University of Alberta

Space-based and Object-based Attention in a Spatial Cuing Task.

by

Andrew Duncan Macquistan ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Doctor of Philosophy

Department of Psychology

Edmonton, Alberta

Fall 1996

National Library of Canada

Acquisitions and Bibliographic Services Branch

395 Wellington Street
Ottawa, Ontario
K1A 0N4

Bibliothèque nationale du Canada

Direction des acquisitions et des services bibliographiques

395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file Votre référence

Our file Notre référence

ISBN 0-612-18074-3

Canada

University of Alberta

Library Release Form

Name of Author: Andrew Duncan Macquistan

Title of Thesis: Space-based and Object-based Attention in a spatial cuing task.

Degree: Doctor of Philosophy

Year this Degree Granted: 1996

Andrew Macquistan

11136 86th Avenue
Edmonton, Alberta
CANADA
T6G 0X2

October 4, 1996.

University of Alberta

Faculty of Graduate Studies and Research

The undersign certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Space-based and object-based attention in a spatial cuing task submitted by Andrew Duncan Macquistan in partial fulfillment for the degree of Doctor of Philosophy.

Peter Dixon

Raymond Klein

Jorge Frascara

Norman Brown

Alan Kingstone

Dedication

To my parents, and for the future.

Abstract

The effect of objects on spatially directed selective attention was examined in three experiments. In all experiments, two rectangular objects were presented on either side of fixation, and subject's attention was directed by a cue to a location (all Experiments) or to locations (Experiment 3) on the objects. In Experiments 1 and 3, target recognition was slowed by presenting a target on a different object from the cued location, even when spatial factors were controlled. Experiment 2 indicated that this object-effect occurs only when exogenous cues are used to direct attention. Experiment 3 demonstrated that directing attention to two locations on two objects eliminates the cuing effect, but that directing attention to 2 locations on one object does not. The results are discussed in terms of a modified version of the gradient model, as well as their implications for the distinction between endogenous and exogenous attention.

Acknowledgements

A Ph.D. is one of those milestones in life where you pause, look backwards and examine the path you've taken. You look at the meandering and doubling backs, the false starts and the wrong turns, the distance you've walked and the progress you've made. And you scratch your head and ask yourself, "What was I thinking."

Well, it's been so long that I don't even have a clear answer, but I'd like to thank a few people who helped me along the way: Socially, I'd like to thank my fellow graduate students, past and present, particularly Barb and the Karens, Corinne and Leslie, Besté, Kevin, Karsten, the Daves, Dawn, Bob and Michael. My family provided me with emotional support and good advice when the going got rough, and it made all the difference. Economically, the Psychology Department, NSERC and Concordia University College at one time or another provided economic assistance in various forms, which made the job doable. Michael Dawson permitted me to use space in his lab well after he had formally taken the space over from my previous supervisor, and for his generosity I thank him.

Intellectually, I must thank my committee members, past and present, for their input into the dissertation. I would particularly like to thank my external supervisors, Dr. Klein and Frascara, for their enthusiasm for my work. The genesis of the experiments reported here was in discussions with John M. Henderson, who is now at Michigan State University. Piloting of the experiments, the defense of the research proposal, and all things subsequent were done after John had left, and Peter Dixon had taken up the supervisory reigns. I must especially thank Pete for his unabashed and encouraging enthusiasm for research (when the underlying idea is good and progress is being made), and his efforts on my behalf, particularly when he had entered the process at its later stages. Perhaps I could have finished if Pete had not been supervising me, but there would be much less to recommend my dissertation than there is now, and I would have had less faith in scientific research as a worthwhile goal in itself.

Looking to the distant past, I would like to acknowledge the influence that the late T.W.S. Seeger had on my life. For the brief time that I knew him, he inspired me to work on the basis of principle, and to struggle towards excellence for it's own sake. I rarely come anywhere near to living up to the model he provided, but all of us who knew him were the better for it.

Table of Contents

List of Tables

List of Figures

Psychologists have studied attention since at least the time of Helmholtz, Wundt, and James (James, 1890/ 1950). The concept of attention has been used in explaining phenomena from partial report performance (Sperling, 1960), to short term memory retention (Shiffrin & Schneider, 1977), to the programming of motor responses (Kahneman, 1973). Despite this widespread application, finding consensus on a general theory of attention, or even a general definition of attention, has proved elusive. Allport (1990) notes that when authors are faced with the question "what is attention?," they tend to avoid providing a definition or theory, either by simply cataloging attentional phenomena (c.f. Johnston & Dark, 1986), or by restricting their studies of attention to a single domain, such as vision (c.f. Treisman, 1982, 1988; Treisman & Gelade, 1980; Treisman & Gormican, 1988). While not committing itself to Allport's conceptualization of attention, this dissertation follows the latter strategy of limitation: The dissertation's topic is confined to attention in vision ("visual attention"), a choice with considerable benefits. The relevant research literature is large but well defined, as is indicative of a coherent topic. Vision is an important human sense, so attention in vision must be an important aspect of everyday cognition for the vast majority of people. Studying purely visual attention therefore addresses an interesting and important aspect of the mind.

Attentional Selection

For the purposes of this dissertation, attention is defined as the selection of visual information for use by higher level processes such as the preparation of motor responses (Posner, 1978; 1980; Posner, Snyder & Davidson, 1980), or the storage of information in memory (Rock & Gutman, 1981). The amount of information passed to higher level processes per unit time is assumed to be limited, which necessitates a process of selection to control what information is transferred. In this "bottleneck" conception of attention, visual information is initially registered by unlimited capacity processes (Broadbent, 1982; Duncan, 1980a; 1980b; Kahneman, 1973; Kahneman & Treisman, 1984). This registration of information is seen as relatively data-driven, although there is some evidence for top-down effects (Baylis & Driver, 1994; Prinzmetal & Keysar, 1989; Tsal & Kolbert, 1985; Wong & Weisstein, 1983). In terms of low level processes, visual attention has been shown to affect early processes (Hawkins, Shafto & Richardson, 1988), such as the speed of registering visual information (Stelmach & Herdman, 1991) and the quality of subject's perceptual representations (Downing, 1988). In terms of higher level processes, although visual attention can influence memory for a visual form (Rock & Gutman, 1981), or response competition (Eriksen & St. James, 1986; Murphy & Eriksen, 1987), it does so by influencing the availability of information for memory or response selection, not by influencing the processes themselves. Such two-stage models of cognition are common in the literature (Broadbent, 1982; Duncan & Humphreys, 1989; Fodor, 1983; Hoffman, 1978; 1978; Neisser, 1967; Pinker, 1984; Treisman & Gelade, 1980), so defining attention in their terms does not limit the dissertation's generality.

Why attention is necessary for perceptual processing has been a matter of debate since the 1960's (Broadbent, 1982; Deustch & Deustch, 1963; Kahneman & Treisman, 1984; Treisman, 1964). Traditionally, early selection theorists (Broadbent, 1982; Treisman, 1964) have held that the initially unlimited capacity registration of information was restricted to simple physical properties of the stimulus. More complex processing, including the assignment of meaning, was carried out by limited capacity central processes. The limited processing capacity of these central processes necessitated some process of selection to determine what information was to be analyzed. Late selection theorists (Deustch & Deustch, 1963), in contrast, argued that all perceptual information is completely analyzed, up to the assignment of meaning, and that limitations in performance arose only when action had to be taken, such as making a response or storing the information in long term memory. This dissertation tends to follow an early selection approach, with some departures. It is assumed, consistent with early selection, that the initially registered information is not semantically interpreted before selection. However, it is assumed that non-semantic properties of the stimulus may be used to organize visual information before attention is deployed (Neisser, 1967). The extent of these processes of attention-free organization is left an open question. For example, Driver, Baylis, and Rafal (1992) have argued that at least one gestalt process, figure-ground segmentation, is preattentive, while Mack, Tang, Tuma, Kahn and Rock (1992) have argued that some form of attention is required for some gestalt grouping processes, such as grouping by similarity.

The assumption of an early selection viewpoint in this dissertation is not meant to deny the possibility of selection also operating at higher levels of the visual system, after the selection of perceptual information. However, the experimental work of the dissertation focuses on the effects of selective visual attention on the processing of perceptual information. The stimuli used are relatively non-semantic (oriented triangles and rectangular shapes), and the task itself, spatial cuing, can be well explained within an early selection framework (LaBerge & Brown, 1989; Prinzmetal, Presti & Posner, 1986; however, see Duncan, 1980a, for a different view). Given that there is no manipulation of semantic qualities of the stimuli used in this experiment, the data cannot really address questions about semantic processing and its interplay with visual attention. The early selection approach is preferred because it allows a straight-forward account of the data.

Overview

The experiments presented in this dissertation address the question of how selective attention is affected by the presence of objects in the visual field. This question arises out of the theoretical distinction between space-based and object-based models of visual attention (Duncan, 1984). In space-based models, selection is mainly controlled by spatial factors (Downing & Pinker, 1985; Eriksen & Yeh, 1985; Posner, 1980). Space-based models assume that locations and regions of the visual field are selected for further processing, and emphasize the role that spatial factors such as proximity play in attending to stimuli (Hoffman & Nelson, 1981) These models suggest that visual information is indexed primarily by its location in space (Downing & Pinker, 1985; LaBerge & Brown, 1989). As a class, space-based models do not explicitly deal with the effects of visual objects or gestalt groups on attention. In contrast, object-based models assume that attention selects objects or potential objects in the visual field, and, typically, that gestalt grouping phenomena reflect how these objects are structured (Duncan, 1984; Driver & Baylis, 1989; Kahneman, 1973; Kahneman & Henik, 1981). Considerable evidence has been produced that support the predictions of object-based models, which in turn indicates the need for a complete theory of attention to have both space- and object-based components (Baylis & Driver, 1992).

Until recently, however, different paradigms were often used to examine the two classes of models. One large class of research supporting space-based models involved the directing of attention to locations by a spatial cue, while object based research employed manipulations of objects and groups in the visual field. Recently the two approaches were combined by Egly and his associates (Egly, Driver, & Rafal, 1994; Egly, Rafal, Driver, & Starrveveld, 1994), who used spatial cues to direct attention in a display containing objects, and found object-based effects. This dissertation examines in more detail how spatially cued attention is directed over a visual field containing objects, and whether the object-based effects depend on the type of cue used (endogenous or exogenous, see Jonides, 1981; Yantis & Jonides, 1984).

The plan of the dissertation is as follows: The discussion first turns to a review of the spatial cuing paradigm, followed by a discussion of space-based theories of attention and the evidence in favour of object-based models of attention. Then the experiments by Egly, Driver and Rafal (1994;; Egly, Rafal, et al., 1994) that demonstrate object-based effects on the allocation of spatially directed attention are discussed, followed by a discussion of the distinction between endogenous and exogenous cuing. It is pointed out that the spatial cues used by Egly, Driver and Rafal (1994; Egly, Rafal, et al., 1994) had both endogenous and exogenous properties, and it is therefore ambiguous as to whether the object-based effects they report arise from their cue's endogenous or exogenous properties. The results of three experiments examining the effect of objects on spatially directed attention are then reported, which resolve this ambiguity. The implications of these results for the concept of attention then are discussed.

The Spatial Cuing Paradigm

The canonical version of the spatial cuing task is associated with the work of Posner (1978; 1980; Posner, Snyder & Davidson, 1980). In Posner's initial studies, subjects maintained fixation on a central point throughout each trial of the experiment. Excepting catch trials, subjects were presented with a target stimulus, a luminance increment, that could occur on either side of fixation. Subjects pressed a response key as soon as they perceived the target, and the latency and accuracy of their responses served as the dependent measures. On some proportion of trials, subjects were given a warning signal before the target event that indicated it was about to occur, but not where it would occur. These trials served as a baseline (neutral condition) for the larger proportion of trials where subjects received a symbolic cue (an arrow at fixation) indicating the most probable location of the subsequent target. Consistently, targets at the cued location showed faster detection times, and those at the uncued location slower detection times, relative to the neutral condition.

These results have been replicated many times, with a variety of tasks and dependent measures (e.g., Bashinski & Bacharach, 1980; Briand & Klein, 1987; Eriksen & Yeh, 1985; Henderson, 1991; Jonides, 1980; 1981; Keifer & Siple, 1987; Klein & McCormick, 1989; McCormick & Klein, 1990; Prinzmetal, Presti & Posner, 1986). Other stimuli, such as the onset of a bar marker or a sudden luminance increment at the cued location, have also been used to direct attention (Henderson, 1991; Jonides, 1980, 1981; Nakayama & Mackben, 1989), and they show a similar pattern of response times and accuracies. As will be discussed later, this type of cue, called an exogenous cue, also shows interesting differences from endogenous cues, such as arrows at fixation, in how they orient attention and in the consequences of that orienting.

Posner's theoretical account of the effects of location cues was relatively straight forward (although there alternative accounts, e.g. Shaw, 1984; Sperling, 1984). In Posner's conception, attention can only be directed to a spatially limited region (Posner, 1980; Posner, Snyder and Davidson, 1980). In order to make arbitrary, non-habitual responses to the targets, subjects have to covertly direct attention to the target's location (Posner, Snyder & Davidson, 1980). If the cue directed the subject's attention to the target's subsequent location, this results in a savings in response time, because the need to orient attention is eliminated. If the cue directs subject's attention to a location different from the target's subsequent location, this results in a cost in response times, due to the need to orient attention to the target's location. Costs and savings are assessed relative to a neutral condition, which differs only from validly and invalidly cued trials in that no specific location is cued (see Jonides & Mack, 1984, for cautions concerning the interpretation of neutral cue conditions). Neutral cue trials typically show response times intermediate between those of valid and invalid trials. Posner's research has also looked at the various putative stages of directing attention about the visual field, such as disengaging attention from one location, shifting it to a new location, and re-engaging it at the new location (Posner, Inhoff, Friedrich & Cohen, 1987).

Space-based Theories of Attention

Three models of space-based attention are often used to explain the results of spatial cuing paradigms: The spotlight, zoom lens, and gradient models. In general, all three models share the assumption that attention operates over visual space, or some topographic representation of it (Downing & Pinker, 1985; Eriksen & Yeh, 1985; LaBerge & Brown, 1989; Posner, Snyder & Davidson, 1980), and they conceptualize the process of attention as the extraction of information from locations in the visual field for use by higher level processes (LaBerge & Brown, 1989). Proponents of space-based theories argue that even when the task requires target selection by a non-spatial feature, such as color or shape, a location must still be accessed (Nissen, 1985; Tsal, 1983; Tsal & Lavie, 1988; 1993). Selection is therefore determined primarily by spatial factors. The models differ on issues related to the distribution of attention over space, such as whether the size of the attended region can be changed, and how attention's effects attenuate over spatial separations. As will become apparent, the spatial cuing literature is most consistent with the notion that attention selects a continuous region of space whose total spatial extent is flexible, and that increasing the size of the region cued results in changes in how attention's effects attenuate with distance. When other factors (such as the relative frequencies of targets in a block of trials or the ease of encoding different stimuli) are controlled, space-based theories assert that spatial factors determine the efficiency of selection.

The spotlight model was one of the first of the space-based models to gain widespread popularity. In common usage (Henderson, 1991; McCormick & Klein, 1991), the size of the region selected by attention is assumed to be constant, and locations are either within this region or not. This fixed spatial area is often assumed to be about 1 degree of visual angle (Eriksen & Eriksen, 1974), and it is assumed that the attended region must be reoriented from location to location on invalid trials, a time consuming process (Posner, 1980; Posner, Snyder & Davidson, 1980; see, however, Klein &

Briand, 1986). This version of the spotlight model well accounts for the decrease in reaction times and errors when detecting or identifying targets at a cued location, and for the increase in reaction times or errors for targets that occur at uncued locations (e.g., Eriksen & Yeh, 1985; Eriksen & Hoffman, 1972; Henderson, 1991; Henderson & Macquistan, 1993; Keifer & Siple, 1987; Posner, 1980; Posner et al., 1980; Posner & Cohen, 1984; see Bashinski & Bacharach, 1980 for d' results). These results naturally follow from the model's assumptions.

However, a fixed-area spotlight model has difficulty in accounting for the effects of cue size (Eriksen & St. James, 1986; Henderson, 1991; LaBerge & Brown, 1989; McCormick & Klein, 1990). When two or more cues are presented at adjacent locations in the visual field, the response times to targets presented at the cued locations are slower than response times to targets presented at a location cued by only a single cue. Response times to targets at uncued locations are faster when more than one location is cued, even when the distance from the uncued location to a cued location is taken into account. These changes in response times are not easily predicted by fixed-area spotlight models (Henderson, 1991; Keifer & Siple, 1987; McCormick & Klein, 1991), but they are explicable by models such as the zoom lens or gradient of attention, which propose that the size of the attended region can be altered in response to task demands.

The zoom lens model. Like the spotlight model, the zoom lens model proposes that attention selects information from a bounded region in the visual field. As in the spotlight model, when a target occurs at an uncued location, subjects must orient this spatially bounded region to the location. Unlike the spotlight model, however, the zoom lens model also suggests that the size of the region attended to can be flexibly increased or decreased in response to cues (Eriksen & St. James, 1986; Eriksen & Yeh, 1985). Changes in the size of the area attended to result in changes in the rate of information uptake from attended locations. In the zoom lens model, the effect of attention can be conceptualized as activation in a preattentive representation; the level of activation determines how long it takes to transfer information to higher level processes (c.f., Eriksen & St. James, 1986; Eriksen & Yeh, 1985; Eriksen & Webb, 1993). When the zoom lens is spread over a large area of the visual field, the activation at each point within the region is lower and it therefore takes longer to transfer information from any point to higher level processes. When the zoom lens is limited to a small region, the activation at each point is higher, and the transfer of information faster. Because activation in the zoom lens model is allocated over a spatially bounded region, locations outside the region are not selected for higher level processing, although some automatic processes, such as the priming of letter identities, can occur outside of the attended region (Eriksen, Webb & Fournier, 1990).

Gradient models. Like the spotlight and zoom lens model, gradient models also assume that attention operates over some spatial representation of the visual field; however, the various versions of gradient model differ in their conceptualizations of this underlying representation. For example, LaBerge and Brown (1989) argue that attention facilitates the selection of feature information from an initial feature register, while Downing and Pinker (1985) describe attention as operating over a representation similar to Marr's (1982) 2 & 1/2 D sketch, one that includes depth information. The empirical findings that motivate gradient models are those that are difficult for fixed area spotlight models to explain: When more than one location is simultaneously cued, the pattern of response time means and variances, as well as accuracies, do not fit the predictions of a fixed area spotlight model (Henderson, 1991; Keifer & Siple, 1987; McCormick & Klein, 1991). Besides the faster response times at uncued locations and the slower response times to cued locations when more than one location is cued, the effects of attention on performance of perceptual tasks tends to fall off over distance in a negatively accelerated fashion (Downing, 1988; Downing & Pinker, 1985; McCormick & Klein, 1991). LaBerge and his colleagues (LaBerge & Brown, 1986; 1989; LaBerge, Brown, Carter, Bash & Hartley, 1991) also report results that are consistent with an attended region whose size is alterable in response to task demands.

Like the zoom lens model, gradient models explain these changes in response time by suggesting that the time it takes to select information from the representation of the visual field is directly proportional to the concentration of activation at represented locations corresponding to visual field locations (LaBerge & Brown, 1989), or to an activation of locations that spreads from the cued location to adjacent locations (Downing & Pinker, 1985). Unlike zoom lens models, however, activation in response to cues is distributed continuously over the entire visual field, rather than over a spatially bounded region. The amount of activation at a location is assumed to decrease with increases in the distance of that location from the cued location. The level of activation at each location varies continuously across the visual field from fairly high to fairly low, and the attended and unattended regions therefore grade into each other (Downing, 1988; Downing & Pinker, 1985; Henderson, 1991). The distribution of activation at locations is often described as guassian in cross section (Downing, 1988; Downing & Pinker, 1985; Henderson, 1991), with the effects of attending to a large or small region being analogous to changing the variance of the distribution: With a wider distribution of activation, there is less difference between cued and uncued locations in terms of activation, and therefore less difference in response times. Also, when several adjacent locations are cued, each cued location also receives relatively less activation than when it alone is cued, and thus the response times to targets presented at cued locations are slower when two locations are cued, rather than one.

The experimental results reported in this dissertation will generally be discussed in terms of the gradient model. The model gives a more parsimonious account than the zoom lens model of the gradual change in response times or accuracy that accompanies increases in the distance of the target's location from the cued location (Downing, 1988; Downing & Pinker, 1985; Henderson, 1991; Henderson & Macquistan, 1993). The gradient model attributes the change in performance to an underlying distribution of activation. While the zoom lens model can account for graded patterns of response time and accuracy changes, its explanation would have to be less direct, as attention in the zoom lens model is evenly directed over a bounded spatial region, rather than continuously varying over the visual field. The fixed area spotlight model can be ruled out as an alternative to the gradient model on the basis of experiments manipulating the number of locations cued (Keifer & Siple, 1987; McCormick & Klein, 1991; Henderson, 1991).

In the version of the model discussed below, attention will be conceptualized in terms of some activation of locations within a structured representation of the visual field. Spatial cuing has its effects by activating portions of this initial representation that correspond to the cued location. Costs and benefits in cuing arise because the activation of a location in the representation decreases the amount of time it takes to select information from that location, relative to other locations that are less active. It is assumed that the representation is topographically organized, so that the spatial relationships between locations in the visual field can affect the relative activation of locations and thus response times. Activation is assumed to spread from the attended location to other locations in the representation, and to attenuate with distance from the cue. Thus, targets presented at locations that are closer to the cued location will be positioned at locations in the representation that are relatively more activated than others, and will therefore be selected more quickly than those at locations that are relatively less activated.

Evidence Supporting an Object-based Account

The critique of the space-based approach offered by those favoring object-based models is not so much that attention is never affected by spatial factors, but that the presence of objects in the visual field can also influence attention (Baylis & Driver, 1992; Duncan, 1984). Researchers favoring object-based models propose that processes of gestalt grouping organize the visual environment into tentative objects (Duncan, 1984; Kahneman, 1973; Neisser,

1967) that are then selected for further processing. The empirical evidence supporting the object-based approach include investigations of how grouping affects response competition in the flankers task (Baylis & Driver, 1992; Driver & Baylis, 1989: Kramer & Jacobson, 1991), and how well subjects can report the two properties of one object or two properties of two different objects (Baylis & Driver, 1993; Duncan, 1984), as well as other effects of objects on attention (Kahneman & Treisman, 1984; Kahneman, Treisman & Burkell, 1983). These lines of investigation are reviewed below.

Response competition. Several studies have modified the flankers task of Eriksen and Eriksen (1974) to demonstrate the effects of grouping and objects on selective attention. In Eriksen and Eriksen's original study, subjects made an identification response to a single target letter presented at fixation and attempted to ignore irrelevant letters that were spatially proximal to the target. The targets were drawn from two sets of letters, each set requiring a different, incompatible response. For example, subjects had to move a lever in one direction if the target letter was an "H" or a "K", and in a different direction for an "S" or a "C". Irrelevant, or flanker, items were drawn from either target set, or from a set of letters that were neutral with respect to the responses (i.e., 'N,' 'W,' 'Z,' 'G,' 'J,' or 'Q'). When flankers were response compatible or neutral with respect to the target, subject's response times were faster than when the flankers were response incompatible. The effect is not specific to letter stimuli; for example, Kramer and Jacobson (1991) used dashed or solid lines as stimuli and found response competition.

Variants of the flankers task that test the object-based approach typically hold constant the spatial separation of flankers and targets and show that varying grouping, the presence of objects in the visual field, or both modulates the response-competition effect. When spatial separation is controlled, grouping by shared color and good continuation modulates response competition (Baylis & Driver, 1992), as does similarity in color (Kramer & Jacobson, 1991; Experiments 1 & 2) and whether or not the flankers and target item are included within the same geometric object (Kramer & Jacobson's Experiments 1 & 3). All of these studies support the predictions of object-based models -- when the spatial proximity of interfering items is controlled (Baylis & Driver, 1992; Kramer & Jacobson, 1991), object-based models predict response conflict should occur from the stimuli that are either grouped with the target, or belong to the same object as the target, while space-based models predict no effect of grouping. If attention selects on the basis of objects and groups, it should be easier to filter out information from a different group or object than from the same group or object that the target belongs to. (Driver and Baylis, 1989, have reported similar object-based response competition results using motion to group stimuli, but this effect has since failed to replicate (Kramer, Tham & Yeh, 1991; Berry & Klein, 1993).)

Reporting two properties of one or two objects. Another result that suggests the presence of objects in the visual field influences attentional selection is the finding that when spatial proximity is controlled, it is easier to report two properties of one object than it is to report two properties of two different objects (Baylis & Driver, 1993; Duncan, 1984; see also Neisser & Becklin, 1975). This indicates that, even when spatial factors are controlled, directing attention over two objects adds an extra cost. Baylis and Driver's (1993) study will be discussed as an example of this research, because this study also demonstrates that subject's perceptual set can influence how they parse the visual field into objects.

Baylis and Driver's (1993) studies took advantage of the phenomena that contours are perceived as belonging to figure rather than ground. They used an ambiguous figure modeled on the Ruben's vase illusion. The figure consisted of three regions defined by differences in color: A central region and two flanking regions to either side. The flanking regions were always the same color (red or green), and the central region was always the opposite color from the flanking regions (green or red). In a between-subjects manipulation, subjects were instructed to consider the displays as either red objects on a green background, or green objects on a red background. Their task was to make a judgment about the pair of contours dividing the regions. Naturally, when the display was interpreted as red objects on a green background, the contour would be seen as belonging to the red regions. When the central region was red, both contours would be on one object, and when the central area was green, the contours would belong to different objects. When the contours were on the same object, the decision would be easier than when the contours were on different objects, which was the pattern observed. When subjects were instructed to interpret the display as green objects on a red background, the object-based pattern of results were replicated, although this time for the green regions.

Baylis and Driver's (1993) result not only demonstrates that it is easier to report two properties of one object than two properties of two different objects (see also Duncan, 1984), it also demonstrates that manipulating subject's perceptual set can affect how subjects parse the field into objects. A similar point about subject's expectancies and display parsing was made by Tsal and Kolbert (1985) and Wong and Weisstein (1983).

Other object-based phenomena. Effects of objects and groups on visual selection have been reported in several other experimental paradigms. In visual search, speed of subject's search has been shown to depend upon the number of groups present in the field and the uniqueness of targets in each group (Banks & Prinzmetal, 1976; Farmer & Taylor, 1980; Bundesen & Pedersen, 1983; Treisman, 1982). Illusory conjunctions, also called feature migrations, have been shown to be more frequent between locations within a single group than between locations in different groups (Baylis, Driver & McLeod, 1993; Prinzmetal, 1981). Irrelevant objects have been shown to slow the reading of three letter words in situations where the location of word and distracters is unpredictable (Kahneman, Treisman & Burkell, 1983). Treisman, Kahneman & Burkell (1983) have demonstrated that the interference from an irrelevant object is eliminated when the irrelevant item (a frame in their case) is presented as part of the same perceptual object as the word to be read. Yantis and Hillstrom (1994) have demonstrated that attention may be automatically drawn to the appearance of a new perceptual object. The visual search and illusory conjunction results indicate that the presence of objects in the visual field influences the allocation of attention to stimuli, while the work of Kahneman and Treisman (1984; Kahneman, Treisman & Burkell, 1983; Treisman, et al., 1983), and Yantis and Hillstrom (1994) indicate that selective attention may be allocated obligatorily to new objects.

Object-based Effects in the Spatial-Cuing Paradigm

Yantis and Hillstrom's (1994) work suggests that the attentional system is engaged by the appearance of objects. This leaves open the empirical question as to what effects pre-existing objects in the visual field have on the allocation of attention. When objects are present in the visual field before subject's attention is directed to a location on one object, are object-based effects of attention apparent?

Recently, Egly and his associates (Egly, Driver & Rafal, 1994; Egly, Rafal, et al., 1994) have demonstrated that the presence of objects can modify the allocation of attention in response to a spatial cue. In Egly, Driver, and Rafal (1994), subjects were presented with a stimulus display consisting of a pair of outline rectangles, one on either side of fixation, whose separation was equal to their length. Subject's attention was directed to one end of one rectangle by a spatial cue, a brightening of one end of one rectangle that indicated the most likely location of a detection target. The target followed the cue after a 300 ms SOA. On trials where the target did not occur at the cued location, it occurred with equal probability at the other end of the cued location's rectangle, or on the end of the uncued rectangle nearest the cued location.

In their experiments, Egly, Driver and Rafal (1994) tested both normal and parietal lesioned subjects. Their data is displayed in Table 1. The normal subjects and those subjects with unilateral right parietal lesions showed slower detection of targets at uncued locations when the uncued location was on the uncued object (on average, 13 ms for normals, 24 for right lesioned subjects), and the effect was apparent in both visual hemifields. In addition, Egly, Driver, and Rafal (1994) found that subjects with unilateral left parietal lesions showed a large object effect in their right visual hemifield (a 76 ms difference between the uncued location on the cued object and the uncued location on the uncued object, when these locations were in the right visual hemifield), but no effect in their left visual hemifield (-3 ms difference). From this result, and other work using this paradigm (Egly, Rafal, et al., 1994), Egly and his associates have proposed that there are distinct neural mechanisms for both space-based and object-based attention, with the object-based attentional system located in the left parietal lobe. Subjects with right parietal lesions show relatively the same pattern of object-based effects as neurologically intact individuals, indicating that the object-based attentional system is unaffected by these lesions, whereas subjects with left parietal lesions show an abnormal pattern of object-based effects, relative to the neurologically intact, indicating that the object-based attentional system is affected by these lesions. Because only lesions to the left parietal lobe lead to an abnormal object-based effect, Egly and his colleagues localize the object-based system in the left parietal lobe. In Egly's conception, space-based and object-based attention are governed by neurologically distinct processes that can be disassociated in clinical cases.

Table 1.

Mean response time difference (in ms) between cued and uncued locations in Egly, Driver & Rafal (1994).

	Left Visual Field Targets		Right Visual Field Targets	
Parietal Lesions	On Cued Object	On Uncued Object	On Cued Object	On Uncued Object
None	35	50	35	46
Right	75	102	54	75
Left	59	56	73	149

In terms of the model of attention used to frame the discussion in this dissertation, the effects observed by Egly, Driver and Rafal (1994; Egly, Rafal, et al, 1994) can be explained if the underlying representation that attention operates over contains information about both space and objects. The basic effect of cuing can be explained by assuming that when a location on an object gets cued, activation from that cue tends to spread over locations, and that the level of activation at a location is inversely proportional to its distance from the cued location, as in gradient models. Egly, Driver and Rafal (1994) found a significant response time difference between the cued and uncued locations on the same object, a space-based effect that is consistent with this model. The object-based effect that they describe, a slowing of detection response times by 13 or 24 ms at an uncued location when that uncued location was on the uncued object rather than the cued object, can be explained if more activation from the cued location tends to spread over the cued object than to locations on the uncued object. This differential spreading would result in uncued location on the same object as the cued location being more highly activated than the equally distant location on the uncued object, in turn leading to faster selection of information from the more activate location. That left hemisphere parietal lesions result in an abnormal object effect can be explained by assuming that brain areas within the left parietal lobe control either the formation of object representations or their activation by attention.

Exogenous versus endogenous orienting of attention.

Crucial to a clear interpretation of Egly, Driver and Rafal's (1994; Egly, Rafal, et al, 1994) results is the distinction between endogenously oriented attention, attention oriented under the subject's control, and exogenous attention (Briand & Klein, 1987; Jonides, 1981; Nakayama & Mackben, 1989; Posner & Cohen, 1984), attention oriented in response to some sudden perceptual event at a location (Yantis & Jonides, 1984). Research examining these two types of attention has indicated considerable differences between the two types of cue in terms of both their functions and the time course of their effects.

Endogenous cues are those that require interpretation by the subject, such as an arrow or number at fixation indicating a location. The efficiency of selection in response to endogenous cues depends upon the predictive validity of the cue: Non-predictive endogenous cues have little or no effect on selection (Jonides, 1981). Selection in response to endogenous cues reaches its maximum efficiency (as measured in by the difference in performance between cued and uncued locations) by about 300 ms after the cue's onset, and can then be sustained at the cued location for a protracted time (Jonides, 1981; Maylor, 1985; Maylor & Hockey, 1985; Müller & Rabbitt, 1989; Nakayama & Mackben, 1989; Posner & Cohen, 1984; Remington & Peirce, 1984). Selection in response to exogenous cues, in contrast, is controlled by sudden perceptual events at the cued locations, and is relatively insensitive to manipulations of subject's expectancies or the predictive validity of the cue (Jonides, 1981; Nakayama & Mackben, 1989). It reaches its maximum extent within 100-150 ms of the cue's onset, and then begins to decline. About 300 ms after the cue, a sustained inhibition called inhibition of return occurs at the cued location, lasting at least 1,200 ms (Abrams & Dobkin, 1994, who find evidence for both space-based and object-based inhibition of return; Maylor, 1985; Maylor & Hockey, 1985; Posner & Cohen, 1984). However, if the exogenous cue is predictive of the target's subsequent location, a benefit at the cued location may be observed due to a subsequent endogenous process of selection at the cued location (Nakayama & Mackben, 1989; Klein, 1994) whose facilitation compensates for the inhibition.

There is some support for the assumption of qualitative differences between selection in response to exogenous cues and selection in response to endogenous cues, suggesting that different representations may be involved. Briand and Klein (1987; Klein, 1994) have demonstrated that the type of cue used to direct attention interacts with the type of perceptual task subjects must perform. When feature integration is required to identify a target, the overall cuing effect for exogenous cues is larger than when feature integration is not required. When endogenous cues are used, the overall size of the cuing effect is unaffected by whether target identification requires feature identification (Briand & Klein, 1987). Additionally, Klein (1994) has presented evidence that endogenous cues, but not exogenous ones, interact with subject's expectancies about the likely form of a subsequent target. Taken together, these results indicate that selection following exogenous cues is involved in the process of feature integration, while selection following endogenous cues is involved in processes of response selection (Kingstone, cited in Klein, 1994; Klein, 1994). Given that different functions are performed by the two different kinds of attention, it is reasonable to suggest that different representations may be involved. Either or both of these representations may be structured into representations of objects.

It is not entirely clear whether the cues used in Egly, Driver and Rafal's (1994; Egly, Rafal, et al, 1994) work should be categorized as endogenous or exogenous cues, as they have properties of both types of cue. Egly, Driver and Rafal's (1994; Egly, Rafal, et al., 1994) cues meet some of the criteria of endogenous cues, because they had predictive validity and a cue to target SOA of 300 ms, but they also meet some of the criteria of exogenous cues, because they were a sudden perceptual change at the to be attended location. Given the functional differences between selection controlled by exogenous cues and selection controlled by endogenous cues (Briand & Klein, 1987; Klein, 1994; Klein, Kingstone & Pontefract, 1994), it is crucial to examine whether Egly's effect depends on the endogenous properties of their cues, or their cues' exogenous properties. One of the goals of this dissertation is to examine this question. While the current literature indicates that space-based effects, and gradient-like effects, can be found with exogenous and endogenous spatial cues (Downing, 1988; Downing & Pinker, 1985; Henderson, 1991; Henderson & Macquistan, 1994), it remains to be seen if object based effects occur with exogenous cues, endogenous cues, or both. Finding an effect of objects with only one type of cue would demonstrate another functional difference between endogenous and exogenous cues (Briand & Klein, 1987; Klein, 1994). In terms of Egly's preferred explanation of the effect, it would imply that different neural substrates are engaged by different kinds of cue. On the other hand, finding an effect of objects with both kinds of cue would indicate that the underlying representations from which attention selects structured in terms of objects.

To outline the experiments: In Experiment 1, the costs and benefits of orienting attention to locations on objects were assessed, as well as the distribution of attention over the uncued object, points not examined by Egly, Driver and Rafal (1994) or Egly, Rafal, et al. (1994). Non-predictive, exogenous spatial cues were used to see if the effects they observed replicate with unambiguously exogenous cues (Jonides, 1981; Henderson, 1991). Experiment 2 explicitly compared exogenous cues and endogenous cues using the same object manipulations as in Experiment 1. Experiment 3 examined the space-based versus object-based issue by comparing how easily attention can be directed to two locations on one object versus two locations on two objects.

Experiment 1

In Experiment 1, the presence of objects in the visual field was manipulated by placing two identical rectangular shapes in the field, with the separation between them equal to their length, and with the entire pair centered on fixation. Following a single exogenous cue at any one end of a rectangle, the target was presented at any one of the four ends of the rectangles with equal probability. The test for object-based effects was the comparison of target identification at the uncued location on the cued object with the equally distant location on the uncued object. If objects affect the allocation of attention, target identification should be significantly faster on the cued object than the uncued object. The test for space-based effects were the comparison of the two locations on the cued object, and the comparison of the two locations on the uncued object. In these cases, each pair of locations is on the same object and only differ by their distance from the cued location.

If objects alone determine selection, and spatial factors are irrelevant, then one would expect no difference between locations on the same object and a difference between locations on different objects even when spatial separation is equated (Vecera & Farah, 1994). In contrast, if spatial factors alone determine selection, then there should be a difference between locations on the cued object and no difference between the uncued location on the cued object and the nearest location on the uncued object because, in this case, spatial separation is equated. A purely space-based model could account for a lack of a response time difference between locations on the uncued object if it is assumed that the gradient of attention reaches an asymptote with large spatial separations. A hybrid model of attention, where both space-based and object-based factors affect selection, would predict a difference between locations on the cued object, a difference in response times between targets presented at the uncued end of the cued object and the end of the uncued object nearest the cue, and possibly, although not necessarily, a response time difference between targets presented at opposite ends of the uncued object.

In addition to the use of purely exogenous cues, there are several other ways in which the current experiment differs from Egly, Driver, and Rafal's (1994). Their targets occurred more frequently on the cued object than on the uncued object (87.5% of trials on which a target was presented versus 12.5%), and there was only one location on the uncued object, relative to the cued location, at which targets could occur. This situation could have biased subjects to have a lower criterion for detection reponses to stimuli occurring on the cued object than to targets occurring on the uncued object. The current Experiment 1 removes these problems by making the target equally likely to occur on either object after the cue, and through the use of a discrimination task, where changes in bias are of less concern.

Method

Subjects. Twenty four subjects from the University of Alberta subject pool participated in this experiment in return for course credit. All had normal or corrected to normal vision (according to self report) and none had previously participated in a spatial cuing experiment.

Apparatus and stimuli. Stimuli presentation and response recording were controlled by a 808286 based Zenith datasystems computer with a dedicated I/O board. The experimental stimuli were drawn using a computer paint program and imported onto the experimental computer. Stimuli were presented in high resolution EGA graphics. Subjects viewed the displays from a distance of 35 cm, with their head on a chin-rest. Responses were made on a button box.

Stimuli. A central fixation cross, subtending 40' by 40', was present on the screen throughout the experiment. The objects used in this experiment were two solid rectangular shapes, drawn to either side of the fixation point, positioned so that the center point of their long axes were 4° 30' from fixation. Each subtended 12° 33' by 3° 15'. The ends of the rectangles, where targets were presented, were all equally distant from the fixation point (6° 41'). The rectangles could be oriented either both vertically or both horizontally. The cues used to direct attention consisted of three lines drawn around one end of one of the rectangles, forming a segmented "C" shape enclosing the cued end. Each line was 59' of a degree wide and 3° 15' long, and was separated from the sides of the object by 59' visual angle. The fixation point, objects, and cues were drawn in white on a black background. An example of a single cue around one end of a rectangle is diagrammed in Figure 1.

Targets were drawn in a light gray, and were always presented at the ends of the objects, with their center points 6° 41' from fixation. The targets were outline isosceles triangles, subtending 1° 38' along the base and 2° 8' along the sides, drawn with a line thickness of 10 minutes. When presented on the screen, the apex of the target pointed either up or down, relative to the top of the screen. See Figure 1 for an example of a target located on an object.

Procedure. Subjects were run individually. Upon arriving at the experiment, they were given a verbal description of their task and then participated in a block of 20 practice trials. Any questions that they then had about experimental procedures were answered. After the practice block, the subjects participated in one block of 160 experimental trials.

The time course of events on each trial was as follows: Each trial started with the fixation cross at the screen's center. When the computer was ready to present the display, a prompt, "Press any button to start trial," appeared in red at the bottom of the screen. Subjects had been instructed to maintain fixation on the cross and press either response button to initiate the trial. When the button was pressed, the prompt disappeared, and the two rectangles appeared on the screen, oriented both horizontally or both vertically with equal probability. The rectangles remained on the screen until the end of the trial.

The time course of trials is diagrammed in Figure 1:

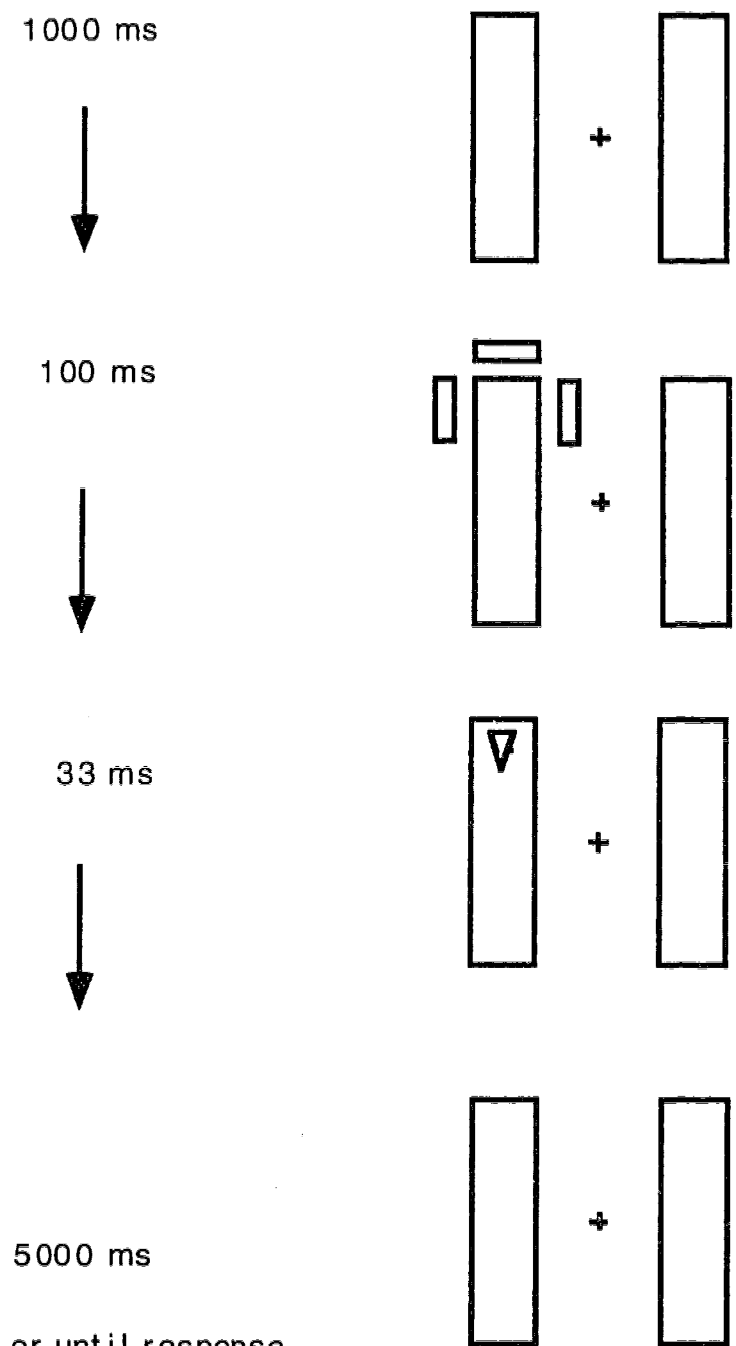

Figure 1: Time course and stimulus arrangement of a cued object -- cued location trial, Experiment 1. Rectangles were a likely to be oriented horizontally as they were to be vertical. The triangle could be pointing up or down with equal probability, and could appear at any one of the four ends of the rectangles. Each of the four ends of the rectangles were equally likely to be cued.

After the rectangles had been displayed for one second, a cue was presented for 100 ms. On 80% of trials, a single cue appeared, and this cue could occur at any one of the four ends of the rectangles, chosen at random. Following a single cue, the target could be presented at either the cued location (cued-object, cued-location condition), at the uncued end of the cued object (cued-object, near-location condition), at the end of the uncued object equally distant from the cue (uncued-object, near-location condition) or at the end of the uncued object directly across fixation from the cued location (uncued-object, far-location condition), all with equal probability. On 20% of trials, a neutral cue was used. On neutral cue trials, four cues were presented, one at each end of an object, and the target was equally likely to appear at any of the four ends of the rectangles. In all conditions, the target was equally likely to be pointing up or down and was displayed immediately after the offset of the cue for 33 ms. Subject's task was to identify the direction in which the target pointed. The objects remained on the screen until either the subject responded or 5000 ms had elapsed. The computer then recorded the subject's key press and response time and readied the next trial. When the computer was ready for the next trial, the prompt reappeared.

Design. The experiment was analyzed using a within-subjects analysis of variance with a five level factor of spatial cuing (four levels for the cuing conditions, and one for the neutral). Data were collapsed over the type of target used (pointing up or down), the absolute location of the target on the screen, and the orientation of the rectangles (horizontal or vertical). Because there were four possible target locations, two orientations of rectangles and two types of target, and each of these combinations were replicated twice in a block of trials, each subject potentially contributed 32 trials to each cell of the design.

Results

Response times. In the analysis of response times, any trial where the subject's response time was below 100 ms, above 3000 ms, or more than three standard deviations above the mean for that subject in that condition was classified as an outlier and excluded from the analysis. Of all the trials, a total of 1.0% were so excluded. Trials where subjects made the incorrect response were also excluded from the response time analysis.

Overall mean response times for all five conditions are presented in Figure 2. An analysis of variance on the response times showed a significant effect of cuing [$F(4, 92) = 12.71$, $p < 0.01$, $MS_{error} = 1236$]. Targets presented in the cued-object, cued-location condition were discriminated approximately 20 ms faster than those presented in the cued-object, near-location condition [$F(1,23) = 8.37$, $p < 0.01$]. This difference demonstrates a space-based effect of allocating attention within the cued-object. Targets presented in the uncued-object, near-condition were discriminated another 20 ms more slowly than targets in the cued-object, near-location condition, again a significant difference [F(1, 23) = 7.68, p < 0.01], this time indicating

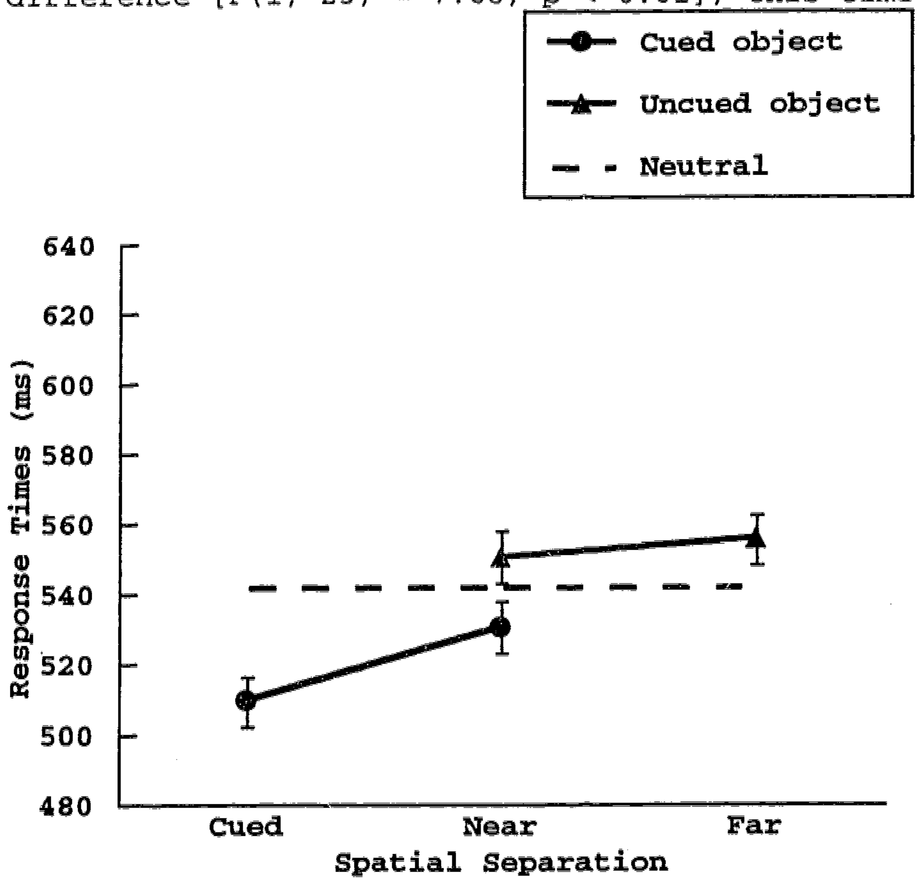

Figure 2. Mean response times Experiment 1, overall analysis. Standard error bars calculated using within subject's error term.

an effect of objects on the allocation of attention. It is easier to recognize targets on the cued object than the uncued object. Response times to targets presented on the uncued object did not differ significantly from each other [4 ms, $F < 1$].

In comparisons to the neutral condition, the cued-object, cued-location condition was significantly faster than the neutral, by 32 ms [$F(1,23) = 20.10$, $p < 0.01$]. The uncued-object, far-location condition was marginally slower than the neutral condition by 13 ms [$F(1,23) = 3.29$, $p = 0.07$], and the remaining conditions did not differ significantly from the neutral (both p's > 0.10).

Post-hoc Response Time Analysis: A post hoc analysis was performed on the results of Experiment 1 to see if the object effect was present at the beginning of trials, or only after experience in the task. Given that subjects perceptual set has been shown to influence the allocation of attention (Baylis & Driver, 1993; Tsal & Kolbert, 1985; Wong & Weisstein, 1981), it is possible that the object-based effect in Experiment 1 may evolve over time, after practice in the task has lead subjects to develop a strategy of attending more to the objects as wholes rather than to the locations within the objects. To examine whether practice in the task affects the object-based effect, each subject's data was divided into two groups, by order of presentation. The resulting means were then analyzed in a 2 X 5 factorial design, with the first factor being whether the target occurred in the first or second part of the block of trials. Mean response time for these analyses are presented in Figure 3.

In the second half of trials, there was a smaller difference between the cued-object conditions than in the first half, which lead to a significant interaction between order of trials and cuing condition [$F(4,92) = 2.865$, $p < 0.05$, MSerror = 850]. Pairwise comparisons indicated that the cued-object, near-location condition was significantly

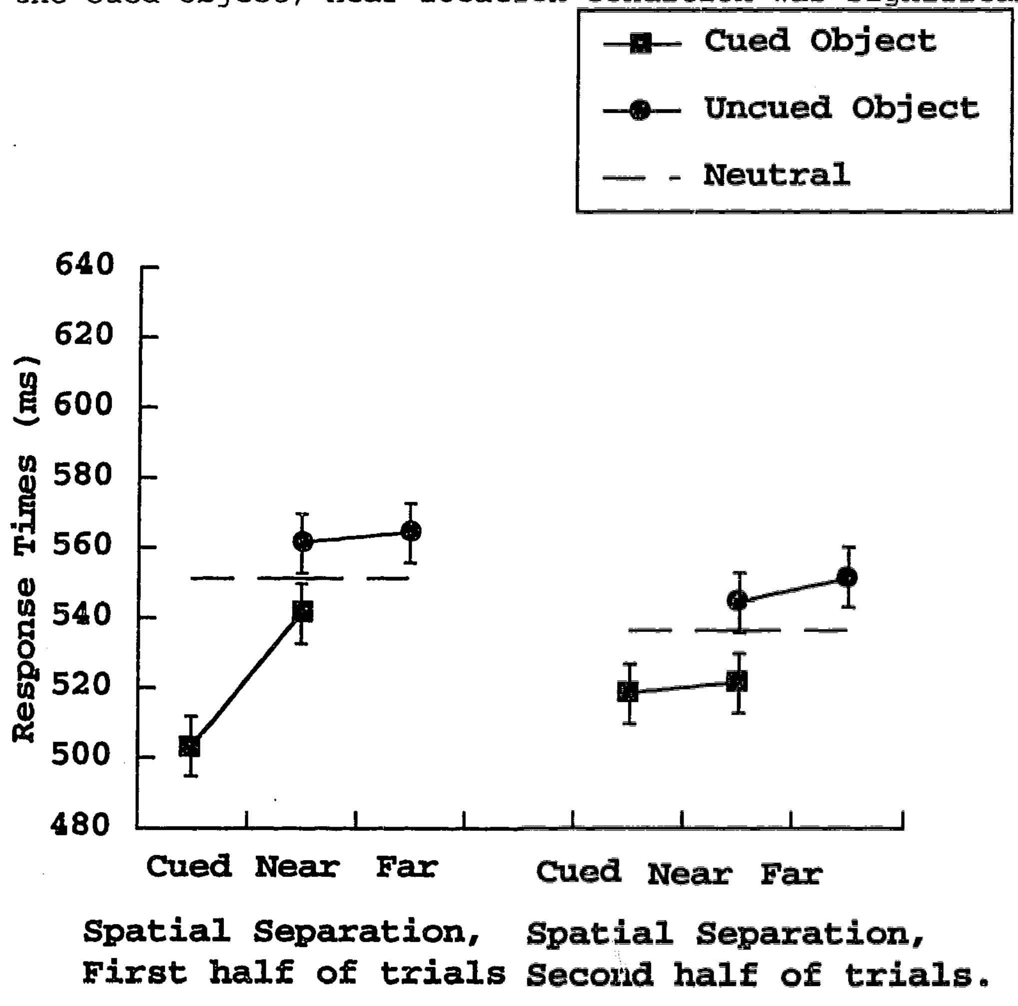

Figure 3: Mean response times for the post-hoc analysis of Experiment 1. Error bars calculated using within subjects mean square error term.

slower than the cued-object, cued-location condition in the first half of trials [$F(1,23) = 20.26$, $p < 0.05$], but not in the second half [$F < 1$], and the interaction of the two was significant [$F(1,23) = 8.59$, $p < 0.05$]. However, in both halves of the experiment, the difference between the cued-object, near-location condition and the uncued-object, near location condition was significant ($p > 0.05$ for both comparisons), and did not change in magnitude over half of experiment [$F < 1$ for the interaction over half of experiment]. For locations on the uncued objects, response times tended to speed up as the experiment progressed, significantly so for the near condition [$F(1,92) = 4.06$, $p < 0.05$], but there was no interaction between uncued-object conditions and order of trials as there was for the cued-object conditions [$F < 1$]. Obviously, the object effect observed in Experiment 1 does not arise from practice in the task: Subjects show an object effect in the first half of the experiment.

Accuracy. In the calculation of mean accuracy, trials which had been classified as response time outliers were included in the accuracy analysis, counted as correct or incorrect as per the subject's button press. Mean accuracy for all conditions is presented in Table 1, for both the overall and post-hoc analyses. The analysis was the same as that used for the response times. Accuracy across conditions was high (95.9%), and neither the initial analysis or the post-hoc analysis revealed any significant interaction or main effects of any of the factors in the experiment (all p's >0.10). The correlation of accuracy and response time was calculated, with the correlation between each subject's mean response time and mean accuracy partialled out. The resulting correlation was -0.0087. There is no indication of a speed-accuracy trade off from these data.

Table 2.

Mean Accuracy (Percentage) in Experiment 1, for Post-hoc and Overall Analysis.

Condition		1st half	2nd half	Overall
Cued Object	Cued	96.9	97.1	97.0
	Near	96.6	95.8	96.2
Uncued Object	Near	96.6	94.0	95.3
	Far	94.5	95.3	94.9
Neutral		94.8	97.1	96.0

Discussion

In Experiment 1, both object-based and space-based effects were observed in the spatial cuing paradigm. Object-based effects were demonstrated by the faster discrimination of a target at an uncued location on the cued object rather than a location on the uncued object, even when spatial separation was controlled. A space-based effect on attention was demonstrated by the significant cost of reorienting attention within the cued object. The pattern of data is consistent with those found by Egly, Driver, and Rafal (1994), even though the current experiment used unambiguously non-predictive exogenous cues. Response times to targets presented at different locations on the uncued object were roughly equal, regardless of their spatial separation from the target. Comparisons to the neutral condition showed mainly facilitation for the cued location, and little inhibition of the other locations.

A gradient model, or any space-based model of attention, cannot account for the pattern of results observed in Experiment 1 and in Egly, Driver and Rafal (1994; Egly, Rafal et al, 1994), unless it also includes some mechanism that allows the presence of objects to affect selection. If no such mechanism is included in the gradient model, then presenting targets at four locations arranged around fixation as the points of an imaginary square should lead to equal response times to targets presented at the locations equally distant, horizontally and vertically, from the cued location (as in Egly & Homa, 1991; Henderson & Macquistan, 1993). These equal response times should occur because in the gradient model the activation of locations in the underlying representation decreases with increases in the distance of the cued location from the target's eventual location. Because the decrease with increasing distance is presumably symmetrical, the model predicts equal activation of the two locations closest to the cued location. Because relative activation determines response times, targets presented at the locations horizontally and vertically displaced from the cued location should show equal response times.

Instead, these results suggest that attention selects from a representation containing information about objects, and that this object-based information influences the selection of information. One way to conceptualize the representation is as a hierarchy that contains information about the target's possible locations as well as their relationship to the object they belong to. This approach is related to the hierarchical models proposed by Duncan and Humphreys (1989), Marr (1982) and Marr and Nishihara (1977). In Experiment 1, the possible target locations were arranged around fixation like the points of an imaginary square. This spatial layout of locations could be modeled at the lower level of a hierarchical model as four linked nodes. The links between the nodes would reflect their spatial relationship to each other, such as 'above' or 'below,' 'to-the-right-of' or 'to-the-left-of.' When no objects are present in the field and a location is cued, activation from the cued location spreads over these links to the locations closest to the cued one (cf. Downing & Pinker, 1985). In this case, the cued location would be the most active location, followed by the two near location, and then the far location. The time to select information from a location would follow from the levels of activation: Selection from the cued location would be fastest, selection from the far location slowest, and selection from the two near locations equal to each other and intermediate between the response times of the cued and far locations. Experiments in the empty field have yielded just such results (Egly & Homa, 1991; Henderson & Macquistan, 1993). Selection in this model is therefore closely related to selection in Hoffman's (1978; 1979) similarity model, except that here similarity is dependent on distance from the cued location.

In this tentative model, the next level up in the hierarchy is the level of object representations. These representations can be thought of as temporary, episodic representations that keep track of what perceptual information belongs to which object, akin to Kahneman and Treisman's (1984) object files (see also Kahneman, Treisman & Burkell, 1983; Kahneman, Treisman & Gibbs, 1992; Treisman, 1988). When objects are present in the visual field, the locations that belong to those objects are linked to the representation of that object. Whether these object files themselves are hierarchically defined, with parts and sub-parts corresponding to the parts and sub-parts of the perceived object, is left an open question (in contrast to Duncan & Humphreys, 1989 or Marr, 1982, who advocate hierarchically defined object representations). A cue at a location on an object activates that object's representation, and activation spreads from the cued object to those locations linked to that object's representation. When a location on an object is cued in Experiment 1, both the node representing the location and the node representing that location's object are activated. Activation from the cued location spreads to the near location on the cued object from both the spatial link between the two locations, and from near location's link to the cued object. Activation also spreads from the cued location to the near location on the uncued object; however, the uncued-object, near-location does not receive additional activation from having its associated object cued. This results in the near location on the cued object being more highly activated than the near location on the uncued object, with a resultant faster selection of information from that location.

The post-hoc analysis revealed that, over the course of the trials, there was a reduction in the response time difference between locations on the cued object. One explanation for this effect would be to suggest that both the spatial relationships between locations and the organization of those locations into objects are salient and important at the start of the experiment, but the presence of objects becomes more important as the experiment progresses. This could be instantiated in the above model by suggesting that the strength of links between nodes can vary, and that the strength of the links determine how much activation spreads to the target locations. Kramer and Jacobson (1991) present data indicating that the strength of grouping can be increased by using redundant grouping manipulations. Increased grouping in the current model would be analogous to strength of the links between locations. Prinzmetal and Keysar (1989) have demonstrated that manipulations of attention can be used to affect the subjective organization of display elements into horizontal and vertical rows, which is consistent with attention affecting the strength of the links between elements. More activation spreads over stronger links. As the experiment progresses, the linking of each location to its associated object would become stronger, leading to more activation of locations due to the correct object being cued. This would result in less of a difference in activation between locations on the object, and equal response times. In other words, early in the experiment, the cue leads subjects to expect a particular location in a particular object, while later in the experiment, the cue leads subjects to expect a particular object. Subjects process the objects more globally as the experiment progresses, rather than manditorily processing all aspects of the object on all trials (Kahneman & Henik, 1981).

An alternative account of the practice effect in Experiment 1's post-hoc analysis can be derived from Klein and McCormick's (1991) mid-location placement hypothesis. The essence of the mid-location placement hypothesis is that when subjects know that targets can occur at one of several location in the same general region of the visual field (such as the left or right visual hemifield), they will direct the locus of their attention to a location midway between the two locations. In this experiment, the mid-location placement hypothesis would suggest that subjects learn over trials to direct their attention to the middle of the cued object. Because the attended location becomes closer to the cued object, near location and further away from the cued object,cued location, response times to targets at the cued object, near location decrease, and response times to targets at the cued object, cued location increase. There are two potential arguments against this model: First, subjects are directing their attention in response to exogenous cues, and therefore should not have strategic control over where in they are attending; second, as the locus of attention is placed further towards the middle of the object, it will also become further away from the near location on the uncued object and closer to the near location on the cued object. Thus, one would expect the response time difference between cued object near and uncued object near location conditions to change, in the direction of a larger difference between the two.

The first argument against the mid-location hypothesis might be countered by pointing out that the subject's exogenous orienting to the cued location may be immediately followed by an endogenous orienting of attention towards the center of the object. However, Yantis and Jonides (199o) have demonstrated that endogenous cuing can override exogenous cuing only under conditions of high endogenous cue validity, which was not characteristic of Experiment 1. The second argument might be countered in two ways. One could argue that there is little relative change in the size of the object effect because the total change in the distance from locus of attention to the near locations is small. The mid-location placement hypothesis will be addressed later on in the discussion of Experiment 3.

The pattern of small costs and large benefits seen in Experiment 1 departs from the usual patterns seen in spatial cuing experiments, those of either larger costs than benefits (Hawkins, Shafto & Richardson, 1988; Henderson, 1991; Henderson & Macquistan, 1993; Hughes & Zimba, 1985; 1988) or equal costs and benefits (Posner, 1980; Posner, Snyder & Davidson, 1980), relative to the neutral. However, comparisons between the neutral condition and cuing conditions in Experiment 1 may not be appropriate (Jonides & Mack, 1984) because the presence of objects in the visual field may have interacted with the neutral cues in a different fashion than with the single cues. For example, cuing one location in the visual field when objects are present leads to a single location and a single object being cued and leads to activation of a single object representation. When all the locations in the display are cued, both objects are cued as well. Having both object representations equally activated may lead to slow selection of a target because no location is more active than any other. Research on the spreading of attention over more than one object is consistent with this argument in that it indicates that attention cannot be directed to more than one object at a time (Baylis & Driver, 1994; Duncan, 1984). A similar concept could be implemented in terms of the mid-location hypothesis by suggesting that, in response to the neutral cues, attention's locus is at fixation, and the gradient of attention is spread thinly over the possible target locations.

Experiment 2

Although Experiment 1 demonstrated that object-based effects are observed with exogenous cues, it does not rule out the possibility that purely endogenous cues may produce such effects as well. Experiment 2 examined whether this is the case by comparing purely endogenous cues and purely exogenous cues in the same experimental situation as in Experiment 1. The comparison was made between subjects. If the object-based effect can arise in response to either type of cue, then both groups of subjects should show an object-based effect. If the object-based effect arises purely in response to the exogenous properties of the cue, then subjects receiving the endogenous cues should show no object-based effect.

Method

Subjects: Ninety-four subjects participated in the experiment (47 in each group) in return for course credit. All had normal or corrected to normal vision (according to self report), and none had previously participated in a spatial cuing experiment.

Apparatus: Experiments were run on a Macintosh computer. Responses were made on a computer keyboard, using the 'z' and '/' keys. Response times were measured by an on-board clock; some slight error was introduced into the response time measurements due to the microprocessor polling the keyboard.

Stimuli: The stimuli were closely modeled on those of Experiment 1, and except where noted, were identical. The stimuli were presented on a white background. The rectangular objects subtended 10° by 2°. Their midpoints were 3° 53' degrees from the fixation dot. As in Experiment 1, the rectangles could be oriented vertically or horizontally, and the triangular targets were presented at the ends of the rectangles subtending 1° along the base, and 50' from the base to the apex. The fixation dot and targets were drawn in black. The rectangles themselves were grey in order to make each object clearly discriminable as a coherent whole and distinct from its background.

Two types of cues were used in the experiment. Exogenous cues were comparable to those used previously in the dissertation, consisting of three lines drawn around one end of one of the rectangles, forming a segmented "C" shape. Each line was 36' wide and 2° 9' long, and was separated from the sides of the object by 36' of visual angle. Endogenous cues were a line segment of 1° 9' in length and 22' in width. Endogenous cues were presented with one end 30' from the fixation point and the other end 2° 23' from the target location, and were oriented at 45, 135, 225 or 315 degrees from vertical.

Design: A 2 X 4 mixed design was used, with one between subjects factor, type of cue used, and one within subjects factor, cue-target relationship.

Procedure: Subjects participated in one block of practice trials and two blocks of 192 trials. Data from the practice trials were not analyzed. Each subject participated in the endogenous cuing condition or the exogenous cuing condition only, but except for the differences noted below, the procedures were identical.

The procedures also closely followed those of Experiment 1, except for the modifications noted. When the experimental task was explained to the subject, the importance of maintaining fixation was stressed. During the block of practice trials, the experimenter was seated where he could observe subjects' eyes, and the practice block continued until subjects completed 20 practice trials without eye movements during the trials. The two blocks of test trials followed.

Exogenous cuing conditions. The time course of events closely followed those of Experiment 1. Each trial started with an empty screen. When the computer was ready to present the display, a fixation cross appeared at the center of the screen. Subjects initiated the trial by pressing the space bar on the keyboard. The rectangular background then appeared.

As in Experiment 1, the rectangles were presented for one second, followed by a 100 ms cue. This cue occurred at any one of the four ends of the rectangles, chosen at random. The sequence of events that followed was the same as that in Experiment 1, except that there was no neutral cue condition (although the other four cuing conditions were included), and targets were present on the screen for 50 ms. Subjects' task was again to indicate, by key press, the orientation of the triangle.

Endogenous cuing conditions. Again, the two rectangles were presented for 1000 ms, followed by a cue. For these trials, however, the cue was a line segment presented close to fixation, and the duration of the cue was 300 ms. The target was presented immediately after the cessation of the cue, again for 50 ms. An example of an endogenous cuing trial is diagrammed in Figure 4.

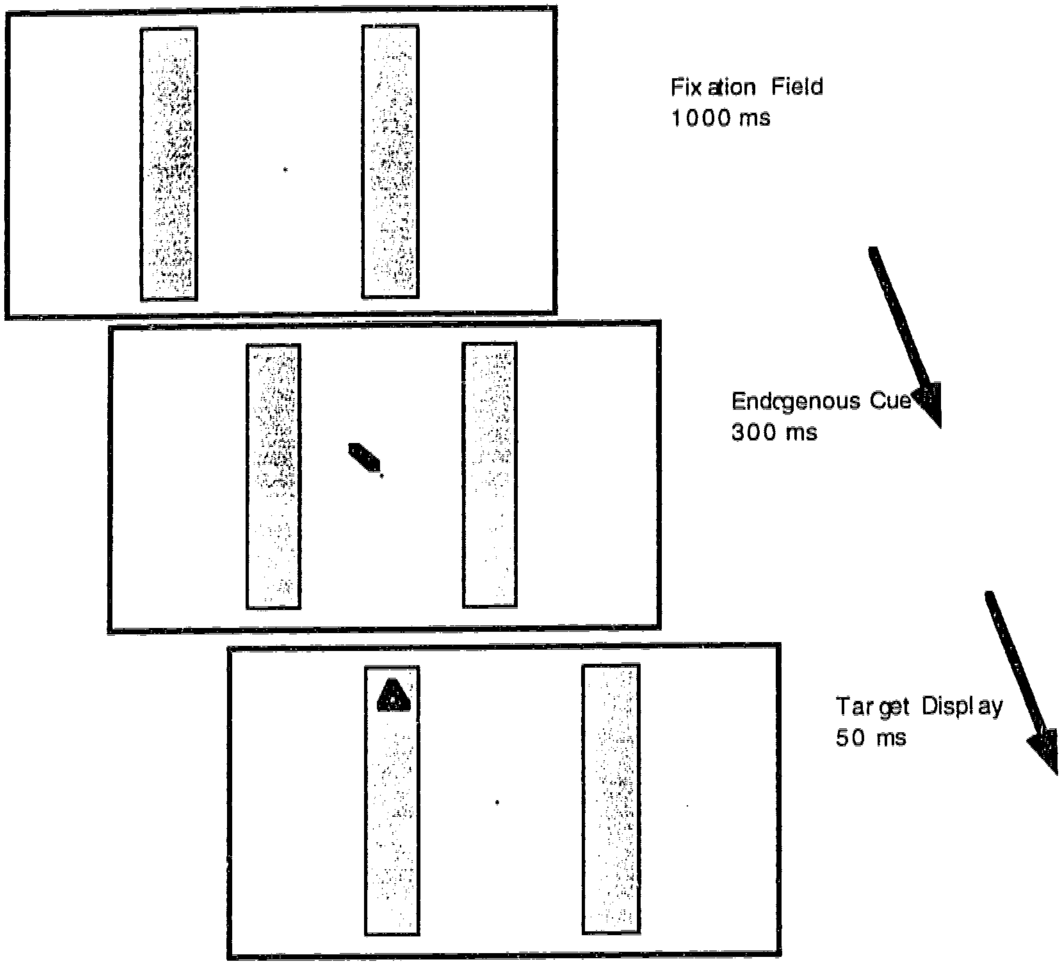

Figure 4: time course of an endogenous cuing trial. There is zero milliseconds ISI between successive frames of the diagram. After offset of the target, the fixation field remains on the screen for 5000 milliseconds, or until the subject responds.

The endogenous cuing condition also differed from the exogenous cuing condition in the frequency of the cue object-cued location condition relative to the other three conditions. In each block of 192 trials, 144 trials were cued-object, cued-location trials, 16 cued-object, near-location condition trials, 16 uncued object near location trials and 16 uncued-object, far-location trials. Thus, the endogenous cue indicated the correct object and location on 75% of trials.

In all other respects, such as the orientations of the rectangles or the four possible relationships of cued location and target, the endogenous cuing trials were the same as the exogenous cuing trials.

Results

Response times. Subjects with less than 80% accuracy in one or more conditions were eliminated from the data set. This resulted in the elimination of 10 subjects in each condition, leaving 74 subjects in total. Inspection of the data revealed that many of the subjects with high error rates produced a large number of miskey errors, where they would press buttons other than the 'x' or '/' response keys. It seems likely that these subjects used a poor strategy for producing responses, such as pressing the space bar with an index finger and then attempting to press the response key quickly with the same finger after the target had appeared. Analysis of the remaining 74 subject's response time data was based only on correct responses. In addition, response times faster than 100 ms, slower than 3000 ms, or more than three standard deviations from the mean of that subject for that condition were excluded from analysis. The response time criteria lead to the exclusion of 1.47% of trials.

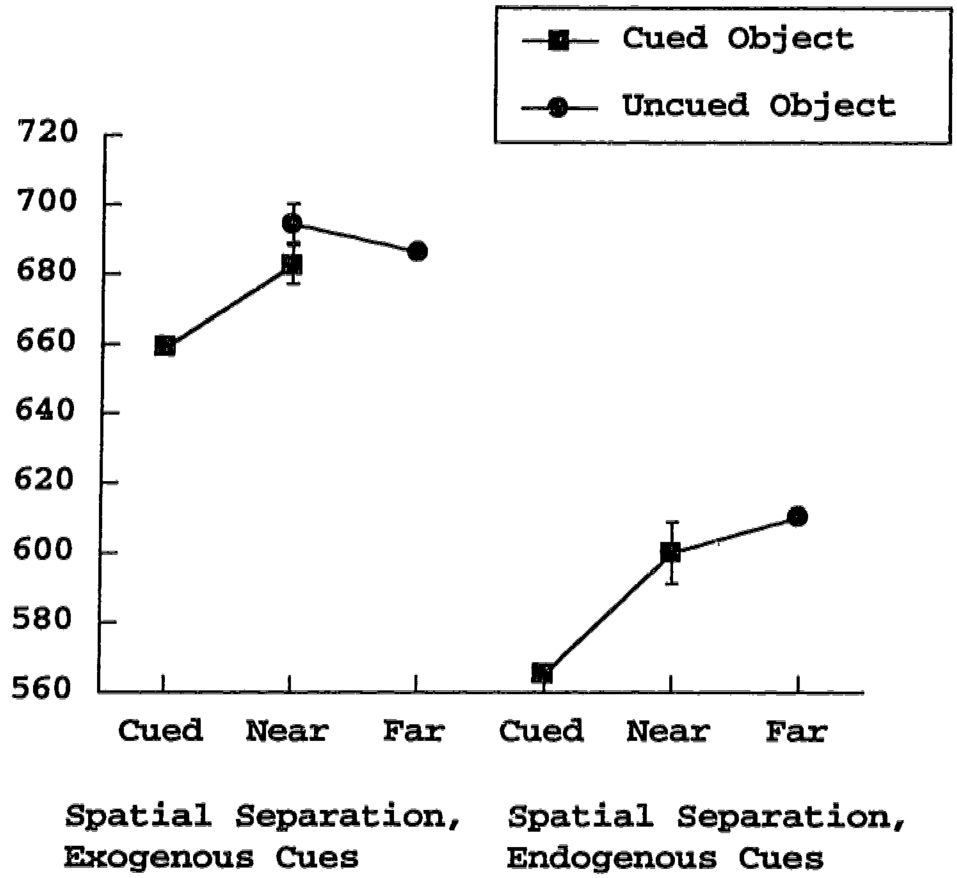

Figure 5: Mean response times for different types of cue, Experiment 2. Confidence intervals calculated from paired t-tests.

Mean response times for the accurate subjects are presented in Figure 5, broken down over cuing and the between subjects factor of cue type. In the overall analysis of variance, there was a significant effect of cuing [$F(3, 216) = 19.95$, $p < 0.05$]; the interaction of cuing with group was non-significant [$F(1,216) = 1.40$, $p > 0.05$].

While the interaction of cue location and type of cue was not significant, Figure 5 suggests an effect of objects like that found in Experiment 1, but only for exogenous cues. A paired t tests on the difference between cued-object, near-location and uncued-object, near-location conditions was significant for the exogenous cuing condition [$t(36) = 2.11$, $p < 0.05$], but not for the endogenous condition [$t(36) = 0.06$, $p > 0.10$]. Further, sign tests indicated a reliable difference between the uncued-object, near-location condition and the cued-object, near-location condition with exogenous cues [27/37, $p < 0.05$ by sign test], but not with endogenous cues [15/37, $p > 0.05$, by sign test]. A Wilcoxon signed-rank test indicated that the size of the difference between cued-object, near location conditions and the uncued object, near-location conditions differed with the type of cue used [$W_X = 1174$, $z = -2.308$, $p < 0.05$].

In view of the significant effect of practice in Experiment 1's post-hoc analysis, the response time means for Experiment 2 are presented in Figure 6, broken down by the non-significant three way interaction of cue type, cuing and block of trials (first or second). In light of the data's variability, firm conclusions are difficult to draw. However, in both blocks of the exogenous condition an object effect is apparent, which is larger in the second block. There is also a slight tendency for the difference between locations on the cued object to be smaller in the second block than the first, at least for exogenous cues. No consistent object effect is apparent for subjects in the endogenous condition, and the size of the difference between cued-object locations seems relatively stable.

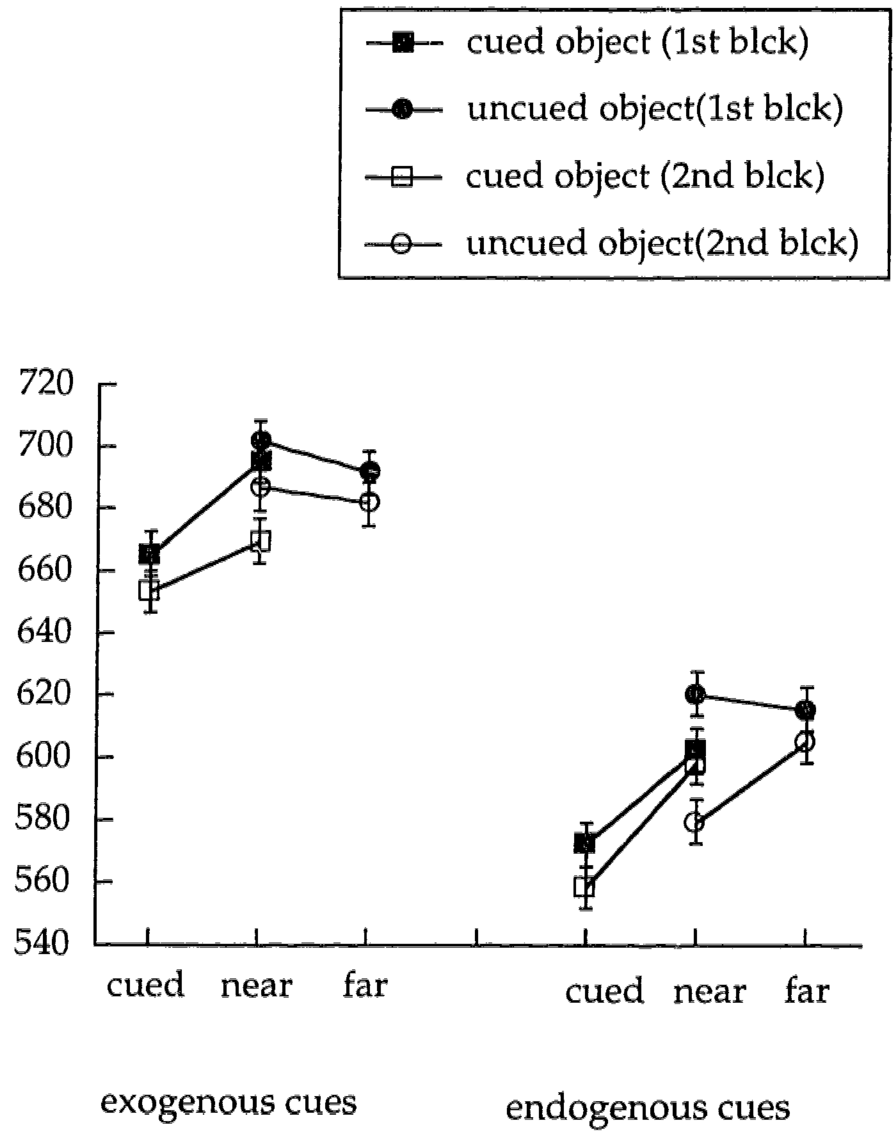

Figure 6: Data for Experiment 2, broken down over the non-significant interaction of block (first or second) and type of cue (exogenous or endogenous).

Accuracy. Mean accuracies are presented in Table 3. Accuracy was analyzed using the same design as the response time data. There was a significant effect of cue type [$F(1,72) = 5.20$, $p < 0.05$], with subjects in the exogenous condition being more accurate than those in the endogenous condition (95.9% accuracy vs. 94.4%), and there was a significant effect of block [$F(1,72) = 5.06$, $p < 0.05$], with subjects performing more accurately in their first block of trials than their second block of trials (95.9% accuracy vs. 94.4%). There were no other significant main effects or interaction in the accuracy measures. The correlation of response time and accuracy, with the correlation between each subject's mean response time and accuracy partialled out, was -0.048 for the endogenous cues and -0.043 for the exogenous cues. No speed accuracy trade-off is indicated by these results.

Discussion

In the exogenous cuing condition of Experiment 2, there was a 12 ms difference between near locations on the cued and uncued objects, averaged over blocks, but in the analogous endogenous cuing condition there was no difference between near locations on the cued and uncued objects. The effect in the exogenous cuing condition is of roughly the same size, and in the same direction, as the pattern seen in the work of Egly, Driver and Rafal (1994; Egly, Rafal, et al, 1994), and in Experiment 1. The difference between endogenous and exogenous cues suggests that object-based effects in the spatial cuing paradigm depend upon some qualities of the exogenous cues; specifically, those properties of the

Table 3.

Mean accuracy (percentage) in Experiment 2, broken down by cue type.

Condition		Exogenous Cues	Endogenous Cues	Overall Accuracy
Cued Object	Cued	95.8	95.2	95.5
	Near	96.1	94.6	95.4
Uncued Object	Near	95.8	94.0	94.9
	Far	95.9	93.8	94.9

exogenous cues used in Experiments 1 and 2 that were also shared by Egly, Driver and Rafal's cues, such as being presented at the to be attended location, or there being a salient physical change in the visual field. The object-based effect cannot arise from those properties that the endogenous cues in Experiment 2 shared with Egly, Driver and Rafal's (1994) cues, specifically, the long cue to target SOA and the predictive nature of the cues as indicators of the to be attended location. If the object effect could arise from endogenous cuing, an effect should have been apparent in Experiment 2's endogenous condition.

The finding in Experiment 2 of no object-based effect for endogenous cues, but an object-based effect for exogenous cues, is similar to Briand and Klein's (1987) demonstration that exogenous cues, but not endogenous cues, affect feature integration. Briand and Klein interpreted their results as indicating that exogenous attention affects a basic level of perceptual processing, but that endogenous attention affects later stages of processing. In support of this notion, Klein (1994; Klein & Hansen, 1990) has demonstrated a phenomena of 'spotlight failure' when attention is directed by endogenous cues. When one stimulus in a stimulus pair is more likely to occur than another, responses to the more likely stimulus of the pair benefit from valid endogenous cues and show costs from invalid cues, while responses to the unlikely stimulus show neither cost nor benefit. Exogenous cues do not result in any difference between likely and unlikely stimuli, in terms of the size of their cuing effect, and the effect is specific to choice response tasks: When the task is changed to simple detection, both likely and unlikely stimuli benefit from endogenous cues (Klein, 1994). These results can be attributed to endogenous attention biasing decisions to respond to a stimulus (Klein, 1994; Klein & Hansen, 1990). From Klein's perspective, exogenous attention affects a stage of processing that is also responsible for the integration of features and possibly the formation of object representations

(Klein, 1994, Figure 3; Klein, Kingstone & Pontefract, 1992, Figure 4.5), while endogenous attention affects later stages of decision making and response selection (Klein, Kingstone & Pontefract, 1992). Both exogenous and endogenous attention do, however, facilitate the registration of raw perceptual information.

Considered in conjunction with other results in the literature, the results of Experiment 2 suggest that exogenous attention affects a stage of processing where object representations are formed and features are integrated. Exogenous cuing effects are modulated by the presence of objects (Experiments 1 & 2), novel objects draw exogenous attention to themselves (Yantis & Hillstrom, 1994), and the inhibition of return following an exogenous cue is associated with a cued object rather than a cued location (Tipper, Driver & Weaver, 1991). Briand and Klein's work indicates exogenous cues interact with feature integration, while the work of Prinzmetal (1981) and Baylis, Driver and McLeod (1992) indicates that feature integration, as measured by illusory conjunctions, interacts with the presence of objects. On the basis of these results, one can argue that exogenous cues affect the episodic representations of perceptual information that Kahneman and Treisman (1984; Kahneman, Treisman & Gibbs, 1992) have dubbed 'object files.' Object files maintain the perceptual identity of objects by keeping track of the location of a particular object in the field, as well as the perceptual features currently assigned to that object. The overall pattern of these various results in the literature is consistent with exogenous cues affecting the activation of object files and the accumulation of information in them. The object-based effect observed in Experiments 1 and 2 can be explained in terms of object files if it is assumed that the exogenous cues resulted in a general priming of a specific object file, so that information from that cued object could be more easily accessed.

Normally, exogenous cuing has a relatively short time course, with the costs and benefits of exogenous cues reaching their peak by about 100 ms, and being absent, or greatly reduced, by 300 ms (Nakayama & Mackben, 1989). On this basis one might have assumed that only the endogenous properties of Egly, Driver and Rafal's (1994) cues could give rise to their object-based effect, because relatively little effect should have been observed from the exogenous properties of their cues at 300 ms. The results of Experiment 2, surprisingly, indicate that it is the exogenous properties of the cues that give rise to the object-based effect. One way to account for this anomaly is to suggest that the object-based components of exogenous cuing are longer lasting than the space-based components usually engaged in spatial cuing studies. Relatively long duration object-specific priming of letter identities, up to a second in duration, has been reported by Kahneman, Treisman & Gibbs (1992), and while this priming of letter identities may not be the same process responsible for the object-based effect seen in Experiments 1 and 2, it makes the notion of a long-lasting object-based component of cuing plausible. The spatial component may decline quickly, but the object-based component may last well past 300 ms.

The space-based effect observed in the endogenous condition suggests that endogenous cuing operates over the spatial representation of the display but that the level of object representations is not engaged. In neither endogenous nor exogenous conditions were subjects explicitly told to attend to the object, which leaves open the possibility that subjects could have activated their representations of the objects in the endogenous cuing condition if they had been instructed to attend to the objects. The exogenous cue's appearance as a physical change at the location to be attended may automatically engage processes of attention involved in updating or creating object files (Hillstrom & Yantis, 1994). When attention is directed to a specific location by a centrally located cue, no automatic activation of the cued location occurs. Because subjects in this task have no motivation to attend to the object, and therefore activate its representation, there is no opportunity for activation to spread from the cued object to its associated locations.

While the results of Experiments 1 and 2 indicate that objects do have an effect in the spatial cuing paradigm, it is obvious that space-based theories of attention, such as the gradient model, are still viable accounts of the spatial component to the orienting of attention. Experiments 1 and 2 indicate a need for a general theory of visual attention to specify the relationship between space-based and object-based components to attention and the conditions under which the two processes interact. The type of cue used to direct attention is one factor that determines when object-based effects will be seen, with endogenous cues not giving rise to the object-based effect seen in response to exogenous cues.

Experiment 3

The goal of Experiment 3 was to further specify how the space-based and object-based components of attention relate to one another by comparing the simultaneous exogenous cuing of one location on one object with the exogenous cuing of two locations, either both on the same object or at adjacent locations on different objects. The same arrangement of rectangular objects was used in Experiment 3 as in Experiment 1. Space-based models of attention such as the gradient model assume that attention is directed to a region of the visual field, and that cuing more than one location should lead to a larger region of the visual field being attended to. This assumption of space-based models has been tested and been found to give a good account of the results of experiments comparing reaction time distributions of trials where one location is cued with trials where more than on location is cued (Henderson, 1991; Keifer & Siple, 1987;

McCormick & Klein, 1991). In contrast, work by Duncan (1984) and Driver and Baylis (1994) on object-based attention suggests that only a single object may be attended to at one time. Directly applying this result to the spatial cuing paradigm suggests that simultaneous cuing of two locations on different objects should not lead to the subjects attending to both objects simultaneously, but cuing two locations on the same object could lead to subjects attending to both locations simultaneously. Experiment 3 was designed to answer the question, Are the predictions of space-based theories or object based models are supported when two cued locations are on different objects, or only when they are on the same object? More generally, how does the presence of objects affect the spatial cuing of different sized regions of the visual field?

There are three possible outcomes of Experiment 3 that are of interest. One possibility, unlikely in view of Experiments 1 and 2, is that the presence of objects in the visual field has no affect on the simultaneous cuing of two locations. In this instance, the cuing of two locations engages exactly the same space-based processes that would be engaged if no object were present. In terms of the hierarchical model of attention used in this dissertation, both cued locations would be activated about equally. Because two locations were cued, each cued location would be less activated than if it alone was cued, and the uncued locations would be more activated than with a single cue.

Because the time to select a target depends upon the relative activation of locations, the result would be a smaller overall difference between cued and uncued locations than when a single location is cued. If objects do not affect the process of selection when more than one location is cued, then the same sized cuing effect should be apparent when the two cued locations are on the same object or on different objects.

Similar predictions are made by the mid-location placement hypothesis (Klein & McCormick, 1991; McCormick & Klein, 1991) discussed in Experiment 1. Under the mid-location hypothesis, on dual-cue trials the locus of attention should be directed to a point in between the two cued locations. One could reasonably assume that in this case, when two exogenous cues are used, orienting to the mid-location is reflexive rather than the result of a strategic reorienting. Mid-location placement would predict a reduced cuing effect when two locations are cued but no difference between conditions when one or two objects are cued. When two locations are cued, the locus of attention should be equally far from the two locations that are actually cued, and closer to the cued locations than to the more distant uncued locations.

The second, more likely, possibility is that objects affect selection when more than one location is cued. If objects affect selection when two locations are cued, an interaction is predicted between the number of objects cued and whether a location is cued or uncued: The cuing of two locations on the same object should give rise to a cuing effect, but the cuing of two locations on different objects should lead to a reduced cuing effect. The predicted interaction arises because cuing two locations on one object would result in the activation of both locations in the object, as well as the activation of one object's representation with little or no activation of the uncued object's representation and its locations. A cuing effect would then be apparent when the cued locations (both on the same, cued object) are compared to the uncued locations (both on the same, uncued object). In contrast, cuing two locations on two different objects should lead to the activation of both objects' representations, as well as one location on each object. Activation could then spread from each cued location to the uncued locations by both the spatial link between locations and by the activation of the relevant object representation. This would lead to all the potential target locations receiving activation and, as a consequence, relatively little difference between the cued and uncued locations. The results of Experiments 1 and 2 do suggest some effect of cuing, however, as the spreading of activation over the cued object in these experiments was not sufficient to entirely eliminate the difference between cued-object locations. Thus, the second alternative suggests that cuing locations on two objects should lead to no cuing effect because both object representations would be activated. The presence of such an interaction is also inconsistent with the mid-location placement hypothesis, which predicts an effect of cuing when two locations are cued, but no effect of objects.

A third alternative is to suggest that number of objects cued does affect selection, but to further suggest that only one object representation can be activated by cuing at a time. This alternative is consistent with Duncan's (1984) work showing that subjects have difficulty selecting information from more than one object at a time (see also Baylis & Driver, 1993). Under the third alternative, cuing two locations on the same object should also lead to a cuing effect, as in the second alternative, because only one object and its locations are activated. When two locations are cued on different objects, however, only one of the object representations is activated, presumably determined at random, and the other representation is not activated. This alternative suggests that the distribution of response times when two locations on different objects is cued should be the average of the relevant cued-object and uncued-object conditions. Suppose the two adjacent locations on the different objects are cued, and the target is presented at one of the cued locations. Half the time, this target will be presented on the object whose representation is activated by cuing, the other half of the time it will be presented on the unactivated object.

In this case, dual-cue response times can be predicted from single cue response times. If one object is activated at random when two objects are cued, the predicted response times should be equal to the average of the cued-object cued location condition and the uncued-object, near-location condition for single cue trials. Essentially, the overall distribution of response times on these types of trials where two locations on two objects are cued can be predicted from the response time distributions of single cue trials. Response time variances can also be calculated from the relevant conditions, although the formula is a little more complex. The equation for calculating predicted response time variances from the single cue trials is presented in Equation 1.

$$s_p^2 = \frac{\left(s_a^2 + s_b^2\right)}{2} + \frac{(m_a - m_b)^2}{2} \qquad [1]$$

Where:
s_p^2 is the predicted variance;
s_a^2 is the observed variance for single cue condition a;
s_b^2 is the observed variance for single cue condition b;
m_a is the observed mean for single cue condition a;
m_b is the observed mean for single cue condition b.

Basically, the predicted variance is the average variance of the two relevant single cue conditions, plus a term to correct for separation of the means of the two single cue response time distributions.

Another interpretation of the third option is that when two objects are cued on dual-cue trials, subjects might refrain from selecting a location on either object until the target appears. If this were the case, one would expect little or no cuing effect when two objects are cued and departures from the response times and variance predicted by the averaging model when two objects, but not one object, are cued.

Comparisons of the means and variances predicted by alternative 3 to those actually observed in Experiment 3 can be used to test and reject alternatives. If the first alternative is correct, and the presence of objects does not affect the simultaneous cuing of two locations, then the same sized cuing effect should be apparent when either one or two objects are cued, and the predicted and observed results for cuing two locations should differ, as in Henderson (1991), Keifer and Siple (1987) and Klein and McCormick (1991), whether or not both cues occur on the same object. If the second alternative is true and both object representations receive some activation when the two objects are cued, then there should be no cuing effect when two objects are cued, but a cuing effect when two locations on one object are cued. In addition, when two objects are cued the results predicted from the single-cued conditions and the observed results should differ when the two cues occur on the two different objects. In contrast, if the third alternative is correct, the predicted and observed results in the dual and predicted results for the predicted and observed results should not differ when the two cues occur on the two different objects.

Method

Subjects. Twenty four subjects participated in this experiment. All met the same criteria and received the same compensation as those who participated in Experiment 1.

Apparatus. The apparatus used in this experiment were the same as those used in Experiment 1.

Stimuli. The stimuli used were the same as those used in Experiment 1, except for the addition of trials where two locations were cued. On these dual-cue trials, the two cues were positioned either at each end of one object or at adjacent ends of two different objects, but never at the two locations diagonally opposite each other across fixation.

Procedure. The procedure was identical to that used in Experiment 1, except for the inclusion of dual-cue trials in the practice and experimental blocks of trials. On dual-cue trials, the two cues were presented, and the target could occur either at either of the cued-locations or either uncued location, all with equal probability. The time course of dual-cue trials was identical to that of the single cue trials.

There were 20 trials in the block of practice trials and 144 trials in each experimental block. The experimental block was divided into conditions as follows: 80 trials that replicated Experiment 1 (16 trials each of cued-object, cued-location; cued-object, near-location; uncued-object, near-location; uncued-object, far-location; and neutral condition trials), and 64 dual-cue trials. On 32 of the dual-cue trials, the cues occurred at opposite ends of the same object (one object cued conditions). On the remaining 32 dual-cue trials, the cues occurred at adjacent ends of the two different objects (two objects cued conditions). For both types of dual-cue trials, the target was as likely to occur at either of the cued-locations as at either of the uncued-locations. All conditions were run within subjects. The single and dual-cue trials were analyzed in separate analyses of variance, with the single cue analysis replicating that of Experiment 1, and the dual-cue analysis being a 2 X 2 factorial, with the factors being number of objects cued, and whether the target occurred at the cued or uncued locations.

Results

Response times. In the response time analyses, any trial where the subject's response time was below 100 ms, above 3000 ms or more than three standard deviations above the mean for that subject in that condition was classified as an outlier, and excluded from the analysis. The total number of trials so excluded was 1.9%. Incorrect responses were also excluded.

Analysis of single cue trials. Mean response times for the single-cue trials are presented in Figure 7. An analysis of variance on these five conditions (including the neutral)

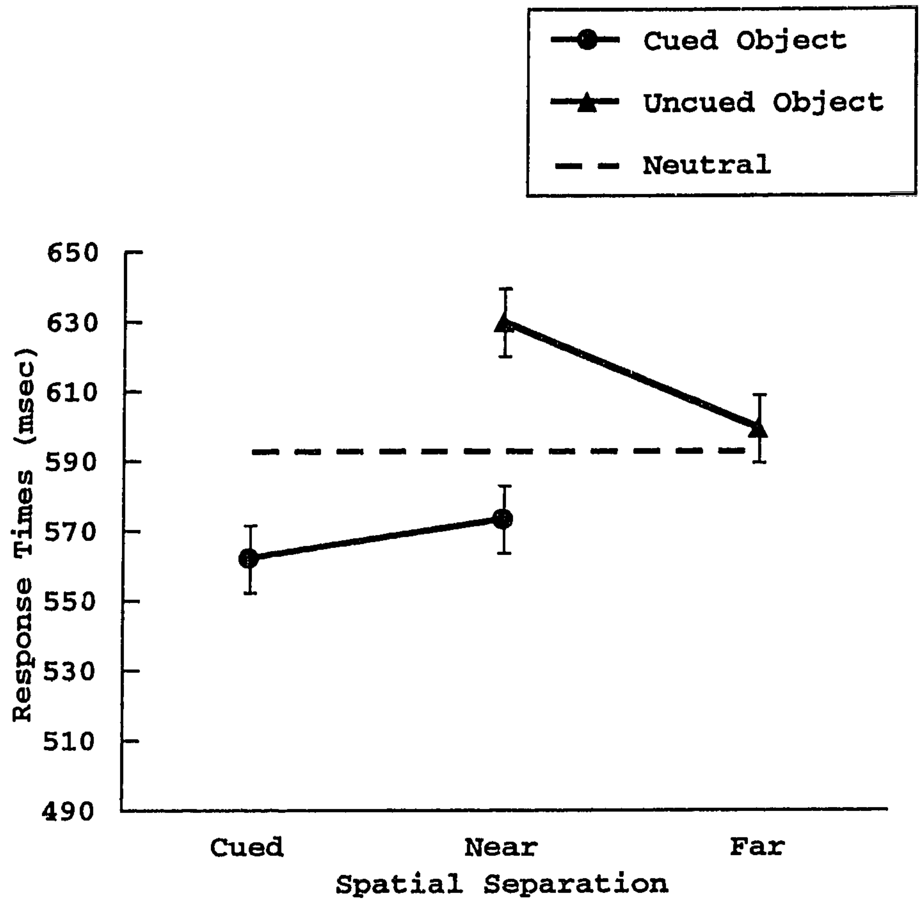

Figure 7. Mean response times, single cue trials, Experiment 3. Error bars calculated using within subjects error term.

was significant [$F(4,92) = 7.18$, $p < 0.01$, $MS_{error} = 2265$, used in Figure 7]. As in Experiment 1, response times in the cued-object, near condition were faster than those in the uncued-object, near-location condition [56 ms, $F(1,92) = 16.54$, $p < 0.05$], and in the uncued-object, far condition as well [26 ms, $F(1,92) = 3.59$, $p = 0.061$]. The object-based effect apparent in Experiments 1 and 2 reoccurs in these conditions. Unlike in Experiment 1, however, the cued-object, cued location condition and the cued-object, near-location conditions do not significantly differ from each other [11 ms, $F < 1$], and target discrimination in the uncued-object, near condition was significantly slower than in the uncued-object, far-location condition [$F(1,92) = 4.72$, $p < 0.05$], a pattern not seen in Experiment 1.

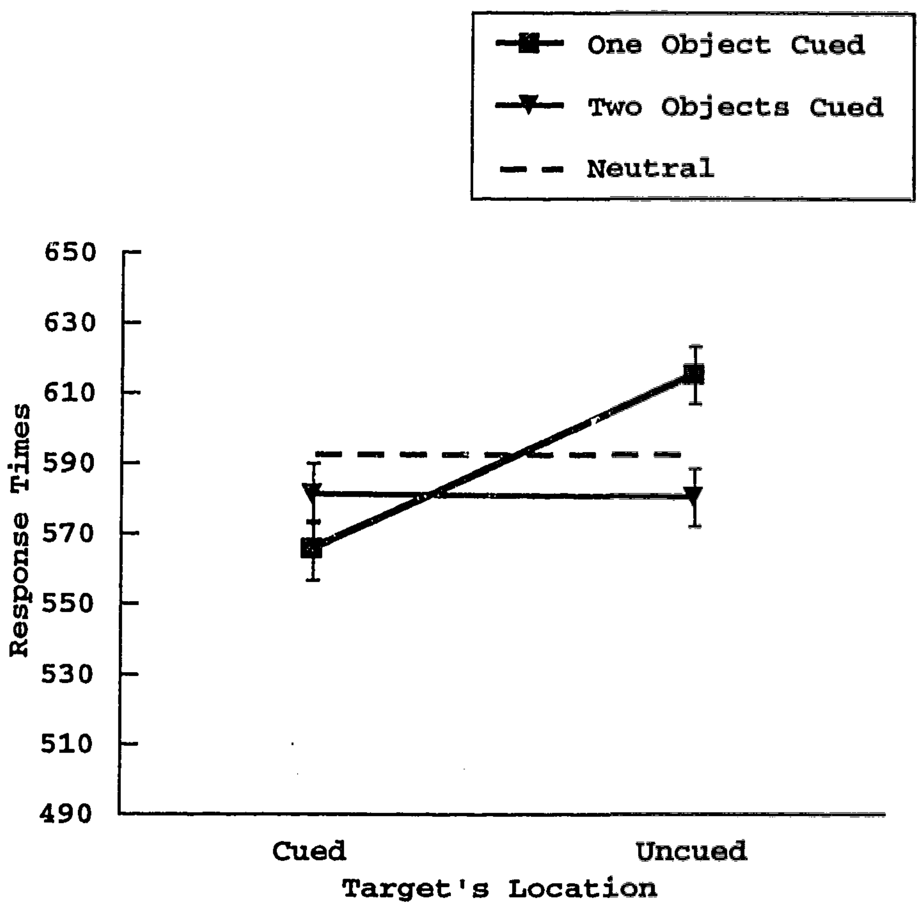

Figure 8. Mean response times, dual cue trials, Experiment 3. Error bars calculated from within subjects error term.

Analysis of the dual-cue trials. Results for the dual-cue trials are presented in Figure 8. There was a significant main effect of presenting targets at a cued or uncued location [$F(1, 23) = 7.18$, $p < 0.05$], no main effect of whether one or two objects were cued [$F < 1$], and a significant interaction of these two factors [$F(1, 23) = 9.84$, $p < 0.05$, MSerror = 1676, used in Figure 8]. When one object is cued, targets presented on the uncued-object are discriminated significantly more slowly than targets on the cued-object [$F(1, 23) = 18.46$, $p < 0.05$]. When two objects are cued, time to identify targets at cued or uncued locations does not differ [$F < 1$]. The effect of the number of cued-objects was not significant when the target appeared at a cued location [$F = 1.98$, $p < 0.10$], but was significant when the target appeared at the uncued location [$F(1,24) = 9.18$, $p < 0.05$]. This pattern is consistent with an effect of objects on attention: A cuing effect is observed when two locations on the same object are compared, but not when two locations on two different objects are cued.

Comparisons to the neutral cue. Comparisons to the neutral condition were made by including all conditions as one nine level factor in a within subjects ANOVA, and then making pairwise comparisons between the neutral condition and the others (MSerror = 2031). In the single cue conditions, the cued-object, cued-location condition was significantly faster than the neutral (31 ms; $F(1,184) = 5.78$, $p < 0.05$), the uncued-object, near-location condition was significantly

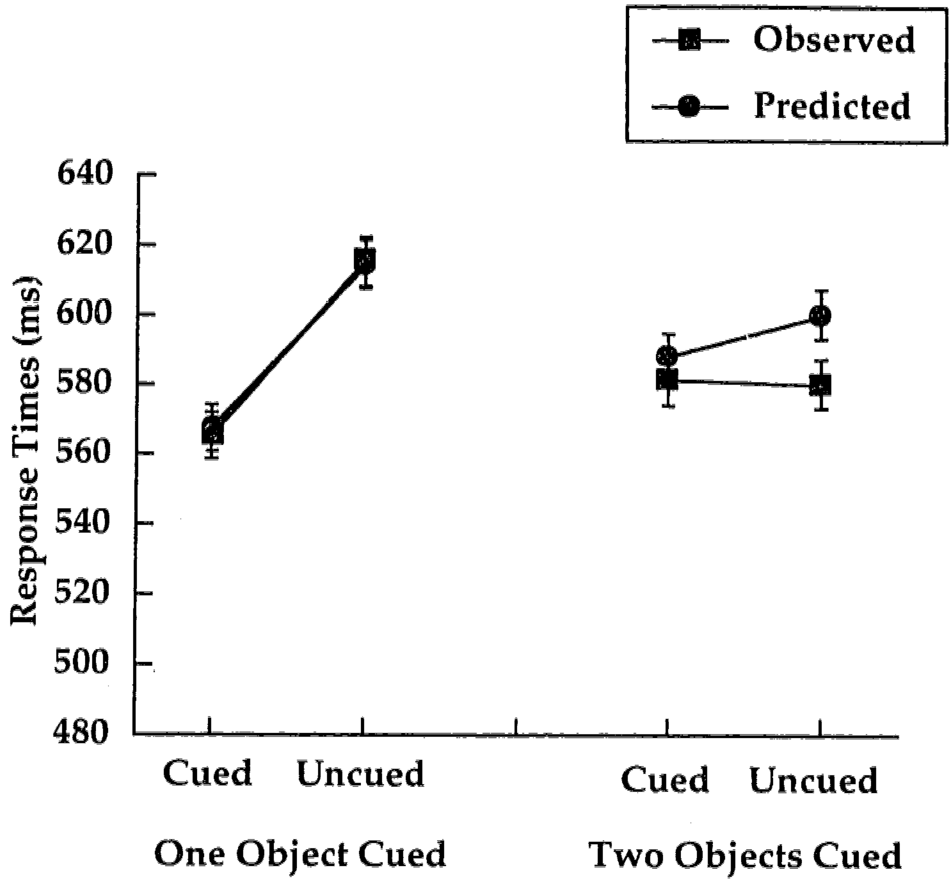

Figure 9. Observed and predicted response times, dual cue trials. Error bars calculated using the within subject error term.

slower (36 ms; $F(1,184) = 7.80$, $p < 0.05$), while the cued-object, near-location and uncued-object, far-location conditions did not differ significantly from the neutral [both p's > 0.10]. For the dual-cue trials, the only condition that differed significantly from the neutral was when one object was cued, and the target occurred on the cued-object [$F(1, 184) = 4.70$, $p < 0.05$]. This condition was 28 ms faster than the neutral. The 23 ms difference between the neutral and the condition where one object was cued and the target occurred on the uncued-object was marginally significant [$F(1,184) = 3.01$, $p = 0.084$]. For all of the other conditions $p > 0.10$.

Observed versus predicted results, dual-cue conditions. Predicted response time means and variances were calculated from the single cue conditions for the dual cue conditions when one object and when two objects are cued. Predicted and

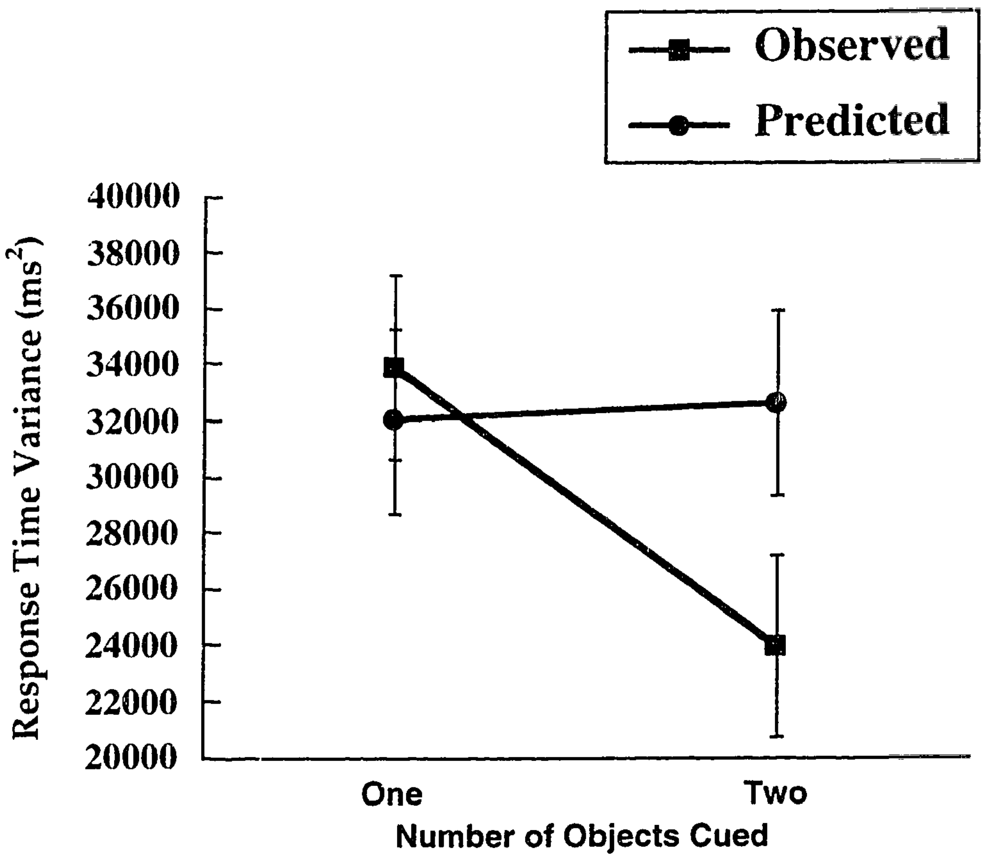

Figure 10. Observed and predicted response time variances, dual cue trials, Experiment 3. Data collapsed over cued and uncued locations. Again, squares represent observed results, circles represent predicted results. Error bars calculated from within subjects error term.

observed means for the dual-cue trials are presented in Figure 9. For the means, pairwise comparisons were made between predicted and observed results. When both objects were cued, and the target occurred at an uncued location, the predicted results significantly overestimated the observed results [$F(1,23) = 5.723$, $p < 0.05$]. None of the other pairwise comparisons showed a significant effect. (Error bars in Figure 9 calculated using MSerror = 925 from the three-way interaction of cue location, cued versus uncued target location and observed versus predicted results).

Table 4.

Mean Accuracy (Percentage) for Experiment 3, Single Cue Conditions.

Condition		Accuracy
Cued-object	Cued	95.1
	Near	93.5
Uncued-object	Near	95.3
	Far	95.8
Neutral		96.8

The tendency for mean response times to be faster than predicted when two ob[illegible]s are cued is exacerbated in the reaction time variances, presented in Figure 10. There was a significant interaction of number of objects cued by observed vs. predicted results [$F(1,23) = 5.20$, $p < 0.05$, MSerror = 2.41×10^8]. The observed variances match the predicted variances when one object is cued, but variances are significantly lower than those predicted when two objects are cued [$F(1,23) = 8.23$, $p < 0.01$]. Obviously, cuing two locations on two different objects has different consequences than cuing two locations on the same object.

Table 5.

Mean Accuracy (Percentage) for Experiment 3, Dual-cue Conditions.

Cuing Condition	Cue Position	
	On One Object	Across Two Objects
Cued	95.3	95.1
Uncued	94.5	94.5

Accuracy. The analysis of accuracy included those trials excluded as outliers in the response time analysis. Mean accuracy for single cue conditions is presented in Table 4, dual-cues in Table 5. Overall accuracy in all conditions was high (95.1%). For single cue trials, there was no significant effect of cuing [$F(1,23) = 1.71$, $p > 0.10$]. For dual-cue trials, there was no significant main effects of cuing or cue placement, nor did they interact [all F's < 1].

The correlation of subject's response times and accuracy, again partialling out the correlation of subject's overall response time and accuracy, was -0.026 for this data set. The analysis of observed versus predicted results for the reaction time means and variances were also conducted for the accuracy data. There were no significant effects in the analysis [all F's < 1]. Thus, there was no evidence for a speed-accuracy trade-off for either single- or dual-cue trials.

Discussion

The results of Experiment 3 further delineate the relationship between the space-based and object-based components to exogenous cuing, as well as replicating the basic finding of an object-based effect in Experiment 1 and 2 following exogenous cues. The data for cuing two locations simultaneously indicate that the presence of objects affects how well attention can be directed to two locations at once. When two locations on two different objects are cued, there was no cuing effect, in that the response times of targets presented at cued or uncued locations did not differ significantly, and the response times for these cued and uncued locations also did not differ significantly from the neutral condition. In contrast, a significant cuing effect was apparent when two locations on the same object were cued. Response times to targets presented at the cued locations were faster than to targets presented at the uncued locations, and the response times for targets presented at the uncued locations were significantly slower than the neutral, although response times for targets at the cued location did not differ from the neutral. These results indicate that the presence of objects do affect selection when two locations are cued. If objects were irrelevant to selection when two locations are cued, then this interaction of the number of objects cued and size of the cuing effect should not have occurred.

The results are consistent with the cuing of two locations on two different objects causing relatively equal activation of all potential target locations, as was described in the introduction to Experiment 3: Cuing two locations on two different objects leads to the activation of both object files, as well as the representation of the cued locations. Activation then spreads from each cued location to the uncued locations by both the spatial link between locations and by the activation of the relevant object file. The relatively equal activation of all locations that result leads in turn to little or no difference in response times between the cued and uncued locations when two adjacent locations on different objects are cued. Similar mechanism were invoked in discussing the neutral cuing condition in Experiment 1, and this general explanation is consistent with the lack of a significant difference between the neutral conditions and the dual-cue, two-objects conditions. Conceptually, on both neutral cue trials and the dual-cue, two-object conditions, two objects are primed, and therefore the subject's representations of both objects would receive relatively equal activation on both types of trials. This equal activation of object representations and the locations linked to them would lead to considerable delay in selecting a target from a location, and subsequently long response times in the neutral condition.

Further, when the observed result for dual-cue conditions are compared to predicted results generated from the single-cue conditions, it is apparent that the process occurring when both cues are on different objects is not a mixture of the relevant single-cue processes, as would be predicted if only a single object representation were activated at one time. Activation of one representation at a time in response to two objects being cued would lead to response time variances equal to those predicted from the single cue conditions, but when locations on two different objects are cued, the variances differ significantly from predictions. Although the deviation is not significant, the means also tend to depart from the values predicted from the single cue conditions.

When two locations on the same object are simultaneously cued, however, the results predicted from single-cue trials and those observed on dual-cue trials do not differ significantly. This lack of a difference between the predicted and observed results may arise from the small response time difference between single-cue, cued-object, cued-location and cued-object, near-location conditions used to make response time predictions, which itself may arise as a carry-over effect from the presence of the dual-cue, one-object cued condition. When two locations on one object are cued, the subject's representation may be more global, in that the linkage of locations on the object to their object representation dominates over their spatial separation. This would lead, on single-cue trials, to a reduced cuing effect within the cued object, by essentially the same mechanism as was used to explain the lack of a response time difference between cued-object, cued-location and cued-object, near-location conditions in the second half of Experiment 1's trials: Because the locations on the cued object differ little in their level of activation, response times to targets presented at these locations show little difference. In turn, the averaging together of the relevant single-cue conditions to yield predicted response times for the dual cue conditions gives predicted response times close to those observed simply because the distribution of activation in response to single-cues and dual-cues happen, in this case, to be relatively similar.

One oddity in Experiment 3's results is the relatively slow response times to targets presented in the single cue, uncued-object, near-location condition. None of the three models discussed in the introduction to the experiment predict this result. This condition is actually slower than the single-cue, uncued-object, far-location condition, which is opposite from what one would expect from any space-based model. This effect may arise because of the dual-cue context in which adjacent locations on two different objects are sometimes cued. Obviously, it does not arise from a general inhibition of the uncued object. However, cuing adjacent locations on different objects may make it more salient to the subjects that the locations are on different objects, which in turn may lead to inhibitory spatial links between the adjacent ends of the objects. On single-cue trials, these inhibitory links would result in the uncued-object, near-location conditions being the slowest condition. On dual-cue trials where one object is cued, the inhibitory links would serve to inhibit both uncued locations on the uncued object. On dual-cue trials where two objects are cued, the two cued locations are adjacent, so the inhibition of the adjacent locations would cancel out the effects of the cues, resulting in response times similar to those observed in the neutral condition.

Presumably, the purpose of these inhibitory links would be to facilitate the selection of information from only one object at a time. Tipper (1992; Tipper, Brehaut & Driver, 1990; Tipper, Weaver, Cameron, Brehaut & Bastedo, 1991) has emphasized the importance of inhibitory processes in the selection of response relevant information by attention, and perhaps similar inhibitory mechanisms are engaged in this experiment. So far, it has been assumed that when subjects are presented with objects in the visual field, locations on the same object are connected with facilitory links, in that more activation spreads to the near-location on the cued object. A further assumption is that this facilitory linking is formed automatically when objects are present. That the locations on the uncued object in Experiment 1 showed no response time difference in the direction of the uncued-object, far-location condition being faster than the uncued-object, near-location condition suggests that the inhibitory links are not automatically formed whenever there is more than one object in the visual field. Assuming that the putative inhibitory links only arise when subjects' attention is directed over more than one object suggests that the attentional system relies on inhibition only when there is a chance that information from more than one object could be selected (Tipper, 1992, Tipper, Brehaut & Driver, 1990; Tipper, Weaver et al, 1991), such as situations where more than one object is cued. In the natural world, selecting information from more than one object could give rise to response confusions and behavioral incoherence (Kahneman & Treisman, 1984; Tipper, Brehaut & Driver, 1990).

An alternative explanation for the results of Experiment 3 could be given in terms of any space-based model of attention, such as the gradient model. The presence of the dual-cue, one-object conditions might encouraged subjects to move the locus of their attention to the center of the object, and away from the cued end. This would result in the reduced effect of spatial separation within the cued object.

Such a mid-location placement strategy has been tested by McCormick and Klein (1991; Klein & McCormick, 1991), and found to give a good account of the results of some cuing studies. It can also account for the decrease in the difference in response times between locations on the cued object observed with practice in Experiment 1, by suggesting that on later trials, subjects tend to orient more towards the middle of the object. On the other hand, such an account would require one to hypothesize a greater degree of strategic control over attentional responses to exogenous cues than has generally been assumed. In addition, such a mid-location strategy does not provide a very clear interpretation of the inhibition of the uncued-object, near-location condition, or the interaction on dual-cue trials of cuing and number of objects cued. In point of fact, the mid-location placement account predicts no interaction of cuing and number of objects cued because the locus of attention should always be in the same position relative to the cued locations on both kinds of trial. One possibility is that the presence of the dual-cue trials encourages subjects, after a relatively small number of trials, to alter the shape of their attended region so as to withdraw attention from the uncued-object, near-location. The purpose for so doing would be, again, to prevent information from more than one object being passed on to higher level processes in order to avoid information from two different objects being passed on to processes of identification and response selection.

General Discussion

The three experiments reported here examined the relationship between space-based and object-based factors in the allocation of visual attention. In all three experiments, when spatial factors were controlled and a single exogenous cue directed subjects' attention to a location, recognition of targets in the cued-object, near-location condition was faster than recognition of a target in the uncued-object, near-location condition by 12 to 56 milliseconds. Experiment 3 also demonstrated that attention cannot be effectively spread over two objects. Experiment 2 demonstrated that when endogenous cues are used to direct attention in this paradigm, no effect of objects is apparent. This lack of an object effect with endogenous cues, when taken in combination with Egly, Driver and Rafal's results, indicate that it is the exogenous properties of spatial cues, such as sudden appearance at the cued location, that give rise to the object effect. While it certainly is possible for subjects to endogenously orient to an object (Baylis & Driver, 1993; Tsal & Kolbert, 1985; Wong & Weisstein, 1983), it is the case that when subjects are endogenously cued to attend to a location on an object, without explicit instructions to attend to the entire object, their attention is not affected by the presence of objects.

The object-based effect found with exogenous cues is somewhat small, on the order of 12 to 20 ms, if the results of Experiment 3 are ignored. Despite the effect's small size, there is every reason to believe the object-based effect in spatial cuing is real, given the findings of Egly (Egly, Driver & Rafal, 1994; Egly, Rafal, et al., 1994), experiments by Yantis and Moore (1995), and the current three experiments. Considered as a group, experiments examining exogenous spatial cuing with perceptual objects present in the visual field indicate a persistent, small effect of objects on attention. This object-based effect can be added to the extensive list of object-based effects in a variety of other paradigms (e.g., in visual search, Banks & Prinzmetal, 1976; Bundesen & Pedersen, 1983; Farmer & Taylor, 1980; Humphreys, Quinlan & Riddoch, 1989; Treisman, 1982; 1988; in letter identification, Kahneman, Treisman & Gibbs, 1992; in feature migration experiments, Baylis, Driver & McLeod, 1993; Prinzmetal, 1981; Prinzmetal & Keysar, 1989; Treisman, 1988; in negative priming Tipper, 1992; Tipper, Brehaut & Driver, 1990; and in inhibition of return Abrams & Donkin, 1994; Tipper, Driver & Weaver, 1991). This research indicates that organizing the visual field into potential objects must be a process basic to the visual system.

In my account of Experiments 1 through 3, I assumed that the visual display is represented preattentively using a hierarchical organization (Duncan & Humphreys, 1989; Marr, 1982). The spatial layout of locations in the display is represented at one level by a set of linked nodes, with the links between the nodes representing their spatial relationship. Cuing of a particular location leads to activation of that location, and this activation spreads over the links between nodes, with more distant locations receiving less activation. Time to select information from a location depends upon the degree of activation of that location relative to others in the representation (Duncan & Humphreys, 1989; Hoffman, 1978; 1979). Information at more activated locations is selected more quickly than information at less activated locations. When no objects are in the display, only this spatial linking determine response times to the target, so that cuing in the empty field gives rise to only space-based effects.

Objects, when present, are represented at the next level of the representation, in temporary representations akin to Kahneman and Treisman's object files (1984; Kahneman, Treisman & Burkell, 1983; Kahneman, Treisman & Gibbs, 1994; Treisman, 1988). Locations on an object are linked to the corresponding object file. When a location on an object is cued, both the node representing the cued location and the object file are activated. Activation spreads over the spatial link, as when no object is present in the visual field, but all locations belonging to the cued object also receive activation from their object file. Relative activation determines response times (Duncan & Humphreys, 1989; Hoffman, 1978; 1979), and because all the locations on the cued object are relatively more activated than locations on the uncued object, targets presented on the cued object are selected more quickly.

The above model can provides a coherent account of the slow response times in Experiment 3's single-cue, cued-object, near-location condition if it is assumed that inhibitory links between the ends of different objects are formed in response to the cuing of adjacent locations on different objects. This inhibition of adjacent cued objects would be similar to the inhibition reported by Tipper and his colleagues (Tipper, 1992; Tipper, Brehaut & Driver, 1990; Tipper, Driver & Weaver, 1991; Tipper, Weaver et al., 1991), in that such links would only be formed when there is a chance of information being selected from more than one object. In such cases, inhibiting the location adjacent to the cued location reduces the chance of confusing information from two different objects (Kahneman & Treisman, 1984; Tipper, Brehaut & Driver, 1991).

In light of the results of Experiment 2, it is obvious that endogenous cues do not engage the mechanisms that give rise to the object-based effect. This is consistent with the findings of Klein and his associates (Briand & Klein, 1987; Klein, 1994; Klein & Hansen, 1990; Klein, Kingstone & Pontefract, 1992), who have reported different functional consequences when attention is directed to stimuli by exogenous rather than endogenous cues. When attention is directed exogenously, the costs and benefits of attentional cuing are larger for stimuli requiring feature integration than for stimuli not requiring integration. Only the usual effect of cuing is observed when endogenous cues are used

(Briand & Klein, 1987). In contrast, when a choice response time task is used and stimulus likelihood is manipulated, the opposite pattern of results is obtained: Endogenous, but not exogenous cues yield an interaction (Klein & Hansen, 1990; Klein, 1994), although both do affect the detection of stimuli.

In terms of the hierarchical model used to explain the results of this dissertation, endogenous cuing may only operate just at the level of spatial representations and links, but it does not, at least in this paradigm, give rise to activation of the object's representations. Cuing a location with endogenous attention results in information from that location being selected more quickly, and activation spreads to other locations, resulting in the normal effects of cuing in response to targets seen in Experiment 2. In order to explain Klein's (1994; Klein & Hansen, 1991) findings of target likelihood affecting response times in choice tasks, endogenous cuing must also have an effect at the level of response selection, although effects at this level of processing are beyond the scope of this dissertation. On the other hand, exogenous cuing must affect the level of object files for it to explain the effects observed in this dissertation and the interaction with feature integration reported by Briand & Klein (1987). In order to determine what features or attributes belong to a particular object, that object's representation must be accessed. The current experiments show that exogenous cuing does interact with the presence of objects in the visual field, consistent with exogenous cuing automatically activating some representation of the object. Object-based effects do not occur in the spatial cuing paradigm in response to endogenous cues, but this may be because subjects are not provided with any motivation to attend to the objects as a whole. Possibly, if subjects were lead to believe that objects were important to their task, they would show an effect of objects following an endogenous spatial cue.

In addition to Experiment 2, there are other results in the visual attention literature that are consistent with a common representation being involved in exogenous cuing, feature integration, and object-based effects. Both objects and illusory conjunctions (also termed feature migrations) have been shown to interact with each other in non-cuing paradigms (Prinzmetal, 1981; Baylis, Driver & McLeod, 1992). Briand and Klein (1987) have demonstrated that feature integration and exogenous cuing interact, and the current experiments demonstrate that exogenous cuing is also affected by the presence of objects. That exogenous attention interacts with the presence of objects in the visual field (the current experiments and Egly, Driver & Rafal, 1994; Egly, Rafal, et al., 1994), and that both exogenous cuing and the presence of objects affect feature migrations is consistent with a common representation, object files, being affected. Possibly, novel objects (Yantis & Hillstrom, 1994) are initially selected for purposes of setting up an object file (Kahneman & Treisman, 1984; Kahneman, Treisman & Gibbs, 1992), and when some perceptual change occurs on the object the file is selected for updating. Object-specific priming of letter identities can be of considerable duration, so it is possible that the priming of objects by exogenous attention can last longer than the exogenous priming of locations, typically seen in the literature (Jonides, 1981; Nakayama & Mackben, 1987). The object-based effect observed after the 300 millisecond SOA between cue and target in Egly's work could therefore be attributable to the exogenous properties of their cues, simply because the exogenous priming of objects may persist longer than the exogenous priming of a location.

The current results indicate that the object-based system is automatically engaged by exogenous spatial cues, but not by endogenous cues (Experiment 2), although both types of cues had spatial effects. This dichotomy may simply reflect the nature of the task used in Experiment 2, as subjects were not explicitly instructed to direct endogenous attention to the cued object, but it does indicate that object-based effects in the spatial cuing paradigm are not a necessary consequence of using endogenous cues. It is likely, though, that the object-based system can be engaged endogenously, as the data indicating that subject's beliefs can alter how they parse the field into objects (Driver & Baylis, 1994) shows that object-based effects are alterable by subjects' higher level cognitions.

The three experiments reported here can be accounted for in terms of a hierarchical gradient model of attention (Downing, 1988; Downing & Pinker, 1985; LaBerge & Brown, 1989), and can also be accounted for in terms of Klein's (1994; Briand & Klein, 1987; Klein & Hansen, 1990; Klein, Kingstone & Pontefract, 1992) distinction between the different functions of endogenous and exogenous attention. It is important to note that the version of the gradient model discussed here does not really conflict with Klein's typology, at least in terms of object-based effects in the exogenous cuing paradigm. The gradient model is silent on the issue of whether endogenous cuing can give rise to response biases, so it does not conflict with Klein's conceptualization on that account. Both the gradient model and Klein's typology are consistent with the occurrence of costs and benefits for featural stimuli, as a result of either endogenous or exogenous spatial cuing. The modifications proposed to the gradient model in this dissertation, that the presence of objects in the visual field links together locations by a common object file, essentially lets the model account for the object-based effects found with exogenous cues.

Future directions in research. The current research demonstrates that objects affect spatially cued selective attention when that attention is directed in response to exogenous but not endogenous cues. A tentative model is laid out in the dissertation, and it is noted that results reported in the literature are consistent with objects, processes of feature integration, and exogenous cuing all affecting a common representation or stage of processing (see Baylis, Driver & McLeod, 1992; Prinzmetal, 1981 for object based results in feature perturbation; Briand & Klein, 1987; Treisman, 1988; Prinzmetal, Presti & Posner, 1986 for evidence of feature integration interacting with exogenous cuing; Egly, Driver & Rafal, 1994 and the current document for evidence of spatial cuing interacting with objects). This demonstration and the ideas presented in the discussions lead to several possible directions for further research.

A few research projects using the paradigm reported here immediately suggest themselves. For example, it was left an open question as to whether the object-based representation that are affected by exogenous cues are themselves hierarchically defined (Duncan & Humphreys, 1989; Marr, 1982; Marr & Nishihara, 1977). Research in which the objects presented are themselves sub-parts of a larger object would bear on the question of whether the objects are hierarchically structured. Another research question is concerned with the fate of objects presented at locations outside the objects. The current model suggests that there should only be space-based effects of distance -- targets further from the cued location should show longer response times and lower accuracies. Showing a different pattern of response times would be evidence against the current model. Similarly, while the mid-location placement hypothesis of

Klein and McCormick (1991) was rejected because it could not account for the interaction of number of objects cued and cuing in Experiment 3, a further test of the hypothesis could be conducted by presenting targets at the uncued location in the middle of the objects. In the experiments reported here, no target was ever presented at such a location. Experiment 3 leaves other questions open. For example, it was suggested thta the slow response times for near-location, uncued-object targets was related to carry-over effects. This suggestion could be tested by presenting subjects with several blocks of trials, some using entirely single-cue trials and others using different combinations of single-cue and dual-cue trials.

Some parametric manipulations suggest themselves: For example, if the SOA between cue and target presentation is lengthened, what will happen to the object-based effect? Egly, Driver and Rafal's (1994) paper suggests that the object-based effect should be present at 300 ms but provides no evidence concerning when the effect should fade. Given that combining lengthy SOA's and exogenous cues lead to inhibition of return (Maylor, 1985; Maylor & Hockey, 1985; Posner & Cohen, 1984), it might be worth examining if, and under what conditions, inhibition of return arises in this paradigm (see Abrams & Dobkin, 1991 for evidence that inhibition of return has space-based and object-based components). The discriminability of the target may matter as well. The current experiments used relatively low discriminability targets, under the assumption that higher discriminability targets might segment out from the background rectangles, and attentuate the object-based effect (Yantis & Hillstrom, 1994). A manipulation of discriminability could address this concern. An obvious control condition to run would be to compare cuing in a background of objects with a situation where the background is in the form of four squares at the target location. This would be particularly important in Experiment 3, as it would make it clear as to whether the presence of the objects or the use of two cues lead to the elimination of the cuing effect in the dual-cue, two objects-cued condition.

Beyond the particular paradigm used here, it would be worth investigating the suggestion that exogenous cuing, feature integration, and objects all affect a common representation or stage of processing with different, converging manipulations. For example, if one directs exogenous attention to an object, this should result in a reduction in the likelihood of feature migrations between that object and others present in the field. If the exogenously cued facilitation is long lasting, would this reduction in feature migrations last for the duration of the facilitation? Would it persist if the object moved behind an occlusion and reappeared (Tipper, Brehaut & Driver, 1990), or if the physical properties of the object were changed in some other way (Treisman, 1988)? What would occur if exogenous attention were directed away from the potential feature miscombination and its attendant objects? A preliminary method to address this last question would be to combine the methodology of Prinzmetal (1981) with that of Egly, Rafal, et al. (1994). Two pairs of adjacent rectangles could be presented, one pair on either side of fixation. Attention could be exogenously cued to one pair, and away from the other. Stimuli that could give rise to illusory conjunctions could then be presented on either pair of rectangles, and either both on the same object or on different objects.

Conclusions. The experiments reported here indicate that both space and objects can influence selective attention in the spatial cuing paradigm when exogenous, but not endogenous cues are used. These results imply that the relationship between space-based and object-based factors is important to any comprehensive theory of visual attention. As Neisser (1967) pointed out, preattentive processes may be capable of considerable organization of the visual field into objects and groups before potentially interesting sources of visual information are selected. The results also indicate that object-based effects may, in general, be more closely tied to exogenously cued attention than to endogenous attention. Further research on the role objects play in attentional phenomena, and how this role varies with the type of cue used to direct attention, will give us a better notion of how the human information processor takes in and organizes information.

References

Abrams, R.A. & Dobkin, R.S. (1994). Inhibition of return: Effects of attentional cuing on eye movement latencies. Journal of Experimental Psychology: Human Perception and Performance, 20, 467 - 477.

Allport, A. (1990). Visual Attention. In M. I. Posner (ed.), Foundations of Cognitive Science. MIT press: Bradford.

Banks, W.P. & Prinzmetal, W. (1976). Configuration effects in visual information processing. Perception and Psychophysics, 19, 361 - 367.

Bashinski, H.S. & Bacharach, V.R. (1980). Enhancement of perceptual sensitivity as the result of selectively attending to spatial locations. Perception and Psychophysics, 28, 241-248.

Baylis, G.C. & Driver, J. (1992). Visual parsing and response competition: The effect of grouping factors. Perception and Psychophysics, 51, 145-162.

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

Baylis, G. C., Driver, J. & McLeod, P. (1992). Movement and proximity constrain miscombinations of colour and form. Perception, 21, 201 - 218.

Berry, G. & Klein, R. (1993). Does motion-induced grouping modulate the flanker compatibility effect?: A failure to replicate Driver & Baylis. Canadian Journal of Experimental Psychology, 47, 714-729.

Briand, K. A. & Klein, R. M. (1987). Is Posner's "beam" the same as Treisman's "glue?": On the relation between visual orienting and feature integration. Journal of Experimental Psychology: Human Perception and Performance, 13, 228-241.

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

Bundesen, C. & Pedersen, L. F. (1983). Color segregation and visual search. Perception and Psychophysics, 33, 487 - 493.

Deustch, J.A. & Deustch, D. (1963). Attention: Some theoretical considerations. Psychological Review, 70, 80-90.

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: Volume XI, (pp 171-188). Hillsdale, NJ: Erlbaum.

Driver, J. & Baylis, G.C. (1989). Movement and visual attention: The spotlight metaphor breaks down. Journal _of Experimental Psychology: Human Perception and Performance_, _15_, 448-456.

Driver, J.S., Baylis, G.C. & Rafal, R.D. (1992). Preserved figure-ground segmentation and symmetry in a patient with neglect. _Nature_, _360_, 73-75.

Duncan, J. (1980a). Directing attention in the visual field. _Perception and Psychophysics_, _30_, 90-93.

Duncan, J. (1980b). The locus of interference in the perception of simultaneous stimuli. _Psychological Review_, _87_, 272-300.

Duncan, J. (1984). Selective attention and the organization of visual information. _Journal of Experimental Psychology: General_, _113_, 501-517.

Duncan, J. & Humphreys, G.W. (1989). Visual search and stimulus similarity. _Psychological Review_, _96_, 433-458.

Egly, R., Driver, J.S. & Rafal, R.D. (1994). Shifting attention between objects and locations: Evidence from normal and parietal lesion subjects. _Journal of Experimental Psychology_, _123_, 161-177.

Egly, R., & Homa, D. (1984). Sensitization of the visual field. _Journal of Experimental Psychology: Human Perception and Performance_, _10_, 778-793.

Egly, R. & Homa, D. (1991). Reallocation of visual attention. _Journal of Experimental Psychology: Human Perception and Performance_, _17_, 142-159.

Egly, R., Rafal, R., Driver, J. & Starrveveld, Y. (1994). Covert orienting in the split brain reveals hemispheric specialization for object-based attention. Psychological Science, 5, 380-383.

Eriksen, B.A. & Eriksen, C.W. (1974). Effects of noise letters upon identification of a target letter in a non-search task. Perception and Psychophysics, 16, 143-149.

Eriksen, C.W. & Hoffman, J.E. (1972). Some characteristics of selective attention in visual perception as determined by vocal reaction time. Perception and Psychophysics, 11, 169-171.

Eriksen, C.W. & St. James, J.D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. Perception and Psychophysics, 40, 225-240.

Eriksen, C.W. & Yeh, Y. (1985). Allocation of attention in the visual field. Journal of Experimental Psychology: Human Perception and Performance, 11, 583-97.

Eriksen, C.W., Webb, J.M. & Fournier, L.R. (1990). How much processing do nonattended stimuli receive? Apparently very little, but... Perception and Psychophysics, 47, 477 - 488.

Farmer, E. W. & Taylor, R. M. (1980). Visual search through color displays: Effects of target- background similarity and background uniformity. Perception and Psychophysics, 27, 267-272.

Fodor, J. (1983). The modularity of mind. Cambridge MA: MIT Press.

Hawkins, H. L., Shafto, M. G. & Richardson, K. (1988). Effects of target luminance and cue validity on the latency of visual detection. Perception and Psychophysics, 44, 484-492.

Henderson, J. M. (1991). Stimulus discriminations following covert orienting to an exogenous cue. Journal of Experimental Psychology: Human Perception and Performance, 17, 91-106.

Henderson, J.M. & Macquistan, A.D. (1993). The spatial distribution of attention following an exogenous cue. Perception and Psychophysics, 53, 221 - 230.

Hillstrom, A. & Yantis, S. (1994). Visual motion and attentional capture. Perception and Psychophysics, 55, 399-411.

Hoffman, J.E. (1978). Search through a sequentially presented display. Perception and Psychophysics, 23, 1-11.

Hoffman, J.E. (1979). A two-stage model of visual search Perception and Psychophysics, 25, 319-327.

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

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

Hughes, H.C. & Zimba, L.D. (1988). Natural boundaries for the spatial spread of directed visual attention. Neuropsychologia, 25, 5 - 15.

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

James, W. (1890/1950). The principles of psychology. New York: Dover.

Johnston, W.A. & Dark, V.J. (1986). Selective attention. Annual Review of Psychology, 37, 43-75.

Jonides, J. (1980). Towards a model of the mind's eye's movement. Canadian Journal of Psychology, 34, 103-112.

Jonides, J. (1981). Voluntary versus automatic control of the mind's eye. In J. Long & A. Baddeley (Eds.), Attention and Performance (Vol. 9, pp 187-203). Hillsdale, NJ: Erlbaum.

Jonides, J. & Mack, R. (1984). On the cost and benefit of cost and benefit. Psychological Bulletin, 96, 29 - 44.

Kahneman, D. (1973). Attention and effort. Eaglewood Cliffs, NJ: Prentice-Hall.

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

Kahneman, D. & Treisman, A.M. (1984). Changing views of attention and automaticity. In R. Parasurman & D.R.

Davies (eds.), Varieties of Attention (pp 29-61). Orlando, FL: Academic.

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. J. (1992). The reviewing of object- files: Object- specific integration of information. Cognitive Psychology, 24, 175 - 219.

Keifer, R.J. & Siple, P. (1987). Spatial constraints on the Voluntary control of attention across visual space. Canadian Journal of Psychology, 41, 474-489.

Kingstone, A. & Klein, R. (1991). Combining shape and position expectancies: Heirarchical processing and selective inhibition. Journal of Experimental Psychology: Human Perception and Performance, 17. 512 - 519.

Klein, R. (1994). Perceptual-motor expectancies interact with cover visual orienting under conditions of endogenous but not exogenous control. Canadian Journal of Experimental Psychology, 48, 167- 181.

Klein, R. & Briand, K. (1986). Allocation of attention in visual space. Allocation of attention in visual space. Paper presented at the Banff Annual Seminar in Cognitive Science, May, 1986.

Klein, R. & Hansen, E (1990). Chronometric analysis of spotlight failure in endogenous visual orienting. Journal of Experimental Psychology: Human Perception and Performance, 16, 790 - 801.

Klein, R., Kingstone, A., & Pontefract (1992). Orienting of visual attention. In K Rayner (Ed.) *Eye movements and visual cognition: Scene perception and reading.* New York: Springer-Verlag.

Klein, R. & McCormick (1989). Covert visual orienting: Hemifield activation can be mimicked by a zoom lens and midlocation placement strategies. Acta Psychologia, 770, 235-250.

Kramer, A.F. & Jacobson, A. (1991). Perceptual organization and focused attention: The role of objects and proximity in visual processing. Perception and Psychophysics, 50, 267 - 284.

Kramer, A.F., Tham, M.P. & Yeh, Y.Y. (1991). Movement and focused attention: A failure to replicate. Perception and Psychophysics, 50, 537-546.

LaBerge, D. & Brown, V. (1986). Variations in the size of the visual field in which targets are presented: An attentional range effect. Perception and Psychophysics, 40, 188 - 200.

LaBerge, D. and Brown, V. (1989). Theory of attentional operations in shape identification. Psychological Review, 96, 101 - 124.

Mack, A. Tang, B. Tuma, R. Kahn, S. & Rock, I. (1992). Perceptual organization and attention. Cognitive Psychology, 24, 475-501.

Marr, D. (1982). Vision. San Francisco, CA: Freeman.

Marr, D. & Nishihara, H.K. (1977). Representation and recognition of the spatial organization of three-dimensional shapes. Proceeding of the Royal Society of London, B200, 269-294.

Maylor, E.A. (1985). Facilatory and inhibitory components of orienting in visual space. In M.I. Posner & O.S.M. Marin (Eds.), Attention and Performance XI (pp 189 - 204). Hillsdale, NJ: Erlbaum.

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

McCormick, P. & Klein, R. (1990). The spatial distribution of attention during covert visual orienting. Acta Psychologia, 75, 225 - 242.

Müller , H.J. & Rabbitt, P.M.A. (1989). Reflexive and voluntary orienting of attention: Time course of activation and resistance to interruption. Journal of Experimental Psychology: Human Performance and Perception, 15, 315-330.

Murphy, T.D. & Eriksen, C.W. (1987). Temporal changes in the distribution of attention in the visual field in response to precues. Perception and Psychophysics, 42, 576-586.

Nakayama, K. & Mackben, M. (1989). Sustained and transient components of visual attention. Vision Research, 29, 1631-1647.

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

Neisser, U. & Becklin, R. (1975). Selective looking: Attending to visually significant events. Cognitive Psychology, 7, 480-494.

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: Erlbaum.

Pinker, S. (1984). Visual cognition. Cognition, 18, 1-63.

Posner, M.I. (1978). Chronometric explorations of mind. Hillsdale, NJ: Erlbaum.

Posner, M.I. (1980). Orienting of attention. Quarterly Journal of Experimental Psychology, 32, 3 -25.

Posner, M.I. & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. Bowhuis (Eds.), Attention and Performance X (pp. 531-556). Hillsdale, NJ: Erlbaum.

Posner, M.I., Inhoff, A.W., Freidrich, F.J. & Cohen, A. (1987). Isolating attentional systems: A cognitive-anatomical analysis. Psychobiology, 15, 107-121.

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. (1981). Principles of feature integration in visual perception. Perception and Psychophysics, 30, 330 - 340.

Prinzmetal, W. & Keysar, B. (1989). Functional theory of illusory conjunctions and neon colors. Journal of Experiment Psychology: General, 118, 165-190.

Prinzmetal, W., Presti, D.E., & Posner, M.I. (1986). Does attention affect visual feature integration? Journal of Experimental Psychology: Human Perception and Performance, 12, 361-369.

Remington, R. & Peirce, L. (1984). Moving attention: Evidence for time-invariant shifts of visual selective attention. Perception and Psychophysics, 35, 393 - 399.

Rock, I. & Gutman, D. (1981). Effect of inattention on form perception. Journal of Experimental Psychology: Human Perception and Performance, 7, 264-272.

Shaw, M. (1984). The division of attention among spatial locations: A fundamental difference between letter recognition and luminance detection. In H. Bouma & D.G. Bouwhuis (Ed.), Attention and Performance X (pp. 109-120). Hillsdale, NJ: Erlbaum.

Shiffrin, R.M. & Schneider, W. (1977). Controlled and automatic information processing: II. Perceptual learning, automatic attending, and a general theory. Psychological Review, 84, 127-190.

Sperling, G. (1960). Information available in brief visual presentations. Psychological Monographs: General & Applied, 74, 1- 29.

Sperling, G. (1984). A unified theory of attention and signal detection. In R. Parasuraman & D.R. Davies (Ed.), Varieties of Attention, (pp 103-181). New York: Academic Press.

Stelmach, L.B. & Herdman, C.M. (1991). Directed attention and perception of temporal order. Journal of Experimental Psychology: Human Perception and Performance, 17, 539-550.

Tipper, S.P. (1992). Selection for action: The role of inhibitory mechanisms. Current Directions in Psychological Science, 1, 105 - 109.

Tipper, S., Brehaut, J.C. & Driver, J. (1990). Selection of moving and stationary objects for control of spatially directed attention. Journal of Experimental Psychology: Human Perception and Performance, 16, 492-504.

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

Tipper, S.P., Weaver, B., Cameron, S., Brehaut, J.C. & Bastedo, J. (1991). Inhibitory mechanisms of attention in identification and localization tasks: Time course and disruption. Journal of Experimental Psychology: Learning, Memory and Cognition, 17, 681-692.

Treisman, A. M. (1964). Selective attention in man. British Medical Bulletin, 20, 12-16.

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

Treisman, A.M. (1988). Features and objects: The fourteenth annual Bartlett memorial lecture. Quarterly Journal of Experimental Psychology, 40A, 1-25.

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

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

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

Tsal, Y. (1983). On interpreting the effects of location preknowledge: a critique of Duncan. Perception and Psychophysics, 34, 297-298.

Tsal, Y. & Kolbert, L (1985). Disambiguating ambiguous figures by selective attention. Quarterly Journal of Experimental Psychology, 37A, 25-37.

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

Vecera, S.P. & Farah, M.J. (1994). Does visual attention select objects or locations? Journal of Experimental Psychology: General, 146-160.

Wong, E. & Weisstein, N. (1983). Sharp targets are detected better against a figure, and blurred targets are detected better against a background. Journal of Experimental Psychology: Human Perception and Performance, 9, 194 - 202.

Yantis, S. & Hillstrom, A. (1994). Stimulus-driven attentional capture: Evidence from equiluminant visual objects. Journal of Experimental Psychology: Human Perception and Performance, 20, 95-107.

Yantis, S. & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. Journal of Experimental Psychology: Human Perception and Performance, 10, 601 - 621.

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

Yantis, S. & Moore, C.M. (1995). Spread of visual attention behind an occluding surface. Paper presented at the 36th Annual Meeting of the Psychonomics Society, Los Angeles.

Appendix

Analysis of Data by Visual Field and Orientation of Rectangle

In this appendix, the data for Experiments 1, 3 and the exogenous condition of Experiment 2 are reported, decomposed by visual field of target presentation and vertical orientation of the rectangles.

Data for Experiment 1 are reported in Table 6.

Table 6. Response time and accuracy data for Experiment 1, decomposed by visual field and background orientation.

Condition		Left Visual Field		Right Visual Field	
		Vertical	Horizontal	Vertical	Horizontal
Cued Object	Cued	500 (96.4)	501 (97.4)	524 (96.4)	523 (97.9)
	Near	525 (97.9)	520 (97.9)	537 (95.3)	549 (97.4)
Uncued Object	Near	545 (97.4)	560 (96.9)	565 (94.3)	546 (92.7)
	Far	558 (95.8)	550 (96.9)	561 (92.2)	570 (94.8)
	Neutral	540 (95.3)	547 (95.8)	547 (95.8)	543 (96.9)

Response times and accuracies for Experiment 2's exogenous cuing condition are presented in Table 6 and 7, decomposed trial block (first or second) as well as target's visual field and orientation of the background. Data for the first block of trials is presented in Table 7, data for the second block in Table 8.

Table 7. Response time and accuracy data for Experiment 2's exogenous cuing condition, decomposed by trial block, visual field and background orientation.

Condition		Left Visual Field		Right Visual Field	
First Block		Vertical	Horizontal	Vertical	Horizontal
Cued Object	Cued	666 (94.1)	662 (95.0)	654 (96.4)	678 (95.7)
	Near	694 (95.7)	691 (95.3)	681 (96.2)	714 (96.6)
Uncued Object	Near	707 (93.9)	677 (95.3)	714 (97.7)	707 (95.0)
	Far	687 (94.4)	680 (94.8)	675 (96.6)	722 (96.2)

Table 8. Response time and accuracy data for Experiment 2's exogenous cuing condition, decomposed by trial block, visual field and background orientation.

Condition		Left Visual Field		Right Visual Field	
Second Block		Vertical	Horizontal	Vertical	Horizontal
Cued Object	Cued	637 (95.3)	662 (96.2)	650 (97.1)	628 (96.6)
	Near	659 (96.4)	651 (97.1)	678 (96.2)	654 (95.3)
Uncued Object	Near	703 (93.2)	677 (96.2)	656 (98.4)	682 (96.4)
	Far	683 (96.2)	666 (97.3)	686 (94.8)	653 (97.5)

Response times and accuracies for Experiment 3's single cue conditions are presented in Table 9.

Table 9. Response time and accuracy data for Experiment 3, single cue conditions, decomposed by visual field and background orientation.

Condition		Left Visual Field		Right Visual Field	
		Vertical	Horizontal	Vertical	Horizontal
Cued Object	Cued	560 (93.8)	620 (93.8)	587 (95.8)	561 (96.9)
	Near	637 (91.7)	584 (94.8)	588 (92.7)	573 (94.8)
Uncued Object	Near	648 (96.9)	660 (92.7)	620 (95.8)	657 (95.8)
	Far	639 (95.8)	618 (96.9)	600 (94.8)	632 95.8)
	Neutral	600 (95.8)	601 (96.9)	627 (96.9)	618 (96.9)

Response times and accuracies for Experiment 3's dual cue conditions are presented in Table 10.

Table 10. Response times and accuracy data for Experiment 3, dual cue conditions, decomposed by visual field and background orientation.

Condition		Left Visual Field		Right Visual Field	
		Vertical	Horizontal	Vertical	Horizontal
One Object	Cued	591 (93.8)	559 (95.8)	586 (96.9)	582 (94.8)
	Uncued	603 (94.8)	656 (91.7)	686 (94.8)	620 (96.9)
Two Objects	Cued	609 (95.8)	568 (93.8)	572 (94.8)	586 (95.8)
	Uncued	576 (94.8)	569 (92.7)	615 (95.8)	600 (94.8)