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Moving attention: Evidence for time-invariant shifts of visual selective attention

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Two experiments measured the time to shift spatial selective attention across the visual field to targets 2 or 10 deg from central fixation. A central arrow cued the most likely target location. The direction of attention was inferred from reaction times to expected, unexpected, and neutral locations. The development of a spatial attentional set with time was examined by presenting target probes at varying times after the cue. There were no effects of distance on the time course of the attentional set. Reaction times for far locations were slower than for near, but the effects of attention were evident by 150 msec in both cases. Spatial attention does not shift with a characteristic, fixed velocity. Rather, velocity is proportional to distance, resulting in a movement time that is invariant over the distances tested.

Our ability to attend to objects in the visual world without having to move our eyes has been documented at least since the last century. There are numerous demonstrations of the consequences of attending to objects or locations distant from fixation (e.g., Colegate, Hoffman, & C. W. Eriksen, 1973; C. W. Eriksen & Hoffman, 1972, 1973), but the subjective experience itself is compelling proof that such ability exists. The question of interest here is how attention is shifted from one object, or location, to another. Consider two points on a sheet of paper, or two objects in the room at the same depth plane. Attend first to one, then shift attention to the other without moving your eyes. Choose points farther apart. Does it take longer to shift? That is, does attention shift across visual space with some fixed velocity irrespective of the distance to be traveled?

To answer this question, it is necessary to examine changes in the direction of visual attention with time. Attention is a covert process, but the direction of attention can be inferred from performance differences between expected (attended) and unexpected (unattended) spatial locations (Posner, 1978; Posner, Nissen, & Ogden, 1978). Subjects are given a cue to indicate the most likely spatial location for a target stimulus. The target is then presented at either the cued (expected) position or the uncued (unexpected) position. The difference in performance between the expected and unexpected locations is an estimate of the degree to which attention has been directed to a specific location. Both the detection of threshold stimuli (Bashinski & Bacharach, 1980; Remington, 1980) and reaction time to the onset of suprathreshold events (Posner, 1980) are facilitated for stimuli at attended locations relative to those at unattended positions. With such a central cue, the cost for stimuli at unattended locations and the benefit at attended locations reflect central attentional mechanisms, and not sensory processes. Attention mediates entry to consciousness when an arbitrary response such as a keypress can be made to the input signals. Cost is assumed to result because priority access to consciousness is being given to information from a location other than where the signal has originated (see Posner, 1980).

One can investigate the time course of an attentional shift by varying the time between the presentation of the cue and the onset of the target stimulus (stimulus-onset asynchrony). This will measure the time it takes for attention to influence performance (McLean & Shulman, 1978; Posner, 1980; Remington, 1980; Shulman, Remington, & McLean, 1979). C. W. Eriksen and his colleagues (Colegate et al., 1973; B. A. Eriksen & C. W. Eriksen, 1974; C. W. Eriksen & Hoffman, 1972, 1973; Skelton & C. W. Eriksen, 1976) have investigated both the spatial and temporal characteristics of visual attention by examining the buildup of benefit for cued locations. They have shown that the time to name letters presented in a background of distractors monotonically decreases as the time between cue and target letter increases up to 250-350 msec. By probing at unexpected locations and varying the distance attention must travel, one can examine the development of both the cost for unexpected events and the benefit for events at expected locations. From this, one can infer the approximate locus of attention with time.

Using this time course procedure, Shulman et al. (1979) found that attention moved in a continuous,

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analog fashion across the visual field, passing through intermediate locations prior to reaching the destination. They measured reaction time to the onset of a target located between the fixation point and the cued location, as a function of stimulus-onset asynchrony (SOA). The intermediate point, although never cued, was attended to prior to the more distant cued location, consistent with an analog movement. The difference in reaction time between the far (cued) and near (uncued) targets increased following the cue, reaching a peak at 150 msec and decreasing thereafter. This is what one would expect with a constant-velocity, analog shift. The initial divergence results from attention being directed at the intermediate rather than the cued location, while the later convergence represents attention being centered on the more distant (cued) location.

Some analog mental operations are accomplished with a constant velocity. Mental rotation is an example of an analog cognitive transformation whose completion time is a linear function of angular distance (Cooper & Shepard, 1973; Shepard, 1975). Pinker (1980) found a nearly linear increase in travel time with distance when he asked subjects to mentally move from one point to another in a remembered three-dimensional scene. Similar results have also been noted for size scaling (Larsen & Bundesen, 1978). The experimental paradigms used to establish the linear relationship between time and distance for these mental operations are similar to expectancy paradigms. The method used by Shulman et al. (1979), for example, uses the same logic as Cooper and Shepard (1973) in that probes are introduced at intermediate positions prior to the completion of the required act.

Other analog movements maintain a constant movement time by adjusting the velocity in proportion to the distance. Hand movements are of this type, so long as the destination targets for longer movements are made larger. Saccadic eye-movement velocity is also proportional to distance (Bahill, Clark, & Stark, 1975; Clark & Stark, 1975). Such analog movements are characterized by a nearly constant travel time for different distances within a considerable range, and are referred to as time-invariant movements. There is a close functional relationship between saccades and visual attention, and the method of movement might be related even though the mechanisms are separate (Posner, 1980; Remington, 1980).

In an attention shift a time-invariant movement, or does it shift with a constant velocity? Results from Tsal (1983) suggest a constant-velocity shift. He measured the time to attend to targets 4, 8, and 12 deg of visual angle from fixation, by probing at various times after the onset of the movement cue. Performance typically improves during the first 500 msec following a warning cue, thereafter remaining constant or rising at longer SOAs (Posner, 1974; Posner & Boies, 1971). Tsal reasoned that if attention moved outward from fixation at a constant rate, this minimum should occur earlier for nearer target locations, and this is what he found. Reaction time to targets at 4 deg reached a minimum by 83 msec, and each additional 4 deg added 33 msec to the time to reach minimum. Other interpretations of Tsal's results are possible. He used the onset of a light at the target location to cue the attention shift. Since it takes longer to perceive more peripheral stimuli, the constant difference he found could reflect a delay in the perception of the cue. Also, Tsal did not include conditions in which the cue was invalid (cost) and only considered valid (benefit) conditions. To measure the time course of attention, it is necessary to measure reaction times to both expected and unexpected events.

The present experiments examined the effects of distance on the time to shift attention under conditions more comparable to those used by Shulman et al. (1979). A central arrow pointed to either the left or the right to cue the most likely target location. Subjects had only to press a single key to the onset of a probe dot in either of the two locations, whether or not that location had been cued. The probe occurred at varying times after the central cue. Fixed-velocity models make clear predictions about reaction times for cued locations as a function of SOA and distance. Reaction times should be longer for the more peripheral locations because of the increased processing time for peripheral retinal stimuli. For a time-invariant, proportional velocity model, the difference between far and near locations would be constant, because retinal position would be the main factor contributing to the difference in reaction time to far and near targets. The fixed-velocity analog model predicts a specific interaction between distance and SOA. Since attention will reach nearer points sooner, reaction times for these points should decline more rapidly and reach a minimum sooner than points at more distant locations. This interaction of SOA and distance should resemble the Shulman et al. (1979) results.

EXPERIMENT 1

Method

All experiments were controlled by an Apple II+ computer, and stimuli were presented on an Electrohome high-resolution video monitor. Each subject was tested individually in a sound-attenuated chamber with his/her head positioned in a chinrest 21 in. from the monitor screen. The only light in the room was that provided by the monitor, whose intensity was adjusted to a comfortable level. Each subject was tested for 60 to 80 min on 3 consecutive days. The subjects were six paid volunteers recruited from the Ames subject pool. All subjects were well practiced in the task, having served in similar experiments, but naive with respect to the hypotheses of the present study.

Four sessions of 250 stimuli each were presented on each day, with a session divided into blocks of 50 trials with rest periods at the end of each block. The display consisted of two open rectangles, each subtending a visual angle of 1.5 deg, placed an equal horizontal distance from the center of the screen. The rectangles were centered either 2 or 10 deg to the left and right of fixation, and remained on for the entire session. Distance was alternated between sessions, and the order of presentation counterbalanced across subjects.

Every trial began with the presentation of a fixation cross at the center of the screen, midway between the two rectangles. Subjects fixated the cross and remained fixated for the remainder of the trial. Eye movements were not monitored.[1] Half a second later an arrow pointing either left or right was presented 1 deg above fixation. The arrow subtended 30 min of visual angle on each side of the fixation cross. This arrow predicted the location of the subsequent probe dot 80% of the time. No specific instructions were given to use the arrow to attend, other than to mention its predictive validity. The probe was the onset of a dot in the center of either the cued or uncued rectangle. The probe dot subtended about 9 min of visual angle, and was easily visible at both distances. Probes could occur at any of 10 stimulus-onset asynchronies (SOAs) following the arrow cue: 16, 50, 100, 150, 200, 250, 300, 400, 450, or 600 msec. The SOAs were chosen randomly from trial to trial with the provision that, within each cue condition, there be an equal number of trials at each SOA. The subjects pressed a single key to the onset of a probe dot in either rectangle, regardless of where the cue pointed. It was stressed that the primary task was to respond as quickly as possible to the probe, but not to anticipate its occurrence. On 20% of the trials, no probe was presented. These were catch trials added to discourage anticipation responses. Reaction-time feedback was presented at the end of all probe trials where responses were less than the 1 sec maximum. The word "correct" was presented on catch trials to which the subjects correctly withheld a response. The word "error" was presented if a subject responded before the probe was presented, failed to respond within 1 sec of probe onset, or responded to a catch trial. Trials on which the reaction time was less than 120 msec were assumed to be anticipation responses and were presented again later in the block, as were error trials.

Results

Only correct responses greater than 120 msec were included in the analyses. Errors on catch trials and anticipation responses were less than 2% overall. The left panel of Figure 1 plots the mean reaction time across subjects for cued (expected) and uncued (unexpected) locations at both 2-deg (near) and 10-deg (far) horizontal eccentricities. These means were calculated from the median reaction times for each subject in each condition. A repeated measures analysis of variance, with distance, SOA, and cue as within-subject fixed effects, showed significant main effects (alpha = .05) of distance [$F(1,5) = 7.8$, $p < .05$], SOA [$F(9,45) = 16.8$, $p < .001$], and cue [$F(1,5) = 111.4$, $p < .001$]. Responses were slower overall to far probes than to near probes and slower to unexpected than to expected locations. The main effect of SOA can be seen in the general U-shape function relating reaction time to SOA for all conditions. This U-shape is well documented in the reaction time literature and is attributed to the alerting properties of the cue (Posner & Boies, 1971). This alerting effect has been found to be independent of the selective effects of spatial attention (Posner, 1980; Shulman et al., 1979). There were significant interactions of distance with SOA [$F(9,45) = 3.5$, $p < .01$], of SOA with cue [$F(9,45) = 17.8$, $p < .001$], and of distance, SOA, and cue [$F(9,45) = 2.1$, $p < .05$]. These interactions reflect the different time courses of the reaction times for expected and unexpected locations.

FIGURE 1

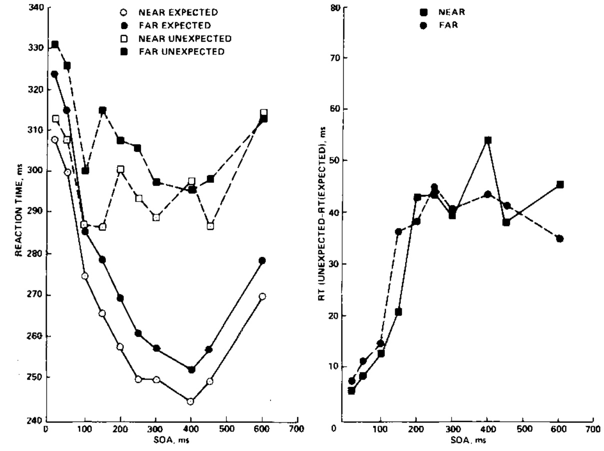

Figure 1. Results of Experiment 1. Left panel plots reaction time as a function of SOA for all distance and expectancy conditions. The right panel plots the development of the attentional effect with SOA for far and near targets.

To examine the effects of distance in greater detail, reaction times to the near location were subtracted from reaction times to the far location at each SOA. A separate analysis of variance was performed on these reaction time differences, with SOA as a within-subjects fixed effect. There was a significant effect of SOA [$F(9,45) = 3.07$, $p < .01$] resulting from the steady decline in this difference with time. This would not be predicted by a fixed-velocity analog model (see Figure 3).

Discussion

Experiment 1 failed to find any evidence for a fixed-velocity attention shift. There were consistent differences in reaction time to stimuli different distances from fixation, but no evidence of the interaction between distance and SOA that would indicate a fixed-velocity movement. Also, the development of the attentional effect was not influenced by distance. When the reaction time to probes at expected locations is subtracted from the reaction time to probes at unexpected locations, as in the right panel of Figure 1, there is little effect of distance on the amount, or time course of the attentional effect. Figure 1 shows that these effects built steadily for the first 150 to 200 msec.

When does attention shift, and is this shift more clearly reflected in the time course for expected or unexpected positions? The only clear indication of a selective attentional effect was the increase in reaction times to probes at unexpected locations 150 and 200 msec after the cue. Is there any benefit, then, for attended locations, or only cost for unattended locations? If there is both cost and benefit, when does each occur? Experiment 2 examined these questions by including a neutral condition in which the cue gave no information about the location of a probe. The time course of this neutral condition should provide a baseline against which to compare the expected and unexpected conditions. Also, Experiment 2 included many of the conditions of Experiment 1 and, thus, provided a test of the robustness of the results of the first experiment.

EXPERIMENT 2

Method

Five of the six subjects from Experiment 1 participated in Experiment 2 after the completion of the first experiment. Six SOAs (50, 100, 150, 250, 400, 550 msec) were used, and one-third of the target trials were neutral trials. On these trials, subjects saw a cross in place of the arrow and were informed that probes would occur equally often to the left or right with this cue. The cross subtended 1 deg of visual angle, centered 1 deg directly above the smaller fixation cross. In all other respects, Experiment 2 was identical to Experiment 1.

Results

The left panel of Figure 2 plots mean reaction time across subjects for all cue conditions as a function of SOA. A repeated measures analysis of variance found main effects of SOA [F(5,20) = 8.1, p < .001] and cue [F(2,8) = 30.5, p < .001], but no main effect of distance [F(1,4) = 2.5, p > .10]. Reaction times to probes were faster overall at expected locations than at unexpected or neutral locations. The failure of distance to have a main effect reflects the complex interactions between cue, SOA, and distance. When each cue condition is considered separately, reaction times were consistently higher for far locations than for the near locations. There were significant interactions of distance and SOA [F(5,20) = 6.0, p < .01], distance and cue [F(2,8) = 4.8, p < .05], and SOA and cue [F(10,40) = 9.7, p < .001], but no three-way interaction of distance, cue, and SOA [F(10,40) = 1.1, p > .10].

FIGURE 2

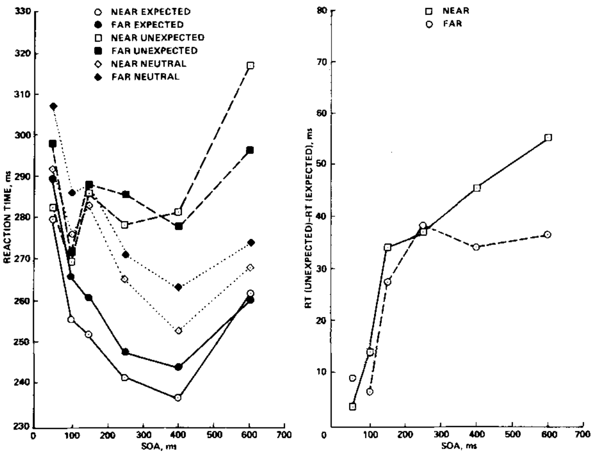

Figure 2. Results of Experiment 2. The left panel shows reaction time for all distance and expectancy conditions. The right panel plots the difference between unexpected and expected positions as a function of SOA.

Many of the salient features of Experiment 1 were evidenced in the results of Experiment 2. Figure 2 shows the general U-shape function for all curves. The curves for the expected locations declined steadily with SOA, reaching a minimum at 450 msec. The neutral and unexpected curves showed a similar decline through the first 150 msec, but reaction time increased for both between 100 and 150 msec, similar to the unexpected positions in Experiment 1.

The right panel of Figure 2 shows the difference in reaction time between unexpected and expected positions. These results are quite similar to those of Experiment 1 shown in the right panel of Figure 1. There were no consistent effects of distance on either the magnitude or time course of the attentional effect, which seems well established by 150 msec.

Discussion

The results of Experiments 1 and 2 are identical in all important respects. Neither showed effects of distance on the time to shift attention consistent with a fixed-velocity analog movement. When reaction times in the near condition were subtracted from reaction times in the far condition at each SOA, for each experiment, there was no pattern of divergence followed by convergence as predicted by the fixed-velocity model and as found by Shulman et al. (1979). This is illustrated in Figure 3, in which the difference between far and near conditions is plotted as a function of SOA for the two experiments of Shulman et al. and the present two experiments. The difference functions in the Shulman et al. experiments conform to predictions of a constant-velocity model. The discrepancy between the present work and that of Shulman et al. can be resolved by noting that the procedures differed in an important respect. In the Shulman et al. study, all required attention movements were the same distance. The subjects were instructed to prepare for the far target on all trials. To the extent that subjects complied, this would insure a constant velocity at the rate appropriate for the required 18-deg shift. The present results then place two important constraints on analog models of attention shifts. First, the time to shift to a specific target is constant regardless of that target's distance from the current attentional focus. Second, when there is a visible target, its characteristics, such as distance, will determine the dynamics of the shift. Were this last condition not true, then attention would always be programmed to shift at maximum velocity, and the shifts would, therefore, have constant velocity.

Since few studies have mapped the time course of central attention shifts (see Remington, 1980; Shulman et al., 1979), it is worth pointing out a few salient features of the reaction time functions. In

FIGURE 3

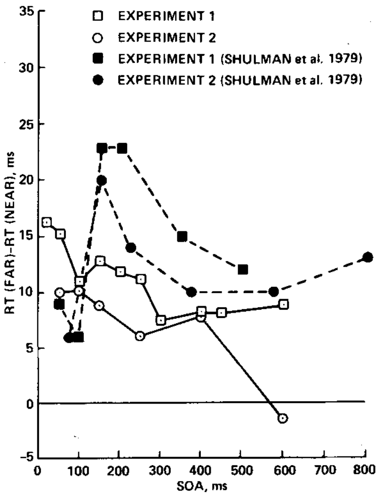

Figure 3. Comparison of the present study with the results of Shulman et al. (1979). The difference in reaction time between far and near positions is plotted as a function of SOA.

both Experiment 1 and Experiment 2, the expected location most clearly shows the U shape associated with reaction time studies with a variable warning interval. This is not surprising, since spatial uncertainty has not typically been a variable in studies of warning interval. There are two distinct portions of the curves for expected positions in Figures 1 and 2. First, the pronounced decline between 50 and 100 msec, followed by a gradual decline at subsequent SOAs. The curves for the neutral and unexpected locations show a similar initial decrease in reaction time between 50 and 100 msec and evidence of a U shape following an increase at 150 msec, although it is quite shallow for the unexpected position. The increased reaction time for the final SOA in all conditions is assumed to reflect the decreased probability that on a given trial a probe would occur after such a long delay. It is difficult to infer how well attention was maintained in the trials with long SOAs, and the portions of the curves at and before 250 msec are of most interest here.

Together, Figures 1 and 2 suggest that benefit for cued positions may develop earlier than cost for uncued positions. Reaction times to probes were slower at the neutral and unexpected positions than at expected locations by 100 msec. While the rise in reaction time at 150 msec for the neutral and unexpected is a clear indication of a selective process, there is a consistent advantage for the cued location at 100 msec that suggests an earlier selective facilitation for the cued position. The facilitation at 100 msec is apparent in the data from both experiments but is small relative to the overall initial decrease in reaction time for all positions. This initial reaction time decrease is not selective, and probably represents the combined effects of alerting and completion of cue processing (C. W. Eriksen & Hoffman, 1972).

Previous time-course studies of visual attention shifts have found that letter-identification times continue to improve for SOAs up to 250 to 350 msec (Colegate et al., 1973; C. W. Eriksen & Hoffman, 1972, 1973; Jonides, 1980). The results presented here are in agreement in showing that reaction time to the cued location continues to improve for SOAs up to 250 to 400 msec. However, the increase in reaction time for the neutral and unexpected positions around 150 msec most clearly signals the presence of cost. A study by C. W. Eriksen and Hoffman (1972) examined reaction time to a target letter as a function of the time between the presentation of the letter and subsequent, spatially adjacent distractors. They found that an SOA of 150 msec was sufficient for asymptotic performance—a time course that corresponds well to the results presented here. The cost in responding to unattended locations may share important properties with the ability to ignore events at unattended locations.

Are our mental processes so fast that one can see the arrow, understand its meaning, and shift attention within 200 msec? Our data clearly show selective attentional effects prior to the 200-msec SOA. However, the processes intervening between the presentation of the cue and response execution may not be ordered in a strict serial fashion, and the answer would require knowing the degree of overlap, or parallelism, in their organization. For example, while it is logically necessary to begin establishing a visual code for the arrow cue before attention can be shifted, it may not be necessary to complete the code before sufficient information has accrued to initiate the shift (see Posner, 1978, chap. 2). Also, attention need not be at the target before the probe appears in order to facilitate reaction time, but could speed reaction for some time afterwards by influencing processes up to the decision to respond (Remington, 1980; Shulman et al., 1979). Thus, the time course for reaction times can establish the order of events, but the appearance of cost or benefit at a given SOA probably underestimates the time required to complete some processes. Remington (1980) has shown that the time course for threshold detection is almost identical to the time course for reaction times, and the results here agree well with letter-detection times. Thus, our estimates of the time to shift attention are not greatly in error.

GENERAL DISCUSSION

Two experiments examined the development of a spatially selective attentional set and found the time to shift attention to be constant and independent of the distance to travel. Distance had no effect on the time for the attentional effects to develop or on the magnitude of these effects. These results are not consistent with fixed-velocity, analog attention shifts. The manner in which attention shifts across the visual field, at least in experiments involving the detection of simple stimuli on an uncluttered display, does not correspond to the type of analog movement that occurs in the transformation of mental representations (Shepard, 1975) or when mentally traversing a remembered scene (Pinker, 1980). In those cases, velocity is constant and the relationship between distance and travel time is well fit by linear functions with positive slopes. Rather, the dynamics of an attention shift appear to be more closely associated with hand and saccadic eye movements. These analog movements achieve time-invariance by adjusting velocity in proportion to distance to assure constant travel time.

Attention is a mental process, yet its movement dynamics resemble the movement of the eyes and hands more than those of other mental operations. Attention acts in concert with both the hands and the eyes, and its movements must be closely coordinated with both. In particular, efficient coordination with the saccadic eye-movement system in such tasks as reading or visual search would dictate rapid, time-invariant movements to match the saccade dynamics in these demanding tasks.

Our results have been discussed within the framework of the spotlight analogy, in which attention is conceived of as a beam that illuminates a region of the visual field. It makes sense, then, to talk of attention moving through space with the beam on (analog movement) or, like saccades, with the beam turned off (discrete movement). An attempt has also been made to reconcile these results with those of Shulman et al. (1979), which suggest analog attention shifts. Our results do not, however, imply strong support for this framework, or require a strong commitment to the analogy or analog movement. We have measured the time to reallocate visual attention as a function of distance, and in so doing have provided important information about spatial attention that does not rely on assumptions about the nature of an attentional shift. Our results would not have been anticipated by the analog, spotlight model, but they do not seriously challenge that view, or question the spotlight analogy. There are examples of time-invariant analog shifts, and our results can be reconciled with those of Shulman et al. Rather, time-invariance is a property of an attentional shift that will force more specific predictions from an analog model.

On the other hand, our results are perhaps more consistent with discrete attention shifts, in which attention "jumps" from one location to another. The time to select a new target would not depend on distance, except that distance would define the similarity between objects. Indeed, it is difficult to see why attention should traverse "empty" visual space, since attention is closely associated with our perception of objects. Because we can use spatial location to select objects to attend to does not require us to treat visual space as a more unique attribute of the object than, for example, its color or shape. Unlike hand or eye movements, attention has no known physical properties that would restrict its manner of movement, nor would coordination with the saccadic eye movement system require that attention shift in continuous, analog fashion. Moreover, support for the analog model is not conclusive. The interpolated probe technique used by Shulman et al. (1979) clearly showed that attention was at an intermediate point prior to the completion of the shift, leaving no doubt that attention moved outward from the center. However, this is not proof that attention passed through all spatial locations between the potential targets. Other factors, such as the near light's more central location, could have attracted subjects' attention first, without the shift necessarily having traversed the intervening space. The fate of the analog model will depend in part on its ability to predict the results of experiments that use the time-invariant properties of attention shifts in a more analytic manner.

Shulman et al. (1979) found an interaction between SOA and distance in their cost functions, which we failed to replicate. In both of the Shulman et al. experiments, the far, unexpected location behaves like the unexpected positions in the present studies. The increase between 150- and 200-msec SOA is present, although smaller, and the time course of attentional effects referenced to the far, expected location fits well with the data shown in the right panels of Figures 1 and 2. However, the reaction time function for the near, unexpected position in Shulman et al. located 8 deg from fixation, does not resemble either the 2- or 10-deg cost functions found here. Curves for the near, unexpected position show a steady decrease in reaction time for the first 400 msec, like the expected positions in the present studies. The reasons for this discrepancy are not clear. It is possible that some attentional resources were devoted to the near, unexpected position. Shaw and Shaw (1977) have shown that attention can be allocated to multiple targets. Subjects in the Shulman et al. (1979) study could have decreased their reaction time on about 20% of the trials by monitoring three of the four positions. The allocation and reallocation (shifting) of attention may differ as the number of potential targets is increased from two to four or more.

How are attentional resources dispersed across the visual field? Our results failed to show any evidence for a gradient of attention centered on the current attentional focus. Under the conditions we tested here, attention seems to produce facilitation for a confined region, outside of which cost is uniform. The right panels of Figures 1 and 2 show that the magnitude of the attentional effect was not influenced by the distance between the expected and unexpected locations. The difference in distance is considerable. The near locations are separated by 4 deg, the far by 20 deg. This is consistent with results from Posner (1978, chap. 7) and Eriksen and his colleagues (B. A. Eriksen & C. W. Eriksen, 1974; C. W. Eriksen & Hoffman, 1973; Hoffman & Nelson, 1981; Skelton & C. W. Eriksen, 1976). If there were a gradient of attention centered at the attentional focus, it must be steep, reaching a minimum within 4 deg, otherwise the attentional effect would have been stronger for the 10- than for the 2-deg separation. C. W. Eriksen and his colleagues have repeatedly shown that distractor items more than 1 deg from the target do not interfere with target identification. C. W. Eriksen and Hoffman (1972) failed to find evidence for a gradual focusing of attention as it shifted, and concluded that there was a region of about 1 deg that defined the attentional focus (however, see Downing & Pinker, 1982, for evidence of a gradient of attention for depth). Distance alone seems insufficient to establish such a gradient, but with multiple locations certain allocation policies would produce such gradients.

By investigating the time course of events following informative and uninformative warning cues, it has been possible to witness the development of a spatial attentional set. The present experiments were able to identify two components of this process, an alertness component, evidenced by an early, rapid facilitation for all visual signals, and the shifting of attention seen in the selective facilitation (inhibition) for signals at attended (unattended) locations. It is important to stress that these effects could not have been discerned from the reaction times to expected locations alone. It was only by comparing the time course for expected, unexpected, and neutral curves that the time course of the attentional effects could be established.

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NOTE

1. Eye movements were monitored by a television camera in earlier pilot work. The subjects in those studies made no detectable eye movements. This monitoring was abandoned in part because it required the testing chamber to be illuminated, and also because of the low-event-rate vigilance task it imposed on the experimenters. Moreover, the subjects reported no problem in maintaining fixation, and the reaction times are much too fast to have been accompanied by a saccade. Note also that the important observations take place at SOAs of less than 200 msec, barely enough time to initiate a saccade.

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