reaction time to report the presence of the target signal (Posner 1980), by the probability of detecting near-threshold stimulus events (Bashinski & Bachrach 1980; Remington 1980) or by changes in electrical activity induced by the target (Goldberg & Wurtz 1972). We have indexed these changes of efficiency in a variety of experimental situations that involve either simple detection of the presence of a luminance change or the recognition of the semantic category of the visual event (Posner 1978, 1980).

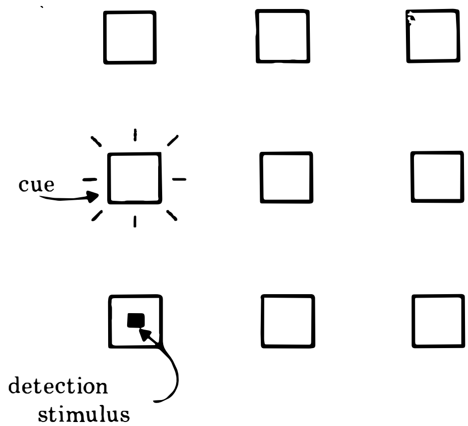

FIGURE 1. Paradigm for studying covert orienting in normal subjects. Three boxes are always present in the visual field. Subjects fixate on the centre box. At the start of the trial, one of the two peripheral boxes brightens (cue). After a specified interval a detection signal is presented in one of the boxes.

The changes in efficiency that we observe are sufficiently time-locked to cues that it seems reasonable to call them movements. For a peripheral visual cue 7° from the fovea we find that it takes approximately 50 ms for the changes in efficiency at the target location to begin and that there is a marked improvement in the efficiency at the target location over the first 150 ms after the cue.

This time-locking is shown quite exquisitely in a recent study. The basic experimental arrangement is shown in figure 1. Subjects fixated the central box (eye position was monitored by e.o.g.) and their task was to press a single key whenever a bright detection stimulus (target) appeared. Each trial began with a cue which was the brightening of one of the two peripheral boxes. In one condition the target appeared on the side that was brightened (cued side) 80 % of the time and on the side opposite to the cue 20 % of the time. In a second condition the target was on the side opposite to the cue 80 % of the time and the cued side 20 % of the time.

Results are shown in figure 2. The peripheral cue serves to summon attention in both conditions, leading to an initial advantage for the cued side. This occurs whether or not the target is likely to fall on the same side as the cue. However, in the condition where the target is unlikely to appear on cued side (triangles) the subject shifts attention to the side opposite the cue, showing an advantage there 300 ms after the cue. It might be suspected that the initial advantage to the cued side was due to brightness enhancement or some other purely sensory factor but we can show this is not so by using a peripheral cue involving dimming of the box or by the use of a purely central cue (Posner & Cohen 1980*b*).

The shifts of attention first toward the cue and then to the expected side are sufficiently time-locked that they can be observed over the 500 ms interval between cue and target. It has also been shown that probe events that occur with low probability at positions through which attention is passing become more efficient at a time intermediate between the cue and maximum facilitation at the end point for the attention movement (Shulman *et al.* 1979). This result suggests an analogue movement of facilitation from fixation toward the target position. A related finding has also suggested that attention moves between locations within a visual image in an analogue fashion (Pinker 1980). Figure 2 also illustrates that attention can be drawn from an external source or can be moved in accordance with internally generated expectations. Thus, the cue seems to draw attention toward a location even if there is a low probability of finding a target there, but the expectation of a target also has a powerful control over orienting.

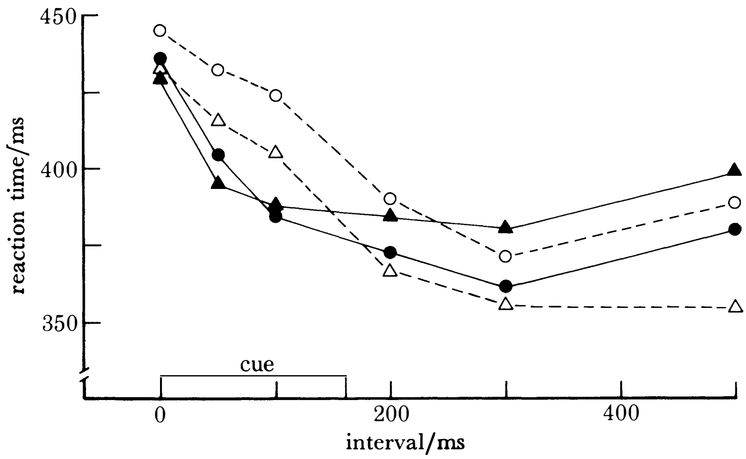

FIGURE 2. Reaction time for reporting the presence of the detection signal as a function of the interval (milliseconds) between cue and detection signal. The circles refer to a condition in which the detection stimulus is on the cued side with probability 0.8 and on the side opposite to the cue with probability 0.2. The triangles refer to a condition in which the detection stimulus is on the cued side with probability 0.2 and the side opposite to the cue with probability 0.8. Solid line, cued side; broken line, side opposite to the cue.

We have shown in separate experiments that attention will be drawn toward the cued side even when all locations are equally probable (Posner & Cohen 1980*b*). When an eye movement is summoned by a peripheral cue, attention moves to the cue approximately 200 ms before the eyes begin to move (Posner 1980). However, attention movements are not an inevitable consequence of eye movement. When the subjects can pre-programme changes of the eyes, they may do so without a shift of attention and indeed may move attention in the opposite direction of an eye movement (Posner 1980). This constellation of relations between covert orienting and eye movement provides evidence of a functional relation between the two systems, but one that can be decoupled. The systems can operate independently but, like hand and eye, usually tend to operate in close coordination. No doubt this learning occurs very early in life (Posner & Rothbart 1981) as attentional systems mature and come to control various peripheral devices such as hand and eye.

Recently, we have reported (Posner & Cohen 1980*b*) that a peripheral cue produces two opposed effects upon the information processing system. On the one hand, it summons a movement of attention that, as described previously, enhances efficiency of processing information at the target location. On the other hand, it also produces a temporary inhibition. This can be seen quite well in figure 2. At 500 ms the facilitation of a probable event on the side opposite to the cue is much greater than the facilitation of an equally probable event that occurs on the cued side. This appears to be due to the inhibition that arises when sensory information is used to summon attention.

In our first experiment (PSP no. 1) we studied three PSP patients. In this study we provided a long lasting visual cue (500 ms) followed by a target to which the subject has to respond. Cues were a 1° hexagon presented 8° above or below fixation in the vertical condition and 10° to the left or right of fixation in the horizontal condition. The target remained present for 1 s after presentation and we waited 5 s for a response before proceeding to the next trial. The target was presented on the cued side on 80 % of the trials (valid trials) and on the side opposite to the cue in 20 % of the trials (invalid trials). Details of the intervals between cue and probe are shown in figure 3. Each subject was run for several sessions of approximately 200 trials in each condition (horizontal and vertical).

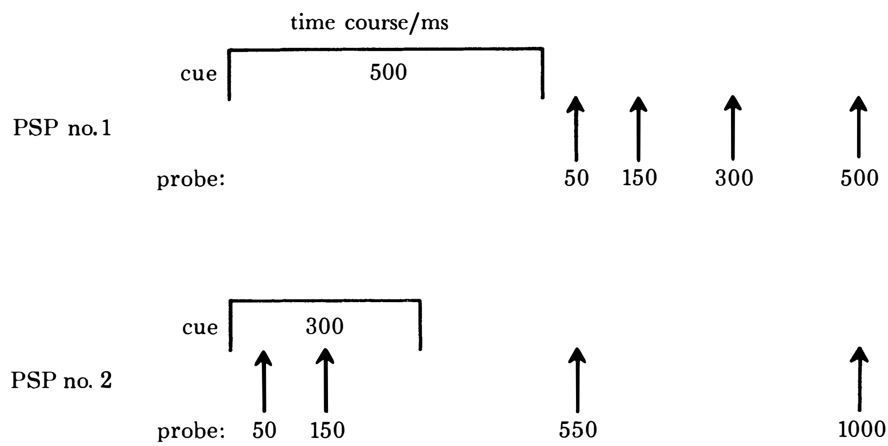

FIGURE 3. Paradigm used for the study of mid-brain and cortical patients. In PSP no. 1 the cue was left present in the field for 500 ms before presenting any detection stimuli (probes). In PSP no. 2 the detection stimuli (probes) are presented at short and long intervals following the cue onset.

The results of this study were simple and clearcut. Reaction times differed greatly between the three subjects ranging from speeds that would be roughly normal for this age range (500 ms) to reaction times more than twice normal. In general reaction times were slightly faster in the vertical than in the horizontal direction, but this result turned out to be accounted for by the differences in the eccentricities of the targets and appear to be equivalent when the same eccentricity is used. Each subject showed a clear advantage of the cued side over the side opposite to the cue at the earliest probe position studied that tended to decline over the interval (see figure 4). The initial advantage of the cued side was significant in each patient, and there was no overall interaction between direction (vertical against horizontal) and the magnitude of the advantage of the cued side. The results showed quite clearly that patients unable to make saccades in the vertical direction could still move covert attention in that direction. A more detailed analysis of the data of each patient suggested that there were longer reaction times when the cue was presented in the direction in which eye movements were relatively intact followed by a target in the direction in which eye movements were severely impaired. This suggested to us that there might be impairments in the latency of covert orienting in directions that showed the strongest eye movement problems.

For this reason we designed a second study (PSP no. 2) in which we presented a peripheral cue for 300 ms followed by targets occurring 50, 150, 550 and 1000 ms after the cue's onset (see figure 3). This allowed us to compare the speed of covert orienting in the horizontal and vertical direction. Otherwise the study was the same as outlined above. Four patients were studied, one of whom had been in the original experiment. The results of this study are somewhat more complex than in the previous study in that different patients had different patterns of eye movement and covert orienting deficits. The overall results (see figure 5) indicate that covert orienting was quite rapid in the horizontal direction. An advantage of the cued side is present at 50 ms and remains present over the entire interval. In the vertical direction there is no clear advantage of the cued side over the opposite side until 1000 ms after the cue.

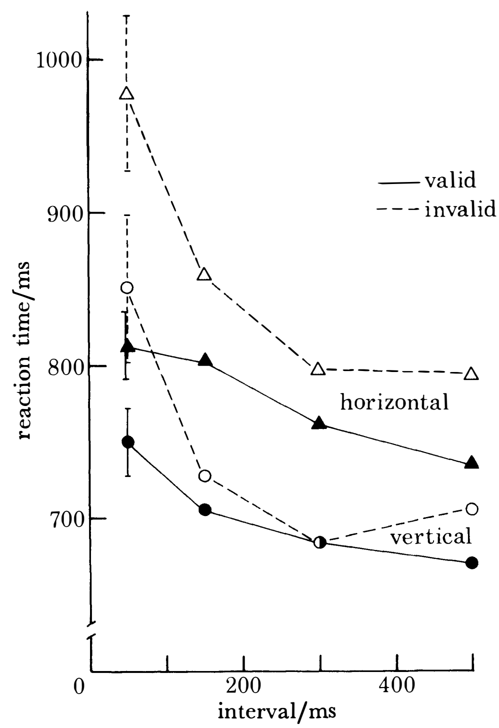

FIGURE 4. Reaction time as function of the interval between cue and detection stimulus (probe) presented in the vertical and horizontal dimensions. The valid side (solid lines and symbols) is the one that had the cue and on which 0.8 of the detection stimuli occur. Data from PSP no. 1. Bars indicate one standard error.

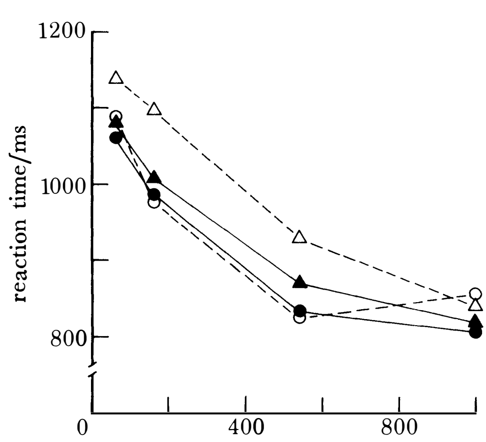

FIGURE 5. Reaction time as a function of the interval between cue and detection stimulus (probe) for stimulus presented in the vertical (circles) and horizontal (triangles) dimensions. The valid side (solid lines and symbols) is that the one that had the cue and on which 0.8 of the detection stimuli occur. Data are from PSP no. 2.

usually does not detect the target within the 5 s allowed. This represents a confirmation of the classical extinction phenomena where on double simultaneous stimulation the subject is unable to report information contralateral to the lesion. However, even with intervals of 1000 ms, so that the cue has been gone from the field for more than 700 ms, there is still a massive interference with reaction time., R.S. generally detects the presence of the target, but he is extremely slow in doing so.

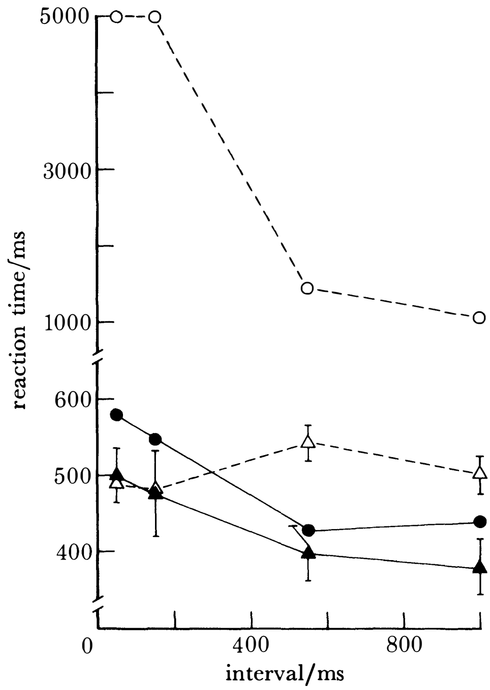

FIGURE 6. Median reaction time for valid (solid lines) and invalid (broken lines) trials for one right parietal patient (R.S.). Bars indicate one standard error from the median. The *Y* axis is broken between 600 and 1000 ms to allow data to be shown conveniently. A median reaction time of 5000 ms indicates that most targets were not responded to within the allowed interval. ●, ○, Left target; ▲, △, right target.

Let us now examine the other patient, not diagnosed as suffering from visual neglect but who had a form of extinction on double simultaneous stimulation in the tactile domain. Valid trials for this patient showed no difference between the damaged and undamaged side in reaction time. However, like R.S., an invalid trial in which the target is presented to the side opposite the lesion produces a very powerful interference effect. When the interval is short, many targets are missed and the interference shows a very gradual reduction with this interval but still remains present to the longest time studied.

Of particular interest is a finding that we made in patient R.S. that has not yet been documented in other patients. In this condition, we used a central cue that was an arrow at fixation extending less than $\frac{1}{4}°$ across the mid-line with the arrowhead pointing either to the right or left of fixation. The patient is instructed to orient attention in the direction of the arrow because 0.8 of the targets occurred on the cued site. For valid trials we get similar results to those obtained with the peripheral cue. He was faster on the side ipsilateral to the lesion that contralateral to the lesion. For invalid trials, we also get the same result as obtained with the peripheral cue. Thus, when the physical event is a central arrow that instructs orienting rather than a stimulus