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ORIENTING OF ATTENTION*

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Bartlett viewed thinking as a high level skill exhibiting ballistic properties that he called its "point of no return". This paper explores one aspect of cognition through the use of a simple model task in which human subjects are asked to commit attention to a position in visual space other than fixation. This instruction is executed by orienting a covert (attentional) mechanism that seems sufficiently time locked to external events that its trajectory can be traced across the visual field in terms of momentary changes in the efficiency of detecting stimuli. A comparison of results obtained with alert monkeys, brain injured and normal human subjects shows the relationship of this covert system to saccadic eye movements and to various brain systems controlling perception and motion. In accordance with Bartlett's insight, the possibility is explored that similar principles apply to orienting of attention toward sensory input and orienting to the semantic structures used in thinking.

Introduction

Sir Frederic Bartlett wrote a book, *Thinking*, during the last part of his life (Bartlett, 1958). It is not as widely known as his earlier work, *Remembering* (Bartlett, 1932), but it had a strong impact on me, perhaps because it was among the first psychology books I read. Bartlett's theme was as simple as it was powerful. Thinking is a skill and should be studied with the techniques that had proved successful in the study of other skilled behaviour. In particular, I was struck with Bartlett's metaphor that thinking like swinging a bat, has a "point of no return". Once committed in a particular direction, thought is ballistic in that it cannot be altered.

It may be hard to understand why this idea should have been so exciting to someone reading the psychological literature in 1959. In retrospect, what captured the imagination must have been the idea that a hidden psychological process like the formation of a thought might be rendered sufficiently concrete to measure. Twenty years later, when psychologists routinely measure the speed of rotation of visual images (Cooper and Shepard, 1973) or the time needed to scan the next item of an internally stored list (Sternberg, 1969), it is hard to reinstate the excitement that the prospect of such research could have engendered in at least one reader of Bartlett's book.

During the last few years of research on human cognition, there has grown up a number of similar views of how the human nervous system is organized in the performance of species—specific human behaviour such as reading (LaBerge and

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Samuels, 1974; Posner, 1978). The idea of a limited capacity attentional system has been a central feature of these views. Although some have argued that a skills approach is antithetical to the study of internal attentional mechanisms (Neisser, 1976), most work on skill has also assumed, with Bartlett, the importance of mechanisms of limited capacity (Broadbent, 1977).

Currently, the study of spatial attention in alert monkeys (Mountcastle, 1978; Wurtz and Mohler, 1976; Robinson, Goldberg and Stanton, 1978), brain injured persons (Weiskrantz, Warrington, Sanders and Marshall, 1974) and normal subjects (Posner, 1978, Chapter 7) seems to me to be a most promising model system for relating an important component of complex human cognition to studies of the neural systems underlying performance. While orienting to stimuli in visual space is a restricted sense of attention, I believe that its study is capable of providing us both with important tests of the adequacy of general models of human cognition and with new insights into the role of attention in more complex human activity. Accordingly, this paper will be devoted to a discussion of the results of experiments in human spatial attention and a comparison of them with animal approaches to the same topic. If there should emerge satisfactory convergence between human performance and physiological approaches with this simple model system, I believe that the psychological methods used to explore attention in more complex tasks will receive added support. In addition, studies of human performance may help investigators of neural systems toward the needed integration of their studies of separate anatomical structures.

Orienting

I will use the term *orienting* to mean the aligning of attention with a source of sensory input or an internal semantic structure stored in memory. The term orienting has been closely tied to a reflex (Sokolov, 1963), the operation of which is indexed by a variety of autonomic, CNS and overt changes. The idea of an orienting reflex is related to the mental operation of orienting as I use it. However, the orienting reflex does not distinguish between aligning of attention and the resulting perception of a stimulus.

Detecting

I distinguish orienting from another cognitive act that I call *detecting*. By detecting I will mean that a stimulus has reached a level of the nervous system at which it is now possible for the subject to report its presence by arbitrary responses that the experimenter may assign. These may be verbal ("I see it") or manual (pressing a key). Detecting means to be aware or conscious of the stimulus. The distinction between orienting and detecting allows one to explore the proposition that some responses (e.g. saccadic eye movements) may be available to a stimulus before it has been detected in the sense used here. This distinction makes it reasonable that a normal subject may move his eyes toward a stimulus, but not be able to otherwise report it, or that a brain damaged subject might have impairments in detecting an event to which he can orient (Weiskrantz, Warrington, Sanders and Marshall, 1974).

Locus of control

It is also important to make a distinction between external and central control over orienting. If orienting to memory and to external stimuls events is to have a common base, it is clear that we must be able to orient attention in the absence of an external stimulus. Similarly, movements of the eyes can either be driven by stimulus input or result from a search plan internal to the organism.

Overt and covert orienting

Finally, it is important to distinguish between overt changes in orienting that can be observed in head and eye movements, and the purely covert orienting that may be achieved by the central mechanism alone. In order to make this distinction, one must be able to measure covert orienting by means other than observation of overt head and eye movements. With human subjects it is possible to manipulate the direction of attention by an instruction, by changing the probability of a target event, or by the use of appropriate overt movements. To measure whether orienting occurs, changes in the efficiency of detecting events that occur at various spatial positions are examined. Some variant of mental chronometry (Posner, 1978) such as reaction time (Posner, Nissen and Ogden, 1978), threshold detection (Remington, 1978), evoked potential amplitude (Von Voorhis and Hillyard, 1977) or changes in firing rates of single cells (Mountcastle, 1976) can be used as a dependent measure of processing efficiency.

It is important to keep in mind the definitions of orienting and detecting and the distinction between external and central control as we review experimental evidence. Evidence is examined in four major sections. The first establishes the ability of subjects to shift attention around the visual field in accordance with instructions. By measuring both the facilitatory and inhibitory effects of orienting on the efficiency of detection, it is possible to examine the relationship of the covert attentional mechanism to the fine structure of the retina. The second section supports the idea of analogue movements of attention across the visual field that are measured by time locking of attention shifts to external cues. The third section examines the relationship between movements of attention and overt changes of eye position. In this section it is possible to compare our results with those arising from single cell recording and to distinguish between theories outlining the relationship between perceptual and movement systems. The fourth section deals with the crucial role of peripheral stimuli in controlling attention movements. The concluding portion of the paper examines the implications of our results on spatial attention for more complex performance.

Attention shifts

It is not obvious that shifting spatial attention involves anything more than the movement of the eyes to positions in the visual field. Certainly, no one would dispute the close connection between movements of our eyes and shifts of attention. Nonetheless, there has always been speculation that one can shift attention independent of eye movements. For example, Wundt (1912, p. 20) commented on the ability to separate the line of fixation from the line of attention. Natural language refers to the ability to look out of the corner of our eyes, and athletic coaches instruct their players to do so in order to confuse their opposition.

Many experimental studies using methods of mental chronometry (Grindley and Townsend, 1968; Mertens, 1956; Mowrer, 1941; Shiffrin and Gardner, 1972) were not successful in showing this ability, at least in empty visual fields. More recently, successful reports of attention shifts in the absence of eye movements have been frequent (Eriksen and Hoffman, 1973; Klein, 1979; Posner, Nissen and Ogden, 1978; Shaw, 1978; Von Voorhis and Hillyard, 1977; Wurtz and Mohler, 1976).

We (Posner, Nissen and Ogden, 1978) sought to determine whether responses to clear above threshold luminance increments in dark fields would occur more quickly when subjects knew where the stimulus would occur than when they did not. We used differences in reaction time to a stimulus at expected and unexpected positions in the visual field as a measure of the efficiency of detection due to turning attention toward the expected position. To insure that the differences in reaction time did not depend upon shifting one's eyes, we monitored eye movements by use of EOG. We used only those trials in which the eyes remained fixated. In order to eliminate overt response preparations as a contributor, we used either a single key (simple RT) which the subject pressed regardless of where the stimulus occurred or made the response choice unrelated to stimulus position. Figure 1 illustrates the sequence of events within a trial. The subject was presented with a plus sign or an arrow pointing to the right or left. If the plus sign was presented, the detection stimulus was equally likely to occur to the left or right of fixation. If an arrow was presented, the probability was 0·8 that the detection stimulus would occur on the indicated side (valid) and 0·2 that it would occur on the other side (invalid). One can then examine both the benefits from knowing where in space the stimulus will occur, and the cost when it occurs at a position other than the expected position.

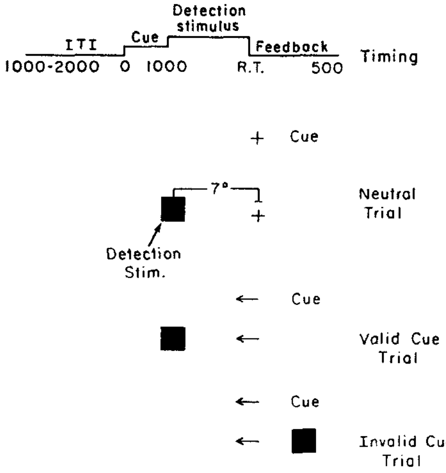

FIGURE 1. Organization of individual trials in the central cue experiments.

We have now tried this basic design with a variety of tasks. Figure 2 shows highly significant benefits from valid information and highly significant costs when

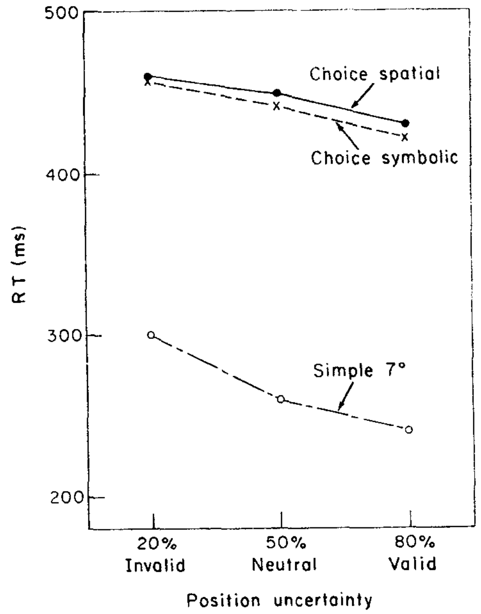

Figure 2. Reaction time for valid, invalid, and neutral trials for simple RT to luminance increments (Posner, Nissen and Ogden, 1978); choice RT to determine whether the stimulus is above or below the middle of the display and choice RT to letter versus digit judgements (Posner, Snyder and Davidson, in press).

the trial is invalid in all these studies. For any one task the costs and benefits are of roughly the same magnitude. The simple RT conditions involve only a single key that the subject presses irrespective of the location of the signal. The choice spatial task involves a report about whether the stimulus was higher or lower than the cue. As in the simple RT task, the cue provides no information about the response that is most likely. The symbolic task involves a report concerning whether the target is a letter or digit. In the choice tasks there are no more errors in the valid condition than in the invalid condition although the effects of the cue on error rate are always small.

The costs and benefits of a spatial cue are highly regular and it may seem surprising that many previous efforts were not successful in finding improvements in RT or threshold detection in similar experiments. One reason is that the overall effect seems to get smaller as the task is made more difficult. Because our studies were run on separate subjects at different times, no direct comparison is appropriate, but the tendency for the effects of the choice RT tasks to be smaller than the simple RT tasks is striking. This is especially true because many people expect attentional limitations only when overall task complexity is high (Kahneman, 1973; Norman and Bobrow, 1975). If the effect really is smaller in complex tasks, I believe that this may be because subjects have to reorient attention from visual input to internal structures. If subjects are required to discriminate between a letter and a digit, for example, calling attention to a position in space will not be very useful in an empty field such as used in these experiments. Subjects will have to reorient attention from spatial position to the area in memory that is available for analysis of the discrimination. Indeed, we (Posner, Snyder and Davidson, in press) found that when given a single key to press whenever they saw a digit, subjects could hardly avoid false alarms when a letter appeared at the correct spatial position. If two keys were given, subjects did benefit from their knowledge of spatial position in RT without compensating increases in error as shown in Figure 2, but the benefits were small. These ideas fit with the usual observation that knowledge of spatial position only helps complex tasks when the field is cluttered. In tasks where there are good methods of quickly summoning attention, one might be better off not to know where the stimulus will occur rather than having to reorient from visual position to semantic code.

There is another reason that previous investigations have not always found knowledge of spatial position to aid performance. Our basic method involves cuing on each trial. If, instead, one spatial position is made likely for a whole block of trials, we found no benefits for the frequent position in comparison with conditions in which all positions are equally likely (Posner, Snyder and Davidson, in press), although there were small costs at the infrequent position. This result fits with the active nature of orienting. Orienting does not seem to involve a passive filter that can easily be set in place and left. Rather, an active process of maintaining the orientation seems important.

Our method can be exploited in an effort to understand the way in which the visual system constrains spatial attention. It is a common conviction that foveal stimuli have a more direct relation to attention than peripheral stimuli. Physiologists sometimes believe the reverse based on the idea that transient (*y* cells) dominate in the periphery. In fact, costs and benefits from attention did not vary much when we studied stimuli from 0·5 to 25 degrees eccentricity (Posner, 1978, p. 202).

This result led us to examine more completely the costs of an unexpected foveal stimulus when the subject was attending outside the fovea vs. those of an unexpected peripheral stimulus when he was attending to the fovea. We found roughly the same cost for an unexpected event when it is foveal as when it is peripheral* (Posner, 1978, p. 202).

What accounts for the strong subjective feeling that the fovea represents the centre of the attentional field? In my view, it is as important for a psychologist to account for this subjective feeling as it is to account for the objective data. Fortunately, it turns out to be possible to study this question. If subjects are given a cue as to which side is more likely, but are not told if the stimulus will be a peripheral or a foveal one, they uniformly prepare for the peripheral stimulus (Posner, 1978, Figure 7.8). Their strategy assumes that the fovea will take care of itself, even though our data say clearly that the costs in RT will be as great as

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*This result has implications for some of the theories arising from single cell recording at parietal levels. For example, Yin and Mountcastle (1977) argued that the attention system they were studying did not involve foveal representation. If they had been right, this would be evidence against area 7 being crucial in the kind of spatial orientation reported here. More recently, foveal representation has been found in these cells (Bushnell *et al.*, 1978; Mountcastle, Note 3).

for the periphery. The strategy must arise from the correlation between the fovea and attention brought about by the eye movement system.

When a task demands acuity (upper panel, Fig. 3), as in the work of Engle (1971), the fovea does play a special role (middle panel, Fig. 3). This contrasts with the luminance detection results illustrated in the bottom panel of Figure 3 in which attention is unrelated to the fovea. Although orientation to the periphery allows detection to occur more quickly, it does not provide an increase in the retinal grain and thus does not produce strong acuity changes. Attention represents a system for routing information and for control of priorities. It does not provide a substitute for the sensory specific wiring intrinsic to the visual system. Ells and I (Note 1) observed that subjects adjust their behaviour differently in luminance detection and in acuity experiments. In a luminance detection experiment, if subjects are told they can move their eyes on each individual trial if they wish, after a few trials they give up doing so. They quickly recognize that it is an effort to move their eyes and that it does not help performance. On the other hand, if free to move in an acuity demanding task, they clearly prefer to do so and the different levels of performance with foveal and nonfoveal vision confirm the wisdom of their preference.

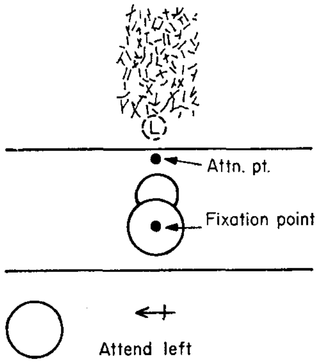

FIGURE 3. Upper panel indicates a high acuity task of searching visual noise for an L shaped figure studied by Engle (1971). As shown in the middle panel the fovea always plays a special role even though attention can expand the area of high conspicuity in the direction of the attention point. Lower panel contrasts our results in which the focus of attention shifts away from the fovea to be centered on the expected position.

Overall these results have something to say about the problem of ecological validity in perceptual experiments. It is true that the separation between attention and the fovea that occurs in our experiments is not a normal property of visual perception. It is revealed only under the close experimental control of the laboratory. Nonetheless, it appears that subjects do not adopt a special strategy in our experimental task, but rather carry over their natural tendencies from everyday perception. Under our special conditions we learn that the normal correlation between fovea and attention occurs as a result of the usual demands for high acuity and not as a result of any special wiring that ties attention to foveal stimulation. Only because our luminance detection task does not demand high acuity are we able to observe that the covert mechanisms of attention are not tied intrinsically to the fine structure of the visual system.

Attention movements

The introduction to this paper remarked on the importance of time locking as a way of bringing together physiological and behavioural methods for the investigation of spatial attention. It is important to ask whether the shift in efficiency that we have found when subjects move their attention is sufficiently time locked that measurements of attention movements might be made. One indication of such time locking is found in work by Jonides (Note 2). He varied the time interval between the cue and stimulus in studies otherwise like those I have described. Jonides found quite clearly that he could trace the time course of efficiency changes over a few hundred milliseconds. He also found a rather marked difference between the time course of efficiency when the subject's attention was brought to a position in space by a peripheral cue and when it was so directed by a central cue. The differences between a central and a peripheral cue will become important as we begin to look at the relationship between the time locked attentional movement and time locked movements of the eyes.

For the moment we will consider only the use of a central cue. Shulman, Remington and McLean (1979) asked the question whether movements across the visual field are digital or analogue in form. The eye moves across the visual field continuously, although in one sense the efficiency of its performance is digital since thresholds for taking in stimuli tend to be raised during the saccade. The technique used by these three investigators was to ask whether a visual detection stimulus that occurred on less than 10% of trials at a position between the fixation point and a target would show facilitation in latency at a time intermediate between leaving the home position and reaching the target. If so, one could expect RT for this position first to improve relative to the target as attention moved through it, and then to get worse relative to the target.

Each trial began with an arrow cue which instructed subjects to move attention to a visible target 18° from fixation. At varying intervals following this cue (SOA), detection stimuli were presented. The detection stimuli occurred on 75% of the trials, the remainder serving as catch trials. On trials where there was a detection stimulus it occurred at the designated target of 70% of the time. It occurred at the intermediate position on the cued side, at a position opposite the target or at an intermediate point on the side opposite the target, each with probability 0·1.

The result of one experiment is shown in Figure 4. The most salient feature in the data is the U-shaped function relating reaction time to interval following the cue (SOA) for all positions. This alerting effect is well documented in reaction time literature. There is also an advantage to those lights near the fovea. Reaction time to lights near fixation is generally faster than to lights far from fixation.

In these experiments the crucial measure that addresses the question whether movements are analogue or discrete is the difference between reaction time to target (far expected) and intermediate light on the target side (near expected) as a

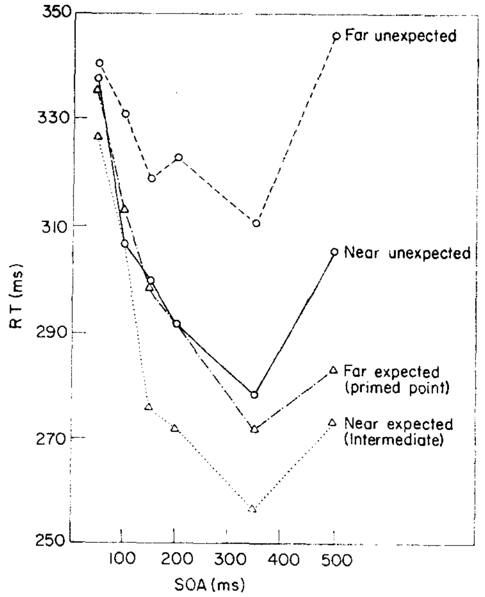

FIGURE 4. Reaction time to target stimulus (far expected) and three infrequent probe positions including one on the expected side intermediate between fixation and target (near expected). After Shulman, Remington and McLean (1979). Stimulus onset assynchrony refers to the time between the cue to move attention and the probe detection stimulus.

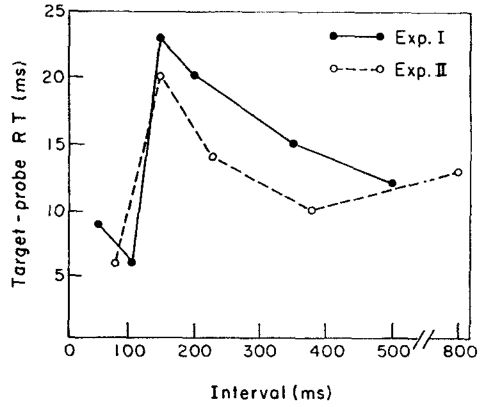

FIGURE 5. Subtraction from the target stimulus RT of the RT to the near expected probe as a function of interval following the cue to move attention. Two separate experiments are plotted. After Shulman, Remington and McLean (1979).

function of SOA. This subtraction is displayed in Figure 5, both for the original experiment and its replication.

In both experiments this subtraction shows a divergence followed by a convergence.* The maximum difference appears at 150 ms in both experiments. At this point attention appears to give the greatest relative advantage to the intermediate probe. Although these effects are small they are sufficiently consistent to reach statistical significance and to allow us a provisional decision that time locking can occur and that the analogue model is supported by the data.

Relationship between attention and movement

Orienting to positions in space can be obtained covertly through movements of attention or overtly through shifts of the head and eyes. No one would doubt that these two are very closely coupled in daily life. There has been interest in the degree of relationship of the internal mechanisms controlling attention and eye movement. Much of the relevant literature comes from single cell recording in alert monkeys. Goldberg and Wurtz (1972) showed at the level of the superior colliculus enhancement in the firing rate of single cells whose receptive field was to be the target for an eye movement at a latency well before the eyes began to move. At first they were inclined to identify this system with a general attention mechanism because the time course did not seem to couple it closely with eye movements. Later, it was shown (Wurtz and Mohler, 1976) that methods of producing attention to events outside of the fovea other than by inducing eye movements did not produce enhancement of collicular cells. At the level of the superior colliculus it appeared that selective enhancement was intrinsically related to eye movements. Work by Mountcastle (1976) could be viewed as suggesting a direct relationship between enhancement of single cells in the parietal lobe and movement of the hands and eyes into the surrounding environmental space. However, Mountcastle (1978) explicitly recognizes the contingent nature of the movements generated in response to parietal activity.

There was reason from our data to deny too close a relationship between attention and overt eye movements. The costs and benefits of attention shifts neither depend upon movements of the eyes nor seem to be closely related to distance from the fovea. Indeed, our finding that attention shifts are symmetric between periphery and fovea suggests a different structure from that of the eye movement system. Subsequent work on single cell recording (Robinson, Goldberg and Stanton, 1978; Bushnell, Robinson and Goldberg, 1978) shows selective enhancement of single cells in parietal lobe (area 7) without eye movements and argues that such cells are more closely related to visual properties of the stimulus than to motor commands.

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*It is important to note that no similar pattern of divergence or convergence is found with stimuli that occur on the side opposite the cued target. In unpublished work we found that alerting alone, with no cue as to where to direct attention, produces uniform improvements in RT to detection events at differing places from fixation. The usual advantage of foveal over peripheral events was also present. Thus the pattern of interaction found for the intermediate and target events on the cued side depends on the instruction to move attention in that direction. The results that we obtained for pure alerting argue that alerting does not introduce a bias in the distribution of attention over the visual field as might be expected from some views of the relationship between arousal and performance.

Logical possibilities

Figure 6 outlines a series of logically possible relationships between overt and covert attentional mechanisms. The behavioural evidence, discussed previously, that attention can be shifted with eyes fixed, together with results showing enhancement of evoked potentials (Eason, Harter and White, 1969; Von Voorhis and Hillyard, 1977) and of the firing rates of single cells (Bushnell *et al.*, 1978), eliminates the idea that attention and eye movements are identical systems.

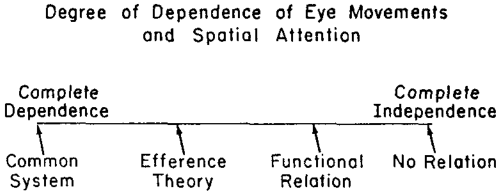

FIGURE 6. Logical relationships between overt and covert orienting of attention.

These findings led Wurtz and Mohler (1976) to propose that attention shifts were programmes for the movement of the eyes. This might be called an efference theory. Klein (1979) describes this view as follows: "When attention to a particular location is desired, the observer prepares to make an eye movement to that location; the oculomotor readiness, via as yet unknown feedforward pathways, has the effect of enhancing processing in or from sensory pathways dealing with information from the target location".

A less restrictive notion of the relationships between the two forms of movement would be that attention and eye movements are both summoned by important peripheral events and thus have a close functional but no intrinsic physiological relationship. An even less restrictive view would be to posit complete functional and physiological independence between the two systems.

Efference

The efference view proposes a restricted relation between our ability to move attention and the eyes. It indicates that whenever one moves attention to a location, eye movements in that direction are facilitated and that the readiness to move the eyes to a target necessarily improves detection there. Klein (1979) examined both of these hypotheses. His technique is shown in Figure 7. Each trial begins

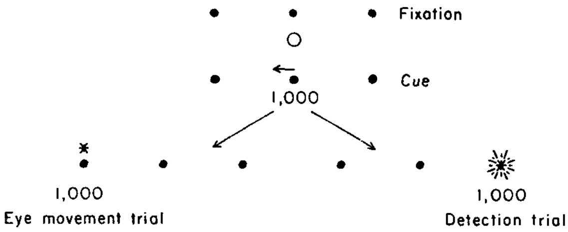

FIGURE 7. A paradigm for testing the efference view. Subjects are given a cue as to where to shift attention and then are commanded either to move their eyes or to report a detection stimulus by pressing a key. After Klein, 1979.

with a cue. There are two kinds of trials. On eye movement trials an asterisk appears to the left or right of fixation. On detection trials the subjects must respond to a luminance increment by pressing a key.

Experiment I has only a small proportion of eye movement trials. Most trials involve detection to insure that the subject uses the cue to shift attention to the expected position. He found clear costs and benefits on detection trials. There was no effect of the cue on eye movement latencies. When the subject has to move his eyes in the direction he is attending, he is no faster than when he moves opposite to the direction of attention.

In Experiment II eye movements are the primary task and detection trials were used to assess the prediction that detection will be faster for a stimulus presented at the target for the eye movement. One group of subjects was instructed to move their eyes right and a separate group to move them left on each eye movement trial. When the imperative stimulus for the eye movement is in the direction of the actual movement (compatible) eye movements are faster than when it is not (incompatible). However, the detection task is totally unaffected by the direction in which the subject moves his eyes.

These results show clearly that there are conditions under which one gets no relationship between spatial attention shifts and eye movement latencies. Thus they are sufficient to reject an efference theory as a full account of the relationship of eye movement and attention movement. However, Klein's experiments involve difficult conditions for the subjects. The subject first has to determine if he is in a detection or an eye movement trial based on the type of stimulus change. On some trials eye movements are opposite to the direction of the visual input. These conditions produce long RTs. As illustrated in Figure 1, complex conditions produce the poorest evidence for spatial attention effect. While the experiments are sufficient to refute the forced conjunction between eye movement and attention, they do not give us a very good handle on how these two might be linked under less difficult conditions. Some recent studies (Nissen, Posner and Snyder, Note 4; Remington, 1978) provide a view of the relationship between eye movement and attention movements under simpler conditions.

Combined eye and attention movements

In our experiments the subject's attention and eye movement are summoned by a 1° unfilled box that occurs 8° to the left or right of a similar fixation box. The detection stimulus is a clear dot well above threshold. The sequence of events in a trial is shown in Figure 8. The detection stimulus occurs with equal probability in the fixation box or at the target.

Figure 9 shows mean RTs for detection stimuli at fixation and at the target as a function of time following the peripheral eye movement cue. The results show that by 50 to 100 ms after the occurrence of the target stimulus for the eye movement, one gets benefits in reaction time to a detection event that occurs at the target, in comparison to the position at which the subject is currently looking. This time course is roughly consonant with the results obtained by Goldberg and Wurtz (1972) for the latency of collicular unit enhancement. Thus where eye movements

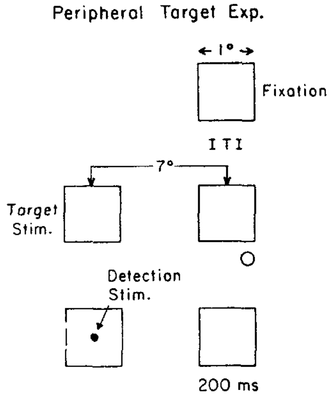

FIGURE 8. Organization of a trial to study eye movements and attention movements simultaneously. The target stimulus commands a movement. The detection stimulus is reported by pressing a key. After Nissen, Posner and Snyder, Note 4.

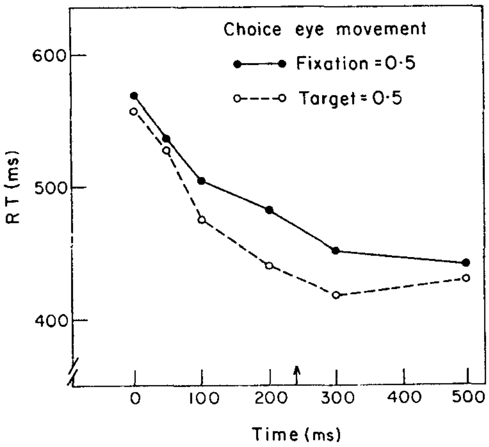

FIGURE 9. Reaction time as a function of the time the detection stimulus follows the target stimulus when the location of the detection stimulus is equally likely to be at fixation or at the target. The arrow indicates mean RT for an eye movement (see text).

and attention are conjoined by the occurrence of a peripheral stimulus, the movement of attention seems to precede the movement of the eyes.

Because of the use of the reaction time technique, it is difficult to be sure that the earliest point at which one gets facilitation is the point at which attention has shifted to the peripheral position. To address this question, Remington (1978) required his subjects to detect a 3 ms luminance increment. Otherwise, the basic paradigm is similar to the one shown in Figure 8. Each trial begins with three boxes in the field. At time 0 a plus sign appears over one of the peripheral boxes indicating the eye movement direction. The detection stimulus occurs with equal probability at the fixation point, the target, or on the side opposite the target.

Prior to the presentation of the eye movement target (plus sign) the subject is most sensitive at the fovea. By 100 ms after the occurrence of the target event and well before the eyes have started to move, the subject shows higher sensitivity at the target position than either at fixation or opposite sides. Shortly before the eyes begin to move there is a reduction in probability of detection that could be due to saccadic suppression. Finally, when the eyes reach the target, the subject is now more sensitive in the position of the target than at the original fixation. The effects are all small but sufficiently consistent to be statistically significant. They show that in the presence of a stimulus which elicits eye movement, the subject's attention tends to move prior to his eyes.*

These two experiments show that there is a strong tendency for attention to shift to the target position for an eye movement prior to the eye leaving the fixation point. The time course for this attention shift is in the neighbourhood of 50–100 ms following the peripheral target presentation which is about the same as reported for selective enhancement of collicular units by Goldberg and Wurtz (1972). This result argues for a firmer link between attention and eye movements than was suggested by Klein's result. In both of these experiments detection stimuli were equally likely to occur at the target for the eye movement or at the fixation point. In order to investigate the strength of the link between overt and covert orienting, we wanted to see if subjects would be able to maintain attention at fixation if given incentive to do so. It is very difficult to know introspectively whether attention can be maintained at fixation when generating an eye movement.

To provide an incentive for subjects to attend to the fixation if they could, we increased the probability that the detection stimulus would be presented there to 0·8, with a probability of 0·2 that it would occur at the target. We ran two different conditions. In one condition the subjects were not to make eye movements but were to remain fixated at all times. In the other condition they were to move their eyes as quickly as possible after the target box was presented. In all other respects the two conditions were identical In our first experiment six subjects were run under each of these conditions.

The results of our experiment are shown in Figure 10. In the fixation condition it is clear that a high probability stimulus that occurs on the fovea is detected much more rapidly at all intervals than a low probability peripheral event. There is no evidence that the occurrence of the peripheral target event *per se* improves detection in its location relative to fixation. In the movement condition the detection stimulus is responded to more rapidly when it occurs at the target rather than at fixation at about 50 ms following input. These subjects become faster at detecting a peripheral event of low probability than at detecting an event which falls on the fovea and is of much higher probability.† There is a reversal after the eyes land

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*There are a number of other interesting features of the Remington study. There is a small but not significant tendency for the detection of events on the opposite side of the target to be facilitated in the period shortly before and after target presentation. This suggests that subjects may first show increased sensitivity to both sides as they await the cue as to the direction of movement. This ability to split attention has not been found in other luminance detection studies, however (Posner, Snyder and Davidson, in press). It is also of potential importance that the attention shifts Remington found seem to occur prior to evidence for saccadic suppression.

†This experiment showed the most striking results favouring the target. Subsequent experiments using similar procedures have not always yielded a striking cross over favouring the target during the period before the eye movement. We have replicated the relative shift in detection RT favouring the target even though many subjects do not reverse the normal advantage in RT favouring foveal stimuli.

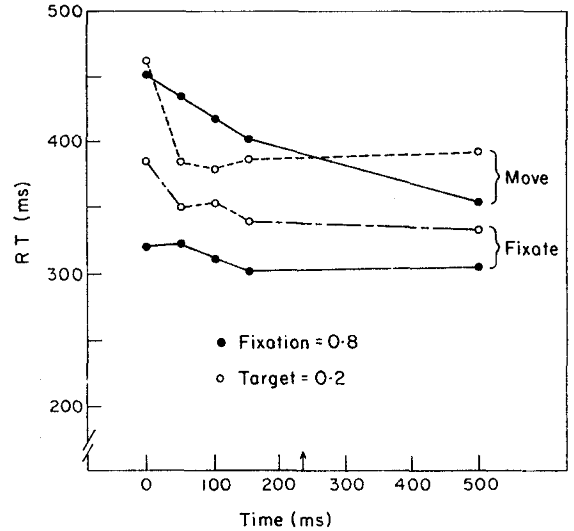

FIGURE 10. Reaction time to the detection stimulus for an eye movement condition (move) and a fixation condition (fixate). The detection stimulus occurs at fixation with probability 0·8 and at the target with probability 0·2. Arrow indicates mean RT for an eye movement (see text).

on the target stimulus. By 300 ms the subjects are fixating the target, but at our next probe time, which is 500 ms, they show more sensitivity to the original fixation point at which they are no longer looking than at the target. Once they reach the target attention seems clearly under the control of the probabilities.

These results confirm in a different paradigm the idea that the trajectories of attention movements can be traced dynamically over time (Shulman *et al.*, 1979). Attention moves rapidly prior to the eye movement and returns to the original fixation as the fovea settles in at the target. Even with the incentive of a high probability detection stimulus at fixation, subjects do not maintain attention while programming the eye movement. At first this finding may seem to contradict Klein's rejection of efference theory. Certainly it suggests a non-trivial tie between overt and covert orienting that cannot easily be resisted by the subject. However, we had the distinct impression that we were able to return attention to fixation even as the eye was moving toward the target. Since there were no probe events around 300 ms we were not able to confirm the impression in this experiment.

To see if attention could move in a direction opposite to eye movement programming, we instituted blocks in which the subject fixated at the left edge of the cathode ray screen. At time 0 a target occurred 8° to the right of fixation. Four hundred milliseconds later a second target occurred 8° further to the right of fixation. The subject's task was to move his eyes as quickly as possible from the original fixation point to the first target and then, following the occurrence of the second target, to move his eyes again. Detection stimuli occurred at the original fixation with probability 0·8 and at the position of the first target with a 0·2 probability. Our interest was in whether the subject would tend to move attention back to the original fixation point, even as his eyes were preparing to move to a target still further away. Thus we were interested in detection events which occurred shortly before and during the reaction time to the second target event. The results are shown in Figure 11. Detection stimuli that occur at fixation are initially responded to somewhat faster than those that occur at the target. As the subject begins to prepare to move his eyes to the first target there is an improvement in the efficiency of detecting stimuli at that target by comparison with the fixation point. This replicates the shift found in the previous studies, but here does not actually yield reliably faster reaction times to the target than to the fixation point. However, for the crucial events (300–400 ms following the original target) that occur during the time the subject reaches the first target and is preparing to begin the movement to the second target, reaction times back at the initial fixation are significantly better than at the first target stimulus at which he is currently fixated. Since reaction times to the second movement are very rapid, it is clear that the programming of the eyes is in the direction opposite to the movement of attention. These results agree with Klein's (1979) conclusion and seem fatal to an efference theory.

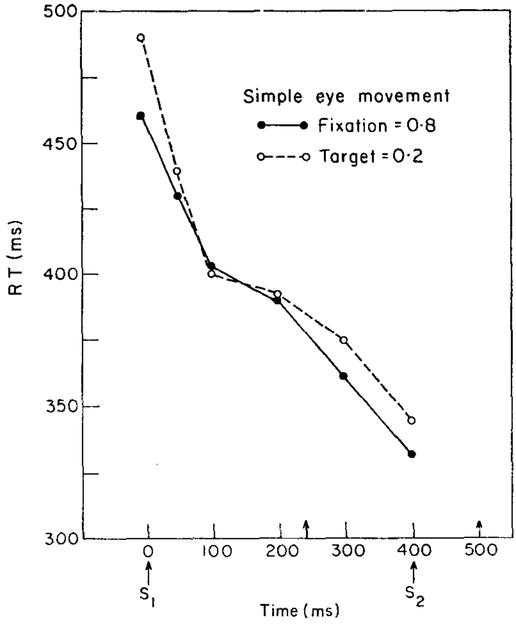

FIGURE 11. Reaction time to the detection stimulus when embedded in a double eye movement experiment. Command for the first eye movement occurs at S1 and the second at S2. Arrows indicate mean RT for each movement (see text).

Functional relationships

Overall, our results suggest that the relationship between eye movements and attention is not as close as either a complete dependence or an efference view requires. Our studies showing attention movements with eyes fixed, Klein's finding of no influence on eye movement latencies of shifts of attention, and our result showing attention movements in the opposite direction to eye movement programmes are fatal to these notions.

However, the two orienting systems are not completely independent. The striking tendency of attention to move to the target prior to an eye movement even when detection signals are more probable at fixation shows that the two can be exquisitely related.

We conclude that the relation is a functional one. It often depends more upon the presentation of an important peripheral event than on the eye movement toward that event. If the peripheral event is not important, subjects can clearly avoid moving attention to it, as is shown by the fixation condition of Figure 10. Making the stimulus a target for an eye movement is a particularly good way to make it important, but very clearly not the only way. An instruction to attend to the stimulus is also sufficient, as we have shown in the central cue experiments*

In many ways the relationship between eye and attention movements resembles that found to hold between eye and hand movements (Posner and Cohen, in press). The eye and hand function in close relationship to one another in many tasks, yet the physiological systems for their control are quite distinct. The eye frequently moves to stimuli in anticipation of hand movements, but one can easily move the hand with the eyes fixed. Indeed, even when one is instructed to move the two in synchrony toward a target, they may become erroneously dissociated (Posner, Nissen and Ogden, 1978). If one is instructed to move hand and eye rapidly toward a visual stimulus that is very likely to arise from one position, then on occasions when the expectancy is wrong the hand has a tendency to follow the expectancy while the eye is controlled by the visual input. Comparisons of central cues and peripheral input have proved useful in understanding the functional interconnections of the control systems for hand and eye movements. The next section examines a similar strategy for understanding the control of the overt and covert components of orienting.

Central and peripheral control of orienting

Attention can be directed by a central decision, as discussed in section two of this paper, or it can be drawn by a peripheral stimulus, as is done in the experiments discussed in the last section. Comparisons of exogenous (reflexive) and endogenous (central) control of orienting is made difficult because external signals do not operate completely reflexively but will only summon attention and eye movements if they are important to the subject. Moreover, central mechanisms that may control covert orienting, such as the parietal lobe also receive input from subcortical centres involved in overt orienting. Nonetheless, it would be useful to attempt to compare central and peripheral systems for producing changes in orienting as a model system for the interaction of external and internal control.

Remington (1978) compared peripheral and central cues for eye movements in

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*These conclusions appear to be in accord with recent observations (Kowler and Steinman, 1979) showing oculomotor drifts in the direction of the subjects expectancy when they are induced either by the requirement to move the eyes or by the expectation of a peripheral signal even when fixation is maintained. The extent of voluntary control over the oculomotor drift may be less than for attention movements, however.

order to determine their relationship to shifts of attention. When he used a peripheral cue he found improved sensitivity in the vicinity of the peripheral target about 50 ms after the cue and well before the eye movement. When a central arrow was used to cue the movement, there was no evidence of any change in sensitivity in the direction of the target until after the eye movement began. This result is not consistent with as strong a connection between attention and eye movements as an efference theory would require. It is consistent with the idea that both attention and the eyes tend to be drawn to peripheral stimuli, with attention movements occurring somewhat more rapidly. A comparison of the eye movement latency in Remington's two experiments confirms the general advantage of peripheral over central eye movements of about 50 ms.

Recently, Yoav Cohen and I (Posner and Cohen, in press) have reported behavioural evidence of a qualitative difference between control of eye movements from peripheral and central cues. In these experiments we compared binocular viewing with conditions in which only the left or right eye viewed the stimulus. Subjects were instructed to move their eyes in the direction that seemed most natural. In all trials the stimuli were pairs of dots that occurred 10° to the left or right of fixation. On most trials one of the dots led the other by 150 or 500 ms. Under these conditions subjects got used to moving their eyes to whatever stimulus occurred first. When the two stimuli occurred simultaneously, with binocular viewing there was no movement bias, but with monocular viewing subjects moved their eyes 80% of the time in the direction of the temporal visual field.

This result was not due to a general movement bias. When a central visual or auditory cue was substituted for the lateralized input, the bias of moving toward the temporal visual field was lost.

There were also clear differences between conscious judgement of which stimulus occurred first (temporal order judgements) and eye movements induced by the same stimulus conditions. In these studies pairs of dots with time differences of 0, 10, 30 or 60 ms were used. Conscious judgements were greatly influenced by which stimulus came first (ranging from 80–90% correct when either event led by 60 ms) and were only slightly influenced by the eye that was occluded. Eye movements were influenced much less strongly by the time difference but were markedly affected by the viewing eye. These results suggest that temporal visual field input has more direct access to systems controlling exogenously produced eye movements than does nasal visual field input.

There are also anatomical reasons for supposing that crossed fibres have stronger input to the superior colliculus than do uncrossed fibres (Kaufman, 1974). However, to our knowledge, this is the first exploration of functional asymmetry of external control over eye movements to be reported with normal human adults.* It will be interesting to find out whether covert orienting resembles the eye movement system in being more influenced by contralateral input or whether it appears to be more like conscious judgements in being relatively symmetric.

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*A very recent abstract (Lewis, Maurer and Milewski, 1979) suggests that new borns have a strong functional asymmetry favouring the temporal visual field that is reduced over the first two months of life. This observation seems to fit closely with our adult data and may provide an opportunity to investigate its neural locus by studies of maturation.

These studies provide potential methods for studying fundamental differences in the external and central control of overt orienting.

Conclusions

The most important outcome of this research concerns our ability to measure the movements of attention across the visual field. The time locking of shifts of attention, both to central instructional cues and to changes in eye position, provides evidence that covert orientation can be measured with almost as much precision and ease as overt shifts in eye position. The convergence of measurements of sensory thresholds, reaction time and electrical activity on common questions and, to some extent, common results, gives some assurance that the observed change of efficiency is genuine. These findings may do more than add to the catalogue of internal mental activity that has been successfully measured in recent years. The centrality of attention to mental theories and the breadth and precision of methods involved in its measurement suggest a wealth of new issues that may now be ready for analysis.

An alternative language for discussing orienting is in terms of signal detection theory. One could discuss our results as being due to shifts in criterion as probability and momentary expectancy varies. Elsewhere we have discussed some of the disadvantages of this signal detection language as applied to our results (Posner, Snyder and Davidson, in press). Some of our findings place constraints on the nature of criterion shifts that seem antithetical to the use of that language. These include differences between cued and blocked presentation, reductions in costs and benefits with increases in task difficulty, facilitation of low probability probes that lie between fixation and target, shifts in efficiency toward the target for the eye movement even when fixation stimuli are more probable, and the relative difficulty of dividing attention between non-contiguous spatial positions (Posner, Snyder and Davidson, in press). While such results may be described as placing gambles at expected spatial positions, they seem to imply a mechanism that severely limits and constrains the possible criteria.

Much work on orienting (Sokolov, 1963) has confounded the alignment of attention to a source of input with the detection of a stimulus event. The orienting reflex does not distinguish between the processes that occur prior to detection and that which occurs subsequently. The relatively slow nature of autonomic changes often precludes such a division. Although our method of measuring orienting is via changes in the efficiency of detecting, the two mental operations must be quite distinct. Since one can move attention to a potential source of signals before any input has occurred, it is clear that orienting can occur without detection. For overt orienting this is obvious, but it has not been as obvious that orienting and detection are two quite distinct internal operations of attention.

The ability to dissociate the two in normal subjects fits well with observations that emerge from data on brain injured individuals. In the case of occipital lesions (field cuts) it has been shown that there can be a relative sparing of the ability to do overt orienting combined with a striking deficit in the ability to detect (be aware of) stimuli in the blind field (Gassel and Williams, 1963; Perenin and

Jeannerod, 1978; Weiskrantz, Warrington, Sanders and Marshall, 1974). On the other hand, damage in the right parietal region can be described as producing a severe deficit in orienting with a less severe loss in the ability to detect a stimulus once orienting is accomplished (Heilman and Watson, 1977). When only one event is presented, subjects may show good acuity in the neglected field, but when competing events are presented there is a deficit in orienting toward the side opposite the lesion. The view that brain injury may dissociate more completely mental functions that are isolable by chronometric analysis in normals (Posner, in press) seems one of the general principles that may emerge from sustained interaction of cognitive and neuroscience thinking.

The important effect that parietal lobe damage has for orienting in humans supports the view that some portions of the mechanisms for selective attention to space rely upon this part of the brain. This line of reasoning underlies the effort made in this paper to relate our findings on spatial attention to observations being made in area 7 by single cell investigators.* There is a tendency when looking at association areas of the brain to identify their activity with either sensory or motor systems. An important idea emerging from studies of attention suggests that there are unique properties of internal structures that preclude their identification with either sensory or motor systems. Our data show that attention is not intrinsically tied to the foveal structure of the visual system nor slaved to the overt movements of the eye.

Attention movements have properties that are analogous to the skilled movements of the hand and eye. This is the theme that Bartlett proposed as a way toward the objective study of thought. It remains to establish that attention in the sense developed in this paper is related to the attentional system postulated by cognitive theories of internal thought processes. It is one thing to claim that ideas for the study of spatial attention arose from an effort to confirm models of the role of attention in tasks related to language and thought, but it is quite another to show that studies of simple luminance detection will increase our understanding of complex performance. On a very general level it seems that evolution has selected similar principles of movement for the hand, the eye and covert visual attention. It seems reasonable to suppose that orienting in semantic memory will take advantage of these same principles.

There are a number of promising avenues open for linking evidence on spatial orienting to the mechanisms used for orienting to internal mental structures. Let me outline a few places where concepts arising from work in spatial orienting and those from work in orienting to higher level systems seem to be related. Analogue processes have been shown in mental rotation (Cooper and Shepard, 1973) and scanning of images (Kosslyn, 1973). Similarly, the effects of distance in semantic space (Rosch, 1975) on reaction time suggest they are also applicable to verbal concepts. This work suggested the studies on analogue attentional movements. The buildup of benefits and costs with the shift of thought from one idea (e.g. letter or semantic category) to another has been traced in some detail (McLean and

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*There is nothing in our results that can prove that the spatial attentional mechanisms that we study are identical to those under investigation in area 7 of the parietal lobe. Our results are suggestive of this link. Single cell studies will need to be informed by the known properties of spatial attention as they seek to relate their results to attention.

Shulman, 1978; Neely, 1977). It remains to be shown if evidence of activation-based orienting found in semantic memory (McLean and Shulman, 1978) will also apply to spatial orientation. When stimulus input controls the shift of attention toward an internal structure it has been found that benefits occur before costs. When a letter primes a pathway there is first a general commitment of attention followed after time by the specific costs to letters other than the one primed. One might expect that the arrow cues used in spatial orienting will produce a similar structure. Becker and Killion (1977) have shown that the amount of cost to an unexpected word is reduced as the signal to noise ratio increases. One would suppose this to be a reasonable expectation for visual orienting as well, although there is no convincing evidence of it as yet.

Twenty years after Bartlett first suggested that thought exhibits a "point of no return" we seem able to make a genuine commitment to an exploration of his insight. Perhaps we have reached a point on this road where we will not wish to turn back.

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