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Selective attention in the peripheral visual field.

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SELECTIVE ATTENTION IN THE PERIPHERAL VISUAL FIELD

A Dissertation Presented

by

LINDA F. ALWITT

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of the requirement for the degree of

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Psychology

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A Dissertation Presented

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ABSTRACT

SELECTIVE ATTENTION IN THE PERIPHERAL VISUAL FIELD

(May, 1976)

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We selectively pay attention to the aspects of the visual world to which we will respond. The mechanism of selective attention is related to two stages in early visual information processing, grouping of the visual field into units, and differentially processing features of those units. The purposes of the present research were to demonstrate that selective attention can facilitate feature processing and to examine some temporal and spatial characteristics of the mechanism of selective attention. An array of 12 letters was briefly presented on a computer-programmed display oscilloscope with the task of identifying one of the letters. During the presentation of the letter array, one or more letters changed position slightly. The position change, or movement, was intended to attract attention to the moved location. Any effects of eye movements on the results were ruled out by the brief presentation durations. There was an advantage for moved over non-moved letters in identification when few letters moved in the array, and an advantage for non-moved over moved letters when many letters moved in the array. Reaction time to a correct identification was shorter for moved than for non-moved letters when few letters moved but was not different for moved and non-moved letters when many letters moved in the array. These results support the idea that selective attention facilitates processing of features.

Selective attention facilitated identification in less than 90 msec, and this facilitation was still evident 590 msec after attention was presumably attracted. Selective attention appeared to take time either to move to or to take advantage of the features at an eccentric spatial location; processing of features was delayed or slowed for attended letters at large eccentricities in the visual field. Attention attracted by a stimulus movement could be controlled by the observer; if the movement was not important to the task to be performed, it could be ignored. However, it took practice to eliminate interfering effects of stimulus movement on identification of a letter elsewhere in the array.

The results of this experimental series may be accounted for by assuming that units are formed in an early stage of visual information processing, attention is allocated proportionally to units on the basis of the number of units in the field, and moved stimuli have a temporal advantage in processing over non-moved stimuli.

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CHAPTER I

BACKGROUND AND PURPOSE

Not all of the information available in the visual world is used by the viewer. We select the aspects of the visual input to which we will respond. Often, attention is attracted by a heterogeneity in the visual field. For instance, Mackworth & Morandi (1967), recording eye movements across photographs, found that fixations cluster on locations rated high in information-content. Yarbus (1967), in similar studies, found that "...often an observer will focus his attention on elements that are unusual in the particular circumstances, unfamiliar, incomprehensible, and so on" (p. 191). In ordinarly viewing, eye movement is necessary because the human visual system is not uniform in its ability to process input at different retinal eccentricities. The eye moves so the area of interest falls on the most sensitive part of the system.

Early visual information processing has been described as a two-stage system. The first stage provides information to the observer about gross characteristics of the set of stimuli in his visual field. Using the information available from the initial stage, the second stage allows a limited part of the stimulus array to be selected for priority in encoding of stimulus features. The first stage is concerned with the relation of parts of the visual field to each other; the second stage is concerned with relations of stimulus features within a limited part of the visual field. Neisser (1967) referred to the first process as "preattentional" and to the second as "focal attention". Kahneman (1973) referred to the first process as "unit formation" and to the second as "figural emphasis". The first stage in early visual information processing may serve at least two functions. First, it may select a spatial location in the visual field where the second stage of information processing can operate. That is, it may direct focal attention, or create figural emphasis, at a location in the visual field. Second, it may encode the cues which initiate saccadic eye movements to foveate a part of the visual field. These cues must necessarily come from the peripheral visual field or eye movement would not be required.

In many situations, selective focal attention and eye movements are made to the same spatial location. However, these two mechanisms for optimizing the encoding of information about stimulus features in a limited part of the visual field need not always act together. It has long been proposed that attention can move independently of eye movement (Helmholtz, cited in Kahneman, 1973, p. 59; Purkinje (1825), cited in Clemmesen, 1945, p. 119). Evidence to support the independence of eye movement from selective attention comes from tachistoscopic partial-report studies (e.g., Sperling, 1960; Averbach & Coriell, 1961; von Wright, 1968; Well & Sonnenschein, 1973). These studies demonstrate that information about certain features can be encoded from a display well before the eye can move to the location of the target. For example, Averbach & Coriell presented a 2 x 8 array of letters for 50 msec. After a variable delay, one letter was probed by presenting a bar above or below its position. Accuracy of identifying the probed letter was better when the probe was presented within 100 - 200 msec of the letter array onset than when it was presented more than 100 - 200 msec after the array onset. Since the latency to a saccadic eye movement is 180 - 250 msec (Alpern, 1971), eye movement to the probed position cannot explain the greater accuracy for short intervals between array and probe. These results are consistent with the idea that selective attention may move to a position before the eye can move there.

The tachistoscopic studies are generally carried out in foveal vision, where acuity for detail is far better than in the rest of the visual field. Averbach & Coriell point out that the letters in their 5° horizontal test field were clearly legible (p. 315). Sperling's stimuli subtended a horizontal visual angle of about 5.8° for the three-item wide arrays and about 8.2° for the four-item wide arrays (assuming $.45^{\circ}$ letter width and one letter-width between letters), and are within the area of clearest vision. Well & Sonnenschein presented a circular display with an outer diameter of 1.8°. von Wright's four-item wide array was about 8° of visual angle. Since acuity is highest in the area that these stimuli covered, it may not be necessary to direct selective attention in order to encode the features required for identification of letters. Examination of selective attention in peripheral vision would circumvent this drawback to these studies as evidence for the role of selective attention in encoding feature information.

In the tachistoscopic studies, the probe which indicated the aspect of the array to be attended was often not presented until after the array was removed. This means that the observer was attending to a persisting visual image of the array, called an icon (Neisser, 1967), rather than to the actual display itself. It is not clear that either selective attention or eye movements can scan an iconic image in the same way they scan an actual display. It has been suggested that iconic images can be scanned by eye movements (Hall, 1974; Crovitz & Davies, 1962). However, the evidence which supports scanning of icons by eye movements might reflect instead the effects of eye movements made to confirm the location of a previously attended and encoded stimulus. Other evidence suggests that the icon moves as the eye moves. Davidson, Fox, & Dick (1973), Doerflein & Dick (1975), and Matin (1972) have demonstrated that an icon moves in the same direction as the eye moves. For example, Doerflein & Dick had observers move their eyes rhythmically between fixation points. A linear eight-letter array which covered the area between and across the fixation points was briefly presented when the eye was at one fixation point. A probe marker indicating the target letter at the other fixation point was triggered by the eye movement to the other fixation point such that the time between the letter array and the probe marker was 100 msec or more. They found that when an eye movement was made, the iconic images of the letters were shifted one or two positions from their physical locations in the direction of the eye movement. For a three degree eye movement, the letter array was displaced 70 min relative to the probe bar in the direction of the eye movement. The displacement of the array icon in the direction of the eye movement was less than the displacement of the eye but was still substantial. Further support for the assertion that the icon moves when the eye moves is provided indirectly by Sakitt (1975). She offers evidence that the icon is stored at the retinal level by rod activity. Since the icon is stored retinally, it should move when the retina moves. The evidence cited suggests that the icon cannot be effectively scanned by eye movement. There is no evidence, to my knowledge, that selective attention can or cannot scan an icon in the same way it may scan an actual display.

The first stage in early visual information processing, pre-attentional analysis of gross stimulus set characteristics, is derived from a logical need for an operation which can direct the location of later processing of details. Experimental evidence that two functionally distinct stages exist in early visual information processing is offered by two kinds of studies. First, Eriksen and his associates have carried out a series of studies of selective attention using the Averbach & Coriell probe method (e.g., Eriksen & Colegate, 1971; Eriksen & Hoffman, 1972, 1973, 1974; Hoffman, 1975). Eriksen & Hoffman (1974) had observers identify a single letter which was preceded by a probe indicating the location of the letter. The probe preceded the letter by a variable interval. In this situation, reaction time decreased as the time between the probe and the target increased, up to the 150 msec maximum interval used. Their method ruled out interpretations in terms of response competition and order of encoding since only one letter was presented. It also ruled out masking of the letter by the probe; in a control condition where masking could occur but location of the target was not indicated, reaction time was identical when the target and probe were presented simultaneously but did not change as the probe/target interval increased. These results suggest that some early attentional process enhances later detail processing for identification by directing attention to the spatial location of the target. Hoffman (1975) offered further support for two functionally distinct stages in early visual information processing. He presented an array of filler symbols and a probe indicator, followed at varying intervals by a target symbol. The task was to identify the target. In terms of reaction time to identify the target, the presence of the target was not necessary for the first 50 msec. This result implies that, in this experimental situation, the first 50 msec were not used for operations related to feature analysis in order to identify the target. The first 50 msec may have been used to direct focal attention to the target position.

A second set of evidence which supports a distinction between stages in early visual information processing comes from studies by Beck and his associates (e.g., Eichelman, 1970; Beck, 1974; Beck & Ambler, 1972, 1973). Beck and his associates, studying the discriminability of differences in the peripheral visual field, offer evidence for two attentional modes. One mode, active early in processing, encodes features of the stimulus field which can be used to separate the field into units based on feature similarity. For example, line orientation facilitates grouping of stimulus elements so that tilted-Ts can be discriminated from upright Ts. The second mode, active later in information processing, encodes details within a stimulus unit. In this mode, stimulus configuration is encoded so that L can be differentiated from T; note that the orientations of the lines comprising letters L and T are the same but their configurations differ.

Beck (1974) presented four letters at $5^{\circ}7'$ eccentricity for a time well below that of the saccadic eye movement threshold ($\bar{x}$ = 30 msec). One letter differed from the others in either slope (T vs. tilted-T; and T vs. X) or configuration (T vs. L or T vs. right-angle T). When three of the letters in the display field were T, it was easier to locate the remaining letter when it was a tilted-T than when it was an L or a right-angle T. When only one letter was displayed, errors were the same for all letters. Beck concluded that, when the observer does not know where to look, similarity of the three filler items can produce grouping. The basis for grouping, though, depends on the mode of attention used; when attention is spread across the field, as in the four-item display, slope differences promote grouping more effectively than configuration differences.

Beck & Ambler (1972) presented six letters on the perimeter of a circle 30° in diameter, followed after a variable interval by a mask. Five letters were Ts and the sixth was an L or a tilted-T. The task was to indicate whether or not a disparate letter was present. At short mask delays, there were more errors when the disparate letter was L than when it was a tilted-T. When a single letter was presented, T vs. tilted-T in one condition and T vs. L in the other condition, there was no difference between conditions with mask delay. Beck & Ambler say these results are consistent with the hypothesis that under spread attention, which is the major mode of attention during short mask delays, slope differences are better able to promote similarity grouping than are configuration differences.

In a second report, Beck & Ambler (1973) attempted to manipulate the degree of spread of attention by varying the kind of information available about potential target locations. Using a display like that of the previous study but with eight letters, they presented one, two or eight dots 150 msec before the letters appeared. A dot, which appeared on a radius with a letter position, indicated the potential position of a disparate letter. It was hypothesized that spread of attention would increase with the number of dots presented. In agreement with their earlier work, discriminability of configuration (T vs. L) decreased with an increase in the number of dots but discriminability of slope (T vs. tilted-T) did not differ with the number of dots. Beck & Ambler's results indicate that some sort of structuring of the visual field occurs outside of foveal vision. This structuring, based on grouping of elements of the field into units, can potentially facilitate further processing of the visual input.

The results of the Beck studies and the Eriksen studies are consistent with the idea that an early attentional mode (a) operates over the entire visual field, both in the periphery (e.g., Beck & Ambler) and in the center (e.g., Eriksen & Hoffman), (b) acts early in visual information processing, and (c) probably directs the second attentional mode to a part of the visual field.

How does the first attentional mode direct the second, feature-encoding, attentional mode? Beck's results suggest that information relevant to grouping the stimulus array into units is encoded in this early mode; stimuli are grouped in terms of similarity to each other. Presumably, by decreasing the number of units to be analyzed, feature information can be more effectively encoded from each stimulus unit. Eriksen & Colegate (1971, p. 326) postulated that the visual field is "structured" prior to encoding of its contents. Kahneman (1973) proposed that the initial stage of visual information processing involved "unit-formation" based on Gestalt perceptual laws which lead to figure-ground grouping of the visual field. Neisser (1967) suggested that the field is "ordered" before focal attention operates on that field. The features which can be used to differentiate among groups of stimuli include line orientation (Beck, 1974; Eichelman, 1970), color (von Wright, 1968), position (e.g., Averbach & Coriell, 1961), brightness (Engel, 1974), size (von Wright, 1968; Engel, 1974) and movement (Julesz, 1971).

Once a field is "grouped", "structured", or "ordered", criteria must exist to direct selective attention to one unit or set of units rather than to another. In some situations, the criteria are determined by the task; e.g., "report the top line" or "report the red letters". In other situations, the decision as to which units will be selectively attended first is determined by characteristics of the stimulus display. One decision criterion may be that selective attention will focus on the smaller unit in the field (Koffka, 1935; Graham, 1929). For example, if a disc is divided into pie segments so that some segments contain more area than do others, the smaller segments tend to be seen as the figure and the larger segments as the background.

A second decision criterion may depend on the degree of difference among units. For instance, Engel varied the size, brightness (1974) and number of lines (1971) of a target element relative to background noise elements. He found that the more a target differed from background noise elements, the further it could be detected into the visual periphery. Engel also varied the amount of information given the observer about target location and the direction of target difference (e.g., "larger" or "smaller") from background noise elements. When they were pre-informed of the target location, observers could detect the target further into the periphery (by about a 5° advantage) than when not pre-informed of target location. These results also support the idea that there are two functionally-distinct attentional modes; that is, when selective attention is directed either by pre-informing the observer of the location to be attended or by differences between the target and background elements, encoding of the content of the attended location is facilitated.

Two decision rules related to the stimulus array have been suggested to selectively direct attention to a particular spatial location: (a) select the smaller unit; (b) select the most different unit.

The issues discussed so far allow some tentative proposals about the nature of early information processing. First, there are two functionally distinct stages in early visual information processing. The first stage involves analysis of features of the stimulus array which allow grouping of the elements of the array. In the second stage, on the basis of this grouping, some aspects of the array are selectively attended for encoding of features. The decision criteria used to determine which elements first become the focus of selective attention include instructional or task set, the smaller unit, and the more discriminable unit.

Recent neurophysiological evidence distinguishes between two kinds of visual pathways which might underlie stages of visual information processing. This research, carried out primarily on cats (e.g., Cleland, Dubin & Levick, 1971; Ikeda & Wright, 1972; Fukada & Stone, 1974) but also on primates (Gouras, 1969; Bartlett & Doty, 1974; Dow, 1974), suggests that transient visual channels optimally encode temporal modulation while sustained visual channels optimally encode spatial modulation of brightness of the visual field. A sustained visual cell at the retinal ganglion level of the cat has the following properties: (a) it gives a sustained response to stimulation; (b) the center of its receptive field has a sharp boundary which suggests that it has a strong inhibitory surround; (c) it responds to sharply-focussed, high spatial frequency stimuli; (d) since it is relatively insensitive to temporal modulation, it does not respond to stimulus movement greater than about 20 degrees/second. The conduction velocity of sustained cells at the retinal ganglion level is relatively slow. A transient retinal ganglion cell has the following properties: (a) it typically responds at the onset or offset of a stimulus; (b) it has a larger receptive field and apparently a weaker inhibitory surround than do sustained cells; (c) because it is sensitive to low spatial frequencies, it responds to defocussed stimuli; (d) it is sensitive to high velocities of stimulus movement (e.g., 200 degrees/second); (e) it will respond to moving stimuli far from its normal receptive field. Transient cells have a high conduction velocity. Dow (1974) reports that response latencies of transient cells in the visual cortex of the monkey are about 50 msec faster than latencies of sustained cells. In general, sustained cells project to sustained cells in the lateral geniculate nucleus (LGN) and hence to sustained cells at the visual cortical level. Transient cells at the retinal ganglion level (of the cat) project to transient cells of the superior colliculus and the LGN, and then to transient cells of the visual cortex (Fukada & Stone, 1974; Hoffman, 1973). In the cat, both sustained and transient retinal ganglion cells are found at all eccentricities sustained cells constitute the majority of cells at all eccentricities, but the relative proportion of transient to sustained cells increases with retinal eccentricity (Fukada & Stone, 1974). That the fast-conducting transient cells project to the superior colliculus is particularly interesting in the light of several other neurophysiological results: (a) the superior colliculus is implicated in saccadic eye movements and it has been proposed that a function of this center is foveation (Schiller & Stryker, 1972); (b) Goldberg & Wurtz (1972) found cells in the superior colliculus which fire pre-saccadically to a stimulus designated as a "target" by a temporally-encoded brightness change; (c) the superior colliculus projects to the pulvinar, which has been implicated in functions of selective attention (Gross et al, 1974) and of acquisition of the significance of cues in the visual field (Gould et al, 1974). This neurophysiological data suggests that the transient visual channel is implicated in the first stage of visual information processing, while the sustained visual channel is implicated in the second stage of information processing.

Some psychophysical studies suggest that human visual functions may maintain the sustained-transient distinction found in other mammals (e.g., Tolhurst, 1973, 1975a, b; Kulikowski & Tolhurst, 1973; Spitzberg & Richards, 1975). Tolhurst (1973) demonstrated that temporal modulation (which appears either as flicker or as apparent movement) increases the contrast sensitivity to low spatial frequency gratings (up to about one cycle/degree) but not to high spatial frequency gratings (above about two cycles/degree (c/d)). Recently, Tolhurst (1975a) demonstrated that the distribution of reaction times to detect the presence of a low spatial frequency grating (.2 c/d) is time-locked to the onset and offset of the grating. This produces a bimodal distribution of reaction times with time from stimulus onset. The distribution of reaction times to detect a high spatial frequency grating (3.5 c/d) is time-locked to stimulus onset but is unimodal. The reaction times are about 100 msec longer to high than to low spatial frequency gratings. Tolhurst concludes that low spatial frequency gratings are encoded by a transient visual channel and high spatial frequency gratings are encoded by a sustained visual channel.

This neurophysiological and psychophysical evidence suggests that the transient visual channel may underlie some aspects of early selective attention, particularly when temporal modulation of the brightness of the visual field attracts attention, but also in the peripheral visual field early in processing when low spatial frequency input is predominantly available. Breitmeyer & Ganz (1976) have recently commented on this physiological basis for visual information processing.

The purposes of the present research were to demonstrate that selective attention can affect the identification of form in peripheral vision and to examine some of the characteristics of selective attention. In this research, selective attention was manipulated by changing the locations of some letters of a multi-letter array, producing apparent movement of those letters. Selective attention should be attracted to the moved letters and facilitate processing of their features. The array of letters was presented in the periphery of and outside foveal vision for a duration too short to allow eye movement. The purpose of this spatial arrangement was to ensure that the letters could not be identified by foveal processes. The array was followed by a probe of either a moved or a non-moved letter for the purpose of identification. The following questions were examined using this approach.

(1) Can selective attention facilitate later form processing at the attended location, prior to eye movement? Despite the shorter exposure duration of moved compared to non-moved letters, moved letters should be identified better than stationary letters if movement attracts attention.

(2) How does movement attract attention? Evidence from neurophysiology, perception, and visual psychophysics suggests that movement <u>per</u> <u>se</u> attracts attention. However, when some elements move and some are stationary in an array, movement may constitute a heterogeneity in the field which, like similarity grouping, may structure the field to influence the distribution of selective attention. This question was explored by varying the number of moved letters in the array. If movement attracts attention, it should do so regardless of the number of moved letters in the array. If heterogeneity attracts attention, the smaller group of letters should be facilitated regardless of whether or not they moved.

(3) What are some temporal characteristics of selective attention? Specifically, how long does it take for selective attention to be attracted to a location, and how long is it effective in facilitating form processing? Eriksen & Colegate (1971) have shown that focal attention takes 200 - 300 msec to reach an asymptotic level when focal attention was directed by a probe in foveal vision. In the present experimental situation, selective attention may move faster because the letter itself served as the cue to focus attention. The time course of early selective attention was studied by varying the time between the offset of a letter in its initial position and the onset of the probe. The advantage of an attended over a non-attended letter should increase as the difference increases between onset of the initial letter and the probe; encoding of features of an attended letter, started when attention is focussed on its location, is closer to completion when the probe is delayed.

(4) What are some spatial characteristics of selective attention? Specifically, is selective attention equally effective at all eccentricities, and does selective attention take time to move to a distant location? These questions were examined by varying the eccentricities at which letters were presented in the display. Although the over-all accuracy should decrease with retinal eccentricity, "structuring" of the visual array should

occur equally at all eccentricities. If either (a) time is required for selective attention to move to a spatial location or (b) the lower quality of feature and acuity-related information available at far eccentric positions places an upper limit on the accuracy of encoding, there should be a smaller advantage for attended over non-attended letters as eccentricity increases.

(5) Is selective attention under the observer's control or is it an automatic process? Specifically, if attraction by selective attention is not important for the observer's task, can its effects be ignored?

Five experiments are reported. In Experiment I, three aspects of selective attention were examined: (a) the role of movement in attracting attention; (b) some temporal parameters of selective attention; (c) some spatial parameters of selective attention. Experiment II further examined the role of movement, and Experiment III further explored temporal parameters. Experiment IV asked whether selective attention is automatic or under voluntary control. Experiment V was designed to examine some specific letter effects in this experimental design.

CHAPTER II

GENERAL METHOD AND EXPERIMENT I

General Method

Apparatus and stimuli. Displays were plotted on a Hewlett-Packard Model H33-1300A X-Y display with a P31 phospher by a Hewlett-Packard 2114B computer. Responses were recorded by pressing one of two response keys. The left key represented letter "E" and the right key, letter "H". Data on stimulus parameters and response variables were stored on each trial by the computer for later analysis. Each trial consisted of a fixation square, a letter array, a probe marker, and feedback. The four corners of the fixation square of 1.7° visual angle side-length were plotted for 500 msec and were immediately followed by the letter array. Each letter array consisted of twelve letters in a cross configuration, three letters to an arm. The inner four letters were centered at 2.6° retinal eccentricity, the middle four at 4.3° eccentricity, and the outer four at 8.7° eccentricity. Thus the central four letters were viewed at the periphery of the fovea, the middle four were viewed parafoveally and the outer four perifoveally (Polyak, 1941). Except in Experiment V, there were four letter "E"s, and eight letter "H"s in each 12-letter display. The letters E and H, .50 cm or .61° of visual angle high and .35 cm or .44° wide, were randomly assigned to each of the twelve positions on each trial except for the probe position. At the probed position, each letter appeared on half the trials. Horizontal apparent movement of a letter could occur for one or more letters in the array. Apparent movement was accomplished by (a) presenting all 12 letters for time A1 (20 or 25 msec), (b) presenting only "stationary" letters for time IAI (70 or 75 msec), (c) presenting the "stationary" letters in their initial positions and the moved letters in their final positions for time A2 (20 or 25 msec). The initial letter position and the direction of movement left or right was determined randomly for each letter on each trial. A letter was moved one letter width, or $.44^{\circ}$. Thus, although a letter might be centered at an eccentricity of 2.6°, its initial position might be at 2.18°, 2.60°, or 3.04° eccentricity. If the letter moved, its final position might also be at one of those eccentricities. For simplicity, results will only refer to the center position, e.g., 2.6°.

The letter which was to be identified was indicated by a .61 cm or $.75^{\circ}$ long diagonal probe bar located .30 cm or $.37^{\circ}$ to the upper right and pointing to a letter position. The probe was presented after a variable blank interval of time ISI after the offset of the letter array. The probe was presented until a response key was pressed, at which time feedback as to correctness of the identification was presented in the lower right corner of the display screen.

Figure 1 shows the time course of events within each trial. Durations of times A1, IA1, and A2 adequate to produce apparent movement of letters were established during pilot testing and agree with times used to produce such motion by other researchers (e.g., Pollack, 1972; Eriksen & Colegate, 1970).

The display was observed from a distance of 46 cm. This distance was maintained by use of a chin and forehead rest adjusted to the height of the observer. Brightness of the display was kept constant at 18.85 cd/m^2. The brightness of the background of the screen was 9.42 cd/m^2 and ambient luminance from the wall surface beyond the screen was about 90 cd/m^2 as measured by a Textronix J16 digital photometer. The brightness of the display was checked frequently during the course of the experimental sessions.

Procedure. The initial session for each observer consisted of visual acuity testing using a Snellen chart followed by training to achieve at least 60 per cent correct identifications of the probed letter at time ISI = 0 when one letter moved in the array. During training, the display durations were decreased until the durations required for the experiment were reached. Letters A and K were used in the training sessions. The observer was informed that letter E and H would each appear at the probed position

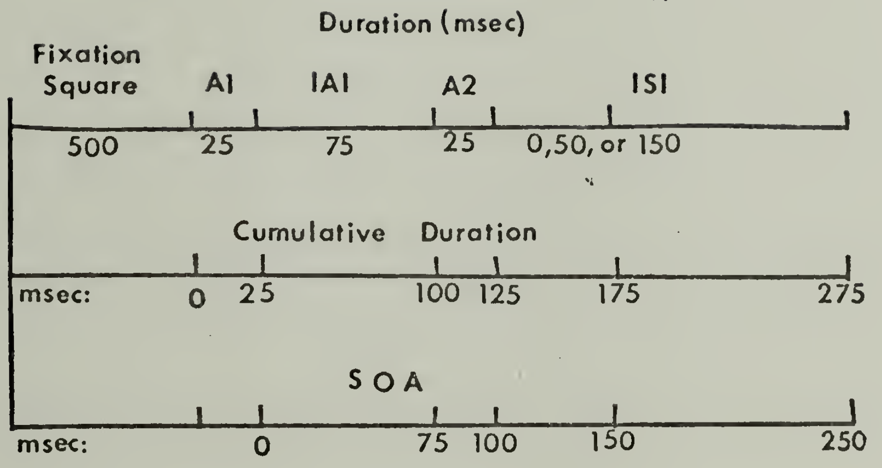

Figure 1. The time course of events within each trial. The duration of each event is shown on the first line, the cumulative duration on the second line, and the time between movement onset and probe onset on the third line.

on half of the trials, and that moved and non-moved letters would each appear at the probed position on half of the trials. Observers were instructed that it was to their advantage to pay attention to the moved letter since the moved letter was a cue to the position to be probed on half the trials. Each observer served in one training and two to eight experimental sessions of about an hour each. Each experimental session started with 24 practice trials using time ISI = 0 or 20 msec with one or no movements in the letter display unless otherwise noted. The number of correct identifications and the reaction time to a correct identification were dependent variables. Reaction time was measured from the onset of the probe to the response. Observers were told that response time was recorded but that they should emphasize accuracy. No reaction time feedback was provided.

Each trial was self-initiated by pressing one of the two response keys. Trials were presented in blocks of 48, and each block consisted of four probes at each of the 12 positions in the letter array unless otherwise noted.

For all the experiments reported in this series, accuracy and response speed were analyzed via BIOMED08V ANOVAs. Accuracy data, the proportion of correct identifications, averaged over all replications, were transformed using an arcsine transformation to fulfill the requirement of homogeneity of variance for the ANOVA.

Reaction times to correct identification were averaged over array positions for each combination of conditions in the experiment. Replications were considered as a variable in these ANOVAs, which were performed on log transformations of the reaction time data. The analysis of accuracy as a function of retinal eccentricity from fixation was carried out on the number of correct responses at each eccentricity (maximum = four responses) averaged over the replications. The ANOVA was carried out on a square root transformation of this data (Myers, 1972) to fulfill the homogeneity of variance requirements of the ANOVA. Results of ANOVAs on the raw data were similar to those on transformed data. All figures, tables, and descriptions of data in the text are presented in terms of the raw proportions of correct identifications or reaction times to a correct identification, as appropriate. The presented raw means were calculated from the transformed data means and transformed back to their raw form. Unless otherwise noted, F-ratios refer to contrast effects. For post hoc analyses, the Scheffé method was used with the recommended criterion of $p < .10$ (Myers, 1972).

Experiment I

The purposes of this experiment were (a) to demonstrate that selective attention can facilitate identification of a letter, (b) to examine some temporal parameters in the development and maintenance of selective attention, (c) to examine selective attention at different retinal eccentricities, and (d) to examine the effect of varying the number of moved letters in the letter array. In this experiment, selective attention was manipulated by moving one or more letters of the array horizontally one letter-width.[1]

Method. Five variables were varied orthogonally:

(1) probe of a moved or stationary letter (M);
(2) letter E or letter H at the probed position (L);
(3) position of the probe (P);
(4) stimulus onset asynchrony (SOA);
(5) number of moved letters in the array (NOM).

The first three variables were varied within blocks and the last two were varied between blocks. Each of the 12 letter positions was probed under each M x L condition for a total of 48 trials per block. The probability of probing a moved letter was .50, and the probability that an E or an H would be probed was .50. The temporal parameters of the display were: A1 = 25 msec, IAI = 75 msec, A2 = 25 msec. Time ISI between the offset of the letter array and the onset of the probe was 0, 50, or 150 msec. Stimulus onset asynchrony (SOA) is defined as the time between the

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[1] In a pilot experiment, letters were stationary and selective attention was manipulated by moving a dot adjacent to each letter in the array. The results of this experiment are summarized in Appendix I.

offset of moved letters in their initial positions and the onset of the probe. Thus the SOAs for this experiment were 100, 150, and 250 msec (see Figure 1). The number of letters which might have moved on each trial was 0, 1, 2, or 8 out of 12 letters in the array. The design was replicated four times for each observer, providing 2304 data points per observer. The stimuli and apparatus were described in the General Method section.

After a training session, each observer participated in eight experimental sessions consisting of 24 warm-up trials followed by six blocks of 48 trials each. The order of blocks was counterbalanced over observers and replications. Trials were randomized anew for each block.

Three students served as voluntary paid observers. They all had uncorrected normal visual acuity, were right-handed, and indicated that they were able to perceive letter movement for the temporal parameters used in this experiment.

Results

A. Does selective attention attracted to a location by movement facilitate identification of a letter at that location?

The intent was to attract selective attention to a location by making that location easily and rapidly discriminable from other locations in the display. This was attempted by changing the position of a letter at the to-be-attended location in the display. Although the change in letter position is referred to as "movement", the cue which attracts attention may be brightness onset, offset, or both offset and onset rather than change of position. These parameters are not separated in this research. Before characteristics of selective attention can be examined, one must demonstrate that selective attention can be attracted by movement. This can be demonstrated if selection facilitates identification. If selective attention is attracted by letter movement, the proportion of correct identifications should be greater for a moved than for a non-moved letter, and the reaction time to a correct identification should be smaller for a moved than for a non-moved letter.

Figure 2 shows the mean proportions of correct identifications for moved and stationary letters in each number-of-movement (NOM) condition. The proportions are averaged over the three observers. Figure 3 presents this accuracy data separately for each observer. The vertical lines in Figure 3 represent the standard errors for each observer under each NOM condition.

The interaction between letter movement (M) and the number of moved letters in the array (NOM) was significant ($F(3,6) = 18.42$, $p < .005$). When one or two letters were moved in the array of 12 letters (NOM = 1 or 2), there were more correct identifications of moved than of sta-

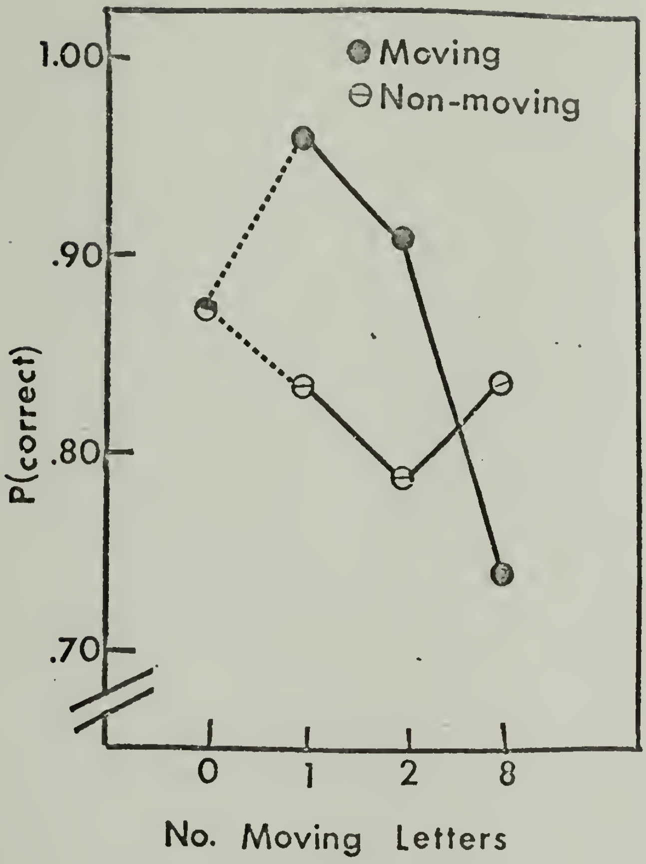
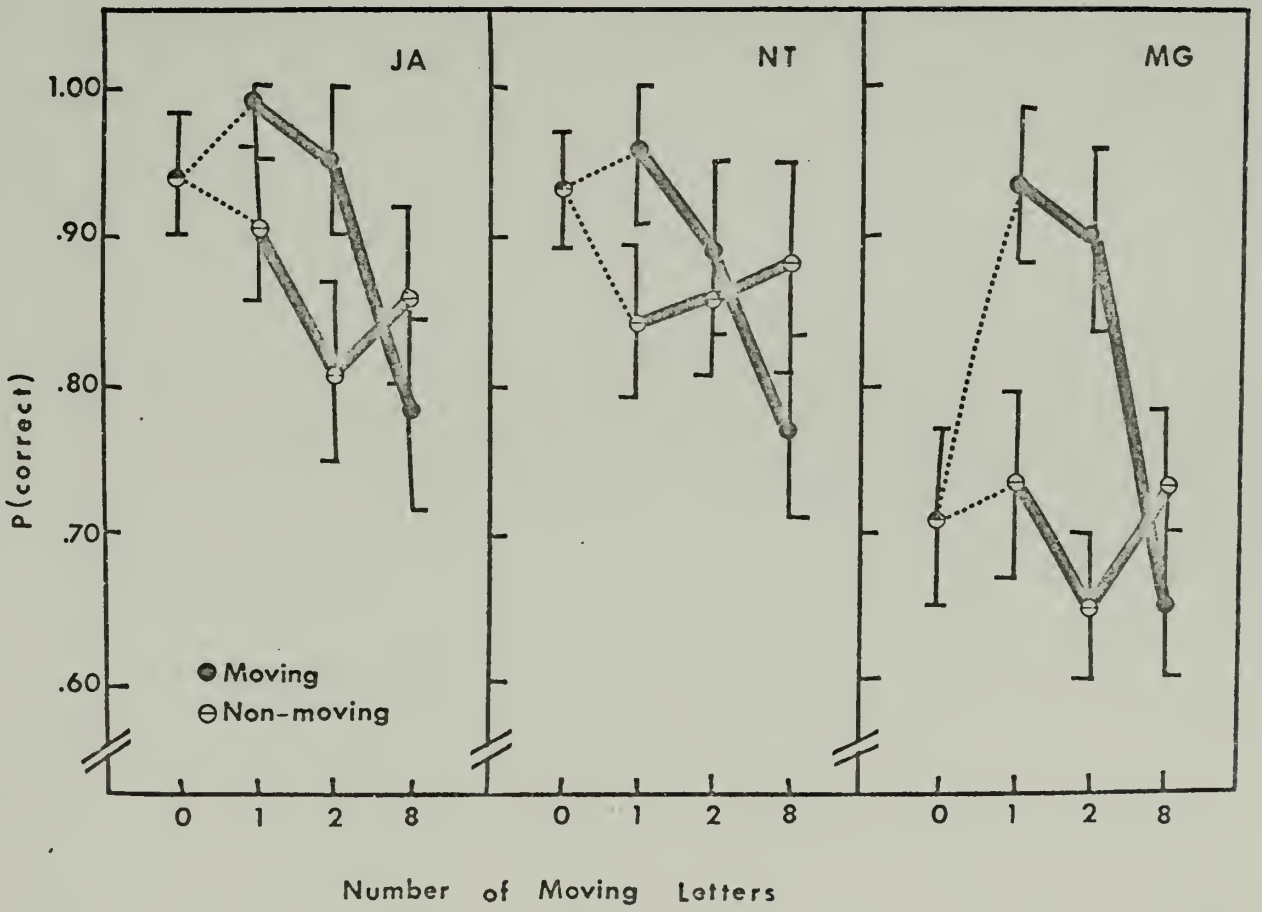


Figure 2. The proportion of correct identifications for moved and non-moved letters at each NOM condition (Experiment I).

Figure 3. The proportion of correct identifications for moved and non-moved letters at each NOM condition for each observer separately (Experiment I)



tionary letters (NOM = 1: F(1,4) = 47.88, $p < .005$; NOM = 2; F(1,4) = 32.46, $p < .005$). However, when eight of the 12 letters were moved (NOM = 8), there were more correct identifications of a stationary letter than of a moved letter (F(1,4) = 10.80, $p < .05$). The response speed is consistent with the accuracy results when one or two letters moved in the array. The interaction between the number of moved letters (NOM) and letter movement (M) was significant for reaction time (F(3,6) = 10.66, $p < .01$). Reaction time to a correct response (RT) was longer for a stationary letter than for a moved letter (NOM = 1: F(1,4) = 89.23, $p < .001$; NOM = 2; F(1,4) = 31.10, $p < .01$). However, when eight letters were moved in the array, the reaction times did not differ for correctly identifying moved and stationary letters (F(1,4) $<$ 1). Figure 4 presents the mean reaction times for moved and stationary letters at each NOM for all observers combined.

Several aspects of these results are important. First, letter movement does appear to result in better accuracy, but only when few letters moved in the field. This suggests that attention attracted by movement may facilitate encoding of features under some conditions. When many letters moved in the field, accuracy was better for stationary than for moved letters. These results raise a question about the role of movement in attracting selective attention, which will be considered in the Discussion section.

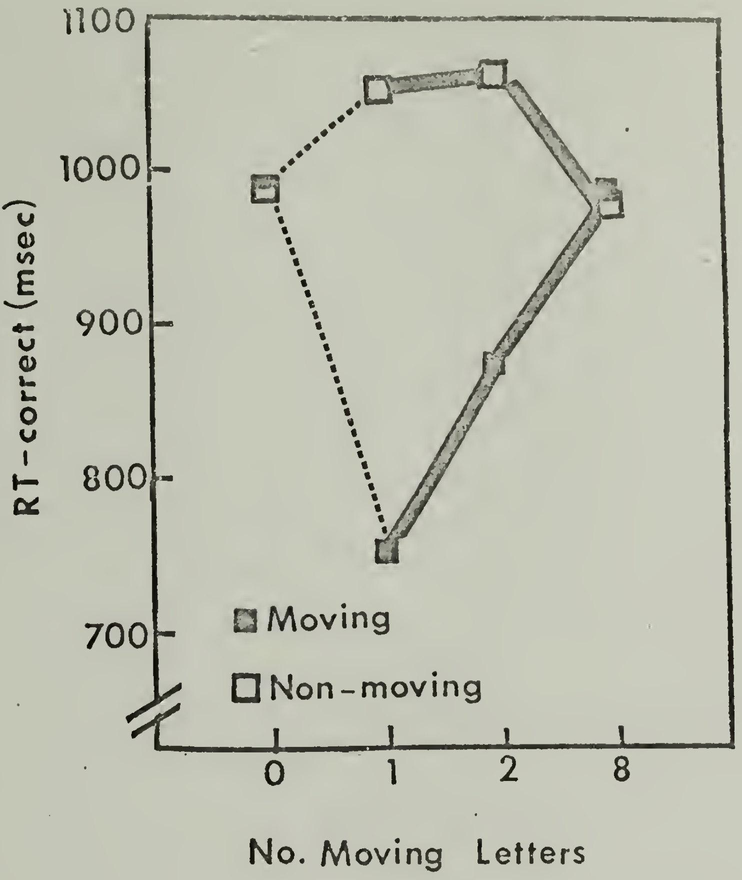


Figure 4. Reaction time to a correct identification for moved and non-moved letters in each NOM condition (Experiment I).

Second, when few letters moved, accuracy of the moved letters was facilitated despite the shorter exposure duration of moved letters (50 msec) compared to stationary letters (125 msec). If identification were a function of brightness, the brighter stationary letters should have shown an advantage over the less bright moved letters. Third, reaction time to a correct response covaried with accuracy when few letters moved in the array but not when many letters moved. This disparity between accuracy and RT may represent real differences in the way these dependent variables reflect effects of visual information processing, particularly since RT has been shown to be sensitive to movement parameters (e.g., Tolhurst, 1975a, Breitmeyer, 1975). However, since RT was not emphasized in the task instructions and no RT feedback was provided to the observers, the RT may not be as efficient a dependent variable as is accuracy.

B. <u>What are some temporal characteristics of selective attention?</u>

When a movement is perceived in the visual world, it is likely not only to attract attention but also to attract eye movement. This is a highly adaptive response for the observer since the moved object can be foveated for optimal form analysis and encoding. Acuity for form-related judgments is best when stimuli fall on the foveal area of the retina (Riggs, 1965). In order to show that the advantage in identifying moved over stationary letters in this experiment is due to selective attention (which logically precedes and may influence eye movement) rather than to eye movement itself, the displays were presented for a duration below the eye movement threshold of about 180 msec (Alpern, 1971). Further, in two conditions, both the letter array and the probe were presented for a duration shorter than eye movement latency. The duration of stationary letters was 125 msec while the duration of moved letters was 50 msec; 25 msec in the initial position, 75 msec off, and 25 msec in the final position. "Movement" of a letter in this experiment was initiated after 25 msec at the offset of the initial position and, for 75 msec, included only a brightness change at a single location. For the next 25 msec, it included a brightness change at a different location. Apparent movement cannot be evident until the onset of the moved letter in its final position. However, since attention may be attracted by temporally modulated brightness, brightness change of the "moved" letters occurs first at the offset of those letters in their initial position. Stimulus onset asynchrony (SOA) is defined for this series of experiments as the time between the offset of the moved letter in its initial position and the onset of the probe (see Figure 1). In this experiment, the SOA was 100, 150, or 250 msec. If offset of a letter initiates eye movement to the "moved" position, the eye movement cannot occur in less than about 180 msec from the letter offset. Note that the two shorter SOAs did not allow eye movement which might be cued by letter movement before the onset of the probe. The longest SOA did allow eye movement which might have been cued by letter movement. Since all observers were naive to the experimental method and were given only one hour of practice prior to the initial collection of data, it is reasonable to assume that their eye movement thresholds were greater than 150 msec.[2] Even if the eye moved while the array icon was present but before the probe appeared, the location of the probe with respect to the icon would be spatially offset by the eye movement. This is because the icon moves in the direction of the eye movement (e.g., Doerflein & Dick, 1975), and accuracy would suffer for the letter at the probed position.

It was hypothesized that the advantage of an attended over a non-attended letter would increase with SOA because

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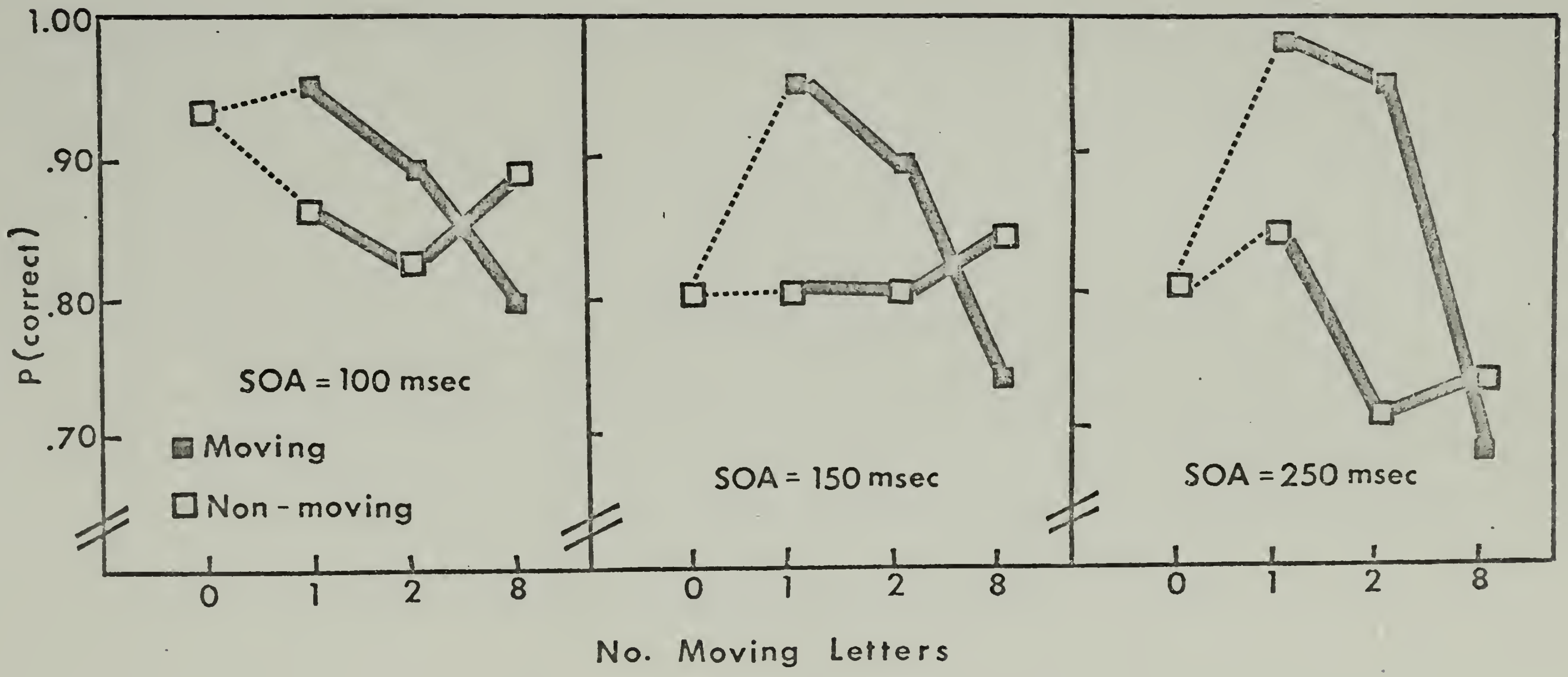
[2] Since observers participated in eight experimental sessions, it is possible that their eye movement latencies may have decreased with practice. This possibility would be supported by an increase in accuracy for moved compared to non-moved letters with each replication of the experimental design. An ANOVA was carried out in which replications were considered as a variable. The replication main effect was significant ($F(3,6) = 16.79$, $p < .005$); accuracy increased with replications. However, there was no significant replication x letter movement interaction ($F(3,6) = 1.32$,ns). One can conclude that any decrease in eye movement latency or other practice effects did not affect the letter movement variable.

selective attention would allow early initiation of feature processing, and thus feature processing would be nearer to completion when probe delay increases. Figure 5 shows the proportions of correct identifications for moved and stationary letters at each NOM condition separately for each SOA. The data is averaged over all observers. The interaction of letter movement x SOA was marginally significant ($F(2,4) = 4.33$, $p < .10$), suggesting that the advantage of a moved over a stationary letter may increase with SOA. There was no interaction between letter movement x SOA x NOM condition ($F(4,8) = 2.36$, ns). The SOA x letter movement results are consistent with the hypothesis that selective attention allows detail processing to be initiated prior to encoding of the other elements in the array so that encoding of the selected elements is nearer completion with increased SOA. One reason why the increased advantage for moved over non-moved letters with increased SOA is not more pronounced may be that encoding of a moved letter may be completed in less than 100 msec. In this case, longer SOAs offer no further advantage for the moved letter; encoding is completed for the moved letter and the remainder of the long SOA does not contribute to any advantage for moved letters.

Figure 5. Proportion of correct identifications for moved and non-moved letters at each NOM condition for each SOA separately (Experiment I)



C. What are some spatial characteristics of selective attention?

The letter array extended to about 8.7° of eccentricity in each vertical and horizontal direction. Both acuity for form and for movement decrease with eccentricity (LeGrand, 1967), and the decrease is greater on the vertical axis than on the horizontal axis, which produces horizontally elongated oblongs of isoacuity for form (e.g., Low, 1951) and velocity (McColgin, 1960). The visual acuity function is reflected by the proportions of correct identifications at the 12 positions in the letter array in this experiment. There were more identifications at horizontal than at vertical positions ($F(1,22) = 6.44$, $p < .025$) and the proportions of correct identifications decreased with eccentricity ($F(2,4) = 41.05$, $p < .005$).

There are three reasons to predict that the advantage in identifying an attended over a non-attended letter will decrease with eccentricity. First, if selective attention takes time to move to a spatial location, encoding will take longer to be initiated for more eccentric letters. This should result in a smaller advantage for attended over non-attended letters at far eccentric positions. Second, even if selective attention can move instantly to any spatial location, acuity for movement detection decreases with retinal eccentricity. Since the extent of letter movement was the same at all positions in the array, letter movement was less likely to be encoded at the more eccentric positions. This means that the advantage of attended over non-attended letters should decrease with eccentricity. Third, there may be a tendency for attention to be attracted preferentially to less eccentric positions. There is evidence that eye movements tend to be made toward letters closer to fixation. For instance, Levy-Schoen (1974) presented letters in pairs at two of 12 locations in a cross configuration with eccentricities of 7°, 14°, and 21°. Initial eye fixations were made to the letter nearest fixation three times more often than to the letter at the largest eccentricity. If eye movements are directed by a mechanism related to selective attention, it is possible that selective attention also tends to be attracted to less eccentric positions. In this case again, the advantage of attended over non-attended letters should decrease with eccentricity.

Figure 6 shows the proportions of correct identifications for moved and non-moved letters under each NOM condition separately for each eccentricity (also see Figure 10). There was no interaction between letter movement and eccentricity ($F(2,4) < 1$), nor between letter movement x eccentricity x NOM ($F(4,8) = 1.58$, ns). An examination of eccentricity x letter movement functions for each NOM condition separately revealed no interactions for NOM = 1 or 8. However, a contrast between moved and

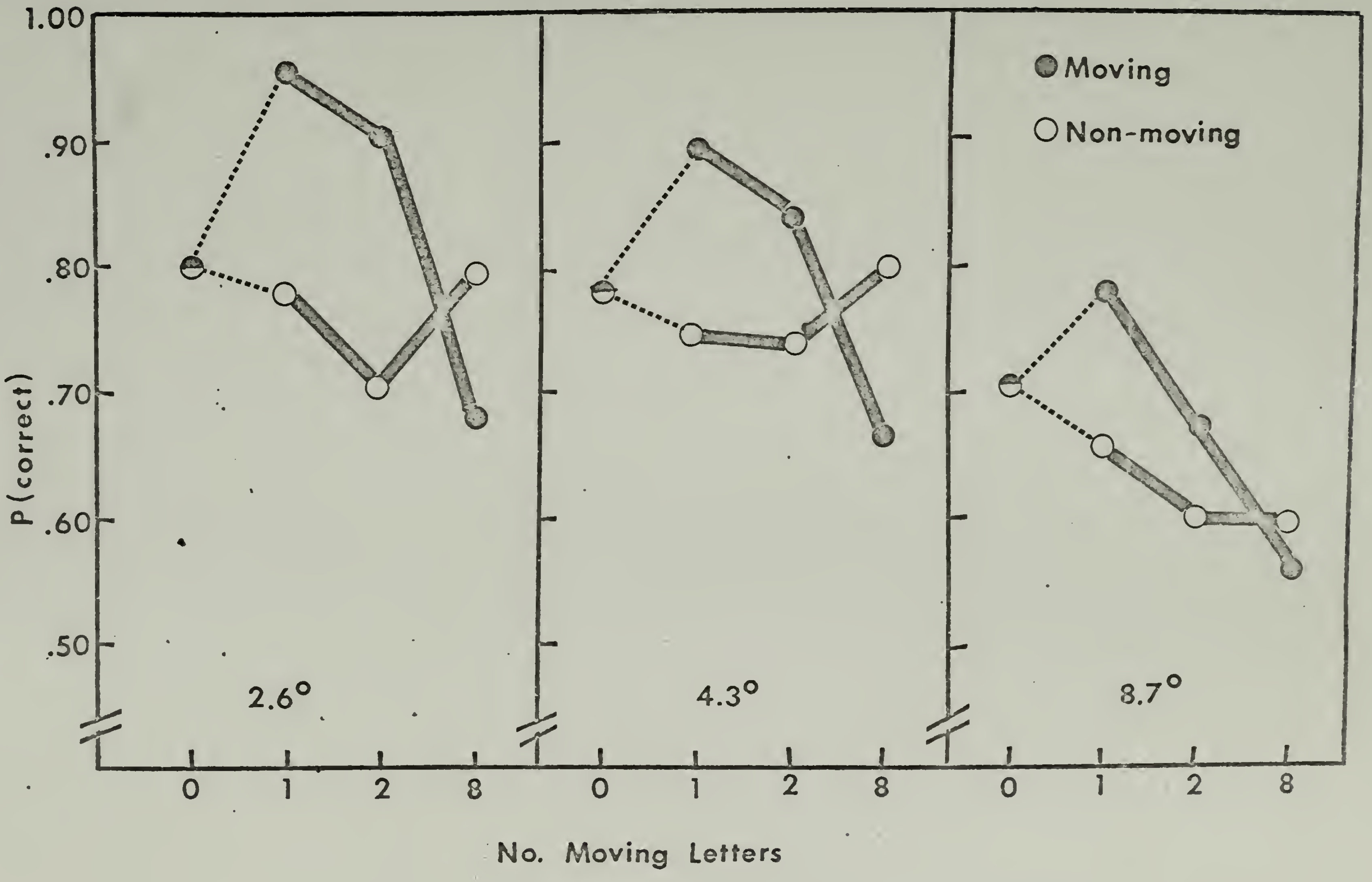


Figure 6. Proportion of correct identifications for moved and non-moved letters in each NOM condition for each eccentricity separately (Experiment I)

non-moved letters at each eccentricity when two letters moved in the array (NOM = 2) was significant at $p < .05$ post hoc using the Scheffé method (contrast: F = 40.50; Scheffé: criterion F(.05,2,4) x 4 = 27.76). This result is evidence for a decrease in the advantage of moved over non-moved letters with eccentricity when two letters moved in the array. Since the only evidence for support of the hypothesized decrease in the effect of selective attention with eccentricity is offered by the results of condition NOM = 2, it is possible that (a) this NOM condition has unique features which lead to the interaction or (b) an eccentricity analysis is not sensitive enough to test the hypothesis. (Of course, it is also possible that there is no significant eccentricity x letter movement effect and the results in condition NOM = 2 are due to chance.) With regard to the first alternative, note that condition NOM = 2 is a choice situation similar to that used by Levy-Schoen. If an observer must choose between two elements to attend, he might indeed choose the less eccentrically located element, just as Levy-Schoen demonstrated that an eye movement is made to the less eccentric of two choice elements. With regard to the second alternative, a more sensitive test of the hypothesis would be to examine the eccentricity x letter movement interaction separately under each SOA condition. If it takes longer to move to more eccentric positions (or to take advantage of the feature information there), the eccentricity x letter movement interaction should be greater at short SOAs than at long SOAs. This is because encoding of attended eccentric items does not have as much of a "headstart" over non-attended eccentric items at short SOAs; at long SOAs, the "headstart" of attended eccentric items may be adequate to produce a substantial advantage for attended items.

Table 1 shows the difference in the proportions of correct identifications between moved and stationary letters for each SOA x eccentricity in each NOM condition. When one letter moved in the array, the shortest SOA (100 msec) was sufficient for moved letters to facilitate identification of letters closest to fixation but not letters further from fixation. However, at SOAs of 150 and 250 msec, there was facilitation at all eccentricities. When two letters moved in the display, an SOA of 100 msec was not long enough for moved letters to facilitate identification at any eccentricity. However, an SOA of 150 msec was long enough for facilitation of letters at the positions closest to fixation; when the SOA was 250 msec, letters at the two smallest eccentricities were facilitated. The results when eight letters moved in the array are difficult to interpret (see Table 1).

The data presented in Table 1 is consistent with the hypothesis that the effect of selective attention on en-

Table 1

Difference in the proportion of correct identifications between moved and stationary letters for each SOA x eccentricity separately for each NOM condition (Experiment I)

	SOA(msec)		
Eccentricity	100	150	250
NOM = 1			
2.6°	$.19^{a}$	$.22^{b}$	$.19^{a}$
4.3°	.05	$.21^{b}$	$.20^{b}$
8.7°	.05	$.23^{b}$	.16
NOM = 2			
2.6°	.11	$.18^{a}$	$.34^{e}$
4.3°	.06	.01	$.28^{d}$
8.7°	.00	.12	.15
NOM = 8			
2.6°	$-.17^{a}$	-.09	-.13
4.3°	-.16	$-.23^{c}$	-.06
8.7°	.04	-.07	-.05

a: $p < .05$
b: $p < .025$
c: $p < .01$
d: $p < .005$
e: $p < .001$

coding features for identification decreases with retinal eccentricity of the letters. When the time in which selective attention could show its advantage was short, more eccentric letters accrued less of an advantage from movement. When moved letters had a longer headstart in encoding over non-moved letters, no disadvantage due to letter eccentricity was evident.

Two main points emerge from the eccentricity results. First, when one or two letters moved in the array, selective attention did not equally facilitate identification at all spatial positions. Rather, time was required for more eccentric locations to benefit from attention attracted by movement or, alternatively, attention took time to move to a spatial position. Second, when observers had to choose between two moved letters, they tended to select the less eccentric letter for priority in encoding in order to identify it.

Discussion. There were five major results of Experiment I.

(1) Moved letters showed an advantage in accuracy of identification over non-moved letters when one or two letters moved; stationary letters showed an advantage over moved letters when eight letters moved.

(2) Reaction time to a correct identification was lower for moved than for non-moved letters when one or two letters moved in the array; RT was the same for moved and non-moved letters when eight letters moved in the

array.

(3) The advantage of moved over non-moved letters tended to increase as SOA increased.

(4) The advantage of attended over non-attended letters did not vary with retinal eccentricity of the letter except when two letters moved in the array.

(5) As SOA increased, the accuracy advantage for moved letters appeared at more eccentric positions, which implies either that selective attention takes time to move or to focus spatially or time is needed for letters at more eccentric positions to benefit from selective attention.

This pattern of results might be due to attentional aspects of vision, of basic perceptual processes, of encoding or of immediate memory. It would seem appropriate to attempt to account for these results by appealing to visual processes first, perceptual processes next, and so on deeper into the cognitive hierarchy.

In order to attempt to explain these results, some questions must be asked about the mechanisms of selective attention. The alternative answers to these questions can form the assumptions upon which models of selective attention are based. In this section, three questions will be presented which form the basis for a set of models. The models will then be tested against the results of Experiment I.

First, if the purpose of selective attention is to facilitate processing of features of the selected location, and unit formation is instrumental in directing selective attention, how is selective attention allocated to the units? Two of the many alternative ways of allocating attention to units are: (1) selective attention is allocated to one unit until all elements of that unit are processed, and then it is allocated to another unit; (2) selective attention is allocated proportionally to units on the basis of the number of units in the visual field; the elements of a unit, then, receive attentional capacity in proportion to the number of elements in the unit.

Second, assume that selective attention is allocated to units proportionally on the basis of the number of units in the field. In this case, biasses for certain values of features which allow units to be formed are not relevant to the allocation of selective attention. However, if one assumes that attention is allocated to one unit before it is allocated to a second unit, then *a priori* biasses for certain features of a unit can determine which unit is processed first. The decision rule for priority in allocating attention could be "moved-letter unit first" or "smaller unit first".

Third, in this experimental approach, units are formed on the basis of letter movement. Some psychophysical and neurophysiological evidence suggests that information about movement or other temporal modulation of brightness is transmitted faster than is information about spatial modulations in the visual array. Dow (1974), for instance, found that transient visual cortical cells of the monkey, which optimally encode information about temporal modulation, show a 50 msec shorter latency than do sustained cortical cells, which optimally encode information about spatial modulation. Breitmeyer (1975) and Tolhurst (1975a) have demonstrated that the reaction time to low spatial frequency gratings is about 50 - 100 msec faster than to high spatial frequency gratings. Since transient channels are optimally responsive to low spatial frequencies as well as optimally stimulated by temporal modulation, reaction time to temporally modulated input should also be shorter than to "stationary" input. This suggests that moved letters may have a temporal advantage over stationary letters in the initiation of processing. Alternatively, processing of moved and stationary letters may be initiated at the same time.

A combination of these alternatives yields six potential models. Table 2 summarizes the questions and their alternative solutions, and shows which assumptions are used by each of the models. In the following paragraphs, the adequacy of each model in explaining the five main experimental results will be assessed.

Table 2

Alternative assumptions of models of the mechanism of selective attention

Assumptions	Model					
	1	2	3	4	5	6
1. <u>Attention Allocation:</u>						
a. each unit in turn	x	x	x	x		
b. proportionally					x	x
2. <u>Unit Selection Priority:</u>						
a. moved units first	x	x			-	-
b. small units first			x	x	-	-
3. <u>Initiation of Processing:</u>						
a. same for both units	x		x		x	
b. temporal advantage for moved unit		x		x		x

Model 1: This model assumes that all moved letters are processed before any non-moved letter is processed (1a and 2a), but that processing is initiated at the same time for moved and non-moved units (3a). Since the assumptions conflict, this model is rejected.

Model 2: The assumptions are that all moved letters are processed before any non-moved letter (1a and 2a), and that there is a temporal advantage in processing moved letters (3b). Model 2 predicts that moved letters should show an advantage over stationary letters regardless of the amount of movement in the field. Since this prediction is not supported by the accuracy data, Model 2 is rejected.

Model 3: The assumptions are that letters of the small unit are processed before letters of the large unit (1a and 2b), and processing is initiated at the same time for moved and non-moved letters (3a). The accuracy results are predicted for all NOM conditions. In addition, accuracy for stationary letters in NOM = 8 should be greater than for stationary letters in NOM = 1 and 2. A Scheffé post hoc test of the contrast of accuracy for stationary letters in NOM = 8 compared to NOM = 1 and 2 showed no difference (contrast: F = 2.25; Scheffé: criterion F (.10,3,6) x 3 = 9.87). However, a comparison of stationary letters among NOM conditions may be biassed by the overall lower accuracy as NOM increases (see Figure 2).

If letters of the small unit are processed prior to letters of the large unit, RT should be lower for the small unit in all NOM conditions. The data supports this prediction for NOM = 1 and 2 but not for NOM = 8. One can counter this anomaly in three ways: (a) since the number of non-moved letters in NOM = 8 is greater than the number of moved letters in NOM = 1 and 2, one cannot predict an RT for non-moved letters in NOM = 8, particularly since the RT x NOM function is not established; (b) RT was not emphasized in the task instructions and thus may be less sensitive than accuracy to experimental manipulations; (c) the RT for non-moved letters is significantly lower ($p < .10$ post hoc) in NOM = 8 than in NOM = 1 and 2 (contrast: $F = 14.75$; Scheffé: criterion $F(.10,3,6) \times 3 = 9.87$).

As SOA increases, the likelihood that all letters of the small unit will be processed before the probe appears increases. Model 3, then, predicts that, regardless of NOM, the advantage of letters of the small unit should increase with SOA. The data support this prediction.

At each eccentricity, the relative advantage of letters of the small unit over the large unit should be the same. The data support this prediction. If one assumes that time is needed for attention to move spatially, as SOA increases, the increased advantage of smaller over larger unit letters should predict the results presented in Table 1. At longer SOAs, the advantage of the small unit appeared at greater eccentricities, but only for NOM = 1 and 2.

Model 4: It is assumed that attention is allocated to letters of the small unit first and then to letters of the large unit (1a and 2b), and that moved letters have a temporal advantage over non-moved letters (3b). The assumptions of this model need not conflict if they are interpreted to mean that when the small unit consists of moved letters, processing is initiated at time (t), and when the small unit consists of stationary letters, processing is initiated at time (t + x), where (x) represents the temporal advantage of moved letters. Nevertheless, the letters of the small unit are processed prior to those of the other unit. Implications of the "temporal advantage" assumption cannot be adequately tested on the data of Experiment I because two variables, the number of letters in the small unit and whether or not those letters moved, are not varied orthogonally. Under this interpretation, Model 4 would make the same predictions as Model 3.

Model 5: It is assumed that attention is allocated proportionally to units (1b) and there is no temporal advantage for moved over stationary letters in the initiation of processing (3a). An accuracy advantage for moved letters is predicted when there are few moved letters in the array because the amount of attention per letter is greater for few than for many letters in a unit. When there are many letters in a unit (NOM = 8), there should be an advantage for non-moved over moved letters. The data support these predictions.

This model accounts for the RT advantage for moved over non-moved letters in NOM = 1 and 2. When more attention is allocated to a letter, the rate of processing may be increased so that an identification decision should be reached sooner. Following this reasoning, the model predicts that in conditions NOM = 8, RT for non-moved letters should be shorter than for moved letters, a prediction which is not supported. Further, in the control condition NOM = 0, where attention was presumably allocated equally to each of the 12 letters, the amount of attention per letter is less than in the other NOM conditions, so the RT should be greater in condition NOM = 0 than in the other NOM conditions. A contrast F-test shows no difference in RT between NOM = 0 and the other NOM conditions ($F(1,2) < 1$).

As SOA increases, more time is available for letters to be processed before the probe appears. In NOM = 1 and 2, where each moved letter has more attention allocated to it than each non-moved letter, processing of moved letters is more likely to be completed before the probe appears. The advantage of moved over stationary letters should increase with SOA, as is suggested by the results. When eight letters move (NOM = 8), each moved letter has less attentional capacity than non-moved letters and the rate of processing should be slower for moved letters. The probability that a letter will be processed before the probe appears should increase with SOA and be higher for non-moved than for moved letters. This leads to the prediction that non-moved letters should show an increased advantage over moved letters with SOA, which is supported by the results.

This model predicts no difference in the relative accuracy of moved and non-moved letters with eccentricity, a prediction which is supported by the results.

In order to explain the results presented by Table 1, it is necessary to assume that time is needed for attention to move spatially. Model 5 predicts that the advantage of letters of the small unit will increase with SOA. As SOA increases, attention can move further and more eccentric letters will increasingly benefit from the processing advantage for small units. This prediction holds for NOM = 1 and 2 but is not clear for NOM = 8.

<u>Model 6</u>: It is assumed that attention is allocated proportionally to units (1b) and processing of moved letters

is initiated earlier than is processing of stationary letters (3b).

The accuracy results for each NOM condition are predicted by Model 6. Since less attention is allocated to each non-moved letter in conditions NOM = 1 and 2 than in NOM = 0, accuracy should be lower for non-moved letters in NOM = 1 and 2 than in NOM = 0. Similarly, accuracy should be greater for non-moved letters in NOM = 8 than in NOM = 0. However, a Scheffé post hoc test of the contrast of accuracy for non-moved letters in NOM = 0 compared to the other NOM conditions shows no difference in accuracy (contrast: $F = 4.51$; Scheffé: criterion F $(.10,3,6) \times 3 = 9.87$). The comparison of non-moved letters across NOM conditions may be biassed by the decrease in overall accuracy as NOM increases.

Since processing of moved letters starts before non-moved letters, reaction time for moved letters should be shorter than for non-moved letters. However, when NOM is large, an early processing advantage for moved letters may be masked by a faster rate of processing of non-moved letters, which is a result of a greater allocation of attention to each of the non-moved letters. The RT results for all NOM conditions can reasonably support these predictions.

As SOA increases, the advantage of moved over non-moved letters should increase in NOM = 1 and 2. Because more attention is allocated to moved letters, the rate of processing their features is faster than for non-moved letters. As the SOA increases, this rate difference increases the advantage of moved over non-moved letters. In condition NOM = 8, the early initiation of processing of moved letters provides a constant headstart in all three SOA conditions. Since the rate of processing non-moved letters is higher than for moved letters, the advantage of non-moved over moved letters should increase with SOA in NOM = 8. However, the amount of attention per letter is more similar for moved and non-moved letters in NOM = 8 than in NOM = 1 and 2. This implies that, in NOM = 8, the increased advantage of non-moved over moved letters with SOA will be smaller than the advantage of moved over non-moved letters in NOM = 1 and 2. The data support the former predictions. Although there is no letter movement x SOA x NOM interaction, there is a tendency to support the latter prediction.

On the basis of the assumptions stated for this model, there is no reason to predict an eccentricity x letter movement effect. However, one may additionally assume that acuity decreases at a faster rate with eccentricity for moved than for stationary letters. This implies that there should be a decreased difference for NOM = 1 and 2 and an increased difference for NOM = 8 between moved and non-moved letters. The results show no changes in the difference between moved and non-moved letters with eccentricity for Experiment I. The increase in the advantage of moved over non-moved letters with SOA, however, should predict the results presented in Table 1.

Models 1 and 2 fail to predict the basic accuracy results of Experiment I. Model 3 cannot adequately test the possible temporal advantage of moved elements. Model 4 may be interpreted in several different ways, one of which makes the same predictions as Model 3. The predictions of Models 5 and 6 appear to best fit the results, but Model 6 provides a better explanation of the RT results.

Of the above models, then, the one which best accounts for the data of Experiment I assumes that selective attention is allocated proportionally to units on the basis of the number of units in the field, and that there is a temporal advantage in the initiation of processing of moved letters.

CHAPTER III

MOVEMENT AS AN ATTENTION ATTRACTOR

In the first experiment, the number of moved letters in the letter array was varied, but did not allow a comparison of the relative contributions of movement and heterogeneity to the mechanism of selective attention in facilitating encoding. That is, an analysis of results on four heterogeneous non-moved letters (NOM = 8 of Experiment I) compared with one (NOM = 1) or two (NOM = 2) heterogeneous moved letters does not allow an analysis of the relative effects of movement and of heterogeneity in selective attention.

Experiment II was designed to further examine the effect of varying the number of moved letters in the array and, in particular, to assess the roles of heterogeneity and movement in selective attention during early stages of visual information processing. There were two experimental conditions, (a) all letters were stationary but for one (NOM = 1) and (b) all letters changed position but for one (NOM = 11). The first experimental condition was the same as NOM = 1 in Experiment I. The model which best fit the data of the first experiment assumed that selective attention is allocated proportionally to the units and processing of moved letters starts before processing of non-moved letters. In condition NOM = 1 of the present experiment, moved letters should benefit both from a temporal advantage for moved stimuli and from a large proportion of attentional capacity per letter. In condition NOM = 11 of Experiment II, proportionally more attention is allocated to the non-moved letter, but there may be a temporal advantage for moved over non-moved letters. The difference between the two experimental NOM conditions should reflect the relative contributions of a bias in favor of movement and of the allocation of attentional capacity to facilitate processing. To the extent that movement *per se* contributes to the effect of selective attention on encoding of features, there should be an asymmetry in the results of conditions NOM = 1 and 11.

If, in addition, it is assumed that processing of moved letters is initiated before the probe appears, but processing of non-moved letters is only initiated after the probe appears, accuracy for non-moved letters in the experimental conditions should not differ, and should be the same as for letters in a control condition in which all letters are stationary (NOM = 0). Similarly, if all letters of the array change position (NOM = 12), attention should also be equally allocated to each letter, but there may be a temporal advantage in processing compared to when all letters are stationary. These two control conditions, NOM = 0 and 12, are included in Experiment II.

Method. Four variables were varied orthogonally in this experiment:

(1) probe of a moved or a non-moved letter (M);
(2) letter E or H at the probed position (L);
(3) position of the probe (P);
(4) number of moved letters (NOM).

The first three variables were varied within blocks, and the last was varied between blocks. The apparatus and stimuli were the same as for Experiment I. Temporal parameters for the presentation of letters and probe were: A1 = 25 msec, IAI = 75 msec, A2 = 25 msec, and ISI = 50 msec. The SOA was always 150 msec. The four number of movement conditions (NOM) described above were used in this experiment: NOM = 0, 1, 11, 12.

Each observer took part in a training session as described in the General Method section. In addition, a 24-trial block was presented with instructions to report whether or not movement occurred at the probed position, regardless of which letter was presented. The purpose of these trials was to ensure that the observer could perceive letter movement under the temporal parameters used in this experiment. There were two experimental sessions after the training session. In one session, conditions NOM = 0 and 1 were presented. In the other session, conditions NOM = 11 and 12 were presented. When one letter moved in the array (NOM = 1) observers were told it was to their advantage to pay attention to the moved letter because it cued the position to be probed on half the trials. When eleven letters were moved (NOM = 11) observers were instructed that it was to their advantage to pay attention to the stationary letter. Each test session was preceded by 24 warm-up trials for each NOM condition presented in that session. The probe of a moved or a non-moved letter, the occurrence of letter E or H at the probed position, and the position to be probed were varied within blocks to produce 48 trials per block. The number of moved letters was a between-block variable. The design was replicated three times for a total of six blocks of 48 trials each in each of the two experimental sessions. There were 576 data points per observer. The order of presentation of NOM blocks was counterbalanced over observers and replications.

Four undergraduate students served as unpaid volunteers in this experiment. They received experimental credit toward a course grade for participation. Each observer had uncorrected normal visual acuity, was right-handed, was able to perceive movement of the letters in the display, and was naive to the experimental method.

<u>Results</u>. The mean proportions of correct identifications of moved and stationary letters in each NOM condition is presented in Figure 7. The interaction of letter movement

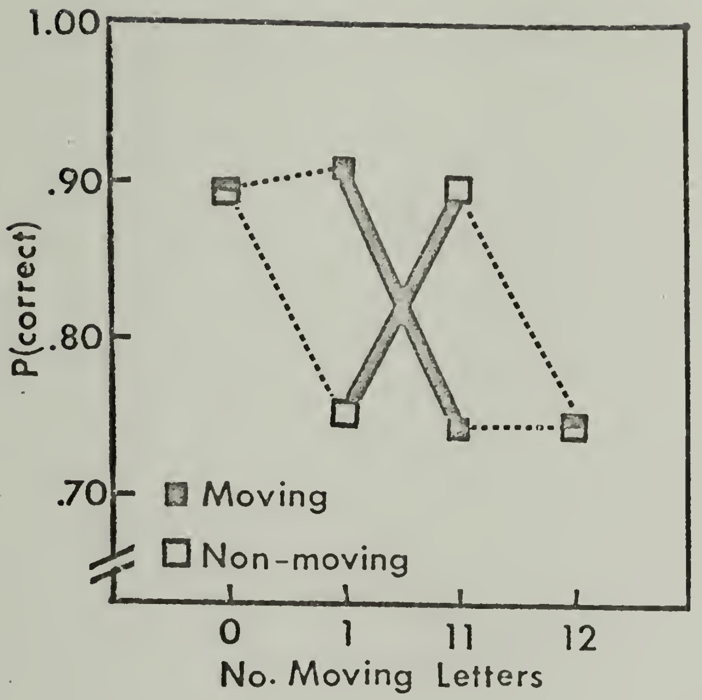


Figure 7. Proportion of correct identifications in each NOM condition (Experiment II).

x NOM was significant ($F(3,9) = 12.77$, $p < .005$). When only one letter in the array moved, identification of moved letters was facilitated compared to non-moved letters ($F(1,9) = 21.37$, $p < .005$). When only one letter in the array was stationary, identification of non-moved letters was facilitated compared to moved letters ($F(1,9) = 24.59$, $p < .01$). The extent of the facilitation was not different for the two experimental NOM conditions ($F(1,3) < 1$). The proportion of correct identifications for a moved letter was lower when eleven letters moved in the array compared to when only one letter moved in the array ($F(1,9) = 22.88$, $p < .001$), and the accuracy for a stationary letter was lower when one letter moved than when eleven letters moved ($F(1,9) = 13.39$, $p < .01$).

The reaction time to a correct response for moved and stationary letters in each NOM condition is presented in Figure 8. The interaction of letter movement x NOM was significant for RT ($F(3,9) = 17.39$, $p < .001$). When one letter moved in the array, the RT to a correct identification of the single moved letter was shorter than to a stationary letter ($F(1,9) = 57.44$, $p < .001$). However, there was no difference in RT between moved and stationary letters when all letters but one moved in the array ($F(1,9) = 2.92$, ns). RT did not differ when all letters in the array were stationary (NOM = 0)and when they all moved (NOM = 12) ($F(1,9) < 1$). However, the accuracy main effect

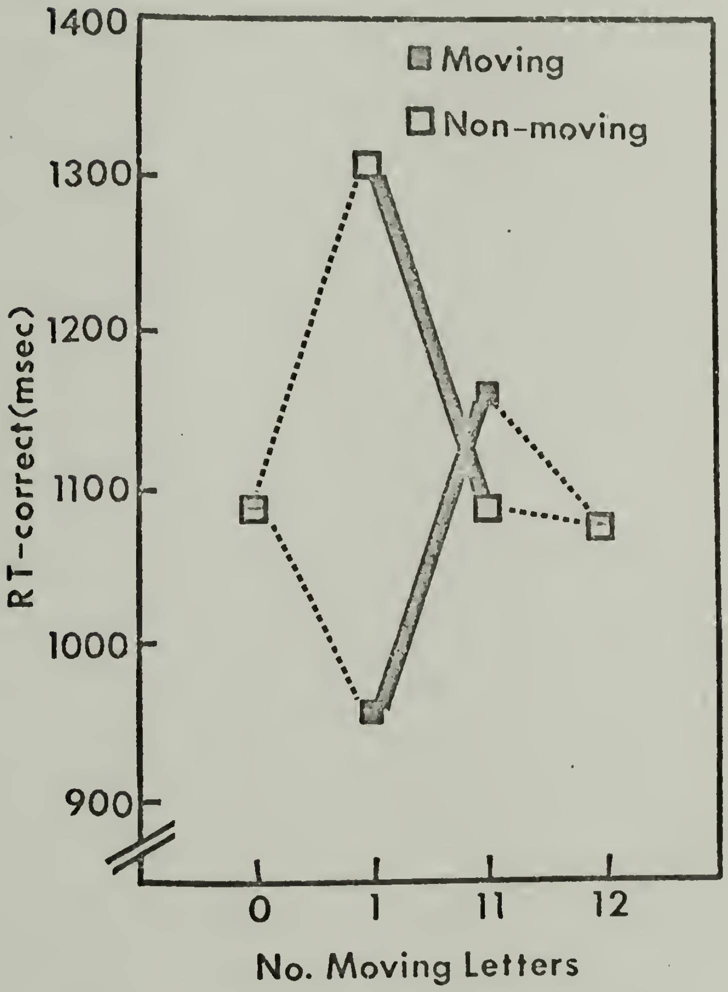


Figure 8. Reaction time to a correct identification for each NOM condition (Experiment II)

for NOM was significant ($F(3,9) = 4.79$, $p < .05$) and accuracy was lower when all letters moved than when all letters were stationary ($F(1,9) = 13.90$, $p < .005$) (see Figure 7).

In Experiment I, the difference between moved and non-moved letters in the different NOM conditions was constant over eccentricity, although the overall accuracy decreased with eccentricity. The results of Experiment II are similar. In Experiment II, accuracy decreased as the eccentricity of the probed letter increased ($F(2,6) = 9.76$, $p < .025$), but there was no letter movement x NOM x eccentricity interaction ($F(6,18) < 1$). Figure 9 shows the mean proportions of correct responses for moved and stationary letters at each eccentricity separately for NOM = 1 and NOM = 11. The eccentricity function for NOM = 0 is plotted on the NOM = 1 panel and the eccentricity function for NOM = 12 is plotted on the NOM = 11 panel.

Two comparisons of the difference between moved and non-moved letters are of particular interest for testing predictions of models of selective attention. First, the simple contrast of moved vs. non-moved letters in NOM = 1 at the positions nearest fixation (2.6° eccentricity) was significant ($p < .10$ post hoc) (contrast: $F = 15.01$; Scheffé: criterion $F(.10,6,18) \times 6 = 12.78$). However, there was no difference between moved and non-moved letters at the smallest eccentricity for condition NOM = 11.

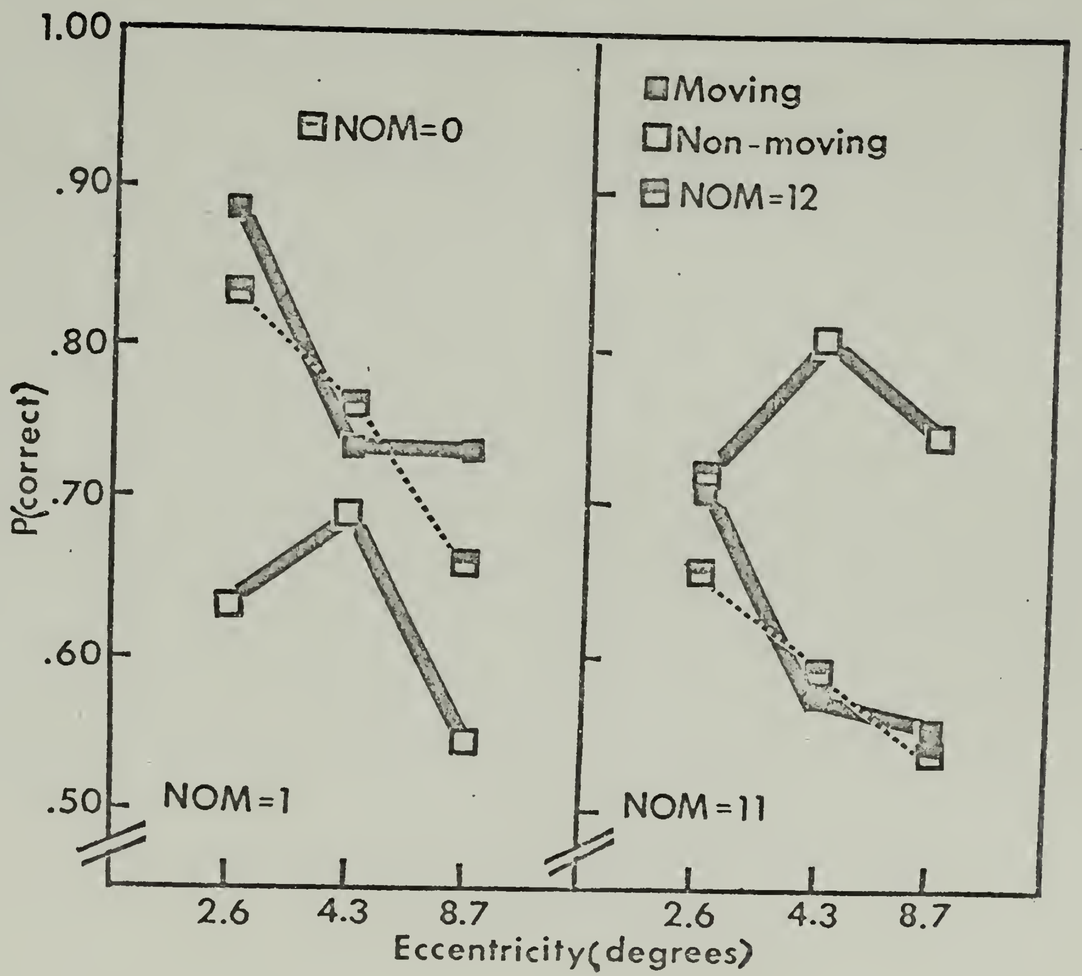


Figure 9. Proportion of correct identifications for moved and non-moved letters at each eccentricity for NOM = 1 and 11 separately (Experiment II)

Second, the simple contrast of moved vs. non-moved letters in condition NOM = 11 at the middle eccentric positions (4.3°) was significant at $p < .10$ post hoc (contrast: $F = 12.91$; Scheffé: criterion $F(.10,6,18) \times 6 = 12.78$). However, there was no difference between moved and non-moved letters at the middle eccentricity for condition NOM = 1. No other simple contrasts between moved and non-moved letters in this interaction were significant using the post hoc criterion.

The eccentricity functions for Experiment I are replotted in Figure 10 in terms of accuracy for moved and non-moved letters at each eccentricity, separately for each NOM condition of that experiment. This figure is presented for comparison with the eccentricity functions of Experiment II. Although the eccentricity functions for moved and non-moved letters appear to differ both in Experiments I and II, there was no significant interaction between letter movement and eccentricity in either experiment.

Discussion. There are several important aspects of the results of Experiment II. First, accuracy of identification was facilitated for the heterogeneous letter in both NOM conditions, and the facilitation was the same in these symmetric conditions. This result is unlike the results of Experiment I, where accuracy for a non-moved letter did not vary with NOM. Rather, in Experiment II,

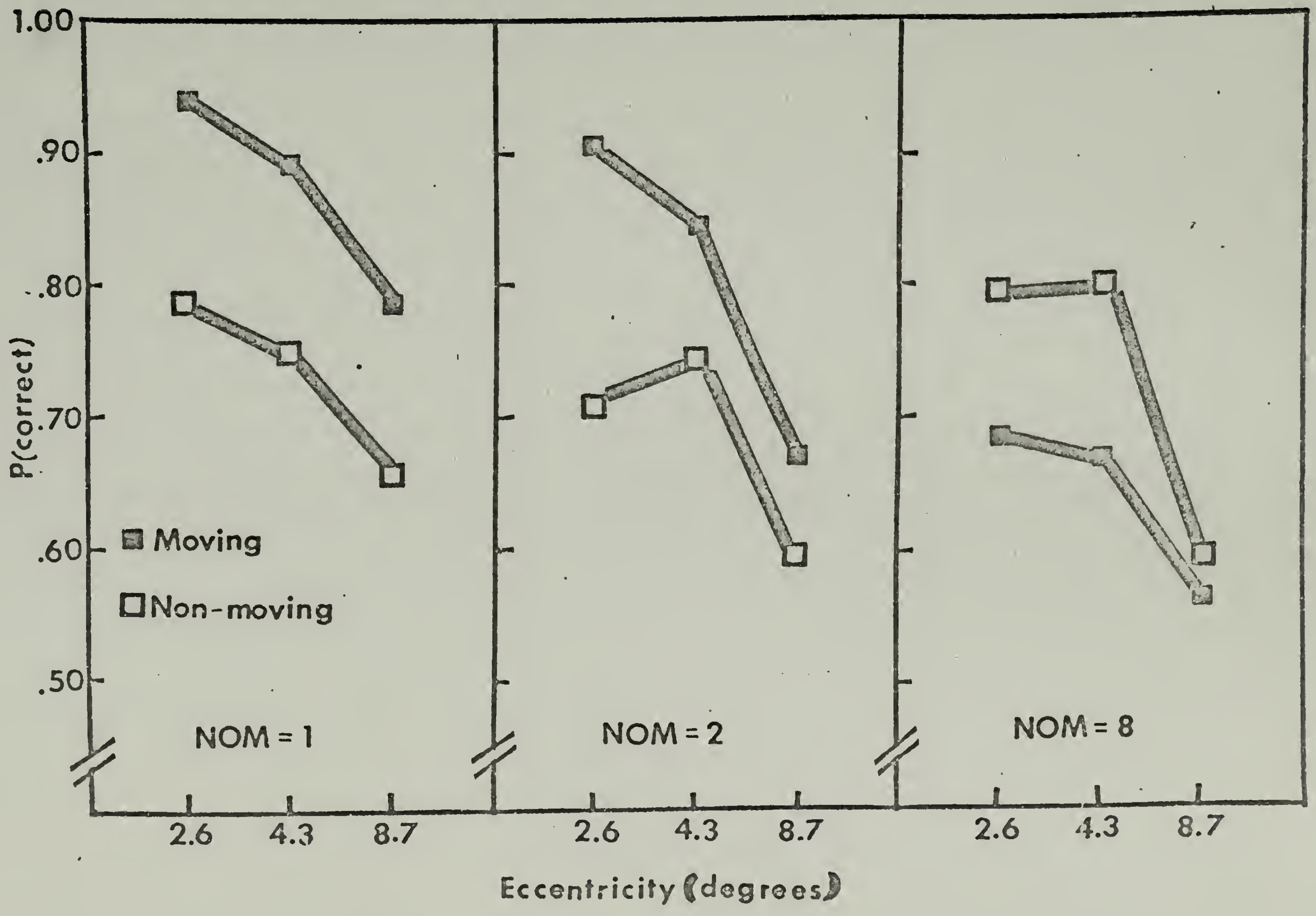


Figure 10. Proportion of correct identifications for moved and non-moved letters at each eccentricity for NOM = 1, 2, and 8 separately (Experiment I).

accuracy for a non-moved letter in condition NOM = 11 was greater than for a non-moved letter in condition NOM = 1. This result is inconsistent with the hypothesis that processing of non-moved letters starts after the probe is presented, since that hypothesis would predict the same accuracy for non-moved letters in both experimental NOM conditions. Unlike the results of Experiment I, when no letters moved in the array (NOM = 0), accuracy was very high in Experiment II. This result may mean that there is a ceiling to accuracy results in Experiment II so that relative differences between moved and stationary letters in the experimental conditions may be underestimated.

Second, reaction time was lower for moved than for non-moved letters in NOM = 1 but there was no difference between them in NOM = 11. This result is similar to that of Experiment I (compare Figures 4 and 8).

Third, the difference in accuracy between moved and stationary letters in the two experimental NOM conditions did not vary with eccentricity. However, two contrasts were significant: (a) the advantage of moved over non-moved letters for NOM = 1 at the smallest eccentricity, and (b) the advantage of non-moved over moved letters for NOM = 11 at the middle eccentricity.

Fourth, accuracy was better when all letters were stationary compared to when they all moved, but RT was the same for these two control conditions. These results may imply that a temporal advantage for moved letters is not additive with an effect of heterogeneity in implementing processing by selective attention mechanisms. Had these effects been additive, one would have expected better accuracy and shorter RT for NOM = 12 compared to NOM = 0. The obtained results may reflect poorer acuity for moved letters. If, in addition, attention is allocated proportionally to units, accuracy for the heterogeneous letters of the experimental NOM conditions should have been greater and accuracy for the homogeneous letters should have been smaller, compared to accuracy in the single-unit control NOM conditions. However, accuracy when all letters were stationary was no different from the heterogeneous letters of the experimental NOM conditions, while accuracy when all letters moved was no different from the homogeneous letters of the experimental NOM conditions.

The results of both Experiments I and II are best accounted for by Model 6. This model predicts the accuracy advantage of heterogeneous over homogeneous letters in the experimental NOM conditions. Since the advantage was the same in both NOM conditions (see Figure 7), the temporal advantage for moved letters appears to play a minor role in determining accuracy. However, the asymmetry in RT between NOM conditions (see Figure 8) depends on both the "movement" and the "allocation" assumptions of the selective attention models. The post hoc tested contrast effects of the eccentricity results in Experiment II offer some support for the eccentricity function predictions of Model 6. For Model 6, additionally assume that acuity decreases at a faster rate with eccentricity for moved than for non-moved letters. There should be a decreased difference between moved and stationary letters with eccentricity for NOM = 1 and an increased difference with eccentricity for NOM = 11. The only two contrasts which are significant by a post hoc criterion are consistent with these predictions (see Figure 9).

CHAPTER IV

TEMPORAL PARAMETERS

In Experiment I, the effect of letter movement on identification of moved and stationary letters was examined at three values of the stimulus onset asynchrony (SOA), the interval between the offset of moved letters in their initial positions and the onset of the probe. In the first experiment, SOAs were 100, 150, and 250 msec. When one or two letters moved in the 12-letter array, the advantage of moved over stationary letters was present at all three SOAs, and tended to increase as SOA increased. The purpose of Experiment III was to examine the advantage of moved over stationary letters when one letter moved in the array at a wider range of SOAs. The lower limit of SOA is constrained by the temporal parameters needed to produce apparent movement of a letter in the display. In Experiment III, SOAs ranged from 90 to 590 msec.

Method. Five variables were orthogonally varied:

(1) probe of a moved or a stationary letter (M);
(2) letter E or H at the probed position (L);
(3) position of the probe (P);
(4) stimulus onset asynchrony (SOA);
(5) number of moved letters (NOM).

The first three variables were varied within blocks, and the last two were varied between blocks. Temporal parameters for the presentation of letters and probe were:

A1 = 20 msec, IAI = 70 msec, A2 = 20 msec, ISI = 0, 20, 40, 60 or 500 msec. Thus the SOAs were 90, 110, 130, 150 and 590 msec. Each SOA block was presented with either one (NOM = 1) or no (NOM = 0) moved letters, for a total of ten blocks of 48 trials each in each test session. The apparatus and stimuli were the same as in the other experiments. The training session, which included a test of movement perception as in Experiment II, was followed by three experimental sessions. The design was replicated three times for each observer for a total of 1440 data points for each observer, half of which were in the NOM = 1 condition.

Four students who had not participated in the previous experiments served as paid volunteer observers. They all had normal uncorrected visual acuity, were able to see movement in the display, and three were right-handed.

Results and Discussion. Figure 11 shows the mean proportions of correct identifications for moved and stationary letters at each SOA when one letter moved in the array. It also shows the accuracy at each SOA for letters in the control condition where all letters were stationary (NOM = 0). There are several results of interest. First, the interaction between letter movement and SOA is significant, ($F(1,3) = 31.29$, $p < .025$). At all SOAs, more moved letters were correctly identified than were stationary letters

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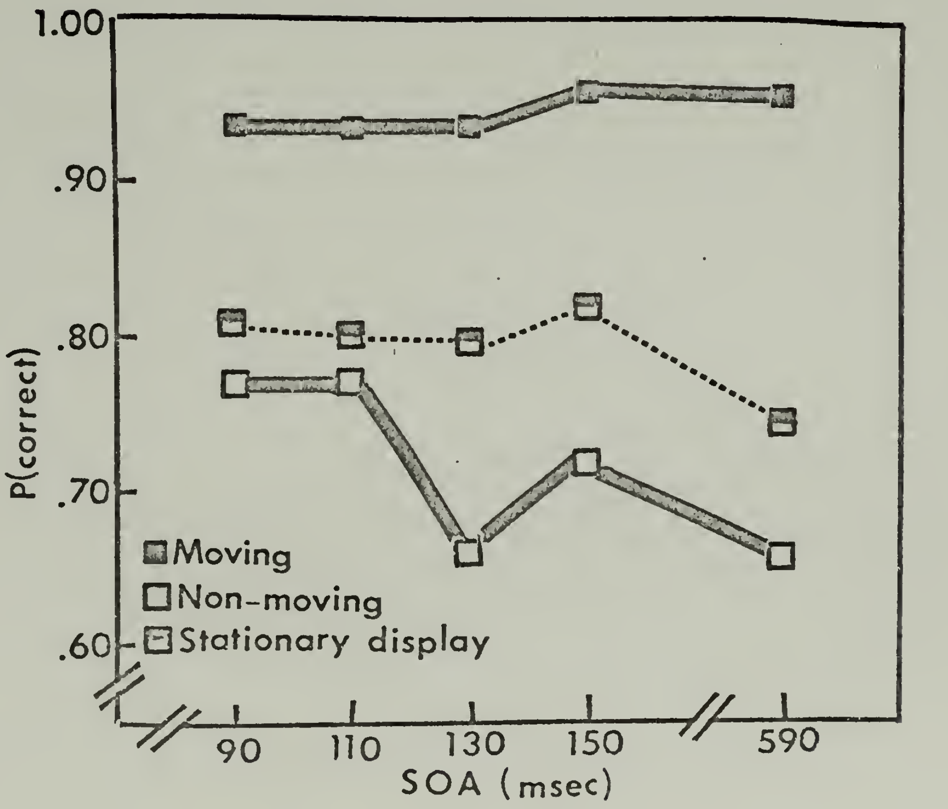

Figure 11. Proportion of correct responses to moved and non-moved letters at each SOA. Half-filled squares represent accuracy when no letters moved in the array (Experiment III).

($p < .001$ for all SOAs in simple contrast tests). Second, the advantage of moved over stationary letters was greater at SOAs of 130 to 590 msec than at SOAs of 90 and 110 msec as tested post hoc by the Scheffé method (contrast: $F = 12.94$; Scheffé: criterion $F(.10,4,12) \times 4 = 9.92$).

As in Experiments I and II, overall accuracy decreased with eccentricity of the probed letter in Experiment III ($F(2,6) = 9.27$, $p < .025$). The results of Experiments I and II showed no interaction of letter movement x eccentricity, although the models which best accounted for the data of those experiments predicted such an interaction. In Experiment III, there was a marginal interaction of letter movement x eccentricity ($F(2,6) = 4.01$, $p < .10$). Figure 12 shows the mean proportions of correct identifications for moved and non-moved letters at each eccentricity. Surprisingly, the accuracy of stationary letters is not different at the three eccentricities when one letter moved in the array (contrast: $F < 1$; Scheffé: criterion $F(.10, 2,6) \times 2 = 6.92$) or when all letters were stationary ($F(2,6) < 1$). The decreased advantage of moved over stationary letters with eccentricity is consistent with the additional assumption of Model 6. That is, acuity decreases at a faster rate with eccentricity for moved than for non-moved letters.

The results of Experiment I suggested that when one or two letters moved in the array, the advantage of moved

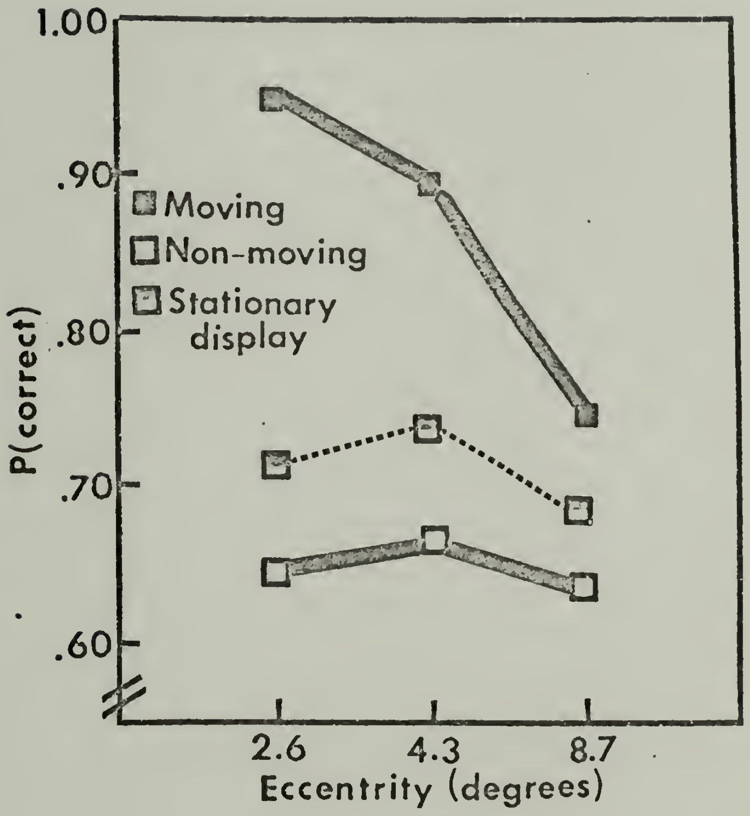

Figure 12. Proportion of correct identifications for moved and non-moved letters at each eccentricity. Half-filled squares represent accuracy when all letters in array were stationary (Experiment III)

over non-moved letters was present for more eccentric letters as SOA increased (see Table 1). Figure 13 presents the mean proportions of correct responses for moved and stationary letters at each SOA separately for each eccentricity in Experiment III. There is no significant interaction between letter movement x SOA x eccentricity (F(8,24) = 1.26, ns). However, since this interaction is of particular interest with regard to the hypothesis that time is needed for encoding of eccentric letters, simple contrast tests were carried out for moved and non-moved letters at each SOA x eccentricity. The *difference* in accuracy between moved and non-moved letters at each SOA x eccentricity combination is presented in Table 3. For the three shortest SOAs, the advantage of moved over non-moved letters was present at the two nearest eccentric positions, but not at the largest eccentricity. However, for SOAs of 150 and 590 msec, the advantage occurred at all three eccentricities. These results are consistent with those of Experiment I presented in Table 1. They suggest that time is needed for selective attention to move to or focus on more eccentric positions for processing their features.

The increase in the advantage of moved over non-moved letters with SOA can be accounted for by assuming that selective attention is allocated proportionally according to the number of units in the array. Assume that the rate

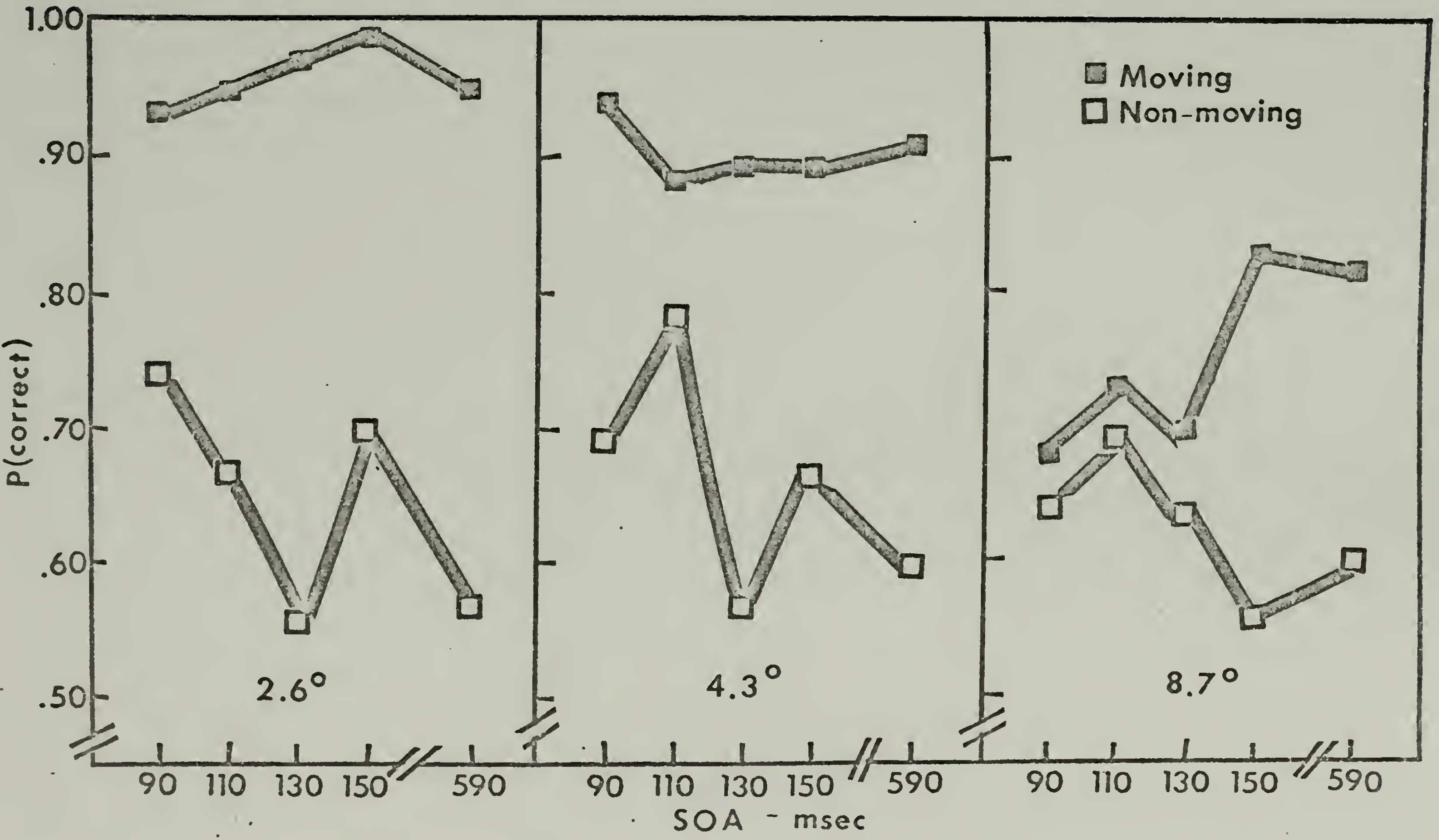

Figure 13. Proportion of correct identifications for moved and non-moved letters at each SOA separately for each eccentricity (Experiment III)

Table 3

Difference in proportions of correct identifications between moved and stationary letters at each SOA x eccentricity (Experiment III)

	SOA(msec)				
Eccentricity	90	110	130	150	590
2.6°	$.19^b$	$.28^c$	$.41^c$	$.29^c$	$.38^c$
4.3°	$.25^c$	.10	$.32^c$	$.22^b$	$.31^c$
8.7°	.04	.04	.07	$.27^b$	$.22^a$

a: $p < .025$

b: $p < .005$

c: $p < .001$

of processing of features of a letter is increased when more attention is allocated to that letter. As the SOA increases, letters processed rapidly are more likely to be sufficiently processed for the purpose of identification before letters which are processed at a slower rate. Thus the probability of processing moved letters should increase over the probability of processing non-moved letters as SOA increases. The data are consistent with this interpretation.

There are two other interesting aspects of these results. First, if the advantage of moved over non-moved letters increases with SOA as a result of the difference in rate of processing the two classes of letters, the difference in accuracy between moved and non-moved letters x SOA should describe a smooth function. Instead, the data appear to describe a step function which changes abruptly when SOA is 130 msec. It is possible that the accuracy of non-moved letters at an SOA of 130 msec is lower than expected because of chance fluctuation. However, there was no significant difference in the accuracy of stationary letters for SOAs from 130 to 590 msec. Further, the apparent increased accuracy for non-moved letters when SOA is 150 msec may be because the ISI for this condition, 60 msec, is optimal to produce apparent movement between the letter and the probe bar. This temporal modulation of the array might facilitate encoding at an SOA of 150 msec just as it has been proposed to facilitate processing of moved letters in this experiment.[3] It is also possible that moved letters have already been processed by an SOA of 130 msec but processing of non-moved letters from the icon of the letter array is still going on at that time. The icon may be sufficiently decayed at an SOA of 130 msec to decrease the accuracy with which non-moved letters can be identified.

A second point of interest is that the advantage of moved over non-moved letters is evident when the SOA is as long as 590 msec. The results of Experiment II suggested that processing of non-moved letters begins before rather than after the probe appears. This result is consistent with that conclusion of Experiment II; accuracy did not differ from SOAs of 130 to 590 msec. The result that accuracy for moved letters is maintained at a high level when the SOA is as long as 590 msec implies that the product of encoding is stored for some period of time. Mechanisms of selective attention in early visual processing may affect the speed with which the features of a letter are encoded but, once encoded, these features, or the products of encoding, are stored for some time.

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[3] This interpretation was suggested by Bill Eichelman.

CHAPTER V

IS SELECTIVE ATTENTION AUTOMATIC OR VOLUNTARY?

In Experiments I and III, observers were instructed to pay attention to the moved element because on half the trials it would act as a cue to the position to be probed. In Experiment II, this instruction was appropriate for one of the two conditions (NOM = 1), which was presented on one of the two test days. For the other condition (NOM = 11), presented on the other test day, observers in Experiment II were instructed that it was to their advantage to pay attention to the stationary letter because it would be a cue to the position to be probed on half of the trials. Phenomonally, movement in the visual periphery is quite compelling, as was noted informally in this series of experiments as well as in the literature on movement perception (e.g., Kaufman, 1974, p. 379; Posner, Nissen, & Ogden, 1975; Breitmeyer & Ganz, 1976). If stimulus movement does attract attention under certain conditions, as demonstrated by the results of this series of experiments, it is important to ask whether this attraction is under the control of the observer or whether it is automatic. The purpose of Experiment IV was to examine this question in one way. In this experiment, two conditions were presented. In one condition, all letters were stationary; in the other condition, one letter moved in the array but the moved letter was never probed. In the movement condition, then, letter motion was never a cue as to which position would be probed. In this experiment, movement may create a heterogeneity in the array but it offers no strategic advantage to the observer in his task of identifying the probed letter. Thus a stationary letter was probed in both movement and non-movement conditions. The experimental question is whether or not the observer can ignore the single movement in the movement condition. If he cannot ignore the movement, accuracy at the probed position should be lower when a single letter moved someplace else in the field than when all letters were stationary. Similarly, reaction time should be shorter in the stationary than in the movement condition. If, on the other hand, the observer is able to ignore the irrelevant moved letter, accuracy and response speed should be the same in both conditions.

Method. The apparatus and stimuli were the same as in the other experiments in this series. Temporal parameters for the presentation of letters and probe were: A1 = 25 msec, IAI = 75 msec, A2 = 25 msec, ISI = 50 msec. The SOA was 150 msec for this experiment. In one condition, one letter moved but the moved letter was never probed (NOM = 1); in the other condition all letters remained stationary (NOM = 0). NOM was a between-block variable. Each block of 48 trials contained two replications of the orthogonal combination of the letter at the probed position (E or H) x position probed. The training session was carried out under condition NOM = 1 as described above, and was followed by two experimental sessions. Three blocks each of the two NOM conditions were presented on each test day for a total of six replications of the design for each observer on each day. The experimental day was considered a variable in this experiment to assess the effect of practice. Six observers, naive to the experimental method, served as unpaid volunteers. All had normal uncorrected visual acuity and were right-handed.

Results and Discussion. There was no difference in accuracy between the two experimental conditions ($F(1,5) = 3.52$, ns). When all letters were stationary, the proportion of correct identifications was .78; when one letter was moved, the proportion correct was .75. For four of the six observers, accuracy was better when letters were stationary than when there was a movement in the array; for the other two observers, there was no difference in accuracy. Accuracy increased slightly but not significantly from the first to the second test day but there was no difference between movement conditions on either day.

On the other hand, the speed of a correct response in the stationary display did show an advantage over the moved display ($F(1,5) = 7.25$, $p < .05$). This advantage was present only on the first test day ($F(1,5) = 13.71$, $p < .025$). On the second test day, RT for the movement condition decreased ($F(1,5) = 25.32$, $p < .005$) but RT for the stationary condition did not change ($F(1,5) = 1.07$, ns). Table 4 presents RTs for movement and stationary conditions on each test day.

These results suggest that the observers were able to ignore movement in the array if it was not important to carrying out the task. However, they required practice to do so; their identification response speeds were slowed by the irrelevant letter movement on the first test day but neither accuracy nor speed was affected on the second test day. It is of interest that five of the six observers, given a block of trials at the end of the second test session in which one letter moved at the probed position on half the trials and elsewhere in the array on the other half of the trials (as in NOM = 1 of the other experiments), showed facilitation of the letter moved at the probed position. This observation suggests that observers could adapt their strategy to suit the experimental task. If letter movement could be used to improve performance, it was attended; if it was irrelevant to performance, it was ignored.

A second question of interest is whether the observer can equally ignore movement at all eccentricities in the display, or if more eccentric movement is more com-

Table 4

Reaction time to a correct response for movement (NOM = 1) and stationary (NOM = 0) conditions on each test day (Experiment IV) (in msec)

NOM condition	Test Day First	Second
Stationary	1079	1052
Movement	1180	1045

pelling and thus more difficult to ignore. As mentioned earlier, it has been commonly observed that motion in the visual periphery is particularly compelling or salient. Indeed, stimuli at the visual periphery are often noticed only when they are moving and not when they are stationary (i.e., Troxler effect). However, the threshold for velocity detection increases with retinal eccentricity. This paradox has been expressed as a difference between motion acuity, which decreases with eccentricity, and motion salience, the functional effect of stimulus movement on subsequent behavior, which apparently increases with eccentricity. It was noted in Experiment III that identification of a moved letter decreases as that letter was presented at more eccentric positions while accuracy for a stationary letter was constant for the eccentricities used in this experiment. This result appears to argue against a more salient effect of attraction via movement to facilitate encoding with greater eccentricity.

In Experiment IV, the location of the single moved letter occurred randomly at one of the eleven positions which was not to be probed on a given trial. In this analysis, both accuracy and speed of identification of a letter at the probed position were examined as a function of the eccentricity of the *moved* letter. An ANOVA was performed on the factors: eccentricity of the moved letter, test day, and letter at the probed position. Each data point for a mean proportion correct, or for an RT to a correct response, was based on a median of 23 observations. The range of observations per data point was 15 to 34. Since movement was only effective in interfering with response speed on the first test day, a movement eccentricity function would also only be expected on the first test day. If stimulus movement is more compelling when it occurs at the visual periphery, it should interfere more with identification of a letter someplace else in the field. Table 5 shows the proportions of correct identifications for the probed letter at each eccentricity of the moved letter on each test day. There is a marginally significant increase in interference with identification as eccentricity of the moved letter increases ($F(2, 10) = 3.30$, $p < .10$). Five of the six observers showed this tendency. If the "saliency" of a moved stimulus increases with eccentricity of the movement, the speed of correctly identifying a probed letter elsewhere in the field should also increase with eccentricity of the movement. Table 6 shows the RT at each eccentricity of the moved letter. Although the RT does appear to increase with eccentricity of movement on the first test day, this trend is not statistically significant ($F(2,10) = 1.67$, ns). It was present for four of the six observers.

Two points are important about this analysis. First, if there is indeed a greater salience of eccentric move-

Table 5

Proportions of correct identifications of the probed letter at each eccentricity of the moved letter for each test day (Experiment IV)

	Eccentricity of Movement		
Day	2.6°	4.3°	8.7°
First day	.75	.63	.65
Second day	.71	.66	.73

Table 6

Reaction time to a correct identification of the probed letter at each eccentricity of the moved letter for each test day (Experiment IV) (in msec)

	Eccentricity of Movement		
Day	2.6°	4.3°	8.7°
First day	1195	1208	1239
Second day	1097	1097	1067

ment, its effect is not very great in the current experimental situation. Second, whatever salience exists can apparently be overcome with practice; neither speed nor accuracy reflected greater interference by the more eccentric moved letters on the second test day.

CHAPTER VI

POSSIBLE ARTIFACTS

Three possible sources of artifactual influences on the experimental results were examined: (a) the effect of a specific letter at the probed position; (b) the effect of the identity of a moved letter on the response to the probed letter; (c) the effect of the identity of adjacent letters on the response to the probed letter.

Specific Letter Effects

In the first four experiments, the probability that the letter E or the letter H would occur at the probed position was .50. Three variables are confounded in the letter variable. First, observers were instructed that one letter (E) was the "target" and the other letter (H) was the "non-target". This instruction could lead observers to use a strategy of processing "target" letters before "non-target" letters, or of biassing the response in favor of the "target" letter. Second, the letter designated as "target" was always E and the "non-target" was always H. Third, of the 12 letters in the array, four were always letter E and eight were letter H. A response bias would tend to favor H since it comprises the majority of stimuli. A stimulus bias based on a "figure" formed by the smaller unit would tend to favor letter E.

The letters E and H were chosen as stimuli because the lines which make up their configuration have the same orientations and because their brightnesses are determined by about the same number of dots plotted on the cathode ray screen. On physical dimensions the two stimulus letters cannot be readily discriminated from each other in peripheral vision. This suggests that any E/H difference would favor an explanation in terms of response biasses rather than stimulus biasses, which requires easily discriminable differences between stimulus categories. A second difference between E and H is that E consists of more horizontal lines. Since letter movement in this experimental series was horizontal, letter E may have been more easily discriminated because the horizontal lines may have appeared elongated during the movement but were not blurred. The two vertical lines of H, on the other hand, may have appeared to blur (even though the movement is apparent and no physical basis for blur is present). A third difference is that the response for E was always assigned to the left key, which was nondominant for all observers but one in the first four experiments. This might tend to produce a performance bias for letter H.

Experiment V was designed to separate the three confounded aspects of the letter variable to assess their significance. In Experiment V, the following variables were orthogonally varied:

(1) moved or non-moved letter probed;
(2) target or non-target letter probed;
(3) position probed;
(4) target = E or H;
(5) number of target letters in the array -- on half of the trials there were four targets and eight non-targets; on the other trials there were eight target and four non-target letters.

Variables (1), (2), and (3) were varied within each block while (4) and (5) were varied between blocks.

Method. The apparatus and stimuli were the same as in the previous experiments. Temporal parameters for the presentation of letters and probe were: A1 = 25 msec, IAI = 75 msec, A2 = 25 msec, ISI = 50 msec. The SOA was 150 msec. On all trials one letter moved, which is equivalent to NOM = 1 in Experiments I - III. There were three replications of the design for each observer. The training session was followed by two experimental sessions consisting of 24 warm-up trials and six blocks of 48 trials each for a total of 576 data points for each observer. In one experimental session, the target letter was E, for which the left key was pressed if it appeared at the probed position. In the other session, the target letter was H and the left key was pressed if H appeared at the probed position. The order of presentation of each letter as the target and of the ratio of target: non-target letters in the array (variable (5)) was counterbalanced over observers and sessions.

There were four volunteer unpaid observers. Two had previously participated in an experiment in this series while the other two were naive to the experimental method. All observers had normal or corrected-to-normal visual acuity and were right-handed.

Results and Discussion.

A. Letter at the probed position. In Experiment V, letter E and letter H could appear at the probed position as "target" or "non-target". When E was probed, regardless of its target designation, and it was stationary, it was less accurately identified (p(correct) = .68) than when a stationary H was probed (p(correct) = .74) ($F(1,3) = 28.61$, $p < .025$). When the letter at the probed position had moved, there was no difference in accuracy between E (p(correct) = .96) and H (p(correct) = .97). Thus the stationary letter H appears to have had an advantage over the stationary letter E, but this advantage did not hold when the letters moved. The lack of difference between moved letters may be due to a ceiling effect since moved letters were virtually always reported correctly. The difference between stationary E and H also influences the measure of selective attention. When an E was at the probed position, the advantage of a moved over a non-moved letter was greater than when H was at the probed position ($F(1,3) = 13.10$, $p < .05$). Whether

E or H was designated as the target letter made no difference in accuracy or speed.

B. Target vs. non-target letter. There was no difference in accuracy when the target or the non-target letter was at the probed position ($F(1,3) < 1$). Thus the results do not support a differential bias or strategy which might favor the letter designated as "target".

C. Number of "target" and "non-target" letters in the array. Neither the main effect nor any interactions were significant for the ratio of target to non-target letters in the array of 12 letters. This confirms the choice of letters E and H as equally difficult to discriminate in peripheral vision and refutes an explanation of the results in terms of a response bias engendered by unequal numbers of Es and Hs in the letter array.

D. "De-confounding" the letter variable. The only aspect of the letter variable which showed a difference in this experiment was the advantage of letter H over letter E when both were stationary at the probed position. This difference is not due to a motor advantage of using the dominant hand for an H response because both hands were used to report on H in this analysis. Nor is this difference due to a response bias due to a majority of Hs in the letter array since the letter at the probed position did not interact with the number of Es and Hs in the display. Nor is the advantage of H due to a designation of one letter as "target" nor to the kind of letter movement used in this experiment, since the advantage was only present for stationary letters. There is no obvious explanation of why the letter H was better identified than was letter E when both were stationary.

Effect of Moved Letter on Probed Letter

If encoding of moved letters starts before encoding of stationary letters, the process and end-products of encoding a moved letter may affect the process and end-products of encoding a probed stationary letter. On the one hand, if the moved letter is the same as the probed stationary letter, identification of the probed letter may be facilitated by a process analogous to priming. On the other hand, if the moved letter is the same as the probed letter, identification of the probed letter may suffer from response interference because the observer knows he must respond to the probed rather than to the more compelling moved letter. In order to assess the effect of letter movement at a different position from the one probed, only the trials for which the probed letter was stationary were examined in condition NOM = 1 of Experiments I, II, and III. A sign test of the direction of difference in accuracy for the probed letter when the moved letter was the same or different showed no differences (p(two-tailed) = .75). Thus the identity of the moved letter does not appear to affect identification of the probed letter.

Effect of Adjacent Letters on Probed Letter

Eriksen & Hoffman (1973) have suggested that the minimum field size of focussed attention is one degree of visual angle, within which "...there seems to be a lack of precision in determining the order of information extraction." (p. 160). Because of the eccentricities used in the present experimental series, on some trials the field of selective attention to a non-probed letter might have included the probed position as well. If this occurred, some processing of features of the probed letter may have been initiated earlier than might be predicted by the models of selective attention presented earlier. To assess this effect, only trials on which the probed letter was stationary were examined in condition NOM = 1 of Experiments I, II, and III. A sign test compared accuracies when the moved letter was in the same and in the opposite arm from the probed position. Accuracy was better for most observers when the moved letter was in the same arm (p(two-tailed) = .07). Thus selective attention appears to have a range broader than the letter itself, but the dimensions of this range cannot be estimated from these experiments.

In summary, only one of the possible artifactual effects examined may have influenced the results; accuracy tended to be greater for stationary letters when the moved letter was in the same arm as the probed stationary letter.

CHAPTER VII

CONCLUDING REMARKS

Five questions about the mechanism of selective attention were examined in this series of experiments. First, the results of all of the experiments support the hypothesis that selective attention can facilitate processing of features. Further, this facilitation by selective attention can be carried out prior to eye movement.

Second, the effect of movement or temporal modulation of brightness in attracting attention may be manifested as a temporal advantage for moved stimuli. This temporal advantage of moved over stationary letters is reflected in the reaction time functions of Experiments I and II and in the eccentricity functions of Experiments I, II, and III. The heterogeneity created by a single moved element in an otherwise stationary field, or by a single stationary element in a field of randomly moved elements, also contributes to the mechanism of selective attention. It may be the basis of unit formation, and it may be the basis for the allocation of attention to units in the stimulus array.

Third, the results of Experiment III suggests that selective attention can facilitate feature processing when there is as little as 90 msec between the presumed initiation of selective processes and the probe. This estimate of 90 msec is compatible with the minimum of 50 msec suggested by the results reported by Hoffman (1975). The facilitating effect of selective attention is evident for at least 590 msec. The advantage accrued by selective attention appears to increase somewhat as the SOA increases. A reason advanced to account for the increase is that stimuli which are allocated more attention are processed at a faster rate than stimuli which are allocated less attention. This means that relatively more processing takes place for faster than for slower-processed letters as SOA increases.

Fourth, overall accuracy decreased with retinal eccentricity in Experiments I, II, and III. The hypothesized decrease in the advantage of "attended" over "non-attended" letters with eccentricity was suggested only at short SOAs; at longer SOAs, there appeared to be no differences in the effect of selective attention with eccentricity. These results are consistent with the idea that time is required for selective attention to move to or focus on an eccentric spatial location.

Fifth, the results of Experiment IV indicate that if movement is not important for the observer's task, it can be ignored. However, ignoring movement requires practice, and movement can be attended and used to facilitate feature processing without delay if the task so requires. Further, there is a suggestion that more eccentrically located movement interferes more with identification of a letter at another place in the array. These results imply that selective attention via movement can be controlled by the observer to optimize his performance, but there seems to be a strong automatic component to this means of directing selective attention.

A set of models of the way selective attention may facilitate processing of feature information were formulated. The models were based on assumptions about three aspects of the mechanisms of selective attention as they apply to the present experimental situation. The assumptions had to do with the way attention may be allocated to units, the basis for unit selection, and a possible temporal advantage for processing moved over non-moved stimuli. Only two alternative means of allocating attention to units were considered. The model which best fit the data of these experiments assumed that attention is allocated proportionally to units on the basis of the number of units in the field, and that moved elements have a temporal advantage over non-moved elements. The first assumption implies that the attention allocated to each letter depends on the number of letters in a unit. The second assumption proposes a bias in favor of moved stimuli.

The results of these experiments support a two-stage model of early visual information processing. The stage of unit formation plays an important role in determining the extent and means by which selective attention can facilitate processing of feature information. The second stage involves preferential processing of the features of elements of some units.

The results of these experiments have raised some questions which might be explored using the same experimental procedures. Among these questions are the following:

(1) Movement appears to play a special role in affecting the way selective attention operates. Other easily discriminable features can be substituted for movement within this experimental approach and may provide a simpler system for analysis. If some other feature were used as the basis for unit formation such as, for example, color or brightness, the "allocation" assumption should remain valid. Depending on the feature and its values, an assumption about a temporal advantage for certain values of a feature might also be required.

(2) Although the results of Experiment III suggest that the facilitating effect of selective attention can be manifested in 90 msec, selective attention may be effective in an even shorter time. By presenting a probe at various times during the presentation of the

letter array, a lower limit to the facilitating effect of selective attention may be more closely estimated.

(3) The results of Experiments I and III suggest that time is needed for attention to move to or focus on a location in the letter array. This effect may also be demonstrated using a somewhat different approach. Suppose that on a high proportion of trials, only letters at far eccentric positions are probed; on the remainder of trials, positions at two smaller, equi-distant, eccentricities are probed. The critical trials are at the two smaller eccentricities. If attention is widely distributed in order to include the four most eccentric positions, time will be required for selective attention to move to or focus on the nearer positions. If more time is needed for a longer excursion, one would expect a smaller advantage of moved over stationary letters at the smallest eccentricity compared to the middle eccentricity. A clearly-discriminable letter movement excursion and a set of short probe delays should enhance the chances of obtaining the predicted result.

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APPENDIX I

PILOT EXPERIMENT

The purposes of the pilot experiment were the same as for Experiment I, to demonstrate that selective attention can facilitate encoding of features, to examine some temporal and spatial parameters of this facilitation, and to examine the effect of varying the number of "moved letters" in the array. The design, apparatus and procedure were the same as for Experiment I. However, in the pilot experiment, a dot was plotted adjacent to each of the 12 letters in the array. The dot was located at one of the four corners of each letter, .30 cm or $.37^{\circ}$ from the nearest part of the letter and was about .016 cm ($.02^{\circ}$) in diameter. The letters themselves were always stationary, but in the "moved" condition, the dot adjacent to a letter changed position either .81 cm (1°) horizontally or .96 cm (1.2°) vertically. The dot never changed position diagonally "across" the letter. The initial dot position and the direction of position change, horizontal or vertical, were determined randomly for each letter on each trial. All observers in this experiment indicated that they were able to perceive a change of position or a "movement" of the dots. Three students served as paid volunteer observers. All had uncorrected normal visual acuity as measured by a Snellen chart, were right-handed, and were naive to the experimental method. The results were analyzed as in the other experiments.

Figure A-1 presents the mean proportions of correct identifications of letters adjacent to a "moved" dot (called a "moved letter") and letters adjacent to a stationary dot (called a "non-moved letter") for each NOM condition. Figure A-2 presents this data for each observer separately. The vertical lines represent the standard errors for each observer under each NOM condition. The main effect for moved vs. non-moved letters was marginally significant ($F(1,2) = 14.51$, $p < .10$), but the interaction between dot movement and NOM was not significant ($F(3,6) = 2.59$, ns).

The main effect of dot movement for reaction time to a correct response (RT) was significant ($F(1,2) = 123.80$, $p < .01$). Considering only NOM conditions 1, 2 and 8, the interaction between dot movement and NOM was marginally significant ($F(2,4) = 5.69$, $p < .10$).

These results suggest that dot movement adjacent to a letter can facilitate the identification of that letter. However, the facilitation effect was small, a difference of .05 in accuracy and 58 msec in RT for the experimental NOM conditions. The size of the effect was attributed to poor acuity for the dot. If it is difficult to detect the stimulus which is intended to attract attention, that stimulus, even when rendered more visible by changing its position, will be unlikely to be effective in attract-

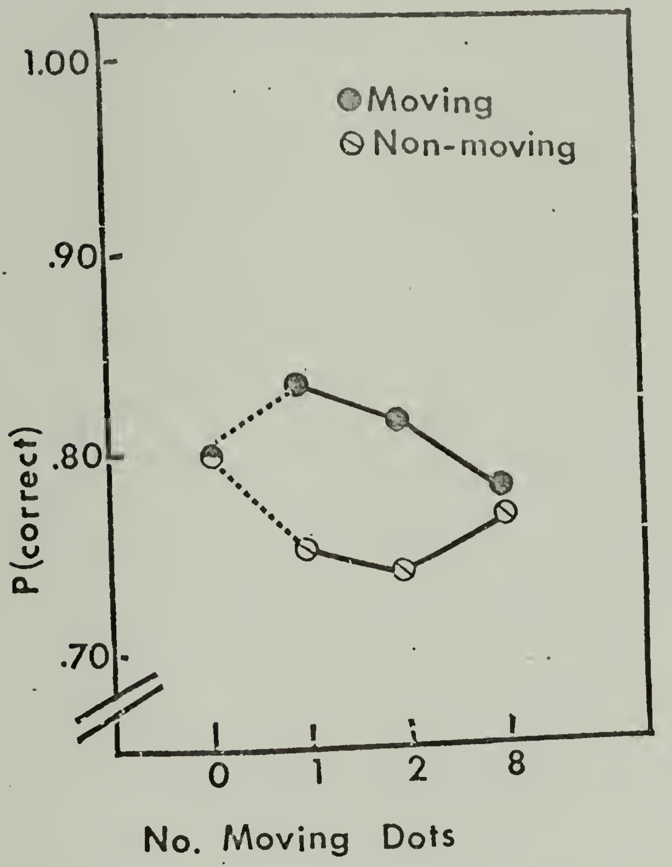

Figure A-1. Mean proportions of correct identifications of letters adjacent to a "moved" dot and letters adjacent to a stationary dot for each NOM condition (pilot experiment).

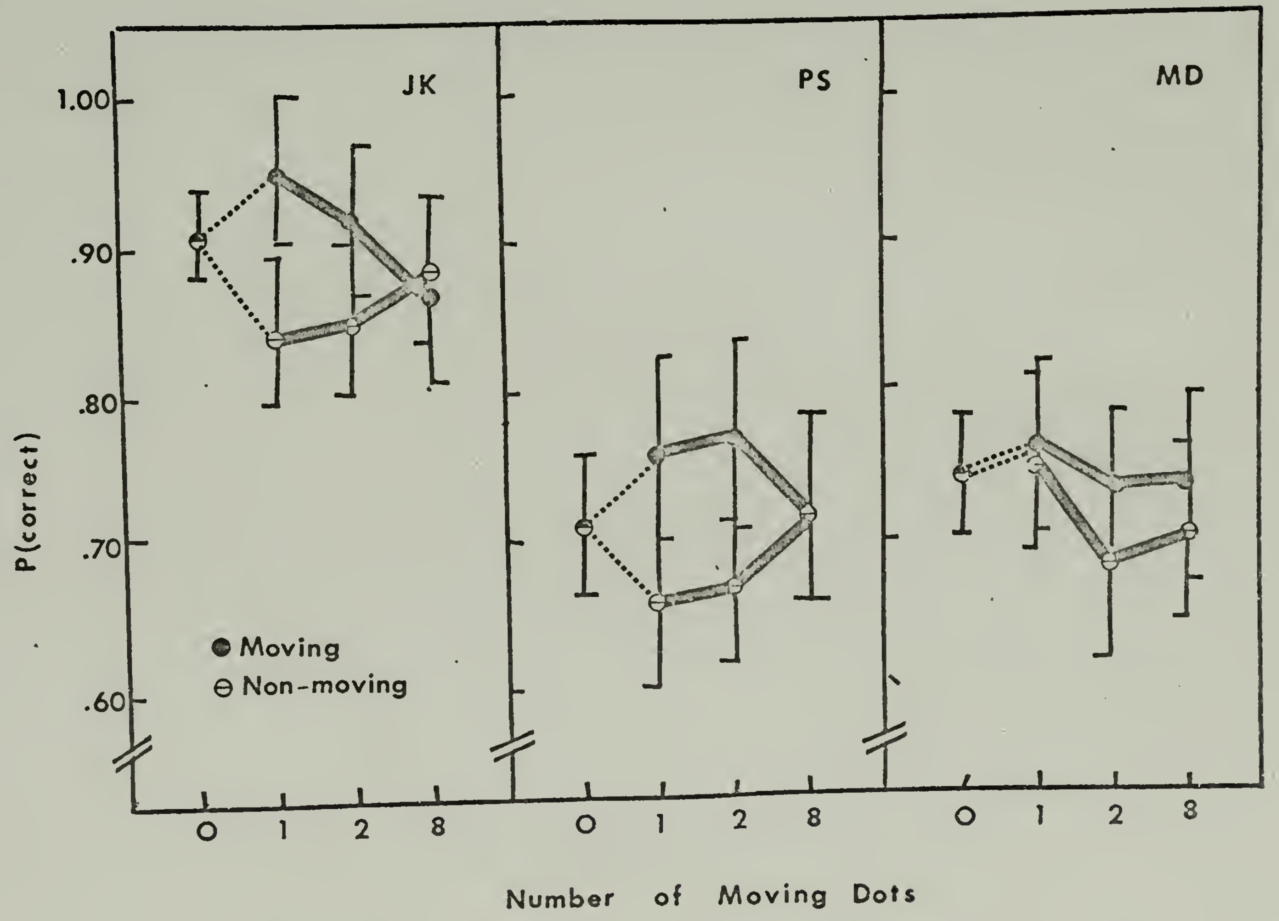

Figure A-2. The proportion of correct identifications of letters adjacent to a "moved" dot and letters adjacent to a stationary dot at each NOM condition for each observer separately (pilot experiment) ing attention. Alternatively, even if the dot were clearly visible, attention might have been attracted to the dot rather than to the adjacent letter. The dot was close enough to the letter to have included the letter in its minimal attentional field (c.f., Eriksen & Hoffman, 1973). Thus the alternative explanation for the small effect is less likely than the first explanation.

There was no significant main effect for SOA ($F(2,4) < 1$) nor for a dot movement x SOA interaction ($F(2.4) < 1$) nor a dot movement x SOA x NOM interaction ($F(4,8) < 1$) in the accuracy data.

There was no overall difference in accuracy with eccentricity ($F(2,4) < 1$) but there was a dot movement x eccentricity interaction for the three experimental NOM conditions ($F(2,4) = 75.42$, $p < .001$), which did not interact with NOM condition ($F(4,8) = 1.75$, ns). As eccentricity increased, there was a decrease in the facilitation advantage of moved over non-moved dots ($F(1,2) = 253.50$, $P < .005$). (The advantage did hold, however, at all three eccentricities (2.6°: $F(1,4) = 492.43$, $p < .001$; 4.3°: $F(1,4) = 50.05$, $p < .001$; 8.7°: $F(1,4) = 26.74$, $p < .01$).) If detection of dot movement decreases with eccentricity, the advantage of moved over non-moved dots will also decrease with eccentricity. Since the dot was about $.02^{\circ}$ or 1.2 minutes of visual angle in diameter, this is not unreasonable. A white dot on a black background which is one minute of visual angle in diameter can be detected no further than $4^{\circ} - 10^{\circ}$ from fixation, depending on the quadrant of the field in which it is presented (LeGrand, 1967, p. 132). The dots presented in the present experiment were probably less easily detected because of the brightness ratio of dot: background was lower than that reported in LeGrand's chapter, and because of possible interference due to the presence of other stimuli in the field.

In summary, the results of the pilot experiment were consistent with some of the main effects of the experiments in which the letter itself moved. However, in general, the effect of moving a dot seems to be smaller than the effect of moving a letter in facilitating letter identification. This difference probably has two causes. First, the dot or its movement was not as visible as was the letter or its movement, and thus was less effective in attracting attention. Second, the facilitating effect of selective attention is likely to be most effective when it is centered on the stimulus to be identified. In the present experimental display, selective attention would be most effective when centered on the letter to be identified.