

REORIENTING ATTENTION ACROSS THE HORIZONTAL AND VERTICAL MERIDIANS: EVIDENCE IN FAVOR OF A PREMOTOR THEORY OF ATTENTION

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Abstract—Stimuli presented in a non-attended location are responded to much slower than stimuli presented in an attended one. The hypotheses proposed to explain this effect make reference to covert movement of attention, hemifield inhibition, or attentional gradients. The experiment reported here was aimed at discriminating among these hypotheses. Subjects were cued to attend to one of four possible stimulus locations, which were arranged either horizontally or vertically, above, below, to the right or left of a fixation point. The instructions were to respond manually as fast as possible to the occurrence of a visual stimulus, regardless of whether it occurred in a cued or in a non-cued location. In 70% of the cued trials the stimulus was presented in the cued location and in 30% in one of the non-cued locations. In addition there were trials in which a non-directional cue instructed the subject to pay attention to all four locations. The results showed that (a) the correct orienting of attention yielded a small but significant benefit; (b) the incorrect orienting of attention yielded a large and significant cost; (c) the cost tended to increase as a function of the distance between the attended location and the location that was actually stimulated; and (d) an additional cost was incurred when the stimulated and attended locations were on opposite sides of the vertical or horizontal meridian. We concluded that neither the hypothesis postulating hemifield inhibition nor that postulating movement of attention with a constant time can explain the data. The hypothesis of an attention gradient and that of attention movements with a constant speed are tenable in principle, but they fail to account for the effect of crossing the horizontal and vertical meridians. A hypothesis is proposed that postulates a strict link between covert orienting of attention and programming explicit ocular movements. Attention is oriented to a given point when the oculomotor programme for moving the eyes to this point is ready to be executed. Attentional cost is the time required to erase one ocular program and prepare the next one.

INTRODUCTION

SEVERAL experiments have demonstrated that an observer is faster and more accurate in responding to a stimulus when it appears in an expected location than in an unexpected one. This facilitatory effect of prior information is usually attributed to the observer's ability to direct his attention to the expected source of stimulation [6, 7, 9, 21, see also 18]. However, while there is a general agreement on this point, many other aspects concerning the orientation of attention are disputed. For example, whereas most authors assume, implicitly or explicitly, that attention can be focused on only one spatial location [8, 12, 21], others claim that under certain conditions attention can be divided and oriented to two points or even to a ring of points in the visual field [5, 26, 27]. Similarly the mechanisms by which attention is oriented are unclear and, as will be shown in this paper, the same concept of a movement of attention can be challenged.

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Very controversial is the problem of the mechanisms that bring about a disadvantage for non-attended positions. The most popular point of view is that originally advanced by POSNER *et al.* [21], that attention must be reoriented to the non-attended, but stimulated, location before a voluntary response can be emitted. This reorienting of attention is time-consuming and therefore causes a delay in response latency. This hypothesis rests on the assumption that a voluntary response depends on stimulus "detection" whereby "detection" means conscious awareness of the stimulus [19]. If this hypothesis is accepted, then the question arises of how attention shifts from the attended to the non-attended location. One possibility is that attention is reoriented without any actual movement, that is without temporary facilitation of the points in the visual space located between the initial and terminal focus of attention. According to this point of view no ordered facilitation of adjacent points occurs in the visual system, but a new point is selected and facilitated by a central mechanism. The alternative idea is that attention moves like a search-light in perceptual space [11] and/or in some cortical area, as, for example, the primary visual cortex [4]. If the search-light idea is accepted there are two main logical possibilities. The first is that attention moves across the visual space at a constant speed [28, 30], the second is that it moves in a constant time, that is in a way roughly similar to that of ocular saccades [22]. If a constant speed is assumed, the response delay should progressively increase as a function of the distance to be covered. In contrast, if a constant time is assumed, no relationship should exist between response delay and distance.

Another way to explain why responses are slower at the non-attended locations is by postulating that information there is attenuated by an active filter. This type of explanation was introduced many years ago by BROADBENT [2] to account for the capacity of the observers to deal with stimuli rich in informational content [13]. Quite recently, however, HUGHES and ZIMBA [10] attempted to explain the effect obtained using the detection paradigm of Posner with a sort of filter theory. They maintained that the non-attended locations are at a disadvantage because of inhibition that spreads over the entire hemifield opposite to the attended one. According to them, the transition from the attended to the non-attended region occurs at the vertical meridian and therefore all locations on the same side of it are equally facilitated or inhibited.

A third possible interpretation of the slowness of the responses to stimuli at non-attended locations is in terms of a gradient of attention which has its peak at the attended location and then falls off with distance [4, 29]. According to DOWNING and PINKER [4], the decaying of the gradient takes place in a negatively accelerated way until an asymptote is reached. The shape of the gradient is distorted (i.e., it becomes steeper) near the fovea, possibly because of the cortical magnification. This hypothesis implies that attention is distributed over a large part of the visual field, and the non-attended positions are those that benefit less from it.

In the present study we will discuss a series of data collected with the aim of clarifying two points which may help in deciding among the foregoing hypotheses. The first point is whether there are differential effects within the two hemifields. The hypothesis put forward by HUGHES and ZIMBA [10] maintains that, when the focus of attention is brought to bear on a specific location, other locations in the same hemifield are all equally facilitated and locations in the other hemifield are all equally inhibited. The constant time hypothesis assumes that all non-attended locations are equally delayed, irrespective of the hemifield. The two hypotheses can be distinguished by comparing the results obtained at non-attended locations in the attended hemifield with those, also non-attended, of the opposite hemifield. The first hypothesis predicts that the former should be facilitated relative to the latter, whereas the

second hypothesis predicts an identical response decrement for all non-attended points. Still another pattern of results would support the constant speed and attentional gradient hypotheses because they both predict an increase in reaction time as a function of distance from the attended location, regardless of hemifield.

In brief, all the hypotheses can be tested by an experimental situation in which there are two or more possible stimulus locations in the hemifield where attention has been directed, as well as in the opposite hemifield. The crucial comparisons are those between the attended and non-attended locations in the attended hemifield and that between the non-attended locations in the non-attended hemifield.

The second point dealt with in the present study concerns the role of some landmarks in determining the distribution of attention across the visual field. Both DOWNING and PINKER [4] and HUGHES and ZIMBA [10] noticed a sharp increase in reaction time to non-attended stimuli located across the vertical meridian, relative to non-attended stimuli located in the attended hemifield at the same distance from the focus of attention. The source of this effect is not clear. DOWNING and PINKER [4] attribute it not to the crossing of vertical meridian, but to the crossing of the foveal region. According to them, the attentional gradient becomes steeper at the fovea because, due to its larger representation in the cortex, two points there are much farther apart, in neural terms, than two equally distant points in the periphery. HUGHES and ZIMBA [10] maintain that attention spreads over the entire visual hemifield and that the vertical meridian acts as a barrier that separates the attended from the non-attended region.

Whichever interpretation is correct, this effect, if confirmed, poses serious problems for hypotheses based on the movement of attention. There is no obvious reason why attention movements should be slowed down when crossing either the vertical meridian or the fovea, unless some neural constraints are introduced. Following DOWNING and PINKER's suggestion [4], one might assume that the movement of attention depends on the organization of the primary visual cortices, in which the crossing of the foveal region entails covering a greater distance. Alternatively, in accordance with HUGHES and ZIMBA [10], the factor responsible for the vertical meridian effect might be the passage of attention from one hemisphere to the other, that is the crossing of the corpus callosum. These hypotheses can be tested by using a series of stimulus locations that cross either the vertical or the horizontal meridian outside the fovea (see Fig. 1). When the stimuli are arranged horizontally, attention still crosses the vertical meridian, but in a region where cortical magnification is absent. When they are arranged vertically, attention also crosses a retinal meridian that divides the visual field in two halves, but this time the meridian does not correspond to an interhemispheric barrier.

METHOD

Subjects

Eight male students of the University of Parma participated in the experiment and were paid for their collaboration. They were all right-handed according to the Edinburgh Inventory [17], had normal or corrected vision and were ignorant of the purpose of the experiment.

Apparatus and stimulus display

The subject sat in front of a CRT screen controlled by an Apple II microcomputer. The head was positioned in an adjustable head-and-chin rest, so that the distance between the eyes and the screen was approximately 50 cm. The visual display (see Fig. 1) comprised the following items: one fixation box with the central fixation spot inside, and four boxes for stimulus presentation. All of the boxes were $1^\circ \times 1^\circ$ in size. The stimulus boxes were 4° apart (center to center) and were marked by an adjacent digit (1-4). The fixation box was always shown at the geometrical center of

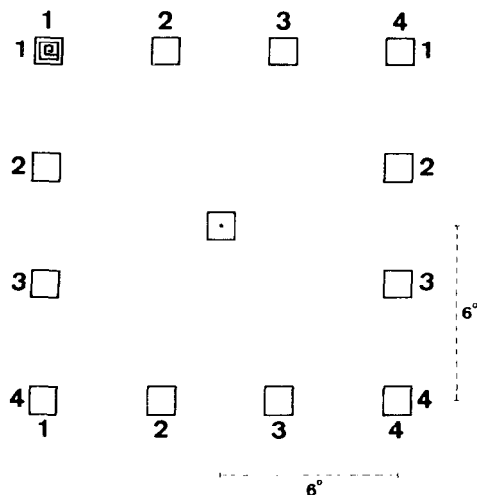


FIG. 1. Arrangement of stimulus boxes. For explanations see text.

the screen, whereas the position of the other boxes varied according to the experimental condition. In conditions 1 and 2 the stimulus boxes were arranged horizontally in the upper or lower hemifield (6° above or below the horizontal meridian), respectively. In conditions 3 and 4 they were arranged vertically in the right or left hemifield (6° to the right or left of the vertical meridian), respectively.

In every condition the cue used for directing attention was a digit (0-4), presented in the fixation box. The command stimulus was a geometrical pattern (see Fig. 1, upper left box), which appeared in one of the stimulus boxes. The response was emitted by pressing a key on the computer keyboard ("B") using the right index finger.

Procedure

On each trial the sequence of events was as follows. First, the fixation box was presented along with the four stimulus boxes and the digits. After a 500 msec interval a digit appeared in the fixation box, indicating either that the stimulus would subsequently be shown with high probability within the corresponding stimulus box (1-4) or that all four boxes were equiprobable (0). The subject's task was to fixate the fixation box while directing attention to the cued box or, if the boxes were equiprobable, to pay attention to all boxes. The importance of maintaining fixation was stressed, and eye movements were monitored by an experimenter sitting behind the subject, using a suitably oriented mirror. Following a further interval, varying randomly from 1000-1600 msec, the command stimulus was shown for 100 msec and the subject had to respond to it as fast as possible, regardless of its position. The response (simple reaction time, RT) ended the trial and was followed for 1 sec by feedback about speed and accuracy. The display was on until the occurrence of a response or a 3 sec time had elapsed.

All subjects attended for four sessions on four different days. Each session consisted of 400 trials, divided into four identical blocks separated by 5 min rests. Within each session the subject was cued to direct attention to one of the boxes on 80% of the trials, and to pay attention to all of them on 20% of the trials. When a specific box was cued, 70% of the time the stimulus would appear in it and 30% of the time the stimulus would appear in one of the non-cued boxes (10% each). Trials in which the stimulus was shown in the cued location will be referred to as "valid", those in which the stimulus was shown in a location different from the cued one will be referred to as "invalid" and trials when all locations were cued will be called "neutral".

Each subject was run under only two of the four experimental conditions, with the constraint that one of the box arrangements was vertical and the other horizontal. Accordingly, two subjects were tested in conditions 1 and 3, two in conditions 1 and 4, two in conditions 2 and 3 and two in conditions 2 and 4. Order of conditions was counterbalanced within subjects and across sessions. At the beginning of each session the subject was given 30-50 practice trials.

RT was measured from stimulus onset to response emission. Trials for which RT was less than 160 msec or in excess of 1000 msec were considered errors, as were those in which an eye movement was detected. All types of errors were discarded and replaced at the end of each session. For each subject 40 medians, 20 for the horizontal and 20 for the vertical arrangement of the boxes, were calculated for subsequent analysis. Of these, 4 were for valid trials (one for each possible stimulus location), 4 were for neutral trials (again corresponding to the 4 possible stimulus locations), and 12 were for invalid trials (3 for each of the 4 possible stimulus locations).

RESULTS

Overall errors were rare (less than 5%) and mostly of the anticipatory type (more than 4%). An analysis of variance performed on arcsin transformations showed that errors of all types were evenly distributed among valid (5.1%), neutral (4.0%), and invalid (4.7%) trials. No further consideration is given to accuracy.

The first analysis of variance on the RT data was conducted to test whether the orienting of attention had any effect on response speed. In it there were two within-subjects factors, namely arrangement of the stimulus boxes (horizontal or vertical) and type of trial (valid, neutral, or invalid). Type of trial was the only significant source, $F(2, 14) = 28.32$, $P < 0.001$. Two planned pairwise comparisons showed that RT for the neutral trials (216 msec) was slower than for the valid (210 msec) and faster than for the invalid (248 msec) trials, $t(7) = 3.75$, $P < 0.01$ and $t(7) = 5.13$, $P < 0.01$, respectively. The benefit for having oriented attention correctly, calculated as the difference between neutral and valid RT, though small overall (6 msec), was present in 7 out of 8 subjects (in the remaining subject valid and neutral trials yielded the same value). The cost for having oriented attention incorrectly, calculated as the difference between invalid and neutral RT, was much larger (32 msec), and present in all subjects.

Even though the first analysis clearly showed that there were benefits and costs for both vertical and horizontal arrangements, this does not demonstrate that responses to all non-cued positions were slowed down. In fact, as pointed out in the Introduction, it is crucial to find out whether, when attention was allocated to a specific position within one hemifield, other positions in the same hemifield (right, left, upper or lower) were facilitated or inhibited. Therefore, a second analysis was carried out using as invalid trials only the responses to stimuli in the non-cued position that shared the same hemifield with the cued one. For example, when box 2 was cued, responses to stimuli in boxes 2 (valid trials) and 1 (invalid trials), but not those to stimuli in boxes 3 and 4, were considered. The two within-subjects factors were again arrangement of the stimulus boxes (horizontal or vertical) and type of trial (valid or invalid). The main outcome was the significance of the type of trial main effect, $F(1, 7) = 17.76$, $P < 0.01$, which confirmed that also within the same hemifield valid trials were faster than invalid trials (210 vs 228 msec). The main effect of stimulus arrangement was marginally significant, $F(1, 7) = 8.06$, $P < 0.05$, because RT in the vertical arrangement was faster than in the horizontal one (215 vs 224 msec). Since this difference was not found in the first analysis, it will not be considered further.

A final analysis was performed on RT for all invalid trials with the aim to test whether distance from the cued location and the crossing of the meridians affected speed of response. The data used for this analysis are shown in Table 1 whereas in Table 2 the data for the four

Table 1

Arrangement of stimulus boxes	Type of trial				
	Valid	4°s	4°o	8°o	12°o
Horizontal	212	234	255	261	265
Vertical	208	222	242	253	266
	210	228	249	257	266

Abbreviations: s, same hemifield; o, opposite hemifield (with regard to the attended location).

Table 2

Type of trial	Arrangement of stimulus boxes			
	Horizontal		Vertical	
	Upper field	Lower field	Right field	Left field
1-1	225	201	220	196
1-2	240	227	240	200
1-3	262	249	272	217
1-4	279	251	298	227
2-2	224	199	218	200
2-1	253	210	246	220
2-3	283	240	273	213
2-4	263	243	274	222
3-3	227	199	216	198
3-1	274	258	303	227
3-2	254	243	270	214
3-4	230	214	221	200
4-4	225	200	221	196
4-1	273	257	304	235
4-2	287	252	284	221
4-3	260	243	244	207
0-1	231	208	228	200
0-2	232	204	229	200
0-3	229	200	224	198
0-4	232	204	233	201

Mean RTs in milliseconds as a function of arrangement of stimulus boxes and type of trial. In the first column, the first digit indicates the cued box, whereas the second digit indicates the stimulated box.

experimental conditions are shown separately. The within-subjects factors were arrangement of the stimulus boxes (horizontal or vertical) and distance from the cued location (4° within the same hemifield or 4, 8, and 12° in the other hemifield, that is across either the horizontal or vertical meridian). Only the main effect of distance was significant, $F(3, 21) = 24.14$, $P < 0.001$. The interaction did not approach significance ($P > 0.23$).

A set of pairwise comparisons using the Newman-Keuls method was performed to see whether RT increased with distance from the cued location and whether crossing the meridians brought about an additional delay. The distance effect could be tested in isolation by comparing the three locations in the same hemifield, which were at 4, 8 and 12° from the cued location. The meridian effect could be tested in isolation by comparing the two locations that were at the same distance (4°) from the cued location but in different hemifields. This latter comparison was significant ($P < 0.01$) and showed that RT was faster in the same than in the opposite hemifield (228 vs 249 msec). In other words, passing from one hemifield to the other caused an additional delay of about 21 msec, regardless of which meridian had to be crossed (see Table 1). As for the distance effect, one can see from Table 1 that there was a tendency for RT to increase as a function of the distance from the cued location (249, 257 and 266 msec for 4, 8 and 12° , respectively). However, only the comparison between 4 and 12° was significant ($P < 0.01$).

DISCUSSION

The main findings of the present study are as follows. First, within one hemifield there is a cost when the stimulus is presented in a location different from the attended one. Second, a

large cost is paid when the stimulus appears at a non-attended location in the opposite hemifield, that is across the vertical or horizontal meridian. In addition, even though the effect is rather weak, there is a tendency for the cost to increase with the distance from the attended location. These findings can be used to discriminate among the various hypotheses proposed to explain why the response is slower when attention happens to be directed to the wrong location.

Two of the hypotheses can be ruled out. The constant time hypothesis [22] would predict the same cost irrespective of the relative positions of the attended and the stimulated location. In contrast, our data clearly show that the amount of cost is not constant and even suggest that its magnitude depends on the distance between the two locations.

Even though, in accordance with HUGHES and ZIMBA [10], we found that the vertical meridian plays an important role in determining the magnitude of the cost (and, as they had hinted, the effect occurred also across the horizontal meridian), our data are clearly against their notion that costs and benefits are distributed in an all-or-none fashion and concern one entire hemifield. In fact, in the present study there were costs and benefits within the attended hemifield, and the costs within the non-attended hemifield showed a tendency to change with distance.

The attentional gradient hypothesis [4, 29] is not incompatible with our data. However, the specific version of the hypothesis proposed by DOWNING and PINKER [4] is not supported because the meridian effect explained by them in terms of cortical magnification, was also present in a region several degrees away from the fovea. Although not mentioned by Downing and Pinker, a possible explanation could be that the gradient becomes steeper at the vertical meridian because there is an interhemispheric crossing at this point. However, this version of the gradient hypothesis is not supported by the present study since the same effect was observed across the horizontal meridian, that is in a region represented within one hemisphere. In our opinion, any hypothesis that makes reference to an attentional gradient is faced with the problem of accounting for the meridian effect, otherwise it becomes a simple description of the empirical findings and, as such, cannot be falsified.

The constant speed hypothesis [28, 30] does not fit the present data because crossing the vertical and horizontal meridians lengthened the RT. There is no obvious way for the hypothesis to accommodate this finding, unless additional assumptions are introduced. One could suggest that a delay is caused in passing from one hemisphere to the other, but any explanation in hemispheric terms is ruled out by the fact that crossing the horizontal meridian brought about the same effect. In conclusion, the constant speed hypothesis has the same drawbacks as the gradient hypothesis. In the absence of a convincing explanation of the meridian effect, it amounts to a mere description of the findings.

A possible way to overcome the difficulties that the meridian effect poses to the above-mentioned hypotheses is to postulate that this effect is related to the way eye movements are programmed. Attention and eyes are undoubtedly closely linked in everyday life; only when eye movements are voluntarily prevented does a covert orienting of attention take place. It would seem highly plausible therefore that overt and covert orienting of attention are controlled by common mechanisms and that the absence of eye movements in case of covert orienting is a consequence of a peripheral inhibition, which leaves unchanged the central programming. In other words, the program for orienting attention either overtly or covertly is the same, but in the latter case the eyes are blocked at a certain peripheral stage.

The notion of a motor program that controls both overt and covert orienting may be the clue to a unitary explanation of our findings. We propose, in accordance with the idea of

ROSENBAUM *et al.* [23, 24, 25], that in a motor program the features of the movement to be performed are specified independently and in series. It is conceivable that under normal conditions when the eyes move to reach a target, the program specifies first the direction of the movement and then the exact distance to be covered. It is also conceivable that extra time is spent in a condition in which the program is set but, before the command for its execution is emitted, a change is called for. This extra time should depend on the importance of the movement feature that has to be changed. In the case of ocular movements a change in direction, which implies the use of a completely different set of muscles, is likely to cause a greater delay than a change in distance, which requires only an adjustment of activation of the same muscles.

If we assume that the same mechanisms are also involved when the orienting is covert, it is possible to explain the effects of distance and meridian crossing without further assumptions. When the cue is presented, a movement of the eyes aimed at reaching the target is programmed and, if the stimulus appears in a position congruent with the program (i.e., the expected location), the manual response is immediately emitted, irrespective of whether the ocular movement is executed or not. When the stimulus occurs in a non-expected location within the attended hemifield, the distance feature must be modified in the program. This change requires time, and large changes require slightly more time than small adjustments. When the stimulus is presented in a non-expected location in the hemifield opposite to the attended one, the direction feature has to be changed in the program, regardless of distance. As already pointed out, this is a more complex change than a mere distance adjustment and it requires more time.

It is obvious that the program for moving the eyes towards the target can be modified only on condition that the stimulus has been detected and located in space. Otherwise, no data are available for changing the program. At this point one may wonder why the manual response is not emitted upon stimulus detection with no realignment of attention. POSNER [19] suggested that an arbitrary response, that is one not automatically triggered by the stimulus (e.g., a keypress), only occurs if the stimulus is within the focus of attention and the correct alignment of attention is therefore a necessary condition for emitting the manual response in experiments similar to those discussed here. There is, however, an alternative interpretation that derives from the notion that motor programs are crucially involved in shifting attention. The appearance of the stimulus in the non-expected position produces a change in the ocular motor program, aimed at directing the fovea to the new target. This change in the ocular motor program could interfere with the programming of the manual response, hence delaying it [14]. The interference effect should of course be greater for more radical changes.

The hypothesis proposed in this paper to explain how attention is reoriented towards a non-expected position assumes that the mechanism responsible for it is strictly linked to that responsible for eye movements. Whereas there can be little doubt that such a link exists, the strictness of the connection has been disputed. The paper by KLEIN [15] has been particularly influential in minimizing the relationship between attention and ocular movement. In one crucial experiment Klein's subjects were presented with three dots, horizontally arranged, and they were instructed to fixate the central one. After an interval, three types of events could occur: (a) the left or right dot brightened, (b) an asterisk was displayed over the left or right dot, (c) there was no change in the display. The subjects had to respond manually if one of the dots brightened, or make a saccadic eye movement in a prespecified direction if an asterisk appeared. According to Klein, since the subjects were instructed to move their eyes towards a fixed point, if the oculomotor hypothesis were true, the detection of stimuli in

correspondence to this point should be facilitated. Since this facilitation was not found, the oculomotor hypothesis was rejected. There is however a logical flaw in Klein's experiment. The subject's task was to detect a stimulus and only afterwards to produce a response. Since the detection of a stimulus requires orienting of attention and therefore a specific oculomotor program, the best strategy was to wait until the stimulus appeared, and then prepare the motor program in the direction specified by the instructions. It was uneconomical to prepare, let us say, a motor program towards the left when the probability of the occurrence of a stimulus in that location was only 50%. Klein's subjects quite rightly waited for each stimulus, directed their attention accordingly and finally emitted a response. In this experiment, then, the motor instructions were irrelevant. Attention was not directed and nothing happened.

Strong evidence in favor of common neural structures for eye and attention movements stems from lesion studies in man and animals. POSNER *et al.* [20] studied a group of patients with progressive supranuclear palsy, who have severe deficits in vertical eye movements but not in horizontal eye movements. When tested for their capability to shift attention while fixating a central point, these patients showed a severe impairment in covertly orienting attention in the vertical dimension, whereas they were normal in the horizontal dimension. A dissociation between the ability to move attention upwards or downwards was found by MATELLI *et al.* [16] in cats after lesions of midbrain structures. Also in this case motor and attentional deficits were congruent. Those animals which had motor deficits towards the upper space showed neglect for stimuli presented in that space sector, whereas those animals which had motor problems with the lower space neglected stimuli in that sector.

As stated in the Introduction, the present study was aimed at clarifying the mechanisms responsible for the costs paid when the stimulus is shown at a non-expected position and was non-committal as to the mechanisms responsible for the correct orienting of attention in response to a directional cue. Although we have no new data, the theoretical formulation proposed for the reorienting of attention no doubt leads to some predictions also for the orienting of attention. When a cue is presented, an ocular motor program is built up, which, if executed, brings the fovea onto the target. Time is necessary for preparing the program, and attention is allocated to the target position only when the program is ready. There is no reason why different positions in space should require different amounts of time for preparing the program and hence for allocating attention. In other words, according to the ocular motor hypothesis allocating attention to a cued position should be a time-invariant process, exactly as it is for saccadic eye movements, which require approximately the same time regardless of the distance to be covered [1, 3]. The substantial difference between attention "movement" and saccadic eye movements is that the eyes indeed move in space, whereas attention changes position according to the motor program, without following any pathway from its initial to its final point. Attention is simply deployed to a given point in accordance to the parameters of the motor program. Recent data by REMINGTON and PIERCE [22] confirm that allocating attention to a cued position is a time-invariant process. In contrast with previous experiments [28, 30], they found that the time needed to direct attention to two targets, one located 2° and the other 10° from fixation, was identical. Note that we rejected Remington and Pierce's hypothesis as an explanation of how attention is reoriented after an invalid directional cue. However, there is no contradiction because, according to the premotor hypothesis, the time required to build up a motor program for moving the eyes should be at a large extent independent of the feature to be specified, whereas the time required to change the program does depend upon the features that must be modified.

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