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Attention and the Detection of Signals

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SUMMARY

Detection of a visual signal requires information to reach a system capable of eliciting arbitrary responses required by the experimenter. Detection latencies are reduced when subjects receive a cue that indicates where in the visual field the signal will occur. This shift in efficiency appears to be due to an alignment (orienting) of the central attentional system with the pathways to be activated by the visual input.

It would also be possible to describe these results as being due to a reduced criterion at the expected target position. However, this description ignores important constraints about the way in which expectancy improves performance. First, when subjects are cued on each trial, they show stronger expectancy effects than when a probable position is held constant for a block, indicating the active nature of the expectancy. Second, while information on spatial position improves performance, information on the form of the stimulus does not. Third, expectancy may lead to improvements in latency without a reduction in accuracy. Fourth, there appears to be little ability to lower the criterion at two positions that are not spatially contiguous.

A framework involving the employment of a limited-capacity attentional mechanism seems to capture these constraints better than the more general language of criterion setting. Using this framework, we find that attention shifts are not closely related to the saccadic eye movement system. For luminance detection the retina appears to be equipotential with respect to attention shifts, since costs to unexpected stimuli are similar whether foveal or peripheral. These results appear to provide an important model system for the study of the relationship between attention and the structure of the visual system.

Detecting the presence of a clear signal in an otherwise noise-free environment is probably the simplest perceptual act of which the human is capable. For this reason it may serve as an ideal model task for investigating the role of sensory and attentional factors in controlling our awareness of environmental events. Although there are a number of empirical approaches to the study of detection, most have not clearly separated between attentional factors and sensory factors and are thus incapable of providing an analysis of the relationship between the two.

The classical psychophysical approach to detection has generally involved the use of near-threshold signals (e.g., Hecht, Schlaer, & Pirenne, 1942). This approach has been concerned with such stimulus factors as intensity, duration, wavelength, and sensory organismic factors such as the degree of dark adaptation, retinal position of the stimulus, and so on. Evidence that a signal has been

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detected usually involves verbal reports by the subjects as an indication that they are aware of the event. An effort is made to optimize the state of attention, and it is assumed that the organism has its attention aligned to the input channel over which the event occurs.

A different approach to signal detection is represented by a body of research using the components of the orienting reflex rather than verbal reports as an indicant of detection. Research on the orienting reflex is concerned with both stimulus and contextual factors controlling its elicitation. Sokolov (1963) has suggested that subjects build up a neural model (i.e., an expectancy) of the repeated signal that blocks elicitation of the reflex by stimuli resembling the model. Little is known about whether the reflex is prior to or only follows our awareness of the signal. Indeed, the relatively slow times of some components of the orienting reflex, such as vasodilation and galvanic skin response (GSR), may prevent precise specification of the temporal relation of the orienting reflex to awareness of the signal. Some components of the orienting reflex, such as alignment of the eyes, may well precede our awareness of the signal, whereas other components of the orienting reflex, such as changes in GSR and vasoconstriction, almost surely must follow it.

The theory of signal detection (Green & Swets, 1974) has greatly influenced studies of detecting stimuli. One needs to distinguish between the mathematical theory and its psychological application. The mathematical theory of signal detection is a powerful tool for the analysis of many problems. It is a normative theory that may be used to describe a large number of psychological situations. However, like many tools it often produces in its users some implicit assumptions.

The use of detection has involved situations all the way from separating a pure tone in white noise (Green & Swets, 1974) to the task of a radiologist locating a tumor (Green & Birdsall, 1978). It seems unlikely that the same processes are involved in these situations. Often, in addition to detecting the presence of a stimulus, a person must identify it in order to discriminate it from complex backgrounds. Accordingly, sometimes it has been concluded that attention aids detection more than would be expected from an ideal observer (Sekuler & Ball, 1977), and sometimes no effects of attention are found (Lappin & Uttal, 1976). The one task in which signal detection theory is not applied is where there is a clear above-threshold signal in uncluttered background. Since the signal would be detected 100% of the time, the method does not apply. Yet in many ways this is the perfect task for understanding the roles of orienting and detecting in their simplest forms.

Users of signal detection theory often assume a two-stage model of information processing in which sensory systems are coupled in series to a central statistical decision process. This view runs counter to studies that have forced the distinction between physical, phonetic, and semantic codes of letters and words (LaBerge & Samuels, 1974; Posner, 1978). In systems involving multiple codes, changes induced in the criterion within one code can affect the inflow of evidence to other systems.

Another approach to the detection of signals has been developing in the last several years. It applies the methods of mental chronometry (Posner, 1978) through the use of evoked potentials, poststimulus latency histograms of single cells, or reaction time to try to determine when and where central attentional states influence the input message produced by a signal. It has been shown, for example, that independent of eye position, the instruction to attend to a particular position in visual space affects occipital recording for that event in comparison to a control stimulus arising at another position within the first 150 msec after input (Eason, Harter, & White, 1969; Von Voorhis & Hillyard, 1977). Similarly, enhancement of single cells whose receptive field is the target of an eye movement occurs well within 100 msec after input (Goldberg & Wurtz, 1972; Wurtz & Mohler, 1976). These enhancements are not necessarily coupled to the eye movement but are unique to the stimulus toward which the eye will be moved. All these studies show evidence of interaction of central systems with input processing. They suggest that central control modifies the stimulus evidence rather than merely providing a criterion for choices among fixed states of evidence. These chronometric studies suggest that it may be possible to study the detailed processes involved in the detection of a suprathreshold signal even in an empty visual field.

By *detection,* we will mean the entry of information concerning the presence of a signal into a system that allows the subject to report the existence of the signal by an arbitrary response indicated by the experimenter. We mean to distinguish detection in this sense from more limited automatic responses that may occur to the event. *Orienting,* as we will use the term, involves the more limited process of aligning sensory (e.g., eyes) or central systems with the input channel over which the signal is to occur. Thus it is possible to entertain the hypothesis that subjects may orient toward a signal without having first detected it. This would mean simply that the signal was capable of eliciting certain kinds of responses (e.g., eye movements or shifts of attention) but has not yet reached systems capable of generating responses not habitual for that type of signal.

The purpose of this article is to examine the relationship of the two component processes, orienting and detecting, in the task of reporting the presence of a visual signal.

In the course of the article, we will try to show that central processes can seriously affect the efficiency with which we detect stimuli in even the most simple of detection tasks and that the nature of these changes in efficiency is such that it implies a separate attentional system in close interaction with the visual system. The article is structured in terms of four propositions. First, knowledge of the location of a clear visual signal can be shown to affect the efficiency of processing signals that arise from that location. Second, this improved efficiency is not due to a general tendency for any kind of information to improve performance nor to an improvement in speed at the expense of accuracy, but implies a centrally controlled attentional system. Third, the attentional system cannot be allocated freely but can be directed only over contiguous portions of the visual field. Finally, this attentional mechanism appears not to be closely coupled to the structure of the saccadic eye movement system nor to differ between fovea and periphery.

Knowledge of Spatial Position Affects Performance

Evoked potential and single-cell results show that when a signal occurs at a position for which the subject is prepared, electrical activity is enhanced in the first 100 msec following input. This result suggests that it should be possible to observe this enhancement in terms of changes in detection. There is much evidence that knowledge of where a stimulus will occur affects processing efficiency in a complex visual field (Engle, 1971); Sperling & Melchner, 1978). However, there has been a great deal of dispute about this fact when above-threshold signals have been used in an empty field. Posner, Nissen, and Ogden (1978) provided subjects with a precue as to whether a given event would occur to the left or right of fixation. One second following the cue, a .5° square was plotted on the cathode ray tube. As shown in Figure 1, when the stimulus occurred at the expected position (.8 probability), subjects' detection (simple reaction time) responses were faster than following the neutral cue (.5 probability each side) and when the stimulus occurred at an unexpected position (.2 probability), they were slower. Careful monitoring of eye position and the use of a single response key insure that neither changes in eye position nor differential preparation of responses could be responsible for such a result.[1]

In addition to the data reported above,

[1] After having found that movements of the eyes of more than one degree occurred on less than 4% of the trials (Posner et al., 1978) and that these trials did not in any way change the cost–benefit results of the study, we did not maintain careful monitoring of eye position in all subsequent studies, although we used the same instructions and training to suppress movements. When monitoring was instituted in some of the later studies, results were not substantially altered by the eye movements that were detected.

some other performance experiments have also shown improvement in performance at expected spatial positions. These experiments include the use of signal detection measures (d'; Smith & Blaha, Note 1), vocal reaction time (Eriksen & Hoffman, 1973), and percent correct identifications (Shaw & Shaw, 1977).

Nonetheless, it has been difficult in many experiments to obtain significant benefits from knowledge of spatial position (Grindley & Townsend, 1968; Mertens, 1956; Mowrer, 1941; Shiffrin & Gardner, 1972). There may be many reasons why some studies have been successful in showing improved performance from expected spatial positions and others not. One of the reasons that seemed most likely to us was that most experiments, other than ours, examined only the benefits involved when subjects knew something about the location of a visual object when compared to a condition where no such knowledge was present. Our design showed about equal costs and benefits. However, in our design, subjects received a cue on each trial indicating the most likely position of the target, whereas in most studies subjects prepared for an expected position for a block of trials. We found that it was difficult for subjects to maintain a differential preparation for a particular location and suspected that many of the studies examining benefits due to knowledge of visual location did not find them because the subjects did not continue to set themselves for the position in space at which the signal was most expected. To test this view, we compared our standard cuing condition with a method in which noncued blocks were used.

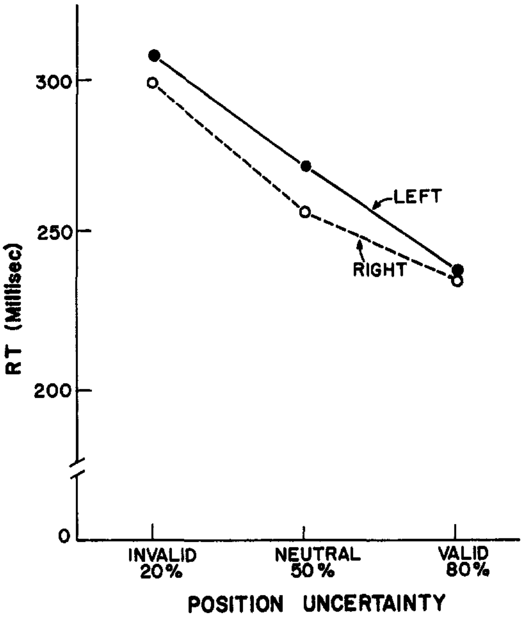

Figure 1. Reaction time (RT) to expected, unexpected, and neutral signals that occur 7° to the left or right of fixation. (Benefits are calculated by subtracting expected RTs from neutral, and costs by subtracting neutral from unexpected.)

Experiment 1

Method

Subjects. Six volunteers were recruited through the subject pool of the Center for Cognitive and Perceptual Research at the University of Oregon. All were college age and possessed normal hearing and vision. The subjects were run individually in two 1-hour sessions on consecutive days and were paid $2 for each session.

Apparatus. All testing was conducted in an acoustical chamber. Subjects were seated approximately 1.3 m in front of a cathode-ray tube (CRT) on which fixation markers, warning signals, and feedback occurred. The displays were viewed binocularly. Four red light-emitting diodes (LEDs) were arrayed horizontally immediately below the CRT. Two LEDs were positioned 24° left and right of fixation (far stimuli). The other two stimuli were 8° to either side of fixation (near stimuli). The LEDs were driven by 15 V through either a 560Ω or a 1.5Ω resistor, producing two suprathreshold intensities. Subjects indicated their responses by pressing a key-operated microswitch with the right index finger. A PDP-9 computer controlled the timing, stimulus presentation, and collection.

Procedure. The experimental task was a simple reaction time (RT) to the onset of an LED. Trial blocks consisted of 120 trials, including 20 catch trials. Stimulus trials consisted of a visual warning signal, a stimulus (LED), subject's response, feedback, and an intertrial interval (ITI). Subjects were asked to fixate the center of the CRT where a 1° square was displayed. Warning signals, either a plus sign (+) or a digit from *1* to *4*, indicating one of the stimulus locations from left to right, were presented in the square. Following a warning interval of 1 sec, the stimulus was presented. Subjects were encouraged to respond quickly, but not so quickly that they anticipated the stimulus. The response terminated the warning signal and stimulus display. Feedback was the RT in milliseconds unless an anticipation had occurred, in which case the word ERROR was presented. To re-

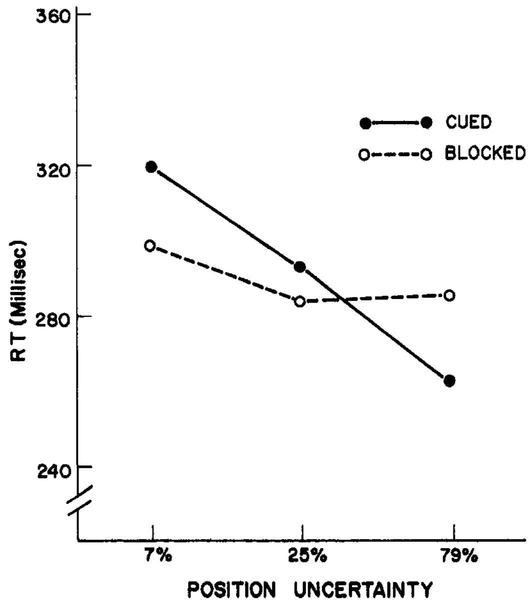

Figure 2. Reaction times (RT) for events of varying probability. (79% = expected, 25% = neutral, and 7% = unexpected for blocked presentation and presentation where cues are presented on each trial.)

duce anticipatory responses, no stimulus occurred on approximately 20 trials per block. These catch trials consisted of only a warning signal and an ITI. The proportion of catch trials was constant across experimental conditions.

The central objective was to compare detection latencies when the stimulus location was cued on each trial (mixed blocks) to a noncued situation in which subjects prepared for one location for a block of trials (pure blocks). Two conditions were used in the pure blocks. In the equal condition, the warning signal was always a plus sign, and each of the four locations was equally probable. In the unequal condition the warning signal was also a plus sign, but during each trial block one location was presented 79% of the time, and the other three locations occurred 7% of the time each. At the beginning of each unequal block, subjects were informed of the most likely stimulus location. In the mixed blocks (i.e., the cued condition), 20% of the warning signals were plus signs, indicating that the four locations were equally probable for that trial. On the remaining 80% of the trials, the warning signal was a digit (*1*, *2*, *3*, or *4*), indicating the most probable location (79%) for that trial. Each of the non-cued locations was equally probable (7%). In both the unequal and cued conditions subjects were encouraged to set themselves for the expected stimulus but not to move their eyes from the warning cue. No actual monitoring of eye position was used, since previous work had shown that costs and benefits were not dependent on changes in eye position (Posner et al., 1978).

Design. Each subject was tested in the three conditions (equal, unequal, and cued) on 2 days in an ABC-CBA order, with order balanced across subjects. There were two blocks in the equal condition, four blocks in the unequal condition (one for each position most likely), and two blocks in the cued condition on each day. Each session for each subject contained a different random order of the four blocks within the unequal condition.

Results and Discussion

The results of these mixed and pure blocks are shown in Figure 2. Note that once again when the cuing technique was used, we obtained very significant costs and benefits over a neutral condition. However, in the pure block technique, only the costs were significantly different from the neutral condition. There was no evidence of benefit.[2]

We attribute this failure to find benefit in the expected position over the neutral condition to the tendency of subjects to avoid the task of placing their attention at the expected position when they were not cued to do so on each trial. It is not clear why benefits are more labile than costs. However, since both costs and benefits are aspects of our knowledge of the position of an expected signal, it is clear that the difference between the benefit trials and the cost trials is a legitimate way of asking whether expectancy changes the efficiency of performance of signals arriving from expected versus unexpected conditions. The failure of most other paradigms to examine the cost of unexpected positions in space makes them far less sensitive than the techniques we have outlined. This, together with the general use of blocking rather than cuing, helps to reconcile several of the conflicts in the literature.

Experiment 2: Attention Is Involved

Investigators using the signal detection theory to guide work on detecting signals often argue that any information provided to

[2] This experiment was subsequently replicated with 12 additional subjects in the same design, except that the LEDs were 2° and 8° from fixation. The results were identical.

the subject about a signal will be useful in disentangling the signal from background noise. For this reason, evidence that some particular type of information, for example, about the location of a signal, improves performance is not taken to mean that there is any special mechanism associated with the utilization of that information. Lappin and Uttal (1976) have argued that knowledge of any orthogonal stimulus parameter ought to improve detection of that stimulus (p. 368). In their experiments they use a high level of background noise and ask the subjects to detect a line within the noise. Detection involves a difficult discrimination between background and signal. They find that the subject's information about the location of the line does improve performance, but not more than would be expected from a model in which no attentional assumptions are used. From this they conclude that the demonstrations of costs and benefits of the type indicated above are not evidence in favor of specific attentional mechanisms.

According to our view, evidence that only some types of information serve to improve performance would indicate that our effects are not due to general knowledge serving to allow separation of signal from noise. For example, consider a comparison of providing subjects with information about the shape of a stimulus with providing information about the location of the stimulus. It seems clear that in the Lappin and Uttal experiment, knowledge of the target shape would affect performance. This fits with the notion that information about the target's shape serves to disentangle the signal from noise. On the other hand, in our experiment it seems somewhat unlikely that information about shape would improve detection of signals.

Method

Subjects. Twelve volunteers were recruited in the same manner as in Experiment 1. The subjects were paid $2 for each of three 1-hour sessions run on consecutive days. Each session consisted of eight blocks of 130 trials.

Stimuli. Warning signals, stimuli, and feedback were presented on the CRT. Warning signals occurred at the center of the CRT. The stimulus, one of 10 capital letters selected at random, was presented 7° to the left or right of the warning signal.

Procedure. The experimental task was a simple RT to the occurrence of a letter. Each trial began with a warning signal indicating either the form or location of the stimulus. The stimulus was presented after a variable warning interval that ranged between 800 and 1200 msec. Subjects were encouraged to respond quickly but not to anticipate the stimulus. About 25% of the trials were catch trials in which no letter was presented. As in Experiment 1, catch trial rates were constant across conditions. Feedback consisted of the RT in milliseconds, or the word ERROR if an anticipation had occurred.

The primary objective was to compare the effectiveness of location and form cues on simple detection. Location cues were left or right arrows. Following a location cue, the stimulus occurred on the indicated side on 80% of the trials. The neutral location cue was a plus sign. Following this cue, each location was equally probable. The form cue was one of the letters that were used as stimuli. On 80% of the trials following this cue, the stimulus was the indicated letter. The form cue always occurred with either a neutral or an informative location cue. Half of the form cues were presented slightly below a plus sign. This warning signal indicated that the cued letter was the most probable stimulus but did not indicate its location (i.e., each location was equally probable). On the remaining trials the form cue occurred below the left or right arrow, informing subjects of both the form and location of the stimulus. Since the location and form cues were each valid on 80% of the trials, the combined form and location cue was valid on 64% of the trials. On 16% of the trials, the cued letter occurred in the unexpected location. On 16% of the trials, an unexpected letter occurred in the cued location. Finally, on 4% of the trials, an unexpected letter occurred in the unexpected location. Each type of warning signal (plus sign alone, arrow alone, letter with plus sign, letter with arrow) occurred equally often. Subjects were encouraged to use the warning signals to prepare for the stimulus but not to move their eyes from the warning cue.

Results and Discussion

The results of this experiment are shown in Table 1. Clearly, information about the location of the letter improves performance, but information about the form does not.[3]

[3] It should be noted that the prime reduced the letter uncertainty from 10 alternatives, whereas the spatial uncertainty had only 2 alternatives. It seems unlikely that a different result would have obtained had only 2 letters been used, however.

Table 1
Mean Reaction Time for Expected, Unexpected, and Neutral Form and Location Cues

	Location			
Form	Expected	Neutral	Unexpected	*M*
Expected	247	263	292	267
Neutral	252	271	299	274
Unexpected	248	263	299	270
M	249	266	297	

Note. Time is measured in milliseconds.

Another form of objection to our studies is to suppose that changes in the latency of processing the stimulus arising at the expected location are a result of changes in the amount of information that the subjects sampled from the expected location. Consider a comparison of the neutral trials with the trials cued by an arrow. In the latter, subjects may decide to reduce their criterion for pressing the key at the risk of making an increased number of anticipations. Indeed, we generally find that conditions involving the arrow do show an increased number of anticipatory responses over those times when the plus sign is used. This is evidence of a shift in amount of evidence that the subjects require to respond. However, this kind of shift cannot account for differences in cost plus benefit, since both of these RTs are from the arrow conditions, and subjects cannot differentially prepare prior to making the response. One might suppose that in some way the subjects are able to reduce their criterion when the stimulus arises from the particular position in space that was cued. It is possible to test whether improvement in reaction time obtained from knowledge of the location of the stimulus is accompanied by an increase in error. To do this we used a choice reaction time task.

Experiment 3

We modified our standard simple reaction time method (Posner et al., 1978) by providing the subjects with a toggle switch that moved up or down. The cues were left or right arrows or a plus sign. The imperative stimulus was a .5° square of light that occurred 7° from fixation and either below or above the line on the scope indicated by the cue stimulus. If it occurred above, the subject was required to move the toggle switch up, and if below, the toggle switch was to be moved down. This was a highly compatible stimulus–response combination that did not require a great deal of learning by the subject. Eight subjects were run for five blocks of 96 trials on each of the 2 days.

The results for Day 2 are shown in Figure 3. It is clear that we did find costs and benefits in reaction time in the same direction but not in as great a magnitude as had been found in the simple reaction time detection experiments. Analysis of variance indicated that both costs and benefits are significant.[4] There clearly is no significant difference in the error rates. Error rates on cost trials are somewhat larger than error rates in neutral or benefit trials. There is no evidence that the reaction time results are produced by an opposite effect on errors. A speed–accuracy tradeoff is not a necessary factor in producing the costs and benefits found in our experiment.

Experiment 4

It seemed important to determine the relationship of our results using luminance detection to those obtained when subjects are required to identify a target. In Experiment 2 it was shown that a subject's knowledge about the form of the target did not influence luminance detection. These findings suggest that luminance detection may be a simpler domain in which to examine the effects of set on performance than the more frequently studied tasks in which it is important to identify or match forms.

[4] There is also an interaction apparent in the graph between the target location (up vs. down) and position uncertainty. This probably results from a tendency to associate an unexpected position with a downward response. Presumably there is also a tendency to associate an expected position with an upward response. Despite this complication, the main result of the experiment is to show highly significant effects of knowledge of spatial position for both choice responses.

To examine this question we displayed four boxes arrayed around a central fixation point. The maximum visual angle of the display was about 1.5° so that all stimuli were foveal. Subjects saw either a neutral warning cue or an arrow pointing to one of the four positions. Following the neutral cue, a stimulus was equally likely to appear at any of the four positions and following an arrow the target appeared at the cued position 79% of the time and at the other positions 7% of the time. The stimulus could be the digits *4* or *7* or the letters *D* or *Q*. The subjects' task was to respond to designated target stimuli.

In pilot research we provided subjects with only a single key that they were to press whenever a digit was presented. If a letter was presented, they were to refrain from pressing a key. In this paradigm RTs to the expected position were very fast, but error rates were always much higher than in unexpected or neutral trials. Subjects found it very difficult to withhold responding when a nontarget occurred in the expected position. This result indicates that there is a strong tendency to react with a false alarm to a visual event occurring in an expected position. Subjectively, it felt as if one were all set to respond when an event ocurred in the indicated position, and it was very frustrating to inhibit the response while waiting to determine if it was a digit (target). When an event occurred in an unexpected position, it felt as though the answer was already present by the time one was ready to make a response. These subjective impressions fit very well with the idea that the attentional system is responsible for releasing the response rather than for the accrual of information relevant to the decision that a target was present.

It was relatively easy to show that costs and benefits were not due entirely to rapid but inaccurate responses. We simply provided subjects with a second key so that on each trial they were required to decide whether the target was a letter or digit. Figure 4 indicates the results from 14 subjects run in such a study for 2 days. Half the subjects were presented with a brief target

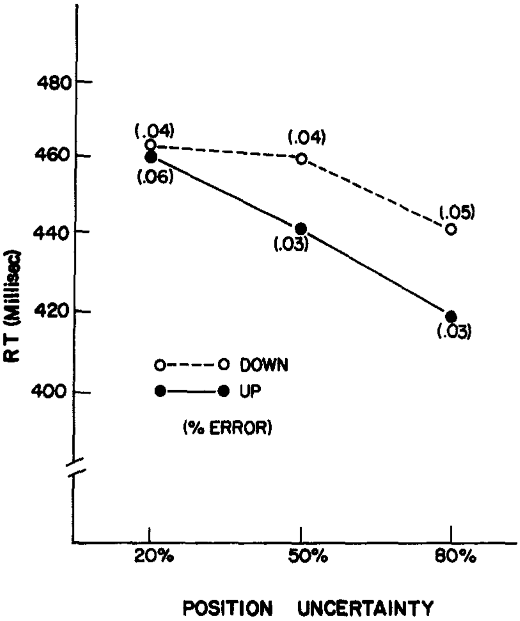

Figure 3. Reaction times (RT) for expected (80%), neutral (50%), and unexpected (20%) stimulus locations. (The task is to determine if the stimulus is above [up response] or below [down response] the center line. Error rates are in parentheses.)

masked after 40 msec (short duration) and half with a target remaining present until the response. For reaction time there are clear costs when the stimulus occurs in the unexpected position and benefits when it occurs in the expected position in comparison with the neutral control. On the other hand, error rates are constant over the various positions. These results argue clearly that subjects did not simply sacrifice accuracy for speed when the stimulus occurred in the expected location. This finding is incompatible with the view that central decision processes are responsible for setting a criterion for the response, since that implies that more rapid responding will be associated with increased error.

The results of the pilot study and of Experiment 4 also indicate to us that there are quite different processes present when subjects are required merely to detect a luminance change from those present when they must identify the stimulus. The false alarms found in the pilot study were far greater than were found in any study involving the detec-

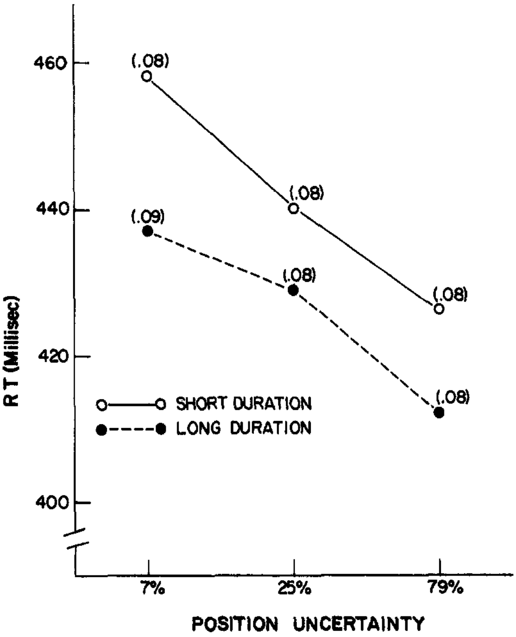

Figure 4. Reaction times (RT) for expected (79%), neutral (25%), and unexpected (7%) positions. (The task requires separate responses for letters and digits. Short duration = 40 msec masked presentation. Long duration = stimulus present until response is made. Error rates are in parentheses.)

tion of a stimulus. It is as though the occurrence of a luminance change at the expected position gives rise to detection of an event. It is the speed of this detection that we have been measuring in our previous work. If the subject is given only one key, there is a very strong bias to use the act of detecting the event as the basis for pressing the key. If the key press is to be made to only one class of stimuli, it is difficult to withhold the response. On the other hand, if subjects have to make a choice between keys, they are able to inhibit rapid responses and still obtain benefits from the cue.

These results all suggest that luminance detection is facilitated when subjects know where in space a stimulus will occur. They also indicate that such facilitation is not due to a bias introduced by the tendency to respond quickly and inaccurately to stimuli occurring at the expected position. On the other hand, they also suggest that the results of luminance detection cannot necessarily be generalized to studies in which subjects are required to identify the form present at a particular position. Although attention is quickly available at the expected position, this may result either in quick but error-prone reactions or in improved speed without increases in error, depending upon how the task is structured.

Although we have not done any formal comparisons, it seems obvious that the size of the effects in the choice RT tasks are much smaller than we have typically obtained in simple RT. This may seem counterintuitive, since the actual RTs are much greater in the choice tasks. We believe that this is due to the necessity of the subject's switching attention from the spatial location indicated by the cue to the internal lookup processes that identify (e.g., digit) or determine (e.g., above) the discriminative responses. Spatial cues are very effective for simple RT to luminance increments because this task does not require determining what the event is before responding, since subjects are required to respond to any event. Whether a spatial cue is effective in a more complex task will depend upon the details of the task and the competing stimuli. Spatial cues will be of great help in complex cluttered fields because they tell the subjects which stimuli are to be dealt with; in an empty field they may or may not help, depending upon the difficulty of reorienting from the location to the internal lookup of item identity.

Another perspective on our results from the point of view of signal detection theory is to suppose that they depend upon the reciprocal nature of the stimulus conditions that we impose upon the subjects (Duncan, 1980). If subjects follow the correlations in the experiment, they may seek to raise their criterion at the unexpected position and lower it at the expected position. This might have nothing to do with capacity or attentional limitations but would simply be an adaptation to the experimental contingencies. This view is more difficult to deal with. It is possible to design a study without introducing a contingency by, for example, presenting a stimulus that occurs with equal likelihood to the left, right, or both positions. However, such an experiment is probably not sufficient to dispose of the more general idea that performance in these tasks is mediated by independent shifts in criterion at different positions in space and not by the allocation of any central mechanism. It is to this question that the next section of the article is addressed.

Attention Cannot Be Allocated at Will

Recently, Shaw and Shaw (1977) have proposed that subjects can allocate their attention pretty much at will over the visual field. Shaw and Shaw presented letters at one of eight positions in a circular array. In one condition, the positions varied in the probability with which a target would occur. Performance was compared with a condition in which targets occurred at all eight positions with equal likelihood. Subjects showed significant costs and benefits in detection according to the assigned probabilities. From this, Shaw and Shaw argued for a model in which subjects were able to allocate a limited-capacity attentional resource to different areas of the visual field. While their results are consistent with allocation of a limited-capacity mechanism, they would also be consistent with the sort of view discussed in the last paragraph. It could be that subjects are able to set criteria for different positions in the visual field according to the probability that those positions will be sampled. However, there is a serious problem with this interpretation. The results of Shaw and Shaw could also be obtained if subjects sometimes attend to one position in space and sometimes to another, and these probabilities match those assigned to target presentation.

Our goal was to determine whether subjects were able to allocate their attention to different positions on a given trial. To do this we gave subjects both a most frequent position and a second most frequent position on each trial. We examined their RTs to the second most likely position in comparison to lower frequency positions to see if they could allocate attention simultaneously both to the most frequent and the second most frequent events.

Experiment 5

Method

Subjects. Twelve subjects participated in two 1-hour sessions on consecutive days. Experiment 5A involved 12 additional subjects and Experiment 5B 7 subjects. All were paid for their participation.

Apparatus. The apparatus from Experiment 1, including the LED displays, was used in this study. The LEDs were positioned either 2° (foveal stimuli) or 8° (peripheral stimuli) from fixation, with two LEDs on either side of fixation.

Procedure. The experimental task was a simple RT to the onset of an LED. Trial blocks consisted of 100 trials, including catch trials. Subjects fixated a 1° square in the center of the cathode-ray tube. Warning signals, either a plus sign or a digit from *1* to *4* indicating one of the stimulus locations from left to right, were presented in the square. After a variable warning interval, the stimulus occurred. Approximately 25% of the trials were catch trials in which no LED was presented. The feedback consisted of the RT in milliseconds or, in the event of an anticipation, the word ERROR.

On Day 1 subjects were seated in the test chamber and allowed to adapt to the dark for about 5 minutes before testing was begun. Prior to each block a most likely (65%) and next most likely (25%) stimulus location were indicated on the cathode-ray tube. Subjects were asked to remember these positions throughout the block and to try to prepare for stimuli at these locations on those trials (80%) when a digit appeared as the warning signal. The digit indicated the most likely position during that block, with the stimulus positions numbered from 1 to 4 from left to right. On trials preceded by a plus sign as a warning signal (20%), subjects were told that all four stimuli would be equally likely to occur and were asked to prepare themselves accordingly. Subjects were also informed that the first four blocks would be practice, and the final three blocks on Day 1, plus nine blocks on Day 2, would be test blocks.

On Day 2, subjects were again shown the apparatus, task instructions were reviewed, and about 5 min. were allowed for dark adaptation. Following testing, subjects were asked for their impressions of the helpfulness of advance information concerning stimulus location and whether they had felt they could prepare for stimuli at two locations.

Experiment 5A was an exact replication of Experiment 5 except that blocks of trials in which one signal had a probability of .64 and the other three had probabilities of .12 were also included. In addition, Experiment 5A was run under light-adapted conditions. Experiment 5B was identical to 5A but run under conditions of dark adaptation as in Experiment 5.

Design. Each subject received the same set of four practice blocks, which sampled the four positions as most likely and as next most likely. Each

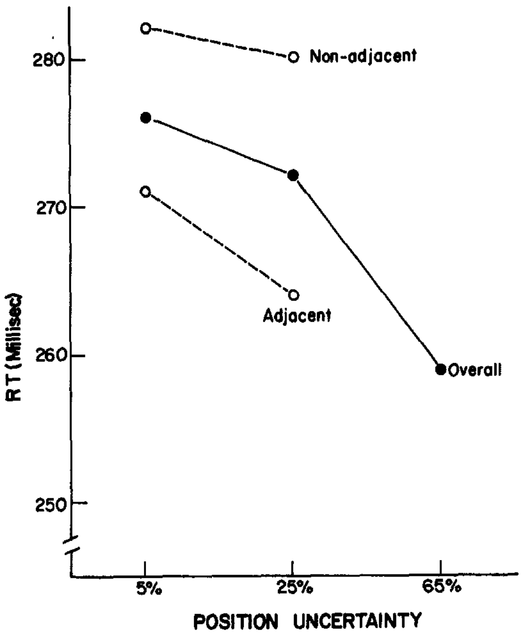

Figure 5. Reaction times (RT) to unexpected (5%), second most likely (25%), and most likely (65%) events as a function of the adjacency of the less probable events to the most probable (65%) event.

subject was then tested at all twelve combinations of most likely and next most likely stimulus locations.

The most likely position was cued on each trial by the central digit while the next most likely position remained constant for three consecutive blocks, with order of the four positions counterbalanced across subjects. Within each three-block set, order of the most likely positions was also counterbalanced.[5]

Results and Discussion

The data of all three experiments are given in Table 2. The statistical analysis of Experiment 5 showed that both the most likely and the second most likely target position were significantly faster in reaction time than the two least likely positions. In addition, foveal events showed some advantage over peripheral events, and intense stimuli showed some advantage over weak stimuli.

However, the important result is a comparison of the reaction times to the second most likely position (25%) and least likely position (5%) when the former was either adjacent to or remote from the 65% position. This is shown in Figure 5. The results are really quite clear-cut. When the second most likely target position was adjacent to the most likely target position, its RT resembled the most likely targets. There was a slight (5 msec) nonsignificant advantage to the most likely over the second most likely position in this condition. However, when the second most likely was separated by a position from the most likely, its reaction time resembled the least likely (5%) position. This constellation of results was independent of whether the two most likely events occurred at the central position or whether one of them occurred at the periphery. These results suggest that for detection, it is not possible for subjects to split their attentional mechanism so that it is allocated to two separated positions in space.

Experiment 5 did not contain a condition in which there was only one likely event. Thus we were unable to tell whether subjects were reducing their efficiency in detecting the most likely event. This condition was present in both Experiment 5A and 5B. From Table 2 it is clear that the requirement to give attention to a second most likely event had no effect on RT to the most likely event. In both experiments the blocks in which there was and was not a secondary focus had the same detection RTs for the most likely event.

In other ways Experiments 5A and 5B are a replication of Experiment 5 except the interaction between adjacency and probability (5% vs. 25%) was not statistically significant. Overall, the 25% event is only 5 msec faster than the 5% event when they are both remote from the most likely event. There is no evidence of an ability to divide attention. When the events are adjacent to the 65% event, the 25% event has a 16-msec advantage. This advantage is statistically significant in each study.

[5] The use of a blocking rather than a cuing technique for the second most likely event was made necessary by the difficulty we found in getting subjects to process two target position cues on each trial. Since the 25% target position (second most likely) is compared in RT to the 5% target position, differences should reflect a sum of costs and benefits that do show up in the blocking method as shown in Experiment 1.

Table 2
Splitting Attention: Reaction Time as a Function of Stimulus Event and Expectancy Condition.

Experiment	One only	Most likely	25% adj.	5% adj.	25% non-adj.	5% non-adj.
			Stimulus central (Positions 2–3)			
5		252	257	270	272	276
5A	256	253	273	281	284	294
5B	270	269	275	280	296	295
M	263	258	268	277	284	288
			Stimulus peripheral (Positions 1–4)			
5		266	272	272	288	288
5A	255	256	272	284	293	303
5B	301	289	312	328	328	337
M	278	274	285	295	303	309
			Overall			
M	270	266	276	286	294	299

Note. Time is measured in milliseconds. Adj. = adjacent.

Overall our results suggest severe limits in the ability of subjects to assign attention to a secondary focus in addition to a primary focus. Clear evidence for such an ability occurs only when the secondary focus is adjacent to the primary focus.

This finding favors the view of a unified attentional mechanism under the conditions of this experiment. These conditions include the use of a luminance detection task and the blocking of the second most likely target position.

Attention and Visual System Structure

The results summarized so far argue that subjects' knowledge about where in space the signal will occur does affect processing efficiency both in facilitating latencies at the expected position and retarding them at the unexpected positions. Our results suggest an attentional mechanism that cannot be allocated freely to positions in space but appears to have a central focus that may vary in size according to the requirements of the experiment. These findings are consonant with the idea of attention as an internal eye or spotlight. The metaphor of attention as a kind of spotlight has been used by Norman (1968), among others.

It seems useful to summarize the relationship between the attentional spotlight and features of vision such as saccadic movements and foveal versus peripheral acuity. Our results have shown that orienting is not dependent upon actually moving the eye. Moreover, the extent of benefit to a signal is not affected by its distance from the fovea (Posner, 1978, Figure 7.9) from .5°–25° of visual angle. This finding for detection differs markedly from one obtained by Engle (1971) for a task demanding a high level of acuity. Engle required subjects to find a single form embedded in a complex visual field. He provided both a fixation point and a point away from fixation where attention was to be concentrated. He found that the field of high acuity (conspicuity) for the ability to identify the target stimulus included the fovea but was elongated in the direction of the subject's attention. This result contrasts sharply with our results. In our detection experiments when subjects are told to attend away from the fovea, the point of maximum speed of reaction shifts to surround the area of attention and does not include any special ability at the fovea itself. Costs of unexpected foveal stimuli are quite comparable to those with unexpected peripheral stimuli (Posner, 1978, Figure 7.9).

This equipotentiality of attention with respect to visual detection shows that the attentional spotlight is not related to the field of clear foveal vision. Moreover, taken with Engle's study it shows that attention cannot compensate for structural deficiencies in acuity. Attending away from the fovea does not compensate for the lack of acute vision in that part of the retina, though it does produce a complete shift in the speed of detection of luminance changes in that area of the visual field.

Our results may seem paradoxical because of the strong belief that attention is tied closely to the fovea. In the real world, we are always moving our eyes to stimuli that interest us, and thus we are habitually paying attention to the stimuli to which we are looking. We found that this belief affected the strategies our subjects employed when events could be either foveal or peripheral in mixed blocks (Posner, 1978, Figures 7.10 and 7.11). When subjects were cued as to which side of the field was most likely, they uniformly prepared for the peripheral (7°) stimulus and not the foveal (.5°) stimulus. The costs and benefits for peripheral stimulus in such mixed blocks were the same as when only peripheral stimuli could occur (pure blocks). The benefits for foveal events were greatly reduced in blocks when they were mixed with peripheral events. This shows that subjects behave as though peripheral events benefit from attention, whereas foveal events do not require attention. This strategy is quite wrong in our task, since both foveal and peripheral events show equal costs and benefits in pure blocks. Nonetheless, it is a reasonable strategy to carry over from the real world in which attention is closely associated with the fovea.

Conclusions

The conclusions from this series of experiments are of two kinds. The first kind is somewhat general and concerns the theoretical framework most appropriate for the study of detection. In the introduction we outlined four alternative approaches based upon whether a distinction is made between central decision and sensory processes and, if it is, whether the two are thought to be independent and serial or interactive. Our experiments have shown clearly that the subject's knowledge about where in space a stimulus will occur affects the efficiency of detection. Moreover, the kind of effect one finds (costs alone or costs and benefits) depends upon whether a general set is maintained over many trials or is precued on each trial. These two results indicate that central factors influence the efficiency of detection. By themselves these results merely reinforce a point made at the advent of signal detection theory concerning the importance of taking central factors into explicit consideration as a part of understanding sensory processes.

How shall these central factors or cognitive factors be viewed? The idea of separate sensory and decision stages suggests an essentially noninteractive mode. Cognitive effects are seen to establish logical criteria for the selection of sensory evidence. These selection criteria modify our reports about the evidence but not the evidence itself. Our data suggest an interactive framework, because they show serious constraints upon the way knowledge of a signal can aid detection. It helps us to know where a signal will occur but not the form in which it occurs. It helps to know that a stimulus will occur in adjacent regions of space, but we cannot prepare efficiently for two separated regions. Knowledge of where a stimulus will occur produces benefits when it is used actively (cued) but not when it is used to maintain a general set (blocked). None of these results disprove the signal detection language but all suggest constraints upon how our knowledge affects processing that go beyond a general improvement to be found by a logical selection criterion. Thus, our data seem to lead one to view detection as an interaction between the structure of the visual system and the structure of the attentional system.

The second set of conclusions deals with the structure of the attentional system implied by our experimental results. It is here that our findings are more specific. Attention can be likened to a spotlight that enhances the efficiency of detection of events within its beam. Unlike when acuity is involved, the effect of the beam is not related to the fovea. When the fovea is unilluminated by attention, its ability to lead to detection is diminished, as would be the case with any other area of the visual system. Subjects' assumption that the fovea is closely coupled to attentional systems is a correlation they carry over from everyday life. It is usually appropriate, because we move our eyes to those things in which we are interested, but when this correlation is broken, the fovea has no special connection to attention. Nor are we good at dividing the attentional beam so as to simultaneously illuminate different corners of our visual space. This failure to find an ability to divide attention contrasts sharply with views arising from more complex tasks (Moray, 1967; Shaw & Shaw, 1977) that stress attentional allocation. Perhaps the difference lies in the complex pathway-activation processes involved when linguistic stimuli are to be identified before responding and in their use of more than one stimulus event.

How is this attentional system brought to bear upon stimulus input? We distinguish between two different aspects of the attentional system. The first we call *orienting.* Orienting involves the direction in which attention is pointed. Since the visual cortex is organized by spatial position, orienting can be viewed as the selection of a position in space. However, orienting may also involve the selection of a modality, and within modalities it may differ based upon the nature of the organization of information in that sensory system (Posner, 1978). When input involves more than one modality, it is possible to compare orienting by modality with orienting by position in real space. When this is done (Posner et al., 1978), modality information dominates over spatial position, supporting the view that the sensory pathways matter more than a reconstructed internal model of space. Orienting, as we have described it, may be an entirely central phenomenon without any overt change in eye position. Usually the eyes do follow the direction of our attention, however. Orienting, as we have described it, cannot be identified with the orienting reflex. The orienting reflex doubtless includes orienting in the sense we have used it, but it also involves the operation that we call *detecting*. By detection we mean the contact between the attentional system and the input signal, such that arbitrary response to it can be made.

In our experiments we provide the subjects with cues that allow them to perform the act of orienting. When this is done, detection proceeds more quickly. In the real world it is usual for a signal to produce both orienting (covert and often overt) and detection. Since the efficiency of detection is affected by orienting, orienting must either be in parallel or precede detecting. It might seem paradoxical that orienting toward a signal could precede or occur at the same time as detecting the signal. This paradox is similar to the problem of subception. How can we orient to something that is as yet undetected? The answer to both paradoxes lies in the specific nature of the attentive system that underlies detection. Much of our information processing does not depend upon this system. It is now well documented that complex semantic analysis can go on outside this system (Posner, 1978). Attention is important for nonhabitual responses such as are implied by detection responses. Habitual responses such as orienting the eyes to an event or aligning attention to the stimulated pathway do not appear to require support from this system.

Our experiments also suggest several directions for the analysis of detection. If the movement of attention can be time-locked to an input event, it should be possible to determine (a) the latency with which attention can be switched, (b) whether the time to reach the target is a function of distance, and (c) how such attention switches relate to the articulation of visual space and to the movement of the eyes.[6] It is clear that the general framework for viewing detection experiments outlined in this article is quite con-

[6] While this article has been in press much of the work outlined here has been accomplished. For a discussion of movements of covert attention see Shulman, Remington, and McLean (1979). A broader treatment of the relationship between overt and covert attention movements may be found in Posner (1980).

sistent with the ideas developing from evoked potential and single-cell work. A more detailed integration of the two approaches may eventually enhance our knowledge of the nature of attention.

Reference Note

1. Smith, S. W., & Blaha, J. *Preliminary report summarizing the results of location uncertainty: Experiments I–VII.* Unpublished experiments, Ohio State University, 1969.

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