VISUAL GRASP: EVIDENCE FOR OBJECT-BASED ATTENTION FROM LETTER ROW DISPLAYS

BY

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

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THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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Dedication

To Brenda Lee,
for faith, love and support

Acknowledgements

I gratefully acknowledge the support, encouragement, insight, and patience of the members of my thesis advisory committee: Drs. John Whiteley and Linda Wilson of the Department of Psychology, University of Manitoba, Dr. Brian Macpherson of the Department of Statistics, University of Manitoba, and Dr. Vincent Di Lollo of the University of British Columbia. Special thanks to my advisor, Dr. John McIntyre of the Department of Psychology, University of Manitoba, for his excellent support and advice.

Abstract

A series of 6 experiments attempted to specify the characteristics of a proposed attentional phenomenon dubbed "visual grasp." It was hypothesized that a visual grasp makes the external contours or elements of a briefly-presented display available for identification before more internally-located elements become accessible. Tests involved having observers report a single letter, cued at display offset, from a horizontal row of letters. Experiments 1 and 1A demonstrated that a visual grasp occurs when observers are required to process all items in a display. Outermost letters in a row were identified more accurately than interior letters. The failure of differential instructions to affect identification scores led to the suggestion that visual grasp involves the exogenous capture of visual attention. Experiment 2 provided evidence that visual grasp is directed toward perceptual objects rather than regions of visual space. Letters in identical retinal positions were recalled with greater accuracy when those positions appeared at row ends than when they appeared within rows. Experiments 3, 3A, and 3B indicated that visual grasp may be directed toward individual perceptual groups within a larger display. Color groups were created within letter rows; letters appearing at the edges of color groups were, in some cases, identified more accurately than letters in identical retinal positions that were not at the edge of a color group. It is suggested that visual grasp represents an early and fundamental aspect of object identification.

1

Defining the Problem: Early Visual Processing

". . . each of us literally chooses by his ways of attending to things, what sort of a universe he shall appear to himself to inhabit."

William James, *Principles of Psychology*, vol. 1, p. 402

James was right. Clearly, we do not take in *all* the visual information available in the environment around us. The information we take in (process) and, just as importantly, what we don't take in determines what we know about our world, and how we interact with it.

This paper examines a basic question in the area of visual perception, namely, how we begin to make sense of the vast array of visual information available to us at a given moment. In the subheading above, the term "early" refers to the chronology of perception or of object identification, and not to a developmental aspect of perception. As Pomerantz (1981) noted, a basic issue in attacking any such complex problem is where to begin. If we consider the "equipment" we are dealing with, the human visual/perceptual system, we realize that understanding a process that *begins* with 125 million receptors providing inputs to the system is not going to be a simple task. Given this complexity, the potential interference from "noise" elements, and the limitations we have in terms of the amount of information we can process at a given time, the task of perception would seem nearly impossible. Still, we know (based on our ability to function effectively) that this system is ordinarily very successful in providing us with a reasonably veridical representation of the world around us. We perceive our surroundings effortlessly, and take little notice of the process until, perhaps, we realize an error has been made. How do we get from the mass of incoming sensory data to an understanding of a world consisting of people and objects that have meaning to us, and with which we interact?

The first goal of the perceptual system is to determine what is "out there." We need to map our surroundings, outlining and locating the major objects and their positions (Pomerantz, 1981). At the same time, the system begins the process of identifying these initially defined objects. The system begins (must begin) with information at the receptor level, and from that information, builds up more global representations. A fundamental part of this task is for the system to determine which bits of local information, which surfaces, blobs, and spots of light, go with which others. These links must be made for us to be able to recognize any object. To understand how we recognize objects, then, we must understand the process of perceptual organization.

The argument may be made that this organization need not be a product of the structural mechanisms of our visual system, but may occur through attentional strategies. Theeuwes (1994) and Yantis (1993) indicated that attention is sometimes captured *exogenously* through properties of the visual stimulus. However, it may also be deployed *endogenously* when stimulus selection occurs in an intentional, goal-directed manner. Rock (1983) claimed that perceptual processes involving attention operate much like conceptual problem solving processes -- they function in a logical manner to meet an observer's goals. If it is claimed that such attentional or stimulus selection processes are under voluntary control, it follows that this selection may be directed in a flexible way – focusing our processing resources on particular parts of the visual field or onto particular objects. Thus, an observer may allocate processing in such a way that provides the best chance for a target object to be identified, recognized, or understood.

From the fact that we do not process all parts of a visual scene in a uniform manner, one may propose that some parts of a scene or display may become identifiable or available to an observer before other parts of that display are sufficiently processed for identification. Most of the currently held views of attention suggest that attention operates serially, processing visual stimuli one at a time. One may ask, then, whether certain features or parts of a visual display are *routinely* processed before others. The question of processing order has been the subject of considerable research in the area of visual perception.

So, the nature of visual processing within the first few milliseconds may provide keys to our understanding of how we recognize or identify the objects that make up our environment. This early processing may be subject to specific strategies, heuristics, or routines that enable an observer to deal with visual information in an effective manner. This paper proposes the existence of one such phenomenon.

The thesis proposed herein is as follows:

> that there exists a *visual grasp* – an attentional process for apprehending visual information (i.e., for object recognition), which operates to identify the outer contours or elements of a display before more centrally located contours or

elements become identifiable.

This visual grasp is envisioned as a grasp of a perceptual object much in the same way as a physical object may be grasped manually. Initial contact is made at the outer surfaces or edges, and further processing of the object is based on this initial segregation process. Such a phenomenon is expected to occur whenever an entire stimulus or an entire array of stimulus elements is to be identified. One commonly occurring instance involves the identification of a string of letters, as in a reading task. The current investigation explores the characteristics of a visual grasp as they would influence the identification of a display of letters. In applying this concept to a letter identification task, I attempt to provide evidence that

(a) when only a very brief interval is provided for visual processing, the outermost letters in a post-masked horizontal array are identified most accurately. Such an outcome would suggest that these outermost elements are the first to become identifiable (available) in such a display -- they are first to be grasped or apprehended by the visual processing system.

(b) whether a post-masked horizontal array of letters appears centered across the visual field, or is displaced relative to a central fixation point, the outermost letters in that array, not those nearest fixation, are identified most accurately. Such a result would support the idea that a visual grasp is directed toward perceptual objects in an array rather than toward an area of space surrounding a fixation point.

(c) when more than one perceptual group (defined according to traditional Gestalt principles of proximity and similarity) is presented in a post-masked array, identification is most accurate for those letters appearing at the outer boundaries of each perceptual group. Such an effect would indicate that a visual grasp is directed toward individual perceptual groups defined by preattentive segregation processes.

As suggested by these goals, several major issues in visual perception are related to the current problem, among them the notion of attention and attentional strategies, the perceptual organization of items or elements in a display, and the order in which the perceptual system processes such items. One might find it curious that, historically, these issues have received rather independent treatment, although some investigators have recognized connections between such issues as the effects of perceptual organization on attentional and object recognition processes (e.g., Kahneman & Henik, 1977; Kramer & Jacobson, 1991; Pomerantz, 1981). In the background sections of this paper, I review findings regarding these important issues before attempting to show how each may reflect upon the construct of a visual grasp.

2

Order of Processing

Given that we, as observers, do not process all aspects of a display or a scene to an equal degree, and given that most of our widely held models of attention suggest that we focus our attention in a serial manner from one perceptual object to the next, we may ask further whether we can know something about the *order* of processing within a display.

EVIDENCE FROM TACHISTOSCOPIC DISPLAYS

The question of processing order has received considerable research attention. The most common paradigm for the study of processing order has involved the presentation of brief displays using tachistoscopes -- displays which are too brief to allow eye movements -- to one side of fixation, or across a fixation point (e.g., Bryden, 1960, 1966; White, 1976). Various researchers have employed as stimuli horizontal rows of letters (e.g., Bryden, 1966), numbers (e.g., Kahneman & Henik, 1977), symbols (e.g., Harcum, Hartman, & Smith, 1963), or non-linear displays of such elements (e.g., Heron, 1957; Kimura, 1959).

Much of the early work addressing processing order was concerned with brain laterality – the idea that the brain is organized having certain functions and capabilities located more into one hemisphere of the brain than the other, such as the concentration of verbal abilities (at least for right-handed persons) in the left hemisphere (Dick, 1974).

Mishkin and Forgays (1952), for example, reported that English words were more easily recognized when tachistoscopically presented to the right visual field than when presented to the left visual field. Conversely, subjects who could read Hebrew words (which are read from right to left) recognized more Hebrew words when they appeared in the left visual field. It was concluded that learning to read the respective language establishes a "more efficient neural organization" (p. 47) in the relevant cerebral hemisphere.

One of the most widely cited studies concerning the order of processing was conducted by Heron in 1957. This study served as a crossroads for laterality studies on one hand and for studies of processing order on the other. Heron was concerned with the latter. He presented horizontal rows of non-alphabetic symbols in either subjects' left or right visual fields, expecting that those seen in the right visual field would be better identified. They weren't; however, when rows of *letters* were displayed, those in the right visual field were reported more accurately. Letters were not uniformly identified. Heron noted a steady decline in accuracy from the point of central fixation toward the periphery of the field. Finally, when Heron presented rows of eight letters across the point of fixation (i.e., four letters in each visual field) and had subjects report all they could see, those letters furthest to the *left* in the display were best recognized (again followed by a steadily declining function toward the right).

Heron (1957) attributed his results to attentional processes of two types. The first involved concentration on one part of the visual field (around the point of fixation). The second consisted of post-exposural processes, perhaps akin to what has since been called iconic memory. Heron argued that letters in his displays were attended in the order that they would be read, and this post-exposural attention was closely related to tendencies toward eye movements established by reading habits.

Two tendencies were suggested in this regard. The first was to fixate at the leftmost position in a display; the second was to move the eyes from left to right. If letters appear to the right of fixation, these two tendencies work together. If the display appeared to the left, the tendencies would be in opposition. Thus, more letters should be recalled from the right visual field, as was the case. When letters were exposed across fixation, the dominant tendency to fixate to the left would cause more letters from this region of the display to be recognized, just as found. The attentional mechanisms postulated by Heron as being closely tied to reading habits accounted neatly for his findings. The lack of visual field superiority found when non-alphabetic symbols were displayed showed that the normal reading scan was applied to a lesser degree to these nonverbal stimuli -- a reading habit would not apply here.

Variables Affecting Letter Span Errors

A considerable literature stemmed from this work, as researchers attempted to determine the factors responsible for letter span error functions. Townsend, Taylor, and Brown (1971) described some of the variables that investigators deemed important, or at least potential, influences on errors in recognition tasks:

1. retinal locus -- how far an element appears away from the fovea. The greatest density of cone receptors occurs at the fovea, and finest visual discriminations are made for stimuli falling on this region of the retina. The farther a stimulus falls from the fovea, the less chance it has of being correctly identified (often attributed to coarsened, less finely

tuned input channels).

2. relative position in an array. The absolute position of an element in a display has proved to be a vital factor in its recognition. In a row display, for example, the first and last letters are consistently better recognized than their immediate neighbors. Under certain conditions, central letters are also recognized at high levels.

3. exposure duration and whether an array is followed by a mask stimulus. Longer durations result in overall higher recognition performance, and mask stimuli reduce performance relative to no-mask conditions.

4. spatial separation of items. Greater separation reduces metacontrast (lateral inhibition) between individual elements and improves performance.

5. number of elements in a display. This factor affects performance when an entire array is to be reported, due to short-term memory factors. It is simply more difficult (a greater memory load) to report 9 items than 5, and a greater load reduces accuracy.

6. type of report – whole versus partial. With partial report, reduced memory load should be found, along with a potential change in the shape of the serial position curve.

In 1960, Bryden compared the perception of letters and non-alphabetic shapes in displays spanning both visual hemifields, finding that, for both types of stimuli, items to the left of fixation were identified better than those to the right. In addition, both letters and shapes tended to be reported in a left-to-right order. When Bryden manipulated report sequence (left-to-right vs. right-to-left) by providing report instructions immediately *after* exposure ("to control for pre-exposural attentional factors" [p. 82]), more letters were reported from the left of fixation under either report condition. Reportability of shapes was determined by report order. More shapes from the right visual field were reported under right-to-left report conditions; whereas, the usual left-field dominance appeared with left-to-right reports. Bryden attributed these results to processes of immediate memory -- a rapidly fading memory trace that allows items early in the report sequence to be correctly identified, whereas those reported later may fade below threshold.

Harcum and Jones (1962) presented eight-letter words in either the left or right visual field. The accuracy function observed across letter position was a U-shape for left-field words, and a gradually decreasing function in the right visual field. (It may be noted that in these displays the last positions in the left visual field had the advantage of near-foveal location, whereas for words in the right visual field, the last letters had no such advantage.)

Crovitz and Schiffman (1965) sought to find *the* critical variable affecting letter-span identification. They presented rows of random letters to the left or the right visual field and found virtually identical results between the two conditions (Figure 1). The

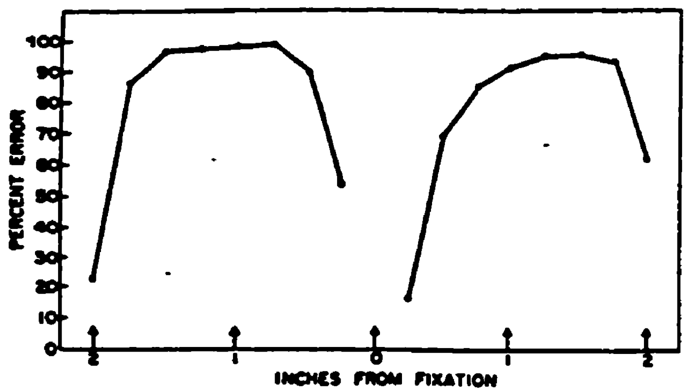

Figure 1. Error rates as a function of letter position in each half of the visual field (from Crovitz & Schiffman, 1965).

leftmost position produced few errors, the rightmost saw the next fewest, and all other positions resulted in a relatively high proportion of errors - the now common inverted U error function. The authors noted the differences in absolute retinal location between row positions in the left and right visual fields. They indicated that visual acuity decreases markedly from fixation outward as the retinal mosaic becomes increasingly coarse, with fewer cones converging on bipolar and ganglion cells. Still, the results did not show "such a relation to visual anatomy. Rather the reportability of a letter depended almost exclusively upon its *relative* position *within a string* of letters ..." (p. 223). This was the same conclusion reached by Bowman and Thurlow (1963) in a serial learning task, and later by Bryden (1966) in an examination of spacing effects on the accuracy of identification.

Crovitz and Schiffman (1965) also explored the possible effects of lateral masking – the difficulty in item identification caused by the presence of adjacent items. It was reasoned that the advantage experienced by the end items in these displays might be due to the fact that those items had only one adjacent item, whereas all other items were embedded in the string, having items on either side. By varying the amount of empty space between items, it was thought that the influence of lateral masking would also be varied. However, no differential effect was found whether items were spaced ¼ or ½ in. apart.

Hershenson (1969) supported the view that retinal location might play an important role in the perception of letters. He provided a different task from most letter-span experiments, because, he argued, most other authors had devised tasks that rely on (and are confounded by) post-exposural processing, such as memory effects. This study attempted to separate the variables of fixation point and position within a string, to test whether the position of a letter relative to the fixation point or its relative position in a string determines what is perceived. Seven-letter arrays were presented under conditions of varying fixation points (these points corresponding to positions 2, 4, and 6 in the array). The task for subjects was not to try to recall letters from an unknown array (as had been done in most previous studies), but to determine which letters of a pre-memorized array were perceptible under very brief (20 msec) displays. It was determined that the letters nearest fixation were those most easily perceived. Hershenson argued that retinal locus, not position in a letter string, was the definitive factor in our *perception* of letters. He said that previous findings were faulty in that post-perceptual mechanisms had been allowed to affect subjects' performance.

Others argued that retinal locus may play as important a role as string position, if appropriate controls are implemented. White (1969, cited in White, 1970), for example, argued that Crovitz and Schiffman (1965) and Bryden (1966) had found inverted U-shaped error curves (indicating the importance of relative position) because all their trials tended to be blocked in either unilateral or bilateral displays (i.e., appearing in one hemifield or across hemifields, respectively). This, White argued, could create an *attentional set* within subjects such that they unwittingly shifted their attentional focus to their advantage.[1]

White found that, by randomizing unilateral and bilateral displays within trial blocks, errors for letters near fixation could be reduced. This procedure presumably led subjects to deploy attention more centrally in each display. White (1970) had subjects fixate at the left edge, at the center, or at the right edge of tachistoscopic (100 msec) letter strings, and found that errors *were* related to the locus of fixation when subjects were asked to write down all letters seen. Letters that appeared next to the fixation point were reported most accurately. (In addition, letters in the leftmost position were reported well across conditions, and were most often reported *first*.)

Further, Wolford and Hollingsworth (1974) claimed that the failure of Bryden (1966) and of Crovitz and Schiffman (1965) to recognize the importance of retinal locus lay in their failure to control processing and report orders. By having subjects process and report items in a particular order (e.g., left-to-right), Wolford and Hollingsworth did obtain the usual string position effects, but they also noted that letters in most string positions (excluding the first and last) were recalled best when that string position happened to fall at a foveal location.

Left-to-Right Scanning

With Hershenson's study excepted, the general picture emerging from these studies was one in which the shape of the letter span is determined by the order in which subjects scan the briefly presented stimuli (White, 1976). The term *scanning* in this usage refers to the post-exposural processing of information being held in, and rapidly decaying from, a very limited iconic storage system. It was generally hypothesized that the iconic trace is scanned from left to right in order to transfer it to short-term memory. Thus, leftmost elements in the trace are reported more accurately because their trace images are strongest. Traces for items further to the right would be more likely to have decayed before identification is possible.

Such an interpretation seems to have been supported by records of the report order of items. As noted, superiority of leftmost items was greatest when subjects were specifically required to report items in a left-to-right order, as opposed to right-to-left (Bryden, 1966). Harcum, Hartman, and Smith (1963) examined further the effects of report order on item identification. They had subjects reproduce 10-element binary patterns (open and closed circles) that were flashed across fixation. Either before or after exposure, subjects were instructed to reproduce the pattern in left-to-right, right-to-left, or center-out order, or they were given the option to report in any of these orders. Given this option, subjects always chose left-to-right. Generally, the fewest errors were made with a left-to-right report order, presumably because such an order is consonant with subjects' normal scanning operations.

Full versus Partial Report

One characteristic that links all of the studies reported in the previous section is a methodological one, which may (as later studies will demonstrate) significantly affect both outcome and interpretation. In each study, subjects were required to report all possible items from each display (i.e., full report). The work by Sperling (1960, 1967) on iconic memory indicated that more may be perceived in a complex display than can be accurately reported in the full-report manner. When Sperling asked subjects for a full report of a 12-letter display they saw for only 50 msec, subjects could recall only 4 or 5 letters. But when he signaled one of three rows of letters to be reported from identical displays, subjects managed to report 3 or 4 of the letters from the row indicated. The signal for which letters to report had to occur immediately at display offset, however. If it were delayed even half a second, performance deteriorated – only 1 or 2 letters were recalled from a row. Sperling concluded from this result that more can be perceived in a brief presentation than is indicated by full report measures. The difficulty with full report is that the information received by the perceptual system fades from sensory (iconic) memory before it can be reported. Thus, items reported later in a sequence are subject to becoming lost from memory, and unreported. This effect, rather than a lack of perceptibility, may account for the declining recognition functions often observed in the full report studies described above. The decline in performance with serial position may reflect a bias toward *reporting* items in a left-to-right fashion, rather than a perceptual effect. Even some partial report tasks, such as a Sperling-type task in which multiple items from a larger display must be reported, may be subject to a left-to-right bias (Dick, 1974).

The partial report technique has been applied to tachistoscopic letter span tasks. These experiments have generally failed to find the left-field superiority claimed in previous full-report studies (White, 1976; see also Averbach & Coriell, 1961, and Haber & Standing, 1969). The partial report studies have tended to find a W-shaped identification curve when letter strings appear across fixation (i.e., with the center of the string at the fovea). Haber and Standing attributed the effect of high reportability at central and end positions to high acuity at the center positions (at fixation) and to reduced metacontast (lateral inhibition) at the ends. As evidence, they pointed to Averbach and Coriell's discovery that parentheses placed around the ends of a letter string could selectively reduce the reportability of letters in the end positions. Acuity and metacontrast are strictly sensory variables, as opposed to the strategic encoding or memory variables that some authors have implicated in these effects.

Ends-First Scanning

An alternative to the left-to-right scanning hypothesis was proposed by Merikle and colleagues (Butler & Merikle, 1973; Merikle & Coltheart, 1972; Merikle, Coltheart, & Lowe, 1971), based on studies involving the masking of tachistoscopic letter strings. They had found that a masking stimulus presented immediately following a tachistoscopic row of letters had a selective effect on reportability, based on the string position of the letters (Merikle, Lowe, & Coltheart, 1970). The mask was effective in reducing reportability of central letters, but not the reportability of letters at the ends of a string.

Merikle et al. (1971) showed that for 8-letter strings diplayed across fixation, letters were best recalled from leftmost and central (foveal) positions in a no-mask, full-report condition. When a mask followed letter presentation, end items were not masked, but central items were less reportable.

Merikle and colleagues also employed a number of partial report techniques. In one instance, they had subjects report a single letter displayed in one of eight possible positions under mask or no-mask conditions (Merikle et al., 1971). Here they found no differential masking effects due to letter position. In another experiment (Butler & Merikle, 1973), one position of an 8-letter string was indicated by a bar cue *at the time of letter onset*, and again, no selective masking was observed. It appeared that any time subjects could complete the task by attending to or processing a single position, no selective masking occurred. However, if an 8-letter string were presented, under mask or no-mask conditions, and a single letter was probed either by asking about the presence or absence in the string of a spoken target letter (Merikle, et al., 1971) or by a bar probe simultaneous with letter *offset* (Butler & Merikle, 1973) (in either case, a task that requires processing of *all* letters in the string), selective masking occurred.

Merikle's interpretation was that selective masking results from an ends-first processing strategy. More precisely, in a multi-element display, the individual elements are processed serially, beginning with the end items. A post-exposure mask has little effect on end items because they have already been sufficiently processed (for identification) by the time the mask appears. Central letters have not been processed, or at least not to the same degree, and their identification may therefore be disrupted by a mask stimulus.

Merikle's position regarding an ends-first processing order (ends-first scan) was supported by the results of a forward-masking experiment (Merikle & Coltheart, 1972). This procedure involved the presentation of a mask stimulus immediately *prior to* the presentation of a letter string. It was presumed that the "processing which takes place immediately after the offset of the forward mask should be more impaired by the mask than processing which occurs some time after the offset of the forward mask" (p. 297). If row ends are processed first, identification of letters in the end positions should be most negatively affected by a forward mask. Results confirmed this prediction.

Several lines of evidence suggest that in fact an ends-first processing strategy, and not a left-to-right scan, may develop in the establishment of reading habits. It has been known for a long time that, given nonsense strings of letters, the first and last letters are often recognized while others are not (Woodworth, 1938). Haselrud and Clark (1957) tried to identify which fragments of a word might be the best clues to elicit the correct word when only those fragmented portions are available, due to short duration, etc. They found that, when subjects tried to recognize tachistoscopic (40 msec) words and could not report the full word, but could make "fragmentary" responses, the first (81%) and the last (75%) letters were reported more often than central letters (average: 5 - 10% in 9-letter words). Thus, the first and last letters may be perceived correctly even when nothing else is.

Bruner and O'Dowd (1958) showed that reversing two letters at either end of a word makes identification worse than does reversing two letters near the middle of the word. Jensen (1962) demonstrated a serial positon effect of spelling errors: Most spelling errors occur in the middle letter positions of words. Brown and McNeill (1966), in describing their tip-of-the-tongue findings, noted that most people have difficulty recalling the middle of words, whereas they might well be able to identify first letters. All of this evidence suggests that the ends of words might be psychologically more important than their middles, which is consistent with the idea that reading processes may rely heavily on the ends of letter strings, and consonant with the notion that an ends-first processing strategy may develop to deal effectively with written verbal material.

The description of a W-shaped accuracy curve across many studies led to several rather different conclusions regarding the underlying cause of this outcome. The initial suggestion was that letters in a multi-element display become available at different rates due to the quality of stimulus information (Merikle & Glick, 1976). This quality was assumed to be greatest for central items due to heightened visual acuity near the fovea (displays in the relevant studies were almost always centrally located). The quality of information regarding peripheral items was also high, due to reduced lateral masking from adjacent items – normally end items have neighbors only on one side.

Another proposal originating from Merikle's masking studies (Merikle & Coltheart, 1972) involved the availability of various letters. It was believed that certain letters become available (fully processed and reportable) before others in the same display. Under the assumption that items processed first would be least affected by a post-mask, Merikle argued that the observed selective masking effects indicate that end items become available to the observer before more central items do.

Merikle and Glick (1976) noted that all the studies above had inferred availability from report accuracy. To extend the validity of this inference, they attempted to assess initial processing order directly, using very brief, variable exposure durations (from 20 to 160 msec), and masking all displays. They assumed that processing order would be reflected in the report of items that had been coded into a nonmaskable state within the brief exposure time. Merikle and Glick found that in 7-letter displays, letters in Position 1 (leftmost) were identified best, followed by Positions 7 (rightmost), 4 (at central fixation), and 6, 5, 2, and 3 (the latter group showing no significant differences). It was argued that explanations of serial position effects based only on factors of acuity and (lack of) lateral masking are inadequate. The authors noted, for example, that at shortest durations (20 msec), all central letters were identified at less than 15% accuracy, whereas Position 1 was correctly identified at 46%, and Position 7 at 18%, a result that parallels that noted by Haselrud and Clark (1957).

The various studies by Merikle and colleagues presented an apparently clear picture of the early steps in human visual processing. In multi-element displays, (in which subjects are required to process all elements and report the one selected by the experimenter), processing occurs in a set, automatic, serial progression, beginning with the outermost elements of a sequence (string) and continuing toward the center of the display. We may note that it is the display itself -- the perceptual object – that determines where processing will begin and end. Processing resources are directed to the letters making up the edges of the display, and then are shifted toward more central letters. Still, despite the ability of this hypothesis to explain the selective masking effects, others have suggested modification of the ends-first idea.

Criticisms of the Ends-First Scanning Hypothesis

Henderson and Park (1973) attempted to clarify the notion of ends-first processing. They noted that Merikle committed himself to a serial processing account by assuming that processing *begins* first at the ends of a display. Yet, they (correctly) argued, what is logically required by the hypothesis is that processing *terminates* first at the ends, that is, terminates in an identification. It is possible that processing is initiated simultaneously across the display, as suggested in models by Sperling (1967), Rummelhart (1970), and since then, by many others.

A second problem identified by Henderson and Park (1973) involved the reversal of the selective masking effect under conditions of forward masking. Why, they asked, should processing terminate early at the string ends, even though those letters have not yet been identified under the current conditions? It would be more reasonable, they said, if greater processing resources were allocated to these positions (with the result that fewer resources remain for other positions, and the accuracy of identification for central position would thus decline) rather than "giving up" on end positions and proceeding to central ones. They believed that Merikle's interpretation "seems indicative of a highly 'ballistic' processing sequence insensitive to the outcome of its own process" (p. 179), (which is not the way we tend to feel about our own cognitive operations).

Henderson and Park attempted a direct test of the ends-first hypothesis, by trying to modify subjects' processing strategies using payoffs weighted to benefit the processing of central letters. They predicted that this manipulation would reverse the usual backward masking effect, causing the end letters to be masked to a greater degree. "Survival of the usual (selective masking effect) at the centre of the row would certainly be regarded as a refutation" (of Merikle's hypothesis) (p.179). It turned out that payoffs *did* increase the overall probability of correct response at the center of displays, but the selective masking effect remained as before. This was interpreted by Henderson and Park as a blow to the ends-first scanning hypothesis.

Another explanation can be made of Henderson and Park's results. The fact that subjects *can* increase reportability of central items when given incentive to do so indicates that, at least to some degree, the deployment of attentional resources is under conscious, voluntary control. The manipulation using incentives changed the demands of the task from that of Merikle et al., and it should, therefore, be expected to change a subject's attentional focus. The task is no longer to process all elements equally (or at least, to the greatest extent possible), but to fully process the center item first and then to process the rest of the display (to maximize the experiment's payoff). Given that we may control the deployment of attention, deployment would be expected to differ between two different tasks. As Pressey (Pressey & Pressey, 1992) stressed (in a different context), to fully understand how attentional resources will be used, it is necessary to know what is expected of the subject. We can then assume that the subject will perform *rationally*, that is, in such a way as to best complete the task as he or she understands it.

Peripheral-Foveal Scanning

A second criticism of Merikle's experiments involved methodology, in particular, the presentation of the stimuli. White (1976) pointed out that, because Merikle's stimuli involved rows of letters centered around a fixation point, position within a row was confounded with retinal position. End-of-row letters were furthest from fixation, while central letters were nearest fixation. Thus, argued White, an ends-first processing strategy might be reinterpreted as a peripheral-to-foveal strategy, where elements located near the retinal periphery are processed before those located near the fovea. White thereby argued that processing order was determined by retinal or spatial position, whereas Merikle et al. had argued that processing order depended on row or object position.

A number of studies seem to support White's notion of a peripheral-foveal scan. The best known was conducted by Mackworth (1965). The task in Mackworth's experiments was to determine whether a match existed between a letter located at a central fixation point and two others located in the peripheral visual field. Noise letters were included either to the inside (toward the fovea) or to the outside (toward the periphery) of the peripheral target letters (see Fig. 2 for a sample display). When the five letters were displayed for 100 msec, the presence of noise letters to the *outside* of the targets greatly reduced matching performance (42% correct, as compared to 80% correct when noise letters appeared to the inside of targets). Mackworth concluded that such displays are scanned from the "outside inward toward the fovea" (p. 68).

TN	**N**	**NR**
NS	**N**	**LN**

Figure 2. Sample displays from Mackworth (1965). Ns represent central and peripheral target letters. Other letters represent distractors, located either inside or outside of the peripheral targets.

Although Mackworth's results have been taken as support for a peripheral-foveal scan, as he himself suggested, it might be argued that they support an ends-first scan equally well. In fact, non-retinal factors seem to be implicated in that increasing the width of the display did *not* affect subject performance.

Schissler and Baratta (1972) performed a study similar to that of Mackworth, in which they displayed letter pairs to the left or right of fixation. Each pair consisted of a target letter with a distractor either in the inside or outside position. Generally, faster reaction times and fewer errors resulted when the noise letter appeared to the inside of the target. The exception was that, for letter pairs appearing to the right of fixation, RTs were slightly faster when the target appeared to the inside of the noise letter. Schissler and Baratta argued that a left-to-right scan might be operating along with a peripheral-to-foveal scan to produce this result. They concluded that the peripheral-to-foveal scan might represent a more primitive type of information-detecting system than the left-to-right reading scan.

Bouma (1970) examined the recognizability of letters presented at various eccentricities. For single letters, recognizability decreased with eccentricity. When a letter was flanked on the foveal side "at normal spacing" by a distractor, perfomance declined somewhat, and a much greater decrement was found when the letter was embedded between two distractors. This indicated that initial and final letters (those outside of any adjacent letters) can be recognized at greater eccentricities than can interior (embedded) letters. Bouma (1973) then demonstrated that this effect holds for words and unpronouncable letter strings as well as for isolated letters. (Bouma attributed the effect to lateral masking operating predominantly toward the fovea.)

White (1976) attempted to unconfound the factors of relative string position and relative retinal position. To do so, he used "unilateral" rows of letters – rows that appeared in only one visual hemifield. He predicted that, in replicating Merikle's masking studies, only peripheral row-ends would be unaffected by a mask stimulus; foveal row ends would suffer the effects of masking as would central row positions. This prediction was confirmed.

A second experiment by White (1976) unconfounded row position and retinal position by displaying rows of (mixed) letters and digits (4 of each) at various eccentricities from a central fixation point. A partial report condition was included in which subjects were told before an experimental session to report either the letters or the digits. While White found no selective masking effects under these conditions, the task demands for subjects were changed by not requiring subjects to process the entire display.

In White's third experiment, RTs were measured for matching of target letters in a design similar to that of Mackworth (1965). A central target (T_C) was matched to a peripheral target (T_P) that appeared either inside of two distractors (N) (i.e., T_C T_PNN), outside the distractors (i.e., T_C NNT_P), or between the distractors (i.e., T_c NT_PN). According to the ends-first hypothesis, targets appearing either inside or outside the distractors should be matched faster than a target appearing between distractors, since both ends of the multiletter groups are processed and identified before the center positions are processed (Merikle et al., 1971). A peripheral-foveal scan would result in fastest RTs for an outside target, next fastest for a target between distractors, and slowest for a target inside of the distractor letters. White's results showed clearly faster times for targets in the outermost locations, but no significant RT result for targets that appeared inside of or between distractors. Although White claimed support for the peripheral-foveal scan by default (because the ends-first scan was not supported) neither the ends-first nor the peripheral-foveal hypothesis of initial cognitive scanning was well supported by this result.

The debate concerning the nature of early scanning processes appears to have been left at this juncture, though it leads to one part of the current investigation. I will return to this discussion in formulating the rationale for one of the proposed experiments. In the meantime, evidence for a particular order of processing is explored, from studies that have not used rows of letters as stimuli.

EVIDENCE USING NON-ALPHABETIC DISPLAYS

Evidence exists to suggest that the perceptual dominance of external elements or contours is not restricted to letter rows. Perhaps the simplest example to describe involves the "rod and frame" effect. A luminous rod presented in an otherwise dark room will appear to change its orientation when enclosed by a luminous rectangular frame which is oriented at some eccentricity (Fig. 3a). However, enclosing this frame within a still-larger frame oriented vertically reduces the distortion of the rod's orientation (Fig. 3b). It is suggested that these effects are explained according to processes of figure-ground articulation, in which only the largest frame is judged to be ground, whereas all other objects are deemed to be figures (including the inner frame), whose attributes are

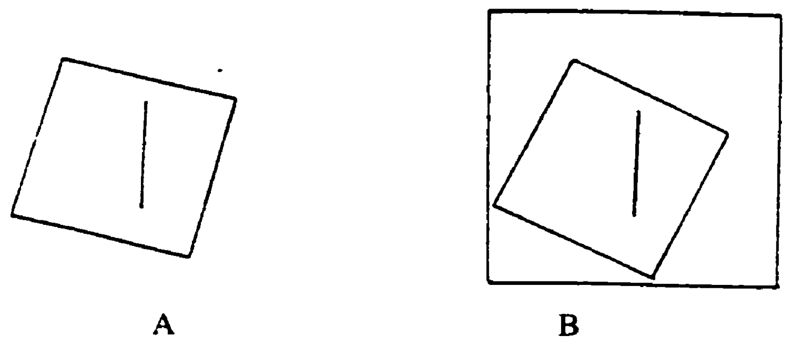

Figure 3. The apparent orientation of a vertical line is affected by a tilted frame (Panel A), but not when that frame is enclosed by a larger, vertically-oriented frame (Panel B).

judged against those of the background. Again, the outermost contour in this situation is psychologically important, as it forms a basis for interpretation of the entire display.

Other evidence of the impact of external contours is found in the work of Pressey (e.g., Pressey & Smith, 1986) and of Earhard (Earhard, 1990; Earhard & Walker, 1985). I will examine them separately.

Pressey: Effects of Contextual Features[1]

Over the course of almost 30 years, Pressey developed a qualitative and quantitative theory of visual processing described first as an assimilation theory (Pressey,

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[1] I am indebted to Dr. Pressey who, to the best of my knowledge, coined the term "visual grasp." He used it to identify a mechanism explaining the effects described below.

1967) and later as integrative field theory (Pressey & Smith-Martin, 1990). This theory has been successful in explaining and predicting the distortions produced by a variety of optical geometric illusions.

To illustrate, assimilation theory can explain the effect produced by the classic Müller-Lyer configuration (Fig. 4). Here, the fins pointing inward operate to phenomenally shrink one of the shafts, whereas the fins pointing outward appear to

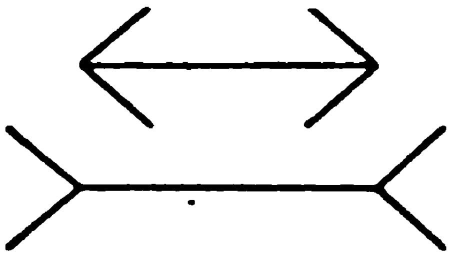


Figure 4. A Müller-Lyer illusion.

expand the other shaft. This distortion is explained by a process of assimilation, in which differences between stimuli are perceptually reduced. This is a common idea in psychology – elsewhere it is referred to as regression to the mean, the central tendency effect, averaging, or entropy (Pressey & Epp, 1992). Put another way, standard magnitudes (those the observer is asked to judge – here the two shafts of the Müller-Lyer figure) "become like" their context. The simplest example of this phenomenon is the parallel lines illusion (Fig. 5): the standard line appears elongated due to assimilation or averaging with the contextual magnitude.

It follows, from the concept of a magnitude assimilating with its context, that the *difference* between a standard magnitude and that context will be vital. Greater difference between standard and context will produce more pronounced assimilation, and therefore greater distortion, whereas smaller differences will result in lesser distortion (Pressey &

Pressey, 1992).

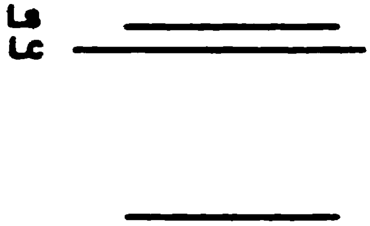


Figure 5. A parallel lines illusion. The standard line (Ls) is objectively equal in length to the comparison line, but is phenomenally expanded due to the influence of the contextual line (Lc) (from Pressey & Pressey, 1992).

According to assimilation theory, illusions which are apparently more complex, such as the Müller-Lyer and Ponzo figures, may be reduced to composite forms of the parallel lines figure (Fig. 6). The fins of the Müller-Lyer and the obliques of the Ponzo serve to define endpoints of a series of contextual magnitudes. Thus the same assimilation process may account for each of these effects.

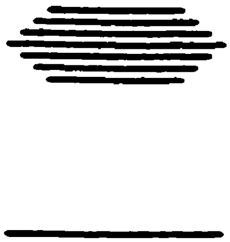


Figure 6. A Müller-Lyer illusion as a composite parallel lines figure (from Pressey & Pressey, 1992).

It is easy to demonstrate that the assimilation concept, by itself, is too simplistic. Consider the Müller-Lyer figure - we can see that extending the expansion fins indefinitely would lead to a prediction of infinite distortion of the shaft, which we know does not occur. Consider, too, the version of the Ponzo figure illustrated in Figure 7. Here the contextual obliques extend an equal length above and below the standard. Straightforward averaging of all of these contextual lengths would result in a value equal to the standard itself, thus yielding a prediction of no distortion. Research data and simple observation tell us that, for this figure, some amount of distortion certainly does exist.

To resolve this problem, Pressey turned to the concept of attention. Specifically, he incorporated into his theory a postulate concerning an attentive field (Pressey, 1971; Pressey & Epp, 1992). The concept of an attentive field goes back to the notion that

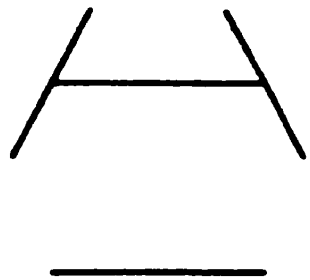


Figure 7. A Ponzo illusion having obliques extending an equal distance above and below the standard line (from Pressey & Pressey, 1992).

perception is an active process of construction. Percepts are not veridical pictures of the world – we do not process all parts of a visual array homogeneously. Rather we attend to certain portions of an array to varying degrees – some information will therefore be processed to a greater degree and will be weighted more heavily in forming a percept (Pressey & Epp, 1992).

We can estimate where an observer's attention will be deployed by assuming that the observer is rational, to the degree that he or she will operate to fulfill the requirements of a task. An observer's intentions determine where he or she will look (Pressey & Pressey, 1992). Thus, if asked to compare two lines in a Ponzo figure, the observer will focus attention on those two lines. To make such a comparison, logically the observer must attend to at least the end points of the standard and comparison lines. As a result, inscribing a circle through those four points (Fig. 8) defines a *minimum* attentive field -- the smallest possible area to be attended for the task to be completed.

Notice that in Figure 8, not *all* of the Ponzo figure remains within the attentive field. What *is* inside the field looks much like the expansion form of a Müller-Lyer figure. If the observer attends only to this portion of the display in forming a judgment of the two lines, or (to put it less stringently) if this portion of the display is weighted most heavily in forming a percept because it falls within the attentive field, the effect of

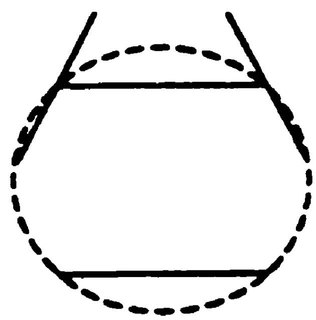


Figure 8. A Ponzo figure superimposed by a minimum attentive field (from Pressey & Pressey, 1992).

expansion of the standard line is readily explained by assimilation processes (Pressey & Pressey, 1992).

Pressey was careful to note that a minimum attentive field as defined above is not necessarily equivalent to an *optimal* attentive field. Real observers do not deploy attention in a highly restrictive manner. Therefore, optimal attentive fields were hypothesized to predict real performance. Pressey believed that observers deploy attention to areas of a display beyond the elements to be judged, and that they do process contextual features to some degree. Still, the attentive field is assumed to be "probabilistically graded varying from 1.00 at the center to 0.00 at the edge of a field" (Pressey & Kersten, 1989, pp.1324-1325). Thus, elements that fall nearer the center of the field will be weighted most heavily, regardless of the actual size of the observer's optimal attentive field.

Mathematical descriptions of these constructs are detailed in Pressey and DiLollo (1978), Pressey and Pressey (1992), and Pressey and Epp (1992), and will not be discussed here. Rather, I will focus on three theoretical puzzles that have arisen in the course of Pressey's research.

The first of these puzzles involves the Baldwin configuration (Fig. 9), in which a line is flanked by two squares of different sizes. When the line is bisected, the distance nearest the large square appears shorter than the distance near the small square. If observers are asked to bisect such a line, their judgments tend to be displaced in the direction of the smaller square. According to assimilation theory, distance B is judged in the context of the distances between the bisecting mark and the outer edge of the right-hand box. These distances are all *longer* than distance B, so through assimilation, that standard distance will appear elongated (Pressey & Smith, 1986).

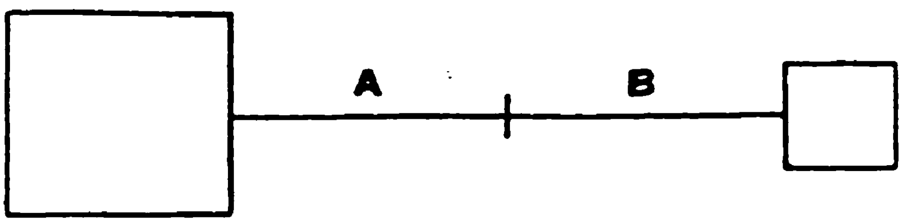


Figure 9. A Baldwin illusion. The shaft is objectively bisected, but the bisecting point appears shifted toward the large square (from Pressey & Smith, 1986).

Pressey and Smith examined the potential for an internal context to affect the magnitude of illusion. They compared a Baldwin configuration having a single contextual box at one end of a standard line to a figure with a series of cumulated boxes of different sizes (Fig. 10). According to theory, *any* context should have the ability to affect perceptual judgments, so it was hypothesized that cumulating boxes should flatten (reduce) the degree of illusion experienced – the illusion should be an average of the distortions produced by each individual box. This was not found to be the case, however. The degree of distortion was virtually the same for single and cumulated boxes, suggesting that only the *outermost* box (context) played a significant role in producing the distortion. Thus, it appears that external contours may not only be processed (available) before other aspects of a display, but they may continue to be weighted most heavily in

Figure 10. A Baldwin illusion with cumulated boxes (from Pressey & Smith, 1986).

the formation of temporally extended perceptual judgments.

A similar problem was noted by Pressey and Wilson (1977), who measured distortion in a multiple-finned version of the Müller-Lyer figure (Fig. 11). Again, assimilation theory would predict distortion equaling the average of the effects produced independently by each set of contextual fins. (It may be useful to note that more acutely angled fins would be expected to produce greater distortion, because assimilation must occur involving greater differences in contextual lengths. The contexts implied by more obliquely angled fins are more similar to the standard length, and would therefore produce less distortion.) Once again, an averaging effect did not occur. For the shrinkage form, the effect was found to be *less* extreme than the average of contexts would produce. Conversely, for the expansion form, the multiple fins produced distortion *greater* than the average. An explanation is apparent if one considers which fins are "outermost" in each part of Figure 11. For the shrinkage form, the more oblique fins are outermost -- they produce less distortion. But for the expansion form, the most acute fins are outermost – they appear to be considered by the observer to be equivalent to a set of acute fins presented alone, in that they produce greater distortion than would be predicted from an average of the two sets of fins. Once again, an unexpected outcome may be explained by the process of attending to, and weighting most heavily, the most external portion of a display.

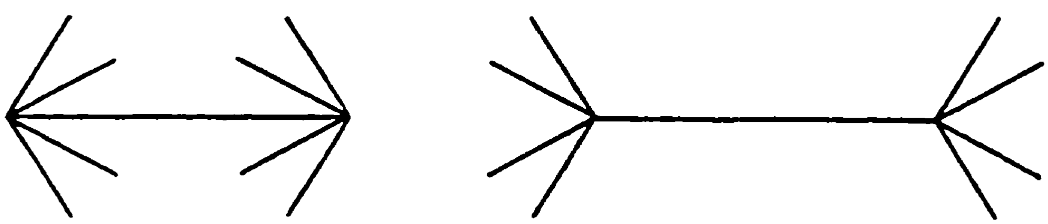


Figure 11. A multiple-finned version of Müller-Lyer illusion (from Pressey & Wilson, 1977).

A third difficulty for Integrative Field theory arose from an attempt to simulate the results of a study by Larsen and Garn (1988). Larsen attempted to measure the contributions of individual sets of Müller-Lyer fins by selectively amputating one set at a time (Fig. 12). Pressey and Kersten (1988) used the mathematical version of Integrative

Field theory to predict distortions for each of these patterns, the results of which correlated highly ($r = .81$) with Larsen's obtained results. On the other hand, attempts to simulate Larsen et al.'s (1989) follow-up study were less successful. Here, Larsen et al. had subjects judge each part of the Müller-Lyer figures separately. Pressey speculated that difficulties in modeling Larsen et al.'s results stemmed from the possibility that Integrative Field theory does not correctly describe "how attentive fields are linked to the stimulus array" (Pressey & Pressey, 1992, p. 427). As described above, attentive fields are assumed to be determined *only* by the standard and comparison stimuli. Further simulations showed that contextual stimuli may also influence attentive fields.

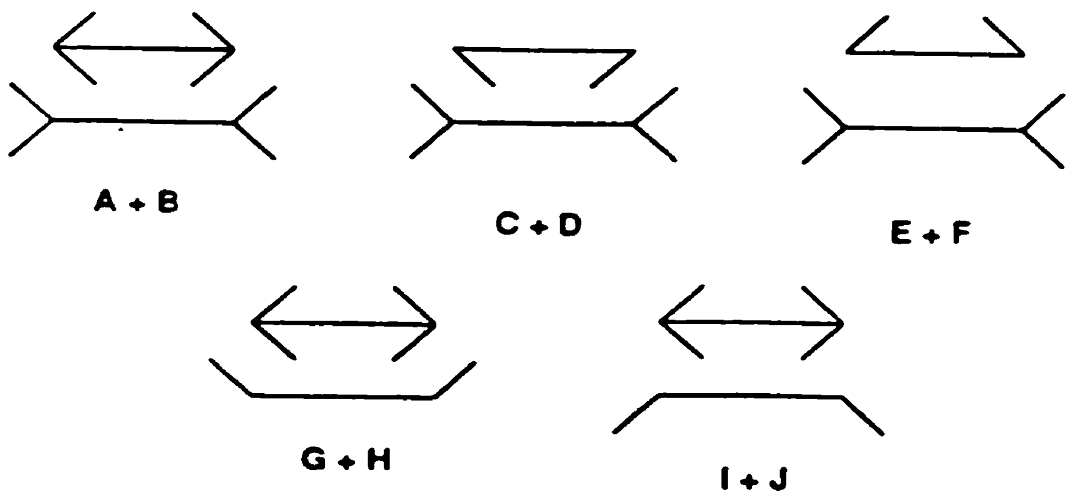


Figure 12. Larsen and Garn's (1988) Müller-Lyer figures: A and B -- full figure: C and D -- shrinkage fins outside the shafts are amputated; E and F -- shrinkage fins between the shafts are amputated; G and H -- expansion fins outside the shafts are amputated; I and J – expansion fins between the shafts are amputated. [The second version of each figure (i.e., B, D, etc.) was inverted so that the shaft having expansion fins appeared above.]

A correlation program was run to determine the best-fitting size of attentive field for each of Larsen et al.'s results. The highest correlation coefficients were found to be obtained by simulations using the *smallest* size of attentive field for the shrinkage forms of Müller-Lyer, and *larger* attentive fields for expansion forms of the figure. This was odd, considering that a single, circular attentive field had always been postulated in Pressey's theory. Further simulations confirmed, though, that better-fitting predictions could be made by proposing separate attentive field sizes for each portion of Müller-Lyer target - attentive fields that were closely related to external contexts of the targets as defined by shrinkage and expansion fins. Figure 13 shows best-fitting attentive fields for an expansion form as the length of fins is increased (Pressey & Pressey, 1992).

Thus, once again, it appears that attention deployment is closely related to the size of the object being viewed, with the most external contours, contextual or otherwise, being instrumental in defining such an object. Further, in Pressey's words, "it appears that

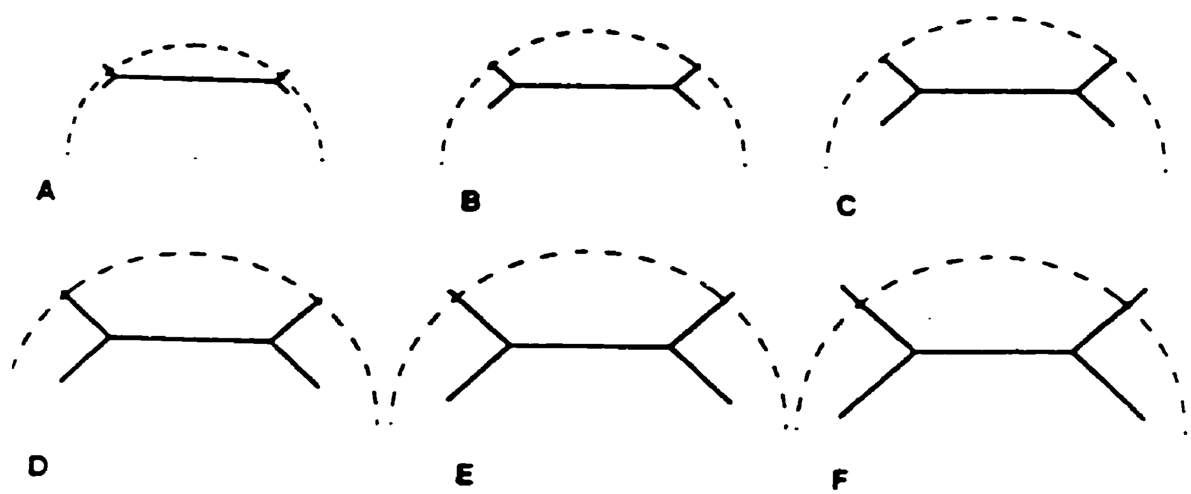


Figure 13. Best-fitting attentive fields for expansion forms of Müller-Lyer with increasing fin length (from Pressey & Pressey, 1992).

the spatial distribution of attention is remarkably similar in temporally constrained and temporally extended tasks"[2] (Pressey & Pressey, 1992).

Earhard: "Outside-In" Processing Strategy

In investigating the way observers analyze geometric forms, Earhard and Walker (1985) attempted to determine what "general processing dispositions, that is, commonly used strategies and heuristics" (p. 249) were most often employed. They cited Navon (1977), who suggested that global information is available to the perceptual system early in processing, and provides the basis for more localized processing or search. They proposed a related, though more specific possibility: that analysis begins at the outer boundaries of figures or scenes and proceeds inward. As indicated above in the current paper, most evidence for this assertion comes from experiments using letter strings.

Earhard and Walker set out to discover whether the effects noted using letter strings would generalize to geometric forms. They assessed the discriminability of line segments within various forms (see Fig. 14 for examples). Subjects were presented tachistoscopically with a series of outline forms, each having one line drawn *thinner* than the other lines. The location of the thin line was varied within the form – it could appear in a central or peripheral part of the form. Subjects were asked to detect that location.

It was found, above all, that outer line segments (i.e., those appearing on the periphery of a form) were discriminated more accurately than inner line segments. It was argued that this outer line advantage was due to attentional processes. Still, Earhard (1989)

[2] Temporally constrained tasks may include the letter span tasks reviewed above.

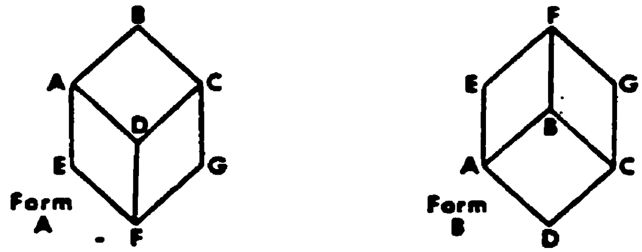


Figure 14. Sample stimuli from Earhard and Walker (1985).

recognized Marr's (1982) edict to explain as much of visual processing as possible without resorting to attentional or cognitive explanations, and he offered two possibilities in this regard.

The first was that outer line segments are more salient because they are less prone to lateral inhibition processes. It is known that adjacent contours may interact perceptually and inhibit each others' discriminability (Breitmeyer, 1984). Thus, the perception of inner lines should be more likely to be inhibited – inner lines have contours on either side, whereas outer lines have at least one side free of adjacent contours. Again, this simple explanation is supported by studies using tachistoscopic letter displays – outermost letters are consistently better identified than are immediately adjacent letters, which do have letters on either side (e.g., Mackworth, 1965).

However, consider Earhard and Walker's (1985) second experiment. Here, various target configurations were presented in blocked presentation conditions. Subjects were made aware that, within each block, target segments would be present in inner (or outer) locations *only*. If differences in performance (speed of identifying an inner or outer segment) were due to lateral inhibition, blocking the trials should have led to no change in discriminability, but a change *did* occur. The outer line advantage present in randomized presentations disappeared when presentations were blocked. Thus, whereas lateral inhibition may occur between adjacent contours in these figures, the process does not adequately explain the outer-line advantage.

A second non-attentional explanation may be considered, involving temporal precedence. This is the idea that outer-line detail is available earlier in the visual processing sequence than is inner-line detail. Ward (1983) suggested that features extracted by early processing might be more easily (and quickly) conjoined into perceptual objects if they were more conspicuous, more easily discriminated, and so on. External features might qualify as being conspicuous, and their identification might interfere with the conjunction of remaining features, decreasing the identification of internal items; whereas external items themselves are relatively free from interference effects. Again, however, if the temporal precedence of peripheral elements were the result of an automatic, stimulus-driven process, then one should observe the outer-line advantage whether presentations are random or blocked. Once again, when information through instructions or through trial blocks indicated that the targets would appear only in inner or in outer regions, detection of inner segments was as efficient as that for outer segments.

Earhard (1990) concluded that an attentionally driven, top-down, outside-in processing strategy best explains the data. Such a process would account for faster reactions and greater accuracy toward outer-line segments, and would explain the disappearance of this advantage under blocked presentations -- subjects, aware of modified conditions, modify their attentional processing.

Earhard and Walker (1985) tried to specify the nature and the object of this attentional process. Did it operate from periphery to fovea in a retinally tied manner, as in the periphery-to-fixation scanning process suggested by White (1976)? If so, any outer-element advantage must depend heavily on the location of a fixation point. Specifically, that fixation point would have to be located *within* the figure being viewed. Earhard and Walker's fifth experiment suggested that the attentional effect is independent of fixation. Fixation points were located above or below the figure in question, such that inner and outer segments were, on average, equidistant from fixation. Even under these conditions, a significant outer-line advantage was observed. In other experiments, in which inner and outer line segments that fell exactly equidistant from fixation were compared, the same outer-line advantage was found. It appears, therefore, that the sort of attentional process involved here is more general, not linked to retinal locations. It may instead be more like the "ends-first" scanning process described by Merikle (1974; Butler & Merikle, 1973), one which is object-focused rather than retinally tied.

Finally, Earhard (1990) asked "why should attentional priority be given to outer-line structures?" (p. 28). He noted that even in early childhood, we attend to outer aspects of a display. Salapatek (1975) indicated that very young (one-month-old) infants are unlikely to scan or fixate on a small shape presented within (framed by) a larger shape. Similarly, Maurer and Salapatek (1976) found that one-month-olds fixate mainly the external countour of a face, and Maurer (1983) found that newborns and one-month-olds ignore a small shape if it is framed. It is only reasonable to think that such an effective strategy should persist into adulthood. "It is, after all, the outer line elements or edge structures that provide the most obvious source of information differentiating a given form from its background and other objects" (Earhard & Walker, 1985, p. 259). By determining first the outer boundaries of a form one can determine the direction and extent of eye movements necessary for further analysis (for large forms), or the degree of attentional shift needed to examine inner detail (for smaller ones).

The research reviewed in this section suggests that the outer elements of a display, whether they happen to be the outermost letters in a row or the outer contours of a geometric form, carry a certain psychological importance. Explanations for these effects based on structural factors within the visual system (such as lateral inhibition) have not been well supported. An explanation based on attentional strategies or dispositions seems more appropriate.

I hold that, across these research domains, a visual grasp phenomenon accounts well for the data presented. It suggests that the outer letters in a row become available soonest because attentional processes operate first on these display elements. It suggests also that the outer elements in geometric forms are processed first and are weighted most heavily in perceptual judgments because they serve to *define* those forms. How does this differ from models proposing outside-in processing, or for that matter, ends-first scanning? I suspect that all of these labels address much the same underlying processes, although I conceive of the visual grasp notion as something more than simply a scanning process applying only to rows of letters, and more than a processing routine for identifying parts of geometric objects. Rather, I contend that visual grasp represents a fundamental characteristic of visual processing, operating to define the outermost elements and contours of any visual object we encounter. Thus, it is a most basic influence of our attentional systems on the identification and recognition of objects. The following section elaborates on processes of attentional selection.

3

Attention

The phenomenon of visual grasp is conceived as a process involving voluntary attention. A closer examination of what is known about attention may lead to a more precise conception of visual grasp. I look first at a number of classic models of attention, and then focus on an issue that has been a point of contention only in the last 10 to 15 years, specifically, whether visual attention is directed toward objects in the visual environment, or toward areas of visual space that may happen to have objects located within them.

CHARACTERISTICS OF ATTENTION

Each of us knows what attention is. As James described it, it is "the taking possession of the mind, in clear and vivid form, of one of what seem several simultaneously possible objects or trains of thought . . . it implies withdrawal from some things in order to deal effectively with others," (James, 1890, p. 403). It is clear to researchers and to anyone from his or her own experience that one does not process all possible stimuli to an equal degree. In a visual display, for example, some elements are thoroughly processed while others are processed little or not at all. When one locates a familiar face in a crowd, many other faces go unnoticed and unrecognized. It is this ability to select from a variety of possible stimuli that is referred to as the process of attention

(Leibowitz, 1965); others have described attention as a concentration of mental activity (Matlin, 1994).

Most often, attention, or perceptual selectivity, is considered to be a *resource*, limited in supply and unevenly distributed. In this view, one draws upon attentional reserves as needed to complete a particular task. If a task, such as driving a car, requires few resources (the weather is clear and there is little traffic), then attentional resources may be sufficient to allow us to perform other simultaneous tasks, such as carrying on a conversation. If weather or traffic conditions make the driving task more complex, more processing resources must be diverted to that task, and conversation stops (Benjafield, 1997).

While the notion of attention as a resource seems clear in this context, it has not been easy to define precisely what *sort* of resource is involved in attention. Kahneman (1973) suggested it may be like a power supply – the tasks one performs tap a full reservoir. If one takes on too much, he will simply run out of fuel. Thus, one's ability to perform a task is limited by the supply of fuel that provides attentional resources. Kahneman referred to this view as a capacity model of attention – I will look more closely at this model momentarily.

An alternative view of attention is that it is subject to structural limits within our perceptual system (Benjafield, 1997). If two tasks, or two stimuli, require similar processing activities, these activities may interfere with each other, at least more so than two tasks that require different processing activities. Thus, listening to the sportscaster on television and to an urgent message from one's spouse may result in misunderstandings for one message or both. Several influential models of attention, beginning with Broadbent (1958), have taken this structural approach.

It seems clear that a fundamental characteristic of attention is that the process is *required* for a viewer to identify or recognize objects. Rock and Gutman (1981) presented overlapping outline forms to subjects, instructing them to attend to the red-colored shape and to ignore the green one. Subjects easily recognized the red forms on a later test, but recognition for green forms was "essentially nil" (p. 275). Moreover, even when the unattended form was a familiar object shape, rather than a novel form, it evidently was not perceived.

Another important characteristic of attention involves the control of attentional selection. Selection is thought to occur in one of two ways. An observer may voluntarily select from the visual field those elements that are required to complete a task or answer a question. This selection is said to be under the observer's endogenous control - influenced by his or her intentions, goals, or beliefs. At other times, properties present in the visual field may *capture* attention, independent of the observer's goals, etc. This selection is described as exogenous, or stimulus-driven (Theeuwes, 1994).

Certain stimulus features or phenomena appear to be more likely to capture attention than are others. Yantis and Jonides (1984) found that the abrupt onset of a visual stimulus could capture attention, and suggested that properties within the visual system are uniquely sensitive to abrupt onsets. This would, of course, be an adaptive response, given that objects that suddenly appear in one's visual field may provide important new information, and should be identified. The possibility was left open in this study, however, that the simple presence of a unique stimulus feature might have caused such an exogenous attentional capture. Thus, *any* unique stimulus feature might yield the same result. Jonides and Yantis (1988) found this was not the case when they compared the ability of various salient stimulus properties -- color, intensity, and abrupt onset – to capture attention. The presence of an odd item, differing in color or intensity, did not produce the same costs in a search task as did the abrupt onset of a distractor. Abrupt onset appeared to be uniquely able to capture attention.

The unique influence of onset stimuli can also be seen in the results of a study by Posner, Cohen, and Rafal (1982). Here, subjects were presented with a peripheral cue, and then a target stimulus. A simple either-or response was to be made when the target appeared to the left or right of fixation, and RT was measured. The experimenter varied the validity of the precue and the inter-stimulus-interval (ISI) between cue and target. In one condition, the cue was invalid 80% of the time (i.e., on 80% of trials, the cue appeared on the *opposite* side of fixation from the target). With a short ISI (100 msec), RTs were still faster when the cue and target appeared on the same side of fixation. This result suggests that attention was captured by the cue onset, even though subjects became aware that the cue was probably an invalid indicator. Only when the cue-target ISI was longer did RTs become faster when the cue appeared opposite the target, as one might expect if subjects were voluntarily orienting attention toward the more probable target location.

Later work indicated that processes of exogenous and endogenous attention may act to inhibit one another. For example, Müller and Rabbitt (1989) provided evidence that exogenous attention may inhibit voluntary orientation. Subjects were asked to detect a target that followed a 75% valid cue (an arrow in the center of the display). At times, the cue was followed by an irrelevant flash of light in the periphery of the display. The central arrow cue presumably resulted in endogenous orientation; whereas this peripheral flash might capture attention exogenously. Subjects were faster in detecting targets when this peripheral flash did *not* occur. Thus, it appeared that exogenous orienting could disrupt endogenous attention.

On the other hand, Yantis and Jonides (1990) showed that, depending on the validity of a precue and on the observer's attentional focus, the effects of a peripheral distractor may be limited. Here, subjects were asked to identify one of two possible target letters from a small (2 to 4 letter) array, guided by an arrow cue. Targets and distractors in the array could be of an abrupt onset or a no-onset (constant) variety. Onset letters appeared in positions that had been empty; No-onset letters appeared in positions where a set of letter segments (like the number "8" on an LED clock display) were selectively removed to reveal a letter. Yantis and Jonides believed that only onset stimuli should result in exogenous orienting, but they discovered a limitation to the effects of onset stimuli. When precues indicating target position were completely valid, presumably inducing a highly focused mode of attention, abrupt onset distractors had little effect. On the other hand, when cues were less valid, subjects appeared to allocate their attention in a more diffuse manner, and abrupt onset distractors had a more significant impact in increasing RTs. Thus, it appeared that endogenous attention to a cued location may inhibit exogenous capture of attention. Only when cues are not present, or not entirely valid, do we find exogenous orienting.

THEORIES OF ATTENTIONAL SELECTION

At any moment, we select only a portion of the stimulation available for further processing, and it is necessary that we do so. William James evidently viewed attentional processes as vital psychological events (see the opening quote to this paper). Still, for much of the early part of this century, the concept of attention was shunned by mainstream psychology, along with all other cognitive or mentalist ideas. Within the behaviorist framework, it was tacitly assumed that an organism takes in *all* aspects of a presented stimulus, without selectivity (LaBerge, 1990). Only in the 1950s did researchers such as Estes begin to discuss notions like stimulus sampling. Estes (1950) assumed that, on a given trial, an organism samples a subset of available stimuli, or elements of a stimulus, and this randomly selected subset determines the nature of the response, and what is learned on that trial.

The study of attentional processes would begin in earnest later in the 1950s. The theories that emerged aligned themselves in two general camps -- those that proposed a structural filter or bottleneck somewhere in the attentional system to explain why we cannot attend to more than one stimulus or message at a given time, and those that focused on the distribution of attentional resources to explain why some concurrent tasks appear to interfere with each other, whereas others do not.

Filter Theories

One of the earliest filter theories was proposed by Donald Broadbent in 1958, in which he proposed that information is filtered soon after it reaches our sensory registers.

Many different sensory inputs may reach the attentional filter, but only one is permitted to proceed beyond the filter to be processed more fully, that is, to undergo processes of pattern recognition or perception (having *meaning* assigned to the sensations) (Reed, 1996; Sternberg, 1996). In addition to the attended target stimulus, stimuli with salient sensory characteristics may pass through the attentional filter, say those which are distinctive in pitch or loudness, but most stimuli will be filtered out at the sensory level and never be processed to the point of being perceived.

This theory was supported by early research involving dichotic listening. In a dichotic listening task, a participant is given two simultaneous recorded messages, one presented in each ear. The participant is required to shadow one of the messages, meaning that he or she must recite the message aloud as it is being presented. It is assumed that this task will occupy the participant's attention fully, resulting in the other message being ignored or unattended. In one such experiment, Cherry (1953, cited in Sternberg, 1996) found that participants might notice sensory information from the unattended ear, such as whether a male or female voice was speaking, or whether tones were presented as opposed to words, but information requiring higher perceptual processes, such as whether the unattended words were spoken in German or English, or whether the recording was played backward, were *not* noticed in the unattended channel.

In one of Broadbent's own experiments (1956), observers were presented with six digits, as in a test of memory span. The digits were presented in pairs, one acoustically and the other visually. Observers performed well when they used the strategy of reporting first all the digits from one modality and then all the digits from the other; with this strategy, performance was comparable to that on a "regular" memory span task (Broadbent, 1982). However, observers performed more poorly when they tried to report digits in the original presentation order (pairs). This result suggested that observers' difficulty was in terms of translating sensory information to a perceived form. Obervers could not alternate efficiently between visual and auditory signals. They could, however, select first the items that shared one sensory property, holding others in a memory buffer, and then process the latter items. Broadbent concluded that a limited system was involved, with a processing bottleneck located between sensory and perceptual processes. This bottleneck requires the operation of a filter to allow information to proceed in sequential order (LaBerge, 1990).

Very soon, other research appeared that suggested that Broadbent's theory was wrong. Neville Moray's (1959) discovery of the cocktail party effect became one of the more influential criticisms. He found that, whereas subjects ignore or miss most high level or semantic aspects of an unattended message, they may still recognize their own name in the unattended ear (in Moray's experiment, this occurred on about 30% of trials in which one's name was presented). Moray suggested this occurs because highly salient messages (and what could be more personally relevant than a message containing one's own name?) may break through the attentional filter. Note that the passage of a name through the filter is not the same sort of intrusion that Broadbent had allowed, one based on salient sensory qualities (unless the name is shouted in one's ear), but it is based on salient semantic qualities (the personal importance of one's name).

Neither Broadbent's model nor Moray's modification could explain Treisman's (1960) findings. In her dichotic listening task, she switched messages between the attended and unattended ear and found that subjects would often, at least momentarily, continue to shadow the message after it switched to the unattended ear. The message being shadowed was not special or personally relevant in any way, except that subjects had been asked to shadow it. Treisman explained this effect as involving the contextual effects of language. At least *some* information about unattended signals must be analyzed; otherwise subjects wouldn't recognize that the sounds appearing in the unattended ear were relevant - a continuation of the shadowed message. Had a filter blocked these sounds completely, they would never be perceived, and such a switch in the shadowing response should never occur (Sternberg, 1996).

To explain this effect, Treisman proposed a different sort of filtering mechanism. Firstly, the filter is again located between processes of sensory registration and pattern recognition, and it operates based on the physical or sensory characteristics of the message. However, this filter does not completely block an unattended message, but *attenuates* it (it weakens its strength, closes the tap to a degree). Furthermore, different stimuli (in the case of Treisman's experiments, different words) have different recognition thresholds. Some salient words have permanently lowered thresholds - a person's name would fall into this category. Thus, even if the signal were attenuated, one's name in an unattended message might still be perceived. Thresholds for other words might be momentarily lowered by one's expectations (contextual effects). For example, if one heard, "the runner advanced to second . . .," the threshold for the word "base" might be momentarily lowered. If such a message switched at that moment to the unattended ear, the word "base" might still be perceived, causing a shadowing response to follow the message to the opposing ear.

Treisman's theory was able to account for a number of curious findings. Normally, little is heard on an unattended channel due to attenuation of those signals. However, when an especially salient signal, or a signal that fits the context of the shadowed message is presented, this signal may be perceived, attended, and shadowed.

The evidence that some information on unattended channels was being perceived led other investigators to suggest an alternative to Treisman's attenuation theory. Deutsch and Deutsch (1963) and later Norman (1968) proposed that we consider the signal-blocking filter to be located after the perceptual processing stage rather than before it. In such a model, items are selected based not only on their sensory characteristics, but on their semantic importance (Deutsch & Deutsch) or their pertinence (Norman). According to Deutsch and Deutsch, words on the attended channel are deemed important because an experimenter asks subjects to shadow them. Words on the unattended channel are usually unimportant because the subject is asked to attend elsewhere. The latter will be recognized, but will quickly fade from memory unless they are important enough to be selected, as would occur for one's name. Norman added that certain words have permanently high levels of importance, whereas others typically have low levels that may fluctuate due to expectations from contextual, grammatical, or semantic cues (Reed, 1996). This sounds like Treisman's argument, pitting her lowered thresholds versus Norman's pertinence, but the key difference is in the location of the competition or bottleneck – prior to perceptual processing in the former case, and following it in the latter.

The controversy over early- versus late-selection theories (having filters located pre- or post-perception) has continued ever after. I will not attempt to solve this dilemma here, but will only illustrate the sort of attempts that have been made to resolve the problem. Treisman and Geffen (1967) had subjects listen to concurrent lists of words in a dichotic listening paradigm, shadowing one of the lists. At the same time, they were asked to listen for a single target word on *either* list and make the simple response of tapping their finger whenever they heard that word. Treisman believed that, if an attentional filter were located beyond the perceptual processing stage, such a simple response would allow subjects to perform equally well for a target's appearance in either ear. Conversely, if the bottleneck occurred prior to perceptual processing, subjects should detect the target only in the attended ear. This test supported the early selection models, in that targets were detected 87% of the times they appeared in the attended ear and only 8% of the times they appeared in the unattended ear. Deutsch, Deutsch, and Lindsay (1967) replied that the test was faulty in that, by asking subjects to shadow words in one ear, those words were made more important, and thus more likely to be recognized. In addition, the fact that on 8% of trials subjects *did* recognize an expected word indicates that some words were leading to recognition on an unattended channel. One senses that, with the overlap of these models, and the difficulty in establishing mutually exclusive tests, this controversy is not one to be resolved readily.

Capacity Theories

One result of the difficulty in resolving the bottleneck controversy was that researchers began to consider alternative descriptions of attention. Some more recent theorists viewed the problem of attention as a question of the allocation of resources. It was assumed that, given a fixed amount of attention, we may choose to allocate this limited capacity resource according to the requirements of a task.

Kahneman's (1973) capacity model suggested that different tasks require different amounts of mental effort, and therefore different amounts of attention. Though we have considerable control over how our resources are dispersed, when our overall supply of attention cannot meet the demands of one or more tasks, our performance will suffer.

Kahneman assumed that our overall attentional capacity is determined by our level of arousal (see Fig. 15). We need to be relatively alert and aroused to perform most effectively. How this capacity is to be allocated is determined by several factors. Involuntary influences, such as attentional capture by novel, onset, or suddenly moving stimuli, are described by Kahneman as *enduring dispositions*. Specific task instructions, personal goals, or desired outcomes may also direct our attention in what Kahneman called *momentary intentions*. In addition, we may evaluate the situation, and determine from that evaluation whether demands are heavy or light (influencing our arousal level) and where attentional resources ought to be applied (directing our attention).

Kahneman's model was not intended to supplant bottleneck models of attention. Indeed, the latter appear to be better suited to explaining attentional phenomena such as the performance costs in attentionally incompatible concurrent tasks. Capacity models seem to be better metaphors for explaining how attention can be divided among complex tasks in which practice effects may be observed (Sternberg, 1996). For example, driving a car and carrying on a conversation may be difficult tasks for the novice driver to

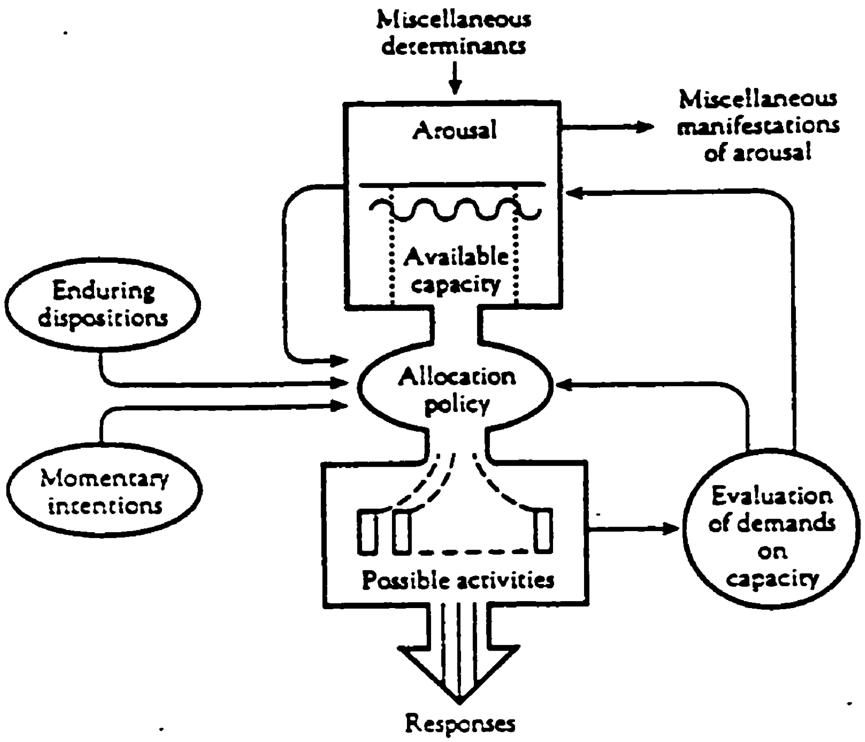


Figure 15. Kahneman's (1973) capacity model of attention.

perform simultaneously, but the expert driver, who needs to allocate fewer resources to the driving task, may perform the tasks at once without difficulty. As any task becomes automatized, it demands fewer attentional resources (Reed, 1996).

It has been suggested that capacity theories are too broad and vague to stand alone in explaining attentional phenomena (Sternberg, 1996). For example, it is pointed out that at least *some* attentional resources may be modality-specific. Simultaneous tasks that pose similar processing demands, such as writing while listening to a news report, should result in greater attentional difficulties than tasks that operate in different modalities, such as writing while listening to music (Navon & Gopher, 1979). Here, a bottleneck theory suggests that interference occurs because the same (verbal) mechanism is required to perform simultaneous and incompatible operations. A capacity model says that interference occurs because the two tasks overwhelm the total available capacity. For the bottleneck theory, the interference is specific, and depends on the degree to which the two tasks require the same processing mechanism. For the capacity theory, the interference is nonspecific, and depends on the total demands of the two tasks. The theories complement each other in that *both* types of interference do occur (Reed, 1996).

Johnston and Heinz (1978) acknowledged that, because we cannot be fully conscious of all the inputs flooding into our information-processing systems, some kind of selection process is required prior to our becoming conscious of any given stimulus. However, they argued that the human data selection system, or attentional system, is much more *flexible* and under an individual's control than previous models had suggested. They described three stages of perceptual processing. In Stage 1, inputs to the system are translated into sensory representations. Stage 2 provides meaning or semantic representations for the sensory information. In Stage 3, the results of the first two stages are admitted into conscious experience. The attentional theories described previously differ in their assumptions of where attentional selection or differentiation occurs. For example, Broadbent (1958) indicated that this selection occurs in Stage 1 (as it's described by Johnston & Heinz); Treisman (1964) suggested it may happen in Stage 1 or Stage 2; Deutsch and Deutsch (1963) argued selection occurs only as information enters Stage 3; and a capacity theory like Kahneman's (1973) assumes that selection may occur at any point during processing.

Johnston and Heinz argued that, on this continuum of selection from early to late stages of perceptual processing, our attentional system can be quite mobile, as task demands vary. A perfect system would enable one to focus on a target and still be able to grasp any relevant input that appears in non-target locations. What is more likely to occur is that a trade-off is made, between efficiency of selection and breadth of attention. It was proposed that selection from later stages increases the breadth of selection, but results in less efficient selection. Specifically, later selection consumes a greater processing capacity than do early modes of selection. As an example, one can attempt to listen to two simultaneous conversations, but the more one tries to collect semantic information from the second source, the more likely that information is going to interfere with the processing from the first source. Thus, one's comprehension of the initial conversation will deteriorate the more one tries to process a second message (Reed, 1996).

The assumption that the deployment of attention requires some processing capacity is interesting, in that this limited capacity is what constitutes the *need* for attention: We need to restrict perceptual inputs to levels that fall within our processing capacity. Thus, using attention may consume some of the very resources that the process is attempting to conserve.

Johnston and Heinz used a dual task methodology to test their notions of the flexibility and capacity demands of attention. The primary task was a selective listening (shadowing) task. Subjects listened to a single list of words, or were asked to attend to one of two binaurally presented lists that differed either according to sensory qualities (a male versus a female voice), which could be distinguished using a relatively early (sensory) mode of selection, or according to semantic qualities (two category lists spoken by the same voice), which would require a somewhat later (semantic) mode of selection. A control condition involving no listening task was also included. The secondary task was to push a button in response to a light signal. This task was intended to measure the capacity expended on the selective listening task. It was assumed that the greater capacity expended on the primary task, the less capacity would remain to monitor and respond to the signal light, resulting in longer RTs to that signal.

The general prediction was that lists differentiated by meaning (semantic qualities) would require the greatest capacity, followed by those differentiated by sensory qualities, single lists, and finally no listening task. The length of RTs to the light signal should follow this same pattern. This prediction was confirmed: RTs were longest during semantically differentiated lists, and more shadowing errors were made on these lists as well (Johnston & Heinz, 1978).

The notion that attentional processes may be used in strategic ways to best conserve resources within a given task is a valuable idea, and one that was echoed by Yantis and Johnston (1990). These authors demonstrated in a focused attention paradigm that we may focus attention efficiently enough that distractor (unattended) stimuli have virtually no facilitative or disruptive effects. They argued that this result implicates early selection, as it would be difficult to conceive of fully processed non-target stimuli producing *no* benefits or costs in RT tasks. Like Johnston and Heinz (1978), they went on to suggest attentional selection may occur early or late, depending on task demands. In focused attention tasks, where it is most effective to minimize the processing of non-target items, an early selection mode would be used, whereas in selective attention tasks where it is useful to process all items more fully, a late selection mode would be employed.

To allow for this kind of flexibility in selection, it was assumed that, whereas the processing system is able to process identities of various items in parallel, it need not do so universally. Early selection may be warranted to avoid capacity limitations, to reduce crosstalk (interference) among various channels, or to reduce the burden of inputs into later processing stages. Yantis and Johnston (1990) proposed that various levels of processors exist within the system – one level to extract physical features, another to determine the identities of various stimuli, and so on. They suggested that the interface between feature and identity levels is a reasonable place to consider an early selection locus. This selection mechanism would thus "control . . . what raw material is fed into the object identification system" (p.147). The late selection mechanism, which operates just before central, capacity-limited mechanisms (such as decision-making and response processes) are activated, would control which object identities are retrieved from such a system.

Remarks

For present purposes, it is not vital to the concept of a visual grasp to know exactly *when* during processing such a strategy is employed. It should occur early rather than late, in that both target and nontarget (or contextual) elements in a display are subject to the phenomena that seem to reflect a visual grasp (e.g., Averbach & Coriell's [1961] finding that parentheses surrounding a letter string affect the identification of outer letters, and Pressey and Pressey's [1992] discovery that attentive fields reflect the presence of contextual contours extending beyond the stimuli to be judged. These suggest that the process is applied before items become fully available for identification; it is argued that visual grasp represents an early aspect of the identification process). What is more important is that attentional processing may operate in a strategic manner, as suggested by Johnston and Heinz (1978). In the first experiment conducted here, it was reasoned that a similarly strategic approach may be taken when an observer grasps visual information.

4

Experiment 1

RATIONALE

Two problems were addressed by the first experiment. The first involves the order in which individual elements in an array become available for identification. The concept of a visual grasp suggests that outermost elements should be processed completely and be available for identification sooner than more central elements. Indeed, the research reviewed above (see especially that by Merikle and colleagues) has suggested that this is the case. For example, Merikle and Coltheart (1972) claimed that observers apply an ends-first scanning strategy, beginning with row ends, and proceeding inward. Such a strategy is believed to be related to word-reading, and possibly to more fundamental processes of figure/ground articulation -- a word's "edges define the edges of a form" (Merikle & Coltheart, 1972, p. 302).

The second problem is whether a visual grasp represents a structural (i.e., fixed) means of processing, or a strategic process, subject to influence by attentional manipulations such as differential instructions. Numerous studies have used instructions to manipulate the focus of participants' attention (e.g., Baylis & Driver, 1993; Rock & Gutman, 1981). The goal in the current experiment was to manipulate observers' attention without changing the goals of the task itself. In other words, the deployment of observers' attention was to be influenced while the observers continued their attempt to identify all letters in a display.

The initial goal of this experiment was to replicate Merikle's findings, with the methodology being a hybrid of methods used by Merikle and others (Bryden, 1966; Merikle & Coltheart, 1972). On each trial, observers were shown a row of letters, and a single position was probed at letter offset for identification. Recall that the general finding in order of processing studies has been that, when the task necessitates processing of the entire display, end items are better identified than the neighboring items nearer the center of the display. The same effect was expected in this experiment. Merikle and colleagues found that stimulus masks presented after the letter display had differential effects on letter identification based on the position of a letter in the array. Post-masks reduced identification for central letters to a greater degree than for outermost letters. It was expected that post-masks would have similar effects here, lending support to the idea that the outermost letters are processed for identification before central letters become available. Thus, it was hypothesized that

(1) the outermost letters in a display will be identified more accurately than neighboring letters located toward the interior of the display.

An attempt was made to influence participants' attentional processing in the following way. Half of the participants were informed that, given a row of eight letters for identification, any of the eight positions in the array may be probed or sampled on any trial. This group is referred to as the *random* instruction group, in that their instructions indicate that positions would be sampled randomly. The remaining participants received specific instructions regarding the probability that any position in the array will be probed (they are referred to as the *specific* instruction group). They were told that "on any trial, there is a one-in-four chance that one of the two leftmost positions will be sampled; likewise, there is a one-in-four chance that one of the two rightmost positions will be sampled; but the four positions in the center of the display will be sampled on fully *half* the trials I present." This is a true statement, and the reader will realize that this statement could also be made under the random probe condition. However, it was anticipated that, to most participants hearing such a statement, the central positions would appear to take on additional importance, which should influence the deployment of attention. This manipulation was intended to influence participants' attention only. The objective task was exactly the same for both groups, and the stimuli presented and probed remained identical. The second hypothesis for this experiment was that

(2) identification scores for the central four positions will be higher under the specific instruction condition than under the random instruction condition.

Such an outcome would indicate that additional attentional resources are being allocated to central positions as a result of the specific instructions. This would imply that visual attention is flexible (Johnston & Heinz, 1978), and that voluntary changes in the focus of attention may affect the identification of particular elements in a display.

METHOD

Participants

Participants were 33 student volunteers from the University of Manitoba who participated in order to earn course credit in introductory psychology. Data for one participant were excluded from analysis due to a failure to follow instructions. (This participant claimed that the task of reporting a different letter on each trial was too difficult, so she decided to respond only with the first letter of the sequence on each trial). The only restriction for participation was that all were to have normal or corrected-to-normal vision (based on self-report and a brief test of participants' ability to read a row of letters similar in appearance to the experimental sequences).

Materials and Apparatus

Participants were presented with 128 letter rows, each containing eight random consonants. The following set of upper case letters was used: B, C, D, F, H, J, K, L, N, P, R, S, T, X, Y, Z. This set omits certain types of letters: those which, in ordinary typeface, are wider or narrower than most (M, W, I), and those which may be easily confused with others (G, Q, and V) (Bryden, 1966). In addition, vowels were omitted in order to attenuate the use of strategies based on pronounceable letter strings. Sequences were designed so that each letter appeared in each possible position eight times, and no letter was repeated within a given row.

All stimuli were displayed using a three-field tachistoscope (Scientific Prototype, Model G). The visual angle subtended by an eight-letter row was approximately 4.0° horizontal x .5° vertical, and the visual angle for a single letter was about .4° x .5°. Letters were displayed in Helvetica (24 point) font, appearing black on white stimulus cards.

The masks, which followed each letter display, consisted of eight regions of small black and white squares (Gregory, 1977, p. 59, see Fig. 16). The positions filled by the

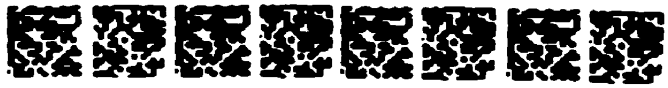


Figure 16. Mask stimuli which superimposed each individual letter position.

mask stimuli superimposed those occupied by the individual letters (see Fig. 17 for a sample stimulus display sequence). A probe stimulus consisting of a solid black arrow located directly below the letter or mask position in question appeared simultaneously with the mask stimuli.

Each letter position was probed 16 times for each participant. The order of presentation of the 128 letter sequences was identical for each participant, but the position probed in each sequence was randomized. with the restriction that each position was probed twice within a block of 16 trials.

Procedure

Participants were seated at the tachistoscope eyepiece and instructed as to the nature of the task (see Appendix A for verbal instructions to participants). A series of five practice trials were provided to familiarize participants with the stimulus sequence. The first two used 1000 msec exposures for each field, and the last three were presented at the test durations indicated below.

Each trial began with an empty pre-exposure field. The participant initiated a trial with a button press, and a small fixation cross appeared in the center of the display (between positions 4 and 5 of the letter display) for 1000 msec, followed immediately by the letter display for 100 msec, which in turn was followed by the mask/probe display for 4000 msec. Participants' verbal responses were recorded by the experimenter, and no

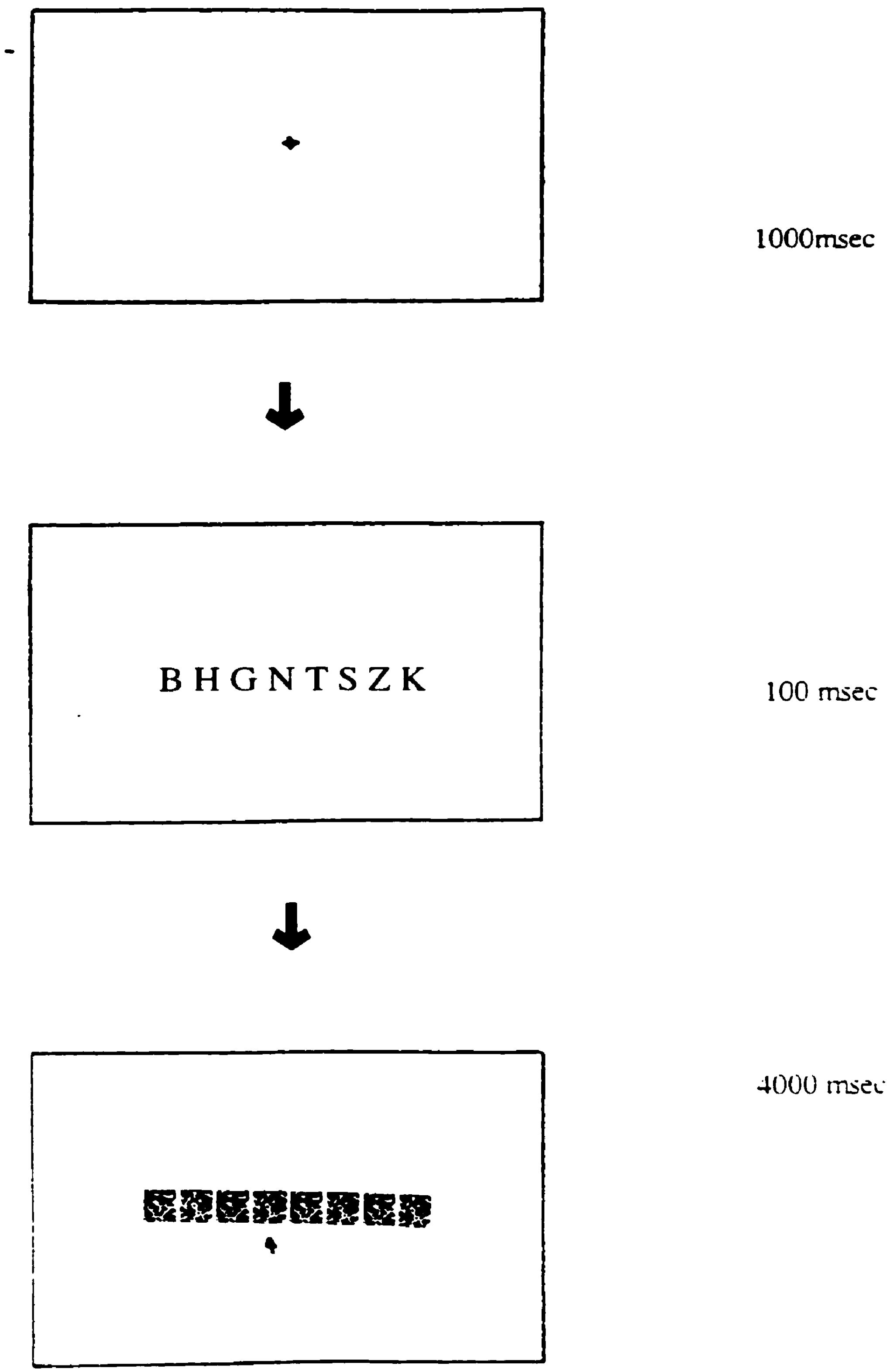


Figure 17. Sample stimulus display for Experiment 1 (not to scale).

feedback regarding accuracy was provided.

Participants were assigned randomly to one of two groups with the restriction that each group consist of 16 participants. Those in the random instruction group were instructed that the letter to be probed may appear in any one of the eight letter positions on any trial. Those in the specific instruction group were told that on any trial, the two leftmost positions had a 1-in-4 chance of being probed, that the two rightmost positions also had a 1-in-4 chance of being probed, but that the middle four positions would be probed on fully half the trials.

RESULTS

A mixed design was employed, having Instruction as a between-subjects variable with two levels (participants were assigned to either the random or the specific instruction condition) and Letter Position as a within-subjects factor (participants made identification responses for each of the eight letter positions). The proportion of letters identified in each

Table 1

Proportion of correct identifications at each letter position as a function of instruction conditions.

	Letter Position							
Instruction Condition	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Random	.74	.16	.11	.16	.23	.16	.19	.53
Specific	.80	.16	.11	.11	.18	.16	.22	.53

letter position was the only dependent measure. Table 1 displays identification scores for the eight letter positions under different instruction conditions.

Identification scores were subjected to a 2 x 8 mixed design analysis of variance (ANOVA), meaning that differences due to the between-subjects factor were evaluated against a subjects (instructions) error term, whereas differences resulting from the within-subjects factor were assessed against a subjects x letter position (instruction condition) error term.

The ANOVA specified Letter Position as a main effect. The anticipated difference in identification scores due to the position of letters within a row was found to be significant, $F\ (7, 210) = 90.21$, $p < .0001$ (ANOVA summary tables for this and all subsequent experiments are found in Appendix C). The precise nature of the effects of letter position was assessed by planned Bonferroni comparisons of outermost letter positions versus their nearest interior neighbors. Four such tests were conducted (Positions 1 vs. 2 and Positions 7 vs. 8 under each instruction condition) at $\propto = .0125$ (one-tailed), and all were found to be significant (random 1 vs. 2: $t\ (30) = 8.76$, $p < .0001$; random 7 vs. 8: $t\ (30) = 6.50$, $p < .0001$; specific 1 vs. 2: $t\ (30) = 5.19$, $p < .0001$; specific 7 vs. 8: $t\ (30) = 10.93$, $p < .0001$). In each case, letters in outermost positions were identified more accurately than those in the next interior position.

The influence of differential instructions on participants' attentional processing, and thereby, on their identification scores, was not significant. No main effect of instruction was found, $F\ (1, 30) = 0.25$, nor was any interaction evident between instructions and accuracy at any given letter position, F (7, 210) = 0.66.

DISCUSSION

Two hypotheses were tested in Experiment 1, with mixed results. The first test provided a replication of previous findings, examining the effects of a letter's position in a row of letters on its identifiability. In accordance with Merikle et al.'s (1971) and others results, it was confirmed that outermost letters in a row are identified most accurately. Figure 18 shows accuracy functions across letter positions, and reveals that the first and last letter positions resulted in much more accurate identifications than did any of the interior row positions. Indeed, the only interior position that appeared to be identified better than others was the fifth position. The unique results for letters in Position 5 will be noted in more detail in discussing Experiment 1A.

The superior identification of outer letters was taken as support for the existence of a visual grasp. Following a brief exposure duration and post-mask, it appears that only the outermost letters in a row are available for consistent recognition. This implies that these letters are the first to be subjected to object recognition processes or, at least, that

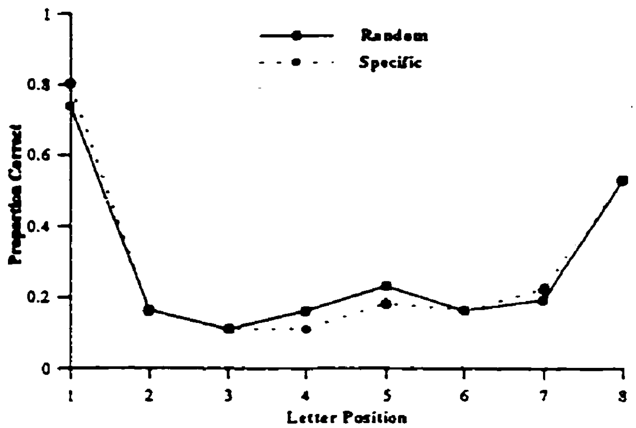


Figure 18. Identification accuracy at each letter position as a function of instruction condition.

such processes are completed first for the outermost items in an array.

The second hypothesis tested in Experiment 1 suggested that central letters (those in Positions 3 to 6) would be identified more accurately when instructions indicated that those positions should be more closely attended. These subtle instructions, which were devised in such a way as to not change the objective task, did *not* have the anticipated effect. No overall or position-specific effect of instructions was found. The problem was *not* one of confusion or misinterpretation of instructions. A post-experimental questionnaire (see Appendix B) revealed that participants easily recalled and understood the specific instructions given to them, but that these instructions generally did not influence how they approached the task.

This outcome indicates that the processes involved in a visual grasp are very powerful effects that may overwhelm a subtle attempt to influence attention deployment. This, in turn, suggests two potential interpretations regarding the processes underlying visual grasp. Contrary to what was originally hypothesized, visual grasp may not be a strategic or voluntarily controlled aspect of visual attention, but may represent a structural or fixed aspect of visual processing. If this were the case, no attempt to influence attentional deployment should be successful. If the stimulus remains the same, then an observer's processing of it should also be fixed. Alternatively, visual grasp may represent a strategic aspect of attention, but the attentional manipulation in this experiment may have been too subtle to overcome such a powerful, overlearned strategy. The results of Experiment 1 did not allow for a distincton between these two interpretations, so a second experiment was devised involving an attempt to influence attention through instructions.

5

Experiment 1A

RATIONALE

In Experiment 1, a subtle instructional manipulation was intended to alter observers' attentional deployment, and thereby, their ability to identify items in the center of briefly presented rows of letters. That manipulation failed to bring about the expected effect. It was reasoned that, if the visual processing that leads to a visual grasp is a strategic, and not a structural, effect, then perhaps a more direct instructional manipulation, albeit one that *does* alter task demands somewhat, might produce a change in identification scores. This was the goal of the present experiment.

Once again, this instructional manipulation targeted the central four positions in an 8-letter row. Here, observers were informed that subsequent blocks of trials would involve having the central four positions (Positions 3, 4, 5, and 6 - hereafter reported as the IN condition) or the exterior four positions (Positions 1, 2, 7, and 8 - reported as the OUT condition) probed on 75% of trials within those blocks. It was assumed that this information would lead observers to deploy greater attention to the positions emphasized, and thus affect identification scores for those positions.

The instructions to participants in this experiment represented a more direct attempt to manipulate attentional processing. Here, task demands were changed to a degree. No longer were observers being asked to process each row item equally (given that each item had an equal possibility of being probed) but now some items within a block of trials were made explicitly more important by the indication that they would be probed more often. Yet, because each row item had *some* chance of being probed under all conditions, it remained that observers would still have to process each row item to maximize their overall performance.

The hypothesis of greatest interest for this experiment was that

(1) identification scores will be higher for Positions 3 to 6 under the IN condition than under the OUT condition.

METHOD

Participants

Participants were 16 Introductory Psychology students from the University of Manitoba who participated for course credit. Normal or corrected vision was determined by self-report and by a brief test of participants' ability to read a sample row of letters similar to test displays.

Materials and Apparatus

All test materials, apparatus, and settings were identical to those used in Experiment 1.

Procedure

Procedures were generally comparable to those in Experiment 1 with the following exceptions. Participants experienced four blocks of 64 trials. Each was instructed that, for the first trial block, the central (or exterior) four letter positions would be probed 75% of the time, whereas the exterior (or central) four letter positions would be probed on only

25% of trials. (This is reported below as the IN (or OUT) block condition.) Before the second trial block, participants were told that for the upcoming block of trials, the probe possibilities would be reversed. Now, the exterior (or central) four positions would be probed on 75% of trials, and the central (or exterior) positions would be probed only 25% of the time. Two block orders were used: IN - OUT - IN - OUT and OUT - IN - OUT - IN, and participants were assigned randomly to a block order, with the restriction that half of the participants completed each block order.

RESULTS

For purposes of data analysis, scores from the two IN block conditions were combined for each participant, as were scores from both OUT block conditions. The primary hypothesis was tested through a planned comparison of central positions in the IN and OUT instruction conditions. Proportions of correct identifications were calculated at each letter position. Proportions for Positions 3 to 6 were then averaged for each instruction condition and compared. No significant difference was found between the mean proportions correct for the central positions (M_{IN} = .191, *SD* = .103; M_{OUT} = .165, *SD* = .106), t (15) = .72. A similar comparison was made of external positions (Positions 1, 2, 7, and 8) across the two instruction conditions. The observed difference was not significant (M_{IN} = .404, *SD* = .121; M_{OUT} = .433, *SD* = .120), t (15) = .97.

The remaining analyses conducted were similar to those performed for Experiment 1. A 2 (instruction) x 8 (letter position) ANOVA was conducted, with both factors being repeated measures. The effect of letter position was significant, F (7, 105) = 52.12, p < .0001. As one may note from Table 2, first and last row positions were identified more often than any other. Bonferroni comparisions (evaluated using $\alpha = 0.0125$) confirmed that these external row positions resulted in higher identification scores than did their next interior neighbors under each instruction condition (Positions 1 vs. 2, IN condition: $t(15) = 8.34, p < .0001$; Positions 7 vs. 8, IN condition: $t(15) = 6.76, p < .0001$; Positions 1 vs. 2, OUT condition: $t(15) = 17.50, p < .0001$; Positions 7 vs. 8, OUT condition: $t(15) = 4.81, p < .001$).

Further, the proportion of correct identifications at each letter position was compared to the proportions obtained under the random condition of Experiment 1. The latter condition represents the most fundamental version of the task that was conducted, and thereby forms the most reasonable point of comparison, or baseline. Visual comparison of results from the IN and OUT conditions with the random condition shows that identification scores at most positions remained consistent, with only two exceptions.

Table 2

Proportion of correct identifications at each letter position as a function of Instruction condition.

	Letter Position							
Instruction Condition	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
IN	.78	.13	.15	.14	.33	.18	.16	.59
OUT	.90	.16	.09	.20	.22	.14	.18	.50
M	.87	.15	.14	.15	.30	.17	.17	.52

Position 1 under the OUT condition (emphasizing the external four positions) resulted in higher scores than its counterpart in the random condition (.90 vs. .74, t (30, 1-tailed) = 2.10, $p < .05$), as did Position 5 under the IN condition (which emphasized the internal four positions) compared to its random condition equivalent (.33 vs. .23, t (30, 1-tailed) = 1.89, $p < .05$).

The attempt to guide participants' attention by emphasizing interior or exterior letters did not, surprisingly, have a significant effect on their performance. The ANOVA revealed no significant difference due to instruction conditions, nor any interaction between instructions and individual letter positions. Considered as a group, the central four positions did show slightly higher identification scores under the IN condition than under the OUT condition (.20 vs. .16), but this difference did not reach statistical significance.

DISCUSSION

Once again, the results were mixed for Experiment 1A. The expected effect of a letter's position in a row was confirmed, with row-end letters being identified more easily than interior letters. This suggests that the processing of outermost letters is being completed first within a sequence, so that these letters are not subject to post-mask effects (Butler & Merikle, 1973).

It was somewhat surprising that even a rather direct manipulation of observers' attentional focus could not produce a difference in their processing of central letters. Telling participants that central letters would be emphasized on upcoming trials would seem to be tantamount to telling them "Pay more attention to the central letters." Yet, to judge from identification performance, this did not greatly change the way that the letter rows were processed. The visual grasp of letter rows appears to be a very powerful effect, one that is not easily overcome by voluntary changes in the focus of attention. Following their participation, several observers reported that they had *tried* to attend more to interior letter positions when instructed that those positions would be probed more often, but that they simply could not do so effectively when the letter display flashed onto the viewing screen.

This implies that a visual grasp may be a *default* attentional strategy directed toward new objects appearing in the visual field. Certainly humans have the ability to voluntarily switch attentional focus from one specific location to another, given sufficient time to do so (e.g., Shulman, Wilson, & Sheehy, 1985). A visual grasp, though, may accompany the attentional capture that is likely to occur toward objects appearing suddenly in brief displays (see Yantis, 1993). Thus, with the sudden onsets of letter rows in the current experiments, visual grasp is most likely to be the result.

Having said this, a visual grasp may not be an inevitable result. Differential instructions did have *some* impact in producing differing patterns of response. Though a comparison of average scores collapsed across the central four letter positions revealed no overall effect of instructions, the comparison of specific position outcomes showed that Position 1 scores were elevated in the OUT condition, whereas Position 5 scores were higher in the IN condition. Thus, when external items were emphasized through instructions, observers may have been encouraged to attend more to the leftmost letter -- the first letter of the display (or the first letter of the group being emphasized). Similarly, when instructions stressed the internal items, the fifth letter (the first letter following the central fixation point) was more closely attended.

An explanation of this result might follow from the left-to-right scanning tendency emphasized in early studies of tachistoscopic reports and described above (Bryden, 1966; Heron, 1957). Although found most often in whole-report studies, this tendency to scan items in the same order that they would typically be read may be present to some degree. Instructions stressing external items might lead observers to process the leftmost item first, whereas instructions stressing central items might cause observers to focus more narrowly on the central fixation point prior to a display's onset, and to begin processing from that point, resulting in the improved performance observed for Position 5 under those circumstances. Given that Heron (1957) attributed the left-to-right scanning tendency to long-established reading habits, it may be that this habitual processing strategy influenced the current pattern of identification scores.

On the basis of the unique outcomes observed for individual letter positions in these experiments, it was decided that data for various letter positions should *not* be combined or collapsed in subsequent experiments. Note again that in both Experiments 1 and 1A, letters in Position 5 were identified more often than were those in any other interior position. Analysis showed considerable variability among observers to produce this outcome. Some observers identified central letters only rarely, whereas a few reported most letters in Position 5 correctly. This suggests that the latter observers were voluntarily focusing their attention quite narrowly on the center of the display, and processing quite effectively the first letter that followed. The difference between Position 5 and other interior positions will continue to be evident in Experiment 3 (see p. 141).

6

Where is Attention Directed?

I have looked at the issue of *when* during processing attention may be employed to select stimuli: the question remains how it is determined *which* stimuli will be attended. To answer this question, Neisser (1967) made a distinction between two types of perceptual processes: preattentive processing and processes of focal attention. Preattentive processing operates first in any perceptual analysis. This activity is assumed to operate in parallel across all parts of the visual field and involves low level stimulus-driven mechanisms. It segments the visual field into discrete objects, based on Gestalt grouping principles, which may include spatial proximity, good continuation, similarities of color or movement (Duncan, 1984), or geometric features such as collinearity and symmetry (Yantis, 1992). Focal attention operates serially to identify and analyze individual objects in detail. It is this process that limits our ability to attend to and to process information about multiple objects at one time (Duncan, 1984).

The question of where attention is directed was put most succinctly by Kahneman and Henik (1981), who asked "If attention selects a stimulus, what is the stimulus that it selects?" (p. 183). No consensus has been reached on this question. In 1994, Egly, Driver, and Rafal acknowledged that in the preceding 20 years, considerable progress had been made in understanding attentional processes, how these processes function to integrate elementary perceptual features, and how such processes relate to certain neural substrates. Still, they pointed out, the issue of the *target* of attentional processing has become increasingly controversial over this time. The controversy over *what* is selected by visual attention is the focus of this section.

Beginning with Kramer and Jacobson (1991), this question has been framed as a distinction between space or location-based and object-based models of visual attention. A space-based model indicates that attention is directed toward certain visual locations – one's attentional focus is on a particular area of the visual field. Object-based models, on the other hand, hold that attention selects the objects or perceptual groups that have been determined by a preattentive segmentation of the visual field.

Vecera and Farah (1994) noted that these two broad classes may reflect an earlier mode of selection in the case of space-based selection, and a later mode for object-based selection. Space-based representations are constructed from elementary features coded as belonging to a particular location. This type of representation echoes the primitive stages of visual processing in Marr's (1982) model of object recognition (the full primal sketch). Conversely, object representations represent an object independent of its location in the visual field. In Marr's view, this kind of representation reflects the more fully processed (and thus later) 3-D model of an object. Here, the features of the object are bound within certain spatial relationships *to each other*, and their representation no longer depends on a particular location in visual space.

Researchers have proceeded to distinguish between two conceptions of object-based attention. The first, and strongest, interpretation suggests that location plays no role in the representations to be selected, that is, each is spatially invariant. This is the view that corresponds to Marr's 3-D object representations. The second, and less extreme, view of object-based attention is that locations in the visual field may be selected *because* they belong to the same object or perceptual group (Egly, Driver, & Rafal, 1994).

At the same time, not all researchers consider this latter view of object-based attention to be, in fact, object based. The fact that two stimulus elements being in close proximity is strongly correlated with their being on the same object, and vice versa, has long been recognized. Vecera and Farah (1994) pointed to research (e.g., Treisman, Kahneman, & Burkell, 1983) which showed that, when multiple shapes form a strong perceptual group such that they could be considered a single object, identification of the individual shapes is easier. Vecera and Farah argued that this result does not mean that attentional selection is being made according to the objects or perceptual groups, so much as it suggests that selection of locations can be influenced by perceptual organization. Perhaps sets of locations that are defined by Gestalt grouping principles are selected by a location-based attentional process. Yet, as Egly et al. (1994) noted, the view of object-based attention being directed toward perceptual objects or perceptual groups has been the position most often advocated. I will describe evidence for this view presently, and further, I will address the question of the impact of perceptual grouping on attention more fully in a subsequent section of this paper.

Before describing the evidence marshaled for space-based versus object-based attention, one other consideration may be worthwhile. As the reader will note, evidence for the competing models has been drawn from very different tasks and different paradigms. It is possible, as Egly et al. (1994) suggested, that there may be *both* space-based and object-based components to visual attention. We have already seen evidence that attentional processes may be more flexible than originally thought: It may not be unreasonable to think that, in differing circumstances, attention may be directed either toward locations in space or toward particular objects.

SPACE-BASED MODELS OF ATTENTION

Space-based models of attention hold that visual attention is distributed across a specific area of the visual field (Kramer & Jacobson, 1991). Elements or contours that fall within this region are processed extensively, whereas those which fall outside are not. This allocation of attention has been described by analogies to a spotlight or searchlight (Broadbent, 1982; Posner, Snyder, & Davidson, 1980) or zoom lens (Eriksen & St. James, 1986), or by attentional gradients (Anderson, 1990). Of these models, spotlight analogies have been discussed most widely.

Spotlight Models

Spotlight models include certain characteristics. Firstly, spotlights operate in contiguous areas of the visual field, that is, one cannot simultaneously attend to two separate portions of a scene (Kramer & Jacobson, 1991; Posner et al., 1980). Secondly, in order to process different elements of a display, the spotlight will normally have to be moved. This is important because such movement requires some amount of *time* (adding, for example, to reaction times in certain tasks). Thirdly, the effect of the attentional "beam" is unrelated to foveal vision. In everyday life, there is usually a close correspondence between foveal vision and attentional processes, because we typically look directly at the things that interest us. This correspondence is not inevitable, however; we can attend to peripheral stimuli. If an observer is asked to attend to peripheral areas of the visual field, the foveal region becomes less able to detect stimuli, as is the case with any unattended region. Finally, spotlights are assumed to be of limited spatial extent. The attentional beam may be narrow or wide. When there is uncertainty about an optimal location for focusing, the beam remains wide. When a cue or an event occurs at some location, the beam narrows at that location. Whatever the size of the spotlight's focus, everything inside it gains access to further processing. The size and movement of the spotlight depend on events already detected (Broadbent, 1982).

Early support for spotlight models of attention appeared in the work of C. W. Eriksen and colleagues. For example, Eriksen and Eriksen (1974) examined the effects of distractor letters on the identification of target letters. Letters were presented briefly to subjects, with a target letter appearing just above a fixation point on each trial. RTs were measured for targets flanked by either identical, response compatible, or response incompatible distractors, or (in control conditions) appearing alone. Subjects were instructed to press a lever in one direction if the target letter were identified as an S or a C, and in the opposite direction if it were an H or a K. Thus, for example, a target C flanked by Hs would represent the response-incompatible condition. Eriksen and Eriksen found that RTs were fastest with no distractor items, and increased under conditions where distractors were less compatible with the target. Of importance to spotlight models, Eriksen and Eriksen varied the amount of separation between target and distractors, from .06 to .5 to 1° of visual angle. They found that, at close or moderate spacing, the type of distractor significantly influenced RTs to targets, but when targets were separated from distractors by a full degree of visual angle, the distractors had little impact. This result was interpreted as an indication that one degree of visual angle represents an approximate minimum focus for a spotlight within which all stimuli are processed (Eriksen & Hoffman, 1973).

Spatial priming tasks (tasks using visual precues) have frequently been used in testing spotlight models. For example, Posner et al. (1980) looked at how precues affect subjects' ability to detect an LED signal. Subjects were cued or primed to expect the signal at one of four potential locations. Under various conditions, cues were valid, invalid, or neutral as predictors of the target's location. Valid cues led to significantly shorter RTs than did neutral or invalid cues. In another experiment, subjects were cued to both the most likely location of a target, and to its second most likely location. Posner et al. hoped by this manipulation to measure whether subjects could allocate attention to multiple distinct locations at will. They found that both cues provided some advantage in RT, but the advantage was considerably greater if the second cued location was adjacent to the first.

Posner et al. concluded that subjects' knowledge about where in space a signal will occur facilitates processing at that expected location, whereas processing at uncued locations is hindered. Their results suggest that orienting mechanisms allocate attentional resources to the cued locations, enhancing processing in that region (Egly et al., 1994). Posner et al. summarized these cuing effects, saying that visual attention fluctuates like "a spotlight that enhances the efficiency of detection of events within its beam" (1980, p.

172).

Other studies have extended the precuing paradigm to show that processing may be enhanced even to more general spatial regions, rather than to specific locations. Egly and Homa (1984) showed that, when a precue identified a particular circular region around a fixation point, even if the exact target location on that circle was not known, RTs to the target were improved. This sort of result indicates that attention can be directed toward spatial regions in a rather flexible way.

Shulman, Remington, and McLean (1979) provided additional support for the spotlight metaphor. They found that, following a central precue, RTs to flashes presented at two eccentricities (8° and 18°) depended on the SOA between cue and target flash. Based on this result, they suggested that attention is shifted in an analog manner, passing through intermediate points before reaching more extremely eccentric locations. Such movement would be consistent with the reorientation of an attentional spotlight. Although others such as Hughes and Zimba (1985) questioned Shulman et al.'s interpretation, and indeed the whole spotlight idea, other work like that by Egly and Homa (1991) suggests that the amount of time needed to shift attention from one location to another may depend on the distance between those locations. Similarly, Shulman, Wilson, and Sheehy (1985) measured subjects' RTs to lights that appeared at various positions in the periphery of the visual field. They found that longer RTs correlated with greater distance between the focus of attention and the target location. Once again, the longer RTs may be interpreted in terms of the need to reorient an attentional spotlight in the visual field.

Certain authors have suggested that at least some spatial cuing effects such as those described above may be best considered as instances of object-based attention. Tipper, Driver, and Weaver (1991) acknowledged that simple precuing experiments seem to implicate spatial attention when target detection is facilitated by a (valid) cue indicating one side or the other from fixation. On the other hand, they noted that, if the cue-target interval is greater than about 300 msec, the effect can be reversed, so that target detection is *delayed* rather than facilitated by cuing. This phenomenon is known as *inhibition of return*. It is assumed to occur because cued locations are tagged to prevent repetitive sampling of locations during visual search.

Tipper et al. (1991) considered this effect in the context of dynamic, real-life scenes, where the objects of our search are often in continuous motion. They suggested that, if we tag certain locations as having been sampled, we may examine an object, have it move, and examine it again (rather needlessly) when it reaches a new location. In three experiments, dynamic displays were created (Fig. 19). Three squares appeared: a central fixation square and two peripheral squares. One of the peripheral squares was cued, and the two peripheral squares rotated around the fixation square. It was found that inhibition

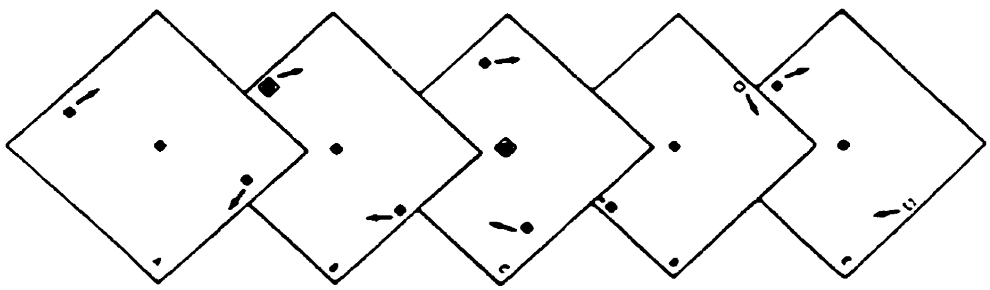


Figure 19. Sample displays from Tipper et al. (1991). Display elements were cued (Panel B) and probed (Panel D) as they rotated (as indicated by arrows) around a central element.

of return operated on the moving *objects* rather than locations. No inhibition of return was found for a square that moved into a location previously occupied by another square. So it appeared that if a previously attended (cued) object *moved*, the inhibition of return moved *with* it, and was not fixed to specific spatial coordinates. From this result, Tipper et al. argued that attention in some precuing experiments might apply to cued objects, and not to cued locations per se (Egly et al., 1994).

Yet, the simplest precuing tests are not easily explained by an object-based account, because no objects *exist* for attention to fix upon before the target appears. For example, Posner (1980) demonstrated that central cues (digits) could provide RT costs or benefits even when they specified a particular location in a completely empty field.

Finally, in support of spotlight models, divided attention studies, such as that by Kramer, Wickens, and Donchin (1985), demonstrate that stimuli located close together are more easily identified. This would be predicted from the idea that nearby objects may fall within the spotlight's beam, or would require less movement of that beam than would more widely separated objects.

Zoom Lens Models

In the studies supporting spotlight models, it is assumed that attention is restricted to a particular area of visual space, and further, it is implied that the field of attention is homogeneous. All elements inside are processed equally. Evidence has suggested that, depending on the demands of the task and on the strategies employed by observers, selective processing may occur over small or large areas of the visual field. In response, Eriksen and colleagues suggested another metaphor for visual attention – the zoom lens model (Eriksen & Hoffman, 1972; Eriksen & Yeh, 1985).

Eriksen and Yeh (1985) attempted to evaluate a model of attention proposed by Jonides (1983). Jonides had used a visual search task in which subjects searched for target letters within a circular array of distractors. He also incorporated a priming technique similar to that of Posner et al. (1980). A position in the circular display was precued by an arrow, but the cue's validity was systematically varied. When the cue was valid, RTs were facilitated in comparison to a noncued condition; whereas invalid cues led to delayed RTs. Jonides concluded that subjects can allocate attention in two distinct ways. They may process an entire display by processing elements in parallel, but slowly. Conversely, when given a prime, attention may be concentrated at one location, facilitating processing there.

The methodology of Eriksen and Yeh's (1985) study was similar to that used by Jonides (1983). A circular display of letters contained one target letter (S or Y) and seven distractors. A precue location was designated by a bar marker appearing 150 msec before display onset; targets could appear at the 12, 3, 6, or 9 o'clock locations. Under three conditions, the cue was valid on 40%, 70% or 100% of trials. In addition, a second location was indicated for which the probability of containing the target also varied. This location was always diametrically opposite to the cued location. In the 40%-valid condition, this opposite location also had a 40% probability of containing the target. The purpose of this manipulation was to determine whether an invalid cue would result in a parallel search of other locations, or a serial search in the focal attention mode. It was found that RTs to targets in the primary location were significantly facilitated, whereas RTs to targets in the secondary locations were delayed in comparison to noncued control conditions (those with no cued locations at all), but faster than RTs for noncued experimental locations (i.e., if the primary location were at the 12 o'clock position, and the secondary location were at 6 o'clock, the 3 and 9 o'clock positions were non-cued, and targets appearing there resulted in the slowest RTs). Presumably, subjects focused attention on primary cued locations, only focusing attention on secondary cued locations when targets were not found in the primary locations. In noncued control trials, display positions were apparently searched simultaneously and in parallel.

In a second experiment, the display was altered so that only one letter appeared on each trial (with no distractor items). Experimental conditions included 40%, 70%, or 100% valid precues. In the 40%-valid condition, the diametrically opposite location again had a 40% probability of containing the target. Results showed that subjects rarely, if ever, focused attention on this secondary location until the primary location had been attended. No differences in RT were found for targets located in the secondary versus the noncued locations. Only primary locations benefitted from precuing. Eriksen and Yeh concluded that subjects cannot allocate attentional resources to separate locations in a display simultaneously. Simultaneous allocation of attention would have resulted in performance at secondary locations that was superior to noncued and control conditions.

Whereas they agreed with Jonides (1983) that attention can be widely distributed or narrowly focused, Eriksen and Yeh felt that the analogy of a zoom lens was more appropriate than a two-distinct-process model of attention. They believed that attention is dynamic, operating over a continuous range of distribution in the visual field. A zoom lens analogy implies an inverse relation between the size of the attentional beam and its resolving power. As the field is constricted, the power of the "lens" to aid in difficult discriminations increases, resulting in rapid, detailed processing such as that found at the primary cued locations described above.

Eriksen and St. James (1986) pursued the zoom lens metaphor, examining (1) whether the spatial extent of attentional focus can be made to vary in response to precues, (2) whether processing efficiency actually declines with a wider attentional focus, and (3) whether the boundary of attentional focus is sharply defined or drops off gradually. Their experimental design was similar to that used by Eriksen and Yeh (1985), consisting of a display of eight letters, with one, two, or three of the letter positions being cued on a given experimental trial. Subjects' task was to discriminate between two letters, S and C: A target would appear in one of the cued locations. A lever press in one direction signaled identification of an S target; a press in the other direction indicated that the target was C. Various distractor conditions were used: a neutral condition, in which the letters A, N, and H filled all non-target positions and presented low confusability with the target; a compatible condition, in which the target letter was repeated in an uncued location; and an incompatible condition, in which the opposing target letter was presented in an uncued location. If the opposing target were processed, response competition would occur, increasing RT. Finally, the distance between compatible or incompatible distractors and the target was manipulated. Eriksen and St. James found that RT increased with the number of precued locations. According to the zoom lens model, this would indicate that some limited amount of processing resource was being more widely distributed as the number of cued locations increased, resulting in decreased efficiency. The disruptive influence of incompatible distractors decreased as they were positioned farther from the precued locations. A similar gradient was found for each size of precued area. Eriksen and St. James concluded that their data supported the idea that attentional resources are *uniformly* distributed within a precued area, and that this area is bordered by a gradual decline of processing resource.

Gradient Models

Other researchers have supported the idea that different amounts of processing resources are available at different locations in the visual field. Downing and Pinker (1985) had subjects focus on a central point in the visual field, and respond to stimuli located at varying eccentricities and at varying depths. Costs in terms of RT were greater as retinal distance increased, and when focus and target appeared at differing depths. The authors concluded that attentional costs are related to the amount of activation defined by an attentional gradient. This gradient is centered (peaked) at the point of attentional focus, and declines in a negatively accelerated fashion, its slope depending on the retinal separation of elements in the visual field.

Kramer and Jacobson (1991) described Downing and Pinker's (1985) model as a *static* gradient model of attention. This may be contrasted to a *dynamic* version of gradient model, developed to account for data suggesting that efficient processing may occur over wide or narrow areas of retinal distance, depending on task demands and observer strategies.

LaBerge and Brown (1986) claimed that the results of their study opposed the notion of a fixed capacity (static) gradient model. They measured subjects' RTs to letter stimuli set at various distances from attentional focus. Little difference in RT was found when more potential locations or more widely spread locations were employed. A static gradient model would predict high RTs when stimuli were widespread, or when many more stimuli must be processed. A dynamic gradient model was suggested in which processing capacity is spread continuously over the expected range -- capacity increases as the expected range (the task demand) increases.

Downing (1988) also suggested a flexible attentional gradient. She employed discrimination tasks involving target brightness, luminance, orientation, and form. In all tasks, spatial expectancy due to precuing influenced performance. If targets appeared at unexpected locations in a circular display, discrimination performance was generally poor. Further, performance was inversely related to (increasing) distance from expected locations. A gradient of attentional sensitivity was assumed to operate both in terms of spatial distribution of information and according to the type of information being processed.

LaBerge and Brown (1989) proposed a dynamic gradient model to account for attentional factors in shape identification. Specifically, these authors attempted to specify how selection occurs in early processes of identification of objects or shapes. Various domains or modules were postulated in their model, including feature register, position analyzer, and location expectation domains. The location expectation domain is responsible for the attentional gradient centered on a target's expected location. This gradient is assumed to bias processing in such a way that locations near the center are processed more quickly than peripheral locations. The feature registration domain copies information about elements of a display onto a filter map – where more information exists, filtering is facilitated. The position analyzer acts in a top-down manner to increase processing in a sub-area of the filter map in response to task demands. For example, if target and distractor items are highly similar, a narrower gradient may be established to filter out distractors. Once again, the gradient is *dynamic*, based on task difficulty and self-instructed strategies (Kramer & Jacobson, 1991).

Each of the space-based models described above proposes a slightly different mechanism to account for variations in processing efficiency. Yet, in each model, physical space plays a central role in controlling attention. It is assumed in each case that visual attention can operate on purely spatial representations (Egly et al., 1994).

Neurological Evidence

One more research area provides support for the space-based nature of attention. Egly et al. (1994) reviewed evidence that suggests that the attentional deficits that follow neurological damage are generally consistent with space-based models of attention. Consider the phenomenon of unilateral neglect. Patients who experience damage, especially (classically) to the posterior association cortex, appear to ignore visual information appearing in regions of the visual field that are contralateral to their lesion. It is claimed that this must be an attentional, rather than a sensory, deficit in that the "afferent pathways for the ignored information may be demonstrably intact" (p. 162). Because this deficit affects a certain portion of the visual field, it implicates an attentional mechanism that operates on spatial representations. Posner, Walker, Friedrich, and Rafal (1984) described several components of a mechanism controlling attention deployment, and suggested that neglect may result from damage to any of these components. According to these authors, at least three operations are required to control attention: an attentional spotlight must be *moved*, be *engaged*, and later be *disengaged* to move to the next appropriate location. When a specific location is precued, attention is presumably moved to that location and engaged. Should the target appear at a noncued location, attention must first be disengaged at the precue location and moved to the actual target location, resulting in a RT cost.

Individual components of this controlling mechanism may be selectively impaired, depending on the nature of the neurological damage, and characteristic deficits result. For example, Posner et al. (1984) found that damage to one parietal lobe results in a specific deficit: When contralesionally located targets are invalidly cued, exceptionally slow RTs result. It is suggested that the impairment here is in terms of the disengagement of attention from invalid locations, as the ability to move and engage attention appears to remain intact. Egly et al. (1994) reviewed additional evidence that damage to other specific areas may affect patients' ability to move attention (seen in deficits in responding to valid cues) and to engage attention (observed in deficits in responding to valid or invalid targets in the contralesional portions of the visual field).

Overall, more than two decades of evidence has provided considerable support for the notion that our attentional processes operate on spatial representations. At the same time, other evidence from other experimental paradigms has suggested that attention may be directed toward particular objects in the visual field, independent of their location.

OBJECT-BASED MODELS OF ATTENTION

Though the space-based models proposed unique mechanisms to account for variations in processing efficiency, in each model physical space plays a central role in determining where attention is deployed. An alternative class of models has been proposed in which factors other than space or proximity determine the deployment of attention. These models are described as object based (Duncan, 1984; Kramer & Jacobson, 1991) and are based in Gestalt theorizing into perceptual organization.

The answer for object-based models to Kahneman's question about the nature of the stimulus selected by visual attention is that attention selects preattentively defined perceptual objects (Yantis, 1992). What constitutes such an object or group depends entirely on the results of preattentive organizational processes that specify the perceptual objects that may be selected. Conversely, according to Yantis, "because attention necessarily selects coherent perceptual objects, grouping may be thought of as a natural byproduct of the process of selection" (1992, p. 299). Whereas most authors, including Neisser (1967), believed that the creation of perceptual objects occurs exclusively through stimulus-driven means, depending only on the properties of the object in question, Yantis (1992) suggested that goal-directed grouping may also occur, such that knowledge about relevant aspects of a stimulus may direct attention to those elements.

Perceptual Organization : Grouping Factors

One can scarcely discuss object-based theories of attention without first describing the concept of perceptual organization. If it is believed that attention is directed toward perceptual objects or groups, an understanding of how such objects may be created or defined becomes necessary. Recall that Neisser (1967) assumed that, whenever two or more objects occupy the visual field, some sort of segmentation process must occur. Many researchers have pointed to classic Gestalt grouping factors as likely candidates to describe the nature of this segmentation. For example, Prinzmetal (1981) wrote that a *perceptual group* is the result of our visual system parsing a stimulus array according to Gestalt organizational principles. (This is one of the few areas in modern psychology where Gestalt-inspired concepts remain prominent.) I will briefly review some of the classic Gestalt laws on perceptual grouping, and look at a contemporary view of how such grouping occurs. Evidence for object-based attention grounded in these grouping or configurational effects will follow.

Gestalt grouping principles. The concept of a perceptual object has its origins in early Gestalt psychology. Kahneman and Henik (1981) noted that, like many other Gestalt concepts, this one is somewhat vague and elusive, and based on an intuition we all experience -- that there is a fundamental difference between the objects one experiences and the properties and characteristics those objects possess. One can imagine an object moving through space, changing position and color and shape as it moves, and all the while being recognized as the same object. Wertheimer's (1923/1938) landmark paper on the laws of organization emphasized what everyone knows: A person's experience is based on a world of perceptual objects, not on collections of random sensory information and not on sensory information that is organized in some arbitrary way. He argued that the organization is present *in* the stimulus array – it is given, and it occurs in a manner that follows definite principles.

Wertheimer (1923/1938) described some of the well-known principles by which perceptual groups are formed. Perhaps most fundamental is the factor of *proximity*. One sees groups of elements (dots were used as his most basic examples) based on their physical proximity. Wertheimer noted that adding more dots to a configuration does not result in an abandonment of the grouping process, but makes the perceived organization all the more compelling (compare Fig. 20a and b). The same principle holds for auditory stimuli organized by proximity in time.

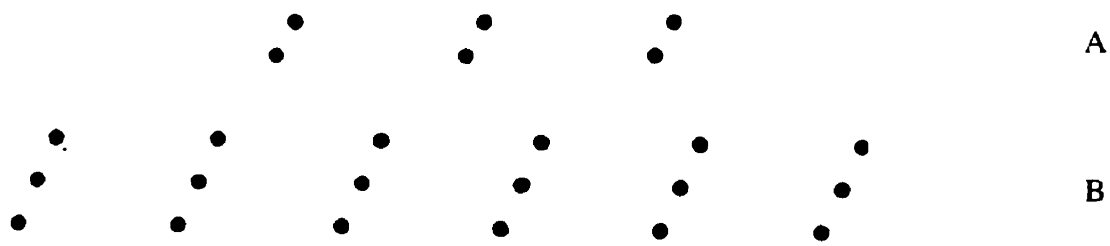


Figure 20. Grouping by proximity (from Wertheimer, 1938).

A second factor involves the *similarity* of elements in a display. If dots in a display are maintained at a constant proximity while the color of the dots is varied (Fig. 21), groups of similarly colored dots are perceived. Palmer (1982) noted that the factor of similarity may be considered in terms of orientation, shape, size, and various dimensions other than color.

Figure 21. Grouping by similarity (from Wertheimer, 1938).

Thirdly, when elements in a display are moved or transformed in some uniform manner, they spontaneously become organized as a group. This happens whether the transformation is an abrupt change in position (producing apparent motion) or a continuous pattern of movement over an extended time (Palmer, 1982). If a few dots from a larger array begin to move, a distinct moving form is perceived, having a clear shape and edges, which may once again disappear when the movement stops. This factor of *uniform destiny* or *common fate* is a powerful grouping influence.

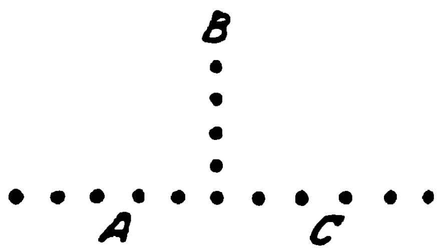
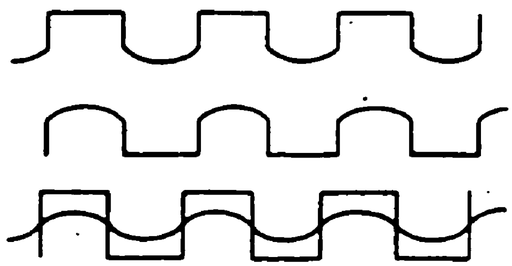


Figure 22. Grouping by good continuation (from Wertheimer, 1938).

The factor of *direction* or *good continuation* indicates that spatial proximity alone will not always account for organization. In Figure 22, points in A and B are closer to each other than are points in A and C. Still, a horizontal line (AC) bisected by a vertical (B) is perceived most often. Indeed, it is almost impossible to perceive the component parts indicated in Figure 23 if those parts happen to be positioned as in Figure 23b.



A

B

Figure 23. The effect of good continuation.

Finally, all of these principles point to the idea that certain organizations are stronger than others. Intuitively, each of us knows how parts of a figure fit together, what constitutes a "good" continuation, how inner coherence is achieved, and so on (Wertheimer (1923/1938). One instantly recognizes a good Gestalt, a simple, coherent, unified perceptual object. Wertheimer warned that to describe an organization as simple does not mean that its component parts are simple: "Simplicity is a property of wholes" (p. 83). The concept of *Prägnanz*, or parsimony of grouping, reflects this type of organization.

How grouping occurs. Contemporary researchers have essentially accepted the factors described by Wertheimer as the primary influences on perceptual organization. This remains true despite the fact that the concepts are rather subjective and not easily quantifiable (other than proximity). The principles remain the means used to *create* perceptual groups in studies of configurational effects.

Palmer (1982) claimed that difficulties exist within the Gestalt view of grouping. Firstly, he said, these laws are purely qualitative/descriptive, and secondly, no means are suggested by which various factors might be integrated. It therefore becomes difficult to understand what characteristics of a stimulus pattern (or of the perceptual system) underlie the observed grouping effects. Palmer suggested grouping effects are based on outputs of first- and second-order stimulus analyzers. When, for example, several analyzers of the same order are similarly activated, the stimuli producing the activation are perceptually linked.

Pomerantz (1981) noted that the classic Gestalt work had identified two classes of factors that cause grouping to occur. The first involved laws such as proximity, similarity, and common fate, which are at least potentially measurable characteristics of a stimulus.

The second class involved good figure, good continuation, and the larger concept of Prägnanz. The latter set of principles indicate that a visual display is grouped to yield the best or most stable organization.

The former class may be considered to reflect bottom-up or stimulus-driven processing, beginning with raw stimulus data and arriving at some conceptual structure (Pomerantz, 1981). Mack, Tang, Tuma, Kahn, and Rock (1992) found, however, that perceptual grouping by similarity or proximity did not occur if subjects were not attending to the stimuli to be grouped. Thus, even such simple grouping processes may not occur without conscious processing, or on the basis of stimulus factors alone.

The latter class of organizing principles may be based on top-down or conceptually-driven processing. "If grouping proceeds so as to yield the 'best' figure, then processing begins with the goal of grouping, and the task is to find some organization most consistent with that goal" (Pomerantz, 1981, p. 152). This may involve the creation of parsimonious hypotheses about the way a stimulus is structured, indicating a bias within the perceptual system toward simple ("good") figures. (In the section describing evidence for object-based attention, it will be seen that perceptual objects may be created due to stimulus factors alone [e.g., Kramer & Jacobson, 1991], or due to an observer's intent to *create* structure [e.g., Baylis & Driver, 1993].)

That one can impose one's own organization was recognized years earlier by Köhler (1947). He argued that an "analytical attitude" may give rise to a change in the organization of a stimulus pattern. As an example, he noted that Figure 24a is typically seen as a symmetrical shape. One can, with some effort, focus on the lines indicated by *a*s and ignore *b*s. Doing so alters one's perception of the entire form, which is evident if one

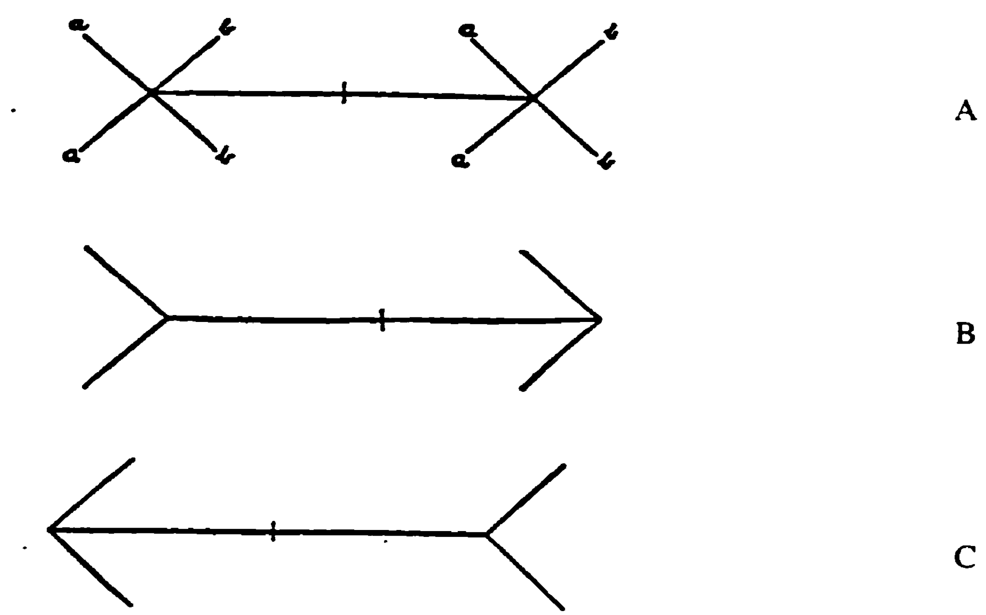


Figure 24. Attentional focus influences perception of stimulus elements such as objective bisection points (from Köhler, 1947).

considers the perceived position of the point bisecting the horizontal. If one focuses only on lines marked *a*, the phenomenal center of the horizontal line shifts to the right of objective center (Fig. 24b). Focusing on lines marked *b* shifts the phenomenal center to the left (Fig. 24c). Thus the importance of organizational processes becomes clear: The way a stimulus array is organized may influence one's interpretation of every part of that stimulus.

Configurational effects on attention. A number of studies have explored the effects of the configuration of elements in a display on target identification. Banks, Bodinger, and Illege (1974) demonstrated these effects of perceptual configuration.

Arrays of seven elements were arranged in a circular pattern around a fixation point. Each display contained a target letter *F* or *T* and noise elements that were either dot patterns or "hybrid *F-T*s." The time required for target identification and detection accuracy depended heavily on the configuration of targets and *F-T*s (distractors). As space-based models would predict, the further that distractors were placed from the target, the better was the observed performance. If the *F-T*s were placed together, but away from the target, they produced little interference. If, however, the *F-T*s were clustered with the target, accuracy and RT were poor. The interesting finding, and the one which lent support for object-based models, was that additional *F-T*s did not necessarily lead to poor performance if those distractors formed a perceptual group with other distractors that did not include the target letter. This conclusion was an important contradiction of earlier models, such as that by Estes (1972), which attributed the effects of similarity and proximity of distractors and target to mutual inhibition at the feature detection level, and to confusion at the decision level. Such a model would predict that increasing the number of distractors in a display should always result in performance costs.

Banks and Prinzmetal (1976) followed up this examination of configurational effects. They used matrices that included a target *F* or *T* and variously arranged hybrid *F-Ts* (Fig. 25). Whether they allowed subjects to scan the display, or limited stimulus duration to less than a second, targets were detected more poorly when they could be clustered with distractors in a "good form" than when they could not be organized in this way.

Humphreys (1981) asked subjects to respond to the curvature of simple bracket stimuli. Two such stimuli appeared on each trial, one being designated the target by a location precue. In some conditions, a color difference existed between target and

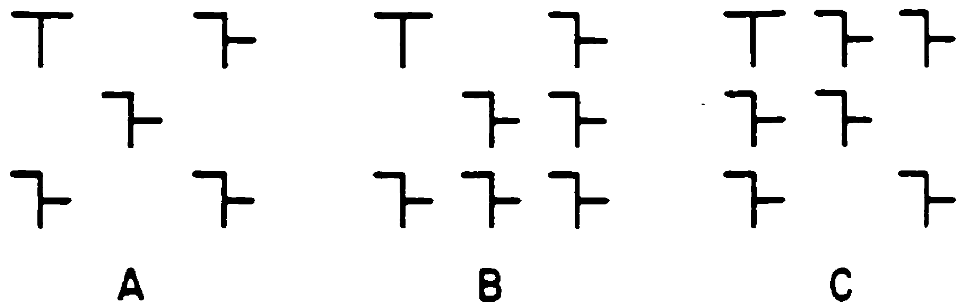


Figure 25. Sample stimuli from Banks and Prinzmetal (1976). Target letter T is segregated from distractors in Panel B, but organized *with* distractors in Panel C.

distractor lines, and under these circumstances targets presented in an unexpected color resulted in impaired performance. It was concluded that both line curvature and color were being used to discriminate distinct perceptual groups. The studies by Banks and colleagues and by Humphreys supported the idea that grouping established by Gestalt organizational factors can influence later processing efficiency.

Further evidence for advantages due to perceptual grouping was provided by Skelton and Eriksen (1976). These authors presented subjects with circles of eight letters, with markers indicating two of the eight positions. Subjects were to judge whether the pair of letters indicated were the same or different. RTs were fastest for adjacent pairs and for diametrically opposite pairs. The former result would have been predicted by Eriksen's spotlight model; the latter seems to require one to consider configuration. Both adjacent and opposite positions would be considered to be most strongly perceptually grouped.

Fryklund (1975) used a 5 x 5 matrix of letters, with five target letters colored red, and the remaining distractor letters in black. Identification of the target letters was better when they formed a row or a column than when they were adjacent but formed no "good" pattern. Grouping factors beyond adjacency seem to influence performance.

Finally, Prinzmetal (1981) examined errors of feature conjunction. In this type of experiment, a target stimulus might be a red letter N. Test stimuli might include a green N, a red X, and a blue S. Given these stimuli, subjects might make a feature error by misperceiving green as red, or they might make a conjunction error by combining the red from the X with the letter N. Either type of error would produce an identification false alarm. Some (e.g., Wolford, 1975) have argued that features are most likely to be integrated on the basis of proximity. Others (e.g., Fox, 1978) have claimed that perceptual grouping principles including similarity and goodness of form are the basis for conjunctions. Often the two positions lead to the same predictions.

Prinzmetal (1981) measured false alarms involving conjunctions of target elements. The targets were circles containing plus signs; some displays contained circles with only a

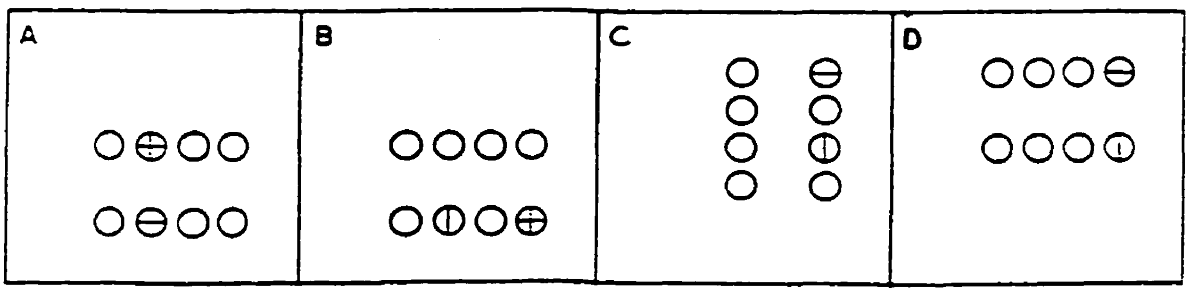


Figure 26. Sample stimuli from Prinzmetal (1981). Stimuli containing targets are on the left (A and B); potential conjunction stimuli are on the right (C and D). Line segments appear in separate objects in samples A and D; in the same objects in samples B and C.

horizontal or a vertical line (a conjunction between these could lead to a false alarm response). The line segments might appear in circles that formed part of the same perceptual object (due to good form or to color), or in circles that were parts of different perceptual objects (see Fig. 26). Note that in either case, their physical proximity was identical. More false alarm conjunctions occurred when features were included in the same perceptual object, indicating that perceptual organization did influence the integration of features.

Evidence for Object-Based Attention

Two types of experiments have supported the object-based view. The first type demonstrates that it is difficult to ignore distracting information that is part of the same object as the target of our responses. The second type shows that it is difficult to attend to multiple objects simultaneously (Baylis & Driver, 1993; Kramer & Jacobson, 1991).

One difficulty faced by those wishing to compare object- and space-based models is the simple fact that objects exist in physical space. Two objects will ordinarily be located at greater distance than will information about two characteristics within the same object. Because objects and space covary, the predictions made by the two classes of models will often overlap.

Consider an experiment conducted by Treisman et al. (1983). These authors attempted to discover the costs of attentional filtering in a dual task experiment. They had subjects locate a gap in a rectangle and simultaneously read a briefly presented word. The word was located either inside the rectangle or outside of it on the opposite side of a fixation point. When the rectangle enclosed the word, presumably integrating the two as a single perceptual object, both word reading and gap identification times improved. When the word appeared outside the rectangle, reading and gap detection times suffered. This occurred despite the fact that the distance between the gap in the rectangle and the word were equated across conditions. (In a follow-up study, Kahneman, Treisman, and Burkell [1983] found that the competition between two objects for attention could be eliminated by providing advance information about the target object's location, or by presenting the targets and distractors sequentially [eliminating the need for parsing]).

Consider then, that each of the attentional models described above would predict this effect. A spotlight model would predict better performance when the two stimuli may be processed without moving the spotlight. A zoom lens model would predict the same result for the reason that a smaller, higher resolution beam of attention (which could be used when the box enclosed the word) would facilitate processing. A gradient model would suggest that greater processing efficiency would result from a more compact display. Finally, object-based models would suggest that superimposed stimuli would form a perceptual group/object, and facilitate processing over separated stimuli. Though each model implicates a unique mechanism, all make the same prediction. As a result of this difficulty, great pains have been taken, and several clever research tasks have been devised, to dissociate attention toward objects from attention toward locations. Some of these efforts may be noted in the evidence described below.

Selective attention studies. Selective attention studies, in which subjects are asked to report various object attributes, have supported object-based models of attention.

Lappin (1967) had subjects identify three attributes of objects under three conditions: all three attributes on one object, three different attributes on three different objects, or the same attribute on three objects. As predicted by object-based models, identification was best when all attributes appeared on a single object.

Whereas focused attention results in the processing needed for letter identification, Rock and Gutman (1981) showed that figures not attended cannot be recognized. Recall that subjects viewing overlapping forms could not recognize the unattended form even if it was a familiar shape rather than a novel form. Apparently, focal attention is part of the descriptive process needed for object identification. Where this study supports the notion that such focal attention is directed at objects is in the fact that the two forms overlapped, that is, they occupied virtually the same physical space, and yet not everything in that spatial region was attended or perceived.

The single object advantage. The need to consider the possibility of object-based attention was made most clear in a seminal study by Duncan (1984). In a series of experiments, Duncan used simple tachistoscopic displays of a box with a line bisecting it to test the predictions of object-based models. The box varied in size (large or small) and in the position of a gap in one of its sides (left or right). The bisecting line varied in orientation (tilted slightly clockwise or counterclockwise from vertical) and in texture (consisting of dots or dashes). Subjects were to report two specified dimensions on a single object (perhaps orientation and texture), or one dimension on each of the two superimposed objects (perhaps orientation and gap position). As predicted by object-based models, two judgments about the properties of one object could be made as easily as one, whereas judging two properties from different objects resulted in mutual interference. This again suggests that it is difficult to attend simultaneously to two objects. With the objects being superimposed, and the attributes of the box (its height and the position of the gap) being at least as far apart as the gap in the box and the attributes of the line, it is difficult to account for Duncan's result in purely spatial terms.

Watt's (1988) computational algorithm, called MIRAGE, did offer an alternative explanation for Duncan's (1984) finding, based on the physical nature of the stimuli involved. Watt noted that the relative spatial frequency of the box and the line differed, and that the two-object performance deficit could be a cost of having to attend to both high and low spatial frequencies, rather than to just one band. Since then, however, experiments have been conducted that cannot be reduced to purely stimulus-bound explanations (Baylis, 1994). One such experiment, by Baylis and Driver (1993), will be described presently.

Having provided evidence for attention directed toward perceptual objects, Duncan addressed the problem of defining a perceptual object or perceptual group. Having a group of letters positioned close together might make them a more cohesive group, and might make them easier to identify than randomly located letters. Distinguishing this group of letters from others by presenting them in a different color might further increase the strength of that group. So one way to consider perceptual objects is in terms of a continuum of grouping strength, based on cumulated grouping factors. (This would be the approach taken by Kramer and Jacobson, 1991.)

Duncan suggested a second way to consider perceptual grouping. He argued that visual information is organized in a hierarchical manner. We may consider perceptual objects to exist at various levels of analysis. His analogy was to a skyscraper (global object) that might contain objects at other levels of analysis – a particular floor (row of windows) or a particular window in the building. At higher levels of analysis, these become parts of a perceptual object, rather than objects in their own right. Similarly, given a row of letters containing a group of red and a group of blue letters, perceptual objects might exist on several levels. The entire row might define the global object or group; the set of red letters might define a distinct group; and the individual letters would be considered objects at still another level.

According to this view, directing focal attention toward a display of letters would be facilitated when those letters form a group at a higher level. In Duncan's words, "this might be analogous to paying attention first to a whole object and then 'zooming in' for a closer examination of a particular part" (1984, p. 515). Yet, because identification of each letter requires that we attend serially to each one individually, these processes may still interfere with each other.

The single group advantage. Others have set out to provide a task that would result in differential predictions for space-based and object-based models. To eliminate the confound between spatial proximity and object relationships, Kramer and Jacobson (1991) held constant the spatial separation between elements in their displays, while object relationships were varied. A set of stimuli was created (Fig. 27), consisting of centrally located target lines and various flanking stimuli.

Perceptual groups were created based on the Gestalt principles of similarity and closure (Wertheimer, 1923/1938). Targets were either dotted or dashed lines, with each type requiring a separate response. Observers' task was to make a perceptual discrimination of this central vertical line in a brief display. Flankers were compatible (same) or incompatible (different) with the target lines. In addition, flankers might be contained within the same object grouping as the target, or in separate object groupings, as determined by horizontal contours at the top and bottom of the display. Color coding was used similarly as a grouping factor. Control targets contained no horizontal grouping contours or color coding, so the figural elements in this condition were considered more weakly grouped.

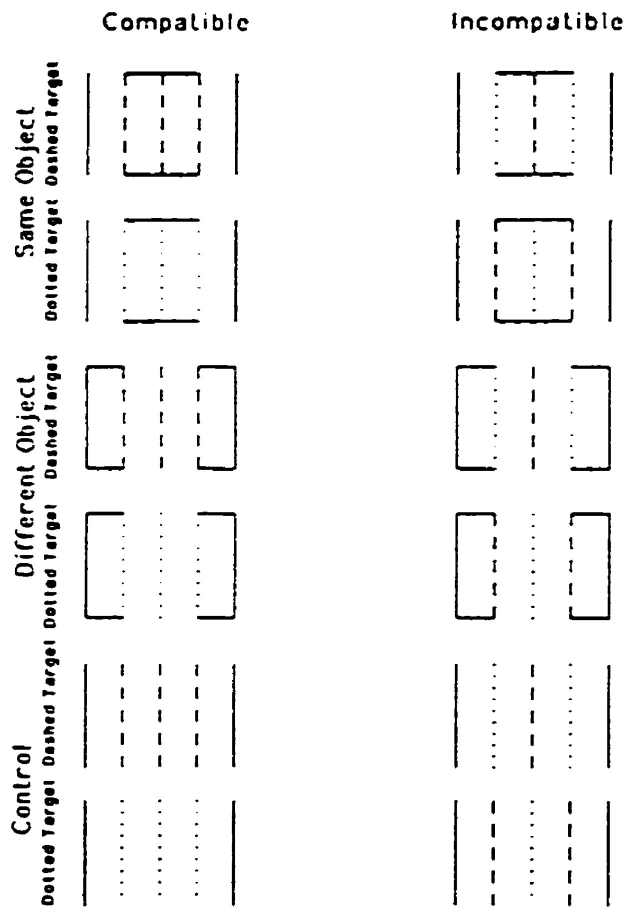


Figure 27. Sample stimuli from Kramer and Jacobson (1991).

Under these circumstances, Kramer and Jacobson claimed, object- and space-based models would make different predictions. An object-based model would predict that, given the fixed spatial separation between elements, disruption by a response-incompatible context would be decreased when flankers and target appeared on separate objects. A space-based model, which relies on proximity to determine selective attention effects, would predict no differences in the magnitude of the response compatibility effect due to the manipulation of target and flankers appearing on the same versus different objects.

A second consideration for Kramer and Jacobson was the nature of perceptual grouping. If grouping were to be viewed as a continuum, the response-compatibility effect should depend on the strength of the grouping in each display. If grouping occurred in terms of qualitatively separate objects or units, little response-compatibility effect should be observed when target and distractors were on different objects, and a large effect should be seen when they were located on the same object.

Thirdly, the influence of spatial proximity was examined. Space-based models hold that any response-compatibility effect (facilitation resulting from compatible context) should decrease with increased separation between target and distractors. Since Eriksen and colleagues (Eriksen & Hoffman, 1972, 1973) had suggested that one degree of visual angle is the minimum focus of attention, displays were created so that distractors were located either .25 or 1.00° of visual angle from the target.

Kramer and Jacobson (1991) reported the following outcomes. Firstly, an incompatible context led to longer RTs and lower accuracy than did response-compatible flankers. Apparently, even when target and distractors are found in close proximity, the object structure of a display determines to a significant degree subjects' ability to focus attention on one part of that display.

Secondly, greater spatial separation between target and distractors improved both performance measures. Proximity did appear to influence attention deployment; as predicted by space-based models, more distant distractors were less effective. Thirdly, the compatibility effect was largest for the same-object condition, smaller in the control condition, and smaller still in the different object condition. This result suggested that perceptual grouping should be considered in terms of a measure of strength rather than as a qualitative distinction. A qualitative model would predict similar small response-compatibility effects in the different object and control conditions, since target and distractors are on separate objects in both conditions. If the graded response compatibility result were interpreted in terms of the strength of grouping between the target and distractors, one sees that, in the different-object condition, distractors would be strongly grouped with the neutral (outermost, solid) flankers, due to their connecting contour and common color. In the control condition, the strength of grouping between the target and distractors would be equal to that between the distractors and the outermost flankers, since connecting contours and colors were absent. In the same-object condition, target and distractors were linked by the connecting contours and color coding. Under Gestalt principles of similarity and closure, target and distractors would be strongly grouped, with the result that response-compatibility or incompatibility effects would be enhanced. The grouping-strength model thus appeared to account for Kramer and Jacobson's findings most parsimoniously.

Kramer and Jacobson explained the decreased response-compatibility effect that resulted from spatial separation between target and distractors according to the principle of proximity. They argued that a decrease in grouping strength could result from the greater (1°) separation of contours, which would result in a decrease in the influence of those distractors. Each of the Gestalt grouping principles of proximity, similarity, and closure was claimed to play a role in this experiment, lending support to the grouping strength model of attention proposed by Duncan (1984). The argument that increased distance between target and distractors reflects a loss of grouping strength rather than a movement out of an attentional spotlight is supported by Driver and Baylis (1989).

Driver and Baylis (1989) also used a variant of the flanker paradigm to argue for the idea of attention based on perceptual groups. They noted that, although Eriksen and Eriksen (1974) showed that the effects of distractor letters diminish as they are moved farther from a target and claimed this as support for a spotlight model, the same result would be predicted by a model holding that attention is directed toward perceptual groups. To test the opposing explanations, Driver and Baylis modified Eriksen and Eriksen's paradigm in the following way. They used horizontal arrays of five letters in which some or all of the letters appeared to move upward or downward on the viewing screen. The central target letter could be flanked by congruent, incongruent, or neutral distractors. Distant distractor letters that moved (or didn't move) together with the target produced more interference (longer RTs) than did near distractors that did not move (or remain still) together with the target. Thus, subjects appeared to attend to the group of letters defined by common movement rather than to those which occupied a contiguous region of physical space.

Baylis and Driver (1992) cast further doubt on the spotlight model's assumption that distractor effects are solely due to their distance from a target (i.e., whether they fall within the attentional spotlight). They showed that, at constant separation distances, distractors that could be grouped with a target by color or by good continuation were more likely to produce interference. This result provided further evidence for the importance of perceptual grouping in directing attention.

As mentioned above, Yantis (1992) claimed that these grouping effects need not be the result of stimulus-driven factors. He demonstrated that perceptual grouping could be goal-directed as well – in this case, based on the subject's attempt to track several simultaneously moving targets. In displays of 10 randomly located objects (plus signs), between 1 and 5 were designated as targets and then all objects moved in a quasi-random manner about the viewing screen. When the movement stopped, (after 4.5 or 7.5 s), one object was probed, and subjects were to determine if that object had been a target. Accuracy was greater when the targets were part of a perceptual group defined by common movement and by convex configuration.

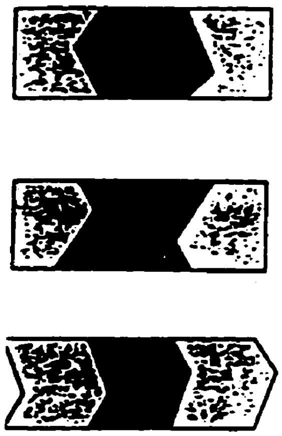
(In Yantis's [1992] discussion of these effects, he drew an analogy between the goal-directed or top-down organization of simple stimulus elements, and the fact that different cultures tend to organize stars into similar constellations. Some constellations, such as the Big Dipper, are universally recognized, although differently labelled. Based on Gestalt principles of proximity, good continuation, and similarity of brightness, we impose a structure onto these randomly-located stars.)

A single object advantage through parsing. Another study demonstrating the effects of goal-directed organization, and a result that cannot be attributed to stimulus factors, was provided by Baylis and Driver (1993). They attempted to replicate Duncan's (1984) finding that information is judged more easily when located on one object than on two. In a clever manipulation, they conducted this test under conditions where the one-object and two-object conditions were physically identical, by using ambiguous displays (e.g., Fig. 28a). These displays could be perceived as one object or two by manipulating subjects' perceptual set to attend to the (one) black or (two) white objects in Figure 28a. Observers' task was to determine the relative height of the two apices appearing at the edges of the solid objects. It was found, as expected by object-based models, that judgments involving two apices on a single object could be made more quickly than could judgments that required comparison between one apex on each of two objects.

In further experiments, Baylis and Driver provided evidence for a hierarchical coding of shape and location. They hypothesized that the location of objects in a scene is determined by a scene-based representation of space. To determine the location of object parts, an object-based representation is produced, and all object parts are located relative to their parent object. Thus to judge two apices (object parts) on a single object requires access only to the one object representation. To judge the relative locations of parts of two distinct objects requires an integrative comparison of the respective scene-based representations and the object representations containing the relevant parts. This should take additional time, as was observed.

Gibson (1994) provided a different account of Baylis and Driver's (1993) finding.

He claimed that the single-object advantage could be accounted for by the fact that the convex region in the center of Baylis and Driver's displays was more likely to be organized as figure and suggested that organization based on this stimulus characteristic was the



A

B

C

Figure 28. Sample stimuli from Baylis and Driver (1993) (Panel A), Gibson (1994) (Panel B), and Baylis (1994) (Panel C).

basis of an apparent single-object advantage. To test this claim, Gibson simply reversed the central contours used by Baylis and Driver (Fig. 28b), which resulted in a concave central region. His results showed faster RTs for the convex two-object judgment than for the concave single object, supporting his claim that convexity was the basis for this advantage.

Baylis (1994) agreed that parsing difficulties might account for some of the RT costs observed in the two-object condition in Fig. 28a or the one-object condition in Fig. 28b. In the latter case, parsing difficulty (seeing the central [black] region as figure) might add enough to a RT measure to reverse the effect. So, Baylis responded by creating displays that were equal in convexity (Fig. 28c). As predicted, RTs in apex comparisons for displays parsed as one object (on the basis of the experimenter's instructions) were faster than for those parsed as two objects. Once again, this result supports a key tenet of object-based theories of attention – that it is easier to attend to parts of a single object than to attend simultaneously to two distinct objects.

Attention to objects and *locations*. Egly et al. (1994) used a precuing paradigm to compare processing within an object with processing of parts of another object set at equal distance. Two outline rectangles were presented to subjects (Fig. 29). One end of one rectangle was cued, and on valid cue trials (75% of trials), that end was "filled in" with a solid square. On invalid trials, the square appeared either at the opposite end of the same rectangle, or at the corresponding end of the *other* rectangle (see Fig. 29, rows A and B, respectively). Having to shift attention to the opposite end of the same rectangle in order to respond resulted in a RT cost. According to Egly et al., a cost occurring when attention is shifted to a new location *within* an attended object reflects a purely spatial component of attentional selection. An even greater cost was found when attention had to be shifted to an equidistant location on *another* object. This reflects the sort of two-object cost previously noted by Duncan (1984) and by Baylis and Driver (1993). Thus, within a single paradigm, components of both space-based and object-based attention were demonstrated.

The studies reviewed in this section indicate that, even when spatial location is controlled or held constant, object-based effects of attention persist. Such results suggest that attentional resources may be directed toward (spatially invariant) object representations, and that the nature of perceptual groups or objects will determine the course of identification processes. Before the space- versus object-based nature of a visual grasp is addressed, one other area of research evidence may be mentioned.

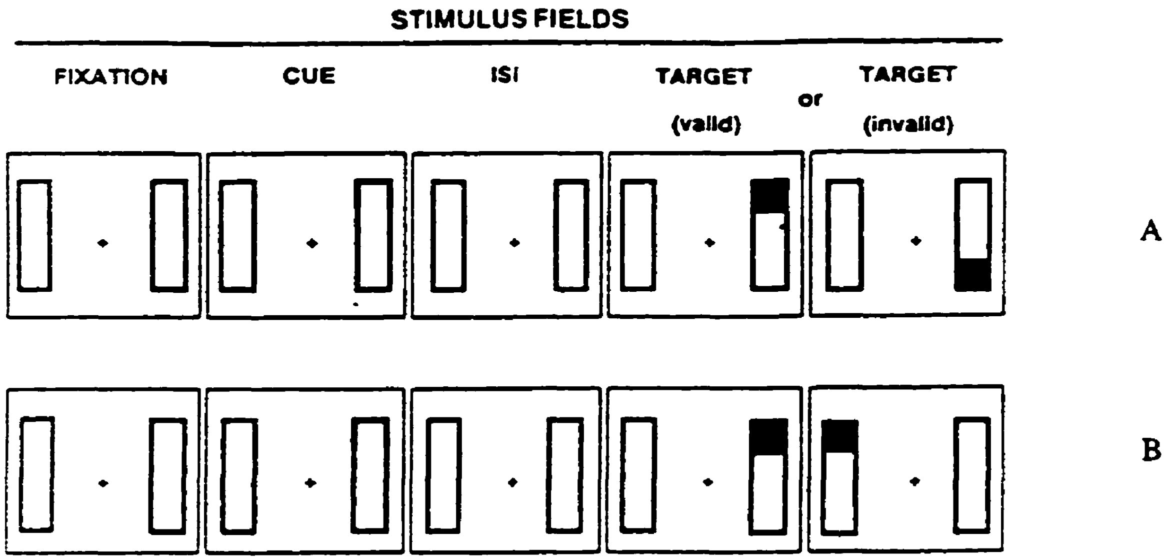


Figure 29. Sample stimuli from Egly et al. (1994).

Neurological evidence. It was noted above that certain neurologically based attentional deficits have been found to be consistent with models of space-based attention. The same claim can be made for object-based models. For example, Farah, Wallace, Brunn, and Madigan (1989) studied object-based effects in patients with unilateral neglect. Recall, this disorder results in the lack of perception of contralesional stimuli. Here, subjects were asked to read randomly located letters on a page. The letters were surrounded (and presumably, therefore, perceptually grouped to some degree) by two ellipses extending across the page – either one on the left and one on the right of the page (i.e., vertically oriented), or one above and the other below (i.e., horizontally oriented).

When an ellipse occupied only contralesional space (i.e., under the vertical orientation condition), patients ignored letters in that ellipse. However, when an ellipse occupied *both* ipsilesional and contralesional space, more contralesional letters were identified. The authors concluded that this spatial deficit could be attenuated by the presence of global object structures extending into the contralesional space.

Driver, Baylis, and Rafal (1992) showed that unilateral neglect can also be affected by the segmentation of a visual scene. They found that when a patient with neglect of the left area of the visual field (due to damage in his right hemisphere) was asked to make figure and ground judgments across the visual field, he made more errors on the left portion of an object located to his right than on the right portion of an object located to his left. This suggested that the neglect experienced by this patient is not simply a neglect of one-half of the visual field, but a neglect of (the left) half of each object to which he attends.

Similarly, Kanwisher and Driver (1992) found unilateral neglect toward perceptual Gestalts. They reported the results of a simple task given to a patient with right parietal damage who, as a result, suffered from left-field neglect. This was evident from a task in which the subject was asked to put a mark through all lines appearing on a page. When the small lines were distributed randomly across the page, omission errors were made for those lines appearing in the left part of the display (Fig. 30a). However, when the lines were grouped into two separate Gestalts, omission errors occurred on the left portions of *each* Gestalt (Fig. 30b). Thus, this attentional deficit may apply to the contralesional side of each object or group in a display (and not exclusively to contralesional *space*). This implies that attention is being directed toward these object representations.

Some of the most convincing evidence for selection based on objects rather than locations comes from patients with Balint's syndrome. The primary characteristic of this disorder, caused by damage to the occipital and/or parietal lobes, is that only one object, the object at the center of attention, is seen at any one time (Humphreys & Riddoch,

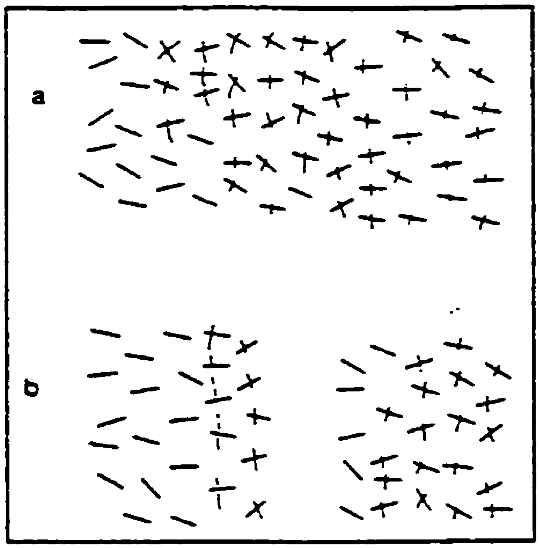


Figure 30. Sample responses from Kanwisher and Driver (1992).

1993). Luria (1959) described a classic case of Balint's syndrome in which a patient perceived a single triangle when two triangles of different color were superimposed, but saw a Star of David when the triangles were presented in the same color.

Humphreys and Riddoch (1993) tested the ability of two Balint's patients to identify whether a display contained only green, only red, or both green and red circles.

Three conditions were employed to test the object-based nature of this attentional disorder (Fig. 31). A *random* condition contained black lines located among an array of red and green circles. In the *single* object condition, the black lines joined circles of the same color. In the *mixed* object condition, circles of different color were joined by the black lines. It was reasoned that if this disorder were due to difficulty in disengaging attention once it is directed at one object (thus the inability to perceive multiple objects in a

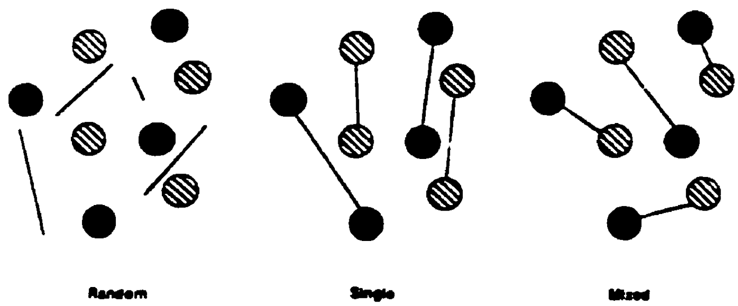


Figure 31. Sample stimuli from Humphreys and Riddoch (1993). Solid circles represent red colored items; hatched circles represent green colored items.

display), then performance here should be better in the mixed object condition, in that this was the only condition where red and green colors were linked in a perceptual object. For both patients, performance was best in the mixed object condition, and about equal in the random and single object conditions. Again, it appeared that the difficulty experienced by these patients occurred in terms of becoming "locked onto" a single perceptual object.

Summary. The evidence for attention being directed toward perceptual objects is strong in that several effects have been demonstrated that are not easily accounted for by current space-based models. The findings by Baylis (1994) on single-object advantages, by Banks and Prinzmetal (1974) on the effects of configuration, and by Kanwisher and Driver

(1992) on the neglect of parts of perceptual objects are convincing.

Still, extensive evidence exists for claims that attention may be *either* space-based or object-based. Indeed, many current authors, in attempting to find evidence for one kind of attention, concede that both may exist in certain circumstances, depending on task demands, and so on (e.g., Baylis & Driver, 1993; Egly et al., 1994). Vecera and Farah (1994) suggested that attention is object-based only when the task requires judgments of shape that use object-based representations. Attention will be space-based under conditions where judgments of color or brightness, which are spatially coded, are to be made. Others have proposed that two separate systems interact -- an orienting system operates to activate certain locations, and a selection system groups features together as perceptual objects that have been identified in the activated locations (Humphreys & Riddoch, 1993; Vecera & Farah, 1994). Recent neurological evidence suggests that distinct attentional pathways, described as dorsal (occipital-parietal) and ventral (occipital temporal) pathways, may exist, and may operate on different types of representations (Humphreys & Riddoch, 1993; Kanwisher & Driver, 1992).

It is proposed that attention, and specifically a visual grasp, is object-based whenever identification judgments must be made of the elements in a perceptual group. Experiment 2 was an attempt to show that this is the case even when such a group appears in a location unexpected by the observer.

7

Experiment 2

RATIONALE

Experiment 1 was intended to support the idea that an attentional phenomenon labeled a visual grasp is employed by observers, and that the processing of external elements prior to more central elements may be influenced by strategic, attentional (i.e., nonstructural) processes. The second facet of this problem is to determine where this attentional process is directed.

In determining an hypothesis regarding the target of attention, I took into consideration the results of the order-of-processing studies (e.g., Merikle et al. 1971; Merikle & Coltheart, 1972), the findings by Pressey and colleagues and by Earhard and Walker (1985) regarding the psychological importance of external contours, and the paradigms in which object-based attention was supported. The question is whether attention is directed to the region of space in which a letter array is to appear, or whether it is directed at the perceptual group or object. I anticipated the latter. Why should object-based attention be expected? Earhard and Walker's (1985) result is most telling: They found that an outside-in strategy was *not* linked to the position of a fixation point, but to stimulus configuration alone.

In Experiment 2, the location of the letter array was altered on various trials. On one-third of trials, it appeared in a central location across fixation, but on other trials it was shifted to the left or right of fixation. This manipulation should influence the identification of individual letters if one assumes object-based attention is operating, but no such influence should be expected if the attentional mechanisms are space-based.

A spatial metaphor such as an attentional spotlight implies endogenous control over the orienting of that attentional beam. A brief exposure duration leaves insufficient time to move and refocus a spotlight of attention, with the result that, if one assumes that such an attentional mechanism is in operation, the most logical strategy must be to widen the focus of the attentional beam and to maintain its central location (i.e., focus across the entire potential array). As a result, no change should occur in the identification of letters based on the location of the letter array. It might be expected that, due to acuity factors, centrally located letters, regardless of their position in a letter array, would consistently be identified more accurately than more peripherally located letters, but the location of the array itself should have no influence on letter identification.

An object-based model of attention might assume that a sudden onset of the stimulus array will be captured by attention directed at the onset object. If attention were directed at this perceptual object, only the relative position of a letter within the sequence should influence its identification. As a result, one could compare the identification of letters appearing in equivalent retinal positions, but in varying row positions as row location is altered. If differences were found under these circumstances, they could be attributed only to attention directed at an object representation. This was the primary comparison in Experiment 2.

Horizontal arrays of six letters were used in this experiment. Ten positions were cued on each trial, with a fixation point located between the fifth and sixth positions, as counted from the leftmost position (see Fig. 32 for examples of stimulus arrangement). Letter displays appeared in positions 3 through 8 on one-third of trials (center condition), in position 1 through 6 on one-third of trials (left condition), and in positions 5 through 10 on one-third of trials (right condition). In each condition, positions not containing letters contained cue stimuli. All displays were masked as in Experiment 1.

A preliminary hypothesis reflected results expected on the basis of Experiment 1. Specifically, it was predicted that

(1) the position of letters in an array will influence identification scores. Letters appearing at the end of a row will be identified more accurately than those located more centrally.

Attention directed toward objects versus attention directed at regions of space would result in differing predictions for some individual items in the array. Consider a letter appearing in position 5. If one assumes attention is directed toward the spatial region occupied by these displays, one would predict uniform identification performance across conditions, because the letter remains in the same retinal position. However, if attention toward perceptual objects is assumed, then, based on the selective masking effects found in previous studies (including Experiment 1 above), relatively poor identification would be expected for this letter in center and left conditions, since it falls in central row positions, but good identification performance would be expected under the right condition, since position 5 is here a row-end position. A similar expectation may be made for position 6. If attention is directed to objects, then attentional effects such as row-end superiority should be found for letters on the periphery of these perceptual objects. It is proposed that visual grasp is an object-based strategy. Therefore, the hypothesis of greatest interest in Experiment 2 was that

(2) identification scores for letters in positions 5 and 6 would be superior when these letter positions fell at the end of row displays than when these letters fell at central positions within rows of letters.

METHOD

Participants

Sixteen introductory psychology students recruited from the same pool as those in Experiment 1 served as participants. All earned course credit for participation. All had normal or corrected-to-normal vision as indicated by self-report and by a brief letter identification test (as in Experiment 1).

Materials

The pre-exposure field consisted of a horizontal row of open squares indicating potential letter positions. The squares were colored light blue and were slightly larger than the letters that followed, in order to minimize any possible masking effects in this field.

One hundred forty-four letter sequences were displayed, each containing six random consonants taken from the set indicated in Experiment 1. Sequences were constructed so that each letter appeared in each row position three times with each row location condition, and no letter appeared twice in a given row. Letters were black on a white background. The visual angle subtended by the 10-item row was approximately

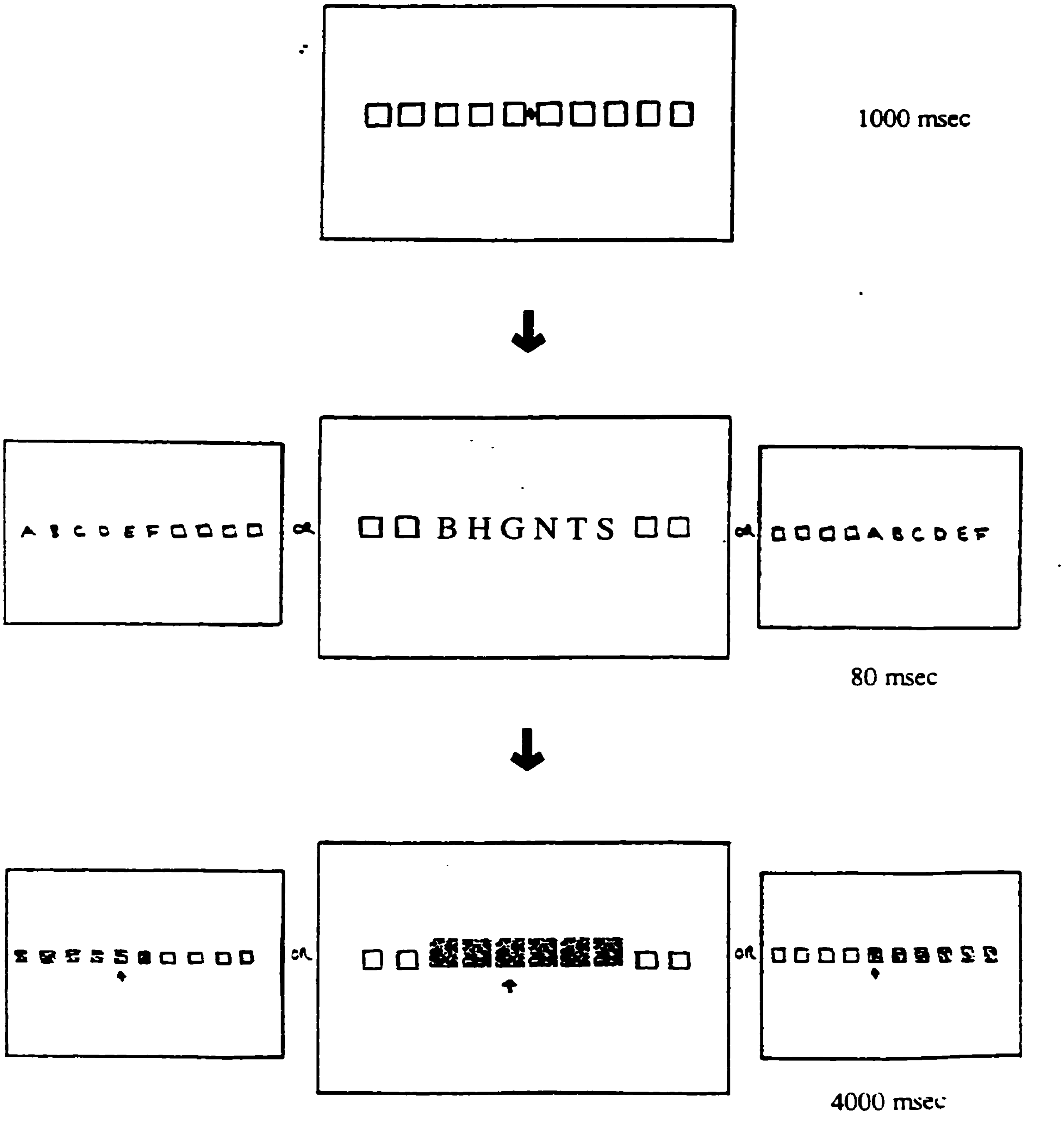


Figure 32. Sample stimulus displays for Experiment 2 (not to scale). Outline squares appeared light blue in color.

5.20°. In each letter display, the four positions not occupied by letters contained blue squares identical to those from the pre-exposure field.

Mask stimuli consisted of six small masked regions corresponding to the six letter positions displayed (identical to those employed in Experiment 1), plus four of the light blue squares used as cues in the pre-exposure field. Thus, within each mask display, all 10 positions were occupied.

The order of presentation of the 144 sequences was identical for all participants, but the position probed in each sequence was randomized, with the restriction that each position was probed twice in every 12 trials within each row location condition. This procedure ensured that each letter position was probed eight times within each row location condition.

Procedure

The general procedure was modeled after Experiment 1. The pre-exposure field (10 squares) appeared for 1000 msec, followed immediately by the letter display for 80 msec. A slightly shorter exposure than in Experiment 1 was warranted due to a smaller stimulus set, and the necessity to restrict possible changes in the orientation of attention. Letter displays were followed by the mask and probe display for 4000 msec, during which time participants made a verbal response.

RESULTS

Experiment 2 involved two within-subjects independent variables: Row Location, having three levels (Left, Center, and Right) and Letter Position (six positions are sampled within each row location). The accuracy of letter identification was once again the sole dependent variable. A 3 x 6 repeated-measures ANOVA was used to confirm a main effect of Letter Position, $F\ (5, 75) = 46.64$, $p < .0001$. As anticipated, letters at row ends were consistently identified more accurately than letters within rows (see Table 3). Once again, this outcome was taken as support for a visual grasp phenomenon.

The interaction between Letter Position and Row Location was not expected to reach significance, on the basis of a purely object -based account of visual grasp. Position within a row (Letter Position) would be expected to be the only determinant of identification accuracy, with no influence of the location of the global object (Row Location) expected. However, this interaction was significant, $F\ (10, 150) = 6.49$, $p < .0001$). Outermost positions and Position 5 were identified best in the Left row condition, whereas other interior letters were identified most accurately under the Central row condition.

Table 3

Proportions of correct identifications at each letter position across three levels of Row Location.

	Letter Position									
Row Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Left	.73	.15	.08	.18	.34	.70				
Center			.70	.31	.23	.21	.19	.45		
Right					.60	.32	.16	.16	.14	.42

The main effect of Row Location was also significant, F (2, 30) = 5.28, p = 0.01. Generally, letters were identified most effectively in the Left row location, less well in the Central location, and least well in the Right location. Marginal proportion means were .36, .35, and .30 for the Left, Central, and Right locations, respectively.

The effect of the row location manipulation on specific letter positions was examined. As indicated, Positions 5 and 6 were of particular interest because these two letter positions fall at the outer edge of a perceptual group in some displays (left row location for Position 5 and right row location for Position 6) and at more central positions in other displays, even though they remain in constant retinal positions. If identification scores differed due to these items' position within a row, it would indicate that this object-based factor is important in determining letter identification, and would thus suggest that attention is being directed toward an object representation.

To assess these effects, simple repeated-measures ANOVAs were conducted on identification scores for Positions 5 and 6 (separately), across three levels of Row Location (left, central, and right). Significant effects of Row Location would indicate that identification of letters in Positions 5 and 6 depends on where those positions fall within a row. The specific prediction made on the basis of the visual grasp concept was that, when a letter in Position 5 or 6 appears at the end of a row of letters, it will be identified more accurately than when that position falls within a row. Significant effects of Row Location were confirmed (for Position 5: F (2, 30) = 28.03, p < .0001; and for Position 6: F (2, 30) = 21.25, p < .0001).

DISCUSSION

Experiment 2 addressed the nature of visual grasp, that is, whether this effect is a phenomenon of object- or of space-based attention. The ends-first effect was confirmed, as outermost letters in a row were identified most accurately, regardless of the row's location in the visual field.

Of greater interest was the effect of row location on particular letter positions. Specifically, would letters in Positions 5 and 6 be identified more accurately when they happened to be outermost row positions than when they were interior row positions? They were. In Table 3, one can see that for both positions, best performance occurred when that position was at a row end. Performance was least when Positions 5 and 6 were most centrally located within a row. This outcome supports the idea that visual grasp makes outermost elements of a perceptual object available for identification before interior elements become available. It further suggests that a letter's position within the visual field is *not* the crucial factor in determining whether it will be identified, as would be suggested by a space-based account of visual attention (Broadbent, 1982; Eriksen & Eriksen, 1974).

One outcome not expected here was the difference in scores across outermost letter positions in the various row location conditions. It was anticipated that these scores would be uniform across conditions, but a clear decline was observed as row location shifted from left to center to right. As proposed following Experiment 1, a tendency to scan, or to be prepared to scan, from left to right may be responsible for this outcome. In previous research (Bryden, 1966; Heron, 1957), this tendency was claimed to result in declining accuracy functions from left positions to right, just as was observed here for the outermost letter positions.

8

Perceptual Organization

ATTENDING TO PERCEPTUAL GROUPS

I have suggested that if a visual grasp is an attentional phenomenon, it may be directed toward perceptual objects, and that this is likely to occur when identification of an entire array (or judgment of an entire stimulus) is required. It has been claimed that perceptual groups or objects are formed on the basis of Gestalt grouping principles (e.g., Prinzmetal, 1981). It follows that, if more than one perceptual group exists in a stimulus array, a visual grasp may be applied toward *each* of these groups.

The relevant evidence supporting this view comes from a series of studies reported by Kahneman and Henik (1977, 1981). Their research was based on Kahneman's (1973) capacity theory of attention, which included an assumption that attention is allocated on the basis of the output of early (preattentive) perceptual analyses. Kahneman called this the *unit formation* stage, and argued that once such perceptual units are formed, they provide the targets of further processing efforts. The theory also proposed that attention can be allocated to groups that are identified during unit formation, but not to individual elements within such a group.

In 1977, Kahneman and Henik sought to examine the effects of perceptual grouping on the recall of briefly presented items. They manipulated grouping through similarity or proximity (by presenting items in groups based on color, or by including a gap in a horizontal row of digits). In the latter case, subjects viewed random sequences of six digits, six digits plus a suffix (the letter K), or seven digits. Displays were presented for 200 msec, and were not masked. Subjects responded by writing all digits recalled from the display (i.e., full report). Table 4 indicates the percentages of correct responses based on display type and digit position.

Table 4. Percentage recall for digits in each digit position as a function of display type (from Kahneman & Henik, 1977).

Kahneman and Henik noted especially the homogeneity of performance within each perceptual group. Whereas wide differences occurred in the report of digits from different groups, recall of digits within a group was generally uniform. They suggested that this reflects the equal allocation of processing resources to all items in a group; whereas differing recall across perceptual groups indicates that differential resource allocation occurs across those groups.

It was noted also that recall of items from any group tended to occur in an all-or-none fashion. This effect was explained according to the hierarchical distribution of attention – first to perceptual groups, and then to individual items for the purpose of identification (recall this notion was reflected by Duncan [1984] in explaining object-based effects).

Finally, the addition of the distractor letter K in some displays was expected to decrease the recall of other items in that group, but not to affect recall from other groups, and it did just that. This was explained as a consequence of limited processing resources being distributed over an increased number of elements, even though one of those elements was an irrelevant distractor.

The results indicated in Table 4 are not readily explained by an appeal to stimulus factors such as retinal position or lateral inhibition among elements in the array, although the model of letter identification proposed by Wolford (1975) suggested that such factors were crucial in understanding letter recall effects. Kahneman drew attention to the comparison between the fifth digit position in configurations A1 and A2. The retinal position relative to fixation for this item is identical in each display, and in A2, the item has neighbors on both sides, whereas in A1, the item has only one neighbor. As a result, a lateral inhibition account would predict poorer performance under configuration A2 than under configuration A1. A group processing model would predict the opposite. Fewer processing resources are used by the first group in A2 (it is smaller than the first group in A1). Therefore more resources remain to process the second group in A2, and because those resources are shared equally, performance should be better for item 5 in A2 than in A1. As seen in Table 4, the group processing interpretation was supported.

9

Experiment 3

RATIONALE

If attention is directed toward perceptual groups in a display, then a strategy such as visual grasp could be expected to be applied to those groups. Experiment 3 was intended to explore this possibility.

Kahneman and Henik (1977) made a strong point regarding the homogeneity of resource allocation (and the resulting pattern of recall) within each perceptual group in their arrays. A closer look at Table 4 may suggest that items were not recalled in a completely uniform manner. It appears that, for each group consisting of four items, the first and last item in the group were recalled better than items centrally located within these groups. (Whether these differences were significant or not is uncertain, as Kahneman and Henik do not mention whether these differences were analyzed.) It may be that with a relatively long exposure duration (200 msec) and no stimulus mask following the digit displays, the results of a visual grasp process were attenuated in this study.

A second consideration is the use by Kahneman and Henik of a full report measure. As indicated by the order of processing studies above, full report measures of accuracy generally show a declining function from left to right in an array. Kahneman and Henik did measure "outsize groups" (containing 5- or 6-item rows) and noted a declining accuracy function after the first three items. Kahneman's interpretation was that subjects have a strong tendency to group items of an array even when the physical structure of the display doesn't promote group parsing. He said that observers appear to group the first three items together, and possibly group any remaining items in some flexible way. It was concluded that effective group sizes involve no more than four separate items. An alternative interpretation is that, as the order of processing studies indicated, the use of a partial report measure may provide a different view of which items are most likely to be available to an observer.

Displays in Experiment 3 were similar to those used in Experiment 1, but reflected Kahneman and Henik's grouping efforts. Color was used to distinguish groups of 3, 4, or 5 letters within 8-letter rows. The unique hypothesis for Experiment 3 was that

(1) identification of the fourth and fifth letters in such an array will be better when those items represent the outer elements of a perceptual group than when they fall within (toward the center) of such a group.

Note that this hypothesis does not contradict the idea that attention may be hierarchically allocated to separate perceptual groups, but it does suggest that a visual grasp strategy may operate *within* such an allocation.

METHOD

Participants

Sixteen additional participants from the introductory psychology pool were

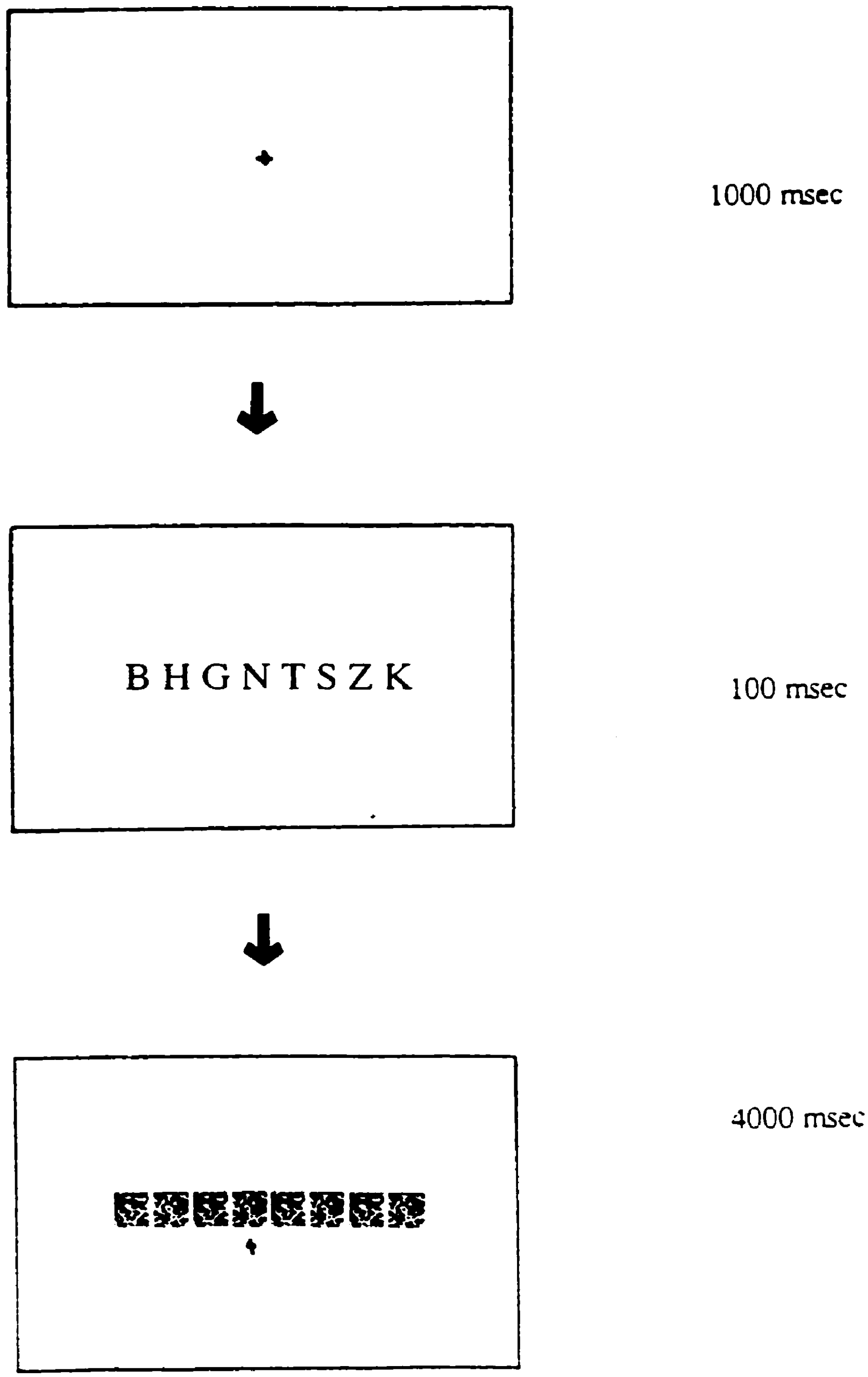


Figure 33. Sample stimulus displays for Experiment 3 (not to scale).

recruited for this experiment and received course credit for their participation. Each had normal or corrected-to-normal vision, as determined by self-report and a brief identification task (in which they were asked to read all letters from one sample row, and only the red letters from a second row).

Materials

Stimulus materials were as described in Experiment 1, except that letters in each display were colored red and blue. Of 256 letter sequences, 32 contained three red letters (Positions 1 to 3) and five blue letters (Positions 4 to 8) (the 3-5 condition), 32 had four red letters (Positions 1 to 4) and four blue letters (Positions 5 to 8) (the 4-4 condition), 32 had five red letters (Positions 1 to 5) and three blue letters (Positions 6 to 8) (the 5-3 condition), and 32 contained all red letters (the 8-0 condition). In addition, 32 sequences in each condition were created with blue and red colors reversed from the positions indicated above. (See Fig. 33 for a sample display sequence.) This arrangement resulted in 32 potential letter conditions (8 Letter Positions x 4 Grouping conditions). Each letter condition (e.g., Position 2 in the 3 - 5 arrangement) was probed eight times for each participant. The position probed in each sequence was selected at random with the restriction that each position was probed twice in every 16 trials within each grouping condition.

The mask stimulus was as indicated in Experiment 1, and appeared black on a white background.

Procedure

Instructions to participants mimicked the Random condition in Experiment 1.

Although the color of the letters was acknowledged, no mention of the relevance of red and blue grouping was made.

The order of stimulus presentation, including mask, remained as in Experiment 1 -- a black fixation cross displayed for 1000 msec, followed by the letter display for 100 msec, followed by the mask and probe stimulus for 4000 msec.

RESULTS

Experiment 3 employed a within-subjects design, having Grouping (four levels as indicated above) and Letter Position (eight positions within each Grouping condition) as independent variables. Identification accuracy was the dependent variable. As expected, an overall repeated -measures ANOVA revealed a significant main effect of Letter Position (F (7, 105) = 94.09, $p < .0001$). As seen in Table 5, outermost letter positions resulted in superior identification performance, whereas little difference was observed in the identification of various interior letters. The one exception was for letters in Position 5, again, the first letter following the fixation point. These letters were once again identified more precisely than those in any other interior letter position.

Of greater interest in this experiment was any difference in performance as a main effect of perceptual Grouping. [Such a difference might support the notion of hierarchical allocation of attention as proposed by Kahneman and Henik (1981) and by Duncan (1984).] Contrary to predictions, no overall effect of Grouping was revealed by this ANOVA, F (3, 45) = 0.74. Likewise, the Grouping by Letter Position interaction was not significant, F (21, 315) = 0.93.

The individual letter positions of interest in this experiment were Positions 4 and 5.

Table 5

Proportion of correct identifications at each letter position as a function of Grouping condition.

Grouping Condition	Letter Position 1	2	3	4	5	6	7	8
3 - 5	.88	.16	.07	.08	.23	.16	.16	.43
4 - 4	.90	.16	.13	.09	.18	.09	.15	.50
5 - 3	.91	.17	.08	.05	.25	.11	.10	.51
8 - 0	.92	.16	.08	.09	.14	.09	.13	.41
M	.90	.16	.09	.08	.20	.11	.13	.46

Separate simple repeated-measures ANOVAs were conducted on Position 4 and Position 5 data across the four levels of Grouping. Under some of these conditions (specified above), these letter positions represent ends of perceptual groups (defined by color); in others, these letter positions are interior group positions. A main effect of Grouping would indicate that a letter's position within a color group influenced its identifiability. Though it was hypothesized that letters at the ends of perceptual groups would be identified more accurately than those within the color groups, neither simple ANOVA revealed an effect of Grouping. For Position 4 data, F (3, 45) = 0.37; for Position 5 data, F (3, 45) = 1.63.

DISCUSSION

The dominance of outermost letter positions in processing order was evident again in Experiment 3. The overall pattern of responses was similar here to that observed in Experiments 1 and 1A, that is, the leftmost position was identified most accurately, followed by the rightmost position, the fifth letter position, and remaining interior row positions.

Groups created by color differences did not lead to significantly different identification scores at the edges of those perceptual groups. Although slight differences between group-end and non-group-end conditions did occur in the expected direction (.085 for Position 4 group-ends vs. .070 for non-group-ends; .215 for Position 5 group-ends vs. .185 for non-group-ends), these differences did not reach statistical significance.

The reason for the failure of the color grouping manipulation may have been revealed by the observers themselves. During debriefing, several observers commented that they really had not noticed the colors of the letter sequences as they concentrated on identifying letters. As a result, the letter colors could not be expected to have much influence. It was reasoned that, if all an observer can process effectively in a masked 100 msec display is the identity of outermost letters, then perhaps a display of longer duration would allow differences due to color grouping to become apparent. This was the approach taken in Experiment 3A.

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Experiment 3A

RATIONALE

The failure of the grouping manipulation in Experiment 3 led to a consideration of the nature of perceptual grouping effects. Most theories of object recognition have been based on the assumption that organizational processes must occur before objects may be recognized (e.g., Hebb, 1949; Rock, 1975). According to Peterson and Gibson (1994), there are two reasons for this assumption. The first suggests that early organizational processes must depend on factors that can be computed directly from the current stimulus array and can operate before higher-level operations such as contributions from memory that lead to object recognition. A second reason for assuming that organizational or segregational processes must occur early in visual processing is that the computations involved in object recognition would be complex to the point of being impossible unless prior processes like those of segregation could reduce that complexity to a significant degree. Thus, it has been held generally that organizational processes must occur before object recognition begins.

Contrary to this position, Peterson and Gibson (1994) provided evidence that some object recognition processes may occur prior to organizational processing. Specifically, they found that regions denoting recognizable shapes were identified as figures more quickly than those same shapes were when inverted in a task requiring subjects to segregate figures and grounds. Similarly, Mack et al. (1992) found that typical Gestalt grouping influences are absent if the stimuli in question are not consciously attended.

What is important about these results for present purposes is that they suggest that some grouping or organizational processes may not occur until somewhat later in perceptual processing. If the segregation of letters into color groups does not occur in the first few milliseconds of observation, it would explain the absence of a Grouping effect in Experiment 3. For Experiment 3A, it was considered that a longer duration of exposure for the letter sequences might result in a greater impact of grouping those letters by color. The same hypothesis regarding the effect of color grouping was maintained, namely that

(1) identification of letters in the fourth and fifth positions will be more accurate when those positions represent the ends of a perceptual group than when those positions are central letters within such a group.

METHOD

Participants

Participants were 16 students of introductory psychology from the University of Manitoba. Each had normal or corrected vision as determined by self-report and a brief letter-identification task.

Materials and Apparatus

All testing materials and apparatus were identical to those used in Experiment 3.

Procedure

The only change in procedures from Experiment 3 was in the duration of letter sequence exposures. Here, this duration was increased to 300 msec.

RESULTS

A 4 (Grouping) x 8 (Letter Position) within-subjects design was used, and identification accuracy was the dependent measure. Table 6 provides a summary of the proportions of correct identifications.

As in the previous experiments, the main effect of Letter Position was significant, $F(7, 105) = 19.10$, $p < .0001$. Outermost letters continued to be identified most accurately. There was, however, a surprising effect regarding the effects of letter position. With the longer display duration relative to Experiment 3 (300 msec rather than the

Table 6

Proportion of correct identifications at each letter position as a function of Grouping condition.

Grouping Condition	Letter Position 1	2	3	4	5	6	7	8
3 - 5	.84	.27	.27	.49	.49	.28	.26	.58
4 - 4	.85	.23	.28	.38	.57	.36	.25	.63
5 - 3	.84	.25	.23	.30	.52	.34	.27	.64
8 - 0	.84	.28	.31	.38	.52	.30	.31	.56
M	.84	.26	.27	.39	.53.	32	.27	.60

previous 100 msec), identification scores were improved for each letter position *except* the first (leftmost) position. In addition, letters in Position 5 were identified more effectively than those in any other interior letter position. Here, Position 5 scores approached those for Position 8.

One-way ANOVAs were conducted on Position 4 and Position 5 data, independently. Grouping (4 levels) was the independent variable of interest. Scores for Position 5 did not differ significantly due to Grouping condition, although the small difference that did occur was in the expected direction (an average proportion correct of .545 for group-end conditions vs. an average of .505 for non-group-end conditions). The one-way ANOVA for Position 4 scores did show a significant difference due to Grouping condition, F (3, 45) = 6.10, p = .0014. A follow-up comparison considering average Position 4 scores at group ends versus average Position 4 scores when those letters appeared within groups also revealed a significant difference, t (15) = 3.37, $p < .05$. Thus, letters at group ends could be identified more effectively, supporting the idea that a visual grasp may be directed toward individual color groups.

One other note may be made in reference to the data shown in Table 6. The highest scores for Position 4 letters were found for condition 3-5: 3 red (or blue) letters followed by 5 blue (or red) letters. The highest scores for Position 5 letters were under condition 4-4: (4 red (or blue) letters followed by 4 blue (or red) letters. Each of these conditions represents a situation where that best-identified letter is the *first* letter in its

DISCUSSION

Most significantly, the results of Experiment 3A provide some evidence that the perceptual organization of a stimulus may influence the identification of its individual elements. Letters appearing at the ends of individual perceptual groups may be identified more effectively than those appearing in central group positions. For perceptual grouping to produce this effect, sufficient time must be allowed to process individual groups.

Other results of Experiment 3A confirmed effects observed in Experiments 1 and 1A. Whereas row-end letters were still identified most effectively, scores for Position 5 letters were not far below those of Position 8. Again, the higher performance at this central position may reflect a narrower focus by some observers on the central fixation cross, and the initiation of processing from that point. At 300 msec exposures, the mask stimuli appear to be losing their effectiveness on outermost and central positions. In terms of overall processing order, it may be that outermost letters, and then foveal letters, hold priority. The lack of a significant effect of grouping on Position 5 scores may be a result of the high overall identification scores. Presumably, the influence of perceptual grouping is reduced when stimuli are no longer being masked effectively - the task of identifying Position 5 items may simply have become straightforward enough that perceptual grouping characteristics are no longer needed or used as an aid to identification.

Secondly, as reported above, highest cell means for Positions 4 and 5 were found under conditions where those letters were in the first position of their respective color groups. Once again, this suggests the influence of a left-to-right scan of letters (Heron, 1957), even within the individual color groups. Thus, several factors may be influencing overall identification performance. A visual grasp may combine with a tendency to read (scan) letters from left-to-right to produce the observed pattern of identification scores.

One unexpected outcome was the reduced performance for letters in Position 1. It was anticipated that, with longer exposure durations, scores should be elevated relative to those in Experiment 3. It was believed, in fact, that scores for outermost positions might reach ceiling levels. Whereas higher identification levels were observed in all other letter positions, this did not occur for Position 1. It might be speculated that, with increased exposure time allowing for the possibility of eye movements, many observers attended more directly to positions other than the first position, because they became aware that other positions are "harder to see." That is, observers may have focused elsewhere because they *could* focus elsewhere under these conditions, and thereby improve their overall performance.

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Experiment 3B

RATIONALE

Experiment 3A demonstrated that, given sufficient time to process color groups, the structure of those groups could influence identification of group elements. However, this outcome was apparent for only one subset of letters taken to be of greatest interest. The identification of Position 4 letters improved when they were group-end letters; scores for Position 5 letters did not.

Experiment 3B attempted to increase the salience of the perceptual groups to determine whether this factor could more strongly influence identification scores at group ends. One way to increase the perceptual salience of a letter's color would be to require observers to *identify* that color along with the letter's identity. This was the approach taken in this experiment. Hypotheses for Experiment 3B remained identical to those in Experiment 3A.

METHOD

Participants

Participants were 16 additional introductory psychology students from the University of Manitoba. Each received course credit for participation. Each had normal or corrected vision according to self-report and a brief letter identification task.

Materials and Apparatus

A subset of the stimuli used in Experiments 3 and 3A was employed. One-hundred twenty-eight of the 256 letter sequences were used, resulting in 16 sequences having 3 red letters (in Positions 1 to 3) and 5 blue letters (in Positions 4 to 8), 16 sequences having 4 red letters (in Positions 1 to 4) and 4 blue letters (in Positions 5 to 8), 16 sequences having 5 red letters (in Positions 1 to 5) and 3 blue letters (in Positions 6 to 8), and 16 sequences having all red letters. An additional 16 sequences in each condition above had red and blue colors reversed from the positions indicated above. Each of the 32 potential letter conditions was probed 4 times for each participant. All other materials and apparatus remained identical to those used in Experiment 3.

Procedure

The procedure was equivalent to that of Experiment 3A, with the exception that participants were instructed to respond to probes with both the identity of the probed letter and its color. Both the response letter and its color were recorded by the experimenter.

RESULTS

Experiment 3B used a within-subjects design having four levels of Grouping and eight levels of Letter Position as independent variables. Because color responses were made with 99% accuracy across conditions, only identification accuracy was analyzed as a dependent measure. Table 7 shows proportions of correct identifications made under various grouping conditions.

An overall repeated-measures ANOVA revealed the expected main effect of Letter

Position, F (7, 105) = 13.06, $p < .0001$. Outermost letters continued to be identified most often, although identification scores for Position 5 were equivalent to those for Position 8. No other effects were significant in this analysis.

Table 7

Proportion of correct identifications at each letter position as a function of Grouping condition.

Grouping Condition	Letter Position							
	1	2	3	4	5	6	7	8
3 - 5	.78	.22	.25	.55	.58	.36	.23	.63
4 - 4	.84	.20	.28	.42	.67	.42	.27	.64
5 - 3	.84	.22	.22	.28	.56	.42	.34	.64
8 - 0	.80	.19	.33	.44	.64	.36	.23	.56
M	.82	.21	.27	.42	.61	.39	.27	.62

Separate one-way ANOVAs having Grouping (four levels) as an independent variable were conducted on cell values for Position 4 and for Position 5. The ANOVA for Position 4 showed a significant effect of Grouping condition, F (3, 45) = 4.36, $p = .009$, and a follow-up comparison of average Position 4 scores at group ends versus average Position 4 scores within groups revealed a significant increase in group-end scores, t (15) = 2.39, $p < .05$. Once again, the one-way ANOVA on Position 5 scores revealed no significant effect of grouping.

DISCUSSION

Experiment 3B confirmed that the creation of separate perceptual groups within a letter array can affect the identification of letters in that display (Kahneman & Henik, 1977). Letters at the edges of displays are, in some cases, identified more accurately than letters in the same retinal position that do not fall at the edge of a perceptual group. This outcome supports the idea that a visual grasp operates on the perceptual objects that appear within our visual fields.

At the same time, however, asking observers to report the color of probed letters did not appear to increase the perceptual salience of those letters or their color groups. The overall pattern of responses appears to be very similar to that in Experiment 3A. In comparing Tables 6 and 7 (especially in terms of the mean scores for each letter position across grouping conditions) one may see that scores for leftmost positions continue to decline slightly, whereas small increases are observed for central positions (Positions 4, 5, and 6). These *are* positions corresponding to the edges of color groups, but the overall impact of color naming was quite small.

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General Discussion

THE NATURE OF A VISUAL GRASP

Is Visual Grasp an Attentional Phenomenon?

A series of six experiments was conducted to explore three questions regarding the nature of early visual processing, or more specifically, of a visual grasp phenomenon. Experiments 1 and 1A demonstrated clearly that, given a horizontal row of letters followed by a post-mask, observers are able to identify the first and last letters effectively, and to a greater degree than interior letters. This conclusion replicated Merikle's findings (e.g., Butler & Merikle, 1973; Merikle et al., 1971) and suggests that letters at row ends are identified accurately because their processing is completed before processing of other letters - and before a post-mask stimulus can be effective in inhibiting that processing.

Although it was hypothesized that a visual grasp was an attentional phenomenon, the results were not strong in support of such an assertion. A subtle instructional manipulation in Experiment 1 had no effect on observers' ability to identify letters in central row positions, and presumably, on observers' attention deployment. Even a more direct instructional manipulation in Experiment 1A failed to produce a change in identification scores over the central letter positions as a unit, although tests at individual letter positions did show differences.

These results recommend a different view of visual grasp than that which was hypothesized (an endogenously-guided process). One possibility is that visual grasp may result from structural aspects of our visual systems. As such, processes involved in object identification should operate in a highly consistent manner, invariant to changes in an experimenter's instructions or an observer's intent. Although this consistency was observed to a large degree, instructions in Experiment 1A directing observers toward interior or exterior parts of the display *did* produce differential processing of the first letter and the first letter following central fixation.

Another alternative view of visual grasp may be taken from the work by Merikle and Glick (1976) and more generally, by that of Haber and Standing (1969). These authors proposed that identification of letters at various row positions was based on the stimulus characteristics or stimulus quality of those letters. Perhaps end letters were identified effectively because of reduced lateral inhibition from neighboring letters (in that end letters had only one neighbor to provide interference rather than one on each side). A letter appearing near the point of fixation may have been identified well due to increased foveal acuity at that location. Whereas this view of the differential identifiability of letters is consistent with the results of Experiments 1 and 1A, it does not explain outcomes for individual letter positions in Experiments 3A and 3B.

A third possibility is that visual grasp *does* reflect an attentional phenomenon, but one which is more automatic than voluntary. It may be that stimuli such as letter strings which are flashed onto a viewing screen capture attention exogenously. Yantis and Jonides (1990) described a mechanism by which abrupt onset stimuli can capture attention in a way that is at least partially automatic. They noted that, when an observer is highly focused on a particular location, an abrupt onset elsewhere may lose its effectiveness to capture attention, but for observers in the current experiments, being aware that several letters would be displayed and not knowing precisely which would be probed, such a focused state would be an unlikely strategy.[3]

It is reasonable to suppose that the somewhat automatic capture of sudden onset stimuli reflects an early stage of object recognition processes. To deal effectively with one's visual environment, one must have a sense of what objects exist there, and of what events or opportunities or threats a newly-appearing object might represent. That such an object is processed beginning from its outermost contours or elements is also reasonable, as Earhard and Walker (1985) suggested, in that those outer boundaries define the size and shape of the object and direct further processing to the appropriate locations.

What situations would prompt the capture of our attention? Here I believe we may appeal to stimulus characteristics for an answer. If we are to argue that no voluntary action has occurred on the part of an observer to direct processing resources toward a particular location or some object, then some feature of the stimulus itself must be considered to promote capture. It may be argued that relative *salience* is the characteristic that sets one perceptual object apart from others and leads to its exogenous capture. Consider characteristics that appear to have prompted attentional capture in this series of

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[3] It is possible that some observers did focus their attention quite narrowly on the cross appearing in the pre-exposure field, and maintained attending to that position. These observers may have been those who demonstrated lower scores at end positions and higher than average scores at foveal letter positions. Still, most observers did not appear to employ this strategy.

experiments (or at least, have resulted in elevated identification scores): sudden onsets, positioning at one end of a sequence: positioning at one end of a color group. A sudden onset is clearly a salient perceptual event, especially compared to a non-onset stimulus. The effectiveness of an onset to capture attention is well documented (e.g., Yantis & Jonides, 1984; 1990). An item at the end of a display is salient given that it signals a boundary for that perceptual object. Likewise, a group-end letter becomes salient in that it forms a boundary. A visual system that inherently strives toward organization and interpretation of vast amounts of visual information must recognize these boundaries as important sources of information (Pomerantz, 1981). This *must* make items in these positions more likely to be processed extensively for identification.

If one is to make a case for the exogenous capture of attention directed toward sudden onset letter rows, one still must account for the fact that letters may be attended (processed) with greater or lesser efficiency when instructions require a change of focus toward interior or exterior letters. This outcome suggests that voluntary (endogenous) attention based on task demands may modulate the exogenous capture of attention (Yantis & Jonides, 1990). Thus, an observer may attend more to a central fixation point when he/she knows that central letters are more likely to be probed. This would be expected to result in better identification scores for letters at the fixation point. Likewise, when instructed that exterior letters are more likely to be probed, an observer may voluntarily attend more to those letters, producing increased performance at the leftmost position.

Thus two modes of attention are implicated – one directed at objects and probably automatic or exogenous, and one directed at spatial locations and voluntary or endogenous – and the two may interact to produce the effects observed in Experiments 1 and 1A. As reported in the introduction to this paper, the notion of multiple forms or modes of attention is not unique. Theeuwes (1994) suggested the exogenous/endogenous distinction. Yantis and Johnston (1990) proposed a model of attention that allowed for the early or late selection of visual objects depending on particular task demands. Vecera and Farah (1994) noted that, although we tend to describe various processing phenomena under the global term 'attention' (suggesting a single mechanism), multiple attentional mechanisms exist which are qualitatively different from one another, and yet may be directed toward the same stimuli.

That two distinct attentional mechanisms may exist and may function in unique ways is supported by recent studies of neural physiology. Some of this literature was reported above (studies by Humhreys & Riddoch [1993] and by Kanwisher & Driver [1992]). In addition, Posner and Peterson (1990) distinguished between anterior and posterior attentional systems. Anatomically, the anterior attentional system is localized in the anterior cingulate gyrus. This system is believed to be responsible for detecting targets or events. Such events may be visual signals, such as newly appearing rows of letters, but may also be more abstract signals, such as semantic word categories. The posterior attentional system is located in the posterior parietal lobe, and may involve the pulvinar of the thalamus and the superior colliculus in the midbrain (Vecera & Farah, 1994). The role of the posterior system is believed to be the allocation of attention to locations in visual space, and the selection of those locations.

In summary, it may be argued that a visual grasp is the result of an attentional phenomenon, though not in the way originally hypothesized. A more valid account may involve the exogenous capture of attention by rows of letters as they appear in the visual field. This would explain the consistency and power of this effect, even when instructions to observers attempted to alter the deployment of attention. At the same time, observers appear to be able, to a degree, to direct their attention to specific locations in order to maximize their likelihood of successfully completing the task. Note again that observers appeared to be able to attend to the first or fifth letter *positions* in Experiment 1A as it benefitted their task performance. This argument leads toward an answer for the second major question asked about visual grasp.

Is Visual Grasp Directed Toward Objects or Locations?

In Experiment 2, the location of letter rows was altered to examine the effects of a letter's row position given that it remains in a constant retinal position. The fact that position within a row was an important factor in determining identification accuracy was taken as evidence that a visual grasp is directed at perceptual *objects*, regardless of their location within the visual field. This, in turn, supports the view of visual grasp emerging from Experiments 1 and 1A in that the attentional capture, which is a function of the anterior attentional system, is directed toward new target objects, not toward locations in visual space.

This is not to say that attentional phenomena are directed only toward perceptual objects. Again, with considerable evidence pointing both toward instances of object-based attention, and to attention directed toward spatial locations, it seems most reasonable to concur with Vecera and Farah (1994), who concluded that *both* objects and locations may be targets of our attention. For a task in which observers are required to attend to an entire row of letters in order to identify one letter in a position unspecified until display offset, the attentional processes involved are most likely to be object-based.

One counter-argument to this conclusion may be that the data for Experiment 2 simply reflect the influence of a reduction in lateral inhibition at the ends of rows. Such an argument places the cause of visual grasp back into the domain of stimulus factors. The nature of the stimulus object itself – the fact that outer letters experience less interference by having fewer neighbors – results in the better identification scores we have attributed to attentional factors. Whereas arguments have been made in the past against the importance of stimulus features relative to other explanations for variations in letter identification performance, the data of Experiment 2 alone cannot refute the lateral inhibition explanation. This, in part, was the motivation to perform the third experiment.

Is Visual Grasp Directed Toward Perceptual Groups in a Larger Display?

If it could be demonstrated that identification scores increased when letters in central positions happened to be the end letters of groups based on color, then it could be claimed with greater confidence that a visual grasp is directed toward or captured by perceptual objects. Creating groups through color meant that no change was required in terms of the spatial separation of letters. Therefore, differences in identifiability could not be a result of reduced lateral inhibition for letters at group ends.

Experiment 3 revealed that any effects of perceptual grouping required some time for the characteristics of central items to be processed. It confirmed that masking very brief displays resulted in a situation in which only the outermost items in a display were processed to a degree sufficient for reasonably accurate identification. Thus, whereas the visual grasp of entire letter rows was confirmed, similar processing directed toward individual color groups was not.

With extended exposure durations in Experiments 3A, the influence of perceptual grouping became more apparent. The visual grasp of the entire display remained a dominant effect, but at least for one of the two centermost positions tested, having that letter position represent a group edge resulted in higher identification scores. Experiment 3B confirmed this effect, although being required to name a letter's color did not increase the impact of the color grouping. Overall the data indicated that, to a degree, the creation of distinct perceptual groups could influence the identification of letters at group edges.

So a Visual Grasp is . . .

The results of the current experiments provide a picture of visual grasp that is somewhat different from that originally proposed. Visual grasp appears to be a product or a component of the exogenous attentional capture of visual objects. It seems to be apparent whenever an observer attempts to identify all elements of a display. Visual grasp may be an attentional effect, but it is unlikely from the data presented here that it is a product of *voluntary* attention. It may, instead, be a function of the anterior attentional system, operating to identify target (perceptual) objects, and to segregate individual perceptual groups within a larger display.

A Note on Neurophysiology

It has been noted that evidence exists from clinical neurophysiology to support the notions of space- and object-based attention. Additionally, there may be evidence at hand to suggest that a process like visual grasp has a neurological basis. For example, a recent study by Lamme, Zipser, and Spekreijse (1998) revealed characteristics of responding in cells of the primary visual cortex (V1) that appear to emphasize a figure's external contours. These cells were thought to signal only the most primitive local information regarding length, orientation, and so on. However, Lamme et al. reported, in measuring activity in the receptive fields of these cells, that cells responding to border regions between a figure and its background responded slightly faster, and with a delay of modulation, in comparison to cells responding to the plane of the figure. Thus, cells at a very basic level of the object identification system appear to be relaying unique information about the presence of an object's borders, underlining the importance of these external contours in the process of object identification.

Multiple Influences

For years, researchers have tried to find simple, straightforward solutions to explain the vast complexities of human behavior. Only rarely have they succeeded, because so few simple solutions exist. So despite the fact that we break down complex problems of human perception into questions like "which letters of a row are easiest to identify (and why)?" the answers to those questions typically become more complex than we had hoped. Even the simple task of identifying one letter from a row of eight reveals complex interactions of processing tendencies, strategies, and stimulus characteristics.

Perhaps this should not come as a surprise. As noted above, Vecera and Farah (1994) realized that, although we use a single term 'attention,' we are often describing very different mechanisms, some which may be determined by top-down goals and intentions, and others which may result from particular stimulus factors. Likewise, Yantis and Johnston (1990) described a model of attention in which attentional selection could occur in at least two different loci in the course of object recognition. Selective attention could control what sensory material is input to the object-identification system (i.e., early selection), and could also determine which identities are retrieved from that system (as in late selection). Thus the long-standing debate over early versus late selection by attention may be resolved by admitting that both may occur – not only under unique circumstances, but within the same identification process.

In a similar vein, the debate described in the introduction to this paper regarding the order of processing of letter strings involved arguments for a left-to-right scanning process versus an ends-first scan, among others. Again, data such as those in the current project may reflect the influence of both of these scanning tendencies. An ends-first tendency was apparent in every experiment in the current series, given that outermost letters were identified with greatest accuracy in every experimental condition. However, a left-to-right scanning tendency was also apparent, despite the fact that most of the previous evidence for such an effect came from full-report measures, and this was a partial-report design. Firstly, in every case, it was the leftmost letter that showed highest identification scores. Secondly, average scores in Experiment 2 were highest for the left row condition, next highest for the center row condition, and lowest for the right row condition. This outcome is consistent with a tendency for observers to focus first on the leftmost part of a region where a stimulus is to appear. Thirdly, in Experiments 3A and 3B, highest scores for interior group-end letters occurred when those letters were the first (leftmost) letter of a color group. Thus, both an ends-first and a left-to-right processing routine may have influenced the pattern of scores in the current experiments.

Others have proposed that these two tendencies may operate in concert. Schissler and Baratta (1972) concluded that both tendencies may operate even in the identification of small groups of letters. I am inclined to agree with their suggestion that the ends-first scanning disposition is more primitive than a left-to-right scan. The latter is most likely a by-product of reading habits, as noted years ago by Heron (1957). Still, with such habits so deeply ingrained in most of us, the effects of a left-to-right scan would seem to be a difficult habit to overcome.

Visual Grasp and Outside-in Processing

The conception of attention as comprising both the exogenous capture of perceptual objects (of which visual grasp is a component) and the endogenous orientation toward locations may explain more than just the outcomes of the current experiments. This view may provide also an alternative account of Earhard and Walker's (1985) findings. Recall, Earhard and Walker found an outer line advantage in each instance where observers were required to process all parts of a geometric object in order to identify a single unique contour (a thin line). Conversely, when trials were blocked so that only the inner or the outer line segments needed attention, this advantage disappeared. As a result, Earhard and Walker attributed their results to a process of voluntary attention they called outside-in processing. Under the blocked trials, it was claimed that observers could easily focus attention more narrowly on the inner portions of the targets, or more widely on outer areas, as appropriate.

It is not logically necessary that the outer line advantage be the result of a voluntary attention process. All that is necessary is that this advantage be subject to modification by voluntary attention under the appropriate circumstances. Consider, then, how a dual model of attention may account for these results. It might be argued that under any condition where all elements of a display are to be processed, attention is captured exogenously by the perceptual object or group in question, and that a visual grasp is a default component of this capture. Thus Earhard and Walker's consistent finding of an outer line advantage might be the result of a visual grasp phenomenon. The fact that this advantage disappears when observers are asked to attend to only part of the entire stimulus may demonstrate that endogenous focusing on the appropriate locations may overcome the effects of exogenous capture. Thus the outside-in aspect of this process may result from a visual grasp, and not from a voluntary strategy on the part of the observer.

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Limitations of this Research and Future Directions

THEORETICAL LIMITATIONS

The goal of the present series of experiments was to identify some characteristics of a visual grasp phenomenon. The choice was made to restrict this investigation to the sorts of verbal stimuli that had been tested in previous research into similar phenomena, even though some evidence, like that offered by Pressey and by Earhard (described above) indicated that similar phenomena occur in other perceptual tasks as well. As a direct result of this choice, the scope of this research and any conclusions that may be drawn about the nature of a visual grasp are restricted in application to situations that involve the processing of horizontal arrays of verbal stimuli (letter rows). Similar studies are planned using other arrangements of letter stimuli (vertical, cross, and / or circular displays) and nonverbal symbols. Applications to geometric forms and illusion figures are being considered as well.

Perhaps a more important limitation of the current research is that some of the expected effects turned out to be of rather small magnitude, and therefore did not provide an especially strong argument for the existence of attentional effects produced by instructions, or for the influence of perceptual grouping. Again, further research may explore alternative measures of visual grasp following other instruction conditions and grouping procedures.

METHODOLOGICAL LIMITATIONS

It is important to note that here, as with many descriptions of psychological phenomena across many contexts, the description of attentional processing I have described is based on the average performance of a group of observers. As with any averaging process, the average score or average behavior may not reflect the actual behavior of most (or even of any one) observers. A review of the responses recorded for various participants, as well as the comments of these observers during post-experimental debriefing, confirmed that this was the case. Consider the patterns of response for three participants from Experiment 1A that are displayed in Table 8. Rather different scores were recorded, suggesting that unique strategies or approaches to the task were being employed. Participant 1 attended to the leftmost position and scored well only at that position. Participant 2 focused on the location around the central fixation point and the outer edges of the display. Participant 3 attempted to read letters from left to right on most trials. This was evident in the declining function across the first few letter positions and reduced accuracy elsewhere. Participants also described the use of various strategies. Some tried to view displays in a global manner; others attempted to read letters as fast as possible (with admitted limited success); some tried to focus on letter positions to the right in the display, being aware that these might be more difficult to identify, and to "just let the first couple of positions take care of themselves." As the experimenter, a conscious effort was made not to encourage (or bias) a particular mode of processing the displays, but clearly, not to do so left open the possibility of many different strategies being employed, with greater or lesser success, and for various durations, adding to the variability among scores.

Does the possibility of individual participant strategies deny the presence of a visual grasp process? Not at all. It may actually support the idea of multiple influences on observer performance, including the interacting effects of multiple attentional systems, perhaps an exogenous visual grasp accompanied by a conscious, voluntary emphasis on a certain part of the display. Notice in Table 8 that, despite differing patterns of response, it remains that

Table 8

Correct identifications (max. = 16) at each letter position for three subjects in Experiment 1A. The different response patterns may reflect different strategies in the letter identification task.

	Letter Position							
Participant	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Participant 1	16	2	3	3	0	1	1	3
Participant 2	14	3	3	5	10	3	5	14
Participant 3	14	6	4	1	4	3	4	9

outermost items at both ends of the row were identified more often than their nearest neighbor, again supporting the notion of a visual grasp's influence on identification scores.

Some limitations in the current research could be grouped under the heading "If I had it to do over again . . ." Certain methodological changes would be made with the intent to reduce between-subject variability as much as possible, thereby strengthening the chance of finding significant results. One or more of the following should aid in that effort:

(1) Using "trained" rather than "naive" observers. This is a common practice in many areas of perceptual research, and reduces the variability caused by many observers employing idiosyncratic viewing strategies.

(2) Providing feedback regarding accuracy. Being given information about one's performance might help to reduce the use of ineffective strategies such as trying to read across a tachistoscopic display by employing eye movements.

(3) Calculating individual criteria for exposure durations based on some predetermined level of accuracy. It is known that some individuals process information more quickly than others. The 100-msec exposures used in the current experiments were adequate for most participants, but too brief for some, and possibly too long for others. A personalized exposure duration would eliminate some of the diversity observed in response patterns.

14

Conclusion

This project was designed to identify some of the characteristics of a fundamental perceptual process described here as a visual grasp. The fact that the outermost items in a sequence are psychologically significant has been known for years, and applies across situations ranging from the words on a to-be-remembered list to the persuasiveness of speeches. The fact the outermost items in a visual display are most readily identified is also a well known phenomenon. The characteristics of this phenomenon are less well known. It has been attributed to stimulus factors such as the lateral inhibition among items (or the lack thereof) (e.g., Haber & Standing, 1969). Alternatively, Earhard (Earhard & Walker, 1985) argued persuasively that a similar phenomenon, labeled outside-in processing, is due to voluntary attentional processes.

The current investigation represents only a small step toward clarifying the picture we have of a visual grasp. It is argued that it may be an attentional effect, and if so, it represents a situation in which attention is captured exogenously. Endogenous attentional processes appear to influence the phenomenon in only limited ways. Visual grasp is directed toward perceptual objects in a display, and may apply to each perceptual group within a larger array.

Given that the capture of our attention by various stimuli is such a basic aspect of our visual processing, many opportunities exist to explore the nature of this early facet of object identification.[4] With converging evidence from studies involving verbal and non-verbal stimuli, and from research delineating the functional anatomy of our visual systems, it appears that a process like visual grasp represents a fundamental aspect of our interpretation of the visual world.

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[4] - Commentary by the external examiner of this thesis, Dr. V. Di Lollo, suggests that exceelent behavioral evidence supporting the concept of visual grasp may be found in the work of Paradiso & Nakayama (1991)(Vision Research, 31, 123-126) exploring the "filling-in" phenomenon.

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Appendix A

Instructions to Participants: Experiments 1 and 1A

"Your task in this experiment is quite straightforward. I'll use this apparatus to present rows of letters to you, very briefly. You're in charge of the pace of the experiment – you'll press this button when you're ready to see the next display.

"The first thing you'll see is a small cross which marks the center of the display. The letter rows will appear across this area. There will be eight letters in each row; four will appear to the left of the cross position, and four will appear to the right.

"Immediately after the letters appear, they'll be replaced by eight squares. One square will have an arrow just below it. Your job is to tell me what letter was in the position indicated by the arrow. If ever you're not sure, guess. On each trial, we only want to know about that one letter, but of course, you won't know which letter we're going to ask about . . .

(Experiment 1, random condition): "it's randomly determined – we could ask about any of the eight positions on any given trial . . .

(Experiment 1, specific condition): "but let me give you a hint. The two leftmost positions have a 1-in-4 chance of being sampled on any trial, and the same holds for the two rightmost positions – a 1-in-4 chance. But on *half* of all trials, the arrow will appear under one of the four central positions. O. K.? You can keep that in mind . . . one-half the time, we'll sample from the center four positions.

(Experiment 1A, IN condition): "but I can tell you this much. For the first set of trials, we'll be emphasizing the central letters. What that means is: On 75% of these trials, we'll sample one of the central four letter positions, and we'll only ask about the four external positions 25% of the time. O. K.? You can keep that in mind . . . 75% of the time, the arrow will appear under one of the center four positions.

(Experiment 1A, OUT condition) "but I can tell you this much. For the first set of trials, we'll be emphasizing the external letters. What that means is: On 75% of these trials, we'll sample one of the outer four letter positions, and we'll only ask about the four central positions 25% of the time. O. K.? You can keep that in mind . . . 75% of the time, the arrow will appear under one of the outer four positions.

"Any questions?

Let's look at some practice displays to get a feel for the procedure."

Instructions to Participants: Experiment 2

"Your task in this experiment is quite straightforward. I'll use this apparatus to present rows of letters to you, very briefly. You're in charge of the pace of the experiment – you'll press this button when you're ready to see the next display.

"The first thing you'll see is a row of 10 blue squares that are there to indicate 10 possible positions in which letters might appear. Now, there be only six letters per row, but on a given trial, those six might appear shifted toward positions on the left, they might appear across the center of the display, or they might appear shifted to the right. They will always appear together – no gaps in the row, and so on.

"Immediately after the letters appear, they'll be replaced by six dark squares. One of the squares will have an arrow just below it. Your job is to tell me what letter was in the position indicated by the arrow. If ever you're not sure, guess. On each trial, we only want to know about that one letter, but of course, you won't know which letter we're going to ask about – it's randomly determined – we could ask about any one of te six positions where letters appeared.

"Questions?

"Let's look at some practice displays to get a feel for the procedure."

Instructions to Participants: Experiments 3, 3A and 3B

"Your task in this experiment is quite straightforward. I'll use this apparatus to present row of letters to you, very briefly. You're in charge of the pace of the experiment – you'll press this button when you're ready to see the next display.

"The first thing you'll see is a small cross marking the center of the display. The letter rows will always appear across this area. There will be eight letter in each row – four will appear to the left and four to the right of the cross position.

"Immediately after the letters appear, they'll be replaced by eight squares. One square will have an arrow located just below it. Your job is to tell me what letter was in the position indicated by the arrow. If ever you're not sure, guess. On each trial, we only want to know about that one letter, but of course, you won't know which letter we'll ask about . . . You will notice that in most displays, some letters will be red in color and some will be blue (Sometimes all will be red or all blue). Color does not affect the likelihood of a letter being sampled – the letter we ask you to report is randomly determined – we could ask about any of the eight positions on any given trial . . .

(Experiment 3B only) "But you will have to take note of the color of the letters, because I want you to tell me not only the identity of the indicated letter, but also its color, red or blue. So if the correct letter happens to be a Z, and it was red, your response would be 'red Z' or 'Z red,' whichever you prefer . . .

"Questions?

"Let's look at some practice displays to get a feel for the procedure."

Appendix B

Post-Experimental Questionnaire, Experiment 1

In order for us to determine the effectiveness of our instructions, we'd appreciate your responses to the following items:

1. While completing this task, I feel that I was directing my attention (please circle one letter)
   A. more toward central letters in most displays.
   B. more toward end letters in most displays.
   C. about equally across all letters in most displays.
   D. it varied from trial to trial.

2. Please describe (in your words or mine) the instructions you were given regarding how often each letter position would be sampled.

____

____

____

3. The instructions I was given (please circle one letter)
   A. encouraged me to attend more toward central letters.
   B. encouraged me to attend more toward end letters.
   C. really meant that I should attend to all letters equally.
   D. didn't really affect how I performed the task.

Appendix C

Analysis of Variance Summary Tables :

Please Note:

The following abbreviations are used in the tables that follow to specify experimental conditions:

POSN → Letter Position
INST → Instruction Condition
LOCN → Row Location
GROUP → Grouping Condition

2 x 8 Mixed ANOVA for Experiment 1
(see p. 68)

Source	df	SS	MS	F	Pr
Between Subjects	31	604.25			
INST	1	0.06	0.06	0.25	0.96
Ss(INST)	30	604.19	20.14		
Within Subjects	224	4358.75			
POSN	7	3253.00	464.71	90.21	<.0001
INST x POSN	7	23.94	3.42	0.66	0.70
Ss x POSN(INST)	210	1081.81	5.15		
Total	255	4963.00			

2 x 8 Repeated Measures ANOVA for Experiment 1A
(see p. 73)

Source	df	SS	MS	F	Pr
Among Ss	15	1.32	0.09		
INST	1	0.00	0.00	0.01	0.91
Ss x INST	15	0.53	0.04		
POSN	7	14.81	2.12	52.12	<.0001
Ss x POSN	105	4.26	0.04		
INST x POSN	7	0.30	0.04	1.84	0.09
Ss x INST x POSN	105	2.41	0.02		
Total	255	23.63			

3 x 6 Repeated Measures ANOVA for Experiment 2
(see p. 129)

Source	df	SS	MS	F	Pr
Among Ss	15	83.52	5.57		
LOCN	2	12.38	6.19	5.28	0.01
Ss x LOCN	30	35.17	1.17		
POSN	5	703.73	140.75	46.64	<.0001
Ss x POSN	75	226.33	3.02		
LOCN x POSN	10	96.95	9.70	6.49	<.0001
Ss x LOCN x POSN	150	224.16	1.49		
Total	287	1382.24			

One-Way ANOVA on Position 5 for Experiment 2
(see p. 130)

Source	df	SS	MS	F	Pr
Among Ss	15	32.58	2.17		
LOCN	2	79.04	39.52	28.03	<.0001
Error	30	42.29	1.41		
Total	47	153.91			

One-Way ANOVA on Position 6 for Experiment 2
(see p. 130)

Source	df	SS	MS	F	Pr
Among Ss	15	58.58	3.91		
LOCN	2	136.79	68.40	21.25	<.0001
Error	30	96.54	3.21		
Total	47	291.91			

4 x 8 Repeated Measures ANOVA for Experiment 3
(see p. 141)

Source	df	SS	MS	F	Pr
Among Ss	15	216.87	14.46		
POSN	7	2303.70	329.10	94.09	<.0001
Ss x POSN	105	367.27	3.50		
GROUP	3	2.32	0.77	0.74	0.54
Ss x GROUP	45	47.28	1.05		
POSN x GROUP	21	20.88	0.99	0.93	0.56
Ss x POSN x GROUP	315	338.27	1.07		
Total	511	3296.59			

One-Way ANOVA on Position 4 for Experiment 3
(see p. 142)

Source	df	SS	MS	F	Pr
Among Ss	15	21.00	1.40		
GROUP	3	0.88	0.29	0.37	0.77
Error	45	35.13	0.78		
Total	63	57.01			

One-Way ANOVA on Position 5 for Experiment 3
(see p. 142)

Source	df	SS	MS	F	Pr
Among Ss	15	89.00	5.93		
GROUP	3	6.86	2.29	1.63	0.19
Error	45	63.13	1.40		
Total	63	158.99			

4 x 8 Repeated Measures ANOVA for Experiment 3A
(see p. 146)

Source	df	SS	MS	F	Pr
Among Ss	15	354.31	23.62		
POSN	7	1255.67	179.38	19.10	<.0001
Ss x POSN	105	986.11	9.39		
GROUP	3	2.44	0.81	0.75	0.53
Ss x GROUP	45	48.71	1.08		
POSN x GROUP	21	38.04	1.81	1.39	0.12
Ss x POSN x GROUP	315	410.55	1.30		
Total	511	3095.83			

One-Way ANOVA on Position 4 for Experiment 3A
(see p. 147)

Source	df	SS	MS	F	Pr
Among Ss	15	146.94	9.80		
GROUP	3	19.81	6.60	6.10	0.0014
Error	45	48.69	1.08		
Total	63	215.44			

One-Way ANOVA on Position 5 for Experiment 3A
(see p. 147)

Source	df	SS	MS	F	Pr
Among Ss	15	207.11	13.81		
GROUP	3	3.55	1.18	1.07	0.37
Error	45	49.70	1.10		
Total	63	260.36			

4 x 8 Repeated Measures ANOVA for Experiment 3B
(see p. 151)

Source	df	SS	MS	F	Pr
Among Ss	15	103.17	6.88		
POSN	7	324.97	46.42	13.06	<.0001
Ss x POSN	105	373.19	3.55		
GROUP	3	0.96	0.32	0.57	0.64
Ss x GROUP	45	25.07	0.56		
POSN x GROUP	21	16.96	0.81	1.27	0.19
Ss x POSN x GROUP	315	200.76	0.64		
Total	511	1045.08			

One-Way ANOVA on Position 4 for Experiment 3B
(see p. 152)

Source	df	SS	MS	F	Pr
Among Ss	15	65.25	4.35		
GROUP	3	9.13	3.04	4.36	0.009
Error	45	31.38	0.70		
Total	63	105.76			

One-Way ANOVA on Position 5 for Experiment 3B
(see p. 152)

Source	df	SS	MS	F	Pr
Among Ss	15	81.11	5.41		
GROUP	3	2.05	0.68	0.84	0.48
Error	45	36.70	0.82		
Total	63	119.86			