The Visual Search Task Reveals Important Functions and Properties of the Spotlight of Attention

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Abstract

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Selective attention can be employed to a restricted region in space or to specific objects. Many properties of the spotlight of attention are not well understood. In the present study, the question examined was whether the putative shape of the attentional spotlight can be determined by endogenous cueing within a visual search paradigm. Moreover, the current investigation examined the role of spatial cueing on the detrimental effect of the irrelevant background elements during a visual search task. The results confirmed that attention was confined to the cued area only. In addition, the cueing technique was successful in partially eliminating the background effect. This study shows that top-down processes, just like bottom-up processes, can be manipulated. Most importantly, this study has provided converging evidence for an attentional spotlight whose shape can be adjusted flexibly by appropriate endogenous cueing. The present experiments have shed some light into the roles that attention plays in perception.

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Introduction

One of the major tools for investigating the visual system and the role of attention in visual object recognition has been the visual search task. The basic idea behind the visual search paradigm is that an observer must search for a pre-specified target among a variable number of distractor elements in some random location, and the reaction time (RT) to the detection of the presence or absence of the target will be measured. Thus, the visual search paradigm is a discrimination task in which the subject must determine if the target stimulus is present among the distractor stimuli. In many instances, the task becomes more difficult as the number of stimuli presented increases, thus it is expected that RT to respond will increase. RT can therefore be used as a measure of difficulty of a discrimination task, as long as the error rate remains constant. The increase of the RT with increasing display size can be described by the slope of the RT-display size relationship. This slope should be twice as steep for the situation where the target is absent as compared to the situation where the target is present if the search is difficult. This can be explained by the fact that, when the target is absent, the observer has to search until all the items have been searched. Conversely, when the target is present, it will on average, be detected after half of the items have been examined, thus, cutting the search time down by half. Where the RT shows how fast the detection of the target among the distractors occurs, the slope shows how much the RT will increase per item. Treisman and Gelade (1980) found that the function relating search times was flat and similar for target present and absent when a single feature was sufficient to define the target, but increased linearly when a conjunction of features was required.

Theories of Visual Search

In 1980, Treisman and Gelade developed a theory of object perception, the Feature-Integration Theory (FIT), which has greatly influenced the research on visual search. This theory assumes that early in visual processing, the visual display is decomposed into a number of elementary features. For instance, color and orientation are regarded as simple features according to the FIT (Treisman & Sato, 1990). If only the target item contains that feature, for example the color red, the target will be detected quickly, and the RT will be independent of the number of distractors. This is known as a parallel search. That is, the information is processed simultaneously across the feature maps, without effort or the need for the involvement of the spotlight of attention, also known as focused attention (Treisman & Gelade, 1980). However, the situation becomes more complicated when the target is defined by the presence of two different features, and each half of the distractors has one of the features but not the other. For instance, when the target is red and vertical, and the distractors are either red and horizontal or green and vertical. This is called a conjunction of features. Conjunctions require a serial search, according to the FIT, but there are cases of fast conjunction searches (Wolfe, Cave, & Franzel, 1989). In a conjunction search, each stimulus has to be attended to one after the other. Only when a location is encountered where there is activity in both feature maps, can the search be abandoned since the target has been found. Thus, the search time will increase with the number of distractors. Therefore RT can be used to determine if the task requires a parallel or a serial search (see Townsend, 1990). Others, for instance Palmer, Ames, and Lindsey (1993), have argued that the manner in which the FIT distinguishes between a parallel and a serial search is too simplistic. Rather than using a flat slope to define a parallel search and a steep slope to define a serial search, Palmer claims that the task difficulty itself can tell us if a parallel or serial search will be required. However, Palmer has used accuracy tests rather than RT measures to formulate his theory of task difficulty on search performance.

The serial-parallel dichotomy proposed in the FIT has been incorporated into other search models. For instance, the Guided Search model (Wolfe, 1994) adopts a two-stage architecture. The first stage detects all simple features in parallel and guides a second stage that is serial and that takes place in limited areas of the visual field. During the first stage, the information activated by simple features is added and registered in a global map of activation in which each location represents the probability of containing a target. In the second stage, attention is directed to the location with the highest activation level. The search stops if the target is detected at this location; otherwise, attention is directed at the next highest location until a target is found or until no remaining location has sufficient activation (Wolfe, 1994).

According to McElree and Carrasco (1999), the RT logic that motivates models such as the FIT and the Guided Search Model (GSM) provides less than satisfactory grounds for drawing a sharp dichotomy between parallel and serial processing. As a consequence, other search models have been proposed to account for the differential impact of set size on mean RT (e.g., Duncan & Humphreys, 1989). Duncan and Humphreys (1989) argued against the FIT. They believed that the similarities of the target and distractors were more important, as opposed to the number of features that was stressed in the FIT. When the distractors are similar to the target, the RT is longer than when the distractors are dissimilar. This suggests that more attention and a longer search will be required in order to identify a target among similar distractors.

In actual fact, the visual display as it has been used in most of the visual search literature is not as general and representative of real situations as most accounts would have us believe. In the real world, we often search for objects that are placed among, irrelevant elements, neither target nor distractors. Galera, Lopes and von Grünau (2000) presented the target and distractor stimuli on an empty background or among a large number of irrelevant background stimuli. They found that the presence of a background in the visual display made the search for the target more difficult, i.e., RT increased when the irrelevant background was present. (The terms "irrelevant stimuli" and "background" will be used interchangeably throughout this thesis). Even though the background elements were clearly different from the relevant stimuli (target and distractors), by having a unique orientation with 45 degrees difference to the relevant stimuli, subjects were unable to quickly disregard the background as a whole. When the background differed in orientation and a large change in luminance contrast for the relevant stimuli, the RT-relevant stimulus number (set size) relationship was shifted in parallel by a constant amount (fixed RT increase of 33 ms). But when the luminance contrast difference was small or absent, the effect of the background interacted with the set size. The main finding that the addition of a background in the visual search task increases RT in a significant way was one of the starting points for the present experiments.

The other starting point was the finding by Posner (1980) that spatial cueing (in this case cueing of the location) can influence target detection in a significant way. Posner (1980) conducted an experiment, in which he provided subjects with a cue as to whether a given event would occur to the right or to the left of fixation. Posner found that when the location of the target was cued, it facilitated target detection. Therefore, cueing the location of the target decreased RT. Posner's experiments have clearly shown that both bottom-up (exogenous) and top-down (endogenous) cueing can be used in this context. With exogenous cueing, some stimulus is briefly presented at the cued location before the target appears in this location. With endogenous cueing, the cue is central and symbolically indicates the cued location (e.g. arrow, "left"). In either case, the subject's "knowledge" about where in space a target stimulus will occur affects the efficiency of detection. Posner studied two types of cues: a valid cue which correctly identifies the location where the target is to appear, and an invalid cue that directs the subject's attention to an incorrect location. The valid cue decreased RT, and the invalid cue increased RT, with respect to a no cue control. Thus facilitation and suppression can be present in the same situation.

How the Visual Search Literature has Contributed to Defining the Concept of Spotlight of Attention

Visual search is involved in many everyday tasks, such as finding one's shoes or looking for a face in a crowd. Since only a small portion of the visual information that reaches the retina can be used at any one time, a great deal of it must be ignored. This is where visual selective attention has an important function. Yet, after much research, we still have only a limited idea of how attention works. Psychologists have described attention as orienting to sensory stimuli (Posner, 1995). Visual attention is also thought of as an enhancement of visual processing at the location or for the object to which attention is directed (the metaphor of the 'spotlight of attention'). Visual attention may also be thought of as a filter that limits the amount of information that the visual system ultimately processes (Broadbent, 1958).

The spotlight of attention has been described in many theories of object detection and object perception (Treisman & Gelade, 1980; Julesz, 1984; Wolfe, 1994; Eriksen & Hoffman, 1972; Broadbent, 1958; Neisser, 1967). Neisser (1967) was one of the early researchers that stated that we need an attentional mechanism, which would focus on some elements while ignoring irrelevant ones. For instance, Neisser (1967) referred to the exponentially increasing conjunction of features that is possible as the number of objects increases in the display to justify the need for a mechanism of focal attention.

More recently, visual attention has also been compared to a "spotlight" that 'illuminates' only the object or objects of interest (Posner & Cohen, 1984). Posner, Snyder, and Davidson (1980) formulated it this way: selective attention is like "a spotlight that enhances the efficiency of the detection of events within its beam" (p. 172). Theories of detection and visual attention have emphasized that the spotlight of attention helps to process the information that falls within its beam faster and more accurately (Posner, 1980; Eriksen & Hoffman, 1972; Julesz, 1984; Yeshurun & Carasco, 1998), and the remainder of the visual field is partially filtered out or suppressed.

Objects nearby the attended location will receive privileged processing, in relation to objects appearing at unattended places. Several studies have shown that the efficiency of processing inside the attended area is inversely related to the size of the area, an effect known as the cue size effect (Eriksen & Yeh, 1985;

Eriksen & St. James, 1986; Laberge, 1983; Castiello & Umiltà, 1990). There is also evidence that the capture of attention by a spatial cue is dependent on the object where the target is presented, showing slower target identification when the target is presented on an uncued object. (Egly, Driver & Rafal, 1994; Iani, Nicoletti, Rubichi & Umiltá, 2001; Macquistan, 1997).

Eriksen and Hoffman (1972) showed that concentrating on a reduced area of a stimulus display increases the speed of stimulus detection. They estimated the size of the spotlight of attention to be 1 deg of visual angle but they stated that the spotlight of attention could be restricted or enlarged, depending on the area of the display, as other studies demonstrated as well (Treisman, 1998; Treisman & Gelade, 1980; Eriksen & Hoffman, 1972; and Julesz, 1984). A restricted focus of attention was hypothesized, by Eriksen and Hoffman, to yield high resolution while a large spotlight of attention was hypothesized to yield low resolution. Also, Eriksen and Hoffman postulated that unlike visual acuity, the mechanism of focal attention was not dependent on retinal sensitivity. That is, visual acuity and focal attention are independent mechanisms. Eriksen and Hoffman conducted an experiment in which the participants had to identify a particular letter in a circular display indicated by a cued line. When the distractors were similar to the target, target detection was slower than when the distractors were dissimilar to the target. For instance, detecting a target letter among distractor letters produced longer reaction times than the detection of a target letter among filled circle distractors. This increase in reaction time suggests that more attention was required in order to identify the target (Eriksen & Hoffman, 1972).

Functions of the Spotlight of Attention

A general function of the spotlight of attention, which is noted in many theories of object perception and attention, is to process the information that falls within its beam (Posner, 1980; Duncan & Humphreys, 1989; Eriksen & Hoffman, 1972; Treisman & Gelade, 1980; Wolfe, 1996). However, there are at least two other functions of the spotlight of attention, which are specifically related to the FIT (Treisman & Gelade, 1980). The first one is the location of features, the second one is the integration of the features.

Theories of detection and visual attention have emphasized that the spotlight of attention helps to process the information that falls within its beam faster and more accurately (Posner, 1980; Eriksen & Hoffman, 1972; Julesz, 1984). Nothdurft (1999) conducted a visual search experiment for features where the participants had to search for a horizontal line among lines of different orientations. The items were arranged in a circle around a central fixation point. A large line between the fixation point and the target or between the distractor at the opposite direction of the target (anti-target) was presented immediately after target detection. The participants were asked to state the direction of apparent motion in the large line. Nothdurft (1999) found that the participants reported seeing a motion from the target to the fixation point, indicating that attention was focused on the target location immediately after target detection. This result supports the idea that the spotlight of attention needs to light up the target in order to detect and locate its presence (also see: von Grünau, Dubé, & Kwas, 1996).

Another hypothesized function of the spotlight of attention is to locate features. In the FIT, it was believed that the attentional processes involved in the detection and the localization of a target were different. It was hypothesized that the detection of features required the use of the spotlight of attention (Treisman & Gormican, 1988). The features needed to be bound to a spatial location in the master map of locations in order to be located and this was done through the help of the spotlight of attention. According to Treisman and Gelade (1980), when the spotlight of attention was not in use, the features were free floating with respect to one another. Treisman and Gelade (1980) found support for this hypothesis with the results of a visual search experiment in which the stimulus display consisted of two rows of six coloured letters. In the feature condition, the possible targets were "H" in blue or pink, or an orange "O" or "X". They found that target identification was well above chance, even when the participants made major location errors. Furthermore, Treisman and Gelade found that the reaction time to detect the feature was short and did not vary as a function of the set size, but the reaction time to locate the feature in space was long and increased as the set size increased. However, this claim has been challenged by a study by Nothdurft (1999) which showed that attention is directed to the target when the participant successfully indicates the presence of the target. Nothdurft (1999) showed that the spotlight of attention is required to detect as well as locate features. This goes against Treisman and Gelade's (1980) claim that the spotlight of attention is only used for feature location and not for feature detection.

In the real world, objects are usually made up of many features. Another function of the spotlight of attention is to integrate the features of an object. According to Treisman and Gelade (1980), "Focal attention provides the 'glue' which integrates the initially separate features into a unitary object" (p. 98). To illustrate the integrating function of the spotlight of attention, Treisman and Gelade conducted a conjunction search in which the display consisted of two rows of six coloured letters. The possible targets were a pink "X" or a blue "O" among pink "O's" and blue "X's". They found that when the participants failed to locate the target, the probability of identifying the presence of the target was at chance level. This result supports the hypothesis that the detection of the presence of an object made up of a conjunction of features requires the use of the spotlight of attention. However, a recent study proposed that the role of the spotlight of attention is to mainly search within the display for salient items rather than to bind features, and that the pre-attentive processing guides the spotlight of attention to the area of the display where the target is most likely located (Wolfe, 1998).

Characteristics of the Spotlight of Attention

The size of the area of focused attention.

The size of the spotlight of attention is an important characteristic to study because it indicates how much information the spotlight of attention can contain and how large an amount of information can be processed by the spotlight of attention.

The size of the spotlight of attention can be enlarged to process larger stimuli or to process a larger number of stimuli. Julesz (1984) conducted a visual search experiment which demonstrated that the size of the aperture of the spotlight is varied according to the size of the stimulus to be processed and that enlarging the size of the spotlight to fit larger stimuli does not affect the accuracy nor the speed of processing. In a visual search experiment where the participants had to find an "L" target among "+ " distractors, the size of the stimuli was enlarged from 2.8 to 24 deg of visual angle but the number of stimuli and the density of the display stayed constant. Julesz found that the performance of the participants was the same whether the display size was 24 deg or 2.8 deg of visual angle. These results suggest that the size of the spotlight of attention can be adjusted to the size of the stimulus being processed. However, enlarging the size of the spotlight of attention to fit more stimuli within its beam decreases the resolution of the spotlight. As a consequence, the time required to locate the target within a group of distractors increases if the target is made of a conjunction of features (Treisman & Gelade, 1980; Treisman & Sato, 1990). This processing impairment is dependent on the complexity of the search, the number of conjunctions of features involved in an item and the similarity between the target and the distractors (Duncan & Humphreys, 1989; Treisman & Sato, 1990). Also, "the more narrowly focused, the more precise the location will be for features within the attentional window" (Treisman, 1998, p. 38).

Focused attention is not divisible.

A visual search task combined with a reading task suggests that the spotlight of attention is either not divisible or if divisible, there is a net reduction in performance. For instance, Treisman, Kahneman and Burkell (1983) found that when attention was divided within two spatial areas, performance was reduced. In this divided attention study where visual search was involved, the participants had to read a word while locating a gap within a rectangle simultaneously and as fast as possible. The participants performed better when the gap and the word were in the same spatial location than when they appeared in different spatial locations. This experiment suggests that either: 1) dividing the spotlight of attention between two spatial areas reduces the speed of the processing or, 2) that the spotlight of attention cannot be divided and the two tasks are processed serially.

Posner et al. (1980) looked at whether the spotlight of attention could be divided to select more than one area of the visual field simultaneously. In their experiment, the participants had to react to the onset of a light emitting diode, which was positioned at different areas in the visual field. On each trial, the participants were given information about both the most frequent position and the second most frequent position. Posner et al. measured the RT of the participants to detect the light emitting diode. They found that the RT for detecting the light at the second most likely position increased as the second most likely position got farther away from the most likely position. Furthermore, Posner et al. found that the time needed to detect the target at the second most likely position became most similar to the time for detecting the target at the least likely position. This finding suggests that the participants directed their attention to the area of the display where the target was the most likely to appear. When the second most likely position fell outside the beam of focused attention relevant to the most likely position, the time to detect the target at the second most likely position increased because the participant could not focus their attention to both areas of the display simultaneously. This finding supports the hypothesis that the attentional beam cannot be divided.

The visual search paradigm alone may be insufficient to answer the question on the divisibility of the spotlight of attention. It is unclear whether the spotlight of attention is indivisible (Eriksen & Hoffman, 1972) or is divisible with a cost in performance (Treisman et al., 1983) based on the results of visual search paradigms.

The duration and speed of the spotlight of attention.

Many researchers have investigated the duration and speed of the spotlight of attention (Wolfe, 1998; Treisman, Sykes, & Gelade, 1977; Treisman & Gelade, 1980). Wolfe (1998) estimated that the spotlight of attention allocates 20 to 30 msec per item in a display. Treisman, Sykes and Gelade (1977) conducted a visual search experiment where the participants searched for a pink O target among green O and pink N distractors and found a similar range of time as Wolfe (1998) or slightly longer (Treisman & Gelade, 1980). The time allocated to each item in a display seems to depend on the characteristics of the stimuli. For instance, a stimulus with many conjunctions, such as a face, will require a longer processing time than will simpler stimuli. Furthermore, the time allocated to each item of a display will depend on the similarity between the distractors and the target and the similarity between the different distractor types (Duncan & Humphreys, 1989). Eriksen and Hoffman (1972) stated that increasing the number of items in the beam of the spotlight of attention reduces the speed with which the information is processed.

According to McElree and Carrasco (1999), the visual search paradigm where the reaction time to detect a target is used to investigate the processing speed of the spotlight of attention is not an adequate procedure. To isolate the processing time of the spotlight of attention, the traditional reaction time measurement method should be replaced by a response signal versus speed accuracy trade off procedure which provides a combined assessment of the accuracy, and the speed of search by deriving time course functions that measure the growth of accuracy over processing time.

Mechanism of motion.

An interesting question is whether the spotlight of attention ignores or processes the encountered information when moving from one location to another. Shulman, Remington and McLean (1979) conducted an experiment that supports the idea that the information that the spotlight of attention encounters on its passage from one location to another is processed. In their experiment, the participants pressed a key whenever one of four horizontally aligned light emitting diodes was turned on. The experimenters started each trial with a cue indicating where a probe was most likely to appear. They assumed that, once the cue appeared, attention would move from the fixation point to the cued location. Using a variety of delays between cue and probe, they tried to catch attention as it moved by occasionally probing at a location between the fixation and the cued location. The cued location was called the "far-expected" location, because it was far from fixation; the "in-between" location was called the "near-expected" location, even though the probe was never expected at that location. They also occasionally probed two locations in the opposite hemifield from the one containing the cue: one at the location in that hemifield corresponding to the cued location (far unexpected) and the other corresponding to the in-between location (near unexpected).

The most striking pattern in the data is a general alerting effect. As SOA increased, RTs for all four probed locations dropped and then rose again after an SOA of about 400 msec. On the expected side, the facilitation for the near location jumped up sooner than for the far location, leading Shulman et al. (1979) to conclude that an attentional spotlight was passing over the near location on the way to the far location.

For many years, this study was the only one to demonstrate attentional facilitation traveling through intermediate points, and its conclusions have been questioned (Eriksen & Murphy, 1987; Yantis, 1988). As Yantis points out, the expected pattern of RTs varies depending on whether the hypothesized spotlight is focused narrowly or is spread over a large area and whether it must be centered on the probe before a response can be made. The results from Shulman et al. (1979), taken as a whole, do not suggest a moving spotlight, but it is not clear what they do suggest. According to Cave and Bichot (1999), it is almost as if two different types of mechanisms were at work: one in the cued hemifield, and the other in the uncued hemifield. The side receiving a cue receives facilitation that starts at fixation and gradually spreads to the periphery. On the side without the cue, a strong inhibition gradually covers the periphery, but only a mild inhibition affects the center.

Murphy and Eriksen (1987) addressed the question of a moving spotlight with methods similar to those used in earlier experiments by Eriksen and his colleagues. Their subjects had to decide which of two letters appeared at a cued location, and the SOA between cue and letter varied from 0 to 175 msec. Rather than occasionally probing at uncued locations, Murphy and Eriksen added an extra distractor letter at one of the unprobed locations in every trial. Murphy and

Eriksen reasoned that the interference from this distractor should increase if the spotlight passed over it on its way to the target. They found no evidence for increased interference, but they examined only the data from the 175-msec SOA. By that time, a moving spotlight might have passed the intermediate locations and arrived at the cued location.

Although there is still disagreement about whether intermediate locations are activated as attention shifts from one location to another, evidence to date appears to suggest that attentional resources are allocated to the new location as they are simultaneously deallocated at the old location, without passing over regions in between.

The learning and memory of the spotlight of attention.

Laberge (1973) suggested that the recognition of highly familiar objects can become automatic. Also, it has been suggested that top-down processing can be used to combine individual features together into an object (Treisman & Gelade, 1980). This processing was proposed to occur due to an expectation based on previous experience (Treisman & Gelade, 1980), suggesting that a form of learning has occurred.

Horowitz and Wolfe (1998) conducted a visual search experiment to investigate the existence of a short-term memory component in visual search. According to Horowitz and Wolfe (1998), some visual search theories have assumed that "search relies on the accumulation of information about the identity of objects over time" (p. 575), which would imply indirectly that the spotlight of attention possesses a memory. However, Horowitz and Wolfe argue, that the spotlight of attention has no memory. The spotlight of attention does not record which item has been visited and which one has not. In Horowitz and Wolfe's visual search experiment, the participants searched for a T element among L distractors. The letters in the display were randomly relocated every 111 msec which made it impossible for the participants to keep track of the progress of the search. They found that the reshifting did not impair the visual search performance. Participants' reaction time to decide if the target was present or absent, was the same whether the letters were reshifted every 111 msec or whether the letters remained stationary.

Even though there seems to be no short term memory for the location of items in a display, it has been shown that participants get better on the visual search task with practice (Sireteanu & Rettenback, 1995; Leonards, Rettenback, & Sireteanu, 1998). Experienced participants produce shallower reaction time by set size curves than inexperienced participants. Also, the reaction time by set size curves for each participant become less steep as the participant gains more experience. This implies that some long-term memory for the task performance itself occurs. Is this improvement in performance the result of a shift from a serial type of search mechanism to a parallel type of search mechanism? Since the set size by reaction time curves for individual features as well as for feature conjunctions get shallower by the same ratio, the practice effect, is not the result of the participant adopting a different search strategy, such as switching from serial to parallel search nor a switch from the utilization of the spotlight to its non-utilization (Leonards et al., 1998).

The spotlight of attention is independent of retinal mechanisms.

Much evidence indicates that the spotlight of attention is independent of retinal mechanisms. Visual searches are usually performed while the participants are fixating in the middle of the display (Treisman & Gelade, 1980; Treisman, Sykes & Gelade, 1977; Treisman & Sato, 1990; Wolfe, Cave & Franzel, 1989). Thus, eye movements are not involved. Since the participant can detect the location and the presence of a target in the display without having to foveate the target, it is believed that the mechanism of the spotlight of attention is independent of the retinal mechanism (Wolfe, 1998). Also, Julesz (1984) estimated that the spotlight of attention could shift from one area to another 4 times faster than the time required for a saccade to occur. This estimate implies that retinal and attentional mechanisms are not the same.

Does attention select objects or locations?

It has been difficult to disentangle the contribution of location-based and object-based components of visual attention. Location-based attention involves the selection of stimuli from spatial representations. A common metaphor for location-based attention is the "spotlight" metaphor, in which attention is moved through the visual field and selects stimuli on the basis of spatial location (Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1973; Hoffman & Nelson, 1981; Posner, 1980; Posner et al., 1980). Posner and colleagues (Posner & Cohen, 1984; Posner et al., 1980) provided a well-known experimental demonstration of location-based attention using a cueing paradigm. In this paradigm, subjects see three side-by-side boxes and are instructed to fixate on the central box. Cues appear as a brightening of one of the peripheral boxes. Following a cue, a target appears in one of the peripheral boxes, and subjects make a simple reaction time response to the target. Subjects respond faster to targets when the cue is on the same side of fixation (valid cue) compared with the other side of fixation (invalid cue).

In a discrimination task with an endogenous predictive cue, Theeuwes (1989), found the classic location cueing effect, but no shape effect. Two experiments were conducted which tested the effect of two different types of cues on the allocation of attention in the visual field. Subjects responded to a target appearing either, 6.5 degrees to the right or to the left of fixation in a field filled with small randomly positioned line segments. The target form was either a circle or diamond in which a horizontal or vertical line segment was positioned. Subjects made a speeded discrimination response on the basis of the orientation of this line segment. In the first experiment, there was always one target at each trial. In the second experiment, both circle and diamond were presented left or right of fixation simultaneously and the line segment only appeared in one of the forms. In different conditions, the most likely target location (left or right) and form (circle or diamond) were cued. Control conditions served as a baseline for determining costs and benefits. Reaction time measures showed that the validity of the location cue resulted in both costs and benefits, whereas the validity of the form cue had no such effects. The results cannot be reconciled with the claim of zoom lens theories that spatial attention can switch between different modes of operations. They are also at odds with theories that claim that attention has no spatial locus. The results are consistent with a simple spotlight theory in which spatial attention involves selecting a particular restricted area of the visual field for which the perceptual efficiency is enhanced.

In a detection task in which the effect of non-predictive location and shape cueing could be examined separately, Schendel, Robertson, & Treisman (2001) found typical location cueing effects. The shape cueing effect was significant just at long SOA, provided the location cue was valid. Finally, the spatial nature of attention has not only been conceptualized as a spotlight. Location-based attentional selection has also been characterized in terms of a "gradient" or activity distribution that is spread across some internal representation of space (Downing, 1988; Laberge & Brown, 1989) or a "zoom lens" that can focus on a particular spatial location or be distributed over a wider area of space (Eriksen & St. James, 1986; Eriksen & Yeh, 1985). However, these terms are not mutually exclusive. The spotlight of attention can also be characterized as having ill-defined edges, rather than being sharply defined.

Object-based attention selects from internal object representations that represent stimuli irrespective of their spatial location. The clearest demonstration of object-based attention was that of Duncan (1984). Duncan presented subjects with targets consisting of two overlapping objects, a box and a line. Each of these objects varied on two dimensions: The box could be either short or tall and have a gap either on the left or right, and the line could be either dotted or dashed and be tilted either clockwise or counterclockwise. Subjects were given brief presentations of these targets and asked to report either one or two dimensions. When two dimensions were reported, they could either be dimensions of one object, such as reporting the line's texture and tilt, or they could be dimensions of the two different objects, such as reporting the line's texture and the box's height.

Duncan (1984) found that subjects were no worse at reporting two dimensions than one from a single object, but they were more accurate at reporting two dimensions when they were dimensions of the same object compared with when the dimensions were on different objects. Duncan argued that these results could not be accounted for by a spatial theory (i.e., spotlight) of attention because the dimensions of each object were equidistant. A spotlight account could also be ruled out because the displays were less than 1° of visual angle.

Although these results were presented as evidence of object-based attention, attempts have been made to explain them in terms of location-based selection. For instance, Vecera and Farah (1994) considered a similar explanation for Duncan's (1984) results. They raised the possibility that spatial attention may conform to an object's shape by selecting precisely the spatial locations occupied by the objects. They described this alternative mode as selection from a "grouped-array" representation. Thus, the poorer performance in Duncan's experiment when subjects made judgements about both objects may be attributable to a cost in activating a different group of locations rather than selecting a different object representation. Vecera and Farah set out to test this hypothesis by replicating Duncan's results and comparing them to a condition in which the two objects were on opposite sides of fixation. They hypothesized that if selection in Duncan's experiment was indeed location-based, there should be an increase in the effect size when the objects are placed apart from each other, due to the larger distance attention has to travel in this condition. However, they found no interaction between the two conditions and concluded that Duncan's results were indeed due to visual selection of spatially invariant object representations, as postulated by Duncan.

Finally, Vecera and Farah (1994) demonstrated that when Duncan's objects were used in a cued detection task the results were consistent with location-based selection. They concluded that their results suggest that there may not be a single attention mechanism, consistent with Duncan's original claim that object-based and location-based attentional selection are not mutually exclusive. Rather, attentional limitations may depend on the type of stimulus representation used in performing a given task.

In summary, the results of a large number of attentional studies, including spatial cueing studies, neurophysiological studies (Luck, Chelazzi, Hillyard & Desimone, 1997), and studies that did not emphasize or encourage selection by location, show that location plays a crucial role in visual attention. However, the data obtained to date do not rule out the possibility that both location-based and object-based mechanisms exist.

What is the shape of the spotlight and how much flexibility is there in adjusting this Shape?

Some models suggest that there may be flexibility in the shape of the selected area (Logan, 1996), but this possibility has not been explored in much detail. In a study by Podgorny and Shepard (1983), subjects first viewed a 3 x 3 grid with four or five of the cells shaded. Next, a dot appeared, and the subject judged whether or not the dot appeared in the shaded area. They found that subjects responded more quickly when the shaded area was a simple shape, such as a square or rectangle.

Eriksen and St. James (1986) concluded that the spotlight is probably circular or oval-shaped. Their subjects identified one target letter that appeared along with seven distractor letters in a circle. The target only appeared in a position that had been previously cued. In one of their experiments, they included one condition in which half of the positions (all contiguous) were cued and another condition in which all eight were cued. Because performance was slightly better when half of the positions could be ruled out, they concluded that the shape of the spotlight must make it difficult to focus attention on only half of the circle.

In contrast to the Eriksen and St James (1986) study, an experiment by Juola, Bouwhuis, Cooper, and Warner (1991) raises the possibility that attention is much more flexible than a circular or oval-shaped spotlight. They found that subjects responded more quickly to the target when it appeared on the cued ring (i.e. valid trials) than when it did on an uncued ring (i.e. invalid trials). Thus, Juola et al. argued that attention can be allocated in a specific size and shape (i.e. a ring in this experiment).

There are still many more questions than answers concerning visual attention and the relevance of the spotlight metaphor. Cave and Bichot (1999) have argued that the spotlight does not have the well-defined edge that would be expected from such a simple attention window. However, they believe that this explanation might be saved by assuming that the spotlight is positioned imprecisely on each trial. Another alternative is to assume that the output of the spotlight is fed into a processing buffer that analyzes its center more thoroughly and precisely than its edges. According to Cave and Bichot (1999), if there is not an attention window with a sharp edge separating selected from unselected information, it implies that visual recognition is robust and does not require the complete elimination of interference form distractors.

Another conception of the spotlight's role in visual processing is that the spotlight works by allocating processing resources over the selected areas of the visual field. According to Kahneman (1973), if attention is allocated to a large area, then fewer resources can be dedicated to any single location, and the entire area will be processed somewhat less efficiently than if a smaller area had been selected. Therefore, spreading attention over a large area entails a cost, even if no distractors appear within that area (Egeth, 1977).

It has also been speculated that a likely reason for the spotlight's existence, and perhaps the only reason, is to block information from distractor objects that would otherwise overload the later stages of visual processing. If this were the spotlight's only mission, then we might expect to see its effects only when distractors are present or at least expected by the subject. However, some of the earliest demonstrations of the spotlight occurred in experiments with a simple target and almost no distractors. Also, if the spotlight is necessary for filtering and not resource allocation, it becomes difficult to explain the cost associated with large regions found by Egeth (1977).

Present study

In the present study, the idea that cueing for the position of the group of items relevant to the visual search task was examined (target and distractors) just prior to the presentation of the search display may affect the detection of the target inside the group. Cueing is seen here in a similar way as it was used by Posner et al., (1980), except that here it is not the target location that is being cued, but some aspect of the area of the relevant items, among which the target can be found. In contrast to Posner et al., neither the particular location nor any property of the target item per se is cued unambiguously. Rather, a certain property of the area, which contains the items relevant for the target search, is cued. Even after using the cued information, the target item still has to be searched for among the distractor items. From preliminary data, it has been shown that cueing the area that contains the target speeds up response times to the detection of the target. This facilitation occurs with both: exogenous and endogenous cues (Panagopoulos, von Grünau, & Galera, 2001; 2002). In the past, by using a cueing paradigm similar to Posner's, the shape, location, and size of the spotlight of attention was manipulated (von Grünau, Panagopoulos, Galera, & Savina, 2002; Galera, & von Grünau, 2003). In the present study, the flexibility of the shape of the spotlight continues to be assessed.

The purpose of the present study is to combine the previous findings that an irrelevant background increased search RT (Galera et al., 2000), and that location cueing can increase the efficiency of target detection and can decrease RT (Posner et al., 1980). The particular problem examined here concerns the question whether cueing the location of the relevant stimuli will reduce or even eliminate the detrimental effect that an irrelevant background has for the efficiency of visual search.

In the first two experiments, cueing is used in a simple search task, and the difference between valid and invalid cueing will give evidence for the shape and location selectivity of the spotlight. A third experiment investigates further the question of the shape of the spotlight by presenting a new object suddenly in the visual field, either inside or outside the attended area. According to Turatto, Benso, Facoetti, Galfano, Mascetti, and Umiltà (2000), an abrupt visual onset captures attention in a stimulus-driven fashion. When a new object appears in the visual field, attention will be directed to this new object, and then an endogenous effort has to be exerted to maintain attention in the focused area.

In an experiment conducted by Facoetti and Molteni (2000), it was found that given the same distance between target and flankers, the effect of flankers was greater when they fell inside the attended spatial area as opposed to the condition when flankers fell outside the attended area. The authors explained this finding by stating that there might be reduced processing resources outside the attended area. They also found that with a large enough Stimulus Onset Asynchrony (SOA = 500 ms) between the target and flankers, the flanker effect disappeared. The suppression of the flanker effect in the condition with sufficient time for narrowing the attentional focus seems to suggest that selection of relevant information may occur through a mechanism that inhibits information coming from distractor locations. Using a flanker or intruder, which varies in compatibility with the target, can provide more evidence about the shape of the attentional area. In a given search task, the occurrence of the intruder is expected to significantly increase the RT to target detection. From previous research (Turatto et al., 2000), it is expected that there will be an intruder type effect (compatible / incompatible). If the intruder is incompatible with the target, search time will increase, whereas, if the intruder and target are compatible, it will have little or no effect on RTs. Most importantly, in accordance with Facoetti and Molteni's (2000) data, it is expected that the effect of the intruder would be greater when it falls inside the cued (attended) area, as compared to when it falls outside.

Visual attention enhances our perceptual sensitivity, and recent research indicates that its effects can be observed at the earliest stages of cortical processing (Posner & Gilbert, 1999; Rees, Backus, & Heeger, 2000). Researchers have speculated that visual attention accelerates the processing of attended stimuli as early as the primary and secondary cortices (von Grünau, Racette, & Kwas, 1996; von Grünau, Saikali, & Faubert, 1995; Hikosaka, Miyauchi, & Shimojo, 1993; Schmidt & Klein, 1997). More recently, the line motion illusion has been taken as support of the view that visual attention increases the speed of processing at the earliest stages of visual processing. When a static line is presented near a brief cue, participants report motion within the line from the cued end towards the uncued end. Recent reports suggest that endogenous and reflexive attention can induce the line motion illusion (Schmidt, 2000; Bavelier, Schneider, & Monacelli, 2002). The fourth experiment uses the line motion illusion to provide a different and direct measurement of attention in this situation. Since the perception of motion in the line motion illusion is away from the attended area, it is hypothesized that if the observer is actually attending exclusively to the cued area, he/she will report illusory motion away from only that area. This will provide new direct evidence that it is possible to change the shape of the spotlight of attention in a rather flexible manner.

Researchers have identified two ways in which attentional selection can be accomplished. Under exogenous (or stimulus-driven) orienting, attention is attracted to a location in the visual field as a result of some external stimulation arising from that location, such as a flash of light (Posner, 1980) or the appearance of a new object (Oonk & Abrams, 1998; Yantis & Hillstrom, 1994). With endogenous (or goal-directed) orienting, an observer can simply choose to attend to one location or another, perhaps as a result of some probabilistic information available about the likely location of an upcoming stimulus (Posner, 1980). Under both exogenous and endogenous orienting, observers enjoy benefits at the attended location, such as reduced latency and increased accuracy in detecting and identifying the target there. All of the experiments in this study involve endogenous cueing, not exogenous. The cue is always symbolic (centrally positioned) and requires top-down processing.

This study will attempt to address two main questions that form the basis of the present experiments. 1) Does this cueing change the shape (and location) of the spotlight, giving it the most appropriate and advantageous form? 2) Does this improved focus of the spotlight lead to a weakening of the detrimental background effect? If cueing can sharpen the attentional focus to a particular location and a particular shape, then the irrelevant background elements should be able to interfere less, thus the background effect would be reduced. Therefore, in some of the present experiments, cueing was done with and without the background elements.

Experiment 1

Location Cueing

Purpose

Posner (1980) provided evidence that cueing the location where the target will appear reduces the time required to detect the target. Cueing affects the position of the spotlight. Posner cued the target itself, but in this study, the area that contains the target is cued and the shape is cued covertly. In this experiment, cueing is expected to change the location of the spotlight, making it an elongated shape (or frame). The investigation of the shape of the spotlight remains the main focus, but location is used here in order to link this experiment to Posner's work.

Instead of cueing for a particular shape (or configuration), the location of the group of relevant items was manipulated. Cues could be valid, invalid, or non-informative. It was expected that the valid cue would reduce RT as compared to the non-informative cue, especially in the presence of the background, while the invalid cue should increase RT. In general, the presence of the background is expected to increase RT.

Method

Participants

The participants were eleven subjects from Concordia University, all with normal (20/20) or corrected-to-normal vision. Six female and five male subjects participated, with an age range between 23 and 58 years. Five subjects participated in return for course credit and the rest of the participants are members of the Visual Perception Lab.

Apparatus and Stimuli

The stimuli were presented on an Apple color monitor at a resolution of 1024 x 768 pixels with a refresh rate of 99 Hz, and controlled by a Power Macintosh G4. The experiment was programmed using the Vpixx software. The distance from the screen to the subject's eye was set at 57 cm. A chin-forehead stabilizer was used in order to prevent the participant's head from moving. The testing took place in a dark and quiet room.

All of the test stimuli consisted of black letters "T" (4.8 cd/m^2) presented on a white background (100cd/m^2). All Ts had a size of 1° x 1°, with a line thickness of .08° of visual angle. The length of the top (horizontal) bar was .8° of visual angle and the length of the vertical bar was 1° of visual angle. The fixation point was a red dot positioned in the middle of the screen and occupied .2° of visual angle. Relevant stimuli consisted of the target and three distractors arranged in a vertical configuration inside a frame, having an overall length of 8° of visual angle, and a width of 2° degrees. There were always two frames present on the screen (one to the right of fixation and the other to the left). The positioning of the stimuli in this configuration was purposefully slightly misaligned. The target was a letter T rotated 90° to the left or to the right. The distractors were upright or inverted Ts. The relevant stimulus configuration was positioned at a distance of 4° of visual angle from the fixation point (either to the left or to the right). The irrelevant stimuli (background), when present, occupied an 11 x 11 grid (15.5° x 15.5° of visual angle). The background stimuli consisted of inverted Ts oriented 45° to the left. The position of each stimulus within the grid was slightly misaligned (see Figure1). All the relevant stimuli, target and distractors, were present on all trials. The target was positioned randomly within each configuration, made up of four stimuli (target position 1, 2, 3, and 4). On half the trials the target was pointing to the left and on the other half to the right.

Valid and invalid location cues consisted of an arrow pointing to the left, to the right, or a non-informative arrow (4.8 cd/m^2) horizontally aligned, with a length of 2.5° of visual angle and a thickness of .2° of visual angle (see Figure 2). The cue was presented at the location of the fixation point, replacing it: A cue was valid when it was followed by the test configuration in the indicated location, and invalid when followed by the test on the opposite side of the fixation point. The non-informative cue consisted of the double-headed arrow.

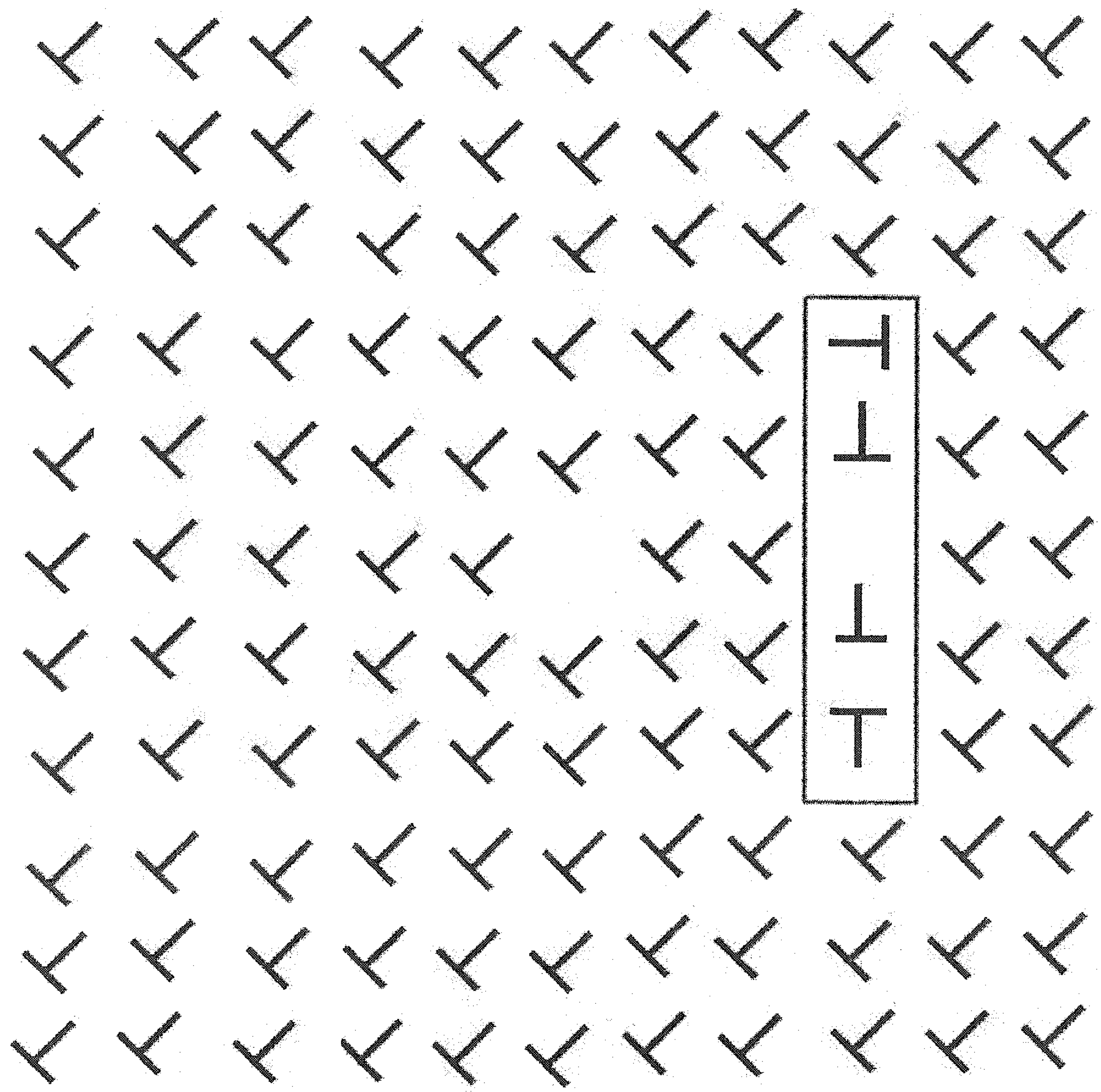
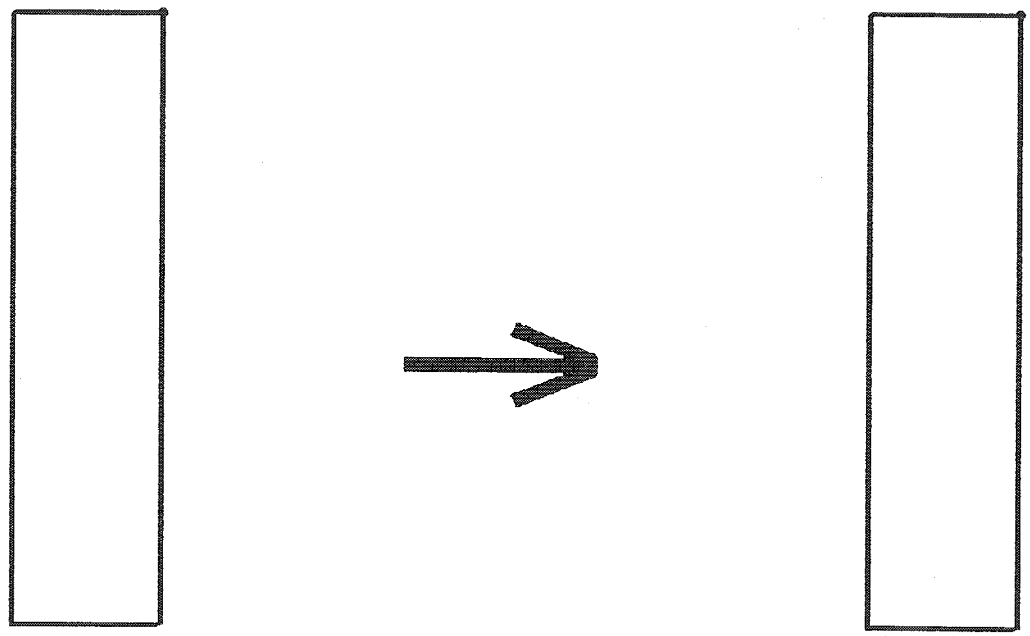
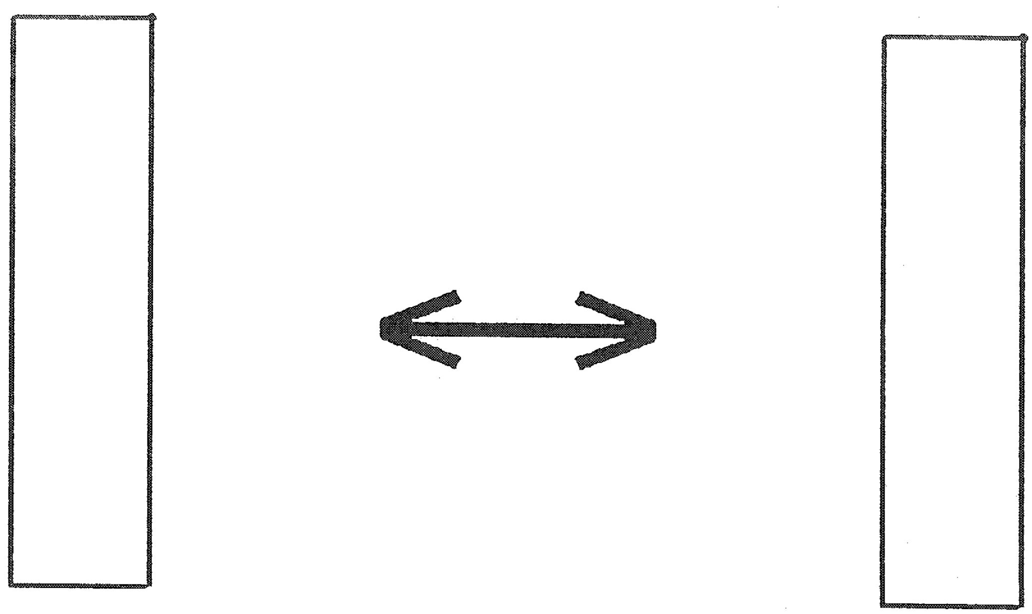


Figure 1. Representative stimuli for Experiment 1. The relevant stimuli are on the right side of fixation, the irrelevant background stimuli are present and the target is tilted to the right in position 1.

a) Informative cue: Arrow pointing to the right



b) Non-Informative cue



<u>Figure 2</u>. Endogenous cues used in expeiment 1

Design and Procedure

This experiment had a 2 x 3 factorial within-subject design. The two independent variables were presence of the background and the location cue. The first factor had two levels: background-present (level 1) and background-absent (level 2). The second factor had three levels: valid (level 1), invalid (level 2), and non-informative (level 3). The dependent variable (response time, RT) was the time required to detect the target orientation (left or right). The response time was measured in milliseconds, and only correct trials were used. The observer was asked to respond as quickly and as accurately as possible. Reaction times and error rates were recorded by the computer.

The background was defined by the irrelevant textural stimuli presented on the screen. A typical trial consisted of the fixation point, which was presented for 500 ms, followed by the cue for 500 ms. After a delay of 750 ms, the test stimuli were presented and remained on the screen until the subject responded.

All of the participants were asked to participate in 2 sessions. One session consisted of the background-present condition and the other of the background-absent condition. These were presented in a counterbalanced order between the subjects. Each session of trials consisted of 320 trials and lasted 20 minutes. The composition of the 320 trials was comprised as follows: the target could be in 1 of 4 positions within each frame (4), the frame could be to the left or right of fixation (2), the target could be pointing to the left or right (2), the cue could be valid (50%), invalid (25%), or non-informative (25%). Each of these 64 conditions was repeated 5 times. This resulted in 4 x 2 x 2 x 4 x 5 = 320 trials. Errors were infrequent (~5%) and were examined for speed-accuracy trade off, but none was found.

Results

Analysis of variance was performed on RTs with Background (present and absent) and Cue Type (valid, invalid, and non-informative) as within-subject factors. The Background main effect was significant: $F(1,11) = 28.536$, $p = .000$, with an effect size of .74. Figure 3 depicts the Background x Cue interaction. The response time is plotted on the y axis and the three types of cue are plotted on the x axis. Figure 3 shows that for all of the three cue types, the background-present condition led to longer RTs than the background-absent condition. The cue main effect was also significant: $F(2,20) = 6.912$, $p = .005$, with an effect size of .41. The Tukey (HSD) post-hoc test revealed that the valid cue was significantly different from the invalid cue ($p < .05$). Figure 4 depicts the results of the cue effect averaged over the two background conditions. The average response time is presented as a function of the cue condition. Figure 4 shows that the valid cue led to the shortest RTs, the invalid cue led to the longest RTs, and the non-informative cue fell in between.

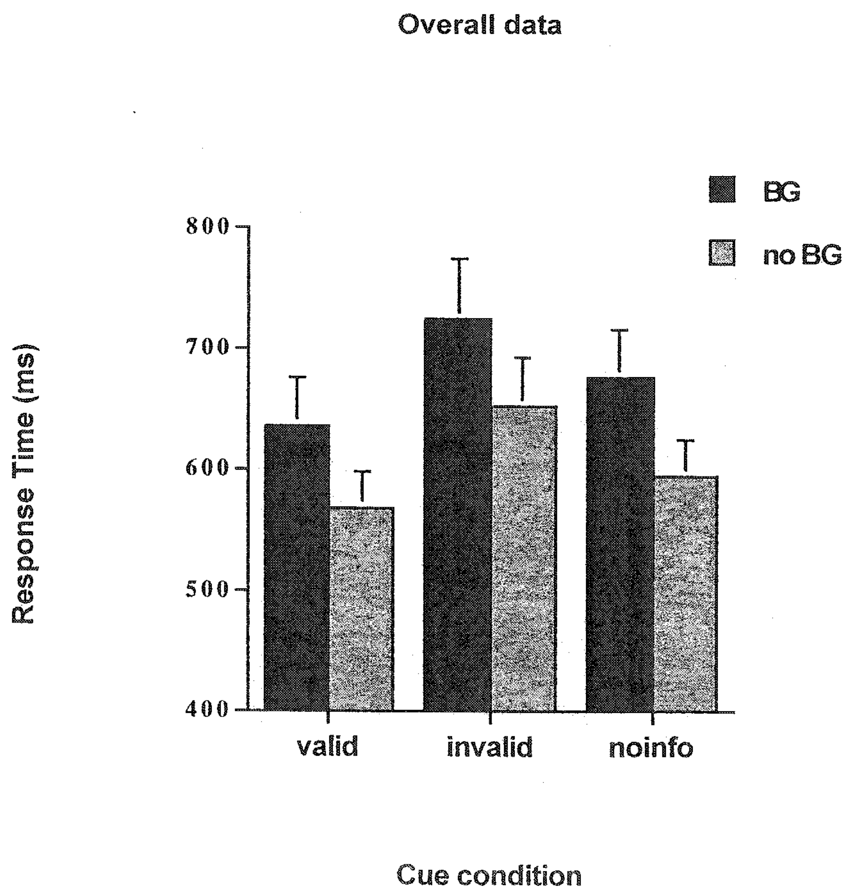


Figure 3. Results for Experiment 1. Overall background effect with standard errors.

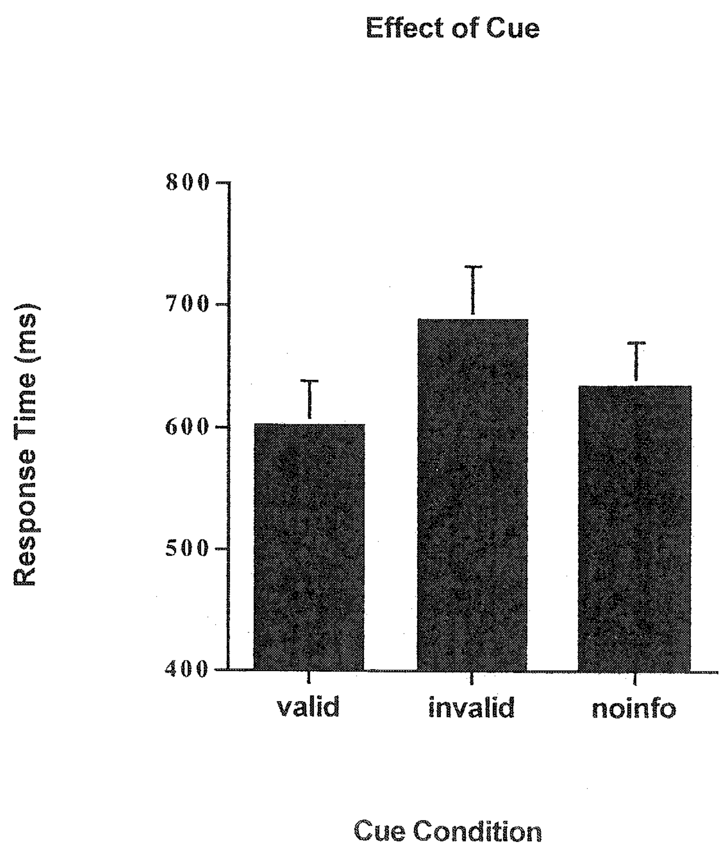


Figure 4. Results for Experiment 1. Overall cue effect with standard errors, averaged over both background conditions.

Discussion

This experiment concerned the location of the spotlight of attention. This experiment demonstrated that the spotlight of attention can change location. The results obtained in this experiment, showed that there was a significant Background effect as well as a significant Cue effect. In general, valid cues decreased RT and the presence of the background increased RTs. The background present condition resulted in an increase in RT, as compared to the background absent condition. This is what was previously found by Galera et al., (2000).

The cues in this experiment were also used in order to help reduce the detrimental effect that irrelevant background items have on search performance. Without cueing, there should be a large background effect, but with non-informative cueing, there is no background effect. The results demonstrated that cueing did not eliminate the background effect. The background effect was the same for all cue conditions.

Cueing was able to move the spotlight to either side of fixation. The cue had a particular rectangular shape. An elongated shape was presented, however it is impossible to know if the shape of the spotlight was affected. The next three experiments will investigate the shape of the spotlight.

Experiment 2

Shape Cueing

Purpose

The purpose of this experiment was to measure the effects of valid, invalid, and non-informative cues on RT with and without irrelevant background items. It was expected that the valid cue would reduce RT as compared to the non-informative cue, especially in the presence of the background, while the invalid cue should increase RT. In general, the presence of the background will increase RT. Using cues and configurations of relevant items in distinctive, easily distinguishable shapes, the effects of valid, non-informative and invalid endogenous cueing were examined.

This experiment set out to explore two goals. The first goal is related to the spotlight. By using cues that have easily discriminable global shapes (vertical and horizontal rectangles), the present experiment will investigate whether this kind of cueing can result in an attentional area that is elongated according to the cue shape. If so, the valid and invalid cueing should give different results for the search task. If not (if the attentional spotlight remains mainly circular in shape), valid and invalid cueing should have no differential effects. This is because if the cue only concentrates attention in the center, the vertical and horizontal cue arrangements will have the same effect, and testing with either search item arrangement (vertical or horizontal) should give equivalent results. Thus valid and invalid cueing become equivalent.

The second goal is related to the background effect. If cueing does succeed in shaping the attentional spotlight then this properly focused attention should weaken the effect of the background, since for valid cueing all the background items would lie outside the attended area and should not be searched. For invalid cueing, some of the background items would be inside the attended area and might thus interfere with the search. The background effect therefore should be stronger for invalid trials.

Method

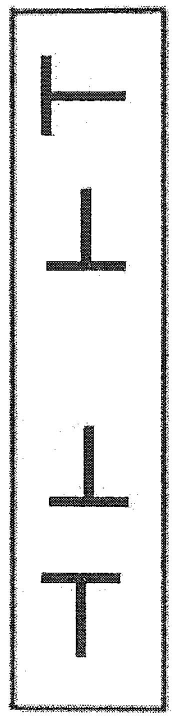
Participants

The participants were eleven subjects from Concordia University, all with normal (20/20) or corrected-to-normal vision. Six female and five male subjects participated, with an age range between 23 and 58 years. Five subjects participated in return for course credit and the rest of the participants were members of the Visual Perception Lab.

Apparatus and Stimuli

The apparatus and visual search stimuli were the same as in Experiment 1. The search stimuli were presented in two configurations within a frame (vertical or horizontal) in the center of the screen, occupying an area of 8° x 2° of visual angle (see Figure 5). The target was positioned randomly within each configuration, made up of four stimuli (target position 1, 2, 3, and 4). The target was presented on all trials. On half the trials it was pointing to the left and on the other half to the right. The background consisted of a matrix of tilted Ts, occupying an area of 13° x 13° of visual angle (see Figure 6). The cue items were letters V, H or O.

a) A vertical stimulus where the background is not present and the target is tilted to the left, in position 1.



b) A horizontal stimulus where the background is not present and the target is tilted to the right, in position 2.

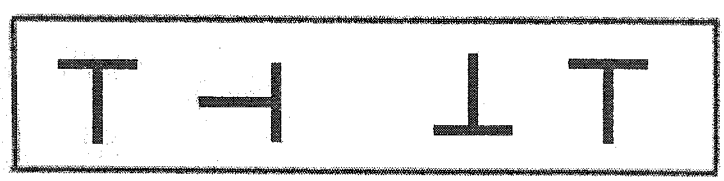


Figure 5. Representative stimuli for Experiment 2.

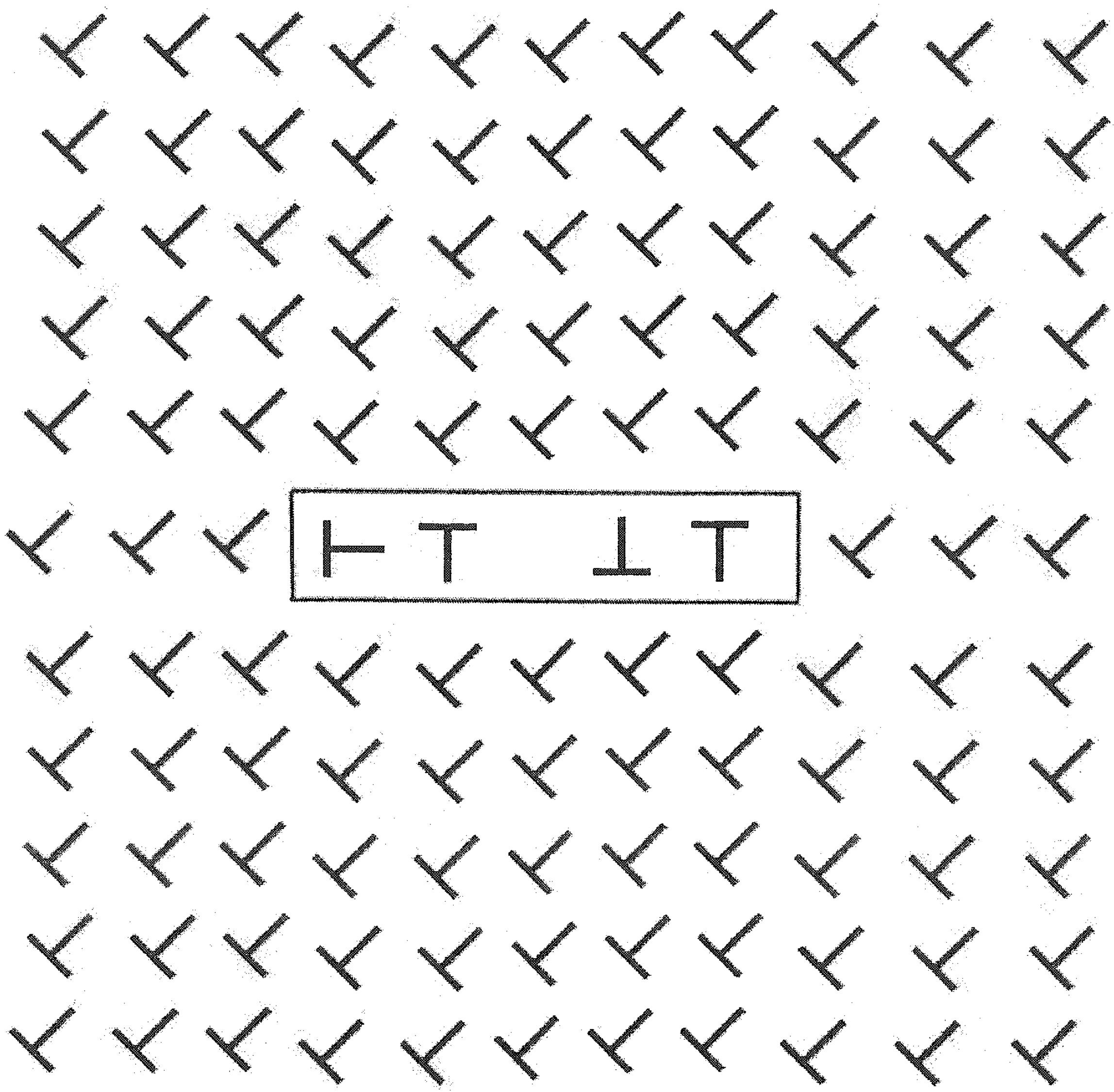
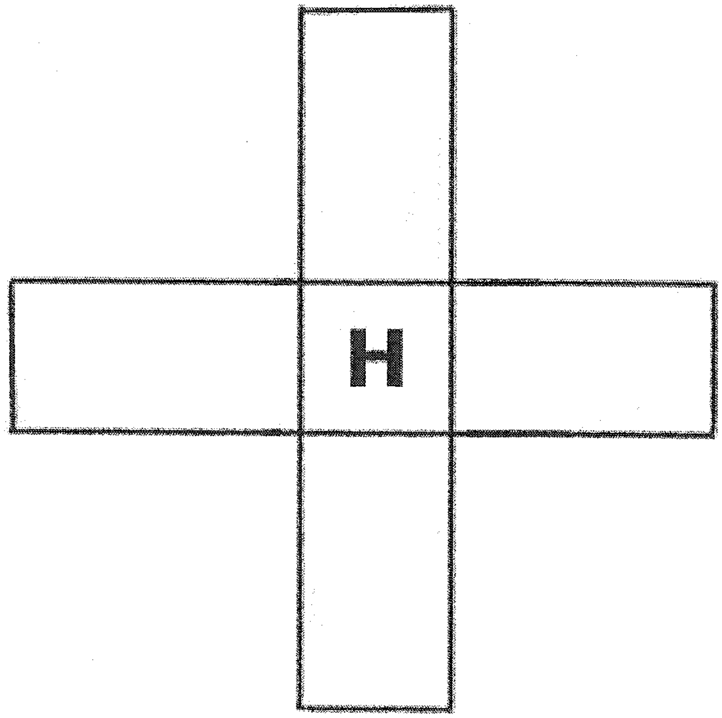


Figure 6. Representative stimuli for Experiment 2. A horizontal stimulus where the background is present and the target is tilted to the left, in position 1.

There were three types of cues: a valid, invalid and non-informative cue for shape (see Figure 7). For a valid cue, the letter V appeared in the center of two superimposed frames, V was followed by vertically arranged relevant items in a frame; or H in the same type of frame was followed by horizontally arranged relevant items. The non-informative cue was a letter O that appeared in the center of the two frames, followed by either vertically or horizontally arranged relevant items. When the cue was invalid, the letter V was followed by horizontally arranged relevant items; or H was followed by vertically arranged relevant items. On 50% of the trials, the cue was valid, on 25% it was invalid, and on another 25% it was non-informative.

a) The endogenous Horizontal cue



b) The endogenous Non-informative cue

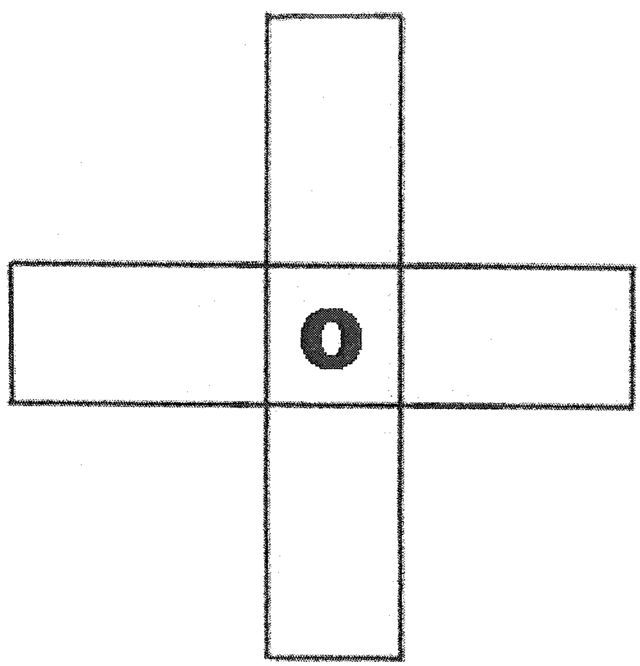


Figure 7. Endogenous cues used in Experiment 2.

Design and Procedure

There were two sessions (background present or not). Each session consisted of 320 trials and lasted about 20 minutes. The target position among the four possible positions, the two configurations, and the cue type were varied randomly. The two configurations (vertical and horizontal) were presented at random an equal number of times. At the beginning, of each session, the subjects were instructed to pay attention to the cue; to attend vertically when the letter V was presented or horizontally when the letter H was presented. The subjects were also told to ignore the background stimuli because it was not relevant to their task and only pay attention to the stimuli arranged in the vertical or horizontal configuration. The subjects were asked to respond as quickly and as accurately as possible (see Figure 8 for a schematic time course). RT and error rates were recorded by the computer automatically. The observer's head was positioned by a chin rest, at a distance of 57 cm from the screen. The subject initiated each trial by pressing the space bar. At the beginning of each trial, a red fixation dot appeared in the center of the screen. This fixation remained on the screen for 500 ms and was replaced by the stimuli of each trial.

The cue appeared and remained on the screen for 500 ms, and was replaced by the test stimuli after an ISI of 750 ms. The stimuli remained on the screen until the subject responded. In each trial, the subject had to search for the target while fixating, and make a decision concerning the target's orientation to the left or right, by pressing the left or right arrow keys of the keyboard.

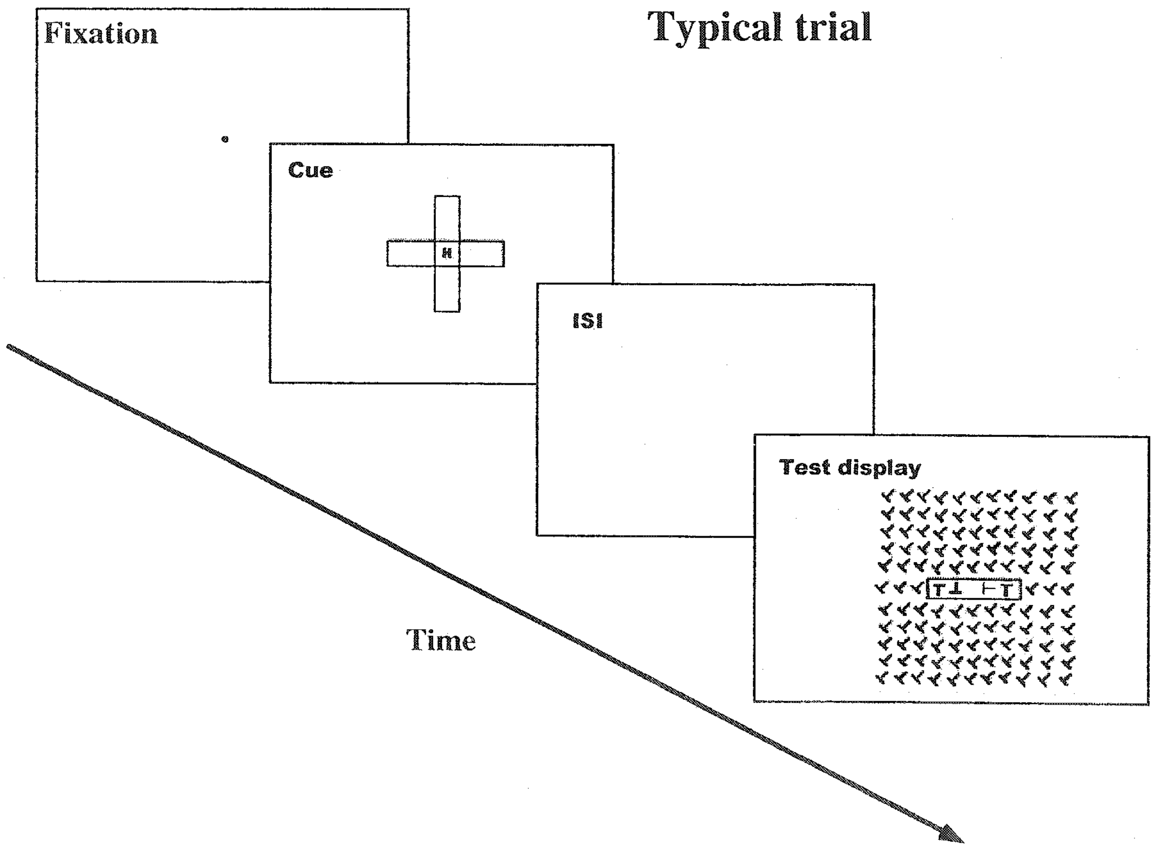


Figure 8. A representation of a typical trial for Experiment 2.

Results

Analysis of variance was performed on RTs with Background (present and absent) and Cue Type (valid, invalid, and non-informative) as within-subject factors. The Background main effect was not significant ($p = .708$). Although the presence of the background led to slightly longer RTs, this did not reach statistical significance in this experiment. The Cue type main effect was significant: $F(2,10) = 4.620$, $p = .022$, with an effect size of .32. The Tukey (HSD) post-hoc test revealed that the valid cue was significantly different from the invalid cue ($p < .05$). Figure 9 depicts the results of the cue effect averaged over the two background conditions. The average response time is presented as a function of the cue condition. Figure 9 shows that the valid cue led to the shortest RT (522 ms), the invalid cue led to the longest RT (599 ms), and the non-informative cue fell in between (539 ms). The interaction of Background x Cue type was also not significant ($p = .230$).

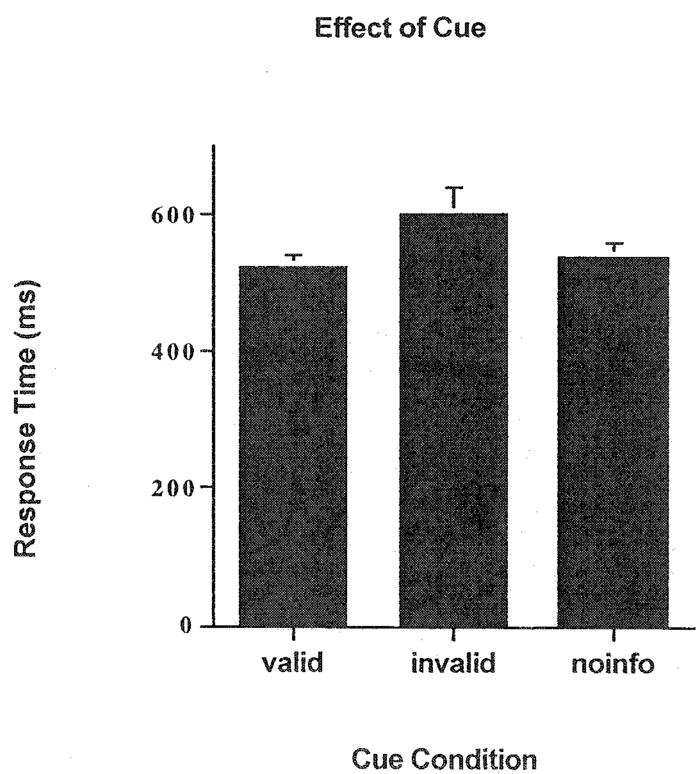


Figure 9. Results for Experiment 2. Overall cue effect with standard errors, averaged over the two background conditions.

Discussion

This experiment investigated whether the shape of the spotlight can be manipulated. Two goals were explored in this experiment. The first goal was related to the spotlight. Specifically, if valid and invalid cueing lead to different results for the search task, then it can be concluded that the attentional area can be elongated according to the global cue shape. However, if the valid and invalid cues should have no differential effects, this can lead to the conclusion that the attentional spotlight remained mainly circular in shape. The second goal was related to the background effect. It was hypothesized that if cueing does succeed in shaping the attentional spotlight then this properly focused attention should weaken the effect of the background, since for valid cueing all the background items would lie outside the attended area and should not be searched. For invalid cueing, some of the background items would be inside the attended area and might thus interfere with the search. The background effect therefore should be stronger for invalid trials.

The results obtained in Experiment 2 showed that there was a significant cueing effect; valid cues led to the shortest RTs while invalid cues resulted in longer RTs. Thus cueing here was able to manipulate the shape of the attended area, i. e., the shape of the spotlight was adjusted to fit the shape of the cue. This shape-dependent focusing of the attended area had the further effect of eliminating any background effect in the present study. Visual search with or without the irrelevant background elements resulted in the same response times for all cueing conditions. That is, the attentional focus seems to have been sufficiently restricted and sharp enough to not include any background elements in the search.

Cueing therefore can be specific not just with respect to the spatial location, but also with respect to the shape of the test configuration. In terms of the attentional spotlight, these results show that the spotlight not only has a changeable location in space, but it also has a changeable shape that can take on very different values.

Experiment 3

Intruder

Purpose

The purpose of this experiment was to explore the spatial properties of cued attention further. While the cued attention part was the same as in the previous experiment, the shape of the spotlight was investigated in more detail by suddenly presenting an extra stimulus (intruder). The intruder stimulus could be compatible (same as) or incompatible with respect to the target, and could be presented inside or outside the cued (attended) area. It was hypothesized that in a given search task, the occurrence of the intruder would significantly affect the RT to target detection. From previous research (Turatto et al. 2000), it is expected that there will be an intruder type effect (compatible / incompatible). If the intruder is incompatible with the target, search time will increase, whereas, if the intruder and target are compatible, it will have little or no effect on RTs. Moreover, the intruder should be most detrimental when it appears at the same time as the target (and distractors), and the intruder effect should disappear with longer intervals between the presentation of the test and the intruder. Most importantly, in accordance with Facoetti and Molteni's (2000) data it is expected that the effect of the intruder would be greater when it falls inside the cued (attended) area, as compared to when the intruder falls outside.

Method

Participants

The participants were nine subjects from Concordia University, all with normal (20/20) or corrected-to-normal vision. Six female and three male subjects with an age range between 23 and 58 years participated. Four subjects participated in return for course credit and the rest of the participants were members of the Visual Perception Lab.

Apparatus and Stimuli

The apparatus and set-up were the same as in the previous experiments. The stimuli for the visual search task were also the same as in the previous experiments, but there were only two types of cues: a valid and an invalid cue for shape. The cues were valid in 75% of the trials and invalid in 25% and consisted of the letters V or H. A cue was valid when it preceded a test with the indicated arrangement of target and distractors. For the invalid cue, the letter V was followed by horizontally arranged items, or H was followed by vertically arranged items.

The intruder consisted of a same size letter T oriented 90° to the right or left (just as the target) and was located 3 degrees from fixation (see Figure 10). The intruder could be compatible with the target (same orientation as the target) or incompatible with the target (opposite orientation from the target). The intruder was only present on half of the trials. When the test configuration was vertical, the intruder appeared either on the left or right of the configuration, randomly and equally often. When the test configuration was horizontal, the intruder could appear on the top or bottom of the configuration.

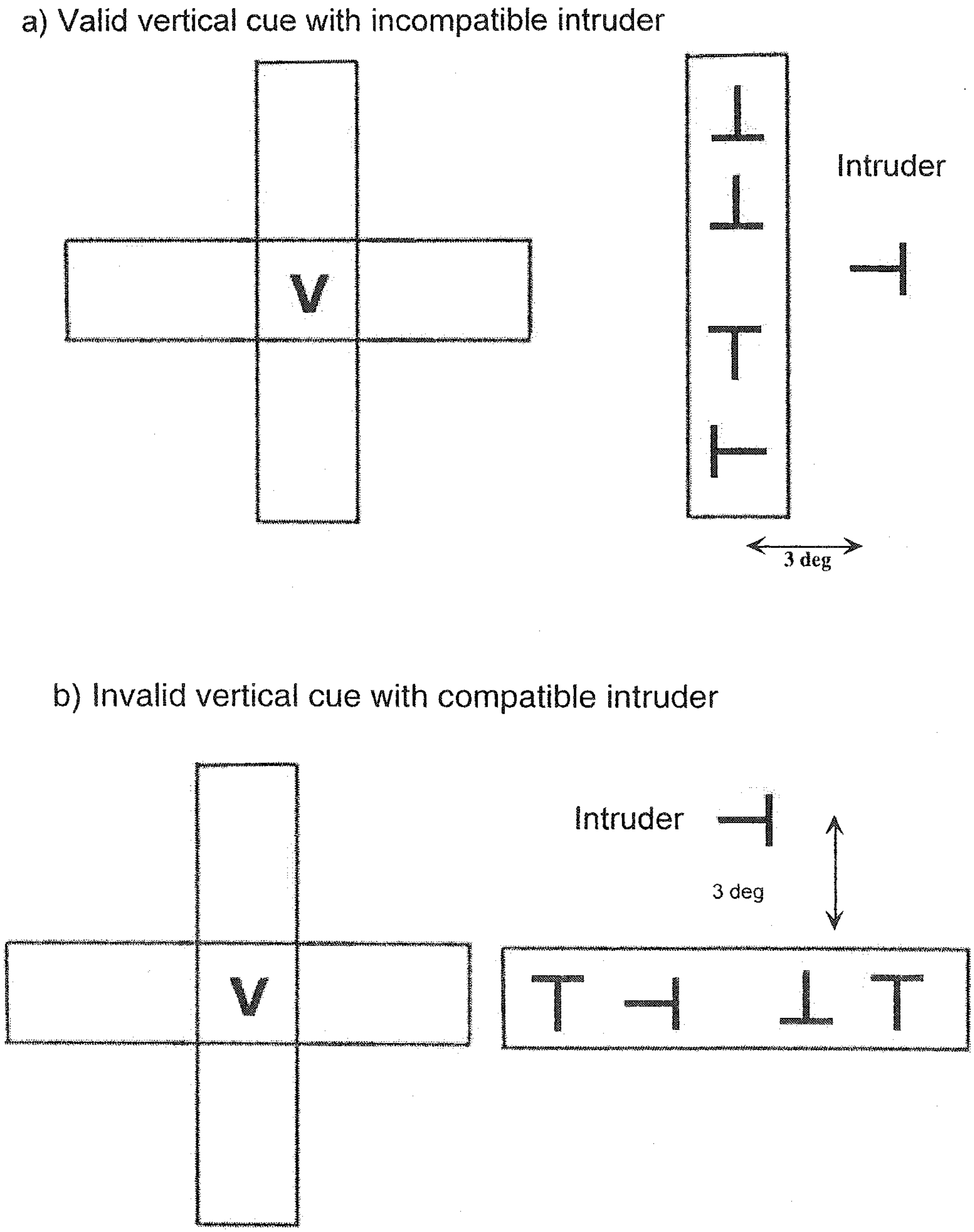


Figure 10. Representative stimuli for Experiment 3. a) A valid vertical cue is followed by a vertical test with an incompatible intruder on the right. The intruder falls outside the attended (cued) area. b) An invalid vertical cue is followed by a horizontal test with a compatible intruder above. The intruder falls inside the attended (cued) area.

When the cue was valid, the intruder was said to be outside of the attended area, and on the invalid cue trials, the intruder would appear inside the cued area. There were also three delays (between the onset of the test and the onset of the intruder): 0, 250, and 500 ms.

Design and Procedure

There were three sessions, one for each ISI: 0, 250 and 500 ms, presented in random order to the subjects. Each session consisted of 384 trials and lasted about 30 minutes. The order of presentations was randomized for each subject. The observer's head was positioned by a chin rest, at a distance of 57 cm from the screen. The subject initiated each trial by pressing the space bar. At the beginning of each trial, a red fixation dot appeared in the center of the screen. This fixation remained on the screen for 500 ms and was replaced by the stimuli of each trial. First, the cue appeared and remained on the screen for 500 ms, followed after an ISI of 750 ms by the test stimuli. The test stimuli remained on the screen until the subject responded. On trials where the intruder appeared, it flashed on at the same time as the test (0 ms), 250 ms later, or 500 ms later, depending on the experimental session and remained on the screen until the subject made a response.

In each trial, the subject had to search for the target while fixating, and make a decision concerning the target's orientation to the left or right, by pressing the left or right arrow keys of the keyboard. At the beginning of the session, the subjects were told that they should pay attention to the cue, in order to direct and focus their attention to the area of the stimuli. Subjects were warned that 75% of the time the cue would be valid and the remaining 25% of the time it would be invalid. Subjects were informed that the intruder would appear at random on half the trials and that they were to ignore it because it was not relevant to their task and to pay attention only to the stimuli arranged in the vertical or horizontal configuration. The subjects were asked to respond as quickly and as accurately as possible.

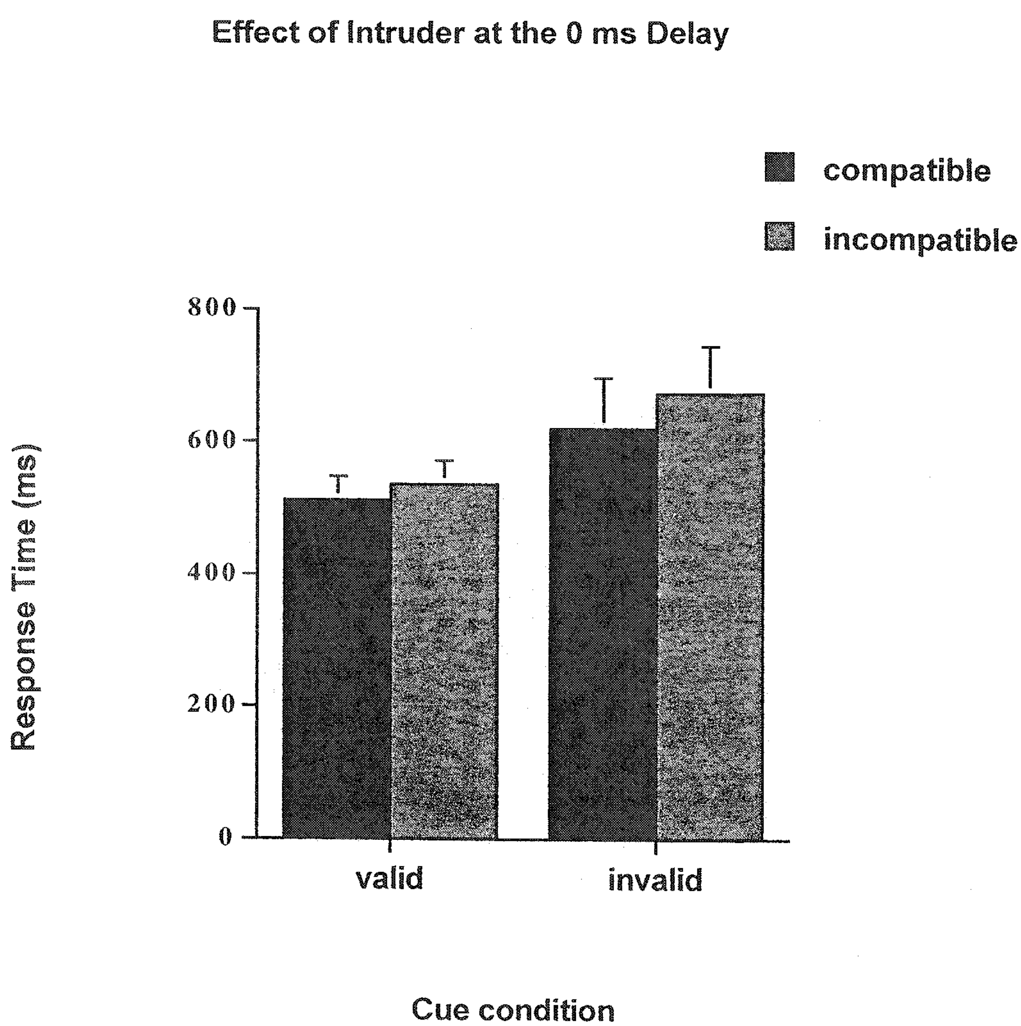
Results

A first analysis was performed on the RT data for the conditions where the intruder did not appear. This is basically a replication of Experiment 2, testing visual search performance with valid and invalid cueing. A two-tailed t-test yielded a marginally significant difference between the cueing conditions [$t(8) = -2.226$; $p = .057$], with invalid cueing giving rise to longer RTs (541.4 ms vs 478.1 ms). This confirms the result of the previous experiment.

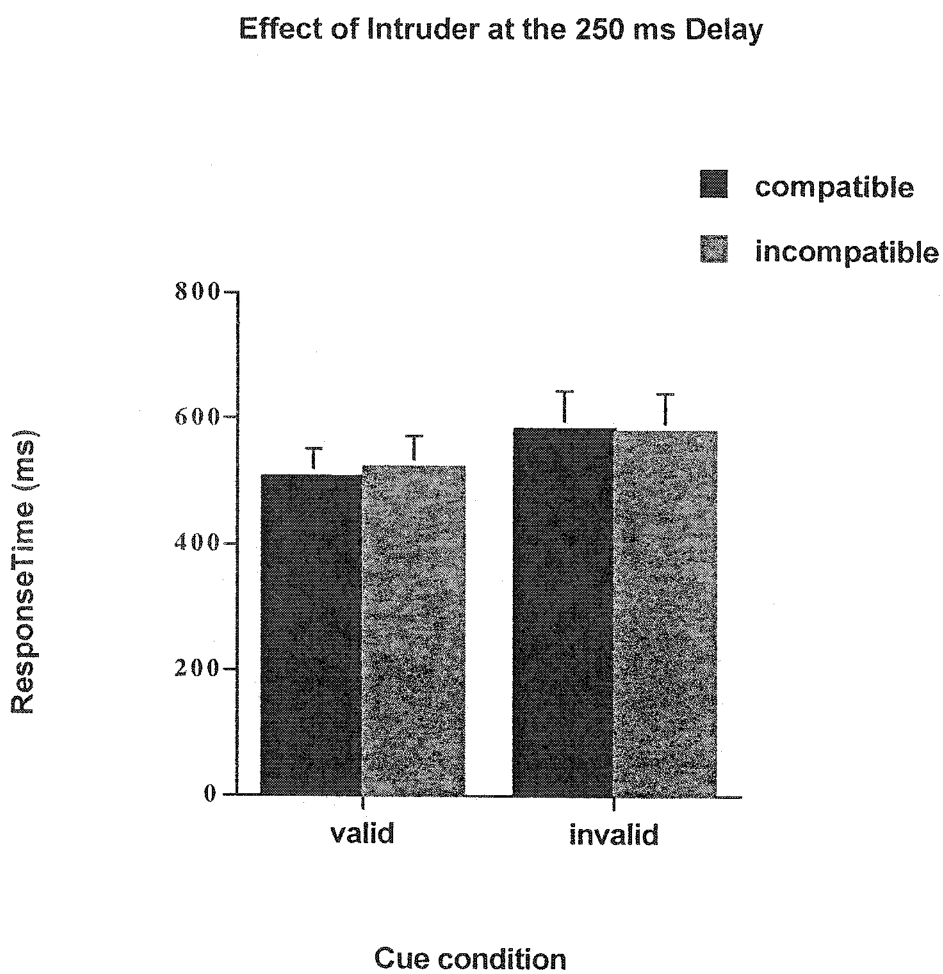
Then an Analysis of Variance on the three factors of Delay (0, 250, 500 ms), Cue (valid/invalid) and Intruder (compatible/incompatible) was performed. The triple interaction was significant [$F(2,16) = 5.19$; $p = .018$; effect size: .39].

To explore the triple interaction effect further, separate ANOVAs on the Cue and Intruder factors were performed for each delay. For delay = 0 ms (see Figure 11 a), both the Cue and Intruder main effects were significant [$F(1,8) = 5.88$; $p = .042$; effect size: .42; and $F(1,8) = 22.16$; $p = .002$; effect size: .74]. The Cue x Intruder interaction was only marginally significant [$F(1,8) = 4.41$; $p = .068$; effect size: .36] and was explored further. Tukey (HSD) post-hoc tests revealed that the intruder effect was significant for invalid cueing ($p < .01$), but not for valid cueing ($p > .05$). For delay = 250 ms (see Figure 11 b), the Cue effect was significant [$F(1,8) = 6.65$; $p = .03$; effect size: .45], and the Cue x Intruder interaction was marginally significant [$F(1,8) = 4.47$; $p = .067$; effect size: .36]. None of the post-hoc tests were significant. For delay = 500 ms (see Figure 11 c), no effects were significant.

a)


Effect of Intruder at the 0 ms Delay
compatible
incompatible
800
600
400
200
0
Response Time (ms)
valid
invalid
Cue condition

b)


Effect of Intruder at the 250 ms Delay
compatible
incompatible
800
600
400
200
0
ResponseTime (ms)
valid
invalid
Cue condition

c)

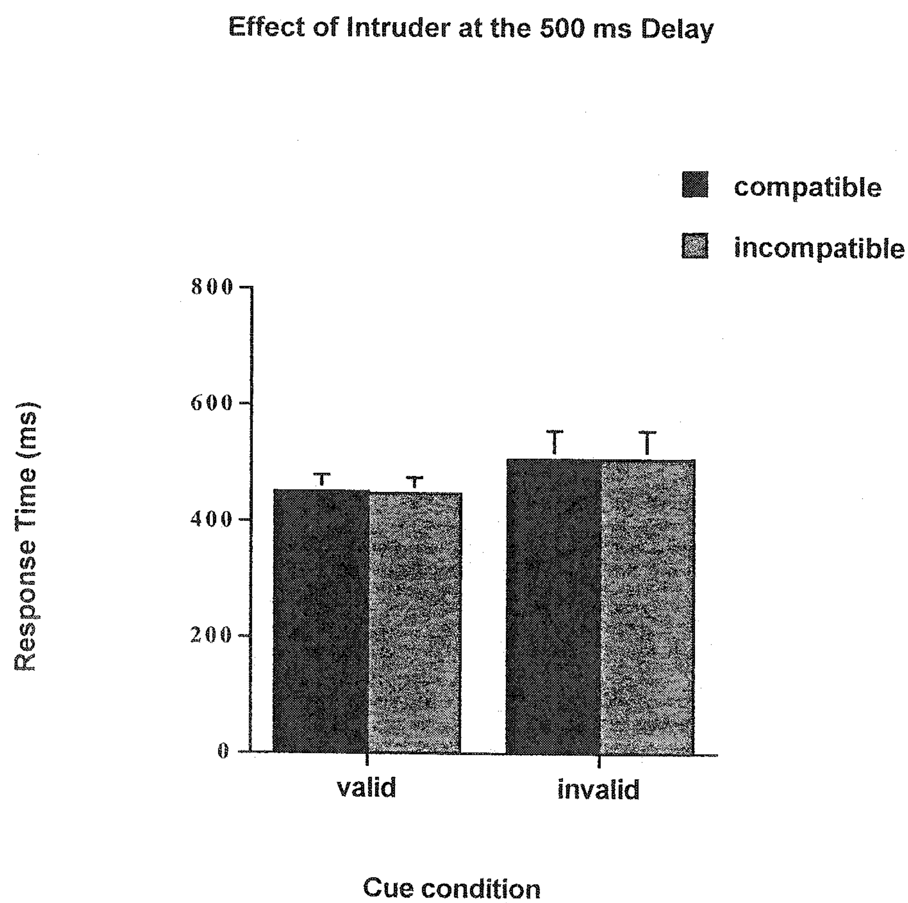


Figure 11. Results for Experiment 3. a) Intruder effect with standard errors for the condition with the 0 ms delay. b) Intruder effect with standard errors for the condition with the 250 ms delay.
c) Intruder effect with standard errors for the condition with the 500 ms delay.

Discussion

In this experiment, the addition of an intruder was used to probe the spatial properties of the cued area. This experiment investigated previous reports (Facoetti & Molteni, 2000), that the effect of an intruder depends on whether it is presented inside or outside the attended area. It usually has a greater effect when inside the area of attention. The main finding in the present experiment was that the difference between a compatible and incompatible intruder was found only when the intruder was presented inside the cued area. This corresponded to the case of invalid cueing, where subjects were instructed to focus their attention in a given elongated area. The test was then presented in the perpendicular uncued area, and the intruder in the attended area. This pattern of results provides further evidence that subjects were able to restrict their attention to a particular elongated area, which might be thought of as the attentional spotlight taking on a particular shape.

This result, however, held only for the case in which the test items and the intruder appeared simultaneously. For longer delays, the intruder effect was not significant. For the longer delays and especially for the longest delay (500 ms), it is likely that subjects had already processed the test display before the intruder appeared, so that the similarity of the intruder to the target was irrelevant. Similar temporal relationships have been reported previously (Facoetti & Molteni, 2000). Present findings seem to indicate that when the intruder is present, is incompatible with the target and appears at the same time as the test, it is most detrimental to the search task. In theory, visual spatial attention selects information by two mechanisms: (1) facilitation of information in the attended area and (2) inhibition of information in the unattended area. These two mechanisms often interact (Facoetti & Molteni, 2000). The present finding that the intruder interfered less with the search when it was outside the attended area (when the cue was valid), can be explained by the fact that the processing resources outside the attended area are reduced. This is further evidence that attention was "shaped" by cueing, since otherwise the intruder effect should have been the same in both cases.

These results extend the cue-size effect produced by the capacity of the focus to adjust to the size of the area to which attention is oriented (Benso, Turatto, Mascetti, & Umiltà, 1998; Castiello & Umiltà, 1990) into the realm of the shape of the attentional focus. Here, evidence was presented that suggests that this shape is flexible and adjustable.

Experiment 4

Motion Induction

Purpose

The goal of this experiment was to employ a different technique to assess the spatial properties of cued attention. For this purpose, the line motion illusion was used (Hikosaka et al., 1993). This motion illusion occurs when an inducing stimulus appears and is followed after a short interval by a line next to it. Motion is seen within the line away from the inducing stimulus. It has been shown that this illusion occurs when attention is captured exogenously by the inducing stimulus (von Grünau et al., 1996), or is directed endogenously to the inducing stimulus (Schmidt, 2000), or is reflexively attracted by the inducing stimulus (Bavellier et al., 2002). In the present situation, it is argued that the endogenous cue directs attention to the vertical or horizontal shape. A thin line (oriented at right angles to a cued area) presented at the right time after cueing was expected to result in illusory line motion away from the cued area. In contrast, a line presented perpendicular to the uncued area would produce little motion in either direction. In this way, it would be possible to examine the extent and shape of the cued attentional area in an independent and direct way.

Method

Participants

The participants were ten subjects from Concordia University, all with normal (20/20) or corrected-to-normal vision. Six female and four male subjects with an age range between 25 and 58 years participated. Four subjects participated in return for course credit and the rest of the participants were members of the Visual Perception Lab.

Apparatus and Stimuli

Apparatus, set-up and stimuli were the same as in the previous experiments. In this experiment, there was also a visual search task as before with a target and three distractors in a vertical or horizontal arrangement and endogenous cueing (letter V or H). Here cueing was always valid, but vertical and horizontal tests were presented in random order.

For the line motion tests, which appeared on 25% of the trials randomly among the visual search tests, one line appeared near the edge of the cued or uncued area. The line had a width of .1 deg and a length of 3 deg of visual angle. The line always appeared at one of the four extremities of either the vertical or horizontal area, but only one line was presented at any one trial. The line could be perpendicular to the cued area or it could be perpendicular to the uncued area (see Figure 12). These two cases were presented equally often and in random order.

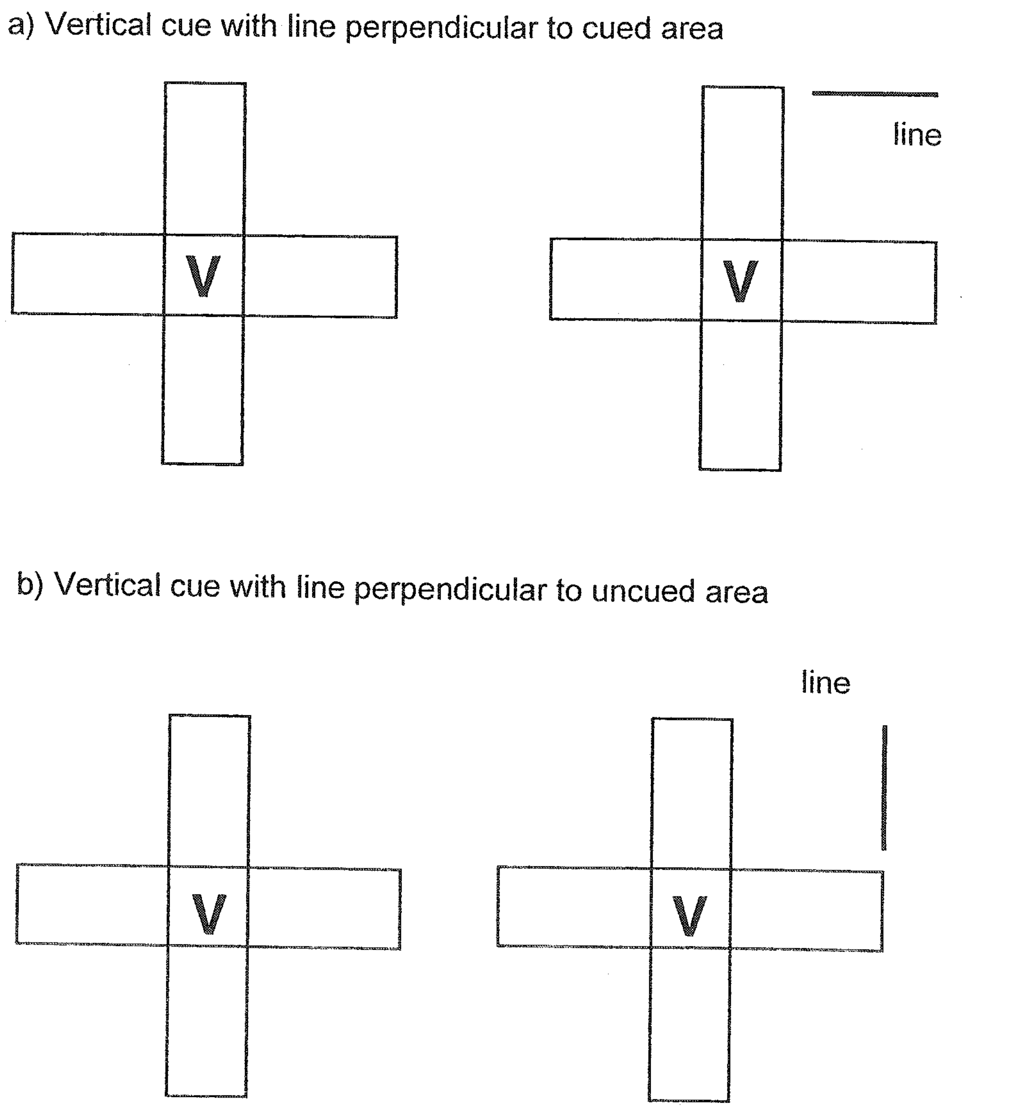


Figure 12. Representative stimuli for the line motion task in Experiment 4. a) A vertical cue is followed by a test with a line that is perpendicular to the cued area. The line appears in the upper right extreme position. Motion to the right is expected. b) A vertical cue is followed by a test with a line that is perpendicular to the uncued area, but is in the same upper right extreme position. No motion is expected.

Design and Procedure

The Vpixx software was used to control the experiment. The experimental session consisted of 320 trials and lasted about 20 minutes. The order of presentations was randomized for each subject by the computer. Subjects were told that on some trials they would have to perform a visual search task and on others they will be required to judge the direction of motion within a line. The participant's head was positioned by a chin rest at a distance of 57 cm from the screen. The participant initiated each trial by pressing the space bar. At the beginning of each trial, a red fixation dot appeared in the center of the screen.

When the task was a visual search, the fixation remained on the screen for 500 ms and was replaced by the stimuli of each trial. First, the cue appeared and remained on the screen for 500 ms. Then, the cue disappeared and after an ISI of 750 ms, the test stimuli appeared. The stimuli remained on the screen until the participant responded. In each trial, the participant had to search for the target while fixating, and make a decision concerning the target's orientation to the left or right, by pressing the Z key for right and the X key for left. The participants were also told that the cue was always valid for shape and they should pay attention to the cue, in order to direct and focus their attention to the area of the stimuli. The participants were asked to respond as quickly and as accurately as possible. RT was recorded by the computer. These responses were not analyzed, but only served the purpose to force the subject to make use of and attend to the cue in order to facilitate target detection.

When the trial consisted of judging the direction of motion in the line motion task, the fixation dot remained on the screen for 500 ms and was then replaced by the appropriate framed area. For the line motion trials, the cue never disappeared to avoid automatic captures of attention. After 800 ms of attending to the cue, a line appeared at one of the extreme positions. There were four extreme positions at the far corners of the cross, made up of the superposition of the vertical and horizontal frames. At each position, the line could be perpendicular to the cued frame or perpendicular to the uncued frame. After each trial, participants had the choice to report a particular direction of line motion by pressing the up, down, left or right arrow key. If no motion was perceived, the participant could report this by pressing the 0 key. Responses were not timed, and only the percentage of the different motion responses was measured for this task.

Results

The data consisted of the number of responses for the four motion directions and the no-motion alternative. When the lines were perpendicular to the cued area, the motion responses were recoded as away from or toward the cued area. When the lines were perpendicular to the uncued area, the motion responses were recoded as away from or toward the uncued area. Thus for all conditions, there were two directional responses and the no-motion response.

An analysis of variance was performed on the two independent variables of Line-orientation (perpendicular-to-cued/perpendicular-to-uncued) and Direction (away/toward/no motion). The Line-orientation x Direction interaction was significant: $F(2,18) = 11.102$, $p = .001$, with an effect size of .55 (see Figure 13). Pairwise comparisons, performed with the Bonferonni method ($\alpha = 0.05$), showed that, for the perpendicular-to-cued condition, the difference between Away and Toward and Away and No-motion proved to be significant. In about 78% of the trials, line motion was away from the cued area, in 18% it was toward the cued area, with 4 % no-motion responses. For the perpendicular-to-uncued condition, there were no significant differences between the three direction levels.

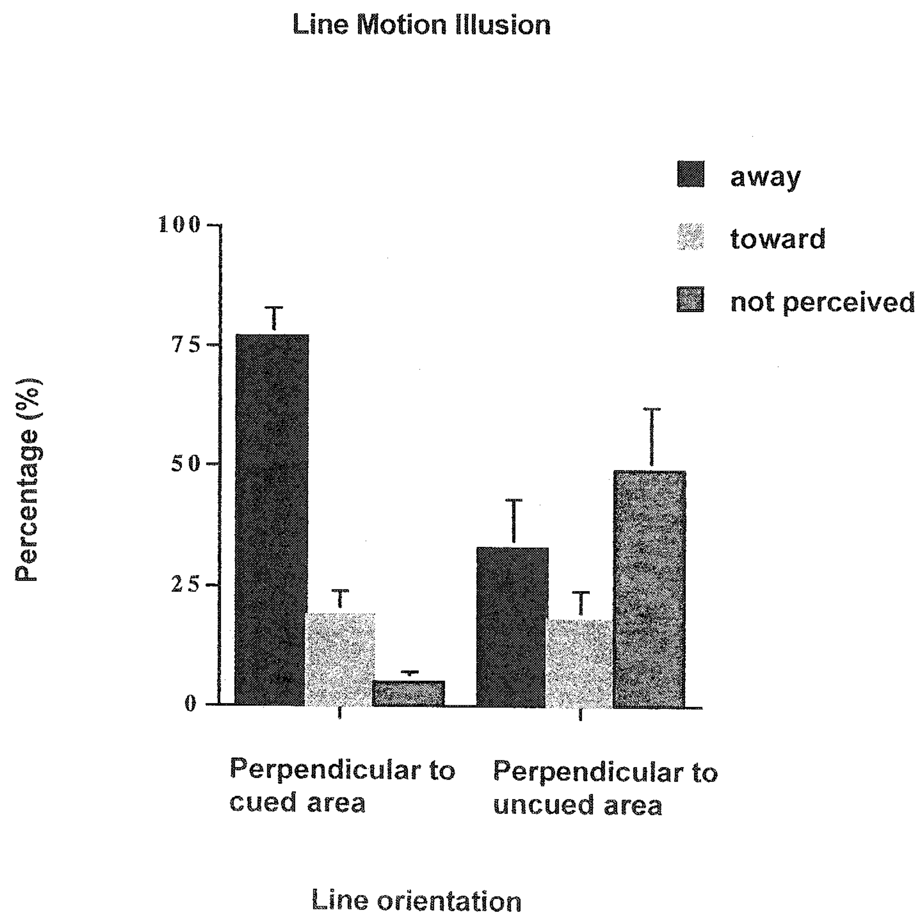


Figure 13. Results for Experiment 4. Perception of the Line Motion Illusion when the line is perpendicular to the cued area and when it is perpendicular to the uncued area. When the line was perpendicular to the cued area, the line was mostly perceived as moving away from the attended area.

Discussion

Results from the line motion task show that participants perceived illusory motion predominantly as away from the cued area, and only rarely towards it, with very few no-motion responses. This pattern would be expected from the line motion literature. It has been found that motion within the line is predominantly in a direction away from the inducing stimulus, whether exogenous (Hikosaka et al., 1993; von Grünau & Faubert, 1994; von Grünau et al., 1996), endogenous (Schmidt, 2000; Shimojo et al., 1993) or reflexive (Bavellier et al., 2002). The widely accepted attentional explanation (but see: Tse & Cavanagh, 1995; Downing & Treisman, 1995) is that attention at the inducing stimulus speeds up processing, and the line end near the center of the attentional focus is speeded up more than line parts further away. This attentional gradient causes the line to be perceived as growing away from the attentional focus at the inducing stimulus.

In the present case, this means that the extremes of the cued areas served as inducing stimuli causing the perceived motion in those lines that were perpendicular to the cued area. When the lines were perpendicular to the uncued area, no clear perceived motion direction was found. Most responses were for no-motion (49%). Toward and away responses were approximately equal (19% and 32%). The latter result would occur if participants perceived no clear motion, and responded by using the alternative directional responses equally often (like a two-alternative forced choice). Together with the strong motion away from the cued area, the overall absence of directed motion in the lines perpendicular to the uncued area, provides strong evidence for the idea that the cues served to allocate attention only in the cued vertically or horizontally elongated area, but not in the uncued area. The shape of the attentional spotlight was thus changed by the cue. This independent evidence corroborates the conclusions from the visual search tasks in the previous experiments. Endogenous cueing thus is able to determine the shape of the attentional spotlight, at least for the simple shapes used here.

One might object that subjects' knowledge of the motion induction illusion could have introduced a bias for the perception of motion away from the attended area. Although 6 of the 10 participants in this experiment were members of the Visual Perception Lab, only one of the participants had prior experience with Motion induction experiments and the rest were naïve with respect to motion induction. Thus it is not likely that the results can be accounted for in this way.

The present findings can also be explained by assuming small spotlights moving in the cued vertical or horizontal direction, starting either from the top and moving downward or starting at the left and moving to the right. For example, when starting at the top, the line would appear there 50% of the time and would result in motion away. In the other 50%, the line would appear at the bottom, and the subject's responses would be 50% away and 50% toward. This gives an overall score of 75% away, which is close to the obtained result (78%). To examine this alternative explanation, the lines in the motion Induction experiment were separated as top, bottom, left and right. For the vertical shape, the responses for the lines on the top were compared with those for the lines on the bottom, and for the horizontal shape, the responses for the lines on the left were compared with those for the lines on the right. A two-tailed t test was used to compare the mean for the lines on the top with the mean for the lines on the bottom and no significant difference between the groups was found. A two-tailed t test was also used to compare the mean for the lines on the left with the mean for the lines on the right, and again no significant difference was found between these two groups. This analysis does not support the claim that the observer scans the cued shape with a small spotlight from the top to the bottom or from the left to the right. However, this alternative explanation of scanning the visual field cannot be completely refuted based on this analysis alone. The explanation using small spotlights needs to be examined experimentally in more detail.

General Discussion

The aim of this study was to provide evidence for the contention that endogenously cued attention can be confined to areas of a particular shape. In the present case, very simple shapes were chosen, a rectangle that could be elongated in the vertical or horizontal direction. Attention was employed in all experiments by cueing endogenously for one of these shapes. In the first experiment, emphasis of the cueing was on the location of the area, but the shape of this area was given in both locations. In light of the results of Experiment 2, one might expect that this cueing also restricted the shape of the attended area to be elongated (as well as move to the left or right of fixation). In the first two experiments, the difference in search RT between the valid and invalid cueing conditions provided some evidence for the idea that attention must have been restricted to particular elongated areas, rather than one circular central area, and also demonstrated that the spotlight of attention can easily move from one location to another. If it had not been, one would not expect the present effect of cueing validity. A further problem examined concerned the question whether cueing the shape and location of the relevant stimuli could reduce or even eliminate the detrimental effect that an irrelevant background has for the efficiency of target detection. In the first experiment, where the location of the area containing the target was cued, the results proved that cueing did not eliminate the background effect. The background effect was the same for all cue conditions. In the second experiment, the shape of the spotlight was successfully adjusted to fit the shape of the cue. This shape-dependent focusing of the attended area had the further effect of eliminating any background effect. Visual search with or without the irrelevant background elements resulted in the same response times for all cueing conditions. Therefore, it can be concluded that the attentional focus had been sufficiently restricted and sharp enough to not include any background elements in the search.

A possible explanation for the finding that the background elements interfered with the search in the location cueing experiment but not in the shape cueing experiment, might be related to the perceptual load of the experimental task. According to Lavie and Tsal (1994), perceptual load is a major factor in determining the locus of selection. They have presented evidence that perceptual load is one of the conditions influencing the processing of irrelevant information. Lavie and Tsal (1994) concluded that a clear physical distinction between relevant and irrelevant information is not sufficient to prevent irrelevant processing; early selection also requires that the perceptual load of the task be sufficiently high to prevent available attentional resources from exerting their effect on irrelevant information. In the present study, it is therefore likely that in the shape experiment, there were no attentional resources left over to process the background elements when they were present, thus the background did not interfere with the search task. This could be due in part because it is more difficult to change the shape of the attentional focus. However, cueing the location of the area that needs to be attended seems to be easier, and therefore there are attentional resources left over that can spill out and allow the background to be processed, thus interfering with the search task.

In the third experiment, a similar task was performed, but an intruder was added to the display. The effect of the compatibility of the intruder with the target was found to depend on the intruder's location within or outside the cued area. This provided further evidence for the spatial restriction of the attentional area. In the fourth experiment, a different technique was used to assess the spatial properties of the attentional area. The line motion illusion showed the existence of attentional resources at the extreme ends of the cued area, but not of the uncued area. Overall, this study provided evidence that endogenous cueing can set up attentional areas that have specific shapes and are fairly sharply delimited.

In all experiments, participants were required to fixate a fixation point throughout the trials, and they were so instructed and reminded during the experiment. The stimuli themselves were symmetrical around fixation and centered, except for Experiment 1. In spite of this, participants might have found it necessary to change fixation during the test to search the display. To examine this concern, eye movements were monitored for some observers for a subset of the experimental conditions with an EyeLink eye tracker. No large or systematic deviations from fixation in any of the conditions or experiments were found therefore, the observers were fixating well throughout the experimental session.

There is some evidence (Carrasco, McElree & Giordano, 2002; Sanders & Brück, 1991; Galera & von Grünau, 2003) showing that the shape of the attentional window without cueing is naturally asymmetrical in the sense that the horizontal extent is larger than the vertical extent. Contrast sensitivity is better along the horizontal than the vertical meridian. This assymetry is more pronounced as eccentricity increases. Covert attention improves discriminability at all locations to a similar degree (Carrasco, Talgar, & Cameron, 2001; Carrasco et al., 2002). Recently Carrasco et al., (2002) found that information accrual is faster at far than near locations and at the horizontal than the vertical meridian.

In the present situation with cueing with a narrow vertical or horizontal shape, the given skewedness of the attentional window might interact with the oriented cues and affect the intruder effect. An analysis was performed separating the two cue configurations (horizontal and vertical) for the Intruder experiment. Although there was no significant difference between horizontal and vertical, response times were faster on the horizontal meridian than the vertical meridian, replicating previous findings (Carrasco et al., 2002; Sanders & Brück, 1991; Galera & von Grünau, 2003).

In theory, visual spatial attention selects information by two mechanisms: (1) facilitation of the information coming from the attended area and (2) inhibition at distractor locations. These two basic mechanisms are not mutually exclusive. They are compatible and interacting (Laberge & Brown, 1989). The crucial role played by attention in suppressing competing information coming from distractors is supported also by neurophysiological studies showing that attentional modulation of neuronal responses is greater when both target and distractor fall inside the receptive field of a neuron and, thus produce competition for representation (Luck, Chelazzi, Hillyard, & Desimone, 1997).

Two key issues that have been addressed in detail by neurophysiologists are the locus of selection and the relationship between the visual search and the spatial cueing paradigms. Studies of the locus of selection have provided strong evidence that attention may operate at an early, sensory stage to select relevant inputs for preferential processing (Luck, 1998). It is important to remember, however, that the existence of early-selection mechanisms does not preclude the existence of late-selection mechanisms: early selection may be limited to conditions of information overload, in which efficient perceptual processing requires a reduction in the amount of sensory information being processed. Although the most detailed neurophysiological evidence for early selection has been obtained using the paradigm developed by Hillyard, Hink, Schwent, & Picton (1973), the same early-selection mechanisms observed in that paradigm also appear to operate in paradigms such as visual search and spatial cueing. The conclusion that the same attentional mechanisms operate across these very different paradigms is encouraging, because it indicates that the theories of attention can validly draw on evidence obtained from both paradigms. However, the findings on which this conclusion is based also add a complication to theories of attention, because they also indicate that both tasks use multiple mechanisms of attention. This conclusion is based primarily on the dissociations that have been observed between P1 and N1 attention effects (Luck, 1998). Specifically, the N1 attention effect appears to reflect a facilitation of processing of attended information and is present only when subjects must perform a discrimination, whereas the P1 attention effect appears to reflect a suppression of unattended information and is present in both detection and discrimination tasks. There are additional dissociations between these attention effects as well (reviewed by Luck, 1995), and it now seems clear that these two attention effects reflect independent mechanisms of attention and are used under different conditions and have different effects on sensory processing (Luck, 1998). According to Luck (1998), the challenge for the future will be to integrate these physiological findings into theories of attention at the cognitive level.

The spotlight of attention analogy has been used in theories of attention and theories of object detection for many years but its functions have been ill defined in most of these theories (Greene, 1991). Nevertheless, most of the theories seem to agree that at least one of the functions of the spotlight of attention is to help process the stimuli that fall within its focus (Treisman & Gelade, 1980; Wolfe, 1994) and to inhibit information that falls outside its focus (Moran & Desimone, 1985).

Throughout, the attentional area has been referred to as the region where the attentional resources would be concentrated. As discussed in the introduction, the spotlight metaphor has generated much research and some controversy. It has been very useful as a conceptual tool to understand many aspects of selective attention. Many of the properties of the spotlight are still under debate (Cave & Bichot, 1999). The question that was addressed in the present study concerns the shape of the region that is selected, and how much flexibility there is in adjusting this shape. The present experiments support the side of the argument that advocates a rather large flexibility in the shape of the spotlight of attention (Logan, 1996). Only very simple shapes were used, like oriented rectangles. There is some evidence, that slightly more complex shapes (circular annuli; Juola, Bouwhuis, Cooper & Warner, 1991) may be possible as well. The technique of employing the line motion illusion to delineate the shape of the spotlight might be developed into a useful tool to examine more subtle differences in the shapes. It seems well suited to discriminate between areas to which attention is directed and those to which it is not directed. How fine a resolution might be possible, needs to be determined in future experiments.

References

Bavelier, D. Schneider, K., & Monacelli, A. (2002). Reflexive gaze orienting induces the line-motion illusion. Vision Research, 42, 2817-2827.

Benso, F., Turatto, M., Mascetti, G.G, Ulmità, C. (1998). The time course of attentional focusing. European Journal of Cognitive Psychology, 10, 373-388.

Broadbent, D. A. (1958). Perception and Communication, London: Pergamon.

Carrasco, M., McElree, B. & Giordano, A.M. (2002). Covert attention speeds information accrual more along the vertical than the horizontal meridian. Journal of Vision, 2(27), 458a.

Carrasco, M., Talgar, C., & Cameron, E. L. (2001). Characterizing visual performance fields: effects of transient covert attention, spatial frequency, eccentricity, task and set size. Spatial Vision, 15, 61-75.

Castiello, U. & Umiltà, C. (1990). Size of attentional focus and efficiency of processing. Acta Psychologia, 73, 195-209.

Cave, K. R. & Bichot, N. P. (1999). Visuospatial attention:Beyond a spotlight model. Psychonomic Bulletin and Review, 6, (2), 204-223.

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, P.E. & Treisman, A. M. (1995). The shooting line illusion: Attention or apparent motion? Investigative Ophtalmology and Visual Science, 36 (Suppl.), 3922.

Duncan, J. (1984). Selective attention and the organization of visual information. Journal of Experimental Psychology: General, 4, 501-517.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. Psychological Review, 96, 433-458.

Egeth, H. (1977). Attention and preattention. In: G. H. Bower (Ed.), The psychology of learning and motivation (Vol. 11. Pp.277-320). New York: Academy Press.

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

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

Ericksen C. W. W. & Hoffman J. E. (1972). Temporal and spatial characteristics of selective encoding from visual displays. Perception and Psychophysics, 12, 201-204.

Eriksen, C. W. & Hoffman, J. E. (1973). The extent of processing of noise elements during selective encoding from visual displays. Perception and Psychophysics, 14, 155-160.

Eriksen, C. W. & Murphy, T. D. (1987). Movement of attentional focus across the visual field: A critical look at he evidence. Perception and Psychophysics, 42, 299-305.

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. Y. (1985). Allocation of attention in the visual field. Journal of Experimental Psychology: Human Perception and Performance, 5, 583-595.

Facoetti, A. & Molteni M. (2000). Is attentional focusing an inhibitory process at distractor location? Cognitive Brain Research, 10, 185-188.

Galera, C., Lopes, E. J., & von Grünau, M., (2000). Stimulus segmentation in the visual search task. Perception an Psychophysics. 62 (3), 505-516.

Galera, C. & von Grünau, M. W. (2003). Size and shape of the attentional spotlight affect efficiency of processing. Paper presented at VSS Annual Meeting, Sarasota, Florida.

Greene, M. (1991). Visual search, visual streams, and visual architectures. Perception and Psychophysics, 50(4), 388-403.

Hikosaka, O., Miyauchi, S., & Schimojo, S. (1993). Focal visual attention produces illusory temporal order and motion sensation. Vision Research, 33 (9), 1219-1240.

Hillyard, S. A., Hink, R. F., Schwent, V. L., & Picton, T. W. (1973). Electrical signs of selective attention in the human brain. Science, 182, 177-179.

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

Horowitz, T. S. & Wolfe, J. M. (1998). Visual search has no memory. Nature, 394, 575-577.

Iani,C., Nicoletti, R., Rubichi, S. & Umiltà, C. (2001). Shifting attention between objects. Cognitive Brain Research, 11, 157-164.

Julesz, B. (1984). A brief outline of the textons theory of human vision. Trends in Neuroscience, 7 (2), 41-45.

Juola, J. F., Bouwhuis, E.E., Cooper, C. & Warner, B. (1991). Control of attention around the fovea. Journal of Experimental Psychology: Human Perception and Performance, 17, 125-141.

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

Laberge, D. (1973). Attention and the measurement of perceptual learning. Memory and Cognition, 1, 268-276.

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

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

Lavie, N., & Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. Perception and Psychophysics, 56(2), 183-197.

Leonards, U.., Rettenback, R. & Sireteanu, R. (1998). Paralle visual search is not always effortless. Cognitive Brain Research, 7(2), 207-213.

Logan, G. (1996). The CODE theory of visual attention: An integration of space-based and object-based attention. Psychological Review, 103, 603.649.

Luck, S. J. (1995). Multiple mechanisms of visual-spatial attention: Recent evidence from human electrophysiology. Behavioural Brain Research, 71, 113-123.

Luck, S.J. (1998). In H. Pashler (Ed.), Attention, (pp. 13-74). London, UK. University Colege London Press.

Luck, S. J., Chelazzi, L.Hillyard, S. A. & Desimone, R. (1997). Neural mechanismsof spatial selective attention in areas V1, V2, and V4 of macaque visual cortex. Journal of Neurophysiology, 77, 24-42.

Macquistan, A.D. (1997). Object-based allocation of visual attention in response to exogenous, but not endogenous, spatial precues. Psychonomic Bulletin & Review, 4, 512-515.

McElree, B., & Carrasco, M. (1999). The temporal dynamics of visual search: Evidence for parallel processing in feature and conjunction searches. Journal of Experimental Psychology: Human Perception and Performance, 25 (6), 1517-1539.

Moran, J. & Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. Science, 229,(4715), 782-784.

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.

Neisser, U. Cognitive Psychology New York, Appleton-Century-Croft, 1967.

Nothdurft, H. C. (1999). Focal attention in visual search. Vision Research, 39, 2305-2310.

Oonk, H. M., & Abrams, R. A (1998). New perceptual objects that capture attention produce inhibition of return. Psychonomic Bulletin and Review, 5, 510-515.

Palmer, J., Ames, C. T., & Lindsey, D. T. (1993). Measuring the effect of attention on simple visual search. Journal of Experimental Psychology: Human Perception and Performance, 19, 108-130.

Panagopoulos, A., von Grünau, M. W., & Galera, C. (2001). Visual search with irrelevant background: Shape and size cueing eliminate background effect only partially. Paper presented at BBCS Annual Meeting, Quebec, Canada.

Panagopoulos, A., & von Grünau, M. W. (2002). Visual search with irrelevant backgrounds: Speeding or slowing search using endogenous cues. Paper presented at VSS Annual Meeting, Sarasota, Florida.

Podgorny, R., & Shepard, R. N. (1983). Distribution of visual attention over space. Journal of Experimental Psychology: Human Perception and Performance, 9, 380-393.

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

Posner, M. (1995). Attention in Cognitive Neuroscience, an overview. In Gazzaniga, M. S. The Cognitive Neurosciences. Boston, MA: Massachusetts Institute of Technology.

Posner, M. & Cohen, Y. (1984). Components of Visual Orienting. Hillsdale, NJ: Lawrence Erlbaum.

Posner M., & Gilbert, C. (1999). Attention and primary visual cortex. Proceedings of the National Academy of Sciences, 96 (6), 2585-2587.

Posner, M. I, Snyder, C. R. R., & Davidson, B. J. (1980). Attention and detection of signals. Journal of Experimental Psychology: General, 109 (2), 160-174.

Rees, D., Backus, B., & Heeger, D. (2000). Activity in primary visual cortex predicts performance in a visual detection task. Nature Neuroscience, 3 (9), 940-945.

Sanders, A.F. & Brück, R. (1991). The effect of presentation time on the size of the visual lobe. Bulletin of the Psychonomic Society, 29, 206-208.

Schendel, K. L., Robertson, L.C.; Treisman, A. (2001). Objects and their locations in exogenous cuing. Perception and Psychophysics, 63, 577-594.

Schmidt, W. C. (2000). Endogenous attention and illusory line motion reexamined. Journal of Experimental Psychology: Human, Perception and Performance, 26 (3), 980-996.

Schmidt, W. C. & Klein, R. (1997). A spatial gradient of acceleration and temporal extension underlies three illusions of motion. Perception, 26, 857-874.

Shimojo, S., Miyauchi, S. & Hikosaka, O. (1993). Line motion can be induced by visual expectation and memory guided readiness. Investigative Ophtalmology and Visual Science, 34 (Suppl.), 1290.

Shulman, G. L., Remington, R. W. & McLean, J. P. (1979). Moving attention through visual space. Journal of Experimental Psychology: Human Perception and Performance, 5(3), 522-526.

Sireteanu, R. & Rettenback, R. (1995).Perceptual learning in visual search :Fast, enduring, but non-specific. Vision Research, 35(14), 2037-2043.

Theeuwes, J. (1989). Effects of location and form cuing on the allocation of attention in the visual field. Acta Psychologica, 72, 177-192.

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

Treisman, A. Theperception of features and objects. In R. D. Wright (1998). Visual Attention. Oxford University Press. New York.

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 visual vision: Evidence from search assymetries. Psychological Review, 95(1), 14-48.

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

Treisman, A., & Sato, S., (1990). Conjunction search revised. Journal of Experimental Psychology: General, 114, 285-310.

Treisman, A., Sykes, M. & Gelade, G. Selective attention and stimulus integration. In S. Dornic (Ed.), Attention and Performance VI. Hillsdale, NJ: Lawrence Erlbaum, 1977. Pp. 333-361.

Tse, P. & Cavanagh, P. (1995). Line motion occurs after surface parsing. Investigative Ophtalmology and Visual Science, 36 (Suppl.), S417.

Turatto M., Benso F., Facoetti A., Galfano G., Mascetti G. G. & Umiltà C. (2000). Automatic and voluntary focusing of attention. Perception and Psychophysics, 62, 935-952.

Vecera, S. P. & Farah, M. J. (1994). Does visual attention select objects or locations? Journal of Experimental Psychology: General, 123, 146-160.

von Grünau, M. W., Dubé, S., & Kwas, M. (1996). Two contributions to motion induction: A preattentive effect and facilitation due to attentional capture. Vision Research, 36(16), 2447-2457.

von Grünau, M. W., Panagopoulos, A., Galera, C. & Savina, O. (2002). Visual search with exogenous and endogenous cueing. Proceedings of the International Society for Psychophysics, 18, 225-230.

von Grünau, M. W., Racette, L., & Kwas, M. (1996) Measuring the attentional speed-up in the motion induction effect. Vision Research, 36 (16), 2433-2446.

von Grünau, M. W, Saikali, Z., & Faubert, J. (1995). Processing speed in the motion-induction effect. Perception, 24, 477-490.

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

Wolfe, J. M. (1996). Extending Guided Search: Why Guided Search needs a preattentive "item map". In A. Kramer, G. H. Cole, & G. D. Logan (Eds.), Converging operation in the study of visual selective attention, (pp. 247-270). Washington, DC: American Psychological Association.

Wolfe, J. M. (1998). What a million trials tell us about visual search. Psychological Science, 9, 33-39.

Wolfe, J. M., Cave, K. R. & Franzel, S. L. (1989). Guided Search: An alternative to the feature integration model for visual search. Journal of Experimental Psychology: Human Perception and Performance, 15(3), 419-433.

Yantis, S. (1988). On analog movements of visual attention. Perception and Psychophysics, 43, 203-206.

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

Yeshurun & Carasco, M. (1998). Attention improves or impairs visual performance by enhancing spatial resolution. Nature, 396; 5. Nov. 72-75.

Appendix A

Summary Tables for Location Cueing With Background Present and Background Absent (Experiment 1)

Table A1

Analysis of Variance Summary Table for the Two Factors of Background (Present and Absent) and Cue Type (Valid, Invalid, and Non-informative) (Experiment 1)

Source	df	SS	MS	F
Within-Subjects				
Background (A)	1	.091	.091	28.536 ***
Error	10	.032	.003	
Cue (B)	2	.082	.041	6.912 **
Error	20	.119	.006	
A x B	2	.001	3.449E-4	.416
Error	20	.008	3.766E-4	

*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

Table A2

Tukey's HSD Multiple Comparison Summary Table for the Cue Type Factor (Experiment 1)

Comparison	Mean Difference
Valid vs. Invalid	-.0856 *
Valid vs. Non-informative	-.0323
Invalid vs. Non-informative	.0533

*$p < 0.05$.

Appendix B

Summary Tables for Shape Cueing With Background Present and Background Absent

(Experiment 2)

Table B1

Analysis of Variance Summary Table for the Two Factors of Background (Present and Absent) and Cue Type (Valid, Invalid, and Non-informative) (Experiment 2)

Source	df	SS	MS	F
Within-Subjects				
Background (A)	1	4.441E-4	4.441E-4	.148
Error	10	.030	.003	
Cue (B)	2	.073	.037	4.620 *
Error	20	.119	.006	
A x B	2	.001	4.728E-4	1.583
Error	20	.006	2.988-4	

*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

Table B2

Tukey's HSD Multiple Comparison Summary Table for the Cue Type Factor (Experiment 2)

Comparison	Mean Difference
Valid vs. Invalid	-.0775 *
Valid vs. Non-informative	-.0167
Invalid vs. Non-informative	.0608

*$p < 0.05$.

Appendix C

Summary Tables for Experiment 3

Table C1

Computed Value of t test Table for Visual Search Performance with Valid and Invalid Cueing Where the Intruder was Absent (Experiment 3)

t	df	Sig. (2-tailed)	Mean Difference
-2.226	8	.057	-63.33

Table C2

Analysis of Variance Summary Table for the Three Factors of Delay (0, 250, 500 ms), Cue (Valid/Invalid) and Intruder (Compatible/Incompatible)) (Experiment 3)

Source	df	SS	MS	F
Delay (A)	2	208170.50	104085.25	9.43 ***
Error	16	176561.33	11035.08	
Cue (B)	1	182862.37	182862.37	5.44 *
Error	8	268721.63	33590.20	
Intruder (C)	1	6225.93	6225.93	16.11 ***
Error	8	3091.74	386.47	
A x B	2	21235.35	10617.68	5.65 **
Error	16	30081.15	1880.07	
A x C	2	7873.91	3936.95	11.66 ***
Error	16	5401.93	337.62	
B x C	1	108	108	.575
Error	8	1503	1503	
A x B x C	2	3018	1509.19	5.19 **
Error	16	4656.11	291.01	

*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

Table C3

Analysis of Variance Summary Table for the Cue and Intruder Factors for the 0 ms Delay (Experiment 3)

Source	df	SS	MS	F
Cue (A)	1	133468.44	133468.44	5.88 *
Error	8	181529.06	22691.13	
Intruder (B)	1	13689	13689	22.162 ***
Error	8	4941.50	617.69	
A x B	1	2240.44	2240.44	4.414
Error	8	4061.06	507.63	

*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

Table C4

Analysis of Variance Summary Table for the Cue and Intruder Factors for the 250 ms Delay (Experiment 3)

Source	df	SS	MS	F
Cue (A)	1	40535.11	40535.11	6.65 **
Error	8	48797.39	6099.67	
Intruder (B)	1	441	441	1.084
Error	8	3255.50	406.94	
A x B	1	940.44	940.44	4.47
Error	8	1683.06	210.38	

*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

Table C5

Analysis of Variance Summary Table for the Cue and Intruder Factors for the 500 ms Delay (Experiment 3)

Source	df	SS	MS	F
Cue (A)	1	30334.03	30334.03	3.51
Error	8	69147.22	8643.40	
Intruder (B)	1	1.361	1.361	.038
Error	8	288.89	36.11	
A x B	1	4.694	4.694	.096
Error	8	389.56	48.694	

$^{*}p < 0.05$. $^{**}p < 0.01$. $^{***}p < 0.001$.

Table C6

Tukey's HSD Multiple Comparison Summary Table for Intruder Type for Valid and Invalid Cueing (Experiment 3)

Comparison	Mean Difference
Intruder Effect for Valid cueing	23.23
Intruder Effect for Invalid cueing	54.78 **

** $p < 0.01$.

Appendix D

Summary Tables for Experiment 4

Table D1

Analysis of Variance Summary Table for Line Orientation (Perpendicular-to-cued / Perpendicular-to-uncued) and Direction of Motion (Away/ Toward / No motion) (Experiment 4)

Source	df	SS	MS	F
Line Orientation (A)	1	6.667E-2	6.667E-2	1.000
Error	9	.600	6.667E-2	
Direction (B)	2	14448.43	7224.22	7.449**
Error	18	17456.23	969.79	
A x B	2	19625.43	9812.72	11.102**
Error	18	15909.90	883.88	

*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

Table D2

Tukey's HSD Multiple Comparison Summary Table for the Perpendicular-to-cued Condition

Comparison	Mean Difference
Away vs. Toward	58.3 *
Away vs. No Motion	72.1 *
No Motion vs. Toward	23.2

*$p < 0.05$.

Table D3

Tukey's HSD Multiple Comparison Summary Table for the Perpendicular-to-uncued Condition

Comparison	Mean Difference
Away vs. Toward	12.31
Away vs. No Motion	-16.5
No Motion vs. Toward	13.8

*$p < 0.05$.

Table D4

Computed Value of t test Table to Compare the Mean for the Lines on the Top with the Mean for the Lines on the Bottom (Experiment 4)

t	df	Sig. (2-tailed)	Mean Difference
-1.356	9	.208	-10.40

Table D5

Computed Value of t test Table to Compare the Mean for the Lines on the Left with the Mean for the Lines on the Right (Experiment 4)

t	df	Sig. (2-tailed)	Mean Difference
1.177	9	.269	4