

Volitional Covert Orienting to a Peripheral Cue Does Not Suppress Cue-induced Inhibition of Return

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Abstract

■ Detection reaction time (RT) at an extrafoveal location can be increased by noninformative precues presented at that location or ipsilaterally to it. This cue-induced inhibition is called *inhibition of return* or *ipsilateral inhibition*. We measured detection RT to simple light targets at extrafoveal locations that could be designated for covert orienting by local or distant cues. We found that cue-induced inhibition co-occurred in an additive fashion with the direct effects of covert

orienting, i.e., it detracted from facilitation at attended locations and increased the disadvantage for unattended locations. Thus, cue-induced inhibition cannot be suppressed by a volitional covert orienting to the cued location; the co-occurrence of different facilitatory and inhibitory effects confirms the simultaneous operation of multiple independent attentional mechanisms during covert orienting. ■

INTRODUCTION

The orienting of attention in visual space takes place overtly, through eye movements, or covertly, with stabilized eyegaze. Orienting, whether overt or covert, can occur under voluntary or endogenous control, regardless of the presence or absence of external stimuli, or be guided automatically by external stimuli through an exogenous control (e.g., Reuter-Lorenz & Fendrich, 1992; Umiltà, Riggio, Dascola, & Rizzolatti, 1991; Jonides, 1981; Posner, 1980, 1986). While the two kinds of control, exogenous and endogenous, appear to have partially different neural bases (Rosen et al., 1999; Yamaguchi & Kobayashi, 1998), covert orienting shares with overt orienting the activation of virtually the same preculomotor cortical areas (e.g., Corbetta et al., 1998). Within the realm of covert exogenous orienting, the term *inhibition of return* (IOR) was introduced by Posner, Rafal, Choate and Vaughan (1985) to allude to an experimental effect previously reported and interpreted by Posner and Cohen (1984). The latter authors found that a spatially uninformative cue, i.e., a change in luminance preceding a peripheral light target without predicting its location, could modulate the reaction time (RT) for detecting the target in different ways. If the stimulus-onset-asynchrony (SOA) between cue and target was shorter than 200 msec, RT was significantly faster if cue and target appeared at the same location than if they appeared at mirror locations in opposite hemifields. But if the cue-target SOA was increased above 200 msec up to 1000 msec, RT was significantly

slower if the cue and target appeared at the same location compared to when they appeared at opposite locations. From these and other results, Posner and Cohen (1984) inferred that a change in luminous energy at the peripheral cued location is apt to generate both RT facilitation and RT inhibition by its contrasting and independent actions on attentional orienting. They attributed RT facilitation to an automatic attraction of attention by the cue, resulting in an improved sensory processing at the cued location, while they attributed RT inhibition to a long-lasting sensory change at the cued location that automatically tends to repel attention toward other locations. The withdrawal of attention from recently sampled positions and its allocation to fresh sources of stimulation would operate in the interest of a balanced and exhaustive exploration of the visual field. The term IOR implies that attention is temporarily prevented from returning to recently sampled positions, with the result that the processing of targets in these positions, unaided by attention, is slowed down, hence, RT inhibition. In Posner and Cohen's study (1984), subjects maintained fixation during the presentation of both cues and targets and, therefore, the observed effects were thought to index processes of covert attentional orienting, but it is known that similar effects can be demonstrated in the exploration of the visual field by overt ocular movements. The tendency to foveate the location of a sudden peripheral stimulus is, of course, a natural response, and a subsequent reluctance to return the line of sight to that

location has been documented (Vaughan, 1984) and shown to be largely innate (Valenza, Simion, & Umiltà, 1994; Chloessy, Posner, Rothbart, & Vecera, 1991). Further possible and different functional links between IOR and oculomotor control have been suggested by several studies (e.g., Spence & Driver, 1998a; Taylor & Klein, 1998; Reuter-Lorenz & Rosenquist, 1996; Chelazzi et al., 1995; Tassinari & Berlucchi, 1995; Sheliga, Riggio, & Rizzolatti, 1994, 1995; Abrams & Dobkin, 1994a,b; Rafal, Calabresi, Brennan, & Sciolto, 1989; Rafal, Egly, & Rhodes, 1994; Berlucchi, Tassinari, Marzi, & Di Stefano, 1989; Tassinari, Aglioti, Chelazzi, Marzi, & Berlucchi, 1987).

Lately, the term IOR has been widely employed for the description of a variety of inhibitory effects in the processing of signals in the visual modality as well as in other sensory modalities, and in tasks involving the discrimination as well as the detection of stimuli, or temporal order judgements (e.g., Lloyd, Bolanowski, Howard, & McGlone, 1999; Pratt & Abrams, 1999; Tipper, Jordan, & Weaver, 1999; Mondor, Breau, & Milliken, 1998; Spence & Driver, 1998a,b; Taylor & Klein, 1998; Weaver, Lupiáñez, & Watson, 1998; Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997; Riggio & Kirsner, 1997; Reuter-Lorenz, Jha, & Rosenquist, 1996; Schmidt, 1996; Tanaka & Shimojo, 1996; Tassinari & Campara, 1996; Gibson & Egeth, 1994a,b; Terry, Valdes, & Neill, 1994; Tipper, Weaver, Jerreat, & Burak, 1994; Kwak & Egeth, 1992; Tipper, Driver, & Weaver, 1991). In light detection tasks, the mechanisms underlying RT inhibition at cued locations have been shown to include orienting-independent and orienting-dependent components (Tassinari & Berlucchi, 1995), and the precise relations between phenomena subsumed under the IOR concept and attentional control, as opposed to sensory factors, or motor set or preparation, are still largely unclear (see reviews by Taylor & Klein, 1998, and Rafal & Henik, 1994).

As already stated, attentional orienting is open to the control of volitional decisions as well as to the automatic action of exogenous stimuli (Posner, 1980); hence, Posner and Cohen (1984) postulated that the cue-induced RT inhibition indexing IOR might be canceled out if the automatic repulsion of attention by the cue could be voluntarily resisted by sustaining concentration at the cued location. The question then is whether an incentive to maintain attention at the cued location can suppress or diminish the inhibitory effects arising from the peripheral cue. An old study from our laboratory (Berlucchi, Di Stefano, Marzi, Morelli, & Tassinari, 1981) seems to provide a negative answer to this question, insofar as subjects with complete foreknowledge of target location were nonetheless slower to respond to targets in cued than noncued locations. This evidence, however, was inconclusive, since we had no direct proof that subjects anticipated target occurrence by directing attention at target location, whether cued or uncued.

Indeed, foreknowledge of target location was ensured by presenting the target at the same location on all trials of an experimental block, and volitional maintenance of attention at that location might have been hindered by a habituation process. Maylor (1985) also obtained evidence that IOR might affect a location in spite of the presence of attention at that location, but again the evidence was dubious, since such presence was inferred from a temporal order judgment task, which may be influenced by other variables (e.g., Gibson & Egeth, 1994b). To our knowledge, the only direct evidence that the maintenance of covert attention at a cued location cannot completely suppress IOR at that location is to be found in preliminary publications from our laboratory (Berlucchi, Biscaldi, Chelazzi, & Tassinari, 1988) and another group (Tanaka & Shimojo, 1993), as well as in unpublished results by Berger, briefly reported by Rafal and Henik (1994).

In the present study, we sought and found conclusive evidence for an additive relation between the effects of volitional attentional control and IOR by means of an experimental design, which allowed the assessment of the separate and combined effects of IOR-inducing cues and the active orienting of attention. The specific question we asked is whether an IOR effect elicited by appropriate stimulation at a given location can be suppressed by an objectively demonstrated maintenance of attention at that location, or whether the two kinds of effect can coexist at the same location. We reasoned that if the former possibility is confirmed, then the IOR effect can definitely be regarded as predicated on the withdrawal of attention from the location of the cue, as originally envisaged by Posner and Cohen (1984) and explicitly assumed by many following researchers. If the second possibility is confirmed, then it is not necessary for attention to move away from a location in order for IOR to occur at that location, at least in the present experimental conditions. Our experimental paradigm allowed us to measure simple RT to light targets at extrafoveal locations as a function of the spatial relation between these targets and similar light cues previously presented at the same or other locations under different conditions of attentional control. In one condition (diffuse attention condition) targets were preceded by *neutral* cues, i.e., cues that did not convey a specific instruction to attend to a potential target location, but which were apt to induce IOR effects at cued locations and other locations within the cued hemifield. We have indeed previously shown that, though IOR effects are maximal at the location of the cue, they also extend to other locations within the cued visual hemifield, hence, the term “ipsilateral inhibition” (Berlucchi et al., 1989). In other conditions (covert orienting conditions) peripheral cues were used to instigate a deliberate allocation of attention either to a position directly marked by a *local* cue, or to other positions designated for attention by a *distant* cue on the basis of a prespecified spatial

code; targets could occur randomly at attended or nonattended locations. When the target occurred at the location where the cue, whether local or distant, had directed attention to, the cue was called *valid*; when the target occurred at a location different from that selected for attention by the cue, whether local or distant, the cue was called *invalid*. By comparing the effects of neutral cues with those of valid and invalid cues, whether local or distant, on simple manual RT to subsequent targets, we have been able to distinguish between the facilitatory and inhibitory components of these effects, and to establish that IOR effects and the benefits of directed attention can be elicited in an almost additive fashion at the same location.

RESULTS

Since in no case did the percentage of response errors, including anticipations, retardations, omissions and fixation failures, exceed 5%, only RT data will be considered in the following description.

General Effects of Covert Orienting and Cue-Target Spatial Combinations

Covert orienting and the cue–target spatial combination are the major independent variables expected to affect RT, and their effects may vary as a function of the temporal interval between cue and target (stimulus onset asynchrony, SOA), which could take one of four values, 0.2, 0.6, 1.5, 5 sec. The general effects of covert orienting were analyzed by comparing RTs of neutral trials, collected in the diffuse attention condition, and valid and invalid trials, collected in the covert orienting blocks; on valid trials, subjects were supposed to have oriented to the location of the upcoming target, whereas on invalid trials they were supposed to have oriented to a location different from that of the upcoming target. The effects of the spatial combination between the cue and the target were analyzed by comparing the RTs of select combinations, in keeping with our previous studies (Tassinari, Agliota, Chelazzi, Peru, & Berlucchi, 1998; Tassinari et al., 1987; Tassinari, Biscaldi, Marzi, & Berlucchi, 1989; Tassinari & Berlucchi, 1995; Berlucchi et al., 1989). To this aim, four cue–target spatial combinations were identified by reference to a combinatorial rule that did not take into account the right or left, or medial or lateral positions of both cue and target. The SP (Same Point) cue–target relation included all instances in which cue and target appeared at the same location; the SF (Same Field) cue–target relation included all instances in which cue and target appeared at adjacent locations within the same hemifield; the OS (Opposite Field Symmetric) cue–target relation included all instances in which cue and target appeared at mirror locations in opposite hemifields; the ONS (Opposite Field Non-Symmetric) cue–target rela-

tion included all instances in which cue and target appeared at nonmirror locations in opposite hemifields. Figure 1 shows graphic examples of all possible cue–target combinations for a left-lateral cue presented in the neutral condition (bottom) as well as in the four orienting-mode conditions, with specifications of the neutrality, validity or invalidity of each actual trial in the five experimental conditions. RTs of each subject were subdivided according to (1) validity, invalidity or neutrality of trials; (2) type of cue–target spatial combination; and (3) cue–target SOA. Each subject thus provided 48 basic mean RTs, which were entered into an ANOVA with trial type (three levels: valid, neutral, and invalid), cue–target spatial combination (four levels: SP, SF, OS, ONS) and SOA (four levels: 0.2, 0.6, 1.5 and 5 sec) as main factors.

The main aspects of the results are illustrated in Figures 2–6. All main factors and the three two-way interactions proved significant in the ANOVA, while the three-way interaction did not ($F(18,162) = 1.1, ns$). Considering the trial type factor ($F(2,18) = 56.3, p < .01$), the RT of invalid trials (316.1 msec) was significantly longer than the RT of neutral trials (284 msec; $p < .01$), and the RT of valid trials (274.7 msec) was significantly shorter than the RT of neutral trials ($p = .03$). The RT of invalid trials was longer than the RT of neutral trials in 10 subjects out of 10, and the RT of valid trials was shorter than the RT of neutral trials in 8 subjects out of 10. Considering the cue–target spatial combination factor ($F(3,27) = 89.3, p < .01$), SP RT (312.9 msec) was longer than SF RT (293.4 msec), which in turn was longer than both OS RT (280.3 msec) and ONS RT (280 msec).¹ The difference between OS RT and ONS RT was statistically insignificant; all the other differences were significant at the $p < .01$ level and were exhibited by all subjects. Considering the SOA factor ($F(3,27) = 8.3, p < .01$), there was a pronounced nonlinear decrease of RT with increasing SOA: overall RT was 306.5 msec at the first SOA, 291.2 msec at the second SOA, 292.6 msec at the third SOA, and 276.3 msec at the fourth SOA. The first SOA differed significantly from the second ($p < .02$) and fourth SOA ($p < .01$), the second SOA differed significantly from the fourth SOA ($p < .05$), and the third SOA differed significantly from the fourth SOA ($p < .01$).

The significant SOA/trial type interaction ($F(6,54) = 5.4, p < .01$) is illustrated in Figure 2. While the RT of invalid trials significantly exceeded the RT of neutral trials at all SOAs ($p < .01$ in all cases), the RT of neutral trials significantly exceeded the RT of valid trials only at the three longer SOAs ($p < .05$ in each case). In fact, at the shortest SOA, the RT of valid trials was insignificantly longer (by 2.4 msec) than the RT of neutral trials.

The significant interaction between the cue–target SOA and the cue–target spatial combination ($F(9,81) = 13.9, p < .01$) is illustrated in Figure 3, which shows marked differences in the SOA-related RT changes for

Figure 1. Examples of all possible cue–target spatial combinations for a left lateral cue in the neutral condition (bottom) and in the four covert orienting conditions, with indications of the validity and invalidity of each trial in the latter four conditions. In the *sp* attentional condition, subjects were supposed to attend to the cue location; in the *sf* attentional condition, they were supposed to attend to the location ipsilateral to the cue; in the *os* attentional condition, they were supposed to attend to the location contralateral and mirror-symmetric to the cue; in the *ons* attentional condition, they were supposed to attend to the location contralateral and non-mirror-symmetric to the cue (see Methods).

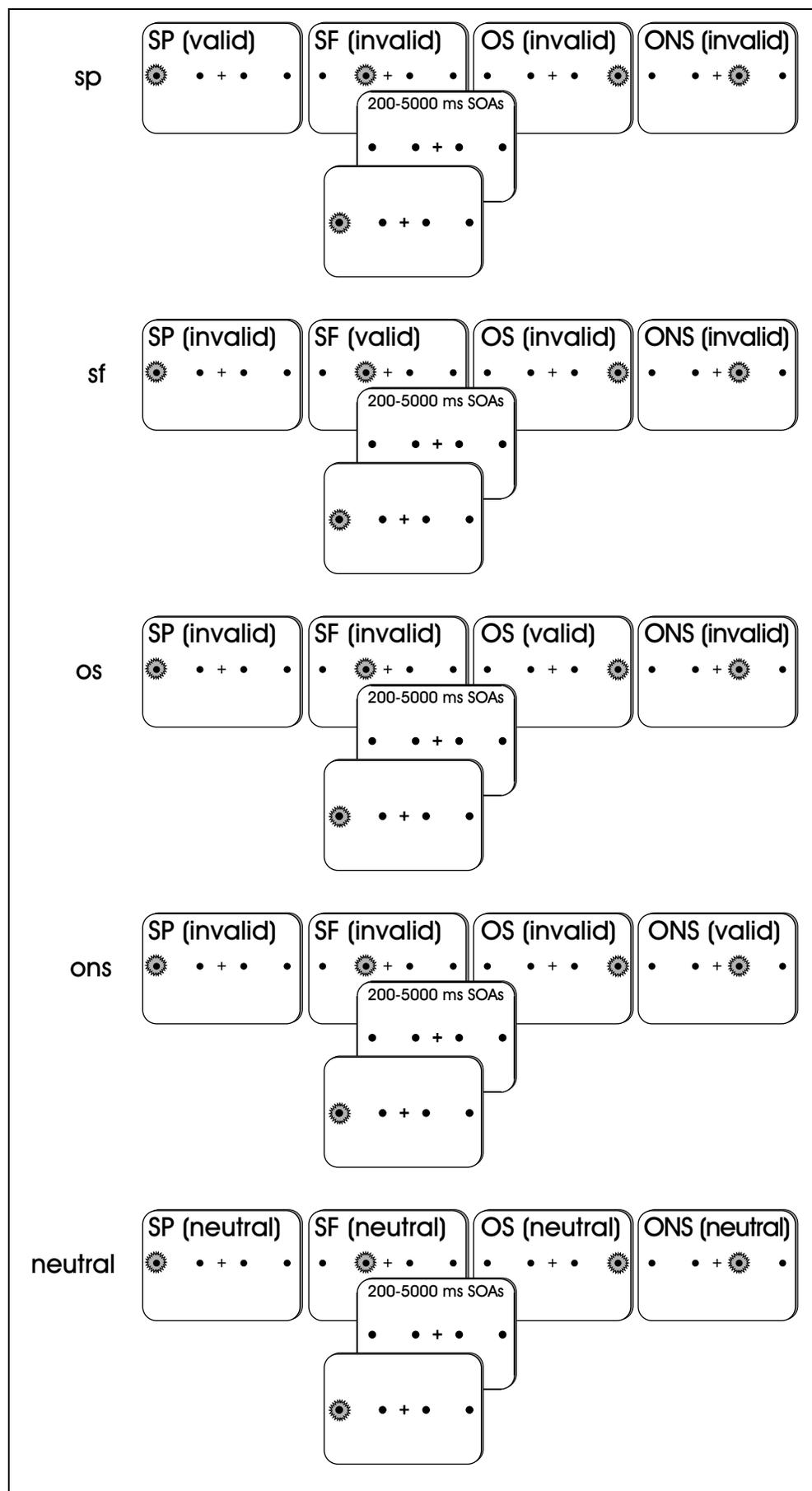
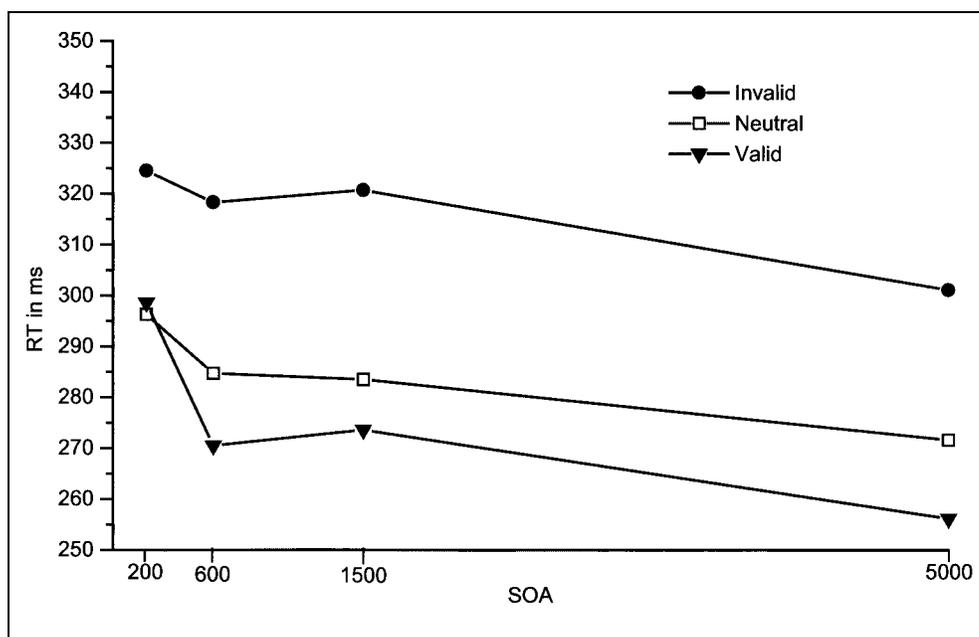


Figure 2. RT for different trial types as a function of SOA.



the four cue–target spatial combinations. Accordingly, the above-mentioned differences between SP, SF, OS and ONS RTs were largest at the shortest SOA and decreased with increasing SOA, such that at the longest SOA there was a trend for all RTs to converge toward the same value. However, SP RT and SF RT were significantly different from both OS RT and ONS RT even at the longest SOA ($p < .05$ in all cases).

After establishing that our paradigm was adequate to produce robust effects from both covert orienting and cue–target spatial combination, it was critical to assess how these effects combined in the covert orienting

conditions. The interaction between the cue–target spatial combination and the trial type is illustrated in Figure 4. The figure shows that the RT of invalid trials was longer than the RT of neutral trials, and the RT of valid trials was shorter than the RT of neutral trials, with all types of cue–target spatial combinations; and, conversely, that the ranking of SP, SF, OS and ONS RTs was the same for all trial types. The significance of the interaction ($F(6,54) = 2.4; p < .05$) reflects the fact that the invalid–valid difference was somewhat greater for the SP relation (48.8 msec) than for all the other cue–target relations (SF 40.6 msec; OS 37.5 msec; ONS 38.5

Figure 3. RT for different cue–target spatial combinations as a function of SOA.

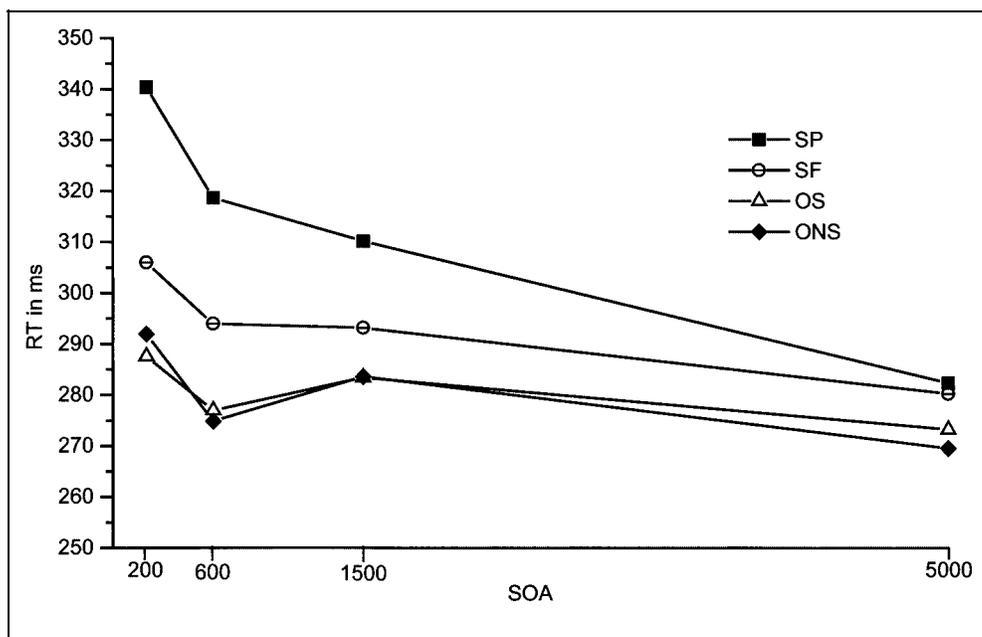
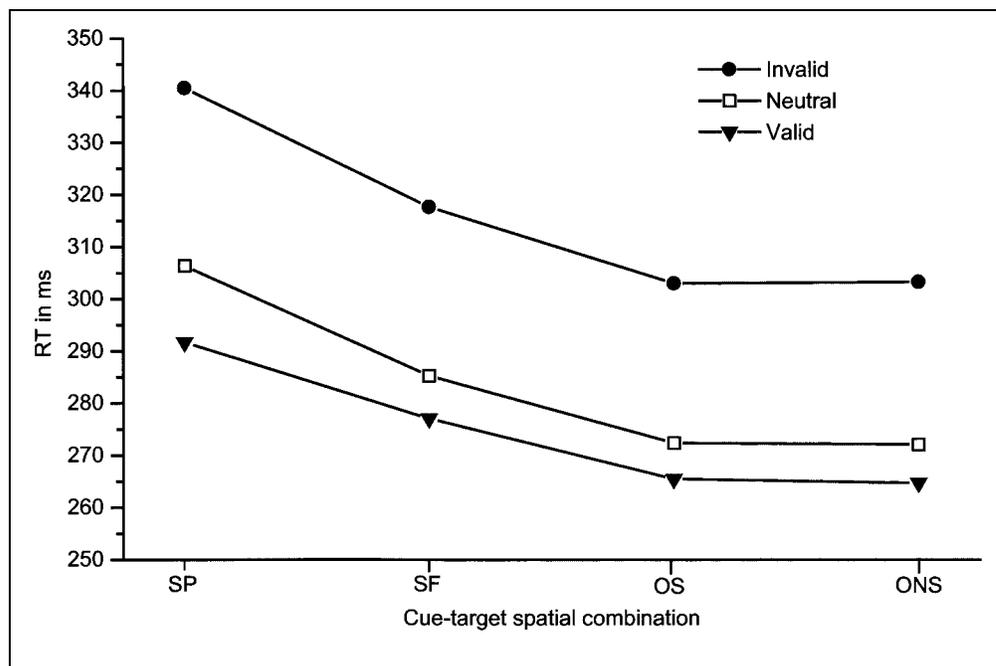


Figure 4. Effects of trial type and cue–target spatial combination on RT.



msec). The SP–OS and SP–ONS differences were significant ($p < .05$ in each case). *These results indicate that the effects of the cue–target spatial combination and those of covert orienting co-occurred virtually independent of one another.*

The insignificant three-way interaction is illustrated in Figure 5, which shows that invalid, neutral, and valid trials exhibited fully comparable effects from the cue–target spatial combination across SOAs.

In summary, the above analysis has demonstrated concurrent effects from the type of trial and the spatial combination between cue and target. As a result of covert orienting, RT was speeded up at attended locations at the three longer cue–target SOAs, and retarded at nonattended locations at all SOAs, relative to RT of neutral trials. Inhibitory effects of the cue per se consisted in a retardation of RT on the side of the cue relative to the other side. This RT inhibition ipsilateral to the cue was fully developed at the shortest cue–target SOA and tended to vanish at longer SOAs.

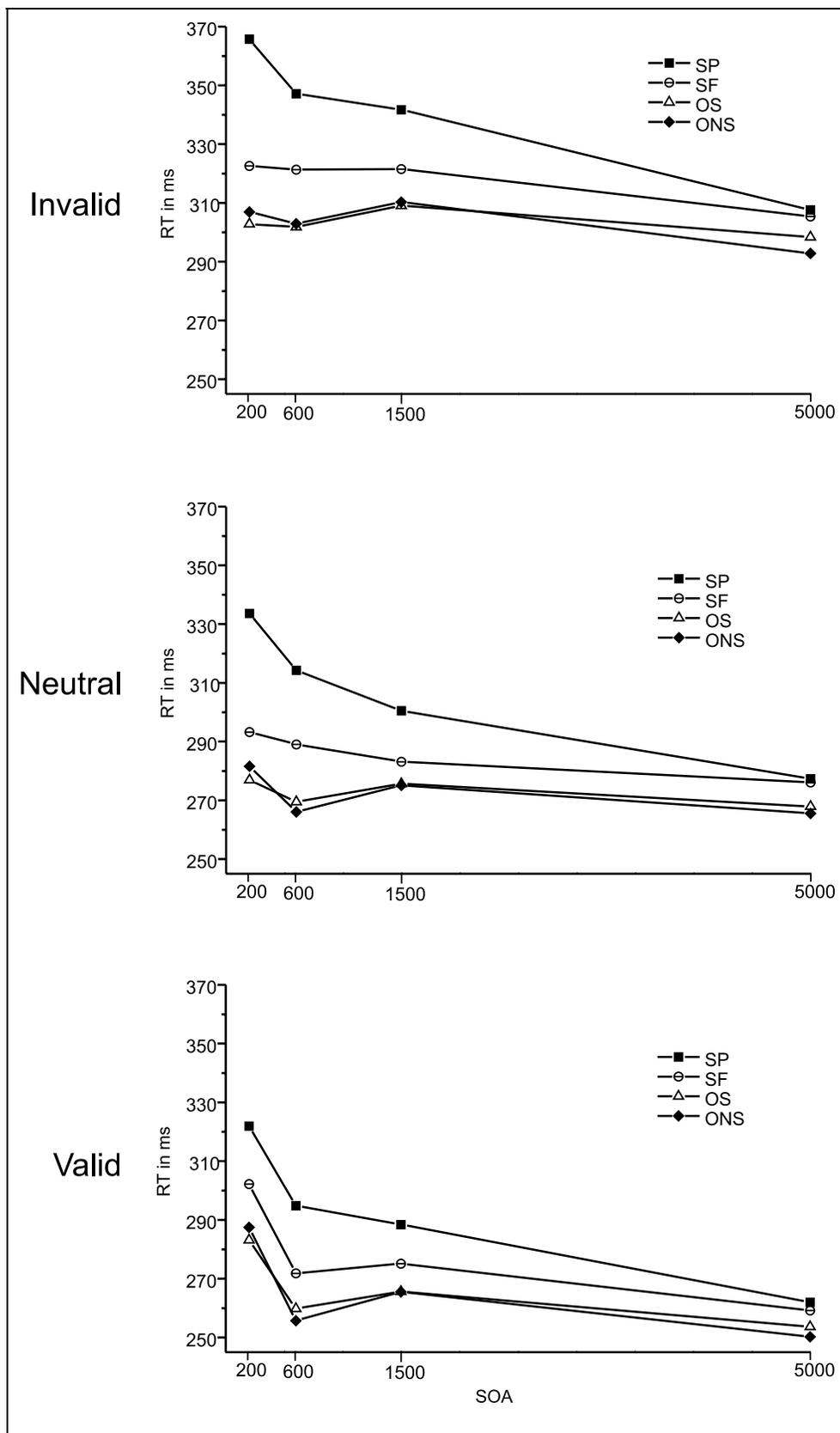
Spatial and Temporal Patterns of Costs and Benefits of Covert Orienting

The patterns of costs and benefits resulting from covert orienting were examined in greater detail with reference to the modes in which orienting was guided by cue position (see Methods). In each of the orienting modes (orienting to the cue, *sp* mode, or to the location ipsilateral to the cue, *sf* mode, or to the location in the mirror location contralateral to the cue, *os* mode or, to the location in the nonmirror location contralateral to the cue, *ons* mode), benefits were computed for each SOA as differences between RTs to each of the four cue–

target spatial combinations (SP, SF, OS, ONS) on valid trials and the corresponding SP, SF, OS, ONS RTs of neutral trials; and costs were computed as differences between RTs to each of the four cue–target spatial combinations on invalid trials and the corresponding RTs of neutral trials. Actual benefits thus computed are negative values, equal to the valid–neutral differences of the previous ANOVA. Actual costs thus computed are positive values; each invalid–neutral difference of the previous ANOVA was broken down by the computation into three costs, corresponding to the three orienting modes whereby the attended location did not coincide with target location. The across-subject means of the RT data from which costs and benefits were computed in the above described way are presented in Table 1.

Each subject provided 64 data (16 valid–neutral differences and 48 invalid–neutral differences), which were entered into an ANOVA with orienting mode (four levels: *sp*, *sf*, *os*, *ons*), cue–target spatial combination (four levels: SP, SF, OS, ONS) and SOA (four levels) as main factors. The only significant sources of variation in this analysis were the two-way interaction between orienting mode and cue–target spatial combination ($F(9,81) = 63.47, p < .01$) and the three-way interaction between orienting mode, cue–target relation, and SOA ($F(27,243) = 2.71, p < .01$). The insignificance of the orienting mode factor indicates that the cost–benefit difference did not vary systematically across the four orienting modes. The insignificance of the cue–target spatial combination factor is an arithmetic consequence of the subtraction procedure used to compute costs and benefits. Subtracting RTs of valid and invalid trials from RTs of neutral trials with corresponding cue–target spatial combinations does indeed cancel out the inhibitory

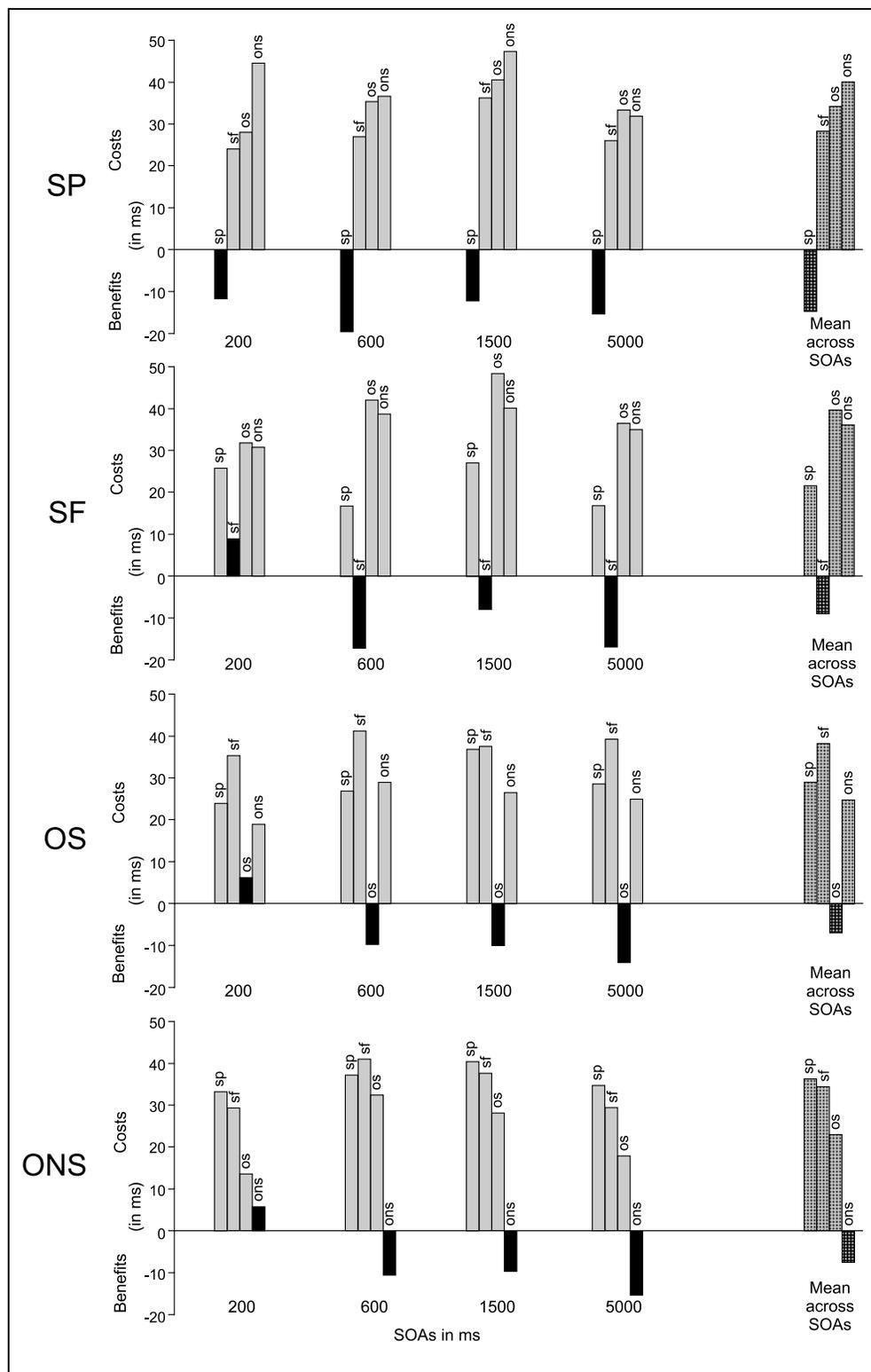
Figure 5. RT for different cue–target spatial combinations as a function of SOA for invalid, neutral, and valid trials. Differences in overall RT between the three graphs reflect the effects of trial type.



effects of the cue, which were shown by the previous analysis to be similar for neutral, valid, and invalid trials.

The cue–target spatial combination/orienting mode interaction is decomposed in Figure 6, rightmost group

Figure 6. Benefits and costs of covert orienting as a function of cue–target spatial combination, orienting mode and SOA. Since benefits and costs were calculated by subtracting from each valid or invalid RT the corresponding RT in the neutral condition, they are assumed to reflect the pure effects of covert orienting, independent of the inhibitory effects of the cue that were the same in the neutral, valid and invalid conditions. Each of the four rows of histograms corresponds to a cue–target spatial combination as specified on the left: from top to bottom, SP, SF, OS, ONS. Each of the four bars in each of the 20 groups corresponds to an orienting mode as indicated on the bar top: from left to right, *sp*, *sf*, *os* and *ons*. Expected benefits are shown as black bars and expected costs are shown as gray bars. Negative values (inverted bars) correspond to actual benefits, and positive values (upright bars) correspond to actual costs. The four columns of bars on the left show benefits and costs for each SOA; the column of four groups of stippled bars on the right shows the means of benefits and costs across SOAs.



of columns. Mean scores are shown in four rows, corresponding to the cue–target spatial combinations, and four columns, corresponding to the four orienting modes. Expected or actual benefits are represented as black bars and expected or actual costs are represented as stippled bars. The rightmost part of the figure bears

out four systematic differences. First, as already shown by the previous analysis, benefits were limited to those combinations between orienting mode and cue–target spatial combination in which targets appeared at the attended location, regardless of whether the attended location was signaled by a local cue (i.e., in the SP/*sp*

Table 1. Means Across Subjects of RTs for Different Cue–Target Spatial Combinations, Orienting Modes and SOAs

	<i>SP</i>	<i>SF</i>	<i>OS</i>	<i>ONS</i>		<i>SP</i>	<i>SF</i>	<i>OS</i>	<i>ONS</i>
<i>200 msec SOA</i>					<i>600 msec SOA</i>				
sp	322	319	301	315	sp	295	306	296	303
sf	358	302	312	311	sf	341	272	311	307
os	361	325	283	295	os	349	331	260	298
ons	378	324	296	287	ons	351	328	299	256
neutral	334	293	277	282	neutral	314	289	269	266
<i>1500 msec SOA</i>					<i>5000 msec SOA</i>				
sp	288	310	312	315	sp	262	293	296	300
sf	337	275	313	313	sf	303	259	307	295
os	341	331	266	303	os	311	313	254	283
ons	348	323	302	265	ons	309	311	293	250
neutral	301	283	276	275	neutral	277	276	268	265

combination) or a distant cue (i.e., in all other combinations). Second, costs occurred in all combinations between orienting mode and cue–target spatial combination in which targets appeared at unattended locations, regardless of the spatial coincidence (first row) or noncoincidence (other three rows) of cue and target. Third, benefits and costs were slightly greater for the *SP* cue–target relation than for all other cue–target relations, in agreement with the finding in the previous ANOVA of a significantly greater invalid–valid difference for the *SP* relation than for *OS* and *ONS* relations. Fourth, for each cue–target relation, costs appeared to be greater when orienting was directed contralaterally (first and second rows, third and fourth columns; third and fourth rows, first and second columns) than ipsilaterally to the target (first row, second column; second row, first column; third row, fourth column; fourth row, third column).

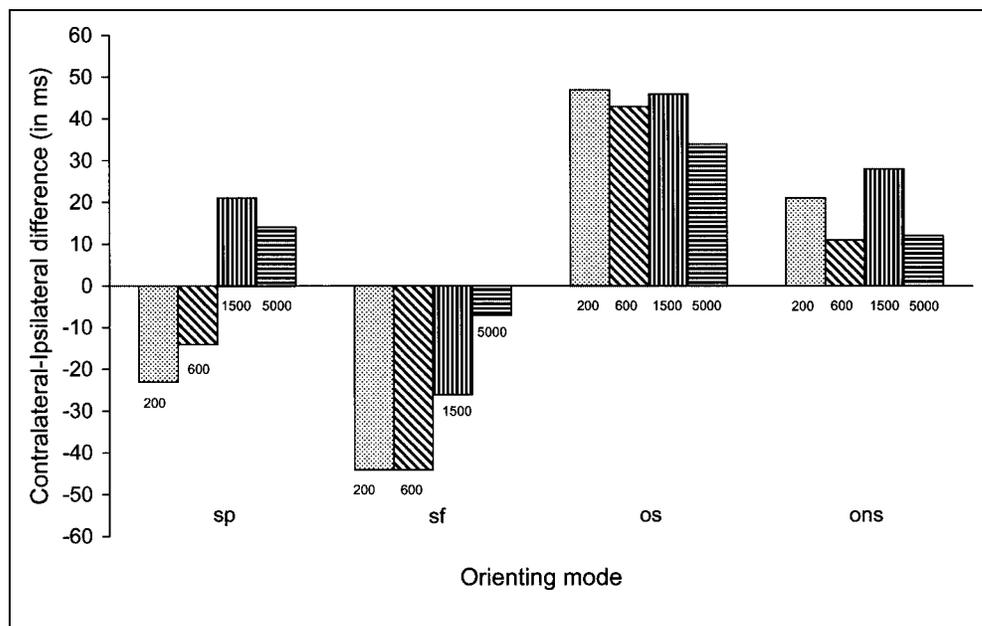
The three-way interaction between cue–target spatial combination, orienting mode and SOA is similarly decomposed in the left four groups of bars in Figure 6, which show two important features in the patterns of benefits and costs. First, at the shortest SOA, only the *SP/sp* combination produced a benefit, whereas no benefits (and actually small, insignificant costs) occurred at the other combinations in which the target appeared at the attended location. Second, at the 0.6 and 1.5 sec SOAs, the benefits were slightly greater for the *SP/sp* combination than for the other combinations, while at the 5 sec SOA benefits were equal for all combinations.

Meridian Effect of Covert Orienting

Insofar as the *sp* orienting mode involved attending to the location of the cue, the results in that orienting

mode can be compared with those obtained in previous studies of the effects of peripheral informative cues on endogenous covert orienting (Reuter-Lorenz & Fendrich, 1992; Umiltà et al., 1991). We were specifically interested in finding out whether in the *sp* orienting mode, the RT was affected differentially if orienting was misdirected to a location ipsilateral or contralateral to the target. Again, we compared the RT to the targets in medial locations when attention was in the ipsilateral lateral locations with the RT to the targets in the same locations when attention was in the medial contralateral locations. The spatial separation between target location and attended location was therefore 20° in both cases. In an ANOVA having as main factors cue–target SOA and the spatial relation between target location and attended location (ipsilateral vs. contralateral), only the interaction between the two factors was significant ($F(3,27) = 6.47, p = .02$). In particular, the contralateral–ipsilateral difference was completely insignificant (294 vs. 294.5 msec), in agreement with previous studies (Reuter-Lorenz & Fendrich, 1992; Umiltà et al., 1991). The significance of the two-way interaction is accounted for by the fact that at the two first SOAs ipsilateral RT was longer than contralateral RT, whereas at the two last SOAs the reverse was true. Invalid orienting to locations contralateral to target locations is known to produce greater costs than invalid orienting to locations ipsilateral to the target, at least with central cues (the so called meridian effect; Reuter-Lorenz & Fendrich, 1992; Umiltà et al., 1991; Rizzolatti, Riggio, Dascola, & Umiltà, 1987; Tassinari et al., 1987; Hughes & Zimba, 1985, 1987). It seems likely that with peripheral cues, the meridian effect can be masked by an opposite *SF* effect induced by the cue, at least when cue–target SOA is comparatively short.

Figure 7. Effects on invalid RTs of ipsilaterality and contralaterality of equidistant target location and locus of attention. Data are shown as differences between RTs to targets contralateral to locus of attention (henceforth called contralateral RTs) and RTs to targets ipsilateral to locus of attention (henceforth called ipsilateral RTs). Downgoing bars indicate shorter contralateral RTs compared to ipsilateral RTs, and upgoing bars indicate shorter ipsilateral RTs compared to contralateral RTs. The four groups of bars correspond to the four orienting modes, and in each group each bar corresponds to a cue-target SOA. The differences are accounted for by two opposite meridian effects, a stronger effect inhibiting responses on the side of the cue, independent of the locus of attention, and a weaker but longer lasting effect favoring ipsilateral RTs over contralateral RTs, independent of the position of the cue. In the *os* and *oms* modes, the two meridian effects add to each other, producing an ipsilateral RT advantage at all SOAs; in the *sf* mode, the strong inhibitory SP effect from the cue prevails on the meridian effect from attention at all SOAs, though the difference decreases with SOA in parallel with the attenuation of the SP effect; in the *sp* mode, the SF inhibitory effect from the cue prevails at the two first SOAs, while the meridian effect due to covert orienting prevails at the two successive SOAs.



This possibility is confirmed by similar analyses carried out in the other orienting modes, which showed that in the *os* and *oms* modes the RT was significantly longer when attention was contralateral than ipsilateral to the target at all SOAs; while in the *sf* mode, RT was significantly longer when attention was ipsilateral than contralateral to the target at the first three SOAs (see Figure 7). These results are consistent with the hypothesis that (1) covert orienting and the cue per se produce opposite meridian effects (see also Umiltà, Mucignat, Riggio, Barbieri & Rizzolatti, 1994); (2) the meridian effect from the cue, which is a SP effect in the *sf* and *os* modes and a SF effect in the *oms* mode, is greater than the meridian effect from covert orienting, though the latter effect is longer lasting; and (3) the two meridian effects detract from or add to each other depending on whether they occur on the same side or on opposite sides of fixation.

Other Effects

RT was not influenced by the right or left position, or medial or lateral position of the cue (left lateral 302.3 msec; left medial 302.8 msec; right medial 302 msec; right lateral 301.4 msec). RT was also insignificantly affected by the right or left position of the target (left 301.1 msec; right 303.1), but there was a large and significant ($p < .01$) advantage of RT to medial (291.6 msec) over lateral targets (312.6). This difference is in accord with well-known changes of RT as a function of the

retinal eccentricity of light targets (e.g., Chelazzi et al., 1988), and provides indirect evidence that subjects maintained fixation up to and during target presentation. Benefits and costs from covert orienting did not vary significantly in relation to the right or left, or medial or lateral position of either cue or target.

DISCUSSION

In the present experimental paradigm with peripheral cues and targets, RT for target detection could be affected by the cue per se, independent of intentional covert orienting, and/or by an intentional covert orienting instigated by the cue according to the instructions. The RTs of neutral trials provided evidence for the RT inhibitory effects caused by the cue in the absence of instructed intentional orienting. RT to targets in cued locations, and to a lesser degree to targets in uncued locations in the cued hemifield, was significantly longer than RT to targets in the hemifield opposite the cue. These inhibitions were maximal at the shortest SOA and much reduced, though still significant, at the longest SOA. The inhibition found at the cued locations in the neutral condition (SP cue-target relation of the present study) corresponds to the effect found in many studies by others (e.g., Taylor & Klein, 1998; Rafal & Henik, 1994; Rafal et al., 1989; Maylor, 1985; Maylor & Hockey, 1985; Posner & Cohen, 1984) and dubbed inhibition of return by Posner et al. (1985). The extension of inhibition to the noncued location in the hemifield containing

the cue replicates the effect that justifies the term ipsilateral inhibition (Berlucchi et al., 1989).

In most studies on visuospatial attention, it is customary to induce benefits and costs of intentional orienting by differentiating the frequency of target occurrence between valid and invalid locations, but in this as in a few other studies (Mangun & Buck, 1998; Walker, Kentridge, & Findlay, 1995; Tassinari et al., 1987) attentional instructions were by themselves sufficient to bring about systematic effects in the face of a completely random occurrence of targets at all possible locations. The effectiveness of our procedure for inducing intentional covert orienting was demonstrated a posteriori by the selective occurrence of benefits at the locations targeted for orienting by either local or distant cues, as well as by the occurrence of costs at all invalidly cued locations. After collapsing RTs across SOAs, benefits resulting from valid local or distant cues were indexed by significant RT decreases, and costs resulting from invalid cues were indexed by significant RT increases, compared to the corresponding neutral conditions. Meaningful information about the voluntary deployment of attention in response to the cue was provided by the temporal course of benefits from valid local and distant cues. Benefits appeared earlier at locations validly cued by local cues than at locations validly cued by distant cues (0.2 sec SOA vs. 0.6 sec SOA). This difference might have been due to an automatic attraction of attention to the cue location prior to the active orienting reaction (McCormick, 1997; Koshino, Warner, & Juola, 1992; Tepin & Dark, 1992; Müller & Rabbitt, 1989; Posner & Cohen, 1984; Jonides, 1981), to the fact that the decision to orient to the cue itself required solely a correct recognition of cue location, whereas the decision to orient to a distantly cued location additionally required an appropriate mental transposition of the perceived cue location, or more probably to a combination of both factors. If errors of orienting occurred, such errors must have been less frequent when orienting was directed at the cue location compared with other locations, since the valid–invalid difference (benefits plus costs) was significantly greater when cue and target occurred at the same location than with the other cue–target spatial combinations. The presence of equal benefits with all valid cues, whether local or distant, at the 0.6 sec SOA and at longer SOAs indicates that after making the correct orienting decision, subjects were generally able to hold attention at the chosen location for at least the duration of the longest SOA, i.e., 5 sec.

The novel and most important aspect of the results is the evidence that on valid and invalid trials alike, the location of the cue and the location ipsilateral to it were affected by an inhibition that was comparable in degree, duration and spatial organization with that seen at the corresponding locations on neutral trials. On valid trials, RT to targets in attended and locally cued locations, or attended locations ipsilateral to a cue, was systematically longer than RT to targets in attended locations contralateral to the cue.

On invalid trials, RT to targets in nonattended and locally cued locations, or nonattended locations in the cued hemifield, was systematically longer than RT to targets in nonattended locations in the noncued hemifield. All these differences between cued and uncued locations, or cued and uncued hemifields, decreased with increasing cue–target SOAs and tended to vanish at the longest SOA, in parallel with the time course of the dissipation of inhibition on neutral trials. In short, benefits from valid cues were significantly smaller, and costs from invalid cues were significantly greater in the hemifield containing the cue than in the opposite hemifield. Since these differences were almost exactly accounted for by the inhibitory effects measured in the neutral condition, we can state that benefits and costs from intentional covert orienting were additive with cue-induced effects, regardless of whether the cues were valid or invalid. This statement is not refuted by the significant interaction between cue–target spatial combination and cue validity: If one grants that a third additive factor, i.e., a greater accuracy of orienting decisions to the locally cued location than to distantly cued locations, was responsible for the comparatively greater valid–invalid difference for the spatially coincident cue–target relation, then the significant interaction appears consistent with the additive factor logic.

In their seminal study, Posner and Cohen (1984) proposed that RT facilitation and RT inhibition in simple detection tasks with peripheral noninformative cues are independent processes. According to them, facilitation would reflect a fleeting presence of attention at the cued location, while inhibition would reflect an increase in sensory threshold at the same location, making it difficult for attention to linger there. Subsequent conceptualizations of inhibition of return have, however, regarded inhibition contingent on facilitation, insofar as inhibition is thought to result from a bias against the return of attention to a recently visited location. This concept logically implies that facilitation should invariably precede inhibition at the cue location, but most studies subscribing to such concept have failed to present evidence for an early facilitation of the performance that is subsequently inhibited, so that the occurrence of facilitation is alleged rather than proven. There are, on the contrary, some direct indications that an inhibition of return may occur in the absence of a prior facilitation (Riggio, Bello, & Umiltà, 1998; Tanaka & Shimojo, 1996; Gawryszewski, Thomaz, Machado-Pinheiro, & Carreiro, 1994; Possamai, 1992; Lambert & Hockey, 1991; Posner & Cohen, 1984), or that facilitation may be a sensory effect rather than an attentional one (Maruff, Yucel, Danckert, Stuart, & Currie, 1999; Tassinari, Aglioti, Chelazzi, Peru, & Berlucchi, 1994). The present finding of a coexistence of attention and an undiminished IOR at the same location, which confirms and extends a preliminary unpublished evidence obtained by Berger and briefly reported by Rafal and Henik (1994), runs directly coun-

ter to the commonly held assumption that response slowing at a cue location is due to the absence of attention at that location. Rather, in relation to Posner and Cohen's (1984) prediction that inhibition might be counteracted by deliberately holding attention at the inhibited location, the results bear out an algebraic summation between inhibition from the cue and facilitation from directed orienting. Briefly, holding attention at the inhibited location may favor this location over other locations for speed of response, but the facilitation is comparatively smaller than that observed at attended locations that are not concurrently affected by cue-induced inhibition.

A discussion of the mechanisms that may underlie the phenomena described under the term inhibition of return, possibly ranging from changes in perceptual sensitivity to response-related processes, is beyond the scope of the present paper. We limit ourselves to state that it is quite unlikely that all such phenomena can be accounted for by a single mechanism, valiant attempts in this direction notwithstanding (Taylor and Klein, 1998). For example, it seems improbable that a single mechanism can explain the simultaneous occurrence of object-centered and space-centered inhibitions of return (Tipper et al., 1991; Tipper et al., 1994; Tipper et al., 1999) or the phenomenologically distinguishable inhibitions of return described in detection and discrimination tasks (e.g., Lupiáñez et al., 1997) and in location- and identity-based choice decision tasks (Pratt, Kingstone, & Khoe, 1997), although in all cases inhibition may favor a balanced exploration of the visual scene. If consideration is restricted to tasks involving speeded responses for the detection of luminous targets preceded by luminous cues, it seems important that inhibitory phenomena can be decomposed into those that occur at relatively short cue–target SOAs (under 0.6 sec) and those that occur at longer SOAs (over 0.6 sec). The former inhibitory phenomena can be obtained regardless of whether the inhibited location is cued singly or in association with a mirror opposite location; therefore, on the assumption that attention cannot be divided between two opposite locations (Heinze et al., 1994; Castiello & Umiltà, 1992), they do not appear to be related to lateral orienting, but rather to a reduction of visual sensitivity akin to forward masking (Tassinari & Berlucchi, 1995; Posner & Cohen, 1984). On the contrary, inhibitory phenomena observed at longer SOAs are caused by unilateral but not bilateral cuing, suggesting their dependence on a lateral orienting reaction (Tassinari & Berlucchi, 1995; Maylor, 1985). While it remains entirely possible that RT inhibition may occur at a location from which attention is withdrawn, e.g., when the eyes are moved away from that location (Spence & Driver, 1998a,b; Chelazzi et al., 1995), this was obviously not the case in the present experimental conditions, which are typical of most inhibition of return studies. We therefore submit that this term should be restricted to

those conditions in which there is proof that the decrease of performance at a location is caused by the withdrawal of attention from that location.

In conclusion, our findings are generally consistent with the notion that even in a simple light detection task, the deployment of spatial attention in the visual field calls for the operation of multiple mechanisms with conjoint facilitatory and inhibitory effects. Electrophysiological studies have shown that the mechanisms whereby reactivity to light targets is enhanced at attended locations and reduced at unattended locations are separable and functionally independent, even though they are concurrently activated by the volitional allocation of attention to a specific place (Luck, 1995). Exogenous stimulus-driven effects can add to these endogenous attentional effects, and previous investigations have emphasized the automatic facilitation that may occur at the location of a peripheral cue because of the involvement of yet another attentional mechanism (e.g., Koshino et al., 1992; Tepin & Dark, 1992; Müller & Rabbitt, 1989; Jonides, 1981). We have shown here that inhibition is an even more powerful effect of peripheral cues, because while a volitional covert orienting toward other locations can apparently suppress the automatic capture of attention by peripheral cues (Yantis & Jonides, 1990), or even reverse a movement illusion engendered by a peripheral cue (Hikosaka, Miyauchi, & Shimojo, 1993), *covert* orienting toward a peripheral cue by no means eliminates the inhibition induced by the cue per se. We have suggested that, in this case, inhibition arises because of the volitional suppression of *overt* orienting to the inhibited location, but we have direct evidence that it may also come about as a result of the withdrawal of the line of sight from a visual field region (see also Spence and Driver, 1998a; Chelazzi et al., 1995). In short, inhibition appears to affect regions of space that are actively attended but also actively vetoed to exploration by the eyegaze, or whose sampling by both attention and eyegaze has just been terminated. This would imply that cue-induced inhibition can be suppressed by a volitional *overt* orienting to the cued location, and by the maintenance of both attention and the eyegaze at this location. While this possibility remains as yet an open question, it is clearly compatible with the finding of a massive facilitation of the RT for the detection of a target at a location to which a saccade is directed (Rafal et al., 1989). Rather than being solely caused by a simple effect of retinal eccentricity, as Rafal et al. (1989) suggest, the magnitude of this facilitation can probably be accounted for by an additional suppression of IOR.

METHODS

Subjects

Seven students and three staff members of the University of Verona served as subjects. Five were males

and five females, and their ages ranged between 22 and 31. All were right handed, had normal or corrected-to-normal vision, and were experienced with RT tasks. Six of them were unaware of the purpose of the experiment.

Apparatus and Stimuli

Visual stimuli were delivered by four light-emitting diodes (LEDs, TIL 222) with round tips 0.5 cm in diameter, two of which were fastened to the right and two to the left of the midpoint of a horizontal arc perimeter. The radius of the perimeter was 57 cm and its midpoint lay 10 cm from the two nearest LEDs and 30 cm from the two farthest LEDs. The LEDs were lighted by single 15 mA square pulses of current, 5 msec in duration, which produced flashes of light with a corresponding duration and a luminance of 70 cd/m². The luminance of the background, a white screen supporting the arc perimeter, was 0.15 cd/m². The response devices were two RT button-keys, which were mounted on brass cylinders rigidly positioned in front and below the perimeter, one on the right and the other on the left. When pressed with a force of at least 60 g each key stopped an electronic msec counter. A headset driven by a pulse generator through an acoustic amplifier delivered a warning auditory signal, consisting in a 1000 Hz tone-pip having a duration of 0.1 sec and a suprathreshold but comfortable intensity.

Procedure

After placing his/her head in a chin-rest at the center of curvature of the perimeter, the subject viewed a white fixation mark on the midpoint of the perimeter and two unlit LEDs in each visual hemifield. At the viewing distance of 57 cm, the visual angle between the fixation mark and either of the nearest LEDs was 10°, while that between the fixation mark and either of the farthest LEDs was 30°. Each trial began with the warning auditory signal delivered through the headset, followed, after an interval varying randomly in a continuous manner from 1 to 3 sec, by the lighting of one LED (the cue), followed in turn, after a variable stimulus-onset-asynchrony (SOA), by the lighting of the same or another LED (the target). The SOA could take one of four values, i.e., 0.2, 0.6, 1.5 or 5 sec. Upon hearing the warning signal, the subject looked at the fixation mark and maintained fixation until the end of the trial. Eye position was monitored through a TV camera. One of the subject's forearms was placed on a rigid support, which allowed the hand to grasp the corresponding cylinder with the thumb resting on the button-key. Five subjects responded with the right hand and five with the left hand. The subject was to detect the cue without making any overt response to it, and to press

the key as fast as possible following the appearance of the target, thus stopping the msec counter that had been started simultaneously with target onset. Following a preliminary training, each subject performed on five sessions, which were run on different days, and each session included five blocks of 64 trials. In each block, cue and target appeared each 16 times in each of the four locations, and there was one trial for each of all possible combinations between cue location, target location, and SOA. The order of these combinations within each block was random, so that on each trial, cue location, target location, and SOA could not be foreseen. RT was measured to the nearest millisecond from the onset of the target to the closing of the switch by the keypressing.

At the beginning of each block, the subjects received a different instruction for allocating attention to possible target locations following cue presentation, in all cases without moving the eyes from the fixation mark. In one block, they were instructed to attend to all four locations (diffuse-attention block); in the other four blocks, they were instructed to orient covertly on each trial to a single location specified by the location of the cue on that trial. The location to be attended could or could not coincide with the location of either cue or target. Each of four covert-orienting blocks was defined by a specific orienting mode: in the *sp* (same point) orienting mode, subjects were to orient covertly to the location of the cue; in the *sf* (same field) orienting mode, they were to orient covertly to the noncued location lying in the same hemifield as the cue; in the *os* (opposite field symmetric) orienting mode, they were to orient covertly to the mirror position contralateral to the cue; and in the *ons* (opposite field nonsymmetric) orienting mode, they were to orient covertly to the nonmirror position contralateral to the cue. Thus, in the *sp* orienting mode, the location to be attended was signaled by a local cue, while in all other orienting modes the location to be attended was designated by a distant cue. Five different sequences of the different types of blocks were prepared using a Latin square design such that the position of block-type within the sequence was completely counterbalanced across sequences. Each subject followed a different block-type sequence in each session, and the order of sequences was counterbalanced across subjects and across sessions, with the constraint that each of five pairs of subjects, made up by a right-hand responder and a left-hand responder, was assigned to the same overall sequence.

The delivery of warning signal and visual stimuli, the control of the timing between warning signal, cue and target, and the measurement and recording of RTs were all performed with an all-purpose computer located in a room adjacent to the test room. The computer recorded but invalidated trials on which RTs were shorter than 150 msec or longer than 989 msec, or on which a key-

pressing had occurred in response to the cue, and replaced each invalidated trial later in the sequence until obtaining an acceptable response. Trials on which an eye shift occurred between the warning signal and the performance of the response were also discarded and replaced.

Data Analysis

Statistical analysis of RT data was carried out with ANOVAs according to a multifactor repeated-measurement design with subjects assumed to be a random-effect variable (Myers, 1979). Selected two-sample comparisons were performed by means of *t* tests for paired data, using the Bonferroni correction as appropriate in the case of multiple comparisons.

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Note

1. One might suspect that SF effect depends on the fact that on average SF targets are closer to the cues than OS and ONS targets, but in one of our previous studies, we showed that when the eccentricity of the target and the distance between the target and a noninformative cue are held constant, RT to targets preceded by ipsilateral cues is significantly longer than RT to targets preceded by contralateral cues (Berlucchi et al., 1989). In an attempt to confirm those findings, in the neutral condition we compared RT to targets at medial locations (10° from fixation) when preceded by an ipsilateral cue (30° from fixation) with RT to targets in the same locations when preceded by an equidistant contralateral cue (10° from fixation in the opposite field). Cue–target distance was therefore 20° in both cases. In an ANOVA having SOA and the relation between target location and cued location (ipsilateral vs. contralateral) as main factors, the latter factor ($F(1,9) = 18.0, p < .01$) was the only significant source of variation. In agreement with our previous findings (Berlucchi et al., 1989), RT for ipsilateral cue–target combinations (279.0 msec) was 15.4 msec longer than RT for contralateral cue–target combinations. Therefore, the ipsilateral or SF effect does not depend on the proximity between cues and targets.

REFERENCES

Abrams, R. A., & Dobkin, R. S. (1994a). Inhibition of return: Effects of attentional cuing on eye movement latencies.

- Journal of Experimental Psychology: Human Perception and Performance*, 20, 467–477.
- Abrams, R. A., & Dobkin, R. S. (1994b). The gap effect and inhibition of return: Interactive effects on eye movement latencies. *Experimental Brain Research*, 98, 483–487.
- Berlucchi, G., Biscaldi, M., Chelazzi, L., & Tassinari, G. (1988). Mechanisms of orienting in light detection. *European Journal of Neuroscience (Suppl.)*, 278.
- Berlucchi, G., Di Stefano, M., Marzi, C. A., Morelli, M., & Tassinari, G. (1981). Direction of attention in the visual field as measured by a reaction time paradigm. *Behavioural Brain Research*, 2, 244–245.
- Berlucchi, G., Tassinari, G., Marzi, C. A., & Di Stefano, M. (1989). Spatial distribution of the inhibitory effect of peripheral non-informative cues on simple reaction time to non-fixated visual targets. *Neuropsychologia*, 27, 201–221.
- Castiello, U., & Umiltà, C. (1992). Splitting focal attention. *Journal of Experimental Psychology: Human Perception and Performance*, 18, 837–848.
- Chelazzi, L., Biscaldi, M., Corbetta, M., Peru, A., Tassinari, G., & Berlucchi, G. (1995). Oculomotor activity and visual spatial attention. *Behavioural Brain Research*, 71, 81–88.
- Chelazzi, L., Marzi, C. A., Panozzo, G., Pasqualini, N., Tassinari, G., & Tomazzoli, L. (1988). Hemiretinal differences in speed of light detection in esotropic amblyopes. *Vision Research*, 28, 95–104.
- Chloessy, A. B., Posner, M. I., Rothbart, M. K., & Vecera, S. P. (1991). The development of inhibition of return in early infancy. *Journal of Cognitive Neuroscience*, 3, 345–350.
- Corbetta, M., Akbudak, E., Contuto, T. E., Snyder, A. Z., Ollinger, J. M., Drury, H. A., Linenweber, M. R., Petersen, S. E., Raichle, M. E., Van Essen, D. C., & Shulman, G. L. (1998). A common network of functional areas for attention and eye movements. *Neuron*, 2, 761, 773.
- Gawryszewski, L. G., Thomaz, T. G., Machado-Pinheiro, W., & Carreiro, L. R. (1994). Spatial distribution of the inhibition elicited by the offset of a visual cue on manual reaction time to a visual target. *Brazilian Journal of Medical and Biological Research*, 27, 75–80.
- Gibson, B. S., & Egeth, H. (1994a). Inhibition of return to object-based and environment-based locations. *Perception and Psychophysics*, 55, 323–339.
- Gibson, B. S., & Egeth, H. (1994b). Inhibition and disinhibition of return: Evidence from temporal order judgements. *Perception and Psychophysics*, 56, 669–680.
- Heinze, H.-J., Luck, S. J., Münte, T. F., Gös, A., Mangun, G. R., & Hillyard, S. A. (1994). Attention to adjacent and separate positions in space: An electrophysiological analysis. *Perception and Psychophysics*, 56, 42–52.
- Hikosaka, O., Miyauchi, S., & Shimojo, S. (1993). Voluntary and stimulus-induced attention detected as motion sensation. *Perception*, 22, 517–526.
- Hughes, H. C., & Zimba, L. D. (1985). Spatial maps of directed visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, 11, 409–430.
- Hughes, H. C., & Zimba, L. D. (1987). Natural boundaries for the spatial spread of directed visual attention. *Neuropsychologia*, 25, 5–18.
- Jonides, J. (1981). Voluntary vs. automatic control over the mind's eye movement. In J. B. Long & A. D. Baddeley (Eds.), *Attention and performance IX* (pp. 187–203). Hillsdale, NJ: Erlbaum.
- Koshino, H., Warner, C. B., & Juola, J. F. (1992). Relative effectiveness of central, peripheral, and abrupt-onset cues in visual attention. *Quarterly Journal of Experimental Psychology*, 45A, 609–631.
- Kwak, H.-W., & Egeth, H. (1992). Consequences of allocating

- attention to locations and to other attributes. *Perception and Psychophysics*, *51*, 455–464.
- Lambert, A., & Hockey, R. (1991). Peripheral visual changes and spatial attention. *Acta Psychologica*, *76*, 149–153.
- Lloyd, D. M., Bolanowski, S. J., Jr., Howard, L., & McGlone, F. (1999). Mechanisms of attention in touch. *Somatosensory and Motor Research*, *16*, 3–10.
- Luck, S. J. (1995). Multiple mechanisms of visual-spatial attention: Recent evidence from human electrophysiology. *Behavioural Brain Research*, *71*, 113–123.
- Lupiañez, J., Milán E. G., Tornay, F. J., Madrid, E., & Tudela, P. (1997). Does IOR occur in discrimination tasks? Yes, it does, but later. *Perception and Psychophysics*, *59*, 1241–1254.
- Mangun, G. R., & Buck, L. A. (1998). Sustained visual-spatial attention produces costs and benefits in response time and evoked neural activity. *Neuropsychologia*, *36*, 189–200.
- Maruff, P., Yucel, M., Danckert, J., Stuart, G., & Currie, J. (1999). Facilitation and inhibition arising from the exogenous orienting of covert attention depends on the temporal properties of spatial cues and targets. *Neuropsychologia*, *37*, 731–744.
- Maylor, E. A. (1985). Facilitatory and inhibitory components of orienting in visual space. In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance XI* (pp. 89–104). Hillsdale, NJ: Erlbaum.
- Maylor, E. A., & Hockey, R. (1985). Inhibitory component of externally controlled covert orienting in visual space. *Journal of Experimental Psychology: Human Perception and Performance*, *11*, 777–787.
- McCormick, P. A. (1997). Orienting attention without awareness. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 168–180.
- Mondor, T. A., Breau, L. M., & Milliken, B. (1998). Inhibitory processes in auditory selective attention: Evidence of location-based and frequency-based inhibition of return. *Perception and Psychophysics*, *60*, 296–302.
- Müller, H. J., & Rabbitt, P. M. A. (1989). Reflexive and voluntary orienting of visual attention: Time course of activation and resistance to interruption. *Journal of Experimental Psychology: Human Perception and Performance*, *15*, 315–330.
- Myers, J. L. (1979). *Fundamentals of experimental design*. Boston: Allyn & Bacon.
- Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*, 3–25.
- Posner, M. I. (1986). *Chronometric explorations of mind*. New York: Oxford University Press.
- Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & G. G. Bouwhuis (Eds.), *Attention and performance X* (pp. 531–556). Hillsdale, NJ: Erlbaum.
- Posner, M. I., Rafal, R. D., Choate, L. S., & Vaughan, J. (1985). Inhibition of return: Neural basis and function. *Cognitive Neuropsychology*, *2*, 211–228.
- Possamai, C.-A. (1992). The effect of a non-informative cueing signal in a three-choice reaction-time task. *Psychological Research*, *54*, 72–79.
- Pratt, J., & Abrams, R. A. (1999). Inhibition of return in discrimination tasks. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 229–242.
- Pratt, J., Kingstone, A., & Khoe, W. (1997). Inhibition of return in location- and identity-based choice decision tasks. *Perception and Psychophysics*, *59*, 964–971.
- Rafal, R. D., Calabresi, P. A., Brennan, C. W., & Sciolto, T. K. (1989). Saccade preparation inhibits reorienting to recently attended locations. *Journal of Experimental Psychology: Human Perception and Performance*, *15*, 673–685.
- Rafal, R., Egly, R., & Rhodes, D. (1994). Effects of inhibition of return on voluntary and visually guided saccades. *Canadian Journal of Experimental Psychology*, *48*, 284–300.
- Rafal, R., & Henik, A. (1994). The neurology of inhibition. Integrating controlled and automatic processes. In D. Dagenbach & T. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 1–50). San Diego, CA: Academic Press.
- Reuter-Lorenz, P. A., & Fendrich, R. (1992). Oculomotor readiness and covert orienting: Differences between central and peripheral precues. *Perception and Psychophysics*, *52*, 336–344.
- Reuter-Lorenz, P. A., Jha, A. P., & Rosenquist, J. N. (1996). What is inhibited in inhibition of return? *Journal of Experimental Psychology: Human Perception and Performance*, *22*, 367–378.
- Reuter-Lorenz, P. A., & Rosenquist, J. N. (1996). Auditory cues and inhibition of return: The importance of oculomotor activation. *Experimental Brain Research*, *112*, 119–126.
- Riggio, L., Bello, A., & Umiltà, C. (1998). Inhibitory and facilitatory effects of cue onset and offset. *Psychological Research*, *61*, 107–118.
- Riggio, L., & Kirsner, K. (1997). The relationship between central cues and peripheral cues in covert visual orientation. *Perception and Psychophysics*, *59*, 885–899.
- Rizzolatti, G., Riggio, L., Dascola, I., & Umiltà, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a premotor theory of attention. *Neuropsychologia*, *25*, 31–40.
- Rosen, A. C., Rao, S. M., Caffarra, P., Scaglioni, A., Bobholz, J. A., Woodley, S. J., Hammeke, T. A., Cunningham, J. M., Prieto, T. E., & Binder, J. R. (1999). Neural basis of endogenous and exogenous spatial orienting: A functional MRI study. *Journal of Cognitive Neuroscience*, *11*, 135–152.
- Schmidt, W. C. (1996). “Inhibition of return” without visual input. *Neuropsychologia*, *34*, 943–952.
- Sheliga, B. M., Riggio, L., & Rizzolatti, G. (1994). Orienting of attention and eye movements. *Experimental Brain Research*, *98*, 507–522.
- Sheliga, B. M., Riggio, L., & Rizzolatti, G. (1995). Spatial attention and eye movements. *Experimental Brain Research*, *105*, 271–275.
- Spence, C., & Driver, J. (1998a). Inhibition of return following an auditory cue. The role of central reorienting events. *Experimental Brain Research*, *118*, 352–360.
- Spence, C., & Driver, J. (1998b). Auditory and audiovisual inhibition of return. *Perception and Psychophysics*, *60*, 125–139.
- Tanaka, Y., & Shimojo, S. (1993). Location priming and probability priming are isolatable in detection and discrimination. *Investigative Ophthalmology and Visual Science*, *34(Suppl.)*, 1234.
- Tanaka, Y., & Shimojo, S. (1996). Location versus feature: Reaction time reveals dissociation between two visual functions. *Vision Research*, *36*, 2125–2140.
- Tassinari, G., Aglioti, S., Chelazzi, L., Marzi, C. A., & Berlucchi, G. (1987). Distribution in the visual field of the costs of voluntarily allocated attention and of the inhibitory after-effects of covert orienting. *Neuropsychologia*, *25*, 55–71.
- Tassinari, G., Aglioti, S., Chelazzi, L., Peru, A., & Berlucchi, G. (1994). Do peripheral non-informative cues induce early facilitation? *Vision Research*, *34*, 179–189.
- Tassinari, G., Aglioti, S., Chelazzi, L., Peru, A., & Berlucchi, G. (1998). On the time course of exogenous cueing effects: A response to Lupiañez and Weaver. *Vision Research*, *38*, 1625–1628.
- Tassinari, G., & Berlucchi, G. (1995). Covert orienting to non-

- informative cues: Reaction time studies. *Behavioural Brain Research*, 7, 101–112.
- Tassinari, G., Biscaldi, M., Marzi, C. A., & Berlucchi, G. (1989). Ipsilateral inhibition and contralateral facilitation of simple reaction time to non-foveal visual targets from non-informative visual cues. *Acta Psychologica*, 70, 267–291.
- Tassinari, G., & Campara, D. (1996). Consequences of covert orienting to non-informative stimuli of different modalities: A unitary mechanism? *Neuropsychologia*, 34, 235–245.
- Taylor, T. L., & Klein, R. M. (1998). On the causes and effects of inhibition of return. *Psychonomic Bulletin and Review*, 5, 625–643.
- Tepin, M. B., & Dark, V. J. (1992). Do abrupt-onset peripheral cues attract attention automatically? *Quarterly Journal of Experimental Psychology*, 45A, 111–132.
- Terry, K., Valdes, L. A., & Neill, W. T. (1994). Does “inhibition of return” occur in discrimination tasks? *Perception and Psychophysics*, 55, 279–286.
- Tipper, S. P., Driver, J., & Weaver, B. (1991). Object-centred inhibition of return of visual attention. *Quarterly Journal of Experimental Psychology*, 43A, 289–298.
- Tipper, S. P., Jordan, H., & Weaver, B. (1999). Scene-based and object-centered inhibition of return: Evidence for dual orienting mechanisms. *Perception and Psychophysics*, 61, 50–60.
- Tipper, S. P., Weaver, B., Jerreat, L. M., & Burak, A. L. (1994). Object-based and environment-based inhibition of return of visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 478–499.
- Umiltà, C., Mucignat, C., Riggio, L., Barbieri, C., & Rizzolatti, G. (1994). Programming shifts of spatial attention. *European Journal of Cognitive Psychology*, 6, 23–41.
- Umiltà, C., Riggio, L., Dascola, I., & Rizzolatti, G. (1991). Differential effects of central and peripheral cues on the reorienting of spatial attention. *European Journal of Cognitive Psychology*, 3, 247–267.
- Valenza, E., Simion, F., & Umiltà, C. (1994). Inhibition of return in newborn infants. *Infant Behaviour and Development*, 17, 293–302.
- Vaughan, J. (1984). Saccades directed at previously attended locations in space. In A. G. Gale & F. Johnson (Eds), *Theoretical and applied aspects of eye movement research* (pp.143–150). Amsterdam: North Holland.
- Walker, R., Kentridge, R. W., & Findlay, J. M. (1995). Independent contributions of the orienting of attention, fixation offset and bilateral stimulation on human saccadic latencies. *Experimental Brain Research*, 103, 294–310.
- Weaver, B., Lupiáñez, J., & Watson, F. L. (1998). The effects of practice on object-based, location-based, and static-display inhibition of return. *Perception and Psychophysics*, 60, 993–1003.
- Yamaguchi, S., & Kobayashi, S. (1998). Contributions of the dopaminergic system to voluntary and automatic orienting of visuospatial attention. *Journal of Neuroscience*, 18, 1869–1878.
- Yantis, S., & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. *Journal of Experimental Psychology: Human Perception and Performance*, 16, 121–134.