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Space- and object-based attention in the functional visual field

Patricia A. Cashion
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SPACE- AND OBJECT-BASED ATTENTION
IN THE FUNCTIONAL VISUAL FIELD

A Thesis

Presented to

the Faculty of the Department of Psychology
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts

by

Patricia A. Cashion

August, 1996

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ABSTRACT

SPACE- AND OBJECT-BASED ATTENTION IN THE FUNCTIONAL VISUAL FIELD

by Patricia A. Cashion

Previous research has shown that eye and head movements exact a cost on the speed and accuracy of responses to spatially separated information (Andre & Cashion, 1993; Sanders, 1970; Sanders & Houtmans, 1985). Attention was hypothesized to improve visual scanning performance in a manner consistent with the predictions of space- and object-based models of attention. To test this hypothesis, 32 participants performed two tasks simultaneously that were separated by up to 72° of visual angle. An object-based attention effect was manipulated with Gestalt grouping principles. In addition, clutter was manipulated to facilitate an object effect as well as to determine how clutter influences scanning overall. It appears that attentive field size was fixed and shifted between the two tasks as predicted by the space-based attention. The results indicate that the object attention manipulation had no effect on visual scanning performance decrements. The results have implications for cockpit layout design.

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TABLE OF CONTENTS

SECTION	PAGE
INTRODUCTION	3
METHOD	26
Participants	26
Design	27
Apparatus	27
Stimuli	28
Independent Variables	33
Dependent Measures	35
Procedure	35
RESULTS	37
DISCUSSION	57
APPENDICES	
Appendix A. Signed Approval Form	67
Appendix B. Examples of Experimental Stimuli	69

LIST OF FIGURES

FIGURE	PAGE
1. A picture of the primary flight display and the navigation display in the MD-11.	5
2. Andre & Cashion (1993) experimental stimuli.	29
3. Experiment stimuli for box size 1.	30
4. Box conditions: a) box size 1 (control); b) box size 2; c) box size 3; d) box size 4.	32
5a. Mean tracking error when the arrow is not visible as a function of distance from fixation.	39
5b. Mean tracking error when the arrow is visible as a function of distance from fixation.	40
5c. Mean percentage of errors as a function of distance from fixation.	41
6a. Mean tracking error when the arrow is <u>not</u> visible as a function of box size and distance.	44
6b. Mean tracking error when the arrow <u>is</u> visible as a function of box size and distance.	45
6c. Mean percentage of errors as a function of box size and distance.	46
7. Comparisons to test object effects while participants were tracking right.	50
8a. Mean tracking error when the arrow is <u>not</u> visible as a function of distance from fixation for box size 1.	51

8b.	Mean tracking error when the arrow is <u>not</u> visible as a function of distance from fixation for box size 2.	51
8c.	Mean tracking error when the arrow is <u>not</u> visible as a function of distance from fixation for box size 3.	52
8d.	Mean tracking error when the arrow is <u>not</u> visible as a function of distance from fixation for box size 4.	52
9a.	Mean tracking error when the arrow <u>is</u> visible as a function of distance from fixation for box size 1.	53
9b.	Mean tracking error when the arrow <u>is</u> visible as a function of distance from fixation for box size 2.	53
9c.	Mean tracking error when the arrow <u>is</u> visible as a function of distance from fixation for box size 3.	54
9d.	Mean tracking error when the arrow <u>is</u> visible as a function of distance from fixation for box size 4.	54
10a.	Mean percentage of errors as a function of distance from fixation for box size 1.	55
10b.	Mean percentage of errors as a function of distance from fixation for box size 2.	55
10c.	Mean percentage of errors as a function of distance from fixation for box size 3.	56
10d.	Mean percentage of errors as a function of distance from fixation for box size 4.	56

Space- and Object-Based Attention in the Functional Visual Field

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Running head: ATTENTION AND VISUAL SCANNING

Footnotes

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Abstract

Previous research has shown that eye and head movements exact a cost on the speed and accuracy of responses to spatially separated information (Andre & Cashion, 1993; Sanders, 1970; Sanders & Houtmans, 1985). Attention was hypothesized to improve visual scanning performance in a manner consistent with the predictions of space- and object-based models of attention. To test this hypothesis, 32 participants performed two tasks simultaneously that were separated by up to 72° of visual angle. An object-based attention effect was manipulated with Gestalt grouping principles. In addition, clutter was manipulated to facilitate an object effect as well as to determine how clutter influences scanning overall. It appears that attentive field size was fixed and shifted between the two tasks as predicted by the space-based attention. The results indicate that the object attention manipulation had no effect on visual scanning performance decrements. The results have implications for cockpit layout design.

Space- and Object-Based Attention in the Functional Visual Field

Visual Scanning

Complex visual tasks, such as driving and walking around in the world require visual scanning. The overall goal of visual scanning is to acquire important information about the environment both for survival and for interaction with the world. This information can be operationally broken down into one or more "targets." People scan to find and perceive visual stimuli; this task is known as target acquisition. Scanning entails searching within a defined area, such as a computer display, with mechanisms such as eye, head, and body movements that help the observer perceive the target. Scanning occurs frequently during tasks that utilize continuously updated visual information. Two examples of scanning tasks are motorists monitoring the scene while driving and assembly line inspectors searching for defective parts on conveyor belts.

Scanning is a key task in the aviation environment as well, where pilots are required to scan between various instruments and objects in the world. Recently, multi-function displays (MFDs) have been introduced in the cockpit. These displays combine many distinct functions and modes based on various phases of flight and conditions, as selected by pilots. Multi-function displays are popular because they provide more features without increasing the overall physical display area (i.e., by combining the information from many instruments into one display). In effect, the modern aircraft cockpit has changed from a collection of many dials and indicators that spanned the length of the cockpit to a few, computer-generated displays, centrally located to each pilot (see Figure 1). Thus, instead of scanning across many

instruments in the cockpit, pilots now scan among a few MFDs and the various pages of information they each contain. This decrease in the distance between displays should be advantageous, as the performance costs associated with scanning displays that are distant from the viewer are greatly reduced.

On the one hand, the grouping of relevant items on a single display (MFD) could help pilots acquire and integrate that information (Wickens & Andre, 1990). On the other hand, scanning and integrating information from two separated MFDs may be difficult because each MFD may assume object identities that hinder processing of the information they both contain. Because scanning performance falls off with distance, it is easy to see how simply reducing the scanning distance would appear to be an adequate solution. However, as just hinted at, there may be other factors at work.

In this paper, visual scanning is discussed in terms of the visual system, and as part of the overall visual field. Next, basic theories of attention and the role of space- and object-based models of attention are addressed. Finally, the ideas from attention research are applied to visual scanning in order to determine how the models of attention may influence visual scanning.

The Human Visual System

To understand visual scanning, it is necessary to understand the human visual system. Humans acquire targets from an area encompassing their field of view. Visual system limitations define this range. The ability to see visual detail depends on an image's position on the retina. Humans perceive the greatest visual detail within the fovea, located at the center of the

Figure 1. Picture of the MD-11 Primary Flight Display and the Navigation Display.

retina. The fovea is a small portion of the retina, encompassing roughly 1 to 2° of visual angle. Acuity falls off rapidly from the fovea to the periphery of the retina. The point of fixation is defined as a point in the environment from which light falls on the center of the fovea. Therefore, to see a small target in detail it must fall near the point of fixation. Eye and head movements are mechanisms that extend the visual range as their movements transport visual targets to the fovea. Although resolution decreases in the periphery, sensitivity to motion increases in the periphery (Livingstone & Hubel, 1988). The sensitivity to motion in the periphery encourages mechanism movements (eye or head movement) in order to foveate a peripheral stimulus. People also adjust their torsos, feet, and their whole bodies in addition to their head and eyes to view a target. Although these movements are important, they are not the focus of the present study and the experimental task will somewhat restrict these movements.

The human visual system works remarkably well because central and peripheral vision are complementary. Generally speaking, detection of images occurs at the periphery of the retina. Detection initiates scanning movements that position the image within the fovea where identification of the target can occur. How observers accomplish target acquisition (i.e., identification of a target) depends on two factors: target distance (distance from fixation) (Eriksen, 1990; Sanders, 1970; Sanders & Houtmans, 1985) and target discriminability (size and clarity). These factors also influence the occurrence of eye and/or head movements. Thus, whether an eye or head movement is used to acquire a target is determined in part by the distance of

the target from the point-of-fixation (Sanders, 1970) and the difficulty in discriminating the target.

Task difficulty is another factor influencing mechanism movement and, subsequently, performance. In contrast to identification tasks, detection tasks reduce the need to make eye and head movements because detection can occur in the periphery. If a task requires identification and the target is small or difficult to resolve, the stimulus must appear near fixation, or eye and/or head movements will be required.

Scanning Mechanisms: Eye and Head Movements. In a scanning task, the need for eye and head movements to acquire a target produces increases in reaction time (Sanders, 1970). Research on visual scanning has shown that it takes about 180-200 milliseconds (ms) to initiate an eye movement (Sanders, 1970). Sanders found that while eye and head movements start almost simultaneously, the eye travels at a greater velocity, and arrives at the target first. Sanders also found that head movements are less precise than eye movements. Apparently, there is a closed-loop system where gross head movements are made in the general direction of the target after which eye movements precisely lock onto the target. Sanders showed that with eye movements, corrective, or additional eye movements, were often unnecessary; that is, participants made only one saccade. However, if head movements were involved, participants typically made additional saccades.

There are two types of eye movements important to this study. The first is the saccade. Saccades are rapid (up to 600° visual angle per second), ballistic, jerky movements, that take approximately 50 ms to execute (Hallet, 1986). Saccades take longer to initiate (200 ms) if planning is necessary to

orient the eyes in the appropriate location. When the location is known saccades require even less initiation time. In this study, the task required saccades to a pre-cued location.

The second type of eye movement is pursuit movement. Pursuit movements are slow (maximum velocity of 100° visual angle per second), smooth movements in pursuit of a specified stimulus. Participants in this study performed two tasks that encouraged both types of eye movements.

It is also important to note that the human eye involuntarily initiates small (1 to 2° of visual angle) movements, while fixating on a stationary target. Without these movements the retinal cells fatigue, and the image fades, resulting in a temporary loss of vision (Ditchburn, 1981). These involuntary eye movements are not the focus of the present study. The eye movements of interest here are saccades and pursuit movements.

The Functional Visual Field

The "functional visual field," also known as field of regard, is defined as the area visually sampled while monitoring a multi-source display (Sanders, 1970). Sanders was the first to distinguish among the stationary, eye, and head functional visual fields in scanning. He had observers respond to two pairs of stimuli located at various degrees of separation. He found that performance declined non-linearly as a function of separation. As separation increased, small linear decrements in performance gave way to much larger decrements in performance. Sanders suggested that the performance cost depends on whether each source of information can be scanned without eye movements (stationary field), scanned with eye movements (eye field), or scanned with the aid of head movements (head field).

According to Sanders (1970), reaction time for trials requiring eye movements increases linearly as the separation of target and fixation increases. In other words, an increase in separation between two targets results in a corresponding linear increase in the time to respond to the two targets. This was not true for head movements. When separation was great enough to require head movements, reaction time increased in a nonlinear, exponential manner. Sanders believed this was due to a shift to another part of the visual field, the "head field." If a target fell outside of the eye's range (eye field), participants made head movements that greatly increased their reaction time. This relationship of distance and eye/head movements on performance is referred to here as a scanning performance cost function. These movement mechanisms are an important contributing factor to the scanning performance cost function, but their effects have yet to be fully investigated.

Martin-Emerson and Wickens (1992) found some support for Sanders' three functional visual fields (stationary, eye, and head). They required participants in a dual-task study to conduct a compensatory tracking task along with a two-choice discrete response task. Participants tracked a moving target while simultaneously responding to discrete stimuli presented at various positions below the tracking window. Martin-Emerson and Wickens reported a performance decline in both tasks with increased target separation. They also reported three unique fields as revealed by a performance cost function. The first portion of the function was essentially flat; the stationary field (from superimposition to 6.4° visual angle of eccentricity) did not produce performance costs as target separation increased. The second

segment increased linearly until reaching the point where it sharply increased; this "eye field" was approximately 6° to $20\text{-}25^{\circ}$ of visual angle. The final segment continued in an exponential manner, and was defined as the head field (beyond $20\text{-}25^{\circ}$).

Martin-Emerson and Wicken's (1992) results were limited because they used a limited range of vertical inter-display distances ($0\text{-}35^{\circ}$ of visual angle). Andre and Cashion (1993) replicated Martin-Emerson and Wickens study with similar stimuli, but expanded the visual range and investigated lateral scanning (scanning left and right). Their stimuli ranged from 0 to 73° visual angle vertical separation and 0 to 89° visual angle lateral separation. They recorded observers' response time and accuracy. Andre and Cashion also gathered participant reports and observations taken from video recordings to help corroborate the distance that defined the onset of head movements indicated by performance. Their results replicated Martin-Emerson and Wickens revealing a scanning performance cost function composed of linear (eye field) and quadratic (head field) trends for each performance measure. As expected, when participants made eye and/or head movements at larger distances, response time increased and accuracy decreased. A trend analysis indicated a linear trend corresponded to the eye field and a quadratic trend corresponded to the head field for both speed and accuracy measures. Furthermore, the variance accounted for by the quadratic trend in the performance data corresponded with observer reports of head movements.

Based on video analysis, observer reports, and performance indices, Andre and Cashion's (1993) results support at least two of Sander's unique subfields: the eye and head fields. Stationary and eye fields could not be

distinguished without an eye tracker, but the performance data suggested a flat slope consistent with the stationary field for inter-stimulus distances less than 8° of visual angle. The stationary field for vertical scanning was similar to Martin-Emerson and Wicken's 6.4° .

These studies raise an important question: are visual system constraints, such as retinal eccentricity, and motor mechanisms, such as eye and head movements, sufficient to account for the performance costs in the functional visual field? The factors that facilitate or inhibit performance may consist of two processing components: visual perception and cognitive processing. Sanders (1970) and Andre and Cashion (1993) have discussed visual and motor mechanisms as the primary variables implicated in their scanning data. However, it is conceivable that a "psychological" or a cognitive component may also interact with physical factors.

Cognitive Factors. In a modification of a classic study by Posner, Boies, Eichelman and Taylor (1969), Sanders and Houtmans (1985) studied the relationship between display distance and scanning performance by looking at the strategies and mechanisms used as a function of separation between information sources. Participants were asked to compare two stimuli and determine if they were of equal numeric value. The stimuli consisted of either a column of dots or a digit. There were therefore four stimuli combinations: dots-dots, digit-digit, dots-digit, and digit-dots. Visual distance was manipulated by varying the 2-D separation of the stimuli on the array and cognitive distance was modulated as a function of the similarity of the two stimuli. They found a performance advantage for the stationary field when both stimuli were the same type; in other words, the range of the

stationary field was larger when the stimuli were similar and subsequently performance was better.

Sanders and Houtmans (1985) suggested their observers used two kinds of strategies to explain their findings which suggested that the physical separation of stimuli was not the only factor influencing reaction time. They proposed that distance required participants to select different scanning strategies. Observers appeared to use a perceptual strategy at close distances and a cognitive strategy at greater distances. They explained the stationary field advantage with the "unitary percept" principle. A unitary percept can be formed when elements are close enough together to form a shape. The new shape permits an easy discrimination. A unitary percept is therefore a perceptual strategy that facilitates an expedient distinction between the two stimuli. For example, in the dots-dots condition when the two sets of dots could be perceived without eye movements, the observer could perceive the dots as either a rectangle or not a rectangle that immediately translated to either an equal or unequal value determination. This strategy becomes more difficult as separation between the stimuli increases and the stimuli fall into both the stationary and eye subfields. In this case, Sanders and Houtmans suggested that observers compared stimuli with "name codes" (Posner, et al., 1969). A name code is a verbal code that allows one stimulus to be compared with another in working memory. Name codes are easier to use when the stimuli fall into different subfields or when the nature of the stimuli support these codes. For example, the digit-dots and digit-digit combination are more likely to prompt name codes than are the dots-dots combination. Therefore,

name codes are potential cognitive strategies that can facilitate discrimination when both stimuli are not simultaneously available.

In short, there may be two sources influencing the performance cost function produced by scanning: the "physical distance" between the stimuli, mediated by resolution limitations, and the "psychological distance" or cognitive factors. Although Posner (1969) and Sanders and Houtmans (1985) suggested cognitive strategies, they did not specifically implicate attention. This experiment attempts to extend their cognitive strategy approach and propose attention as a potential factor in the process of visual scanning. It is conceivable that attention could influence eye and head movements by reducing the need to make them in the first place. In other words, attentional resources could improve performance and may extend the range of a given subfield. A goal of this study is to investigate whether attention influences the range of the functional visual field or whether the functional visual field is strictly the result of visual system limitations. In order for the reader to be able to follow the discussion of attention as it relates to visual scanning, the following is a brief experiment description.

Experiment Description. The present experiment is very similar to Andre and Cashion (1993), but stimuli were added in order to manipulate the participants' attentional focus by introducing an "object." The details are discussed in the method section. Participants were required to perform a compensatory tracking task while responding to periodically displayed targets. That is, the location of the target was pre-cued; however, the specific time the stimulus appeared varied. The discrete response stimulus consisted of either a left-pointing or right-pointing arrow presented inside a small circle. Their

task was to press one button for a left arrow, and another button for a right arrow. The position of this arrow varied in distance from the tracking task. The tracking task consisted of a cursor in the form of a continuously moving small cross. The observer counteracted the cursor's movement in order to move it within a small circle (target area) within the center of a box and correctly respond to the discrete stimulus. The size of the tracking box varied in size between participants. Discrete response locations not located within the tracking box were enclosed within another rectangle. Therefore two rectangles of various sizes were visible, depending on the box size condition. Another independent variable was tracking location, which varied from either the far left or the far right hand side of the tracking box. Clutter was another factor where all potential discrete response display locations were either visible or invisible. Finally, stimuli ranged horizontally from 0 to 72° of visual angle.

Attention

The following is a description of the attention research pertinent to this study.

Selective Attention. Attention is useful in selecting information for further processing. Research has shown that attention facilitates processing of stimuli within its focus, while information outside its focus tends to be ignored. An example of this phenomenon is a dichotic listening task where there are two different messages, one presented to the left ear and the other to the right ear, and participants are asked to shadow one ear. This research has revealed that little of the unattended message (message to the non-shadowed ear) is processed and suggests that information not attended to is usually lost

(Cherry, 1953; Moray, 1959). Therefore attention plays an important role in determining what information is processed. Selective attention is useful in an environment with a constant flow of information because it helps reduce the multiple inputs impinging on the system at once. In terms of visual scanning in a dual task environment, attention facilitates processing of one stimulus (usually primary, in terms of participant motivation) and the secondary stimulus may be ignored. In any case, a stimulus in the focus of attention will continue to be processed.

Overt and Covert Shifting. Recall that attention restricts and selectively prioritizes stimuli for processing. A perceiver has some control of their focus of attention. The perceiver selects the focus of attention in one of two ways, overtly or covertly. Overt attention involves visible signs of shifting, such as eye and head movements. Covert attention shifts without movements or visible behaviors. Posner (1980) demonstrated covert shifting by asking observers to fixate the center of the screen without making eye movements. He then pre-cued the location of a stimulus prior to stimuli presentation. Observers given pre-cues responded significantly faster than observers not given any cues. When given a false pre-cue (cued the wrong location), observers were even slower than observers not given location cues. It follows then that the observer shifted their attention covertly, because behavioral motions were not involved. Remington (1980) examined the speed at which attention could shift in a focused attention task and found that the observer's attention shifted approximately 150 ms before their eyes did. As stated earlier, it takes approximately 180 ms to initiate an eye movement. It follows then that attention could prepare the observer to process a stimulus

before the eyes are oriented to perceive the information. If this is the case, attention would facilitate scanning since attentional resources would already be directed to the cued location. Covert attention is not examined in this study.

Serial vs. Parallel Processing. Attentional resources are limited, which is demonstrated by the fact that it is very difficult to perform two attention-demanding tasks at once (Wickens, 1992). When a task is not practiced or is difficult, it usually requires attention and is processed less efficiently, or serially (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). During serial processing, stimuli are processed one at a time. Highly-practiced tasks and tasks not requiring attention can be performed more efficiently or in parallel. Stimuli are processed simultaneously during parallel processing. For example, in Sanders and Houtmans' (1985) task, the unitary percept strategy involves parallel processing, whereas name codes involve serial processing. As expected, serial processing is much slower than parallel processing. An indication of parallel processing is the set size effect where target search times are not influenced by the introduction of additional distractor stimuli (Townsend, 1990).

How do the concepts of parallel and serial processing relate to eye and head movement mechanisms? Although research has not directly addressed this question, it is logical to assume that parallel processing does not occur when switching between subfields. For example, if stimuli encourage parallel processing, but they are separated by enough distance to require eye movements, it is assumed that serial processing would occur. Based on these assumptions, this study attempts to examine how attention may reduce the

need to make eye movements through parallel processing that results in better performance.

Models of Attention

Duncan (1984) segregated the bulk of attention research into two distinct models that attempt to account for the distribution of attention. The two models are referred to as space-based and object-based models. This distinction is based on the primary factors proposed to influence the distribution and selection of attention. Space-based models presume that spatial properties such as area and distance are the primary drivers of attention. Object-based models do not deny space as an important factor, but they hold that the objects occupying that space may also influence attentional processing and the distribution of attention (Kahneman & Henik, 1981; Kramer & Jacobsen, 1989). Under these models, the "objectness" of stimuli drives attentional allocation in addition to their placement in the visual field. Therefore, the effects of distance and retinal eccentricity on visual scanning may be modulated by the degree to which a group of elements form an object. If the elements are pre-attentively combined and perceived as one object, they would be further processed as a whole, and not as affected by distance. Recall that Sanders and Houtmans (1985) proposed that a switch from perceptual to cognitive strategies occurred as the separation increased between two stimuli or when a mismatch between the type of stimuli encouraged the switch. In contrast, object-based attention would predict that an object effect would widen the stationary subfield in terms of performance, regardless of distance.

Space-Based Models of Attention. Space-based attention models (Eriksen, 1990; LaBerge, 1983; LaBerge and Brown, 1986) propose that attention

is defined by spatial properties and distributed across a continuous, circular area. These models supply analogies such as spotlights and zoom lenses to account for the distribution of attention. The effects of space are clearly demonstrated in a classic experiment by Eriksen and Eriksen (1974) who discovered that incompatible distractors flanking a target increased reaction time to detect the target when distractors are close to the target. In contrast, they found that distractors did not exert as much of an influence at more distant locations (still within the stationary visual field). The largest performance costs in Eriksen's studies occurred when incompatible distractors were located within 1° of visual angle from the target. The closer the distractors to the target, the slower the participants' reaction time, and the greater the response competition effect. This suggests that 1° of visual angle is the minimal size of the attentive field. They explained this finding by suggesting that the observers could successfully ignore the distractor when it fell outside the focus of attention, or outside of the attentional spotlight. This model assumes that the size of the target and the demands of the task define the size of the spotlight. Currently, the most prominent model of space-based attention is the zoom-lens model (Eriksen & St. James, 1986; Eriksen & Yeh, 1985).

A zoom lens model (Eriksen & St. James, 1986; Eriksen & Yeh, 1985) accounts for research findings that support the idea that efficient processing appears to occur over either a narrow or a broad visual range. For example, Jonides (1983) found that attention can operate either in a distributed, parallel-processing mode (divided attention) or in a focused, serial processing mode. This model proposes that attention operates similar to a zoom lens

where a wide field-of-view includes more elements, is processed in parallel, but provides a low resolution of detail. In contrast, a narrow field of view has a fewer number of elements in view, is serially processed, but has a higher resolving ability. Task demands determine the zoom level. Difficult tasks may require a tightly-focused beam, whereas, easy tasks may require less resolving ability and encompass a larger portion of the visual field. As such, the resolution of the attentional system is inversely proportional to the width of the attentional beam (Kramer & Jacobsen, 1992).

The zoom lens model proposes a power-for-space trade off. In terms of the current experiment, the task demands (separation between the tracking task and the discrete target) may determine the width of the attentional beam. However, tracking is a continuous and demanding primary task and as such responses to the discrete response displays are secondary. When the arrow appears, the attentional focus may either expand to contain both tasks (zoom lens model, with a reduced resolution capability, resulting in poor accuracy, or remain the same size but shift between the two tasks (spotlight model). In any case, the attentive field should contract to fit tracking task demands, between the random appearance of the discrete response display.

Object-Based Models of Attention. Unlike space-based models, where space is the primary factor in controlling the distribution and selection of attention, object-based models of attention propose that grouping factors, such as shape (Kramer & Jacobsen, 1991), motion (Yantis, 1991), and color (Kahneman & Henik, 1981), play a part in the distribution of attention (Duncan, 1984). According to Neisser (1967), visual processing of the environment is accomplished through a two-part process. The first stage is

pre-attentive and automatic (Shiffrin & Schneider, 1977). During the pre-attentive stage, all visible elements in the environment are processed in parallel, and effortlessly organized with Gestalt properties. A grouping effect emerges when features are organized in a way that promotes form. During the second stage, the elements are processed in parallel as part of the object. The assumption is that when elements or targets are grouped to form an object they are processed as a whole; that is, in parallel.

Object-based models of attention propose that grouping objects into pre-attentive objects reduces attentional demands since the object can be processed rather than each of the individual elements (Treisman & Gelade, 1980). It is important to note that this is true only if stimuli induce Gestalt organizations that "predispose" perception; that is, they create an "object effect." Potential Gestalt principles capable of creating an object effect are proximity, shape, and symmetry. It is important to note that these principles are interrelated with space. In particular, the proximity principle confounds "objectness" with space, because the closer individual elements are, the more they may appear as an object.

Kramer and Jacobsen (1991) looked at the effects of contour and color on stimulus grouping while they held distance constant. In their set of experiments, space- and object-based models were tested using the response-compatibility effect. They placed distractors and targets either in two separate objects or within a single object, grouped by color or contour. Participants had to distinguish between targets and distractors with response incompatible flankers placed adjacent to the point of fixation. The flankers were placed at either a near ($.25^\circ$ of visual angle) or far (4° of visual angle) distance from the

target. Note that the far condition falls well within the stationary field ($<80^\circ$). Also recall that Eriksen (1974) found that the response compatibility effect was the strongest when the incompatible flankers were within 10° of visual angle from the target, which is larger than Kramer and Jacobsen's near condition. It follows that an object effect will occur within the stationary visual field because all of the information is simultaneously available, similar to the unitary percept concept. Kramer and Jacobsen's results were mixed. Space-based models accounted for the result that performance in the far condition was significantly worse than in the near condition. However, they also found support for object-based models. In the near condition, incompatible distractors had significantly less impact when distractors were located on different objects, but distance was held constant. Consequently, Kramer and Jacobsen found support for both models.

Kahneman and Henik (1977; 1981) also found an object effect on attentional filtering using the visual search task paradigm. In their set of experiments, the most interesting finding pertinent to the study presented here, was that participants could group and process in parallel, stimuli that were separated by intervening stimuli (distractors). It is important to note that these stimuli differed on a single dimension: color.

In terms of the present experiment, object-based attention would influence scanning by predisposing participants to pre-attentively perceive the group of discrete response locations within the rectangular box as an object; this object should be processed in parallel, and performance should be similar within the object and different between objects.

Clutter

Near Fixation. Clutter is a potential display factor, exerting an influence depending on the distance a target falls from fixation. At closer distances, clutter may be beneficial by helping to induce an object effect. If an object effect occurs, a larger number of object elements can be scanned without a subsequent cost in performance. Under conditions where stimuli are near fixation, Wickens and Andre (1990) found that the most important variable in predicting performance with a cluttered display was not simply the degree of spatial separation of stimuli, but the spatial separation of relevant from irrelevant items. In the present experiment, the clutter manipulation involves the visibility or invisibility of inactive discrete response locations. Nevertheless, it is possible that clutter will increase performance in the present experiment by interacting with the object effect. Consider first the clutter condition where all of the discrete response locations are visible. Although all of the discrete response locations are important throughout the experiment, during a given trial the only important location is the one that is currently active. It is possible that clutter may actually improve performance because additional stimuli might encourage the perception of the box and the stimuli contained within the box as an object. In other words, the multiple stimuli created by adding clutter could enhance the perception of the object in which they are contained. According to Kahneman and Henik (1977), this is possible if the number of items in the group does not exceed four, and if they are relatively homogeneous (i.e., they do not vary on more than one dimension such as shape or color). Both of these conditions are met in the present experiment. Thus, if clutter

encourages a perception of grouping, it is predicted that performance will be improved in the clutter condition because all of the elements will be processed in parallel. This should only occur for locations within the tracking box.

Far Locations. In contrast to potential clutter benefits at closer distances ($< 35^\circ$), clutter has a potential cost at more distant locations ($> 35^\circ$). When images are mentally scanned, the time to scan them is directly proportional to the area of the image scanned (Kosslyn, Ball, & Reiser, 1978). Therefore, a larger area would take longer to scan than would a smaller area. Thorndyke (1980) extended this finding to map distance estimations. He asked observers to estimate the distances between two locations on a map. When intervening landmarks were added (clutter), observers over-estimated the distance between the two locations. Apparently, there is a false perception of a greater distance to scan when there are many landmarks to scan over. Thorndyke found this "filled distance effect" for perceived stimuli, although not to the same extent as for mental images. Thus, it is predicted that when targets appear in the head field, clutter would encourage head movements and reduce performance because observers may over-estimate the distance between tracking and the target. Therefore, at greater distances performance in the clutter condition will be worse than performance in the no clutter condition.

Summary

In summary, organizing the elements in a display as a single object can facilitate simultaneous processing of all elements within that object (Kahneman & Treisman, 1984). However, this argument can be confounded

by spatial properties. That is, it is equally likely that any improvements are due to a reduction in a separation of each display component and not the "objectness" created per se. Thus, a problem in differentiating the two classes of models is that objects and space are often confounded. However, as the data of Kramer and Jacobsen (1991) indicate, when space is held constant, both models of attention probably explain the results found with most tasks. The question is, under what conditions do the influencing factors of each model have their greatest effects?

This study attempts to link the scanning and attention research in order to explain the effects of distance on visual scanning performance. One important difference between the scanning and attention research is that the scanning research discussed is mechanistic, whereas the attention research is cognitive. Another important difference is that the majority of the attention research is based on stimuli that never stray from the stationary visual field. This is largely due to the confounds that result when extending to the rest of the field. For example, a major confound is in shifting attention either overtly with eye movements and/or covertly without any observable movement. This is the reason that research on attention has utilized equipment such as a tachistoscope or a computer with which the stimuli are presented quickly (so that no eye movements are possible) and separated by small degrees of visual angle (such as in Kramer and Jacobsen, 1991). The present study attempts to investigate the benefits of attention applied to the phenomenon of visual scanning in the eye and head subfields (up to 72° visual angle).

The Present Study. The present study attempts to assess the effects of physical and attentional influences on scanning performance and behavior. The first goal was to determine if attention plays a role in visual scanning beyond visual system limitations. The second goal was to examine the influence of both object- and space-based models of attention on scanning performance by introducing and manipulating the size of a rectangular object and measuring how it influenced the onset of eye and head movements and performance. The third goal was to examine whether the addition of intervening stimuli (referred to as clutter) mediated the scanning function observed. It is hypothesized that at closer distances, clutter would enhance the Gestalt perception of the tracking box as an object because a stronger perceptual group is formed by increasing the number of elements in each box (Kahneman & Henik, 1977). Therefore, it was expected that in the clutter condition, any observed object effects would be magnified and the performance differences between objects would be greater. However, when the active location was at greater distances, such as within the head field, it was expected that clutter would increase the difficulty for the participant to find the active location among the inactive locations. At large separations, head movements are necessary and clutter might cause them to overestimate the distance and would therefore encourage head movements earlier than they might have occurred in the no clutter condition.

The present experiment manipulated scanning performance by dividing attention between elements either contained within the same object, or contained in different objects. Object-based models of attention predict that stimuli within the same object are processed in parallel and stimuli in

different objects are processed serially. Hence, performance should remain the same between the different elements of an object, but should decrease when scanning between objects. Therefore scanning performance between objects was expected to be worse than scanning performance within objects. Hence, the scanning cost function and subsequently the three fields (stationary, eye, and head) are expected to reflect the tracking box size; tracking box size was manipulated to see if the visual subfields expand to contain the object and the focus of attention.

To test the object-based attention hypothesis, tracking location was varied to control for space while manipulating individual elements so that they were located either within or between objects. It was hypothesized that if an object effect occurs, it will be reflected in a broadening of the stationary field to fit the object and improve performance. A change in performance between the last stimulus in the object and the adjacent stimulus located in the other object would support object-based attention. If the box size does not define the new function, and performance does not gradually decrease, a space-based model may be supported if the rectangles define a proposed zoom lens or spotlight. If visual system limitations drive visual scanning, the trends previously defined by Andre and Cashion (1993) would be replicated.

Method

Participants

Thirty-two participants recruited through the San Jose State University subject pool participated in this study. Eight participants were randomly assigned to each box size group. An equal number of females and males were

distributed among groups. All participants had at least normal or corrected-to-normal vision with the aid of corrective lenses.

Design

The experiment utilized a 4 (box size) x 2 (tracking location) x 2 (clutter) x 8 (distances) mixed design. Box size, referred to the number of discrete response locations within the box, was varied between participants, and ranged in size from one to four (0, 12, 24, 35° visual angle). The box enclosing the tracking task was rectangular and included one or more discrete response locations depending on the box size. For example, box size 2 contained two target locations. Clutter was a within-subjects variable and consisted of two levels, on or off; that is, either all target locations were visible, or only one target location was visible. Tracking location was also a within-subjects variable. Location varied from either the far left or the far right border of the tracking box. The tracking area was a constant size even with larger box sizes. In this way tracking difficulty did not covary with box size and was held constant for all groups. Finally, target distance was varied within-subjects, over eight levels of distance, including 0, 12, 24, 35, 45, 55, 64, 72° visual angles from the far left (0°), to the far right (72°) side of the screen. All within-subject variables were counterbalanced.

Apparatus

All stimuli were generated by a Silicon Graphics Personal IRIS graphics workstation and presented on a 6 ft x 6 ft large color screen using a Projection Systems Electrohome rear projection system. Participants were seated in an elevated chair, placed 4 ft. from the screen, and positioned where their eye point fell at the screen's vertical midpoint.

Stimuli

The stimuli in this study (see Figure 2) were similar to Andre and Cashion's (1993) but appeared as in Figure 3. The main difference was that an object effect was implemented with Gestalt geometric and perceptual organization principles (Wertheimer, 1964). Potential organization principles creating "objectness" are similarity, proximity and symmetry. In addition to these, another grouping principle was the applied geometric principle of "squareness" or a square and/or rectangle composed of 90° angles. This was based on the Law of Pragnanz where the simplest figure is the preferred figure and a 90° rectangle is a simple geometric configuration.

Participants were asked to perform two tasks simultaneously: a continuous tracking task and a two-choice response task, referred to here as the discrete response task.

Task. The goals of the two tasks were as follows: for compensatory tracking, the task was to continually minimize the distance (error) between the tracking cursor and the target area, and for the discrete response, the task was to detect and correctly identify the direction (left or right) of the arrow (see Figure 2) before it disappeared. The performance objective was to score as many "hits" as possible. Hits were defined as a correct response to the discrete response stimulus (left response to left arrow, right response to right arrow) while the tracking cursor is within the target area. To make things even more difficult, they had to respond within 700 ms of the discrete response stimulus. Participants received instant visual feedback, because the box where tracking occurs flashed green when they scored a hit. Participants were

Figure 2. Andre and Cashion (1993) experimental stimuli.

Figure 3. Experiment stimuli for box size 1.

asked to respond to every arrow they saw, even if they are not in the target area, in order to reduce their omissions (failures to respond).

Tracking Task Display. The primary task was a continuous, first-order compensatory tracking task. This task was performed within a box (see Figure 4). The target area was a stationary circle centered within the tracking box. A forcing function drove a green cursor (a small cross) about the tracking box. Participants were to counteract the cursor's movement in order to keep it within the target area. The tracking cursor was controlled by fore-aft and left-right deflections of a two-axis joystick located at the participant's right-hand. Participants were asked to reduce their tracking error as much as possible. Tracking error was defined by the deviation of the tracking cursor from the center of the target area measured in screen pixels. At the end of each trial, participants received feedback on their tracking error and accuracy. Tracking error was displayed in terms of mean deviation in number of pixels. They were told that the lower the number, the better the tracking, and that a score of 0 indicated perfect tracking. Where tracking occurred within the display, depended on the location condition. In some conditions the target area varied between the left and right border of the tracking box (see Figures 4b and 4d).

Discrete Response Display. The discrete response display consisted of a circle, 8 pixels in diameter, that periodically displayed a left or right directional arrow. The arrow was dimly and equally illuminated on the screen across all positions; however, it was not equally illuminated respective to the observers' angle of view due to projection limitations. This display appeared at any one of 8 distances from the far left to the far right of the

Figure 4. Box conditions: a) box size 1 (control); b) box size 2; c) box size 3; d) box size 4.

screen along the horizontal plane. Therefore, distant locations were more difficult to see than were proximal locations. This two-choice discrete response task required a left or right response to a 640 ms presentation of an arrow. The location and direction of the arrow were randomly presented during each trial, at inter-stimulus intervals ranging from (3 to 10 seconds). At the start of each trial, the discrete response display circle flashed 3 times to indicate the active circle (the circle that currently displayed the arrow).

Participant responses to the discrete stimuli were recorded from the same joystick the participants used for tracking, which was manipulated with their right hand. A correct response for a left arrow presentation was a left button press, with the thumb, and a right button press, with the index finger for a right arrow. These buttons were selected to allow participants to keep their fingers on the buttons at all times without interfering with the tracking task.

Independent Variables

Box Size. The boxes varied in size from 1 (control condition) to 4; however, the actual tracking area remained constant (see Figure 3). Box size 1 contained one discrete response location, box size 2 contained two, box size 3 contained three and box size 4 contained four discrete response locations, equivalent to 0, 12, 24, and 35° of visual angle separation, respectively. All discrete response locations outside of the tracking box were also enclosed within a red rectangle. There were always two boxes of variable size but the total distances subtended by both boxes were the same. Participants were randomly assigned to a tracking box condition which was displayed throughout the experiment. Therefore, a participant was presented with the same box size throughout the experiment. One box was located at the

subject's left, where tracking was performed, and the box to the right only contained the various discrete response locations.

Tracking Location. For all tracking box conditions except size 1 (control condition), tracking location varied over two levels. During one half of the trials, participants were tracking at the left-most border of the tracking box and the other half of the trials they were tracking at the right-most border of the tracking box (see Figure 4). Tracking location was counterbalanced and participants received an equal number of trials at each location.

Although there was not a visible separation (line) between the target area and the rest of the tracking box, the tracking location was obvious to the participant through two salient cues: 1) the tracking cursor did not move beyond an invisible barrier (see Figure 4) and 2) a red circle defined the target area. The only time the target area was not the color red was when the active discrete response display was superimposed over it; that is, when it looked like a discrete response display. The discrete response display overlapped the target area depending on the location of the target area (target area location) and the tracking box size. For example, for tracking box size 2 and tracking location right, the discrete response display at position two overlapped the target area.

Clutter. Stimulus clutter was manipulated within two levels. In the clutter condition, all eight of the potential discrete response locations were visible with only one active (contained arrow). In the no clutter condition, only the active display was visible. Before the start of each trial the active circle flashed three times to inform the participant of its location. See Appendix B for a diagram showing examples of the stimuli.

Dependent Measures

The performance measures recorded were frequency of hits (accurate tracking and a correct response), frequency of omissions (no response), Root Mean Square (RMS), tracking error when the arrow was not visible (Primary RMS), and when the arrow was visible (Secondary RMS). Tracking error was sampled at a rate of 33 Hz (.03 seconds).

Procedure

The experiment was conducted inside a dark and quiet room. Each participant completed five blocks of eight trials. Four additional trials required just the performance of the tracking task. Two of these trials were presented at the start of the experiment in order to measure the tracking baseline and two were presented at the end of the experiment. The post-tracking trials were taken to assess tracking performance changes and/or fatigue effects from the initial baseline measurements. The very first block of eight trials was practice. Discrete response distance order (8 display distances) was counterbalanced such that no participant received the same order of the eight discrete response display positions. The timing of the arrow presentation varied; therefore, trial duration ranged from one to one and a half minutes.

A total of 12 arrows appeared per trial. To discourage participants from guessing, the direction of the arrow varied, although, during a given trial, there was an equal number of left and right arrows. At the end of each trial, participants received feedback on their mean tracking error, frequency of hits, and frequency of misses (incorrect response and inaccurate tracking). In order to reduce fatigue effects, participants were able to self-start each trial.

They were informed that they could rest at any time for as long as they wanted after the conclusion of a trial. To allow self-paced trials, following the feedback screen, and after a 10 second delay, a generic tracking box was centered on the screen. The participant was instructed to move the cursor inside the target area to start the next trial. The next trial began immediately at the participant's command. After four trials within the block, participants were given a 45 second break and were unable to start the next trial until this time had elapsed.

To summarize, the experiment consisted of the following five phases. The participant learned the tracking task with two tracking-only trials where a tracking baseline was measured. Next the participant received a practice block of eight trials that included one level of each of the within subjects conditions. An example block of trials, a subject was presented with tracking location right, with clutter, and discrete response location 2. The tracking box size remained constant for each participant. Following the practice trial, the participant received four more blocks of trials. Each condition was counterbalanced for that participant. For example, the second block of trials may have consisted of tracking on the left hand side of the tracking box, without clutter (only one visible discrete response location), and distances from 0 to 8 presented one trial at a time in a counterbalanced order. The participant received an equal number of levels of the three variables. The experiment concluded with 2 tracking only trials to measure post-experiment tracking improvement or fatigue. Finally, participants were debriefed and thanked for their participation. Although each participant set her or his own pace, overall the experiment lasted approximately two hours.

Results

The effects of distance, clutter and box size on three dependent measures were analyzed: primary tracking error (tracking performance when the arrow wasn't visible), secondary tracking error (tracking performance when the arrow was visible) and hit rates (correct and accurate responses). The accuracy measure (hit rates) was transformed into error rates to help with interpretation. Misses were not analyzed. Accuracy was the primary dependent measure as it reflected performance on both tracking and identification of the arrow. Reaction time was measured but not analyzed because there was a maximum duration to respond (700 ms) that reduced variability. Please note too that " F_l " indicates the linear F ratio value and F_q indicates the quadratic F ratio value to visibly contrast from the F ratios for the overall analyses of variance.

The data were analyzed separately for each tracking location. This was due to the complication that when participants were tracking left, the point-of-fixation was constant; however, when participants were tracking right, the point-of-fixation varied with box size (refer to the diagram showing all stimuli, located in Appendix B). It was inappropriate to conduct analyses for distance as if both sets of data measured the same separation distances. In addition, the tracking left data were analyzed to determine the overall effects of distance, box size and clutter on tracking error and accuracy, whereas tracking right data were designed to specifically test for object effects while distance was held constant.

Tracking Left

Distance. Accuracy, primary tracking error, and secondary tracking error were analyzed separately in a 4 (box size) $\times$ 2 (clutter) $\times$ 8 (distances) mixed analyses of variance (ANOVA). Box size was a between-subjects factor. This analysis was conducted to determine if scanning was affected by distance. The omnibus ANOVA revealed a significant main effect of scanning distance on primary tracking error [$F(7, 196) = 20.54, p < .001$], secondary tracking error [$F(7, 196) = 16.94, p < .001$], and accuracy [$F(7, 196) = 20.18, p < .001$] (see Figures 5a-5c). Distance did not interact with clutter or with box size [$p > .10$], in any of the three analyses.

As expected, when distance increased, performance decreased. As shown from the secondary tracking error measure (see Figure 5b), performance decreased as the distance between the location where the arrow appeared from the tracking area increased. Tracking also suffered when the arrow wasn't present (see Figure 5a) which suggests that participants were continuously looking for the arrows. The tracking task also affected participants' correct identification of the arrows. A question to ask: does the relationship change when eye movements are necessary to identify the arrow, compared to head movements? Trend analyses were performed to answer this question, and to determine if the performance cost functions were similar to those found by Andre and Cashion (1993).

Trend analyses were conducted for distance, collapsed across clutter and box size to determine if there was a replication of the three functional subfields as found in Andre and Cashion (1993). As expected, the trend

Figure 5a. Mean tracking error when the arrow was not visible as a function of distance from fixation.

Figure 5b. Mean tracking error when the arrow was visible as a function of distance from fixation.

Figure 5c. Mean percentage of errors as a function of distance from fixation.

analyses revealed both significant linear and quadratic trends for all of the performance measures. In line with Andre and Cashion, two different functional components were found as indicated by two significant trends for each of the performance measures. The trend analysis for primary tracking error revealed both significant linear [$F_l(1, 28) = 33.86, p < .001$] and quadratic [$F_q(1, 28) = 5.81, p < .05$] trends. The trend analysis for secondary tracking error also revealed a significant linear [$F_l(1, 28) = 28.86, p < .001$] and quadratic [$F_q(1, 28) = 4.95, p < .05$] trend. And finally, there was also a significant linear [$F_l(1, 28) = 47.08, p < .001$] and quadratic [$F_q(1, 28) = 6.88, p < .05$] trend for accuracy.

The presence of linear and quadratic trends in the performance functions is the first line of evidence indicating the presence of at least two of the subfields. The second line of evidence is that these trends are almost identical to those found in Andre and Cashion (1993) and are consistent with Sanders' (1970) visual subfields. The cost functions are described in terms of their subfield components. The first segment shows stable performance (stationary field) at distances less than 12° for tracking error (see Figures 5a and 5b). The eye field segment for tracking error is virtually identical to the segment found by Andre and Cashion. As Figures 5a and 5b show, the onset of the eye field begins at 12° of visual angle and roughly terminates at 54° . Andre and Cashion's eye field was similarly defined at distances greater than 14° but less than 56° . Looking at the data there was a change in the function from a linear to a steeper slope at 55° which accounts for the head field. The accuracy data (see Figure 5c) reflects a slightly different function where the eye and head fields begin at the same points as the tracking error data but the eye field segment is much steeper. This indicates that within the eye field,

accuracy performance decreased with distance at a steeper rate. Andre and Cashion reported that distances greater than approximately 56° define the head field. A similar distance of 55° defined the head field in this experiment. Therefore the cost functions are very similar.

Clutter. An ANOVA revealed that clutter was not significant for tracking error and accuracy (primary tracking error [$F(1, 28) = 0.00, p > .10$]; secondary tracking error [$F(1, 28) = 0.01, p > .10$]; accuracy, [$F(1, 28) = 0.01, p > .10$]). Furthermore, none of the interactions was significant [$p > .10$]. This suggests that tracking and accuracy performance were not affected by the addition of and/or the absence of clutter.

Box Size. Box size did not have a significant effect for any of the dependent measures: primary tracking error [$F(3, 28) = 1.46, p > .10$], secondary tracking error [$F(3, 28) = 1.28, p > .10$], or for errors [$F(3, 28) = .98, p > .10$]. This was not surprising, as box size was a between subjects factor, and was consequently less powerful than the other variables in detecting significant differences.

Although the omnibus ANOVA did not reveal a significant main effect for box size, the data suggests that box size may have had an effect not revealed by a comparison of overall group means. Also, planned comparisons were conducted for the tracking right data in order to determine the effects of object-based attention. These comparisons are discussed shortly. Looking at the tracking left data shown in Figures 6a and 6b, tracking performance on each of the dependent measures appears better for box sizes greater than size 2. In addition, performance in the box size 3 condition was consistently better than in the other box size conditions. Trend analyses were

Figure 6a. Mean tracking error when the arrow was not visible as a function of box size and distance.

Figure 6b. Mean tracking error when the arrow was visible box size as a function of box size and distance.

Figure 6c. Mean percentage of errors as a function of box size and distance.

conducted on each box size function for each performance measure in order to determine if the size of the box had an effect on the shape of each function. The argument is that if box sizes greater than size 2 were missing the quadratic trend component, but box sizes 1 (control condition) and 2 had quadratic components, the introduction of the larger boxes (sizes 3 and 4) may have reduced the need for head movements and subsequently improved performance.

Box size 1. Box size 1 trend analyses for both primary and secondary tracking error (see Figures 6a and 6b) showed a significant linear trend [$F(1, 7) = 14.40, p < .01$] and [$F(1, 7) = 9.81, p < .05$], but the quadratic trend was not significant, $p > .10$. The trend analysis for accuracy showed a significantly linear component [$F(1, 7) = 5.92, p < .05$], but not a quadratic component [$p > .10$]. The apparent difference in performance for the larger box sizes (see Figures 6a -6c) is not substantiated by quadratic trends for box sizes 1 and 2 that are not present in the other functions.

Box Size 2. The box size 2 trends for primary tracking showed a significant linear component [$F(1, 7) = 7.79, p < .05$], but not a quadratic component [$p > .10$]. None of the trends for secondary tracking error was significant [$p > .10$]. There was a significant linear trend for accuracy [$F(1, 7) = 9.46, p < .05$], but the quadratic trend did not reach significance [$p > .10$].

Box Size 3. Box size 3 for primary tracking had both a significant linear [$F(1, 7) = 10.66, p < .05$], and quadratic trend [$F_q(1, 7) = 6.76, p < .05$]. However, the secondary tracking error trend showed only a linear trend [$F(1, 7) = 13.39, p < .01$]. Accuracy was also linear [$F(1, 7) = 17.35, p < .01$], but not quadratic [$p > .10$].

Box Size 4. The trend analysis for primary tracking revealed no significant trends. There was, however, a significant linear trend [$F_l(1, 7) = 5.94, p < .05$], for secondary tracking error, but the quadratic test was not significant [$p > .10$]. In contrast to the other box size conditions, box size 4 had both a significant linear trend [$F_l(1, 7) = 20.80, p < .01$], and quadratic trend [$F_q(1, 7) = 6.73, p < .05$] for accuracy.

The trends for each box size are essentially linear and therefore the hypothesis that performance is better with the larger box sizes is not supported, as their trends are not significantly different. This finding is in contrast to the linear and quadratic trends found for distance overall.

In summary, the tracking left data indicate a distance effect that replicates Sanders' (1970) subfields and matches the cost functions found by Andre and Cashion (1993). As expected, performance fell off at a linear rate with distance, until a change to a steeper rate in the head field. It was also found that clutter did not have a significant effect on performance. In addition, performance did not differ significantly across the four box sizes. At this point, it can not be concluded, that the introduction of the various box sizes did not induce an object-based attention effect. In order to determine an object-based attention effect, the data when participants were tracking right were analyzed to determine if performance varied depending on whether the arrow appeared within the object where tracking occurred or between objects while spatial separation was held constant.

Tracking Right

Omnibus ANOVAS were not conducted for the tracking right data, as they were not useful in testing the object-based attention predictions. Rather,

planned comparisons were conducted between various distances contingent upon the size of the box (object) to test the hypotheses of the object-based models of attention. Although other comparisons could be justified, the critical comparisons tested were distances immediately adjacent to the point of fixation and inside the tracking box compared with distances immediately adjacent to the point of fixation, but outside of the tracking box (see Figures 7a-7d). For example, for box size 2, the critical comparisons were between locations 0 (inside the box) and 2 (outside the box) (see Figure 7b). Because the object-based attention model states that elements within the object would be processed in parallel, it was hypothesized that performance would be better within objects than between objects. Recall that distance was constant in this comparison; the only difference was whether the arrow location appeared within the object attended to or within the other object. Planned comparisons were conducted for stimulus separations for each box size, broken out by each level of clutter, because clutter was hypothesized to facilitate an object effect. The comparisons are described in order of smallest to the largest box size for each dependent measure. Refer to Figures 8a-10d throughout the following discussion.

Box Size 1. For box size 1 (control group), the critical comparisons were between locations 0 (in box, and superimposed on tracking) versus 1 (outside box). There was a significant within-object advantage for primary tracking error [$F(1, 7) = 20.22, p < .01$] in that performance was better within the object (tracking box) than it was between the two objects. However, there were not significant differences between these locations for secondary tracking error [$p > .10$] and accuracy [$p > .10$].

a) A comparison for box size 1, location 0 vs. 1.

b) A comparison for box size 2, location 0 vs. 2.

c) A comparison for box size 3, location 1 vs. 3.

d) A comparison for box size 4, location 2 vs. 4.

Figures 7a-7d. Comparisons to test object effects while participants were tracking right.

8a)

Figure 8a . Mean tracking error when the arrow was not visible as a function of distance from fixation for box size 1.

8b)

Figure 8b . Mean tracking error when the arrow was not visible as a function of distance from fixation for box size 2.

8d)

Figure 8d . Mean tracking error when the arrow was not visible as a function of distance from fixation for Box Size 4.

8c)

Figure 8c . Mean tracking error when the arrow was not visible as a function of distance from fixation for Box Size 3.

9a)

Figure 9a. Mean tracking error when the arrow was visible as a function of distance from fixation for box size 1.

9b)

Figure 9a. Mean tracking error when the arrow was visible as a function of distance from fixation for box size 2.

9d)

Figure 9d . Mean tracking error when the arrow was visible as a function of distance from fixation for box size 4.

9c)

Figure 9c . Mean tracking error when the arrow was visible as a function of distance from fixation for box size 3.

10a)

Figure 10a . Mean Percentage of errors as a function of distance from fixation for box size 1.

Figure 10b . Mean Percentage of errors as a function of distance from fixation for box size 2.

10d)

Figure 10d . Mean percentage of errors as a function of distance from fixation for box size 4.

10c)

Figure 10c . Mean percentage of errors as a function of distance from fixation for box size 3.

Box Size 2. For box size 2, the critical comparisons were between locations 0 (inside) versus 2 (outside). The comparisons for both tracking error and accuracy were not significant [$p > .10$].

Box Size 3. The critical comparisons for box size 3 were between locations 1 (inside) versus 3 (outside), none was significant [$p > .10$].

Box Size 4. The critical comparisons for box size 4 were for locations 2 (inside) versus 4 (outside). None of the comparisons was significant for any of the measures [$p > .10$].

Although there was a single within-object benefit for box size 1, during primary tracking, the collective comparisons reveal that overall, there was not a consistent benefit for arrows that appeared within the object nor a disadvantage for arrows that appeared outside of the attended object. In other words, a consistent object-based attention effect was not observed. Comparisons conducted with clutter revealed the same pattern of non-significant effects.

In summary, looking at the primary tracking error data when participants were tracking right, shown in Figures 8a - 8c, performance appears to fall off in a mirror image about the point-of-fixation, regardless of whether the target was included within the same object (targets to the left of fixation) or not (targets to the right of fixation). Performance followed an eccentricity function irrespective of the object manipulation employed here. This data follows the functional visual field scanning performance cost function, and suggests that an object-based model of attention does not describe scanning performance in this study.

Discussion

The present data do not support an object-based model of attention. Contrary to the predictions of object-based attention models, there was not a performance advantage for stimulus locations within the relevant object compared to locations outside of the object. Instead, the performance cost functions appear to be the result of spatial deployment of attention and human visual system limitations. Statistical analyses revealed cost functions similar to Andre and Cashion (1993).

Space-Based Model.

There was some support for the space-based zoom lens model of attention. Recall that there were two predictions. One prediction was that the attentive field would expand to contain the tracking task and the active location (where the arrow appeared), which in some cases was a very wide field of view (zoom lens model). A second prediction was that the attentive field would remain the same size as the tracking task, but would shift to the active location (spotlight model). The data are not consistent with an expanding and contracting attentive field, but are consistent with an attentive field the size of the tracking area that continuously shifted to check for the arrow. Recall that during each trial 12 arrows appeared in the same location and a trial lasted between one and one and half minutes. This means there were only seconds between the appearance of each arrow. It is argued that the timing of the Inter-Stimulus Interval was too minimal for a zooming in and out of the attentional lens. In addition, the decrease in accuracy with distance is consistent with timing decrements of shifting attention. If the attentive field zoomed out when the arrow appeared, distance would have exerted less

of an impact on tracking error when the arrow is visible, indicated by a flat function. This is not the case (see Figure 5b). Finally, the continuous shifting is evident by the fact that tracking error when the arrow was present, varied similarly with tracking error when the arrow was not present, suggesting that participants continually searched for the arrow.

An explanation as to why the attentive field remained the same size may be due to the task demands. Task demands are known to affect attentive field size (LaBerge, 1983). Recall that tracking is continuous and probably demands most of the available attentional resources while the identification task is discrete and periodic. Participants knew where the arrow would appear but they did not know when it would appear. Because the target location was known, the intervening locations in the clutter condition were irrelevant to the task at hand. Had they been relevant, perhaps participants would have zoomed out to process the array of potential locations. To sum up, the space between the tracking task and the active location does not appear to be continuous, rather the data are consistent with an attentive field with a fixed size which periodically shifted between the tracking task and the known discrete response location.

Object-Based Attention

Although the data do not support the influence of object-based attention, the results do not preclude that object-based attention has an effect on visual scanning. There are a few reasons why an object-based attention effect may not have been found. The first reason is that the manipulation of different sizes of rectangles may have been weak in "objectness" and subsequently, parallel processing did not occur. The experimental task is the

second potential reason for a lack of object-based attention. Under the clutter condition, non-active locations were present; however, the task did not require processing of these locations. There was no performance advantage for processing the locations as part of an object. If the task was changed such that the target could have appeared within locations anywhere in the object, it would have been advantageous for participants to perceive the rectangle as an object. The fact that there was not a clutter effect also corroborates the lack of an object effect. Recall that clutter was hypothesized to enhance an object effect.

Scanning Cost Function.

Although the results do not indicate that objects facilitate visual scanning performance, the distance and visual scanning relationship was replicated. Again, the use of eye and head movements are costly to detection and identification performance. As distance increases, performance on two simultaneous but spatially separated tasks decreases.

The present study was unique in that attention theory was applied to scanning in the functional visual field. At this point, it can not be concluded that object-based attention is not useful to explain or improve visual scanning performance. However, it can be concluded that an object effect does not occur with the stimuli used in this study. Recall that the first step proposed by these models is to induce the pre-attentive processing of an object. In the second step the object is processed in parallel. In terms of visual scanning this would have increased the range of the stationary field producing an increase in performance. Unfortunately, this experiment may

have failed at the first step, not creating a strong enough association of "objectness."

Limitations of the Study.

Although this study used valid Gestalt principles, other principles, such as a color, or using motion such that an object forms a shape, due to common fate (Yantis, 1992) may have been more successful in testing object-based attention. Despite the limitations, this study has introduced a new methodology for testing object-based attention effects. Generally speaking, the method used was to create a fixation point with a compensatory tracking task, while stimuli to be integrated appeared at various locations to the left and right of fixation. The tracking task served to absorb attention while space was held constant. Then a Gestalt grouping principle was employed such that only "objectness" was varied.

The possibility that this study failed to create an object effect could be avoided in a future study. For example, stimuli could have been pretested by having participants rate stimuli in terms of a scale of "objectness." In addition, performance contingencies and stimuli could be changed such that performance on the task requires processing of all stimuli within each object. An example is to reverse the randomness in this experiment, randomizing the location, and pre-cueing the timing. Another method that would better externalize this research is to test object-based attention with an actual Multi-function Display such as the MD-11 Navigation and Primary Flight Display (see Figure 1).

Implications for Cockpit Design

This experiment suggests that the cost of scanning distant stimuli is not dependent on their co-location, or lack thereof, on the same object (display). This study supports the location of displays central to the pilots' field-of-view, that is, within the stationary or eye fields. Displays at distant locations that require constant monitoring will likely impose a cost on the continuous manual control task of flying.

In this study, clutter did not have an effect on performance, primarily because it was uninformative, unrelated to the task, and easily ignored. Because the trend in modern aircraft manufacturing is to supply more information to crews than ever before, the effects of clutter should be evaluated to specify when and how it inhibits performance. To this end, there may be ways to add important information on a display without degrading human scanning and processing performance.

Conclusions

In conclusion, this study found the same visual scanning performance cost functions as reported by Sanders (1970) and Andre and Cashion (1993). In addition, the prediction by space based attention models was consistent with the visual scanning data. The object-based attention manipulation had no effect on participants' performance. Finally, it is speculated that participants maintained an attentive field the size of the tracking area, and this field shifted in order to identify the discrete target.

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Appendix A. Signed Approval Forms

A campus of The California State University

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TO: Anthony Andre, Ph.D.
Patricia Cashion
NASA-Ames Research Center, MS 262-3
Moffett Field, CA 94035-1000

FROM: Serena W. Stanford *Serena W. Stanford*
AAVP, Graduate Studies & Research

DATE: November 15, 1994

This letter acknowledges that the Human Subjects-Institutional Review Board has received your request for extension of the following proposed study entitled:

"Attention and Visual Scanning"

Since there are no changes to the protocol, the Human Subjects-Institutional Review Board has granted this project a one-year extension effective from the date on this letter.

If you have any questions, please contact me at (408) 924-2480.

Appendix B. Examples of Experimental Stimuli.

a) Box Size 1, Clutter, Position 0

b) Box Size 1, No Clutter, Position 1

c) Box Size 2, Clutter, Tracking Left, Position 2

d) Box Size 2, No Clutter, Tracking Right, Position 3

e) Box Size 3, Clutter, Tracking Left, Position 4

f) Box Size 3, No Clutter, Tracking Right, Position 5

g) Box Size 4, Clutter, Tracking Left, Position 6

h) Box Size 4, No Clutter, Tracking Right, Position 7

Examples of Experimental Stimuli