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The effects of display size, target eccentricity, and perceptual difficulty on the distribution of attention in the visual field

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THE EFFECTS OF DISPLAY SIZE, TARGET ECCENTRICITY,
AND PERCEPTUAL DIFFICULTY ON THE
DISTRIBUTION OF ATTENTION IN THE VISUAL FIELD

by

LOY A. ANDERSON

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The Effects of Display Size, Target Eccentricity, and Perceptual Difficulty on the Distribution of Attention in the Visual Field

by

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Abstract

The operation of distributing attention to regions of the visual field was investigated in order to further understand the role of attention in the perception of visually-presented stimuli. In each of three experiments, a target letter was presented somewhere within a precued region of the visual display. The task was to determine which one of two possible targets had been presented. The size of the to-be-attended region of the display, the degree of target eccentricity within each region, and the perceptual difficulty of the stimulus discrimination were manipulated factorially. There was evidence that subjects were able to distribute their attention to regions of varying size, but that the focus of attention could not be confined within the boundaries of a non-circular display region. The size of the region to which attention was distributed related to the speed and accuracy of responses to attended stimuli. However, the size of the display did not interact with either perceptual difficulty or target eccentricity. The interpretation that is consistent with these findings is that attention facilitates the localization of a visual stimulus rather than affecting the rate at which a stimulus is processed. Consequently, the operation of localizing a stimulus can occur more efficiently when attention is focused on a smaller region of a visual display than on a larger region.
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Introduction

The idea that it is possible to look out of the corner of one's eyes has been commented on since at least the last century (James, 1890; Wundt, 1880). A good deal of experimentation has since confirmed these early introspections that attention can be directed away from the point at which the eyes are fixated. Attention, then, is focused on some objects present in the visual field in favor of others. In more recent years the metaphor of a "spotlight" has often been used to describe this focusing characteristic of attention (Posner, 1978, 1980; Wachtel, 1967). Specifically, the momentary direction of one's attention is a likened to a spotlight. The focus of this spotlight moves about in the visual field and narrows on specific objects. Objects within the spotlight are processed and identified. Objects that do not fall within the attentional spotlight are not identified. ¹

Research over the past decade has investigated various aspects of the distribution of attention in the visual field. These aspects have included the breadth or size of an optimal attentional focus, the time course involved in directing attention to a specific object, whether attention moves over the visual field in a continuous or discrete manner, what mediates attentional shifts under various task situations, the extent to which unattended objects are processed, and whether or not attention can be distributed to multiple and/or discontiguous locations in the visual field.

The experiments presented in this thesis were conducted to investigate aspects of the operation of attention in the visual field in order to further understand the role of attention in the perception of visually-presented stimuli. Before the research relevant to this topic is discussed, the current theories of attention are presented. Then, research on the operation of attention in the visual field is described and how findings from this research have been interpreted in terms of the major theories of attention are discussed. Finally, the experiments conducted as a part of this thesis are presented.
Theories of Attention

The role of attention in perception is still not clear despite over two decades of research. One view of perception holds that there are two processing systems, one system capable of parallel processing and not subject to severe capacity limitations and the other system capable only of serial processing and subject to capacity limitations. Within this general framework, there has long been controversy about the depth to which stimuli are processed by the parallel system. According to the early-selection position, only crude perceptual analysis is performed by this system whereas according to the late-selection position, extensive processing including semantic analysis is performed.

Treisman's feature-integration theory incorporates aspects of both early- and late-selection views in an attempt to provide a more comprehensive account of existing data. According to this theory, simple, distinguishable features of a stimulus are perceived in parallel and without the benefit of attention. However, attention must be directed to a stimulus before the separate features of a stimulus can be integrated into a unitary object.

An alternative view of perception does not hypothesize separate processing systems. Instead, it views attention as a resource that can be used to speed up processing. The focus of attention can be expanded or contracted like a "zoom lens". The more focused the lens, the more processing is speeded up. This view of attention will be referred to here as "capacity" theory.

In the following sections, the major theories of attention and variations on these theories are described in more detail.

Early-selection theory

Broadbent (1958) observed that when people are faced with a large amount of information, they attend to some stimuli in favor of others. He proposed that a selective filter determines which information is allowed to enter the limited-capacity system for
further processing. This selection can be based on physical properties of a stimulus such as its spatial position or color. However, only one stimulus at a time can be processed by the serial system. The representation of a stimulus that is not selected for processing decays and is never processed for meaning. Welford's (1959) single-channel theory is similar in concept to Broadbent's (1958) filter theory.

Evidence available prior to this time from dichotic listening paradigms supported the concept of a limited-capacity system in which information passes through a bottleneck or filter in order to receive the processing necessary for identification (Broadbent, 1956; Cherry, 1953). Evidence from studies employing visual presentation also supported a single-channel, selective filter hypothesis. For example, Hyman (1953) showed that reaction time to identify stimuli was linearly related to the logarithm of the number of response alternatives. This finding provided evidence that stimuli were being processed serially.

Soon after Broadbent proposed his filter theory, evidence of imperfections in the selective attention filter was reported (Corteen & Dunn, 1974; MacKay, 1973; Moray, 1959; Treisman, 1960, among others). One of the best-known demonstrations of a failure in the hypothetical selective filter was reported by Treisman (1960). She demonstrated that when subjects were asked to repeat a message presented to one ear, words presented to the other ear were occasionally reported if they were semantically related to the attended message. This finding was important because it indicated that some of the unattended information received at least some semantic processing.

Evidence of this sort led some theorists to propose modifications of Broadbent's original filter theory so as to account for evidence that certain words in an unattended message occasionally break through the selective filter (Broadbent, 1971; Treisman, 1960, 1964). Treisman's (1960) filter-attenuation theory is one example of a modification of filter theory. Treisman hypothesized that although the attentional filter
acts to select stimuli for further processing, the filter only attenuates the amount of information from an unattended message. Stimuli present in an unattended message can be perceived if the stimuli have lower thresholds for activating entries in a hypothetical mental dictionary. For example, one's name presented in an unattended message should be noticed more readily than should other irrelevant information. This effect has been termed the "cocktail party phenomenon" (Cherry, 1953). In most situations, however, the "filter" works effectively in keeping out irrelevant information.

Current early-selection views can still be characterized by the postulate that only crude perceptual analysis is performed prior to selection (Broadbent, 1982; Eriksen & Eriksen, 1974; Tsai, 1983). They differ from the first early-selection theories in that they allow for limited parallel processing of information prior to selection. It is important to understand, however, that early-selection views, in which features of unattended stimuli are occasionally processed and the stimuli perceived due to lower perceptual thresholds, are fundamentally different from the view that even unattended stimuli receive extensive analysis. Despite the fact that there seems to be overwhelming evidence against early selection (see discussion on late-selection theory in the next section), this view still receives support in the literature. It is most often the case, however, that support of an early-selection view is tied to specific paradigms and findings. Evidence from other paradigms that is contrary to early selection does not appear to be fully considered.

Late-selection theory

A number of theorists hold that stimuli are processed extensively without the benefit of attention (Allport, Antonis, & Reynolds, 1972; Deutsch & Deutsch, 1963; Duncan, 1980, 1981, 1985; Hoffman, 1978, 1979; LaBerge, 1973; Norman, 1968; Shiffrin, 1975, among others). Late-selection theory arose in response to the evidence of unattended processing referred to in the previous section. Rather than modify filter theory, Deutsch and Deutsch (1963) proposed an alternative in which the selective filter or
bottleneck in the system occurred quite a bit later in the processing sequence than early-selection theorists proposed. They hypothesized that all incoming stimuli automatically receive full perceptual analysis to the semantic level. This analysis is independent of attention although attention controls which stimuli will be remembered.

A recent version of late-selection theory proposed by Duncan (1981, 1985) typifies current late-selection theories of attention and, therefore, will be presented in detail. In Duncan’s theory, perception is said to involve processing stimuli at two levels. Initial processing is relatively extensive, parallel, and not subject to severe capacity limitations. However, the results of this initial processing are not consciously available and cannot serve as a basis for a response until the representation of the stimulus is selected into a second level of processing. This selection mechanism is hypothesized to act on only one stimulus at a time. Selection can be based on any information present at the initial level including semantic information although physical characteristics of stimuli such as color and location have been found to serve as more effective bases of selection than semantic information. In summary, then, late-selection theory holds that processing may be independent of attention, but attention acts to control which stimuli will be remembered and used for responding.

Over the last 15 years there have been a large number of studies reporting results that support late-selection theory. Among the most convincing are those showing either an absence of capacity limitations or evidence of extensive processing of unattended information (Donderi & Zelnicker, 1969; Egeth, Jonides, & Wall, 1972; Eriksen & Schultz, 1979; Hoffman, 1979; Schneider & Shiffrin, 1977; Shaffer & LaBerge, 1979; Shiffrin & Gardner, 1972; Shiffrin, McKay, & Shaffer, 1976). For example, in search tasks in which subjects are required to search for either a target among distractors or search for any target from a set, it has been shown that target detection performance does not vary as a function of the number of distractors or the target set size (Donderi &
Zelnicker, 1969; Egeth, Jonides, & Wall, 1972; Schneider & Shiffrin, 1977). In addition, Schneider and Shiffrin (1977) found that with practice, subjects can monitor four possible target locations just about as well as they can monitor two locations.

There are problems for late-selection theory, however. These problems relate to the fact that much of the evidence contributing to the popularity of late-selection views does not conclusively support the notion that processing of information is performed automatically and in parallel prior to selection. (Broadbent, 1982; Kahneman and Treisman, 1984). In fact, much of the evidence used to support a late-selection position is based on only rare or occasional instances of processing of unattended stimuli. In a review of this evidence, Kahneman and Treisman (1984) found that the proportion of trials that showed processing of unattended information in these experiments ranged from approximately 2 per cent to approximately 38 per cent of the trials. Even Treisman's (1960) dichotic listening study which was one of the first studies to challenge early-selection views by providing evidence that stimuli are sometimes detected even when they are presented in an unattended message revealed that the percentage of detected words comprised only 6 per cent of the total unattended words. Relatively small effects were also apparent in demonstrations of the Stroop effect (Kahneman and Treisman, 1984). Late-selection theorists argue that if there is any evidence of unlimited capacity or extensive processing of unattended information, then selection of information must be occurring late in the perceptual processing sequence. Late-selection theorists have yet to explain convincingly why stimuli appear not to be processed in parallel and/or extensively (and in some cases, not processed at all) if perception takes place in the manner suggested by late-selection theory.

Feature-integration theory

Feature-integration theory (Treisman & Gelade, 1980) incorporates aspects of both early- and late-selection theories in order to explain the role of attention in the perception
of stimuli. Feature-integration theory has since become one of the predominant theories of attention. According to this theory, the detection of simple, distinguishable features takes place in parallel. However, these features are "free-floating" and attention is necessary to integrate them into a single object. Since feature-integration theory holds that initial processing of features can occur in parallel, it can account for some of the evidence of breakthroughs, although unlike the late-selection view, this processing is limited to simple featural analysis. It is believed that stimuli that require more extensive processing necessarily require attention. An important characteristic of this view is that isolated features of a stimulus can be processed and available to serve as a basis for a response even without attention. A more detailed analysis of the entire stimulus, however, requires attention.

Treisman and Gelade (1980) reported evidence from a series of experiments that strongly supports feature-integration theory. In Experiment 4 of this series, the task was to search for a target letter among a varying number of distractor letters. A target letter, "R", was presented among either "P" and "B" distractors or "P" and "Q" distractors. The "R-PQ" stimuli were chosen so that the tail of the letter "Q" could be conjoined with the letter "P" to form an "R". They found that the function relating search time to the number of distractors present was negatively accelerated in the "R-PB" condition and was linearly related in the "R-PQ" condition. Furthermore, the ratio of the positive to negative slopes in the "R-PQ" condition (.45) was almost twice as large as the ratio in the "R-PB" condition (.26). These findings led Treisman and Gelade to conclude that attention was required to serially focus on each individual letter in the "R-PQ" condition and that limited parallel processing occurred in the "R-PB" condition. They also concluded that in the "R-PQ" condition, unattended features sometimes conjoined automatically to form "illusory conjunctions" since false alarm rates were higher in the this condition than in the "R-PB" condition.
Although feature-integration theory is important in that it explains the role of attention in texture segregation tasks, feature/conjunction search tasks, and stroop type tasks (Treisman & Gelade, 1980; Kahneman & Treisman, 1984), this theory has difficulty accounting for evidence of extensive processing of unattended stimuli. Whether this evidence continues to be a serious stumbling block for feature-integration theory remains to be seen (Kahneman & Treisman, 1984; Lane, Martin, & Ashby, 1987). Lane and his colleagues (1987), for example, investigated one finding of extensive analysis of unattended stimuli (e.g., Shiffrin & Gardner, 1972). They found that the processing of stimuli that was able to be performed without capacity limitations was limited to a featural level. They argued that this evidence is consistent with feature-integration theory rather than late-selection theory.

**Capacity theory**

Kahneman (1973) proposed that processing resources available for perception are limited and that attention acts to direct these resources to a specific stimulus. The allocation of resources can be made on the basis of physical properties of a stimulus such as color, spatial position, or stimulus onset. Allocating attention to a stimulus increases the speed with which it is processed and, therefore, increases the probability that it will be processed to completion or be processed at all.

A number of other theorists have proposed capacity views of attention that are similar to Kahneman's (Bashinski & Bacharach, 1980; Eriksen & Hoffman, 1974; Eriksen & St. James, 1986; Eriksen & Yeh, 1985; Hoffman, 1975; Johnston & Dark, 1980; Jonides, 1980, 1983; Keren & Skelton, 1976; Lupker & Massaro, 1979; Moray, 1967; Shaw, 1978; Shaw & Shaw, 1977; Wickens, 1977, among others). For example, Eriksen and Yeh (1985) and Eriksen and St. James (1986) characterized attention as a zoom lens that can be expanded or contracted in order to extract either more or less information from the visual field. A more focused attentional lens, however, is
hypothesized to result in quicker and more accurate processing than a less focused lens. In a similar vein, Eriksen and Hoffman (1974) and Hoffman (1975) proposed that attention acts to enhance a stimulus. This enhancement, then, causes an attended stimulus to be processed at a faster rate than an unattended stimulus. Jonides (1983) proposed a two-process model of resource allocation in which there is either an equal distribution processing resources (unattended mode of processing) or a weighted resource distribution (attended mode).

Evidence supporting capacity theory comes predominantly from two lines of research: research employing divided attention tasks and research employing tasks requiring subjects to attend to multiple stimuli. Most of this research involves a comparison between the amount of attention allocated to different tasks or stimuli and performance. A good deal of evidence suggests that subjects are able to allocate attentional capacity differentially according to performance requirements (Eriksen & Yeh, 1985; Jonides, 1980, 1983; Keren & Skelton, 1976; Shaw & Shaw, 1977; Shaw, 1978; Wickens, 1977, for example). Capacity theory, then, most closely corresponds to the subjective experience of paying either more or less attention to stimuli or tasks.

A potential problem for capacity theory has been raised by Navon (1985). Navon argued that the approach taken in some of the research supporting capacity theory of asking subjects to allocate a given amount of their total attentional resources to specific tasks or stimuli may be causing differences in performance artifically. He suggested that subjects may be responding to demand characteristics. Consequently, performance matches the expectations of the experimenter rather than reflecting the operation of attentional allocation and the limits of attentional capacity. Supporting this contention are results from a divided attention study (Navon, 1985). Navon demonstrated that task instructions alone caused subjects to allocate between two different tasks over 150 per cent of available attentional resources that would be predicted by capacity theory.
Although this finding is a striking one, it does not necessarily contradict capacity theory. Rather, this finding may point out the inaccuracy of current predictions of when time-sharing between tasks can occur and the manner in which available resources are distributed to different tasks. Therefore, it is possible that capacity theory can be revised so as to account for Navon's (1985) findings.

In conclusion, it is not possible to conclusively distinguish among the theories of attention presented thus far. The most troubling aspect of attentional theorizing is that different evidence seems to support entirely different views of attention and perception. One body of research strongly supports one particular theory and appears to be inconsistent with other theories and, yet, other research just as strongly supports an opposing view of attention. Recently, some researchers have focused on task components and possible subject strategies that may influence the allocation of attention in order to reconcile discrepancies between opposing theories of attention (Broadbent, 1982; Kahneman & Treisman, 1984; Briand & Klein, 1987). It has been suggested that there is one attentional system, but that this system is a dynamic one that is able to perform various functions that are more easily accommodated by opposing theories of attention (Kahneman & Treisman, 1984; Lambert, 1987). It has also been suggested that separate attentional systems are invoked in response to both internal influences such as subject strategies and external influences such as task requirements and properties of the stimuli (Briand & Klein, 1987). Although presently, none of these views predominates or is comprehensive enough to challenge the current theories of attention, this seems to reflect the direction some theorizing on attention and perception is heading.
Evidence for Spatial Selectivity of Visual Information

One of the first reports on the ability to selectively direct attention to objects present in the visual field was made by Helmholtz (in James, 1890). Helmholtz presented pairs of stereoscopic pictures in a black box and briefly illuminated the pictures with an electric spark. He controlled for eye movements with the following procedure. A pin-hole made in the center of each picture was illuminated by background light. Consequently, only dots of light were present in the black box. In order to control for eye movements, the observer focused such that the dots combined into a single dot of light. The picture was then illuminated and the observer examined the picture. Some of the pictures were complicated photographs and a number of successive sparks of light were required in order for the observer to examine the entire picture. Helmholtz observed that he could voluntarily attend to a particular portion of the dark visual field so that when the field was illuminated, he was able to detect the portion of the stereoscopic picture to which he had directed his attention.

Since Helmholtz's observations on attention, a good deal of evidence has accumulated to support the idea that attention can be selectively focused on objects present in the visual field. One demonstration revealed that attention can be directed to a particular stimulus presented in the visual field on the basis of a location cue (Averbach & Coriell, 1961). In Averbach and Coriell's experiment, subjects detected a target letter presented in a 2 x 8 array of letters. The most important feature of this experiment was that a bar marker appeared just under the location of a target letter sometime after the presentation of the letter array, indicating the letter that the subject should report. They found that the accuracy of letter detection was highest when the location cue was presented shortly after the presentation of the letter array and decreased monotonically with cue delays up to 250 msec. This indicated that the location cue served to facilitate the operation of focusing attention on a stimulus.
Another important finding in spatial selectivity research was demonstrated in a number of experiments conducted by Eriksen and colleagues (Colegate, Hoffman, & Eriksen, 1973; Eriksen & Colegate, 1970; Eriksen & Collins; 1969). They found that the accuracy of a response to a stimulus can be increased when attention is concentrated or focused on a specific position in a multi-element display on the basis of a cue that is presented before the onset of the elements in the display. Furthermore, attention apparently can focus on the cued location even though the time interval between the cue onset and the display onset is insufficient for eye movements. (On the average, eye movements take approximately 225 to 250 msec to initiate.) Eriksen and Collins (1969) were the first to provide evidence of the effectiveness of location precuing in an experiment employing a circular letter array centered on a fixation point. The array was presented for 50 msec and a bar marker was presented at a varying interval of time before the onset of the array. They found that letter identification accuracy increased as the cue-array SOA (Stimulus Onset Asynchrony, the interval between the onset of the location cue and the onset of the array) increased. The maximum benefit from location cuing occurred with cue-array SOAs of 150 to 200 msec. Increases in SOAs after this point did not provide any additional benefit in identification accuracy and eventually resulted in a drop-off in facilitation from location cuing.

Eriksen and colleagues discovered that the speed of identifying a target letter is also facilitated by location cuing (Colegate, Hoffman, & Eriksen, 1973; Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1972a, 1972b, 1973; Eriksen & St. James, 1986; Eriksen & Schultz, 1979; Eriksen & Yeh, 1985). The pattern of results from a series of experiments employing reaction time as a dependent measure mirrored the pattern of results obtained when accuracy was employed as a dependent measure. Specifically, reaction times to identify a target letter were shortest when a location cue preceded the letter array by about 150 to 200 msec.
The accuracy and reaction time data obtained by Erikson and his colleagues indicate the mechanism of selectively attending to a stimulus takes a measurable amount of time to operate. The fact that the maximum benefit of location cuing occurred when the cue preceded the stimulus by about 150 to 200 msec in these experiments suggests that this is the time required, on the average, to focus attention on a specific stimulus location and exclude the other locations in the display. Since further increases in precue time do not result in any additional benefit in performance, this asymptote in performance reflects the time at which attention is first maximally focused on a stimulus.

Evidence of the time course of attentional focusing revealed in the behavioral studies just described corresponds quite well with evidence from physiological studies employing event-related brain potential (ERPs) indexes of attentional selectivity (Van Voorhis & Hillyard, 1977, for example). ERPs are voltage reflections in an electroencephalogram. Patterns in certain components of ERPs are taken as evidence of cognitive activity specifically related to attentional phenomena. A number of demonstrations have revealed that a precue presented at a to-be-attended location elicits a higher amplitude ERP component about 80 - 250 msec after cue onset, implying that sensory pathways are facilitated during this time.

Taken together, the accuracy and reaction time data and the physiological data demonstrate the selective property of an attentional system that favors a cued stimulus over other stimuli in a display. A location precue, then, allows the process of focusing attention on a stimulus to begin even before the onset of the critical stimulus. Furthermore, the operation of focusing attention takes a measurable amount of time to complete.

A particularly interesting finding in location-cuing research is that a location precue can facilitate the speed with which a stimulus is discriminated even when the stimulus is presented in an otherwise empty visual field (Anderson & Lane, 1986; Erikson &
Hoffman, 1973, 1974; Hoffman, 1975; Posner, 1978, 1980; Posner, Snyder, & Davidson, 1980; Tsal, 1983). The typical task employed in these experiments involved discriminating which one of two stimuli appeared on the display. These experiments demonstrated that when the location of the stimulus was preceded by a location cue approximately 50 to 100 msec before stimulus onset, reaction time to identify the stimulus was facilitated by approximately 30 to 40 msec. A somewhat surprising finding is that facilitation in performance due to location precuing has been shown to result even in the simple perceptual task of detecting a dot of light (Posner, Nissen & Ogden, 1978; Posner, Snyder, & Davidson, 1980; Remington & Pierce, 1984; Shulman, Remington, & McLean, 1979).

The results from location-cuing experiments employing single-stimulus designs indicate that, (1) location cuing can influence stimulus identification performance even when the stimulus is the only element in the display and, (2) stimulus localization can play a role in the processing of visual information even when the processing that is performed on a stimulus is relatively simple.

Although it has been widely demonstrated that cuing the location at which a visual stimulus will appear improves the speed and/or accuracy of a response to the cued stimulus (Bashinski & Bacharach, 1980; Eriksen & Hoffman, 1972a, 1972b, 1973; Eriksen & St. James, 1986; Eriksen & Yeh, 1985; Hoffman, 1975; Johnston & Dark, 1982; Jonides, 1980, 1981; Keren & Skelton, 1976; Lupker & Massaro, 1979; Posner, 1978, 1980; Posner, Nissen, & Ogden, 1978; Posner, Snyder, & Davidson, 1980; Remington & Pierce, 1984; Shulman, Remington, & McLean, 1979, among others), the interpretation of this attentional effect is complex. The fact that location cuing results in improved performance has typically been taken as evidence in support of either a capacity or an early-selection view of attention.

The capacity interpretation of the location-cuing effect is that location cuing causes
an increase in the rate at which a cued stimulus is processed (Bashinski & Bacharach, 1980; Eriksen & Hoffman, 1973, 1974; Eriksen & St. James, 1986; Eriksen & Yeh, 1985; Hoffman, 1975; Johnston & Dark, 1980; Jonides, 1981, 1983; Keren & Skelton, 1976; Lupker & Massaro, 1979; Shaw, 1978; Shaw & Shaw, 1977). According to this interpretation, cuing the location of a stimulus in advance of its presentation draws attention and, hence, processing resources to a stimulus sooner than in the non-cued situation. Since the allocation of processing resources can begin after the onset of the location cue rather than after the onset of the stimulus, more resources can be devoted sooner to the cued stimulus. The result is that it is processed faster and more fully than an unattended stimulus and, consequently, the reaction time to detect or identify the stimulus is reduced. The accuracy of a response may also be improved since more resources may be devoted to a stimulus for a longer duration, increasing the chances that it will be identified. As Yantis and Jonides (1984) summarize it,

"...the cue allows subjects to allocate scarce resources to a particular spatial channel in advance, resulting in rapid processing of whatever signal subsequently occupies that channel." (p. 602).

The behavioral and physiological data indicating that attentional focusing follows a definite time course are also consistent with capacity theory. Capacity theory interprets the time course of attentional focusing as a manifestation of the time required to allocate resources to stimuli in the visual field.

The interpretation that is consistent with early-selection theory is that cuing the location at which a stimulus will appear benefits performance since a stimulus must be located and selected before it can be extensively processed. When a stimulus location is cued in advance of the stimulus presentation, attention can be directed to a stimulus location sooner than when no cue is provided. In this sense, attention gets a headstart in locating the stimulus. Thus, once attention arrives at a cued location, any stimulus in that
location can be selected (i.e. transferred) for processing by a limited-capacity system. Cuing facilitates both detection and discrimination tasks since this locating operation can be based on the cue presentation alone. In addition, attention can even arrive at the cued location before the stimulus is displayed if the duration of cue-stimulus SOA is longer than the time it takes attention to shift to the cued location. It should also be evident that this view predicts that if a stimulus does not receive the benefit of attention, it should not be identified.

The location-cuing effect appears to pose greater interpretation problems for late-selection and feature-integration theories since both theories place the role of attention in the perception of stimuli later in the perceptual processing sequence. Duncan (1981), however, pointed out that a late-selection position can interpret the fact that performance is benefited by location cuing. He hypothesized that although processing of a stimulus occurs whether or not it is attended, a representation of the stimulus must be located before it can be further processed by a limited-capacity system and serve as a basis for a response. According to Duncan, it is this selection rather than the original processing that is facilitated by the advanced location information.

Feature-integration theory is important in that it explains the role of attention in texture segregation tasks, feature/conjunction search tasks, and stroop type tasks (Treisman & Gelade, 1980; Treisman & Schmidt, 1982). Some researchers have argued that feature-integration theory cannot account for some evidence of location cuing, specifically, evidence from detection and discrimination tasks in which the stimuli are relatively easy to discriminate (Briand & Klein, 1987; Duncan, 1985). Although Treisman and her colleagues have acknowledged that location information can play a special role in stimulus identification even in relatively simple perceptual tasks (Kahneman & Treisman, 1984; see also Nissen, 1985), it is important note that feature-integration theory does not directly address the process of stimulus localization in perception.
Rather, feature-integration theory explains under what circumstances attention is required (whenever integration of more than one separable feature is necessary for stimulus identification) and the consequences when attention is not available or is misdirected (conjunction errors). Consequently, although the effect of location-cuing is not directly predicted by feature-integration theory, the effect is not inconsistent with this theory.

Recently, Briand and Klein (1987) suggested that the role of attention involved in the process of localizing a stimulus may be entirely different than the role attention plays in feature integration. In a series of experiments, they directly combined the search task employed by Treisman and Gelade (1980, Experiment 4, i.e. searching for the letter "R" among either "PQ" or "PB" distractors) with two different location-cuing methods (endogenous and exogenous cues) using both valid and invalid cues similar to the method employed by Posner and his colleagues (Posner, 1980; Posner, Nissen, & Ogden, 1978; Posner, Snyder, & Davidson, 1980). A directional arrow appearing at fixation served as the endogenous cue and a dot appearing in the periphery next to the location of the letters served as the exogenous cue. They argued that if the same attentional mechanism controls both location cuing and the integration of features, then the difference between reaction times for valid and invalid cues should be greater when conjunction errors are possible ("R-PQ" stimuli) than when detections can be made on the basis of a single feature ("R-PB" stimuli). In other words, they argued that "PQ" stimuli should result in more illusory conjunctions when the stimuli are presented at an unexpected location than at an expected location. If spatial expectancy does not affect the likelihood of conjunction errors, then location cuing and feature integration are controlled by separate attentional systems, according to Briand and Klein. When endogenous cues served as the location cues, there was no evidence that illusory conjunctions were more likely to be made in the invalid cue condition. However, when exogenous cues were used, the location-cuing effect was larger with the "R-PQ" stimuli. They concluded that there are two attentional
mechanisms, one that is involved in feature integration and responds to exogenous cues and one that is involved in locating a stimulus and responds to endogenous cues.

Although a comprehensive theory of attention and perception must be able to accommodate both feature integration and the benefit resulting from advanced knowledge of spatial position, it is not clear at this point whether or not separate attentional mechanisms are required in order to accommodate existing data.

In summary, the majority of the data that demonstrate selective focusing of attention on visually-presented stimuli are consistent with all of the current theories of attention. Various aspects of the process by which attention is selectively focused on stimuli have been investigated since the first demonstrations of the location-cuing effect in the late 1960's and early 1970's. One area that has received investigation relates to the process by which attention is shifted to a particular spatial position. Although the research discussed previously has demonstrated that attention, with time, can be narrowly focused on a specific spatial position within a display, more recent investigations have examined whether or not attention can be redirected from one spatial position to another.

A number of experiments have demonstrated that attention can be first directed to one point on a visual display and then redirected to another spatial position (Posner, 1980; Posner, Nissen, & Ogden, 1978; Remington & Pierce, 1984; Shulman, Remington, & McLean, 1979). Shulman, Remington, and McLean (1979) were the first to demonstrate that these attentional shifts appear to traverse the visual field in a continuous fashion. They were interested in the operation of shifting the focus of attention from a central fixation point to spatial positions at varying distances to the periphery. In their experiment, subjects were required to detect a target that was located along an imaginary horizontal line. A directional cue was presented at the center of this imaginary line to indicate the most likely side (left or right) on which a target could appear. Although a target could appear at one of two distances (8 degrees, or 18 degrees) on either side of
fixation, subjects were informed that the target would appear at the furthest location on the cued side on most of the trials. Shulman and his colleagues found that targets appearing at distances 8 degrees of visual angle from fixation were maximally facilitated at a time sooner than were targets appearing at distances 18 degrees of visual angle from fixation. Furthermore, responses to targets presented at the near location showed a gradual increase in facilitation as the cue-target increased but additional increases in SOA resulted in a subsequent decrease in facilitation at this location. Their interpretation of these results was attention traveled to the periphery in a continuous fashion and, consequently, arrived at the near location sooner than the far location.

However, another experiment investigating attentional shifts in the visual field led Remington and Pierce (1984) to conclude that attention moves in discontinuous jumps, mimicking saccadic eye movements, rather than moving in a continuous fashion across the visual field. Their design was similar to that employed by Shulman and colleagues (1979) with the exception that the expectancy of a target appearing at each target location (near and far) was blocked. They compared the point at which facilitation in reaction times to detect a target asymptoted for the near and far target locations and found that the functions relating reaction time to cue-target SOA reached asymptote at approximately the same SOA. In other words, the time course of attentional movement was constant and independent of the distance traveled. They argued that the differences between their results and the Shulman et al. (1979) results could be due to fact that a target was expected to appear at a near location in some trials in their experiment. Their interpretation of the results was that an attentional mechanism was able to make an adjustment on the basis of the precue and move to the expected target location in one discrete jump, irrespective of whether the cued location was near or far from fixation. An alternative interpretation, however, is that shifts of attention traverse the visual field in a continuous fashion, but the velocity involved in traversing visual space is not fixed.
An experiment conducted by Tsai (1983, Experiment 1) directly measured the time course of attentional shifts. Tsai employed a discrimination task in which location cues were presented at varying lengths of time before stimulus presentation. Most important for the present discussion, the distance between fixation and the location at which a stimulus appeared was varied on each block of trials so that a stimulus was presented either at a near (4 degrees), intermediate (8 degrees), or far (12 degrees) location to the left or right of fixation. Tsai found that the cue-stimulus SOA at which the Reaction time x SOA functions reached asymptote was smaller for a nearer display location than for a display location that was further from fixation. Tsai then compared the asymptotic SOA for each distance and found that this Asymptotic SOA x Distance function had a slope of about one indicating that the reduction in reaction time to discriminate between stimuli (up to an asymptotic SOA) directly corresponded to the duration of the cue-stimulus SOA. He concluded that attention traveled at a constant rate based on comparisons of the asymptotic SOAs and the distances between display locations. He found that attention appeared to take approximately 8 msec to traverse each degree of visual angle that the display location was displaced from fixation. In addition to this traveling time, he concluded that there was an approximate 50 msec deadtime prior to attentional movement since the Asymptotic SOA x Distance function intercepted the SOA axis at approximately 50 msec. Tsai hypothesized that this deadtime reflects the time necessary to both signal attention and initiate attentional movement toward the cued location.

In a task similar to that employed by Tsai, Anderson and Lane (1986, Experiment 3) also found evidence that the function relating facilitation in reaction time to discriminate a stimulus to cue-stimulus SOA was bilinear. Specifically, the Facilitation x SOA function had a slope of approximately one followed by a slope of zero. They argued that the initial section of the function reflected the time during which attention was shifting to the cued location and the asymptotic point on the function indicated that attention had arrived at the
cued location.

Evidence of a slope of approximately one in the Facilitation x SOA function (or Asymptotic SOA x Distance function) in the above studies (Anderson & Lane, 1986; Tsal, 1983) is important since it suggests that the process of stimulus localization is independent of the perceptual analysis that is performed on the stimulus. This result is inconsistent with capacity theory since this theory holds that the rate of processing is proportional to the amount of attention allocated to the stimulus. Since some processing of the stimulus occurs without attention being focused on it, a finding of a slope less than one would be consistent with capacity theory.

Tsal's (1983) interpretation of his data is consistent with an early-selection hypothesis in which attention operates like a spotlight that travels to the location at which a stimulus appears. Tsal suggested that the attention is first signaled and then the focus of attention traverses across the visual field at a constant rate to the location of a stimulus without concurrent processing. He suggested that processing of a stimulus that is more extensive than that involved in detecting luminance changes does not begin until the stimulus is located and selected to a limited-capacity system.

Although the Tsal (1983) and Anderson and Lane (1986) results are consistent with the hypothesis that the time following the onset of a peripheral stimulus is devoted to attentional movement only, Anderson and Lane (1986) argued that the data do not directly contradict a late-selection position since this latter view also holds that location cuing affects only the selection process. Other evidence provided by Anderson and Lane (1986, Experiment 4) indicates that information about properties of a stimulus that is used in stimulus identification is available prior to the attentional process of localizing the stimulus. In Experiment 4, Anderson and Lane presented targets in the periphery of a visual display either to the left or right of fixation. In addition, they masked the target at an exposure duration that was short enough to precede the point at which attention arrived
at the target location as determined by the point at which the Reaction time x SOA function reached asymptote. This insured that only the mask was present when attention arrived at the target location. They argued that if the target is not processed before attention is directed to the target, then the accuracy of target identification should be poor in this situation. They found, however, that identification accuracy was very high (96 per cent) indicating that the targets were processed to some extent prior to the arrival of attention at the target location. They concluded that the initial processing performed on targets in this experiment was independent of attention traveling to the stimulus location.

The previous speculations (Anderson & Lane, 1986; Tsal, 1983) on the independence of target localization and initial processing must be taken with reservation, however, since others researchers have not observed a one-to-one relationship between facilitation in reaction times and short cue-stimulus SOAs (Kaye, 1984). In a series of attempted replications of Tsal's (1983) results, Kaye also found that reaction time to discriminate between two stimuli decreased as the SOA increased. Facilitation from cuing appeared to asymptote at shorter SOAs when stimuli were presented nearer to fixation and at longer SOAs when stimuli were presented at distances further from fixation although there was a greater amount of fluctuation in these functions than there were in Tsal's. These results provide support for the hypothesis that the focus of attention traverses visual space in a continuous fashion. However, Kaye failed to find evidence of a slope of one followed by a slope of zero even though the methodology of his experiment was quite similar to Tsal's methodology. Consequently, these results are consistent with a capacity theory interpretation.

To summarize, the majority of the data from experiments examining shifts of attention provide support for the hypothesis that the focus of attention traverses visual space in a continuous fashion (Anderson & Lane, 1986; Kaye, 1984; Shulman, Remington, & McLean, 1979; Tsal, 1983) although there are exceptions (Remington &
Pierce, 1984). However, evidence related to the issue of whether or not stimulus localization and initial processing are independent is conflicting and, therefore, cannot be used to distinguish among current theories of attention with any degree of certainty.

Another aspect of attentional focusing that has received investigation is whether the focus of attention subtends a discrete area, consistent with a spotlight metaphor. An experiment conducted by Eriksen and Hoffman (1972b), directly tested this issue by varying the distance between a target letter and flanking distractor letters. A target and distractors were presented at eight locations on a circular display. The target was precued with a bar marker presented just below the target location 0 to 300 msec prior to the onset of the array. The distance of closest distractors to the target was varied such that they were located either .53 degrees, 1.0 degree, or 1.4 degrees of visual angle from the target. They found that benefits from precuing the target location increased as the interval between the onset of the cue and the onset of the array increased and asymptoted at the same SOA for all three distractor distances. However, interference from distractors was more pronounced in the .54 degrees condition than in the 1.0 and 1.4 degrees conditions. Furthermore, the 1.0 and 1.4 degrees conditions did not significantly differ from one another. This evidence suggests that the attentional focus, as measured in terms of the visual angle subtended in the visual field, covers just over one degree of visual angle.

Eriksen and Hoffman (1973) provided additional evidence that the size of the attentional focus at the point in time at which attention is maximally focused on a stimulus subtends approximately one to two degrees of visual angle.

Other researchers, however, have suggested that attention is distributed in a manner likened to a spotlight, but there is a gradual decrement of attentional benefits for regions surrounding the attended location rather than a sharp all-or-none spotlight distinction suggested in the previous studies (Downing & Pinker, 1985; Eriksen & St. James, 1986). Eriksen and St. James (1986) came to this conclusion based on results from an
experiment in which one, two, or three adjacent target locations in a circular array of eight locations were precued with a bar marker. The subject's task was to determine which one of two target letters (S or C) was present in the cued location(s). Eriksen and St. James varied the compatibility of the distractors appearing in the non-cued positions and measured the influence of flanking distractors on responses to a cued target. They found that when the opposite target letter was one of the distractors (incompatible noise condition) and was located one position away from the cued position(s), interference resulted. Their interpretation of this finding was that the distractor letter was competing with the response to the target letter. The gradient of the interference due to the incompatible distractor dropped off as the incompatible distractor was positioned further away from the closest cued position(s) to the point where no interference was evidenced when the incompatible letter was three positions away. These findings are consistent with the notion that attention operates in a manner likened to a zoom lens or flexible spotlight (Eriksen & St. James, 1986; Eriksen & Yeh, 1985). However, there are alternative interpretations that are consistent with these data. For instance, it is possible that the shape of the focus of attention is similar in shape to that of a spotlight, but this attentional spotlight is occasionally misdirected to distractors of close spatial proximity. Another possibility is that in the Eriksen and St. James (1986) experiment, the shape or features of the incompatible distractor drew attention to the distractor since the target letters shared similar features (Duncan, 1981).

Still other evidence indicates that the size of the attentional focus can vary somewhat depending on task demands (Eriksen & Yeh, 1985; LaBerge, 1983; Lane & Pearson, 1983). LaBerge (1983), for example, required subjects to categorize the middle letter of a five-letter string or to categorize the entire five-letter string. Subjects then identified a probe digit presented at one of the five letter positions. He found that reaction times to identify a probe digit were relatively equal across letter positions when the primary task
was to categorize words. However, when the primary task was to categorize the middle letter, a V-shaped function for reaction times was observed with the fastest reaction times being made to probes presented at the middle position. The interpretation of this finding is that the size of the attentional focus varied to encompass either one letter or the entire word. In fact, LaBerge found evidence that attention could be focused on a single letter subtending only .3 degrees of visual angle.

There is also evidence that subjects cannot ignore irrelevant information presented at separations larger than the one to two degrees of visual angle that was previously thought to be the size of the focus of attention (Eriksen & Hoffman, 1972b). Gatti and Egeth (1978) employed a modified form of the Stroop word-color task and found that distractors appearing at separations subtending five degrees of visual angle from a target still interfered with a response to the target. In other words, subjects apparently could not ignore the irrelevant stimuli. It is not clear, however, whether these results reflect a failure to reduce the size of the attentional focus or whether the irrelevant stimuli were processed without attention being focused on them.

To summarize, it appears that attention can be directed in a more flexible manner in the visual field than was originally hypothesized by Eriksen and Hoffman (1972b). The concept of a strictly-limited attentional focus may not be valid. It is possible that the size of the focus of attention can vary, much like a flexible spotlight or zoom lens. Variables that appear to affect the extent to which the size of an attentional focus can vary include the time allowed for attentional focusing (Eriksen & Hoffman, 1973; Eriksen & St. James, 1986), the ease of the task (Eriksen & St. James, 1986; Eriksen & Yeh, 1985; LaBerge, 1983), and the extent to which distractors can be combined with the target (Gatti and Egeth, 1978).

Some researchers have concluded that attention can be split among a number of possible target locations (Shaw, 1978; Shaw & Shaw, 1977). Shaw and Shaw (1977),
for example, found that subjects were able to allocate their attention to a number of
possible target locations in accordance with the most optimal allocation strategy. They
employed a target detection task in which subjects were required to attend to eight
different spatial locations of a circular display that was centered on a fixation marker. The
probability of a target appearing at a given spatial location was varied across blocks.
They found that performance on targets presented at each of the eight spatial locations
matched the probability of a target appearing at each location for that block of trials. They
took this as evidence that subjects were able to distribute their attention to a number of
possible locations in accordance with an optimal allocation strategy even when the two
most-likely target locations were maximally separated.

Posner, Snyder, and Davidson (1980), however, concluded that the distribution of
attention to multiple locations is spatially constrained. They required subjects to detect a
red light-emitting diode (LED) appearing at the perimeter of a circle that subtended either
two degrees or eight degrees of visual angle. Subjects were required to attend to both a
primary location and a secondary location on a display. They found that attention could
be successfully allocated to a secondary location, but only when the secondary location
was adjacent to the primary location. There was no evidence of an ability to allocate
attention to non-adjacent locations simultaneously.

Eriksen and Yeh (1985) also found evidence that subjects were unable to distribute
their attention between discontiguous display locations simultaneously. They employed a
circular array of eight letters and presented a precue of varying validity (40 per cent to 100
per cent) to indicate the target letter. They informed subjects that on some trials, the target
could appear at a second most-likely location that was diametrically opposed to the
primary target location indicated by the cue. Reaction times were shortest when the
validity of the location cue was 100 per cent and steadily increased as the validity of the
cue decreased. Reaction times to targets appearing at a secondary location were much
longer than reaction times to targets appearing at a primary location. In fact, reaction
times to targets presented at a secondary location were longer than were reaction times to
targets appearing at the same location on trials in which no cue was presented. The
interpretation Eriksen and Yeh offered for these data is that subjects were using a focused
approach in distributing attention with the focus being directed to the primary target
location only. If a target did not appear at the primary location, subjects then shifted the
focus of their attention from the primary location to the secondary location. Since this
switching operation took time to complete, reaction times to targets appearing at a
secondary location were quite long.

Although it appears that the results obtained by Shaw and Shaw (1977) are
inconsistent with the results obtained by Posner, Snyder, and Davidson (1980) and
Eriksen and Yeh (1985), Posner and his colleagues provided a possible explanation for
these differences. They pointed out that in their experiment, the most-likely and second
most-likely target locations changed on each trial. In order to split attention between the
two locations, subjects would have had to realign their attention to both the primary and
secondary locations on each trial. In the Shaw and Shaw (1977) experiment, however,
target probabilities were assigned over a block of trials. Therefore, it is possible that the
correspondence between reaction times and target location probability in the Shaw and
Shaw experiment could have been due to the subjects' probability matching over trials (a
criterion effect) rather than reflecting an ability to distribute attention among discontinuous
target locations.

There is evidence from experiments employing luminance detection tasks that the
number of target locations subjects are required to monitor does not affect target detection
performance differentially (Shiffrin, McKay, & Shaffer, 1976; Tsai, 1983). For
example, Shiffrin, McKay, and Shaffer (1976) required subjects to detect a dot appearing
in a grid of either 49 display locations, 9 display locations at the center of the grid, or 9
display locations surrounding the center. They found that detection efficiency did not depend on the number of display locations being monitored. Similarly, Tsal (1983, Experiment 3) found that subjects responded just as quickly to dots of light presented at locations subtending either 2 degrees, 4 degrees, or 8 degrees visual angle from fixation.

There are two interpretations of the luminance detection results. The first interpretation is that subjects are able to split their attention among possible display locations simultaneously. This interpretation is consistent with the interpretation provided by Shaw and Shaw (1977; see also Shaw, 1978). The second interpretation is that these tasks can be performed even without attention (Shiffrin, McKay, & Shaffer, 1976). Consequently, luminance detection efficiency does not depend on the number of display locations or the size of the region in which a target appears. This latter argument is not consistent with evidence provided by Posner, Snyder, and Davidson (1980), however, since the Posner et al. study also employed a luminance detection task. Posner et al. found that subjects were limited in their ability to detect LEDs that were spatially separated from a primary target location.

Although Podgorny and Shepard (1983) found evidence of an ability to monitor a number of spatial positions simultaneously, they also discovered that this ability was somewhat constrained by the spatial proximity of the spatial positions being attended to. They conducted a series of experiments in which subjects were to detect either the onset or the offset of a dot. In Experiments 2 and 3, they presented a 3 x 3 grid subtending 2.4 degrees of visual angle and shaded a subset of the grid. In addition, the number of shaded squares in the grid was varied from one to nine squares. Subjects indicated whether a dot appeared inside or outside a shaded region. They found that reaction time to detect the onset or offset of a target was independent of the number of shaded squares as long as the squares were contiguous. Dots appearing in subsets of the grid that were less compact took longer to correctly classify.
To summarize, it is unclear whether attentional allocation is performed in a manner that is consistent with a spatially constrained spotlight as Posner et al. (1980) hypothesized or in a manner that is consistent with an attentional resource that can be allocated to different spatial positions as Shaw and Shaw (1977; see also Shaw, 1978) hypothesized. In addition, although there is some evidence indicating that luminance detection efficiency does not depend on the number of display locations or the size of the display, it is not clear whether attention is distributed among display locations in these tasks or whether these tasks can be performed without attention. Still other results indicate that although attention can be distributed to multiple locations, the spatial locations must be contiguous (Eriksen & Hoffman, 1973; Eriksen & St. James, 1986; Eriksen & Yeh, 1985; Podgorny & Shepard, 1983).

Evidence that the size of the attentional focus can vary, at least to some extent (analogous to a flexible spotlight or zoom lens view of attention), along with evidence that attention can be split among different spatial positions raise the question of whether or not there is a correspondence between the size of the attended regions and the speed of processing occurring on attended stimuli. This question is of theoretical importance since different theories of attention provide different interpretations of the correspondence between attentional focus size and processing efficiency.

According the capacity view, the more concentrated the attentional resources allocated to a particular spatial area, the faster should be the rate of processing on a stimulus receiving these resources. This is predicted since capacity theory holds that attention acts to increase the rate of processing that is performed on a stimulus. A smaller attentional focus, then, should result in a faster rate of information uptake than a larger focus.

Neither an early-selection nor a late-selection view necessarily predicts that the size of the attended area should directly correspond to the speed of perceptual processing since
these theories are object-based theories (Duncan, 1984). In other words, attention is hypothesized to act on stimuli as whole objects. Since attention acts to localize or select a stimulus in the visual field, the specific size of a stimulus attention is focused on should not affect processing efficiency. However, if the task is to detect a stimulus that will appear somewhere within a to-be-attended region, than the size of the attended region, and consequently, the size of the attentional focus, should affect performance since there is still a degree of uncertainty about the exact spatial position at which a stimulus will appear. Therefore, selection should be more efficient within a smaller to-be-attended region than within a larger region. To summarize, the selection positions are consistent with the hypothesis that the size of the area attention is directed to affects the efficiency with which stimuli are localized rather than the efficiency with which stimuli are processed.

Although feature-integration theory makes predictions about the effects of both attending and not attending to stimuli (see Briand & Klein, 1987), this theory does not directly address the issue whether or not attentional focus size should affect performance differentially. Consequently, feature-integration theory is consistent with evidence that focus size affects processing efficiency as well as evidence that it does not, although this theory cannot predict either result.

On the surface, the expectancy data described previously (Posner, Nissen, & Ogden, 1978) appear to address the issue of whether or not the size of the focus of attention results in differences in detection or identification performance since valid cues speed responses and invalid cues slow responses. It is not possible to distinguish whether these data reflect the amount of attention allocated to a particular location or the speed with which stimuli are localized, however. LaBerge's (1983) findings are relevant to this issue. Recall that LaBerge manipulated the size of the attended region by requiring subjects to categorize either one letter or a string of five letters. Most important for
present purposes, he found that subjects responded slightly faster to five-letter words than to single letters. This finding is the reverse of the prediction made by capacity theory that a smaller attentional focus should allow for a higher concentration of attentional resources on a stimulus. LaBerge's data is consistent with feature-integration, early-selection, and late-selection theories since these theories are consistent with the hypothesis that attention acts on an entire stimulus irrespective of its size. The interpretations of these results must be tempered by that fact that the tasks of categorizing a letter and categorizing a word may differ in difficulty, however. Consequently, it is not possible to determine whether or not task differences masked any benefits of a smaller attentional focus in these data.

Other experiments also failed to find evidence that differences in the size of the to-be-attended region result in corresponding differences in performance. Shiffrin, McKay, and Shaffer (1976) found that detection efficiency did not depend on the number of display locations. Tsal (1983, Experiment 3) found that subjects responded just as quickly to dots of light presented at locations ranging from two to eight degrees of visual angle from fixation. Although these results also appear to be inconsistent with capacity theory, as mentioned previously, it is possible that these tasks were perceptually simple enough that they could be performed even without attention.

Egeth (1977) found evidence that the size of the attentional focus directed to a stimulus corresponds to the speed of the response. In his experiment, subjects were required to perform a target detection task under both small and large display size conditions. A comparison of reaction times only for the targets appearing at fixation in the two display size conditions revealed that reaction times were shorter with the smaller display than with the larger display. Egeth's results, then, match the predictions of capacity theory. It is important to note, however, that Egeth's results can also be accommodated by feature-integration, early-selection, and late-selection theories since these theories are consistent with the hypothesis that the size of the attended region can
affect the efficiency with which a stimulus is localized.

Another method for investigating whether or not attention affects the rate of processing of a stimulus involves examining the effect of location cuing on the perceptual difficulty of the stimulus discrimination to be performed (Anderson & Lane, 1986). Sternberg's (1969) "additive factors" logic is helpful for distinguishing the predictions that are consistent with the theories of attention when both perceptual difficulty and location-cuing variables are manipulated. According to this logic, variables affecting the same stage should interact. However, if variables affect different stages, no such interaction should result. If, as the capacity view holds, location cuing speeds the rate at which stimuli are processed, then the effect of cuing should be greater for more difficult discriminations than for easier discriminations. In the simplest terms, the more perceptual processing required, the larger should be the effect of a variable that increases the rate of processing. Therefore, the prediction that is consistent with capacity theory is that the effect of location cuing should be larger when more perceptual processing is required since there is more processing that has an opportunity to be speeded. Early- and late-selection views do not predict an interaction between location cuing and the perceptual difficulty of the stimulus discrimination. According to these views, the effect of location cuing should be similar for easy and difficult discriminations since cuing affects only the selection of a stimulus rather than the rate at which a stimulus is processed.³

Data reported by Tsal (1983, Experiment 2) are relevant to this discussion. Tsal included both easy and difficult stimuli in a discrimination task in which location cues were presented at varying lengths of time before stimulus presentation. Vocal reaction time to respond to a stimulus presented at one of two distances from fixation was measured. The level of stimulus discriminability (easy and difficult) and the distance from fixation (near and far) were varied by block. Tsal found that a relationship existed between the time that a location of a stimulus was cued in advance and the distance of the
stimulus location from fixation. Reaction times were shorter for stimuli presented closer to fixation than for stimuli presented further from fixation and decreased to an asymptotic level as the cue-stimulus SOA increased. Furthermore, the SOA at which facilitation in reaction times asymptoted was smaller at the near display location than at the far display location. The effect of the difficulty variable is most important for the present discussion, however. Tsal found that the SOAs at which reaction times in the near and far distance conditions reached asymptote did not depend on the difficulty of the stimulus discrimination and slopes of the Reaction time x SOA functions were nearly identical for the easy and difficult conditions. In other words, the effect of cuing was just as large for stimuli that were easy to discriminate as for stimuli that were more difficult to discriminate.

Anderson and Lane (1986) reported similar results in a series of experiments that manipulated both the perceptual difficulty of the stimulus discrimination and the validity of the location cue. Even though the effects of each of the two variables were quite large, there was no evidence of an interaction between the variables in any of the experiments. In other words, valid cues provided as much facilitation for easy discriminations as they did for difficult discriminations while invalid cues inhibited easy and difficult discriminations to the same extent.

Failures to find evidence of an interaction between location cuing and perceptual difficulty cannot be interpreted from a capacity standpoint. Tsal (1983) provided an early-selection interpretation that is consistent with the evidence. Tsal proposed that since location cuing provides an attentional system with a headstart in shifting to the cued location, the difficulty of the processing necessary to perform a stimulus discrimination is not affected by location cuing. Anderson and Lane (1986) pointed out that both early- and late-selection theories can accommodate the existing location-cuing/perceptual difficulty data since both theories hold that the locus of the cuing effect is on selection
rather than on perceptual processing. Since location cuing allows selection to proceed more expediently, selection is facilitated by cuing irrespective of the difficulty of the stimulus discrimination.

The fact that perceptual difficulty and location cuing did not interact in the Tsal (1983) and Anderson and Lane (1986) studies is important since it suggests that the effect of location cuing is not on the rate of perceptual processing. However, this conclusion is inconsistent with Egeth's (1977) conclusion that the size of the attentional focus affects the rate of processing.

The experiments conducted as a part of this thesis directly test whether or not the size of the region to which attention is distributed affects the rate of perceptual processing. Each of the experiments employed a discrimination task in which one of two stimuli appeared somewhere within a precued region of a visual display. The size of the to-be-attended region was varied. In addition, the stimuli were either easy or difficult to discriminate. Both reaction time and accuracy measures were taken.

The perceptual difficulty variable is an important component of the experiments since some of the theories of attention make different predictions when this variable is crossed with a display size variable. Recall that it was not possible to distinguish among theories when only the size of the region in which a stimulus could appear was varied (Egeth, 1977; LaBerge, 1983; Shiffrin, McKay, & Shaffer, 1976; Tsal, 1983). The predictions for the experiments are as follows. If the size of the attended region affects the efficiency with which stimuli are processed, then this effect should be greater for stimuli that are more difficult to discriminate between than for stimuli that are easier to discriminate. In other words, an interaction between display size and perceptual difficulty should result if both variables affect perceptual processing. This prediction is consistent with a capacity view of attention since, according to this view, a higher concentration of attentional resources should facilitate difficult stimuli to a greater extent than easy stimuli. However,
if the size of the attended region of the display does not affect the processing rate, then no interaction between display size and perceptual difficulty should result.

An additional manipulation included in the present experiments should also provide some insight as to whether or not the size of the attended region affects the processing rate of stimuli. Specifically, the degree of eccentricity at which a target could appear was manipulated such that on each trial, a stimulus could appear at either an inner, middle, or outer location. Like the perceptual difficulty variable, the target eccentricity variable should also affect the efficiency of perceptual processing since on some of the trials, targets fall on less sensitive retinal locations. Consequently, it should not be surprising if this variable interacts with the difficulty variable. If the attentional variable (display size) affects performance in the same manner that visual acuity affects performance, then display size should interact with the same variables that target eccentricity interacts with. In other words, the question of theoretical importance is whether or not the display size variable interacts with the target eccentricity and perceptual difficulty variables. Neither an early-selection view nor a late-selection view can interpret these interactions since these theories hold that the display size variable and the target eccentricity and perceptual difficulty variables affect different processes. Capacity theory, however, can accommodate interactions between either target eccentricity or perceptual difficulty and display size.

Another issue that, to date, does not appear to have received direct empirical investigation is examined in the present experiments. This issue relates to the shape of the attentional focus. Specifically, when attention is focused on a region of a visual display, does the focus subtend a circular area, mimicking the retinal sensitivity gradient of the visual system? Or can attention be focused on regions that deviate from the circular shape implied by a spotlight or zoom lens metaphor? Shaw and Shaw (1977) and Shaw (1978) have argued that attention can be allocated to discontinuous spatial positions. Others,
however, have argued that attention can only cover a contiguous region of the visual field, consistent with a flexible spotlight or zoom lens analogy (Eriksen & St. James, 1986; Eriksen & Yeh, 1985; Posner, Snyder, & Davidson, 1980).

To test this issue, the present experiments manipulated the sizes and shapes of the to-be-attended regions. In each of the experiments, a circular display was employed that subtended 4.6 degrees of visual angle. This entire display was used on trials in the whole display condition. For the quarter display condition, the display was divided into four sections, much like sections of a pie. Split displays also covered one quarter of the entire display on any one trial. However, a split display region extended from one perimeter on the circular display (for example, the region surrounding the 12 o'clock position) to the diagonally opposed perimeter on the circular display (the region surrounding the 6 o'clock position). Consequently, a split display covered the same amount of area as a quarter display, but subtended the same visual angle (4.6 degrees) as the whole display, as measured by the amount of visual angle subtended by the two furthest possible stimulus locations in each display.

Since the quarter display covers a smaller area and subtends a smaller visual angle than the whole display, performance in the quarter display condition should be better than in the whole display condition. Of particular interest, however, is the comparison between the split and whole display conditions. If the shape of the attentional focus is circular, then performance in the split and whole conditions should be similar. A circular attentional focusing mechanism would require that the focus of attention expand to encompass 4.6 degrees of visual angle since this is the distance subtended by the maximally separated target locations in each of the displays. However, if the focus of attention is not restricted to a circular shape, then performance should be better in the split display condition than in the whole display condition since the split display encompasses only one-fourth of the area of the whole display.
To summarize, the present experiments provided two means of testing whether or not attentional focus size affects the rate at which stimuli are processed since both perceptual difficulty and target eccentricity were varied factorially with display size. In addition, the extent to which the shape of the attentional focus can vary was examined.
Experiment 1

Method

Subjects. Twelve subjects participated in this experiment. Subjects were undergraduate students obtained from the Psychology Department subject pool at Rice University. Subjects received course credit for their participation. All subjects had normal or corrected-to-normal vision.

Design. A discrimination task was employed in which the subject was required to determine as quickly and as accurately as possible which one of two targets had been presented on the display. A cue preceded each target presentation and indicated the region of the display in which the target would appear. Two levels of perceptual difficulty (easy and difficult), three levels of display size (quarter display, split display, and whole display), and three levels of target location (inner, middle, and outer) were employed. All three variables were manipulated within-subjects.

Each subject participated in a one-hour session composed of six blocks of 60 trials each. In addition, 40 practice trials preceded each of the six blocks of trials. Half the subjects started with the easy condition on the first three blocks of trials and the other half started with the difficult condition. The display size variable was also blocked. The order of display presented on the first three blocks was counterbalanced across subjects. This same order was then used for the remaining three blocks of trials in the alternate difficulty condition. Consequently, six subjects received the display conditions in the same order. The level of target location (inner, middle, or outer) and the target letter were randomly determined on each trial.

Apparatus and stimuli. An Apple Macintosh microcomputer controlled stimulus presentation, timing, and data collection. Each subject was seated in front of the microcomputer with his or her index fingers resting on two response keys on the computer keyboard. The distance from the subject's eyes to the center of the computer
display was approximately 45 cm. The entire display subtended approximately 4.6 degrees of visual angle from this distance. The target letters consisted of an "X" and an "O" in the easy condition and a "D" and a "O" in the difficult condition. Pilot tests using the X-O and D-O stimuli resulted in reliable difficulty effects. Each stimulus character subtended approximately .4 degrees of visual angle in height and .25 degrees of visual angle in width.

On each trial a target letter appeared at one of the possible target locations for that display condition. The distances of the target locations measured from fixation to the closest corner of a stimulus character were .5 cm, 1.0 cm, and 1.5 cm for inner, middle and outer target locations, respectively. These distances subtended approximately .64 degrees, 1.27 degrees, and 1.9 degrees of visual angle, respectively. A location cue preceded each target presentation by 500 msec. The location cue was either a one-way arrow (quarter display), a two-way arrow (split display) or a four-way arrow (whole display). One of four possible regions was cued in the quarter display condition (up, down, right, or left) and one of two possible regions in the split display condition (up and down or right and left). The size of the cued regions in the quarter display and the split display conditions covered the same area. The entire circular region was cued in the whole display condition. An example of the practice and test displays, target locations and cues for the three display size conditions is shown in Figure 1.

The displays for the practice trials differed slightly from the displays for the experimental trials. Specifically, on practice trials the display region was shaded (light gray) while the location cue was presented so that the subject was shown the exact area of the to-be-attended region. This was done in an attempt to strengthen the display manipulation, that is, to direct the focus of attention to the cued region.
Figure 1. Displays and location cues for Experiment 1. The possible target locations for each display are indicated by the Xs. (Note: the line at the perimeter of the circle and the outline of the quarter and split displays are for illustrative purposes only. They were not presented to subjects.)
Procedure. Each subject was given a brief description of the experimental task and was shown several examples of the trial sequence for each type of display. The subject was instructed to keep his or her eyes on the center of the screen as indicated by the fixation marker for the entire trial. In addition, the subject was instructed to respond as quickly and as accurately as possible.

Each trial began with the presentation of a fixation marker (a plus sign, "+") at the center of the screen for 500 msec and was followed by a blank screen for an additional 500 msec. Then a location cue, either a one-way arrow (quarter display), a two-way arrow (split display) or a four-way arrow (whole display), appeared at fixation for 500 msec. The location cue was removed and the screen was blank for an additional 500 msec. In order to remind the subject to maintain his or her gaze on the center of the screen, the fixation marker again appeared at the center of the screen for 17 msec and was followed by a blank screen for 17 msec. A target letter was then presented for 33 msec and was immediately removed. The target always appeared in the cued region. The subject responded by pressing one of two keys on the computer keyboard to indicate the letter choice. A message "CORRECT" or "ERROR" was then displayed below fixation for 500 msec. The screen was again cleared and the next trial began.

Results

Since the displays employed on the practice trials were cued by both a directional cue (arrow) and regional shading, but the test trial displays were cued only by a directional cue, the first 10 trials of each test block of 60 trials were also considered practice and were excluded from the reaction time and error analyses. Therefore, analyses were performed on 300 trials in the six test blocks for each subject. Reaction times greater than 2000 msec or less than 150 msec were considered misses and anticipatory errors, respectively, and were not included in the reaction time analyses. These two types of errors accounted for less than one per cent of the total errors made. The mean correct
reaction time and mean error rate in each condition was computed for each subject. The
means of these means as a function of perceptual difficulty, display size, and target
location are presented in Table 1.

<table>
<thead>
<tr>
<th>DIFFICULTY</th>
<th>DISPLAY</th>
<th>TARGET LOCATION</th>
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<td>Inner</td>
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<td>Easy</td>
<td>Whole</td>
<td>460 .033</td>
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</table>

Reaction time analyses

The mean reaction time in the easy condition was 42 msec shorter than the mean
reaction time in the difficult condition, $F(1, 11) = 12.65, p = .0045$. The mean reaction
times for the quarter, split, and whole displays were 470, 487, and 487 msec,
respectively. The effect of display size was not statistically significant, $F(2,22) = 2.89,
p = .0767$. The mean reaction times for the inner, middle, and outer target locations were
476, 475, and 493 msec, respectively, $F(2,22) = 7.04, p = .0043$. The Difficulty x
Target location interaction was not significant, $F(2,22) = 1.10, p = .3520$. Neither the
Display size x Difficulty interaction nor the Display size x Target location interaction was
significant, $F(2,22) < 1.0$ and $F(4,44) = 1.43, p = .241$, respectively. In addition, the
Display size x Difficulty x Target location interaction was not significant, $F(4,44) < 1.0$. 
Although reaction times were shorter in the quarter display condition than in either the split or whole display conditions, these differences only approached significance, \(F(1,11) = 4.16, p = .0661\) and \(F(1,11) = 3.26, p = .0983\), respectively. Furthermore, reaction times in the split and whole display conditions did not significantly differ from each other, \(F(1,11) < 1.0\). When each display was compared individually to each of the other displays, the effects of both difficulty and target location were significant, all \(p < .03\), but the interactions between difficulty and target location were not, all \(p > .10\). Display size failed to interact significantly with either difficulty or target location when reaction times in each display were compared to reaction times in each of the other displays, all \(p > .10\).

**Error rate analyses**

Errors occurred on .03 of the trials overall with slightly more errors being made in the difficult condition (.038) than in the easy condition (.026). However, the effect of difficulty was not significant, \(F(1, 11) = 3.32, p = .0956\). The mean error rates for the quarter, split, and whole displays were .020, .045, and .034, respectively. The effect of display size approached significance, \(F(2,22) = 3.30, p = .0559\). The mean error rates for the inner, middle, and outer target locations were .027, .032, and .039, respectively, \(F(2,22) = 2.39, p = .1147\). The Difficulty x Target location interaction was significant, \(F(2,22) = 6.11, p = .0077\). None of the remaining interaction terms were significant although the Display size x Difficulty x Target location interaction approached significance, \(F(4,44) = 2.51, p = .0555\).

Fewer errors were made in the quarter display condition than in either the split display condition, \(F(1,11) = 6.23, p = .0298\), or whole display condition, \(F(1,11) = 3.85, p = .0754\), although the latter comparison only approached significance. The difference between error rates in the split and whole display conditions was not significant, \(F < 1.0\). When each display was compared individually to each of the other
displays, the effect of difficulty approached significance only for the comparison of the quarter and whole display conditions, $F(1,11) = 4.47, p = .0582$, and the effect of target location was significant only for this display comparison as well, $F(2,22) = 4.08, p = .0311$. The comparisons of displays also revealed that difficulty interacted target location ($p < .02$), although the interaction between these variables only approached significance when the quarter and whole display conditions were compared, $F(2,22) = 2.76, p = .0850$. In addition, when each display was compared to each of the other displays, display size did not interact significantly with any of the remaining variables, all $p > .10$.

**Discussion**

Reaction times in the quarter display condition were made faster and more accurately than reaction times in either the split or whole display conditions. Although these differences were not always significant ones, taken together, the reaction time and error rate data suggest that subjects performed better in the quarter display condition than in the other display conditions. However, the split and whole display conditions did not differ significantly from each other. These results are consistent with the hypothesis that attention is directed to regions in a visual display in a manner likened to a spotlight that can be expanded or contracted to focus on more or less area of the visual display. In addition, it appears that attention can only be focused to cover a circular area of the visual field. This is indicated since the split and whole display conditions did not significantly differ from each other even though the split display covered only one-fourth the area of the whole display.

The most interesting finding with respect to theories of attention is that display size did not interact with either perceptual difficulty or target location. According to capacity theory, a smaller attentional focus should result in faster and more accurate processing of a target appearing within the focus of attention. Since a more confined distribution of attentional resources should increase the rate at which stimuli are processed, difficult
discriminations should be speeded to a greater extent than should easy discriminations. Consequently, the effect of difficulty should be larger in the quarter display condition than in the other display conditions. However, since both easy and difficult discriminations were facilitated to the same extent in this experiment, the results are inconsistent with capacity theory.

Responses were made faster and more accurately when a target appeared at either an inner or middle location than when a target appeared at an outer location. This pattern was evident on both easy and difficult discriminations. This drop in performance for targets appearing at an outer target location most likely corresponds to the reduction in visual acuity at this degree of target eccentricity. On difficult discriminations, error rates were higher when a target was presented at an outer location than at an inner or middle location. Easy discriminations, however, did not result in as large of an increase in error rates when a target was presented at an outer location. The fact that difficulty interacted with target location supports the contention that these two variables affect similar stages. Most importantly, however, neither the Display size x Difficulty interaction nor the Display size x Target location interaction was significant for either reaction times or errors. This finding provides additional support for the hypothesis that the size of the attentional focus does not affect the rate at which stimuli are processed. Consequently, this finding is inconsistent with capacity theory.

Although subjects were instructed to fixate on the center of the screen during each trial, it should be noted that the time interval between cue onset and stimulus onset was long enough to allow for the possibility that subjects moved their eyes from the fixation point to another point on the display. Although it would not have been advantageous to make eye movements in either the split or whole display condition since a target could appear at positions on either side of fixation in these conditions, it may have been advantageous to make eye movements to the center of the cued region in the quarter
display condition. Since eye movements were not monitored, it is not possible to conclusively determine whether or not subjects made eye movements in this experiment. However, the patterns of the effects of target eccentricity at each difficulty level were similar in each of the three displays. Responses were made faster and more accurately when a target appeared closer to the center of the display than when a target appeared at a peripheral location. In addition, the increase in reaction times and errors to targets appearing at outer locations was more pronounced on difficult than on easy discriminations. Since target eccentricity had an effect on responses to stimuli in the quarter display condition that was equal in size to the effect target eccentricity had in the other display conditions, it does not seem likely that eye movements played a role in this experiment.

Even assuming that eye movements were being made, however, it is important to note that eye movements should contribute to an interaction between display size and difficulty and an interaction between display size and target location rather than mask these interactions. The fact that the display variable failed to significantly interact with either the perceptual difficulty or target location variable on either reaction times or errors is consistent the hypothesis that the size of the attended region does not affect the rate of perceptual processing. That is, the attentional manipulation of display size does not affect responses in the same manner in which target eccentricity affects responses. Rather, it appears that display size affects the efficiency of target localization.

The question of whether or not subjects were able to expand and contract the focus of their attention to displays of different sizes requires further consideration. If the eyes remain fixated on the fixation marker during each trial, then the inner location subtends the same amount of visual angle from the point at which the eyes are fixated (on the fixation marker) in each of the three displays. (Note that the inner location would still subtend this same amount of visual angle if eye movements are made to the center of the
quarter display.) Consequently, if subjects are able to constrict the size of the focus of attention while maintaining their eyes on fixation, then reaction times to targets presented at inner locations should be shorter in the quarter display condition than in either the split or whole display conditions. If subjects cannot constrict the focus of attention, then reaction times should be similar for targets appearing at inner locations.

The fact that reaction times to stimuli appearing at inner target locations were made faster and more accurately in the quarter display condition than in either the split display or whole display condition is consistent with the hypothesis that subjects were able to constrict the focus of attention in the quarter display condition. However, this finding is also consistent with the hypothesis that subjects focused their attention on the entire display, but following the onset of a cue in the quarter display condition, subjects shifted an attentional focus of the same size to the cued region. This hypothesis is inconsistent with the fact that responses to targets at each level of target location in each difficulty condition were made faster and more accurately in the quarter display condition than they were in the split or whole display condition. Therefore, it appears that subjects were able to focus their attention on the quarter display, but were not able to constrict the focus of their attention so as to encompass only the narrowly-defined area of the split display.

It should also be noted that the two cued displays in the split display condition (up and down or left and right) did not differ significantly from each other for either reaction times or error rates. The four cued displays in the quarter display condition (up, down, left, or right) also did not differ significantly from each other. In other words, there was no evidence that the direction of the cued region of the display influenced performance differentially. (Since this result occurred in all three experiments, it will not be mentioned again.)

There is an alternative explanation for the finding that reaction times and error rates in the split and whole display conditions did not differ from each other that must be
considered. It is possible that presenting the fixation marker after the presentation of the location cue may have been distracting, thereby eliminating any advantage for the split display condition. In other words, it is possible that the second presentation of the fixation marker caused subjects to readjust the focus of their attention such that there was no apparent difference in performance between the split and whole display conditions. In the next experiment, this possibility was tested since trials on which a fixation marker was presented both before and after the presentation of the location cue, as was done in Experiment 1, were compared with trials on which a fixation marker was presented only before the presentation of the location cue. The perceptual difficulty and target location variables were again included.

If the presentation method used in Experiment 1 masks or eliminates the operation of focusing attention to the region encompassed by the split display, then performance in the split display condition should be better than performance in the whole display condition when the second presentation of the fixation marker is eliminated. However, if the presentation method used in Experiment 1 does not mask the operation of attentional distribution in the visual field, then performance should be similar under the two presentation methods.
Experiment 2

Method

**Subjects.** Sixteen subjects participated in this experiment. Subjects had the same characteristics as those described in Experiment 1.

**Design.** A discrimination task was again employed in which the subject was required to determine as quickly and as accurately as possible which one of two targets had been presented on the display. The design for Experiment 2 was a $2 \times 2 \times 2 \times 3$ within-subjects factorial design. Two levels of perceptual difficulty (easy and difficult), two levels of display size (split display and whole display), two levels of presentation method (method 1 in which a fixation marker was presented immediately after the presentation of the location cue and prior to the target presentation and method 2 in which a fixation marker was not presented after the location cue), and three levels of target location (inner, middle, and outer) were employed.

Each subject participated in a one-hour session composed of eight blocks of 90 trials each. In addition, 90 practice trials preceded each of the eight blocks of trials. For counterbalancing purposes, subjects were divided into two groups. The first group started with the easy condition on the first four blocks of trials and the other group started with the difficult condition. Both groups received the alternate difficulty condition on the remaining blocks. Within each group, half of the subjects started with the split display on the first two blocks of each difficulty condition and the other half started with the whole display. Subjects received the alternate display condition on the remaining two blocks of each difficulty condition. The order of presentation method was also counterbalanced across subjects. Half of the subjects received method 1 on the first block of trials and the other half received method 2 first. Presentation method, 1 or 2, was then alternated on a block-by-block basis. Consequently, there were eight unique orders with two different subjects receiving the same order of the difficulty, display size, and presentation method.
variables. The level of target location (inner, middle, or outer) and the target letter were randomly determined on each trial.

Apparatus and stimuli. The apparatus and stimuli were the same as those described in Experiment 1.

Procedure. Instructions given to the subjects were the same as those described in Experiment 1. Each trial began with the presentation of a fixation marker (a plus sign, "+") at the center of the screen for 500 msec and was followed by the presentation of a blank screen for an additional 500 msec. Then a location cue, either a two-way arrow (split display) or a four-way arrow (whole display), appeared at fixation for 500 msec. The location cue was removed and the screen was blank for an additional 500 msec. At this point, the trial sequence differed depending on the presentation method for the block. On method 1 trials, a fixation marker was presented at the center of the screen for 17 msec and was followed by a blank screen for 17 msec. Then a target letter was then presented for 33 msec and was immediately removed. However, on method 2 trials, a target letter was immediately presented for 33 msec and was then removed. The target always appeared in the cued region. The subject responded by pressing one of two keys on the computer keyboard to indicate the letter choice. A message "CORRECT" or "ERROR" was then displayed below fixation for 500 msec. The screen was again cleared and the next trial began.

Results

The first 10 trials of each test block of 90 trials were considered practice and were excluded from the reaction time and error rate analyses. Analyses were then performed on 260 trials in the four test blocks for each subject. Reaction times greater than 2000 msec or less than 150 msec were considered misses and anticipatory errors, respectively, and were not included in the reaction time analyses. These two types of errors were made on less than two per cent of the trials on which errors were made. The mean correct
reaction time and mean error rate in each condition was computed for each subject. The means of these means as a function of perceptual difficulty, display, and target location are presented in Table 2.

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<th>TARGET LOCATION</th>
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<td></td>
<td>Inner</td>
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<tr>
<td>Easy</td>
<td>Whole</td>
<td>446 (.067)</td>
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</table>

**Table 2**

**Reaction time analyses**

The mean reaction time in the easy condition was 41 msec faster than the mean reaction time in the difficult condition, $F(1, 15) = 22.01, p = .0003$. The mean reaction times for the split and whole displays were 473 msec and 477 msec, respectively. The effect of display was not significant, $F(1, 15) = 1.41, p = .2532$. The mean reaction times for presentation method 1 (474 msec) and method 2 (476 msec) were also very close, $F(1,15) < 1.0$. The mean reaction times for the inner, middle, and outer target locations were 470, 473, and 482 msec, respectively. The effect of target location was significant, $F(2,30) = 5.41, p = .0099$. None of the interaction terms were significant, all $p > .10$.

**Error rate analyses**

Errors occurred on .08 of the trials overall with slightly more errors being made in the difficult condition (.087) than in the easy condition (.072). The effect of difficulty
was not significant, $F(1, 15) = 2.07, p = .1703$. The mean error rates for the split and whole displays, .077 and .082 were close, $F(1,15) < 1.0$. The mean error rates for presentation methods 1 and 2 were .090 and .070, respectively. The effect of presentation method was significant, $F(1, 15) = 6.03, p = .0267$. The mean error rates for the inner, middle, and outer target locations were .065, .084, and .089, respectively. The effect of target location was significant, $F(2,30) = 6.72, p = .0039$. The Difficulty x Target location interaction was significant, $F(2,30) = 4.63, p = .0177$, as was the Difficulty x Target location x Presentation method interaction, $F(2,22) = 5.54, p = .0327$. None of the other interaction terms were significant, all $p > .10$.

Discussion

The method of presenting a fixation marker after the presentation of the location cue but prior to the presentation of the target (presentation method 1) resulted in more errors being made than when the fixation marker was not presented after the location cue (presentation method 2). However, the difference between error rates for the two presentation methods did not differ as a function of the type of display. In addition, the differences between reaction times in the split and whole display conditions was very small for both presentation method 1 (0 msec) and presentation method 2 (3 msec). Therefore, it appears that the presentation method used in Experiment 1 did not contribute to the failure to obtain a difference between reaction times or error rates in the split and whole conditions in that experiment. Since the mean reaction times and error rates in the split and whole display conditions were also very close in the present experiment, these results replicate the results of Experiment 1.

The interpretation that is consistent with these results is that attention cannot be narrowly confined to areas that deviate from a circular shape. Rather, the focus of attention appears to subtend a circular area. In addition, the results of Experiment 1 indicate that distributing attention to a region of a visual display does not act to increase
the rate of processing on attended stimuli since the size of the display did not interact with either the perceptual difficulty of the stimulus discrimination or the degree of target eccentricity. This finding is consistent with the hypothesis that location-cuing facilitates the localization or selection of a stimulus to a processing system of limited capacity.

The above interpretation is based on the failure to observe interactions between the display size variable and the perceptual difficulty and target location variables in Experiment 1. Since there can be problems inherent in accepting the null hypothesis to support a position, it is important to replicate this experiment before drawing any firm conclusions.

Experiment 3 included the variables employed in the first experiment: the three displays (quarter, split, and whole), two difficulty levels (easy and difficult), and three target locations (inner, middle, and outer). However, the method of determining the location at which a target would appear on a given trial was changed. In Experiment 1, the total number of target locations differed across displays. Since the location at which a target would appear was selected randomly on each trial from the total possible locations for a given display condition, the probability that a target could appear at either an inner, middle, or outer location varied across display conditions. The probabilities of a target appearing at inner, middle, and outer locations were 16.67, 33.33, and 50 per cent, respectively, in the quarter display condition, 25, 25, and 50 per cent, respectively, in the split display condition, and 33.33 per cent at each of the three levels of target location in the whole display condition. Consequently, there is another explanation as to why there were no differences between reaction time and error rates in the split and whole display conditions in the previous experiments. Since a target appeared at an inner location on a higher percentage of the trials in the whole display condition than in the split display condition, and responses to targets appearing at inner locations were made faster and more accurately than were responses to targets appearing at outer locations, it is possible
that the whole display condition was made easier by this probability distribution artifact. Consequently, it is possible that performance on split displays was better than performance on whole displays but the assignment of probabilities to target locations in each display condition counteracted any advantage for the split display. However, responses to targets appearing at an outer location in the split display condition should have been shorter than responses to targets appearing at an outer location in the whole display condition. This alternative explanation does not seem as plausible given that display size failed to interact significantly with target location in either of the previous experiments. The next experiment settles this issue since in this experiment, the probability was equal that a target could appear at any one of the three levels of target location on each trial.
Experiment 3

Method

Subjects. Twelve subjects participated in this experiment. Subjects were undergraduate and graduate students obtained from the Psychology Department Subject Pool at Rice University. Subjects either volunteered or received the sum of four dollars in exchange for their participation. All subjects had normal or corrected-to-normal vision.

Design. A discrimination task was again employed. Two levels of perceptual difficulty (easy and difficult), three levels of display size (quarter, split, and whole), and three levels of target location (inner, middle, and outer) were manipulated within-subjects.

Each subject participated in a one-hour session composed of six blocks of 70 trials each. In addition, 40 practice trials preceded each of the eight blocks of trials. Counterbalancing was achieved in the same manner as was described in Experiment 1 with the following exception. On each trial, the probability that a target could appear at either an inner, middle, or outer target location was equal (33.33 per cent).

Apparatus, stimuli, and procedure. The same apparatus, stimuli, and procedure was as described in Experiment 1 was used.

Results

The first 10 trials of each test block of 70 trials were considered practice and were excluded from the reaction time and error rate analyses. Analyses were then performed on 360 trials in the six test blocks for each subject. Reaction times greater than 2000 msec or less than 150 msec were considered misses and anticipatory errors, respectively, and were not included in the reaction time analyses. These two types of errors accounted for less than one per cent of the total errors made. The mean correct reaction time and mean error rate in each condition was computed for each subject. The means of these means as a function of perceptual difficulty, display size, and target location are presented in Table 3.
Table 3

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<td>Difficult</td>
<td>Split</td>
<td>514 (.039)</td>
</tr>
<tr>
<td>Difficult</td>
<td>Whole</td>
<td>503 (.040)</td>
</tr>
<tr>
<td>Easy</td>
<td>Quarter</td>
<td>439 (.007)</td>
</tr>
<tr>
<td>Easy</td>
<td>Split</td>
<td>466 (.015)</td>
</tr>
<tr>
<td>Easy</td>
<td>Whole</td>
<td>460 (.041)</td>
</tr>
</tbody>
</table>

Reaction time analyses

The mean reaction time in the easy condition was 46 msec faster than the mean reaction time in the difficult condition, $F(1, 11) = 9.68, p = .0099$. The mean reaction times for the quarter, split, and whole displays were 468, 497, and 493 msec, respectively. The effect of display size was significant, $F(2, 22) = 4.26, p = .0273$. The mean reaction times for the inner, middle, and outer target locations were 479, 483, and 496 msec, respectively. The effect of target location was highly significant, $F(2, 22) = 11.98, p = .0003$. The Difficulty x Target location interaction was not significant, $F(2, 22) = 2.26, p = .1286$. Neither the Display size x Difficulty interaction nor the Display size x Target location interaction was significant, both $F < 1.0$. In addition, the three-way interaction of Display size x Difficulty x Target location was not significant, $F(4, 44) = 1.01, p = .4148$.

Reaction times were significantly shorter in the quarter display condition than in either the split display condition, $F(1, 11) = 5.59, p = .0376$, or whole display condition, $F(1, 11) = 5.29, p = .0421$. Reaction times in the split and whole display conditions did
not significantly differ from each other, however, $F(1,11) < 1.0$. None of the other
effects were significant when comparisons of each display with each of the other displays
were performed on reaction times, all $p > .10$.

**Error rate analyses**

Errors occurred on .039 of the trials overall with almost twice as many errors being
made in the difficult condition (.052) than in the easy condition (.027). The effect of
difficulty was highly significant, $F(1, 11) = 27.58, p = .0003$. The mean error rates for
the quarter, split, and whole display conditions were .033, .036, and .050, respectively.
The effect of display size was significant, $F(2,22) = 3.50, p = .0479$. The mean error
rates for the inner, middle, and outer target locations were .029, .039, and .050,
respectively, $F(2,22) = 5.12, p = .0149$. The Difficulty x Target location interaction was
significant, $F(2,22) = 6.27, p = .007$. None of the remaining interaction terms were
significant, all $p > .10$.

Fewer errors were made in the quarter display condition than in whole display
condition, $F(1,11) = 10.28, p = .0084$. However, neither the difference between error
rates in the quarter and split display conditions nor the difference between error rates in
the split and whole display conditions was significant, $F(1,11) < 1.0$ and $F(1,11) = 2.54,
p = .1390$, respectively. The effects of difficulty on errors were significant when each
display was compared individually with each of the other displays, $p < .02$. The effects
of target location on errors were significant for the quarter and split displays comparison
and the quarter and whole displays comparison, both $p < .05$, but was not significant for
the the split and whole display comparison, $F(2,22) = 2.81, p = .082$. The Difficulty x
Target location interaction was significant when only the split and whole displays were
included in the analysis, $F(1,11) = 10.80, p = .0005$. The Difficulty x Target location
interaction was not significant for the other comparisons, however, $p > .10$. None of the
remaining comparisons were significant, all $p > .10$. 
Discussion

The results of this experiment replicate the results of the first experiment. Specifically, responses in the quarter display condition were made faster and more accurately than were responses in either or split or whole display condition. In addition, responses in the split and whole display conditions again did not differ from each other on either reaction times or error rates. Therefore, these results provide additional support for the hypothesis that subjects were able to narrow the focus of their attention to the smaller region of a quarter display, but were not able to narrow or split the focus of their attention to the non-circular region of a split display.

The degree of target eccentricity again had an effect on responses in this experiment such that responses were made faster and more accurately when a target appeared at an inner location than when a target appeared at an outer location. In addition, the effect of target location on errors was larger in the difficult than in the easy condition. The Target location x Difficulty interaction for reaction times was in the same direction as the Target location x Difficulty interaction for errors although the former interaction was not statistically significant. However, neither the difficulty variable, the target location variable, nor the interaction between the two variables interacted with the display size variable.

The failure to find evidence that display size interacted with perceptual difficulty or target location in this experiment replicates the results of Experiment 1. This finding is important since it indicates that although performance was better when the to-be-attended region was smaller than when it was larger, the size of the attended region of the visual display did not result in an increase in the rate with which stimuli were processed. Specifically, the effect of display size was not larger for difficult than for easy discriminations. This finding is inconsistent with a capacity interpretation since this theory holds that a smaller attentional focus should result in an increase in the processing
rate of an attended stimulus. These results provide additional support for the hypothesis that focusing attention narrowly on a stimulus acts to speed the rate at which that stimulus is selected or localized prior to further processing by a limited-capacity system. Therefore, the results consistent with early-selection, late-selection, and feature-integration theories.
General Discussion and Conclusions

The present experiments provide support for the hypothesis that the focus of attention can be expanded and contracted to encompass either more or less area in the visual field. In addition, attending to a smaller region of the visual field benefits performance to a greater extent than does attending to a larger region. Evidence supporting this interpretation was obtained in both Experiments 1 and 3. The speed and accuracy of a response to a target presented in a quarter display was benefited relative to performance on these measures in the split and whole displays. Therefore, it appears that subjects were able to narrow the focus of their attention to the smaller region of a quarter display in these experiments.

Performance at each level of target location and difficulty in the quarter display condition was superior to performance at the corresponding target location and difficulty levels in the split and whole display conditions. Since target eccentricity had an effect on performance in the quarter display condition, the possibility that visual acuity differences between conditions (i.e. the possibility that eye movements were being made in the quarter display condition) may have caused the differences in performance between the quarter display and the other display conditions seems implausible.

The fact that the split and whole display conditions did not differ significantly on either reaction times or error rates in any of the three experiments indicates that subjects were not able to distribute their attention to only the non-circular region of a split display. In other words, there was no evidence of an ability to split attention among discontinuous spatial locations in any of the present experiments. Rather, it seems that subjects distributed their attention over the entire circular display in both the split and whole display conditions.

It should be noted that the target locations in a split display were not quite discontinuous since they were placed along the vertical or horizontal axis. This split
display arrangement should have been easier to monitor than an arrangement in which locations were more spatially separated. However, there was no evidence that subjects were able to distribute attention to only the vertically or horizontally oriented, oblong-shaped area of a split display.

A potential explanation as to why there were no differences in performance between the split and whole displays is that the number of possible displays that could have appeared on a given trial differed in these conditions. Specifically, one of two possible displays could have appeared on each split display trial (up and down or left and right) whereas only one display was presented on each whole display trial. Therefore, it is possible that in the whole display condition, it was easier to discriminate targets since there was no uncertainty as to which display would be presented. This possibility is inconsistent with the benefit due to location-cuing revealed in the quarter display condition, however, since one of four possible displays (up, down, left, or right) could have appeared on each quarter display trial. Therefore, although it is possible that subjects were not making use of the location cue in the split display condition, the fact that they were making use of the location cue in the quarter display condition is inconsistent with this alternative explanation.

Another possible problem with comparisons of the split and whole display conditions is that the size of the area (1/4 to 1) and the number of possible target positions (8 in a split display and 12 in a whole display) were necessarily confounded in these experiments. Obviously, a greater number of target positions can be placed in a region covering a larger area than can be placed in a region covering a smaller area. Target locations in the quarter and split displays were selected so as to strengthen the display size manipulation. Target positions were placed at each level of target location such that they did not overlap with other target positions. However, a number of target positions that met these constraints were available in the whole display. Target positions for the whole
display condition were selected so as to maximize the possibility that subjects would have to direct their attention to the entire circular display in order to perform a target discrimination. If the number of target positions had been reduced in this condition, the ability to infer whether or not subjects were actually focusing their attention on the entire display may also have been reduced. Despite the confound between the size of the display and the number of possible target positions, it is important to note that the advantage resulting from differences in the number of possible target locations should have been in favor of the quarter and split display conditions. Since there was no difference between performance in the split and whole display conditions, it appears that the number of possible target positions for a given display condition was not an influencing factor.

To summarize, the interpretation that is consistent with the present evidence is that the focus of attention can vary in size, but the focus covers a circular area of the visual display. This interpretation is consistent with Eriksen and Yeh's (1985) and Eriksen and St. James' (1986) proposal that the operation of focusing attention to areas of the visual field can be likened to a zoom lens. However, there was no evidence in the present experiments that a smaller attentional focus speeds that rate at which stimuli are processed as Eriksen and his colleagues proposed (Eriksen & Yeh, 1985; Eriksen & St. James, 1986). Rather, the interpretation that is consistent with the present results is that the operation of the focusing of attention on a stimulus acts to speed the rate at which that stimulus is selected or localized prior to further processing by a limited-capacity system. Consequently, it appears that the operation of localizing a stimulus can occur more efficiently when attention is focused on a smaller region of the visual display than on a larger region. This interpretation is based on the finding that display size did not interact with the perceptual difficulty of the target discrimination in either Experiments 1 or 3. This finding is important since it cannot be accommodated by capacity theory. Recall that
according to capacity theory, a smaller attentional focus should result in an increase in the processing rate of a stimulus receiving the focus of attention. Therefore, a smaller focus of attention should speed difficult discriminations to a greater extent than easy discriminations. A finding of an interaction between the size of the attended region of the visual display and the perceptual difficulty of the stimulus discrimination to be performed would be expected by capacity theory. The present experiments, however, revealed that the effect of display size was just as large on easy as on difficult discriminations.

There was evidence in each of the three experiments of an interaction between difficulty and target location for errors. In addition, these interactions were in the same direction in each of the experiments. Fewer errors occurred on easy stimuli appearing at inner target locations and more errors occurred on difficult stimuli appearing at outer target locations. These results suggest that both variables were affecting the perceptual processing performed on a stimulus. Therefore, the finding that display size and target location variables did not interact for reaction times or errors in either Experiments 1 or 3 provides additional evidence that the size of the focus of attention does not affect the rate at which stimuli are processed. The present data are also consistent with other reports of failures to observe interactions between location-cuing and perceptual difficulty variables (Anderson & Lane, 1986; Tsal, 1983). Therefore, it appears that there is a good deal of evidence that cannot be accommodated by capacity theory.

Evidence that the size of the display affects the efficiency of stimulus localization is consistent with early-selection, late-selection, and feature-integration theories. According to early-selection theory, a stimulus must be located (selected) before it can receive extensive analysis and serve as a basis for a response. Late-selection theory also holds that, in most perceptual situations, a stimulus must be located (selected) before it can responded to. Although the process by which stimuli are localized is not a component of feature-integration theory, the fact that stimulus localization can be benefited by
information that reduces the spatial uncertainty of an upcoming stimulus presentation is consistent with this theory.

In conclusion, the present experiments indicate that although attention can be distributed over a region of variable size, attention can only be distributed over a circular region of the visual display. The size of the area to which attention is distributed relates to the speed and/or accuracy of responses to attended stimuli. However, the role of attention suggested by the present results is that attention facilitates the localization of a stimulus rather than affecting the rate at which a stimulus is processed. Consequently, the operation of localizing a stimulus can occur more efficiently when attention is focused on a smaller region of a visual display than on a larger region.
Notes

1 There are, however, some situations in which objects can receive processing even without attention. Circumstances under which this can occur will be discussed in more detail later in this paper.

2 Table 2 shows mean reaction times and mean error rates for perceptual difficulty, display, and target location collapsed across presentation method. Since the effect of presentation method on reaction times was not significant and the effect on errors, although significant, did not interact with the display size variable, the method of presentation does not contribute any information to the questions addressed in this paper and therefore, is not included in Table 2.

3 Lane (1977) pointed out that capacity theory does not necessarily predict that an interaction of primary and secondary task difficulty should result. Lane argued that the prediction of whether or not the difficulty levels of two different tasks interact depends on the shape of the function relating the difficulty of the two tasks and available capacity to performance. However, the capacity available to perform a single task is not an influencing factor for the present discussion. Therefore, the prediction of an interaction between location cuing and perceptual difficulty for single task performance is consistent with capacity theory.
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