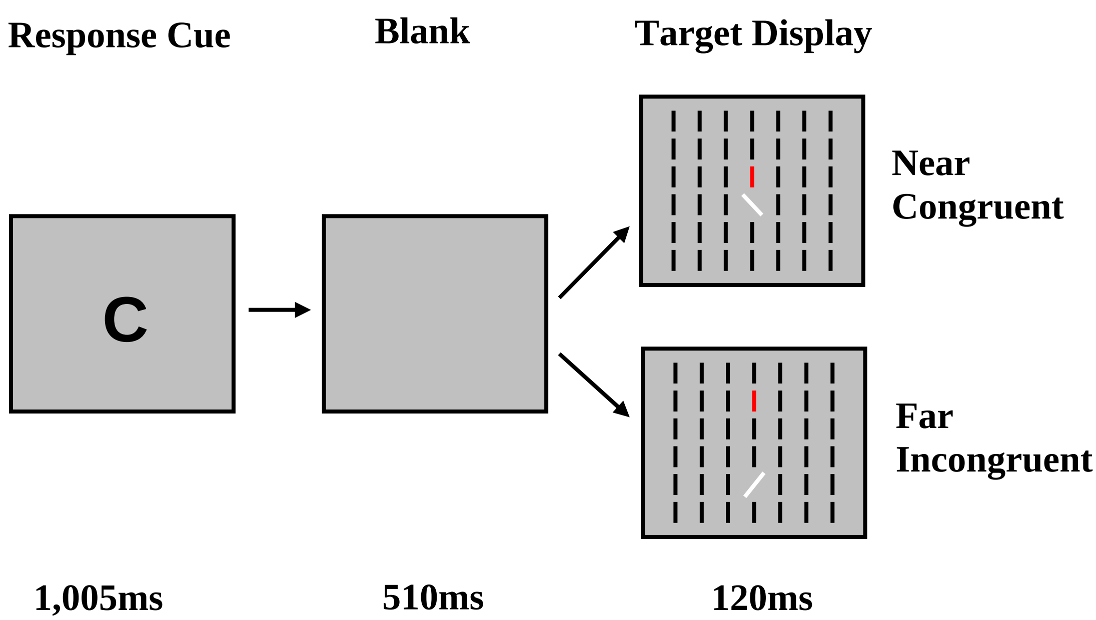
Notes:

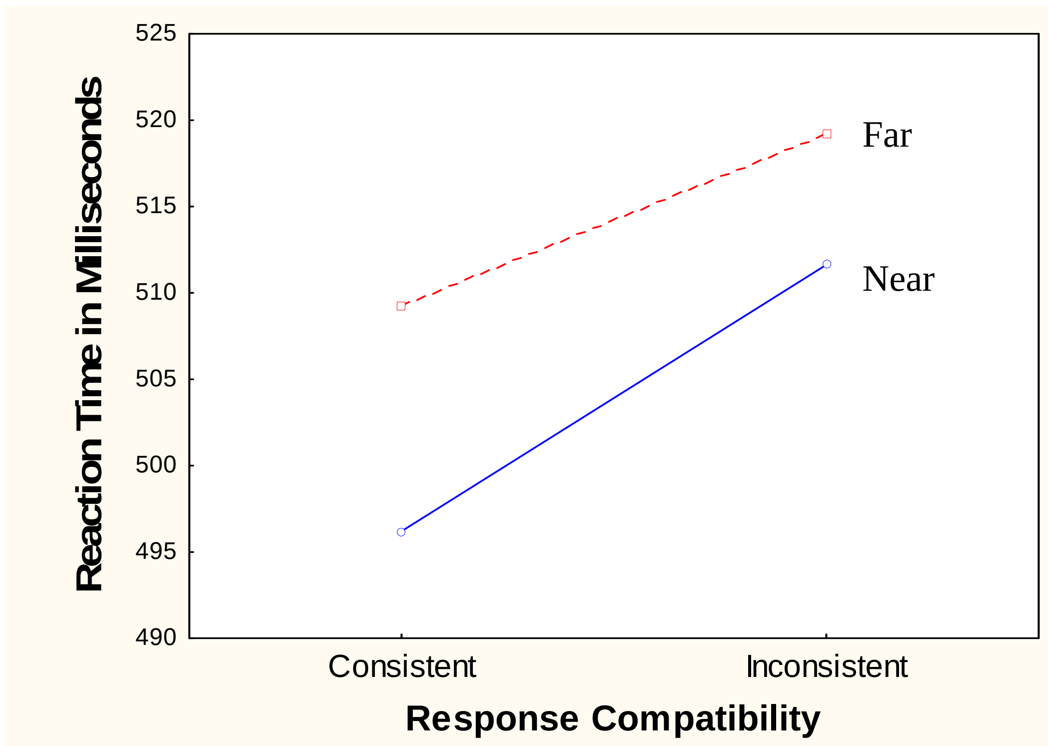
1. Although it is debatable whether singletons capture attention in a purely bottom-up fashion under all circumstances (e.g., Bacon & Egeth, 1994; Theeuwes, 2004), the conditions under which singletons are found not to capture attention do not appear to apply to the specific experimental paradigm used here (e.g., Folk, Remington, & Johston, 1992; Gibson & Jiang, 1998; Gibson & Kelsey, 1998; Jonides & Yantis, 1988; Yantis & Jonides, 1990).
2. We thank Roger Remington and Charles Folk for pointing out this possibility.

Figure Caption

Figure 1. Examples of stimulus displays from Experiment 1. Each trial started with a response cue (C or O), followed by a multi-element array that consisted of a target, a critical distractor whose irrelevant dimension was consistent or inconsistent with the target, and forty other irrelevant foils whose function was to provide a homogenous background. The target was defined on the basis of the response cue on a given trial. If it was a C, the colored stimulus (either red or green, represented by a dashed bar here) was the target, and the oriented bar (left or right orientation) was the critical distractor. If it was an O, the orientated bar was the target, and vice versa for the distractor. Both the target and the distractor were feature singletons. The participants were instructed to press one of two response keys on each trial. Whereas “red” and “left” were mapped onto one key, “green” and “right” were mapped onto the other key. Trials were compatible when the target and distractor indicated the same response key (e.g., a red target coupled with a left orientated distractor), and incompatible when they indicated different response keys (e.g., a red target coupled with a right orientated distractor).

Figure 2. Mean reaction times of Experiment 1 pooled across the color and orientation trials.


Response Cue
Blank
Target Display
C
Near
Congruent
Far
Incongruent
1,005ms
510ms
120ms


Reaction Time in Milliseconds
525
520
515
510
505
500
495
490
Far
Near
Consistent
Inconsistent
Response Compatibility