Perception & Psychophysics
1987, 42 (3), 299-305

Movement of attentional focus across the visual field: A critical look at the evidence

CHARLES W. ERIKSEN and TIMOTHY D. MURPHY
University of Illinois, Urbana-Champaign
Champaign, Illinois

How does attention change from one task or stimulus to another? This question should be a concern of all models of attention. However, research on this problem was neglected until the conception of attention as resources or processing capacities became widespread. A conception of attention as processing resources that can be concentrated on areas or objects in the visual field led to the metaphor of visual attention as a spotlight. The development of precuing paradigms provided a methodology for controlling the locus of this attentional spotlight in the visual field, and the question of how the focus changed location followed naturally from these precuing experiments.

On first thought it would seem a relatively straightforward experimental task to determine how quickly the attentional focus changes from one location to another in the visual field. But three well-known experiments have tackled the problem and have come up with three different answers. Tsal (1983) concluded that the attentional focus traversed the visual field in an analog manner at a constant velocity, with attentional processing ceasing during the course of the movement. Shulman, Remington, and McLean (1979) also concluded that the change was an analog movement across the visual field, but that the "spotlight" continued to process all stimuli that were encountered in the path of the sweep to the location of the new target. Remington and Pierce (1984), on the other hand, concluded that the change in attentional focus was discrete, or, if the focus moved, that the velocity was proportional to the distance to be traveled.

It is our purpose in this paper to evaluate the evidence that has been produced by these three experiments for attentional movement in the visual field, and, in the process, to consider some of the methodological problems involved in this experimentation. These experiments required many assumptions concerning the nature of visual attention, many of which were implicit. In several cases these implicit assumptions, when made explicit, are found to be either implausible or in direct conflict with established evidence.

Tsal's (1983) experiment is perhaps the most dramatic. He concluded not only that the attentional focus traversed the visual field, but that it did so at a constant velocity of approximately 8 msec per degree of visual angle. Tsal reasoned that if the attentional focus did traverse the visual field, the time required for the focus to move from a central fixation point along the horizontal meridian to a target should vary directly with the target's eccentricity. Thus, if a precue designating target location preceded the target by various stimulus onset asynchronies (SOAs), the resulting RT-SOA functions should approach asymptote at different SOA levels for targets at 4°, 8°, and 12° eccentricity. The differences between the SOA values at which these three functions became asymptotic would then directly reflect the difference in traversal time of the attentional focus from one target location to the other.

In Tsal's (1983) experiments, subjects were given a choice reaction time task in which they discriminated the letter O from the letter X. The precue was a small dot that occurred slightly peripheral to the subsequent target locations at SOAs of 50, 83, 116, 150, and 183 msec. Figure 1 is from Tsal's Experiment 1 and shows the RT-SOA functions for targets located at 4°, 8°, and 12° eccentricity. The asymptotes for these functions were

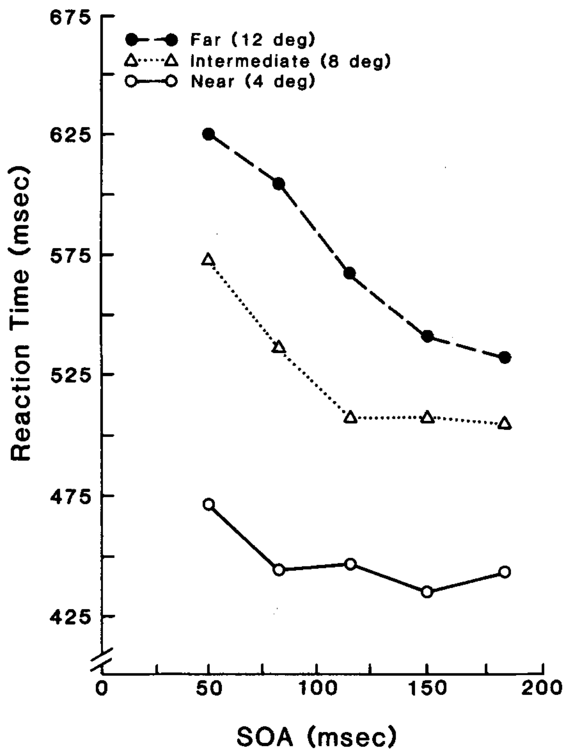

Figure 1. Mean reaction time to targets at three retinal eccentricities as a function of the SOA between the precue and the target. (Adapted from Figure 1 of "Movements of Attention Across the Visual Field" by Y. Tsal, 1983, *Journal of Experimental Psychology: Human Perception & Performance*, 9, p. 525. Copyright 1983 by the American Psychological Association. Adapted by permission.)

This research was supported by Public Health Service Research Career Program Award K6-MH-22014 to the first author and by United States Public Health Service Research Grant MH-01206, also to the first author. Requests for reprints should be sent to Charles W. Eriksen, Department of Psychology, University of Illinois, Urbana-Champaign, 603 E. Daniel, Champaign, IL 61820.

computed to be at 83, 116, and 150 msec for the 4°, 8°, and 12° targets, respectively. Assuming the attentional focus is initially located at the fixation point, these differences in asymptotic SOAs should reflect the differences in time necessary for the focus to traverse the distance from fixation to the different target locations. Following Tsal's argument, a velocity of approximately 8 msec per degree along the horizontal meridian is indicated. Regression analyses were performed on the functions from the shortest SOA to the value of SOA at which the function had been determined to be asymptotic. Linear regression accounted for 99.6% of the variance for the 8° target condition and for 98.1% of the variance for the 12° condition. From this Tsal concluded "that the SOA facilitated performance via movements of attention at a constant velocity" (1983, p. 526).

These conclusions required a number of assumptions. To use the shape and parameters of the RT-SOA function not only to infer that the attentional focus traverses the visual field but also to infer the rate of travel, we must first examine the variables that affect the shape of the function. We will begin by assuming along with Tsal that there is an attentional focus of measurable extent in the visual field. Furthermore, this focus is necessary to discriminate the targets in the experiment, namely, an X from an O. We will further assume that at the beginning of a trial the focus is located at the fixation point. It is also necessary to assume that some attentional resources are distributed over the visual field, in addition to a focused concentration of these resources. Were this not the case, we would have no means of accounting for the subject's ability to perceive the precue and its location.

When the cue occurs, the focus begins to change its location. At zero and short SOAs the target will occur before the focus relocation occurs.[1] At these SOAs, reaction time will be maximal, because the target processing will be delayed until the focus arrives at the cued location. As the SOA increases, focus relocation gets an increasing head start. The RT-SOA function will become asymptotic when the SOA is long enough that focus relocation has always taken place before target presentation.

Given these assumptions, it might seem at first that the differences in RT at zero SOA and at asymptote would directly reflect the time required to relocate the attentional focus from the fixation point to the cued location. But there are at least five distinguishable variables that determine the shape and parameters of the RT-SOA function. First, there is the time required to perceive the cue and its location. Second, a latency in initiating the attentional relocation must be assumed. Third, there is the time required for the relocation to occur. Fourth is the role of individual differences. (The RT-SOA functions represent data averaged over subjects and therefore individual differences in the first three variables will contribute to the shape of the RT-SOA function.) Finally, there is the possibility that the RT-SOA function may reflect in part a first signal or warning effect (Bertleson, 1967; Colegate, Hoffman, & Eriksen, 1973; Eriksen & Hoffman, 1974; Posner & Boies, 1971). All five of these variables operating in concert will determine the shape of specific RT-SOA functions.

Consider now Tsal's conclusion that the RT-SOA functions were linear with a slope of 8 msec per degree of visual angle, which reflects the rate of travel of the attentional focus across the visual field. To accept this conclusion we must assume that the following three times were *constant*: the time required to perceive the cue and its location; the latency of initiating a change in attentional focus; the time necessary to effect this change. Furthermore, we must assume not only no variability within each subject but no individual differences between subjects in the values of these constants. In addition, we must also assume that the precue did not produce a warning or general alerting effect.

In terms of what we know about biological processes, it is far more likely that the latencies involved in attentional change, as well as the temporal course of a warning effect, are variable over trials or occasions within and between subjects. Variance of these latencies and times would cause an RT-SOA function with negative acceleration.

This can be seen in the following example. Let us assume that the mean latency to detect and localize the cue and initiate and move the attentional focus 12° from fixation is 100 msec, with a distribution ranging from 50 to 150 msec for a given subject. Assume further that if the focus is already on the target location when the target is presented, processing time averages 500 msec. Now if target and cue are presented simultaneously (zero SOA), RT will average 600 msec (100 msec average time for focus to reach target location, plus 500 msec average processing time). If the cue precedes the target by 151 msec, RT will average 500 msec, because the focus is always at the proper location when the target arrives. But at a 101-msec SOA, the focus will be at the location approximately 50% of the time when target arrives. The mean RT to the target on these trials will be 500 msec, because having the focus at the location *before* the target arrives results in no saving in processing time. On the remaining 50% of the trials, the target will have to await processing, sometimes for as long as 50 msec, before the focus arrives. The mean RT of this half of the trials will be greater than 500 msec, the exact value depending upon the shape of the distribution of latencies for processing the cue and changing attentional focus. The mean for all trials will thus be greater than 500 msec. A similar effect will occur for SOAs of between 50 and 100 msec. The result is that target RT will be a negatively accelerated function of SOA from 50 to 150 msec, with the exact function determined by the form of the distribution of latencies in processing the cue and changing attentional focus. Only at SOAs of less than 50 msec will RT to the target have a linear relation to SOA. Reflection will show that the point at which the function becomes asymptotic is quite sensitive to the range and variance of the latency distribution. When data are averaged over subjects, both the range and the variance will increase.

In the above example we have considered only latency distributions involved in changing the attentional focus, but the RT-SOA functions obtained by Tsal may also be confounded with an unassessed general warning effect initiated by the precue. Colegate et al. (1973) and Eriksen and Hoffman (1974) found some evidence of this general warning effect in experiments on precuing of visual attention that were comparable to the procedure employed by Tsal. More recently, the experiments of Shulman et al. (1979) and Remington and Pierce (1984) showed pronounced warning effects of the precue over the SOA intervals employed in Tsal's experiment. Recent experiments using precuing have found it necessary to provide a control for this effect (Eriksen & Yeh, 1985; Jonides, 1980, 1983). The effect appears to be much more pronounced on detection tasks (Remington & Pierce, 1984; Shulman et al., 1979) than on choice reaction time tasks (Colegate et al., 1973; Eriksen & Hoffman, 1974), but the possible effect of the precue's serving as a warning stimulus must be controlled or partialed out before interpretations regarding attentional variables can be drawn from the RT-SOA function. This is particularly true if the warning effect interacts with retinal locus of the target.

The above discussion demonstrates that the shape of the RT-SOA function for data averaged over subjects is determined by at least the five components we have considered. The function will not asymptote until the SOA value is long enough to encompass the longest latencies for the slowest subject, nor will it asymptote until any warning effect provided by the cue has achieved it maximum value. Thus it is apparent that we cannot use the difference in SOA values at which the RT-SOA functions for the three retinal eccentricities approach asymptote as a direct reflection of the travel time of the attentional focus from fixation to target location. To do so would be to assume that this asymptotic value is determined only by the travel time of the attentional focus to the target location. But it is quite likely that the experimental variable of *retinal eccentricity* will affect one or more of the other four components.

Consider first individual differences. In the individual-difference literature, it is a common finding that as tasks become more difficult, the differences between individuals increase. The data in Figure 1 show that in Tsal's (1983) Experiment 1, at all SOA values, even at asymptote, performance was appreciably slower with the 12° targets than with the 8° targets, which in turn were slower than the 4° targets. One can conclude that with greater eccentricity on the retina, the task becomes more difficult. If individual differences become greater with this increase in task difficulty, then one would predict that the asymptotic value of the RT-SOA function (averaged over subjects) would increase with retinal eccentricity. This results from the effect of increases in variance that increase the SOA value at which the RT-SOA function becomes asymptotic. One might reasonably expect to obtain asymptotic SOA values directly proportional to the amount of retinal eccentricity solely on the basis of individual differences and irrespective of any possible travel time of the attentional focus.

Perhaps more important than individual differences in determining the SOA value at asymptote is the processing time for the precue. The conclusions drawn from the SOA asymptote values are critically dependent upon the assumption that cue processing time is constant over different retinal eccentricities. But this assumption flies in the face of considerable evidence from both behavioral data and the neurophysiology of the retina. Both choice reaction time (Eriksen & Schultz, 1977; Lefton & Haber, 1974) and simple reaction time (Remington & Pierce, 1984; Shulman et al., 1979) have been found to increase rather markedly as the distance of the stimulus from the fovea increases. The data shown in Figure 1 clearly demonstrate such an effect of retinal eccentricity. RT differences for the three locations persisted even at SOA values that had been determined to be at the asymptotic level. Thus they cannot be attributed to the time required to initiate and change the focus of attention. Instead, they must reflect differences in processing speed at different retinal locations. The data are, of course, for discrimination between an X and an O, rather than for the detection of the location of a precue dot. However, substantially similar results were obtained by Remington and Pierce (1984) for simple RT to a dot stimulus very similar to the dot cue employed by Tsal (1983).[2] The SOA values at asymptote for different retinal loci may in part reflect an analog movement of attentional focus, but they also most likely are determined in part by differential processing times for location of the precue.

There is another tenuous assumption involved in Tsal's (1983) procedure. This assumption concerns the locus of attention before the precue occurs. If we wish to measure the rate at which the attentional focus moves to a given position in the visual field, we have to know its starting point. Tsal assumed that since his subjects were asked to fixate the fixation cross prior to the beginning of a trial, their attentional focus was also on that point. But the basic premise of experiments such as these is that the attentional focus is not necessarily at the point in the visual field where the eye is fixated. An impressive amount of evidence accumulated over the past 20 years (Bergen & Julesz, 1983; Eriksen & Spencer, 1969; Eriksen & Yeh, 1985; Hoffman, 1979; Jonides, 1983; Shiffrin & Gardner, 1972; Shiffrin & Geisler, 1973) has shown that if the visual discriminations required are relatively easy, focal attention is not necessary. Furthermore, Jonides (1983) and Eriksen and Yeh (1985) presented evidence that visual attention can operate in either a distributed or a focused mode. In the distributed mode, the attentional resources are distributed throughout the visual field, with parallel processing of multiple stimuli. In the focused mode, resources are concentrated in a small area in the visual field and stimuli are searched or processed sequentially.

In Tsal's (1983) experiments, some distribution of attentional resources must have occurred in order for the subject to detect the precue. If all resources had been concentrated on the fixation point, there would have been no processing capacity left over to enable the subject to detect the precue and its location. We need to examine what type of results would be expected if Tsal's subjects, after fixating the fixation point before a trial, then distributed their attention throughout the visual field. This would be an optimum strategy for rapid processing of the precue.

Let us assume that continuous processing occurs, rather than that detection of the cue occurs and processing then ceases until attentional focus has shifted to the cued location. With continuous processing, the same resources that detect the cue begin processing the target when it arrives, whether or not attention is highly focused at that point. As attention begins to focus on the cued area, resources are gradually concentrated in that location. Depending upon the SOA, varying degrees of resource concentration will have occurred by the time the target is presented. With easy discriminations, the criterion for the choice response may be reached before maximal attentional focusing or concentration of resources has occurred. We would then expect that the degree of resource concentration at the time of response would vary inversely with discrimination difficulty. Discrimination difficulty can involve retinal acuity, feature overlap or similarity of the stimuli, or the dimensionality of the stimulus. Stimuli located at greater retinal eccentricities would present a more difficult discrimination and thus would require greater attentional concentration, with a consequent increase in time for this concentration of resources to be achieved. This would imply that the easier the task, the earlier the RT-SOA function would approach asymptote. Continuous processing would predict the same results as those obtained by Tsal (1983), but in this case no movement of a constant-size attentional focus across the visual field would be required.

Shulman et al. (1979) also tested the assumption that attentional focus moves in an analog fashion through visual space. At variance with Tsal's (1983) tentative conclusion that attention is inoperative during its journey, their methodology was based on the assumption that the attentional focus continues to process stimuli falling in its path as it moves across the field to the designated target. Thus, if the attentional focus shifts from Stimulus A to Stimulus C, it will process Stimulus B if this stimulus falls in its path during its journey from A to C.

Shulman et al.'s (1979) procedure involved simple RT to the onset of one of four light-emitting diodes positioned 8° and 18° to the left and to the right of a central fixation point. At the beginning of a trial, the fixation cross was replaced by an arrow that pointed to either the right or the left. This arrow indicated to the subject which 18° diode was the highly probable target on that trial. Only the 18° diodes, right and left, were precued, and the arrow was valid on 70% of the trials. On the remaining 30% of the trials, one of the three remaining noncued diodes was the target. The arrow precue preceded the onset of the target by SOAs of 50, 100, 150, 200, 350, and 500 msec.

These experimenters reasoned that if the attentional focus traversed the visual field, processing as it went, then at some SOA value shorter than the SOA required for the attentional focus to reach the 18° cued target, the focus would be located at the 8° target on the indicated side. On an invalid cue trial when this 8° target was illuminated, detection latency should show a relative facilitation at or near this shorter SOA. The RT-SOA functions would be expected to be different for the 8° and 18° targets on the cued side as a function of differences in retinal acuity, but the two functions should interact, with the difference between the 8° and 18° targets becoming less at some relatively short SOA value before becoming greater again as the attentional focus approached and reached the 18° target.

Figure 2 shows the results of Shulman et al.'s (1979) Experiment 1. RT is plotted as a function of SOA interval for each of the four target locations. The function for the far expected (cued) location contains 70% of the data, with the remaining 30% of the trials evenly divided among the other three parameters in the figure. For the hypothesis under investigation, the critical comparison is between the far expected (cued) location and the near stimulus on the

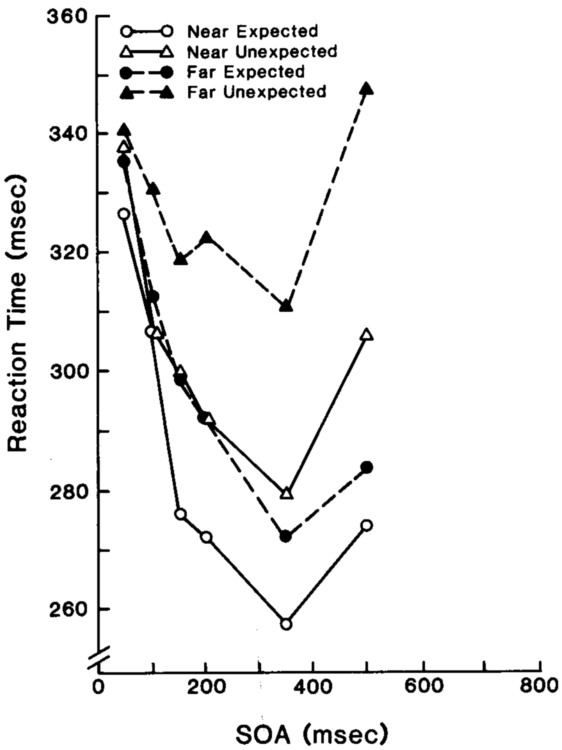

Figure 2. Mean reaction time to near and far targets on the cued (expected) and noncued (unexpected) side as a function of the SOA between cue and target. (Adapted from Figure 1 of "Moving Attention Through Visual Space" by G. L. Shulman, R. W. Remington, and J. P. McLean, 1979, *Journal of Experimental Psychology: Human Perception & Performance*, 5, p. 524. Copyright 1979 by the American Psychological Association. Adapted by permission.)

cued side. If, during the SOA interval, the attentional focus were moving from the fixation point to the 18° cued location, then at some intermediate SOA value, the focus should correspond with the near expected diode. If this diode were illuminated, RT to it should be faster than that to the far cued position. Examination of the curves in Figure 2 shows that such an effect was obtained. At a 50-msec SOA, the functions for the far and near locations on the cued side differ by 9 msec. At SOAs of 150 and 200 msec, the difference increases to 23 msec, and at a 500-msec SOA the difference decreases again to 12. Thus, apparently, the hypothesis is supported.

However, this conclusion becomes suspect when functions for the far and near locations on the uncued side are compared. These two functions show an even greater divergence over the SOA range used by Shulman et al. (1979). Presumably, both of these RT-SOA functions reflect a general warning effect from the occurrence of the precue. Their divergence over the SOA range of 50–350 msec suggests that this warning effect interacts with retinal locus. Since the function for the near location on the cued side is a composite of presumed attentional movement as well as this general warning function, the degree to which it diverges from the function for the far location over the 350-msec SOA range may be due to the greater warning effect for a near stimulus than for a far stimulus. Thus, there is a very real possibility that the divergence between the far and near functions on the expected or cued side reflect the differential efficacy of a warning or first-signal effect, rather than a movement of attentional focus across the visual field. Shulman et al. dismissed this possibility, citing unpublished data of Posner's that showed that the alerting effect did not interact with retinal position; however, one of the most pronounced effects in Shulman et al.'s data, as shown in Figure 2, is this interaction.

Shulman et al. (1979) replicated the effect of the far expected and near expected functions in a second experiment. At a 75-msec SOA, the difference between the far and near lights on the expected side was 6 msec, which increased to 20 msec at a 150-msec SOA and decreased to 10 msec by a 375-msec SOA. However, their Experiment 2 data show the same interaction of the alerting effect on the far and near locations on the unexpected side. At a 75-msec SOA the functions differ by 13 msec, which increases to 29 msec by a 225-msec SOA. Thus, the expected diversions between near and far expected locations were replicated, as well as the interaction of the alerting effect for near and far unexpected locations. Posner may indeed have found no interaction between retinal locus and the alerting effect, but his experiments are not what we are concerned with here. It is obvious from the data that in Shulman et al.'s experiments there was an interaction between these variables.

Other aspects of the data shown in Figure 2 appear to be inconsistent with the attentional focus's moving from the fixation point to a cued target 18° away. Consider the function for the near unexpected location. This is where the diode 8° from fixation on the noncued side is illuminated "unexpectedly." As the figure shows, the function for the near unexpected location is virtually identical to the function for the cued 18° target out to an SOA of about 300 msec. If the focus was moving away from the near unexpected target during this SOA interval, this result is surprising. In the absence of cuing, RT to the near location would be expected to be faster due to the more favorable retinal locus. The equally fast RT to the far 18° location could be attributed to the precue's moving the attentional focus to this far locus and thus facilitating processing. But other evidence from Shulman et al.'s (1979) experiment indicates that very little attentional facilitation occurred at SOAs as short as 150-200 msec. According to the experimenters' interpretation of the divergence in RT between the near and far targets on the expected side, the attentional focus was located about 8° from fixation on the expected side at an SOA of 200 msec. To produce facilitation in the far expected target, the focus had another 10° to travel. In order for the focus to compensate for the lower acuity of the far target location, the focus would have to be exerting an appreciable effect on this far location at SOAs as short as 50–100 msec.

Remington and Pierce (1984) performed experiments similar to those of Shulman et al. (1979), but came to quite different conclusions. They interpreted their data as showing that the attentional focus either moved at a speed proportional to the distance to be traversed (similar to a saccadic eye movement) or, more likely, moved in a discrete shift that was time-invariant with the distance to be traversed. Their precue, like Shulman et al.'s, was a directional arrow that appeared above the fixation point, and targets could occur either to the right or to the left along the horizontal meridian at eccentricities of either 2° or 10°. The target was a small dot and subjects were to respond as quickly as possible to its onset. Remington and Pierce's experiments differed from those of Shulman et al. in that on a given trial the target could occur in only two locations, to the left or to the right of fixation. The 10° locus was tested in one experimental session and the 2° locus in another. In both experimental sessions, the precue validity was 80%, and on the remaining trials the target occurred in the noncued location. In a second experiment, a neutral cue was employed as well: on 30% of the trials, a cross appeared immediately above the fixation point. When the cross appeared, the subject knew that the target was equally likely to occur in the left or the right position. In the two experiments, the SOAs by which the arrow cue or the neutral cross preceded the dot target varied from 16 to 600 msec.

Figure 3 is an adaptation of Remington and Pierce's (1984) Figure 1, which shows the results of their Experiment 1. Consistent with both Tsal's (1983) and Shulman et al.'s (1979) experiments, Remington and Pierce found a clear effect of retinal eccentricity for both the cued and the noncued targets. RT was more rapid for targets located closer to fixation. The data for the noncued locations appear to reflect a warning effect quite similar to that obtained by Shulman et al.

Since eye fixation was not monitored in the experiment, the experimenters wisely based their main interpretation of the data on SOA values of 250 msec or less. To evaluate the effects of retinal eccentricity on the shifting of attention, RTs to the cued near location were subtracted from RTs to the cued far location at each SOA. These differences are shown in Figure 4, which is a reproduction of Remington and Pierce's (1984) Figure 3. (This figure also includes Shulman et al.'s [1979] data.) An analysis of variance of these data yielded a significant effect of SOA resulting from the steady decline in these differences with time. Remington and Pierce (1984) concluded that "this would not be predicted by a fixed velocity analog model" (p. 395).

This interpretation of their data is perplexing, because it would appear that an analog shift model such as that proposed by Tsal (1983) would predict just this pattern of results. This is evident if we apply Tsal's analog movement model to Remington and Pierce's (1984) experimental situations. Let us begin by assuming that retinal processing efficiency is 20 msec faster at 2° eccentricity than at 10°. At zero or very short SOAs (16 msec), the attentional focus is still at the fixation point when the target occurs. If attentional focus is assumed to be necessary for processing the target, then at zero SOA, RT to a target will depend upon the efficiency of retinal processing plus the time it takes to move attention to that retinal eccentricity. Let us assume further that the attentional focus moves at 2 msec per degree. When a target occurs at 10° eccentricity, 20 msec will be required to shift attentional focus to this location, and for targets located at 2°, 4 msec will be required. Thus, when a target occurs at zero SOA, RT to the 10° location will be 36 msec longer, on the average, than RT to the targets at the 2° location (20 msec for differences in efficiency of retinal processing at the different eccentricities and 16 msec for the increase in travel time to the 10° locus as opposed to the 4°). When the RT-SOA functions have reached their minima or have become asymptotic, the presumption is that the SOA is now long enough that attention has always arrived at the cued location before the target occurs. Thus the average difference in RTs to the 2° and 10° locus should reflect only the 20-msec difference in processing efficiency associated with these retinal eccentricities. In other words, RT differences between near and far locations should become less as the SOA increases.

This is exactly the pattern of results that Remington and Pierce (1984) reported. The pattern is more pronounced in their Experiment 1 data than in their Experiment 2, but both experiments show a declining difference as SOA increases to 250-300 msec. Ironically, while this argument shows that Remington and Pierce's data support an analog shift of attention, the data analysis they present of

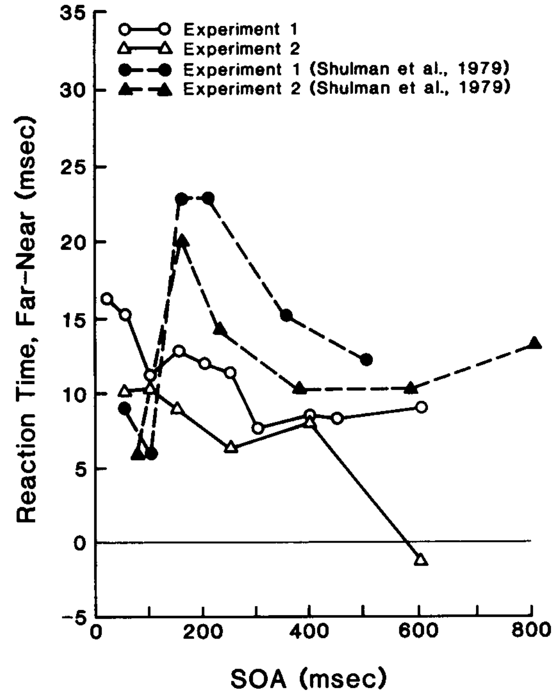

Figure 4. Difference in mean reaction time between cued targets as a function of distance from fixation and SOA between the cue and the target. (Adapted from Figure 3 of "Moving Attention: Evidence for Time-Invariant Shifts of Visual Selective Attention" by R. Remington and L. Pierce, 1984, *Perception & Psychophysics*, 35, p. 397. Adapted by permission.)

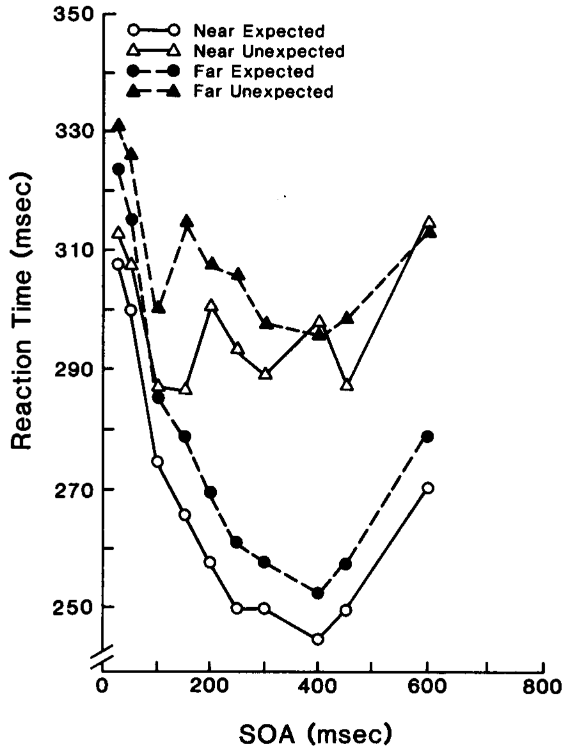

Figure 3. Mean reaction time to cued (expected) and noncued (unexpected) targets as a function of distance from fixation and SOA between the cue and the target. (Adapted from Figure 1 of "Moving Attention: Evidence for Time-Invariant Shifts of Visual Selective Attention" by R. Remington and L. Pierce, 1984, *Perception & Psychophysics*, 35, p. 395. Adapted by permission.)

Shulman et al.'s (1979) experiments does not. As shown in Figure 4, the RT differences between near and far targets in Shulman et al.'s studies show a pattern of increasing differences, which would not be consistent with the analog shift of attention.

Both Remington and Pierce (1984) and Shulman et al. (1979) used a cost-benefit methodology. This may be a useful method for the investigation of certain attentional problems, but when the primary concern is the shape or parameters of the RT-SOA function, the cost-benefit methodology creates problems. The methodology requires that the cue be less than 100% valid, typically 70%-80%. There is substantial evidence that subjects probability match over trials roughly in proportion to the probability of target occurrence at different locations (Eriksen & Yeh, 1985; Jonides, 1980; Shaw, 1978). If subjects were probability matching in Shulman et al.'s and Remington and Pierce's experiments, then the warning effect obtained for targets at unexpected locations was seriously overestimated. Part of the decline in RT with SOA for these targets would be due to the attentional focus's actually being directed to this location on a certain proportion of the trials. Similarly, the benefit of the attentional focus when the target occurred in the expected location would be underestimated. The problem becomes serious when the precise shape or parameters of the RT-SOA functions are items of interpretive importance, because it is quite plausible that the subjects' probability-matching strategies could interact not only with retinal eccentricities of possible target locations but also with the SOA between precue and target appearance.

How attention shifts from one locus to another in the visual field is still an open question. Not only is the experimental evidence conflicting, but the experiments are based on a string of tenuous assumptions that render interpretations of the data quite problematic. This reflects not so much on the design of the experiments as on the uncertain state of our knowledge of the phenomena of attention. We have not definitely resolved the issue of whether attention has a spatial locus in the visual field or whether precuing techniques merely provide early criteria for selection (Duncan, 1981). A similar issue is whether attention is object based or spatial. As a consequence, we are essentially bootstrapping our way in our experimentation. This should not discourage our research efforts, but the tentative nature of the conclusions must be recognized.

REFERENCES

Bergen, J. R., & Julesz, B. (1983). Parallel vs. serial processing in rapid pattern discrimination. *Nature*, **303**, 696-698.

Bertelson, P. (1967). The time course of preparation. *Quarterly Journal of Experimental Psychology*, **19**, 272-279.

Colegate, R., Hoffman, J. E., & Eriksen, C. W. (1973). Selective encoding from multielement visual displays. *Perception & Psychophysics*, **14**, 217-224.

Duncan, J. (1981). Directing attention in the visual field. *Perception & Psychophysics*, **30**, 90-93.

Eriksen, C. W., & Hoffman, J. E. (1974). Selective attention: Noise suppression or signal enhancement? *Bulletin of the Psychonomic Society*, **4**, 587-589.

Eriksen, C. W., & Schultz, D. W. (1977). Retinal locus and acuity in visual information processing. *Bulletin of the Psychonomic Society*, **9**, 81-84.

Eriksen, C. W., & Spencer, T. (1969). Rate of information processing in visual perception: Some results and methodological considerations. *Journal of Experimental Psychology Monographs*, **79**(2, Pt. 2), 1-16.

Eriksen, C. W., & Yeh, Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception & Performance*, **11**, 583-597.

Hoffman, J. E. (1979). A two-stage model of visual search. *Perception & Psychophysics*, **25**, 319-327.

Jonides, J. (1980). Toward a model of the mind's eye. *Canadian Journal of Psychology*, **34**, 103-112.

Jonides, J. (1983). Further toward a model of the mind's eye's movement. *Bulletin of the Psychonomic Society*, **21**, 247-250.

Lefton, L., & Haber, R. N. (1974). Information extraction from different retinal locations. *Journal of Experimental Psychology*, **102**, 975-980.

Posner, M. I., & Boies, S. J. (1971). Components of attention. *Psychological Review*, **78**, 391-408.

Remington, R., & Pierce, L. (1984). Moving attention: Evidence for time-invariant shifts of visual selective attention. *Perception & Psychophysics*, **35**, 393-399.

Shaw, M. L. (1978). A capacity allocation model for reaction time. *Journal of Experimental Psychology: Human Perception & Performance*, **4**, 586-598.

Shiffrin, R. M., & Gardner, G. T. (1972). Visual processing capacity and attentional control. *Journal of Experimental Psychology*, **93**, 72-82.

Shiffrin, R. M., & Geisler, W. S. (1973). Visual recognition in a theory of information processing. In R. Solso (Ed.), *The Loyola Symposium: Contemporary issues in cognitive psychology*. Washington, DC: Halsted Press.

Shulman, G. L., Remington, R. W., & McLean, J. P. (1979). Moving attention through visual space. *Journal of Experimental Psychology: Human Perception & Performance*, **5**, 522-526.

Tsal, Y. (1983). Movements of attention across the visual field. *Journal of Experimental Psychology: Human Perception & Performance*, **9**, 523-530.

NOTES

1. If target duration is short, the focus may not be at the target location until after the stimulus has terminated. In this case we must presume that the focus then processes from a visual icon or persisting stimulus trace.

2. Tsal recognized that differences in processing the cue at different retinal eccentricities would confound his interpretation of differences in asymptotic SOA values. He ran a control study (Tsal, 1983, Experiment 3) that essentially replicated the procedure of his Experiment 1. The precue appeared in one of the three retinal eccentricities to the right or to the left of fixation, followed at one or another of the different SOA values by the target letter. But in this experiment, instead of discriminating the target X from O, the subject pressed one key if the precue appeared in the left visual field and a different key if it appeared in the right visual field. Subjects were instructed to respond only to the precue rather than to discriminate the target letters. No significant or suggestive difference in RT was found as a function of precue location. This result is difficult to reconcile with the evidence cited above, particularly inasmuch as performance in Tsal's (1983) Experiment 1 was progressively poorer with increases in eccentricity at all SOA values.

(Manuscript received January 14, 1987;
accepted for publication April 8, 1987.)