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"Do Peripheral Non-Informative Cues Induce Early Facilitation of Target Detection?"

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Do Peripheral Non-Informative Cues Induce Early Facilitation of Target Detection?

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It has been reported that simple reaction time (RT) to a peripheral visual target is faster if the target is presented within about 200 msec from the onset of a non-informative cue flashed at the same location, as compared with RT to a target presented at an uncued location. This period of facilitation is followed by a period of inhibition during which RT is longer if cue and target are shown at the same location or at different locations within the same hemifield, as opposed to contralateral cues and targets. Early facilitation has been explained by an automatic covert orienting towards the cue, while the following inhibition has been regarded as a consequence of such covert orienting. In a series of four experiments, we have investigated the dependency of these effects on the temporal and spatial relationships between cue and target. Normal, right-handed subjects responded to a target displayed for 16 msec simultaneously with, or following at stimulus-onset asynchronies (SOAs) of 60, 130, 300 or 900 msec, the onset of a non-informative cue. Both cues and targets could appear at random in one of four locations (Expts 1–3) or in one of two locations (Expt 4) disposed symmetrically across the fixation point along the horizontal meridian. Duration of the cue varied between experiments. In Expt 1 it was 16 msec. In Expt 2 the cue remained on view throughout the period of the SOA and terminated 300 msec after target onset. In the remaining two experiments cue duration was 130 msec. In the first experiment, at all cue–target SOAs RTs to targets flashed either at the same location or in the same hemifield as the cue were significantly slower than RTs to contralateral cue–target combinations (RT inhibition). In the other experiments, there was no RT inhibition with targets in cued locations if the cue remained on during target presentation and outlasted target offset. Since at no SOA was RT to targets in cued locations shorter than RT to targets contralateral to cues, there was no direct evidence for facilitation. However, the facilitatory influence of these cues could be inferred from the fact that they countered and masked inhibition. RT to uncued targets ipsilateral to cues was consistently inhibited in all experimental conditions. These results show that at each cue–target SOA the consequences of a peripheral non-informative cue depend on whether or not the cue remains visible during target processing. Further, our findings suggest that facilitation of RT to targets in cued positions, if any, does not precede and cause inhibition, but co-occurs with it.

Reaction-time   Detection   Covert orienting   Early facilitation   Inhibition

INTRODUCTION

The detection or discrimination of a visual stimulus remote from fixation can be differentially influenced by previous events in the visual environment, depending on the location as well as on the informative value of such events. Usually an extrafoveal event will elicit an eye movement, i.e. an alignment of the receptive surfaces of highest acuity with the stimulus. However, because of time limitations or other constraints, it may also act as a cue for a covert orienting of attention towards the stimulus itself, without any accompanying eye movements. Both forms of orienting are instances of attentional reactions (Berlucchi, Aglioti, Biscaldi, Chelazzi, Corbetta & Tassinari, 1989b). Much current interest in attentional phenomena focuses on conditions in which peripheral sensitivity is held constant by preventing eye movements.

When a cue provides information about the location of a subsequent target, it clearly affects the distribution of attention in the visual field, as measured by reaction time (RT) (Posner, 1980; Posner & Cohen, 1984). On any trial the cue may appear either at fixation or in spatial contiguity with the target. In the first case, spatial allocation of attention must follow the translation of the cue code (e.g. an arrow or a digit) into target location, while in the second case the close topological relation between cue and target is sufficient to summon attention directly. In recent studies the consequences of these two types of cue–target relationship have been variously contrasted in terms of temporal course and spatial distribution of the resulting attentional effects (Jonides, 1981; Müller & Rabbit, 1989; Shepherd & Müller, 1989; Warner, Juola & Koshino, 1990; Theeuwes, 1991; Cheal & Lyon, 1991; Umiltà, Riggio, Dascola & Rizzolatti, 1991). A common outcome of this series of experiments

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is that RT is comparatively short for targets presented at cued locations and comparatively long for targets occurring away from cued locations, as compared to a neutral condition. This pattern of benefits and costs of directed attention has generated several metaphors, such as "the searchlight of attention" or "the zoom lens" (Posner, 1980; Eriksen & St James, 1986), each assuming an effortful, serial and time-consuming shift in the deployment of visual attention. In the context of these interpretations, facilitation effects occurring for stimulus onset asynchronies (SOAs) between cue and target shorter than 100–150 msec have been attributed a special status because of their alleged involuntary character. For instance, early facilitation has been attributed to an automatic attraction of attention by peripheral cues, since at very short cue–target intervals predictive central cues speed up discrimination only if they are more frequent than peripheral cues, while peripheral cues are effective independently from their relative frequency (Jonides, 1981, Expt 3). Shepherd and Müller (1989) reported larger benefits following peripheral than central cues as early as at 50 msec of SOA. On the other hand, evidence against a qualitative distinction between the effects of peripheral and central cues has been offered by Warner *et al.* (1990).

Different and more complex results have been obtained in other studies specifically designed to test for the RT effects of cues that provide no information about the location of subsequent targets. Posner and Cohen (1984), Maylor (1985) and Maylor and Hockey (1987) have described a biphasic modulation of RT to light targets by non-informative cues presented at the same location, whereby an early short-lasting facilitation attributable to an automatic summoning of attention by the cue is eventually overcome by an opposite long-lasting inhibitory process. The occurrence of inhibition is inferred from the fact that when a peripheral non-informative cue is followed after at least 150 msec by a target occurring either at the same location or in the opposite hemifield, RT to the target is longer when the locations of cue and target coincide than when they do not. While RT is longest when the two stimuli are presented to the same locations, it has also been shown that RT to targets presented anywhere in the whole hemifield containing the cue is longer than RT to targets in the other hemifield (Tassinari, Aglioti, Chelazzi, Marzi & Berlucchi, 1987). RT inhibition from non-informative cues is either ascribed to some kind of refractoriness of the afferent pathway from the cued location, shifting attention away from places of recent stimuli ["inhibition of return" (Posner, Rafal, Choate & Vaughan, 1985)], or regarded as a more or less direct consequence of covert orienting toward the cue (Maylor, 1985; Tassinari *et al.*, 1987; Tassinari, Biscaldi, Marzi & Berlucchi, 1989; Berlucchi, Tassinari, Marzi & Di Stefano, 1989a; Berlucchi *et al.*, 1989b). In the latter view, it has been proposed that ipsilateral RT inhibition can be the result of a veto to orient overtly towards the first stimulus that comes from the instructions given to the subject. This veto could generate an inhibition of the overall motor reactivity towards stimuli presented in the entire hemifield of the cue, independently of the distance between cue and target and of the horizontal or vertical direction of the inhibited movement. For some time the motor set would contain two instructions that are contradictory with respect to the direction: the vetoing command opposes ocular movements toward the cue, whereas the manual response would depend on a motor predisposition to react to stimuli from that direction (Tassinari *et al.*, 1987, 1989; Berlucchi *et al.*, 1989a, b). A more recent study suggests that the above interpretations need not be mutually exclusive, since sensory and attentional components can separately account for different phases of RT inhibition (Tassinari & Berlucchi, 1993).

By focusing on the temporal and spatial stimulus conditions which are required for obtaining the early facilitation at the cued location, the present report attempts to increase our understanding of the relationships between facilitatory and inhibitory RT effects of non-informative cues as well as of their putative mechanisms. Several recent studies dealing chiefly with RT inhibition have either taken early facilitation for granted without internal evidence for it (e.g. Spencer, Lambert & Hockey, 1988; Tipper, Driver & Weaver, 1991), or demonstrated that it occurs only in select experimental conditions, as contrasted with other conditions in which inhibition is the sole observable effect (Lambert & Hockey, 1991; Possamaï, 1991, 1992). A review of the literature indicates that contrary to inhibition, which is an extremely robust effect, the occurrence of early facilitation may indeed require special stimulus conditions. Posner and Cohen (1984) found early facilitation with cues provided by "a 150 msec brightening of the outline of one of two peripheral boxes" in which the target occurred at 0, 50, 100, 200, 300 or 500 msec after the onset of the brightening. Facilitation was limited to the first three intervals and was followed by inhibition at the longer intervals. In the studies of Maylor (1985) and Maylor and Hockey (1987), a 100 msec brightening of a peripheral box was followed by the target after 100, 300 or 500 msec from cue onset and facilitation was present only at the first SOA (i.e. when the cue was turned off immediately before target onset) to be replaced by inhibition at longer SOAs.

It should be noted that in all of the above studies showing clear evidence of facilitation (Posner & Cohen, 1984; Maylor, 1985; Maylor & Hockey, 1987), early facilitation was observed not only at very brief cue–target SOAs, but also with relatively long cues that overlapped at least partly in time with the target, or were displayed in close temporal contiguity with it. It is therefore unknown if the occurrence of early facilitation crucially requires a very short cue–target SOA, or a temporal (as well as spatial) overlap of cue and target, or both factors conjointly. In this study we sought to disentangle these possibilities in four experiments. In Expt 1, a 16 msec cue could coincide in time with the target, or precede it by SOAs which varied in four steps between 65 and 900 msec, such that the cue disappeared well before target onset. In Expt 2 we employed the same cue–target SOAs as in Expt 1, but varied cue duration so that cue offset always followed target onset by 300 msec, thus ensuring a consistent temporal cue–target overlap. In the remaining two experiments the cue was displayed for a fixed period of 130 msec and SOA was varied as in Expts 1 and 2. Experiments 1–3 compared the effects of cues and targets occurring at the same location, or at different locations within the same hemifield, or in opposite hemifields, in an attempt to decide whether or not facilitation may spread to an entire hemifield as does inhibition. In Expt 4 we endeavored to replicate or approximate as much as possible the conditions in which early facilitation was observed in previous studies by using only coincident or opposite cues and targets.

The present results have been presented in a preliminary form at the Third IBRO World Congress of Neuroscience, Montréal, 4–9 August 1991 (Tassinari, Peru, Chelazzi, Berlucchi & Aglioti, 1991).

GENERAL METHODS

Subjects

Eighteen subjects altogether volunteered to participate in the study. Each of the four experiments employed eight subjects. All were right-handed and had normal or corrected-to-normal vision, including colour vision; they ranged in age from 22 to 39 yr. Three females and five males took part in Expt 1, while all subjects in the remaining experiments were males. Most of them were experienced with RT tasks; the few inexperienced subjects were trained in a preliminary session. About half of the subjects were unaware of the aim of the experiment. In Expts 2–4 the number of new subjects and that of subjects that had already participated in previous experiments of this study was balanced as best as possible.

Apparatus

All experiments were performed in a sound-attenuated room. Background illumination of 0.1 cd/m^2 was provided by two red bulbs. The subject sat in an armchair in front of a large tangent screen, at a distance of 171 cm from it. Stimuli were generated by an IBM-compatible PC programmed in BASIC and were projected on the screen by means of a GE Imager 300 video projector. Throughout each block, the display contained a cross at the centre of the screen, subtending 0.8 × 0.8 deg, and four or two empty square boxes (1.2 × 1.2 deg in Expts 1 and 2; 2 × 2 deg in Expts 3 and 4) centred on the horizontal midline. Two boxes were projected on each side of the vertical midline in Expts 1–3, with their centres at 4 and 12 deg from the fixation; in Expt 4 only one box was projected on each side, centred at 4 deg from fixation. The cue consisted of a change in the outline of one of the boxes (see below). The target was a 0.5 × 0.5 deg greenish square presented inside one of the boxes for the duration of one screen cycle (16 msec) and with a luminance of 15 cd/m^2. Acoustic stimulation was provided by 400 Hz tone pips, 200 msec in duration, delivered through earphones. The response button-key was mounted on a brass cylinder and fastened on the right side of the armchair. The key was connected to an electronic msec counter interfaced with the PC.

Procedure

Each subject participated in four separate sessions, which were run on separate days. Each session consisted of two blocks of 80 trials and each trial involved the same sequence: (1) an auditory warning stimulus, which prompted the subject to look at the central cross and to maintain fixation until the end of the trial; (2) a cue, which was presented after a random interval of 2–3 sec at one of the four positions; (3) a target, which appeared inside one of the boxes after an SOA of 0, 65, 130, 300 or 900 msec. The subject was instructed to make no overt responses to the cue and to press the button-key as fast as possible with the right thumb upon seeing the target. (There were no tests with the left hand because in previous similar experiments we found no significant effects from changing the responding hand.) The 80 trials in each block exhausted all possible combinations of cue position, target position and SOA duration and were randomly intermixed. Responses faster than 150 msec or slower than 500 msec were discarded as anticipations and misses respectively; responses to the cue or trials contaminated by eye movements were also discarded. Discarded trials, which never exceeded 5% of all trials in any subject, were repeated later in the run, until acceptable RTs were available for all combinations. Fixation maintenance was monitored via a video camera.

Data analysis

In previous similar experiments as well as in the present one we found no systematic effects on RT from presentation of cues and targets in the right and left hemifields; further, while RT to targets in medial positions was systematically faster than RT to targets in lateral positions, in accord with the well known effect of retinal eccentricity (see e.g. Haines & Gilliland, 1973), the advantage for medial targets was constant across conditions. For present purposes RTs were sorted in three different groups: Same Point RT (cue and target at the same location), Same Field RT (cue and target in the same hemifield) and Opposite Field RT (cue and target in opposite hemifields). In Expts 1–3, each subject provided 32 Same Point RTs, 32 Same Field RTs and 64 Opposite Field RTs for each SOA. The medians of the three groups of data for each subject were used for repeated-measurement ANOVAs, followed by two-tailed paired t-tests for planned comparisons. The Bonferroni correction was used with repeated comparisons. In Expt 4 each subject provided 64 Same Point RTs and 64 Opposite Point RTs for each SOA and the statistical analysis was run on the medians of the two groups of data.

EXPERIMENT 1

In previous papers (Tassinari *et al.*, 1987, 1989; Berlucchi *et al.*, 1989a, b) we reported a slowing of responses to targets preceded by a 5 msec ipsilateral cue with SOAs of 200 msec or longer and we also have evidence for exclusively inhibitory effects from very short cues of 0.5 msec duration (unpublished observations). This contrasts with the diphasic pattern consisting of facilitation followed by inhibition that has been observed in studies using longer cues and SOAs shorter than 200 msec, such that there was a close temporal contiguity or overlap between cues and targets (Posner & Cohen, 1984; Maylor, 1985; Maylor & Hockey, 1987). In the present experiment we assessed the importance of this cue–target temporal relationship by using cues of constant short duration (16 msec) and SOAs ranging in steps from 0 to 900 msec. We also assessed the effect of peripheral non-informative cues on targets presented ipsilaterally to the cue but not at the cued location, since by using SOAs equal to or longer than 200 msec we have previously shown that RT to targets presented at uncued positions in the same hemifield as the cue is also affected by an inhibition that is not contaminated by local cue–target interactions (Tassinari *et al.*, 1987, 1989; Berlucchi *et al.*, 1989a, b; Tassinari & Berlucchi, 1993).

The present cues consisted in a second outline flashed around and in contact with one of the four boxes for 16 msec. Targets of the same duration were projected inside anyone of the boxes in a random sequence. The boxes and the fixation cross were red and the outline constituting the cue was blue.

Results and discussion

The ANOVA had two factors, Condition (three levels: Same Point, Same Field and Opposite Field) and SOA (five levels: 0, 65, 130, 300 and 900 msec). Both main effects and their interaction were significant [Condition, F (2, 14) = 130.82, $P < 0.001$; SOA, F (4, 28) = 36.2, $P < 0.001$; Condition × SOA, F(8, 56) 2.15, $P = 0.046$]. As shown in Fig. 1, at all SOAs RTs were slowest in the Same Point condition, intermediate in the Same Field condition and fastest in the Opposite Field condition. Overall RTs became faster as SOA increased. The difference between Same Point RT and the RTs in the two other conditions was largest at an SOA of 0 msec (see Table 1 for *post hoc* comparisons).

This pattern of results is consistent with the results of our previous studies (Tassinari *et al.*, 1987, 1989; Berlucchi *et al.*, 1989a, b). There was no indication that the presentation of short, non-predictive peripheral cues could speed up the detection of targets presented either in the same hemifield or at the same location as the cue, even at SOAs shorter than 200 msec. On the contrary, at the 0 msec SOA a significant inhibition was already present for Same Point RT, and also Same Field RT showed a similar inhibitory trend; significant inhibitory effects were present for both Same Point and Same Field RTs at all other SOAs.

At first sight the finding of an RT inhibition at a 0 msec SOA, at which both onsets and offsets of cues and targets were simultaneous, seems to be incompatible with the hypothesis that inhibition is caused by either a sensory refractoriness or an active suppression of

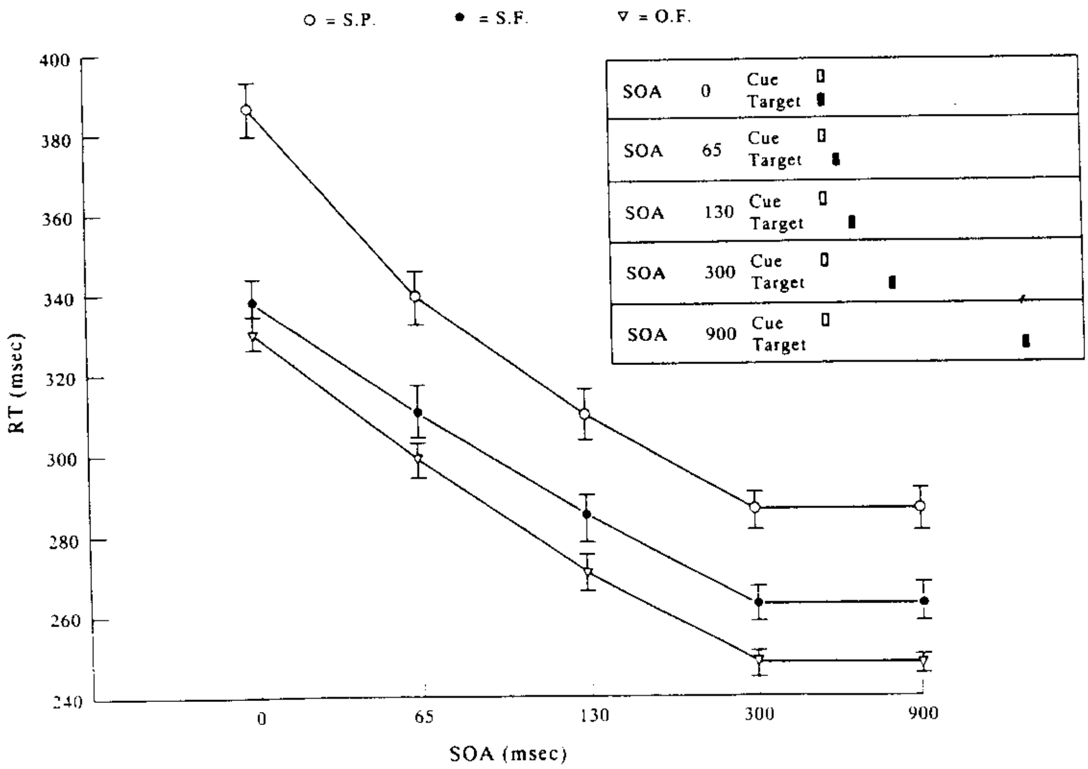

FIGURE 1. Experiment 1: the effect of cues and targets presented on the same area (SP), in the same hemifield (SF) or in opposite hemifields (OF) as a function of the SOA. Each point represents a mean across subjects; error bars represent SEs. Cue duration = 16 msec.

4.

TABLE 1. Experiment 1—differences between RTs of trials with different cue–target combinations

	SOA (msec)				
	0	65	130	300	900
Differences (msec)					
Same Point RT minus Same Field RT	**48.3**	**28.6**	**25.8**	**22.9**	*20.0*
Same Point RT minus Opposite Field RT	**56.0**	**40.5**	**39.0**	**37.5**	**38.8**
Same Field RT minus Opposite Field RT	7.6	*11.8*	**13.2**	**14.6**	**18.8**

Bold differences are significantly different from 0 at the $P < 0.01$ level; italic differences are significantly different from 0 at the $P < 0.05$ level; the other differences is not significantly different from 0.

orienting toward the cue, both of which should start at a measurable time after cue presentation. However it should be considered that cues can influence the speed of responses to simultaneous targets while the production of these responses is already in progress. The comparatively long RT at the 0 msec SOA appears to have been suitable for allowing this influence to take place. Further, it is also possible that targets were processed after the cue even at the 0 msec SOA because of a tendency to generalize the sequential processing of cues and targets which must have occurred at the other SOAs. The possibility that the slowness of Same Point RT at the 0 msec SOA was due to a difficult discrimination of spatially and temporally coincident cues and targets is made improbable by the fact that like Same Point RT, Same Field RT was slower than Opposite Field RT at the 0 msec SOA, although insignificantly so. Since the spatial separation between cues and targets with the Same Field combination posed no difficulty for their discrimination, discrimination difficulty can hardly be regarded as the single factor responsible for RT inhibition at the 0 msec SOA.

In conclusion, it is clear that the temporal cue–target relationships employed in the present experiment were suitable for producing inhibition but not facilitation of either Same Point or Same Field RT. It follows that inhibition need not always be preceded by facilitation.

EXPERIMENT 2

Experiment 1 differed from previous studies demonstrating early facilitation (Posner & Cohen, 1984; Maylor, 1985; Maylor & Hockey, 1987) chiefly because it used very brief cues. In Expt 2 we used longer cues and varied cue duration with SOA so that cue offset always occurred 300 msec after target onset. In this way, cues outlasted targets and usually persisted until after the response had been performed. In all other respects Expt 2 was identical to Expt 1.

Results and discussion

An ANOVA with the same factors and levels as in Expt 1 showed that Condition, SOA and their interaction were highly significant [$F\ (2, 14) = 6.85$, $P = 0.008$; $F\ (4, 28) = 50.54$, $P < 0.001$; and $F\ (8, 56) = 3.26$, $P = 0.004$ respectively].

Figure 2 shows that the effect of SOA was similar to that found in Expt 1, that is, a general increase of response speed with increasing SOAs. However the effects of Condition as well as the Condition × SOA interaction were very different from those of Expt 1. RT was slower in the Same Field condition than in the Same Point and Opposite Field conditions, which in turn did not differ from one another. At no SOA was Same Point RT significantly slower than Opposite Field RT. Same Field RT was slower than Opposite Field RT at all SOAs as in Expt 1, although the single contrasts were statistically insignificant. Finally, Same Point RT was faster than both Same Field RT and Opposite Field at the 65 and 130 msec SOAs. The difference between Same Point RT and Same Field RT was significant at the 65 msec SOA and approached significance at the 130 msec SOA (see Table 2 for *post hoc* comparisons).

The most direct conclusion that can be drawn from these findings comes from a comparison between them and those of Expt 1. In contrast to Expt 1, at no cue-target SOA was Same Point RT significantly longer than Opposite Point RT. Therefore, by definition, the cues of Expt 2, which overlapped and outlasted the targets at all SOAs, were unable to produce inhibition of Same Point RT, unlike the consistently inhibitory cues of Expt 1, which did not outlast the target or terminated well before target onset. Yet the fact that Same Field RT was longer than Opposite Field RT at all SOAs as in Expt 1 suggests that the cues of Expt 2 were not devoid of inhibitory effects. Indeed it may be argued that inhibitory effects engendered by the cue at both Same Point and Same Field locations were countered and masked at the former locations, but not at the latter, by an opposite facilitation, resulting perhaps from the persistence of the cue. This inference also agrees with the fact that in contrast to Same Field RT and Opposite Field RT, which decreased monotonically with increasing cue–target SOA, the Same Point RT function of SOA showed an obvious inflection at the 65 and 130 msec SOAs (see Fig. 2). At these SOAs the Same Point combination yielded faster RTs than the matching RTs of the other combinations, suggesting that the hypothesized facilitation of Same Point RT was particularly effective with the corresponding cue target relationships. Thus, two conclusions can be drawn: (1) facilitation from non-informative peripheral cues is due to a local interaction between cue and target, since it is limited to the case of their temporal and spatial overlap,

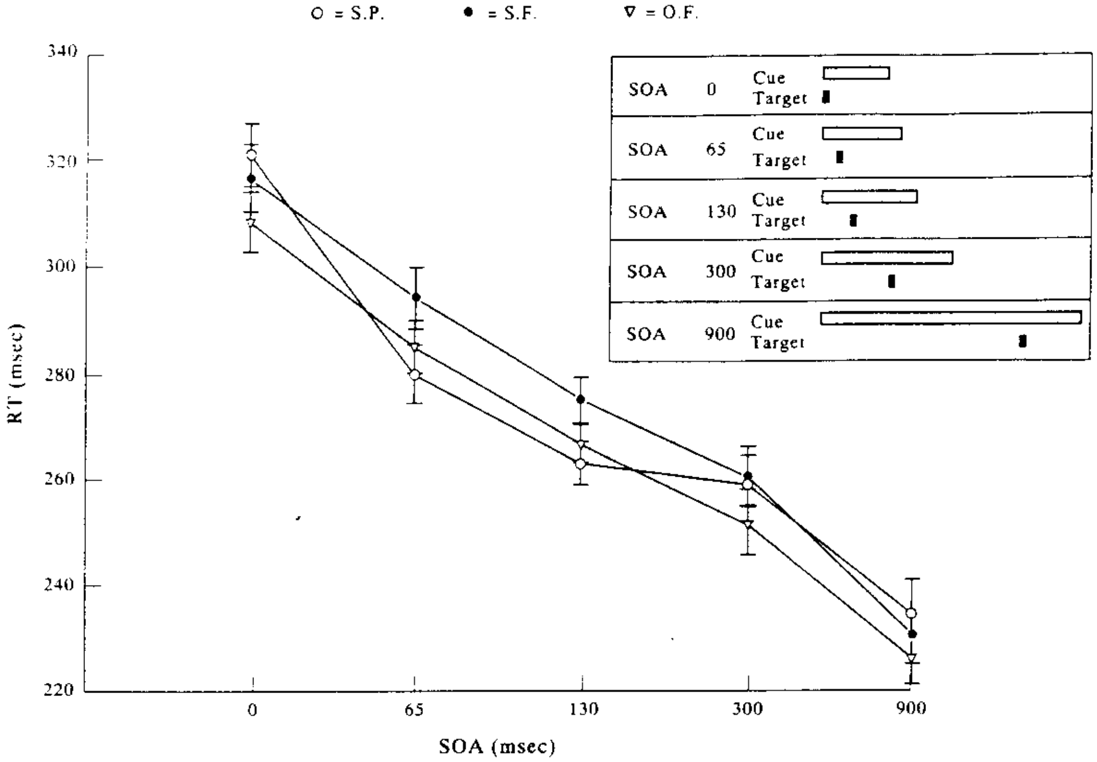

FIGURE 2. Experiment 2: the effect of cues and targets presented on the same area (SP), in the same hemifield (SF) or in opposite hemifields (OF) as a function of the SOA. Each point represents a mean across subjects; error bars represent SEs. Cue duration exceeded by 300 msec target onset.

and (2) if non-informative peripheral cues produce facilitation of Same Point RT, this facilitation does not necessarily precede inhibition, as maintained by Posner and Cohen (1984), Maylor (1985) and Maylor and Hockey (1987), but rather facilitation may co-occur with inhibition.

However, given the limited statistical significance of the differences between Same Point and Same Field RTs on one hand and the insignificance of the differences between Same Point and Opposite Field RT on the other, the hypothesis that the cues of Expt 2 had mixed facilitatory and inhibitory effects on Same Point RT receives only marginal support from the results. Further and more direct support for this hypothesis is provided by the results of Expt 3.

EXPERIMENT 3

The combined evidence from Expts 1 and 2 has led to the suggestion that non-informative cues occurring before or in exact temporal conjunction with the target cause inhibition of Same Point and Same Field RT, whereas cues outlasting the target may produce inhibition of Same Field RT and mixed inhibition and facilitation of Same Point RT. In this experiment we attempted to obtain more explicit evidence for the suggestion that the inhibitory effect of cues on Same Point RT may be mitigated and perhaps reversed if the cue is made to persist after target offset. In order to approximate the experimental conditions in which Posner and Cohen (1984) found cue-induced RT facilitation followed by inhibition, we presented subjects with non-informative cues of about the same duration as used by them, i.e. 130 msec at all SOAs. In addition, the outline of the boxes and the fixation cross were whitish, while the cue was drawn on the box perimeter by means of a blue-whitish colour that appeared as an increase in luminance in peripheral vision. Boxes were larger than in Expts 1 and 2 (see Methods) in order to facilitate the differentiation between cues and targets.

TABLE 2. Experiment 2—differences between RTs of trials with different cue–target combinations

	SOA (msec)				
	0	65	130	300	900
Differences (msec)					
Same Point RT minus Same Field RT	4.1	*−14.3*	−11.9	−1.7	3.8
Same Point RT minus Opposite Field RT	12.6	−4.9	−3.2	6.8	7.8
Same Field RT minus Opposite Field RT	8.4	9.4	8.6	8.5	4.0

The italic difference is significantly different from 0 at the $P < 0.05$ level; other differences are not significantly different from 0.

6.

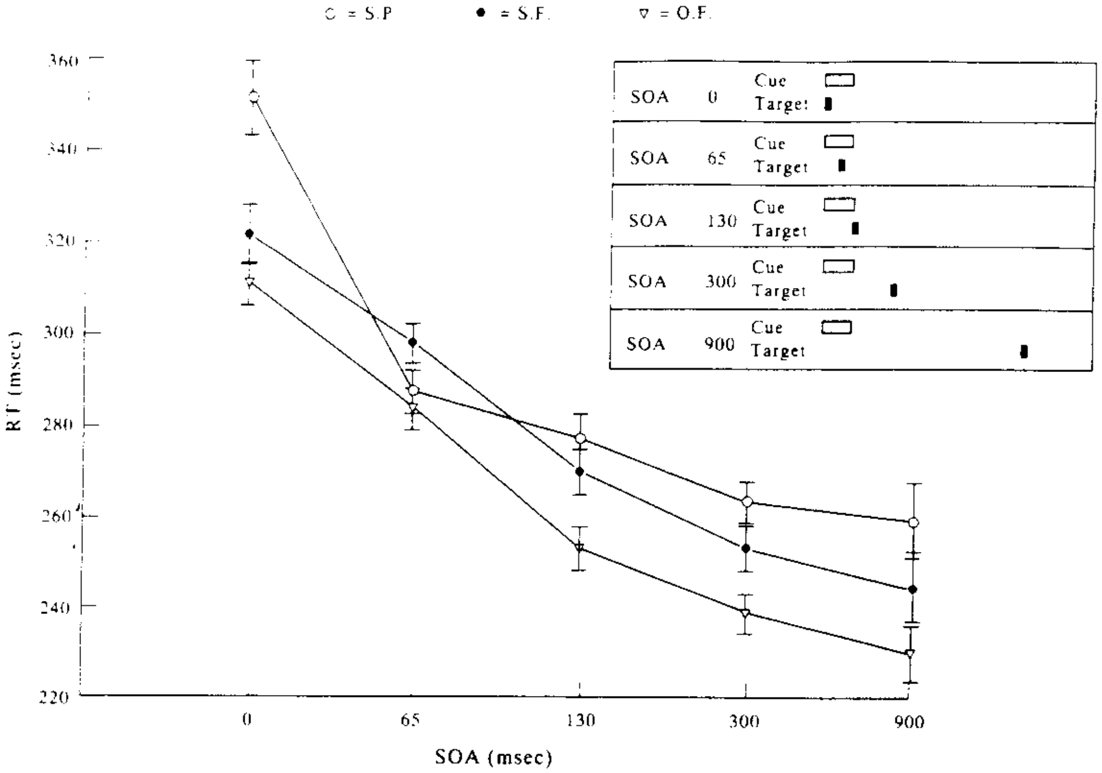

FIGURE 3. Experiment 3: the effect of cues and targets presented on the same area (SP), in the same hemifield (SF) or in opposite hemifields (OF) as a function of the SOA. Each point represents a mean across subjects; error bars represent SEs. Cue duration = 130 msec.

Results and discussion

As in Expts 1 and 2, the two main factors and their interaction were significant [Condition, $F(2, 14) = 25.98$, $P < 0.001$; SOA, $F(4, 28) = 38.31$, $P < 0.001$; Condition × SOA, $F(8, 56) = 4.86$, $P < 0.001$).

As in Expt 1, RT was slowest in Same Point, intermediate in Same Field and fastest in Opposite Field; as in the previous experiments, RT decreased as SOA increased; and Same Field responses were slower than Opposite Field responses at each SOA (see Fig. 3 and Table 3 for *post hoc* comparisons). Same Point RT was significantly slower than RTs of other combinations at all SOAs except at the 65 msec SOA where it was significantly faster than Same Field RT and not significantly different from Opposite Field RT. As in Expt 2, Same Field RT and Opposite Field RT decreased monotonically with the increase in SOA, whereas there was a noticeable inflection in the curve depicting SOA-induced changes in Same Point RT, limited this time to the 65 msec SOA (Fig. 3)

Since Same Point RT was never significantly shorter than Opposite Point RT, once again no direct evidence for early facilitation of Same Point RT was obtained. Nevertheless the results allow us to confirm and extend the following conclusions from the two previous experiments. First, Same Field RT appears to be inhibited by cues regardless of whether they precede, overlap or outlast the target. Second, Same Point RT is strongly inhibited by cues which terminate before target presentation or shortly after target offset. More precisely, when cue onset coincides with target onset, i.e. when the SOA is equal to 0 msec, inhibition of Same Point RT is observed if cue offset occurs during the preparation of the response (Expts 1 and 3) but not if it occurs after the response itself (Expt 2). Third, when cue onset precedes target onset, inhibition of Same Point RT does not occur if the cue outlasts the target, as shown by the results of

TABLE 3 Experiment 3—differences between RTs of trials with different cue–target combinations

	SOA (msec)				
	0	65	130	300	900
Differences (msec)					
Same Point RT minus Same Field RT	*29.5*	−10.6	6.8	10.0	*15.0*
Same Point RT minus Opposite Field RT	*40.0*	3.6	**24.1**	**24.3**	**28.9**
Same Field RT minus Opposite Field RT	10.5	**14.3**	**17.2**	**14.3**	**13.9**

Bold differences are significantly different from 0 at the $P < 0.01$ level; italic differences are significantly different from 0 at the $P < 0.05$ level; other differences are not significantly different from 0.

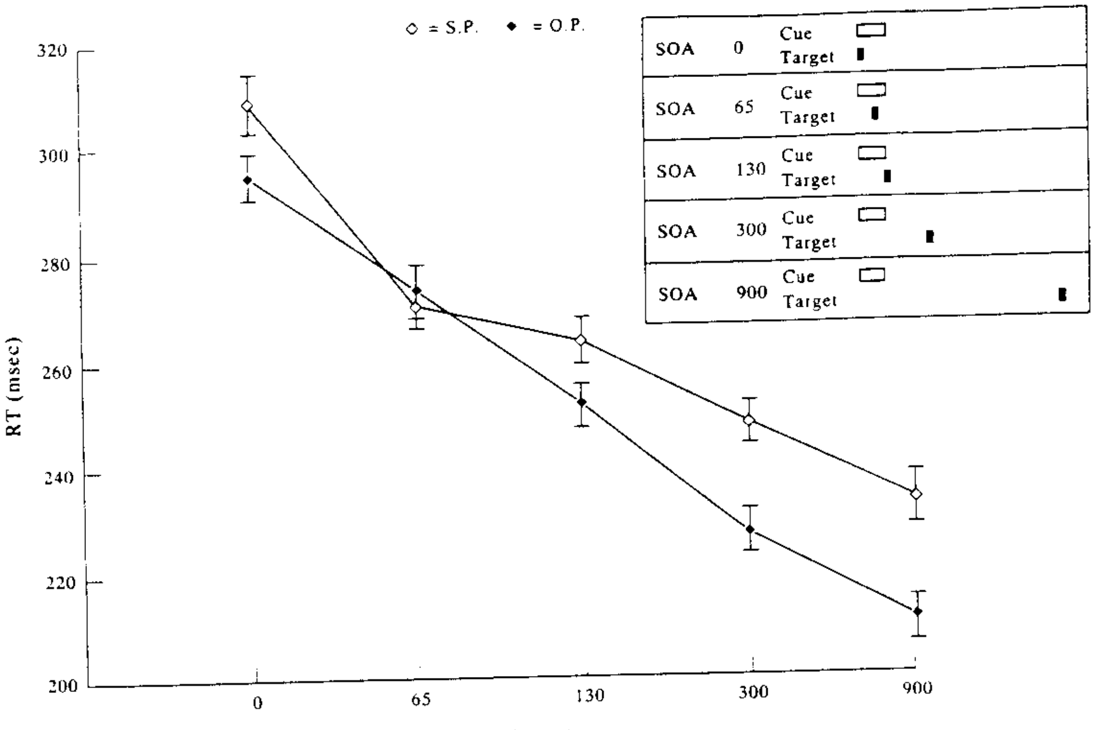

FIGURE 4. Experiment 4: the effect of cues and targets presented on the same area (SP) or in opposite hemifields (OP) as a function of the SOA. Each point represents a mean across subjects; error bars represent SEs. Cue duration = 130 msec.

Expt 2 at the 65 and 130 msec SOAs and Expt 3 at the 65 msec SOA. Finally, even if we were unable to demonstrate an overt early facilitation of Same Point RT, the findings of Expt 3 along with those of Expt 2 are compatible with the assumption that inhibition of Same Point RT can be opposed by a hidden facilitatory process. This process appears to occur at those cue–target SOAs and with those cue durations which revealed overt facilitation in earlier studies by Posner and Cohen (1984), Maylor (1985) and Maylor and Hockey (1987).

EXPERIMENT 4

The diphasic pattern of RT modulation consisting in early facilitation followed by inhibition was originally described using only two possible locations of cues and targets, one on the right and the other on the left of the fixation point (Posner & Cohen, 1984; Maylor, 1985; Maylor & Hockey, 1987). In the unlikely event that the absence of overt early facilitation in Expts 1–3 might be due to our use of four stimulus locations, in this experiment we repeated Expt 3 using cues and targets that could appear only in two locations, 4 deg to the right and left of the fixation cross.

Results and discussion

Condition, SOA and their interaction were significant [F (1, 7) = 112.71, $P < 0.001$; F (4, 28) = 47.62, $P < 0.001$; and F (4, 28) = 5.3, $P = 0.003$]. As shown in Fig.4 and Table 4, the results of Expt 3 were fully replicated.

Once again response speed increased with SOA and ipsilateral responses were slower than contralateral responses at all SOAs except at 65 msec. Obviously the modulation of Same Point RT relative to Opposite Point RT did not depend on the presence of the four stimulus locations of Expt 3.

GENERAL DISCUSSION

A sudden change in light energy in a peripheral visual field location is said to capture attention automatically because it usually attracts the gaze in a reflex-like

TABLE 4. Experiment 4—differences between RTs of trials with the two different cue–target combinations

	SOA (msec)				
	0	65	130	300	900
Differences (msec) Same Point RT minus Opposite Field RT	*13.4*	−3.0	*11.9*	**20.9**	**22.7**

Bold differences are significantly different from 0 at the $P < 0.01$ level; italic differences are significantly different from 0 at the $P < 0.05$ level; the other difference is not significantly different from 0.

fashion, thus facilitating the uptake of visual information from that location. Current models of attentional regulation inspired by Posner and Cohen (1984) assume that even in the absence of eye movements there is a covert automatic orienting toward the location of the peripheral stimulus because of the early facilitation of simple RT to subsequent targets in that location. Early RT facilitation would then be followed by RT inhibition, the so-called inhibition of return (Posner *et al.*, 1985). This account is based on the diphasic modulation, first facilitatory and then inhibitory, of non-informative cues on speed of detection of targets at the cued location, as observed by Posner and Cohen themselves, Maylor (1985) and Maylor and Hockey (1987). In spite of various manipulations of the cue–target temporal relationships, the present series of experiments has failed to afford direct evidence for an early facilitation of RT to targets appearing at the same location as a preceding non-informative cue (Same Point RT). Indeed, Same Point RT was never significantly shorter, and in most cases significantly longer, than Opposite Field RT, i.e. RT to targets contralateral to the cue. In other words, in our experiments RT inhibition was never preceded by an overt early facilitation, contrary to the reports of Posner and Cohen (1984), Maylor (1985) and Maylor and Hockey (1987), but in keeping with earlier findings of an RT inhibition in the absence of prior facilitation. For example, Lambert and Hockey (1991) separated the facilitatory and inhibitory effects of peripheral cues by manipulating the saliency, that is the apparent brightness, of the cue, both types of effects being present in succession with low-saliency cues, but not with high-saliency cues which only produced inhibition. The absence of an overt early facilitation in our study may perhaps be attributed to the possibility that our cues were brighter than those of Posner and Cohen (1984), Maylor (1985) and Maylor and Hockey (1987), but this possibility cannot be assessed since relevant data about cue saliency are not available from those studies. The other difference between the present experiments and those of Maylor (1985), Maylor and Hockey (1987) and also possibly Posner and Cohen (1984), although the latter authors did not give the relevant information, is target duration (16 msec and terminated by the response, respectively). It is difficult to see how this factor could influence the results; anyhow we have unpublished evidence that in experimental conditions similar to those of Expt 4, but with targets outlasting the response, there was no early facilitation as well. It has also been described that contrary to RT inhibition, which tends to be constant across experimental conditions, RT facilitation cannot be obtained if the response is an eye movement rather than a manual movement (Maylor, 1985; but see contrary evidence in Rafal, Henik & Smith, 1991) further, in the case of manual responses, it has been reported that RT facilitation is limited to responses emitted with the hand anatomically ipsilateral to the target in a simple detection task (Possamaï, 1991), or to the hand spatially compatible with the target in a choice RT task (Possamaï, 1992). Taken together, the findings of Lambert and Hockey (1991) and Possamaï (1991, 1992) and those of the present study cannot be reconciled with Maylor's suggestion of a cause–effect link between facilitation and inhibition of manual RT.

Nevertheless, we submit that our data provide some indirect evidence in favour of the existence of an RT facilitation which does not precede inhibition, but rather overlaps in time with it. The presence of RT facilitation in our findings can be inferred from the disappearance of Same Point RT inhibition in conditions in which cue onset preceded or was simultaneous with target onset and cue offset followed target offset. As shown by Expts 2, 3 and 4, the slowing by the cue of Same Point RT relative to Opposite Field RT did not occur if the cue began with or before and outlasted the target, whereas inhibition of Same Point RT was consistently present when cue offset occurred before target presentation, or after the target but during response preparation. The cue–target temporal overlap and the persistence of the cue after the target might suppress the inhibition of return by maintaining a covert orienting toward the cue location (Maylor, 1985) or by hindering the contralateral response bias hypothesized by Tassinari *et al.* (1987, 1989) and Berlucchi *et al.* (1989a, b). Alternatively, inhibition may be suppressed by a facilitation stemming from a sheer summation of the physical energies of the cue and target at the same location. For instance, Rafal *et al.* (1991) showed facilitation by presenting targets on brightened squares; brightening exceeded ground luminance by 12 cd/m^2, and targets added 10 cd/m^2 more (while in our case the increment in luminance was limited to the outline). The hypothesis of facilitation from energy summation (see e.g. Hallett, 1963) is indirectly supported by the parallel absence of inhibition at Same Point locations and presence of some inhibition at Same Field locations in Expts 2 and 3, since the former locations could benefit from energy summation while the latter could not. Spatial summation in turn may not be restricted to the special case of luminance summation, since Posner and Cohen (1984) have seen a facilitation using also dimming cues and Maylor (1985) and Maylor and Hockey (1987) have seen facilitation at the cue offset. These results could be accommodated by possible summation effects between inputs from on- and off-visual channels.

The results with the 0 msec SOA in Expts 1, 3 and 4 seem to indicate that the initial modulatory effect of Same Point cues on speed of detection of simple light targets is purely inhibitory in nature. Inhibition does not follow facilitation, as envisioned by Maylor (1985), but precedes and overlaps with it; so that the analogy between overt and covert automatic orienting reactions to peripheral visual stimuli, as proposed by Posner and Cohen (1984), may not be justified. According to the present results, the predominant automatic effect of non-informative peripheral cues is inhibition rather than facilitation of simple RT, at either short or long cue–target SOAs. If facilitatory effects are present, they do not precede but co-occur with inhibition and are not necessarily an expression of covert orienting. Like RT inhibition (Tassinari & Berlucchi, 1993), RT facilitation may include sensory and attentional components which must be dissociated by appropriate experiments.

Detection of targets following non-informative cues is a special case in the domain of covert attention. Benefits have been described in different conditions, in which a spatial cue indicates the probable location of the target. Early facilitation effects occurring in these conditions seem to be more pronounced following peripheral than central cues and by consequence they are considered automatic in nature (Jonides, 1981; Shepherd & Müller, 1989; but see also Warner *et al.*, 1990). It is impossible to reduce these instances to further cases of spatial summation, since the task is a discrimination between two or more targets at the cued location. The facilitation seen in these conditions may simply not be automatic. Voluntary attentional shifts as fast as 33 msec have been described (Saarinen & Julesz, 1991); it is also reasonable to assume that positional information provided at a peripheral cued location is decoded faster than positional information provided at the fovea, away from the cued location. Alternatively, discrimination (Jonides, 1981) or even detection (Shepherd & Müller, 1989) of targets following informative cues and occurring with different frequencies may be facilitated at early intervals due to a different automatic process, similar to the probabilistic operant conditioning that is effective even in animals (De Weerd, Vandenbussche & Orban, 1990), or a simple repetition effect (Kirby, 1980).

Apparently, the only instances where neither the explanations in terms of spatial summation, nor those in terms of a voluntary shift or probabilistic conditioning apply seem to be those of early facilitated discriminations following non-informative visual cues. For instance, in the study of Nakayama and Mackeben (1989) a positional cue modulated orientation and colour discrimination as early as 70 msec after its onset. However, in such a paradigm the cue tells the subjects where to perform the choice, in spite of its being unpredictive of the *discriminanda* themselves. Nakayama and Mackeben instructed their subjects (after "considerable difficulty") to perform very quickly an effortful operation similar to that requested by Tassinari *et al.* (1987) in a task where attention was voluntarily allocated to a position despite targets occurring randomly at various locations. Facilitation may thus be attributed to a voluntary rather than automatic attentional process. Nevertheless, a few reports of early facilitated discriminations following non-informative cues seem to exclude the influence of voluntary control. In the second experiment reported in Jonides (1981), subjects could not ignore a peripheral cue whose validity was at a chance level and the cue was effective in speeding up the response. Müller and Rabbitt (1989), using hit probability rather than RT, provide a less direct evidence of facilitation from an irrelevant flash that competes with a relevant cue. The assessment of early facilitation of discriminations following non-informative cues seems to deserve further inquiry.

In conclusion, in absence of eye movements speed of detection of peripheral targets is hard to be improved by non-informative cueing, due to the concurrent presence of facilitation and inhibition at the cued position. The transition from facilitation to inhibition at cue–target SOAs of about 200 msec, as previously reported in several studies, presumably resulted from specific spatio-temporal relations between cue and target. Although it cannot be excluded that facilitation may depend on a covert orienting toward the cued location, it is more likely due to a local interaction between cues and targets, independent of attentional reactions and perhaps attributable to sensory summation. Almost nothing is known at the moment about the physiological mechanisms of these facilitatory and inhibitory processes and further research is no doubt warranted to determine both their nature and the possible substrates for their interaction.

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