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"Ipsilateral Inhibition and Contralateral Facilitation of Simple Reaction-Time to Non-Foveal Visual Targets from Non-Informative Visual Cues"

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IPSILATERAL INHIBITION AND CONTRALATERAL FACILITATION OF SIMPLE REACTION-TIME TO NON-FOVEAL VISUAL TARGETS FROM NON-INFORMATIVE VISUAL CUES.

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Abstract

Orienting to an extrafoveal light cue without foveating it induces a temporary inhibition of responses to subsequent targets presented in the same visual hemifield, as evinced from the fact that reaction time (RT) to targets ipsilateral to the cue relative to fixation is longer than RT to targets contralateral to the cue. This study has tested the hypothesis that ipsilateral RT inhibition is associated with contralateral RT facilitation by attempting to divide the difference between ipsilateral and contralateral RTs into costs and benefits. A neutral condition suited to this purpose should involve a cue that does not require a lateral orientation. Such neutral condition was provided by measuring RT to lateralized light targets following a central overhead auditory cue (Experiment 1) or a foveal visual cue (Experiment 2). In both experiments RT in the neutral condition was intermediate between ipsilateral and contralateral RTs, and the differences reached significance in the second experiment. Benefits over the neutral condition measured in the contralateral condition were thus associated with costs in the ipsilateral condition. These results suggest that a reciprocal antagonism between opposite turning tendencies underlies the organization of covert orienting. They also agree with general multi-channel theories of selective attention according to which the facilitation of given channels is an obligatory accompaniment of the inhibition of other competing channels and viceversa.

The speed of a key-pressing response to a simple extrafoveal light target can be strongly influenced by previous positional cues that provide correct or incorrect information about the probable target location (see e.g.Posner, Nissen & Ogden, 1978; Posner, 1980; Posner, Snyder & Davidson,1980). But even when the cue has no predictive value regarding the target location, and therefore it could safely be ignored for the performance of the task, reaction time (RT) to the target varies systematically as a function of the positional relation between cue and target. In the following the cue will also be referred to as first stimulus or S1, and the target will also be referred to as second stimulus or S2.

In a typical experiment, both cue and target appear with equal and unrelated probabilities in one of two mirror-symmetric locations, one in the right visual field and the other in the left visual field. When the stimulus onset asynchrony (SOA) between cue and target is relatively brief - less than 50 ms - RT to a target spatially coincident with the cue is shorter than RT to a target opposite the cue. But when the cue-target SOA lasts more than 50 ms and up to more than 1 s, RT to targets in cued locations is considerably longer than RT to targets in uncued locations (Posner and Cohen, 1984; Maylor, 1985; Maylor and Hockey, 1985; Possamai, 1986). These opposite effects are observed in absence of ocular movements and therefore cannot be the result of overt orienting reactions of the eyes. Rather, they have been interpreted in terms of mechanisms that can shift attention across the visual field independent of eye movements. The early facilitation has been attributed to the summoning of attention to the cued location, whereas the following inhibition has been ascribed to some concomitants or consequences of the initial covert attentional orientation.

More specifically, according to Posner and Cohen (1984), Maylor (1985) and Maylor and Hockey (1985) inhibition is brought about by an automatic mechanism which by diverting attention away from a recently stimulated and/or sampled location favors the handling of new input and thus ensures a balanced reactivity to potential stimulus sources throughout the visual field. Posner and Cohen (1984) maintain that local stimulation by the cue is sufficient per se to engender a temporary inhibition of reactions to targets in the cued location, independent of orienting to them, while Maylor (1985) sees inhibition as the expression of a bias against reorienting toward a location whither attention has recently been called by local stimulation.

By using more than two stimulus locations, our own studies have shown that the prolonged inhibitory influence of a non-informative cue is by no means limited to RT for targets in cued locations (Tassinari, Aglioti, Chelazzi, Marzi & Berlucchi, 1987; Berlucchi, Tassinari, Marzi & Di Stefano, 1988). When the cue follows the target by 200-1500 ms at a widely different location but in the same visual hemifield - whether right or left, upper or lower - RT is longer than when the two stimuli appear on opposite sides of the vertical or horizontal meridian. We regard the slowing of RT to targets ipsilateral to the cue as an effect of a conflict between response tendencies. A cue appearing, say, in the right visual field naturally evokes a tendency to move the eyes toward it which must be suppressed because the experiment requires that the eyes be kept steady. Such a suppression is likely to bias temporarily the whole motor system against reacting to subsequent targets which share the same general direction as the cue, i.e. ,in our example, to targets which also appear in the right visual field: hence the increase in RT to them. This interpretation receives support from the observation that RT inhibition following an ipsilateral cue is considerably reduced when the subject is allowed to orient the eyes toward the cue (Aglioti, Chelazzi, Biscaldi, Berlucchi, Tassinari, in preparation).

One should note that the proposed conflict between the suppression of an ocular response in one direction and the execution of a manual response to a stimulus from the same direction is different from certain forms of inhibitory bias which may arise simply from the withholding of any overt response to the cue. According to Harvey (1980), refraining from making an overt response to a cue may carry over to and retard the emission of a response to a subsequent target, especially when the target can be assigned to the same category as the cue. On a spatial categorization basis, coincident or ipsilateral cues and targets have more in common than contralateral cues and targets, and therefore RT inhibition on coincident or ipsilateral cue-target combinations could be accounted for by a greater carry-over of a generic response inhibition between categorically similar than dissimilar cues and targets. However this explanation cannot be upheld since RT inhibition is still observable when the same overt response is made to both cue and target (Maylor and Hockey, 1985).

According to Posner and Cohen (1984) and Maylor (1985) RT inhibition at the recently cued location should confer an equal relative advantage to all uncued locations. Our findings point instead to a spread of inhibition to other locations in the visual hemifield containing the cue, and our directional conflict hypothesis suggests that such a hemifield inhibition may entail an actual facilitation of reactions to targets appearing in the opposite visual field (Tassinari et al, 1987; Berlucchi et al., 1988). Indeed, on a reciprocal-antagonism basis a set against emitting motor responses to stimuli from one direction in space can reasonably be expected to expedite reactions to stimuli from the opposite direction.

A generally accepted statement about selective attention is that the facilitation of the processing of the attended signals is always accompanied by costs in the processing of other signals (Keele and Neill, 1978). In this paper we examine the question of whether an inhibition of the processing of signals from a point in space is associated with a concomitant facilitation of the processing of signals from other points in space. More specifically, we have attempted to disclose a possible facilitatory effect of a visual cue on RT to subsequent targets presented in the opposite visual hemifield. All previous studies have concentrated on the effects of cues on RT to targets coincident with or ipsilateral to the cue, and have assessed such effects by taking RT to targets appearing in the visual field contralateral to the cue as the reference or baseline for comparison. The choice of a different reference is obviously necessary for evaluating the effect of the cue on RT to contralateral targets, and the following is an account of experiments directed to the solution of such a problem.

It would be inappropriate to use RT to lateralized visual targets unpreceded by cues for revealing a contralateral facilitatory counterpart to the ipsilateral inhibitory effect, because it is known that RT is generally shorter when there is only one signal than when two or more may occur. The RT to targets preceded by cues at very long cue-target SOAs would also be an inappropriate reference for assessing a facilitation of RT to targets preceded by contralateral cues at short cue/target SOAs, because cue-target SOA is per se a major determinant of RT (see e.g. Niemi and Naatanen, 1981). Rather, the term for comparison for demonstrating a contralateral RT facilitation must be provided by the RT to lateralized visual targets preceded by non-lateralized cues at cue-target SOAs equal to those used to demonstrate ipsilateral RT inhibition with lateralized cues and targets.

In Experiment 1 of this paper we have compared RT to extrafoveal visual targets preceded by coincident, ipsilateral and contralateral visual cues with RT to the same visual targets preceded by a non-positional auditory cue. The effects of the various positional relations between visual cues and visual targets were thus assessed against a standard provided by RT to visual targets following positionally neutral cues in a different modality. In Experiment 2 we have examined the relation between RT to extrafoveal targets coincident with, or ipsilateral, or contralateral to the cue and RT to the same targets preceded by a central visual cue, i.e. a cue that belongs to the same modality as the target but is neither coincident with, nor ipsilateral, nor contralateral to it. Our working hypothesis was that RT inhibition from previous cues in one visual hemifield is systematically accompanied by RT facilitation in the opposite hemifield.

Experiment 1

Generally, previous studies have contrasted conditions in which the cue covertly shifted attention toward the location of the following target with conditions in which the covert attentional shift induced by the cue was opposite in direction to target location. In most of our preceding experiments (Tassinari et al., 1987; Berlucchi et al., 1988) subjects had to press a key when seeing the second of two small light flashes, the cue or S1 and the target or S2, separated by different SOAs. Both S1 and S2 could appear at random in one of four positions along the horizontal meridian of the visual field, two on the right and two on the left of a fixation point. RT of a key-press was measured as a function of whether S1 and S2 occurred at the same position (SP combinations), or at different positions in the same field, whether right or left (SF combinations), or in opposite fields (OF combinations).

In the present experiment we introduced an additional condition whereby lateralized visual targets were preceded by cues which could be attended to without having to shift attention in visual space. This condition potentially provided a directionally neutral term of reference for evaluating the effects of covert shifts of attention toward or away from target location independently from one another. The basic plan of the experiment involved the measurement of RT on SP, SF and OF combinations, as well as of RT to visual targets presented in the same four positions but preceded by an auditory cue delivered above the center of the head. In keeping with our usual experimental paradigm, there were trials on which the cue, whether visual or auditory, had to be given attention but did not require an overt response. On these trials however there may be an unwanted difference between auditory-visual (AV) and visual-visual (VV) stimulations, insofar as intramodal combinations might conceivably be affected by the categorical response bias described by Harvey (1980) more than intermodal combinations. Therefore we also ran trials on which the same overt response was to be made to the cue, whether visual or auditory, as well as to the target, so that for the purpose of the experiment the major difference between VV and AV stimulations would hopefully reduce to the presence of directional information from the cue in the former condition and its absence in the latter condition. On the basis of previous studies on ipsilateral RT inhibition (Tassinari et al., 1987; Berlucchi et al., 1988), four values of the cue-target SOA were chosen for both AV and VV stimulations, such that ipsilateral RT inhibition, and by inference contralateral RT facilitation, could be expected at the first three SOAs but not at the fourth.

Method

Subjects. Subjects were 8 right-handed medical students, 4 females and 4 males, aged between 20 and 22, who were naive about the purpose of the experiment and all but two inexperienced with RT tasks. They received a modest fee for participating to sixteen test sessions, each of which lasted about ten minutes, plus a preliminary practice session during which they familiarized themselves with the stimuli as well as with the response instructions.

Apparatus and stimuli. Visual stimuli were delivered by four light-emitting diodes (LEDs, TIL 222) with round tips .5 cm in diameter which were fastened to a horizontal arc perimeter 57 cm in radius. The spacing between any two neighboring LEDs was 20 cm. When ignited by a 15 mA, 5 ms square pulse of current, each LED produced a flash of light with a luminance of 70 cd/sq.m. The luminance of the background, a white screen supporting the arc perimeter, was .15 cd/sq.m.

Auditory stimulation could be performed through both an earphone set and a miniature loudspeaker positioned just above the subject's vertex at a constant distance - about 1 cm - from the scalp. The earphones served to deliver a warning signal consisting of a 100 ms, 1000 Hz tone-pip. The stimulus presented through the miniature loudspeaker - a 50 ms, 3000 Hz tone-pip - constituted the auditory cue or S1. Both stimuli were amply audible but well below the threshold for acoustic discomfort.

The response devices were two button-keys for measuring RT which were mounted on brass cylinders rigidly positioned in front and below the perimeter, one on the right and the other on the left. Each key was electrically connected to its own electronic ms counter, and each counter could be stopped by pressing the corresponding key with a force of at least 60 g.

Procedure. When by using a head- and chin-rest the subject fixated the midpoint of the perimeter from a distance of 57 cm, two LEDs were in his right field and two in his left field. At such a viewing distance the visual angle between the two LEDs in each field was 20 degrees; that between the fixation point and each of the two nearest LEDs was 10 degrees. Each trial began with the warning signal delivered through the earphones, followed after an interval ranging randomly in a continuous manner from 2 to 3 s by an S1, which could be either the lighting of one LED or the tone-pip delivered trough the overhead loudspeaker, followed in turn, after a variable SOA, by an S2 which was invariably the lighting of one of the four LEDs. The SOA between S1 and S2 could take one of four values, i.e. .2, .6, 1.5 or 5 s. The warning signal told the subject to look at the fixation point, and fixation had to be maintained until the end of the trial. Eye position was monitored by an experimenter through a TV camera. The subject's forearms were placed on rigid supports which allowed each hand to grasp the corresponding cylinder with the thumb resting on the button-key. A constant part of the task consisted of pressing either the right key with the right thumb, or the left key with the left thumb, as fast as possible after seeing S2. An additional part of the task involved pressing the other key with the other thumb, or alternatively, refraining from pressing it, upon hearing or seeing S1.

Each subject was run on sixteen test sessions distributed over four days, four sessions a day. In eight sessions both S1 and S2 were visual stimuli (VV sequences). In the other eight sessions the visual S2 was preceded by an auditory S1 (AV sequences). In four VV and four AV sessions the instruction was to respond to both S1 and S2, using the right hand for S1 and the left hand for S2 in two sessions and the reverse hand arrangement in the other two sessions. In the remaining eight sessions subjects were instructed to attend to S1 but to press only in response to S2, using the right hand in two VV and two AV sessions, and the left hand in the four matching sessions. Each session consisted of 64 trials, and the interval between the end of a trial and the beginning of the next trial was about 1 s. In the VV sessions both S1 and S2 appeared 16 times in each of the four positions in a completely random fashion, and the 64 trials exhausted all possible combinations between the positions of S1 and S2 (SP, SF and OF combinations) and the four SOAs. In both VV and AV sessions S2 appeared 16 times at each of the four positions in a completely random fashion, and for each position of S2 there were four repetitions of each of the four SOA values, the SOA sequence also being completely random. The order of the sixteen sessions was counterbalanced across subjects according to a Latin square design.

The delivery of the warning signal and the stimuli, the control of the timing between the stimuli and the measurement of RTs were effected with an all-purpose computer located in a room adjacent to the test room. The computer also rejected RTs which were shorter than 150 ms or longer than 500 ms , as well as RTs which were made with the wrong hand, and replaced the corresponding trials later in the sequence. Further, prior to each session the computer displayed on the screen the specific response instructions which the subject had to read before entering the test room.

Results

In the following account we will ignore errors, anticipations and retardations because of their very low number and random distribution across different conditions. The dependent variable of primary interest was RT to S2, henceforth referred to as RT2. In each subject mean RT2 for each hand was computed across sessions for each location of S2, separately for the four SOAs and the four stimulus-response conditions. The latter corresponded to VV sequences requiring a response to S2 only, AV sequences requiring a response to S2 only, VV sequences requiring a response to both S1 and S2, AV sequences requiring a response to both S1 and S2.

In VV sequences, for each location of S2, RT2s of each hand were separated into four groups according to whether S1 had occurred at the same position (SP), at the other position in the same field (SF), or in the opposite field (OF) at a symmetric or non-symmetric position relative to S2. In AV sequences, mean RT2 for each hand of each subject was computed at each SOA for each of the four locations of S2. Since there were no systematic differences between the right and left hands in both VV and AV sequences, corresponding means for the two hands were pooled.

Consistent with a well established notion (see e.g. Haines & Gilliland, 1973), on a preliminary inspection RT2 was found to increase with the eccentricity of S2 in both VV and AV sequences, but otherwise the pattern of results was the same at each position of S2, whether medial or lateral, or right or left. The effect of the absolute position of S2 will therefore be ignored, and the description will be centered on five basic sets of data, resulting from the grouping at each SOA of mean RT2s across S2 positions and across hands of each subject as a function of S1/S2 combinations. Four sets of RTs were obtained from SP, SF, symmetric and non-symmetric OF combinations in VV sequences, whereas the fifth set of data was obtained from the AV combination. Statistical analyses were carried out on these grouped data. Further separate analyses were performed on RTs to S1 (RT1), after calculating for each subject the means across hands of RT1 at each SOA, separately for auditory and visual S1s, and pooling RTs across stimulus positions in the case of visual S1s.

VV and AV sequences without an overt response to S1. Figure 1 shows RT2 as a function of type of S1-S2 combination and SOA. Considering VV

Figure 1 about here

sequences, it can be seen that at the three first SOAs RT2 was longest on SP combinations, intermediate on SF combinations, and shortest on OF combinations. (Symmetric and non-symmetric OF combinations are collapsed in Fig.1 because they did not differ from one another). At the fourth SOA there was no clear difference between the three VV groups of RT2s. By contrast, RT2 of AV combinations was markedly shorter than RT2 of VV combinations at all SOAs. In all combinations there was a trend for RT2 to decrease as a function of increasing SOA, but while on OF and AV combinations RT2 decreased only from the first to the second SOA and then remained stable, on SP and SF combinations the shortening of RT2 with SOA was more gradual, such that on these combinations RT2 was still clearly longer at the third than the fourth SOA.

An analysis of variance using S1/S2 combination and SOA as main factors and subjects as a random factor revealed highly significant effects from both factors as well as from their interaction (S1/S2 combination: $p < .001$; SOA: $p < .005$; interaction: $p < .001$). The means across SOAs were: 348.1 ms for SP combinations, 327.2 ms for SF combinations, 311.3 ms for symmetric OF combinations, 311.4 ms for non-symmetric OF combinations, and 280.1 ms for AV combinations. All differences between S1/S2 combinations, except that between symmetric and non symmetric OF combinations, were significant (see mean differences in Table 1).

Table 1 about here

Overall mean RT was 334 ms at the first SOA, 313.9 ms at the second, 315.3 ms at the third, and 299.4 ms at the fourth. Each of the first three SOA levels differed significantly from the fourth (p(.005 in all cases), while the difference between the first and second SOA levels approached but did not reach significance (p=.06).

Table 1 presents a break-down of the data accounting for the significance of the interaction between the S1/S2 combination and the SOA. The main points of interest in this analysis are the presence of significant differences between SP, SF and OF combinations at the three first SOAs (with the single exception of the insignificant SF-OF difference at the first SOA, which however is in the right direction), but not at the fourth SOA. The SF-OF differences constitute the ipsilateral inhibitory effect.The differences between VV combinations and the AV combination were significant at all SOAs.

VV and AV sequences with a response to S1. As shown in Fig.2, the findings from VV combinations largely replicated those obtained in absence of a response to S1, but on AV combinations RT2 fell now within the range of RT2s of VV combinations, being intermediate, at the first three SOAs, between RT2 of SP combinations and that of OF combinations. An analysis of variance corresponding to that applied to the previous set of data showed significant effects for the S1/S2 combination (p(.001), SOA (p(.001) and their interaction (p(.001). The mean across SOAs of RT2 on SP combinations (318 ms) was significantly longer than RT2 of SF combinations (296.3 ms); RT2 of SF combinations (296.3) was in turn significantly longer than RT2 of OF combinations (288 ms). RT2 of the AV combination (294.3 ms) was slightly shorter than RT2 of SF combinations (296.3 ms) and longer than RT2 of OF combinations (288 ms), but both differences were completely insignificant. The values of the above differences and their statistical significances are given in Table 2.

Figure 2 about here

Overall mean RT2 was 359.4 ms at the first SOA, 284.1 ms at the second, 273.1 ms at the third, 271 ms at the fourth. The differences between RT at the first SOA and RTs at the other three SOAs, as well as the difference between the second and third SOAs, were all significant (p(.05 or less in all cases); that between the second and fourth SOAs just approached significance (p=.07). The general trend was similar to that seen when the response to S1 was withheld, but the drop from the first to the second SOA obtained when both S1 and S2 were responded too (75.3 ms) was much more pronounced than that obtained when only S2 was responded to (20.1 ms), the difference between the two drops being significant at the p(.001 level.

Table 2 shows the differences between the various S1/S2 combinations at the different SOAs. The data are generally similar to the corresponding data shown in Table 1, except for the important general lack of significant differences between AV combinations and VV combinations. Only at the two first SOAs was the RT2 of SP combinations significantly longer than that of the AV combination. At all SOAs RT2 of the AV combination was equal to or minimally shorter than that of SF combinations and longer than that of OF combinations, but all these differences were insignificant.

Table 2 about here

Figure 2 also shows RT to S1, i.e.RT1, averaged across hands and S1 positions, as a function of SOA in both VV and AV sequences. With AV sequences RT1 was produced in reaction to an auditory S1 while with VV sequences it was produced in reaction to a visual S1. The well known advantage for auditory over visual RT was confirmed by a much shorter RT1 on AV than VV sequences. The relation to SOA was similar for both sets of RT1s, the RT1 at the first SOA being significantly shorter than at the other three SOAs. Since RT1 was on the average longer than the shortest SOA, this was most probably due to a facilitatory effect of S2 on the ongoing response to S1.

Discussion

The results from VV stimulations requiring an overt response only to S2 fully agree with the recent work on the effect of prior stimulation on simple RT to localized visual stimuli as cited in the Introduction. The disadvantage for RT to cued relative to uncued locations (Posner and Cohen, 1984; Maylor, 1985; Maylor and Hockey, 1985; Possamai, 1986; Tassinari et al., 1987; Berlucchi et al., 1988) was confirmed with SOAs ranging from .2 to 1.5 s and beyond. The less pronounced and perhaps shorter but highly significant disadvantage for the cued versus uncued hemifield - the ipsilateral inhibitory effect described in our previous articles (Tassinari et al., 1987; Berlucchi et al., 1988) - was also replicated. Confirming Maylor and Hockey (1986), an essentially similar pattern of results was obtained with VV stimulations requiring the same response to both S1 and S2, consistent with the argument that visuomotor RT inhibition from cues coincident with or ipsilateral to the target cannot be accounted for by the specific response bias demonstrated in different experimental contexts by Harvey (1980).

A specific response bias of the kind described by Harvey (1980) must however have been responsible for the much longer RT on VV than AV stimulations without an overt response to S1. This difference precludes the use of RT to visual targets preceded by auditory cues as a term of reference for assessing the possible occurrence of facilitation on VV stimulations with contralateral cues and targets. In keeping with the hypothesis of a specific response bias, when the same response was made to the cue as well as to the target, RT on VV sequences was faster than when no response was made to the cue. On the contrary, making a response to an auditory cue did not speed up responses to visual targets compared to AV sequences without a response to the cue (compare Figs.1 and 2). Since RTs on AV sequences and VV sequences were thus comparable, it was possible to test for the occurrence of facilitation on OF combinations by contrasting the latter combinations with AV combinations. Facilitation would be demonstrated by a shorter RT on OF than AV combinations.

The results indicate that OF combinations had indeed RT2s shorter than AV combinations, whereas RT2 of AV combinations was in turn slightly shorter than RT2 of SF combinations, and much shorter than RT2 of SP combinations. Although suggestive of the occurrence of facilitation on OF combinations, this evidence is hardly decisive because most of the crucial differences were statistically insignificant. Since the main question addressed by the experiment, cannot be settled by these findings, it was taken up in Experiment 2, which by using non-directional visual cues was intended to allow more clear-cut conclusions.

Experiment 2

The partial failure of Experiment 1 to provide an adequate term of comparison for the demonstration of concurrent facilitatory and inhibitory effects in visuomotor RT following double stimulation may depend on a variety of factors which differentiate the set for responding to two stimuli in one modality from that for responding to two stimuli in different modalities. In the present experiment we have limited ourselves to an intramodal, exclusively visual, double stimulation paradigm and have employed an experimental design providing for five positions of a visual stimulus, four extrafoveal or peripheral

(E) and one foveal or central (C). In addition to the SP, SF and OF combinations of extrafoveal S1s and S2s described in the previous experiment, we thus had further S1/S2 combinations. S2s at extrafoveal positions could be preceded by S1s at the fovea (CE combinations), and S2s at the fovea could be preceded by S1s at extrafoveal positions (EC combinations). Further, SP combinations could include central-central (CC) and extrafoveal-extrafoveal (EE) combinations. We could thus look for differences between those conditions in which S1 was likely to demand a covert shift of attention in visual space and those in which it was not. As in Experiment 1, the first three values of the cue-target SOA were appropriate for seeing ipsilateral RT inhibition and possibly contralateral RT facilitation, while neither inhibition nor facilitation was expected to occur at the fourth SOA because of the phasic nature of the orienting reaction.

Method

Subjects. These were 8 right-handed males ranging in age from 21 to 47. They included five graduate or undergraduate students, who were unaware of the purpose of the experiment, and three of the authors. All were experienced with RT tasks.

Apparatus and stimuli. Visual stimuli were delivered by five LEDs identical with those used in Experiment 1 and attached to the same horizontal arc perimeter. One LED was positioned at the midpoint of the perimeter with two LEDs on each side. The distance between the central LED and the two nearest LEDs on both sides was 10 cm; that between the two LEDs on each side was 20 cm. The LEDs could be lighted individually as described in Experiment 1.

Auditory stimuli could be delivered through an earphone set and consisted of 100 ms , 1000 Hz tone-pips. Their intensity was comfortable but well above threshold.

The button-keys used for measuring RT and their supports were the same as in Experiment 1.

Procedure. The subject sat in a sound-proof room with the head supported by a head- and chin-rest at a distance of 57 cm from the midpoint of the perimeter. He fixated the central LED and therefore had two LEDs in his right visual field and two in his left field. Each trial consisted of a warning auditory signal, i.e. the tone-pip delivered through the earphones, followed after an interval ranging randomly in a continuous manner from 2 to 3 s by S1, i.e. the lighting of one LED, followed in turn by S2 which was again the lighting of one of the five LEDs. The SOA between S1 and S2 could take one of four values, i.e. .2, .6, 1.5 or 5 s. Upon hearing the warning signal the subject had to fixate the central LED and to remain fixated until the end of the trial. Eye position was monitored by an experimenter through a TV camera. Regardless of the position of S1 and S2, the subject had to detect S1 but refrain from making any overt response to it, and to press a key in response to S2.

Each subject completed eight experimental sessions which were run on separate days. Each session comprised 100 trials which exhausted all possible combinations between the positions of S1 and S2 and the four SOAs. In each session both S1 and S2 appeared 20 times at each of the five positions, the positions of S1 and S2 being changed from trial to trial according to two completely independent random sequences that varied from session to session. The repetitions of the four SOAs were also randomly intermixed. On each trial it was thus impossible for the subject to predict with certainty the position of either S1 or S2 and the duration of the SOA. On four sessions responses to S2 were made with the right hand, while on the other four sessions they were made with the left hand. In each subject the reponding hand was alternated from session to session, and the hand order was counterbalanced across subjects. Trials on which the subject pressed the key in response to S1, or responded less than 150 ms or more than 990 ms after S2 were aborted and replaced later in the sequence.

The delivery of the warning signal and the stimuli, the control and sequencing of the positions of S1 and S2 and the SOAs, the measurement and recording of RTs, and the rejection of unacceptable RTs were all computer-controlled.

Results

Errors of anticipation or retardation were too few to warrant analysis, but their distribution across different stimulus combinations suggested a completely random pattern. In each subject median RT was computed across sessions, separately for each hand, for each position of S2 (target) as a function of the position of S1 (cue) and the SOA. Since there was no systematic difference between RTs for the two hands, statistical analyses were performed on means across hands of median RTs.

Figure 3 about here

Figure 3 shows the means across subjects of these basic data. A similar or identical pattern is manifest at the four extrafoveal stimulus positions. At the three first SOAs (.2, .6, and 1.5 s) RT was longest on SP combinations, in which S1 and S2 occurred at the same position, and shortest on OF combinations, in which S1 and S2 occurred on opposite sides of fixation, with no obvious difference between mirror- and non-mirror symmetric positions of S1 and S2. Intermediate between RTs for SP and OF combinations were RTs for SF combinations, in which S1 and S2 occurred at different positions on the same side of fixation, and CE combinations, in which S2s at extrafoveal positions followed central S1s. However, RTs for SF combinations were consistently longer than RTs for CE combinations. Regarding responses to central S2s, at the three first SOAs RT was longer on CC combinations, in which S1 also occurred at the central position, than on EC combinations, in which S1 occurred at extrafoveal positions. All the above differences tended to diminish with increasing SOA and to disappear at the longest SOA (5 s). Also apparent from Fig.3 are additional effects of lesser importance to the study, such as the well-known increase in RT associated with the eccentricity of S2 and decrease in RT with the lengthening of SOA.

As shown by Fig.3 and confirmed by statistical analysis, the pattern of results was the same for each extrafoveal position of S2, whether right or left, medial or lateral. Therefore RTs for SP, SF, OF and CE combinations were pooled across the four extrafoveal positions at each SOA and submitted to an analysis of variance for a repeated-measures design using positional relation between S1 and S2 and SOA as main factors, and subjects as a random factor. The two possible OF combinations - mirror-symmetric and non-mirror-symmetric - were considered as one combination since in no case did they differ appreciably from one another (see Fig.4).

Figure 4 about here

The effects of both factors and their interaction were highly significant ($p<.001$ in each case). RT for SP combinations (287 ms) was significantly longer than RT for SF combinations (266 ms); in turn, RT for SF combinations (266 ms) was significantly longer than RT for CE combinations (259 ms); and RT for CE combinations (259 ms) was significantly longer than RT for OF combinations (252 ms). Overall RT decreased from 277 ms at the first SOA through 261 ms and 262 ms, at respectively the second and third SOA, to 252 ms at the last SOA, the first SOA differing significantly from all the others at at least the $p<.003$ level. The interaction between S1/S2 positional relation and SOA owed its significance to the fact that the differences between different combinations decreased with increasing SOA. These differences and their statistical significances are given in Table 3. They were significant or

Table 3 about here

approached significance at the three first SOAs but not at the last, with the exception of the SP-OF and SP-CE differences which were significant also at the fourth SOA.

A possible link between the effect of the positional relation between S1 and S2 and the physical separation between the two stimuli was considered and rejected on the basis of a separate examination of the RTs to S2s in the medial and lateral positions pooled across right and left fields. Table 4 shows that the descending order SP-SF-CE-OF was seen with S2s in both positions. When S2 occurred in the lateral positions, the descending RT order corresponded to an increasing spatial separation between S1 and S2: no separation on SP combinations, 20 degrees on SF combinations, 30 degrees on CE combinations, 40 and 60 degrees on OF combinations. This may suggest that the closer the two stimuli, the longer the RT. When however S2 occurred at the medial positions, RT for CE and each of the OF combinations was still shorter than RT for SF combinations, even though on the latter combinations the distance between S1 and S2 (20 degrees) was double that on CE combinations (10 degrees) and equal to that on mirror-symmetric OF combinations. This strongly indicates that it was the positional relation between S1 and S2, rather than their physical separation, which produced the observed RT pattern.

Table 4 about here

A second analysis of variance was carried out on RTs to S2s at the central position. Positional relation between S1 and S2 and SOA were again the main factors, both factors and their interaction yielding significant effects (positional relation: $p<.001$; SOA: $p<.05$; positional relation/SOA: $p<.001$). RT to a central S2 preceded by a central S1 (CC combination: 256.4 ms) was significantly longer than RT to a central S2 preceded by an extrafoveal S1 (EC combinations: 232 ms), regardless of whether S1 occurred on the right or left medial or lateral position. RT decreased from 248 ms at the first SOA through 233 and 237 ms at respectively the second and third SOA to 228 ms at the fourth SOA. Only the differences between the first and and second SOAs, and the first and fourth SOAs reached significance ($p=.05$ and $<.0001$, respectively).

The significance of the interaction between S1/S2 positional relation and SOA derived from the progressive decrease of the advantage for EC combinations over the CC combination with SOA, see Table 5. However this advantage was still significant at the longest SOA.

Table 5 about here

Discussion

The adoption of a neutral condition involving a central visual cue followed by extrafoveal targets afforded reasonable evidence for the occurrence of benefits - the contralateral facilitatory effect - alongside of the costs associated with the ipsilateral inhibitory effect. Compared to RT2 with central cues and extrafoveal targets, RT2 with ipsilateral extrafoveal cues and targets was longer, indicating inhibition, whereas RT2 with extrafoveal contralateral cues and targets was shorter, implying facilitation. In a previous paper (Berlucchi et al., 1988) we have described the ipsilateral effect as an inhibition irradiating in all directions from the cued location and arriving at the main meridians of the visual field without trespassing them. This description can now be complemented by the qualification that at least for the vertical meridian RT inhibition on one side of the meridian is accompanied by facilitation on the other side.

We have interpreted the ipsilateral inhibitory effect as the cost of a unidirectional shift of attention associated with an active suppression of the natural tendency to move the eyes along the same direction. The active suppression of the eye movement normally linked with the shift of attention is thought to cause a momentary interference with the motor predisposition to react to stimuli from the same direction (Tassinari et al., 1987; Berlucchi et al., 1988). The present finding of a contralateral facilitatory effect intimates that a directional attentional shift unaccompanied by a matching eye movement also entails a temporary benefit for motor reactions to stimuli which come from the opposite direction.

According to this view, the ipsilateral inhibitory effect and the contralateral facilitatory effect should thus be joint expressions of a change in the state of balance between opposing motor predispositions, one for attending and responding to stimuli from the right and the other for attending and responding to stimuli from the left. A decreased predisposition to respond to stimuli from the right should enhance responsiveness to stimuli from the left and viceversa. Similar variations in the equilibrium of mutually antagonistic influences in lateral orientation and reactivity have been postulated by Kinsbourne (1974) and attributed to shifts in relative functional dominance between the right and left cerebral hemispheres. However, there is comparable evidence for a corresponding antagonistic organization of attentional and motor predispositions in relation to the vertical dimension, such that a bias toward or against responding to stimuli in the upper visual field respectively hinders or facilitates responses to stimuli in the lower visual field, and the reverse. Such pattern of reactivity cannot be accounted for by changes in hemispheric dominance (Tassinari et al., 1987; Rizzolatti et al., 1987; Berlucchi et al., 1988).

It should be stressed at this point that at first sight some results additionally obtained in this work are embarassing for the hypothesis of RT inhibition and facilitation as indicators of a conflict between an attentional shift and a suppression of the ocular reaction naturally associated with it. In confirmation of Possamai (1986) we found that there was a lengthening of RT to targets spatially coincident with the cue even when the locus of stimulation was foveal. In these conditions there was no need to suppress a foveating ocular reaction to the cue, and therefore a motor conflict can hardly be invoked to account for the RT lengthening. One should consider however that the lengthening was assessed by reference to RT to foveal targets preceded by extrafoveal cues, and it cannot be excluded that it was these reactions that were facilitated relative to those to foveal cues and targets. The suppression of an ocular orienting reaction to a peripheral target might perhaps help fixation, thereby enhancing attention to the fovea and facilitating resposes to targets presented to it. Another possibility is that reactions to coincident cues and targets at the fovea suffer from local adaptation at the retina. These possibilities require additional experimental tests which are being dealt with elsewhere (Tassinari, Biscaldi, Di Stefano, Berlucchi, in preparation).

General Discussion

The results bear on the main theoretical issue of the relationships between attention and the integrative mechanisms for dealing with successive signals that are separated by short intervals. Broadly speaking, a signal may affect the processing of another closely following signal in three main ways. First, the prior signal may have a generalized and unspecific influence on the overall reactivity to any ensuing signal, for example by modulating the current state of arousal or alertness. Second, the first signal may provide correct or incorrect information about one or more of the properties of the subsequent signal, such as for example place and time of occurrence, thereby selectively predisposing the subject toward the emission of specific responses to the expense of other competing responses. Third, both signals may engage a common decision mechanism with limited capacity, with a resulting interference between the processing of the first signal and that of the second at one or more stages of the reaction process, from stimulus reception to response execution. These three forms of interaction in the processing of consecutive signals possibly correspond to the main components of attention delineated by Posner and Boies (1971): alertness, selectivity (i.e.specific expectancy), and processing capacity. It seems clear that in most cognitive processes such attentional components are bound to co-exist in varying degrees of respective importance and reciprocal interdependence (Posner and Boies, 1971).

In double-stimulation experiments the alertness factor is usually equated across conditions by providing an additional warning signal which in all cases prompts the subject to attend to the sequence of the cue signal and the target signal. Experiments of this kind in which the first signal is devised to supply valid or invalid information about the second signal have emphasized a multiple channel model whereby selective attention is seen as a differential distribution of processing resources among various input-output channels. As a result of the instructions conveyed by the first signal, processing of the second signal is supposed to be facilitated along those channels to which attention has been directed, and inhibited along other channels which under the same conditions are actively disattended (see e.g.Keele & Neill, 1978; Posner et al., 1978). By comparison with a neutral condition in which a non-informative first signal presumably ensures a homogeneous division of attention among all input-output channels for the second signal- a condition not easy to obtain in practice (see Jonides & Mack, 1984) - the changes in processing along specifically attended and disattended channels can be analyzed quantitatively as benefits and costs (Posner, 1980; Posner et al., 1978, 1980).

Here we have been concerned with the facilitatory and inhibitory effects of first signals which in fact and by design provided no specific information, either valid or invalid, about subsequent signals. Within the tradition of the so-called psychological refractory period, the results from many double-stimulation paradigms with non-informative first stimuli have been commonly interpreted by reference to a limited central processing capacity, usually described as a single-channel

decision mechanism (see Welford, 1986). A common element of these interpretations has been the attempt to establish the existence of a fixed amount of time necessary for the first signal, whatever its physical nature and properties, to clear the decision mechanism thus freeing it for the elaboration of the second signal. However, subsequent work has shown that even when totally irrelevant for the task, the specific content of the first signal is as a rule automatically encoded so that it can affect the processing of the subsequent signal in various ways (see e.g.Neill, 1977; Harvey, 1980; Tipper & Cranston, 1985). RT to the second signal may be short or long depending on the degree of compatibility between the processing of such signal and that of the following signal, and one can therefore submit that even intentionally non-informative cues are to some extent liable to produce selective facilitation and inhibition effects, akin in kind if not in degree to those following deliberately informative and misinformative cues.

Facilitation and inhibition from informative cues are thought to be parallel processes because the enhancement of the transmission of information along specific input-output channels is bound to be accompanied by an active suppression of competing channels (Posner et al., 1978, 1980; Keele & Neill, 1978). The question raised here is whether a similar dual mechanism can be proposed for non-informative lateralized visual cues which appear to selectively affect the processing of subsequent lateralized visual targets depending on the cue-target positional relation. Granted that RT to a target coincident with or ipsilateral to a cue is inhibited (Posner & Cohen, 1984; Maylor, 1985; Maylor & Hockey, 1985; Possamai, 1986; Tassinari et al., 1987; Berlucchi et al., 1988), we asked if RT to a target opposite the cue is concurrently facilitated. The answer to this question obviously requires a standard condition with attention equally distributed among all possible input-output channels, against which the putative facilitatory and inhibitory effects may be gauged.

We have tried to secure such a condition by using non-lateralized auditory (Experiment 1) and visual (Experiment 2) cues. By reference to these supposedly neutral conditions, the occurrence of facilitation of contralateral cue-target channels in parallel with inhibition of ipsilateral cue-target channels is suggested by a cost-benefit analysis of the results of Experiment 1, and downright supported by a similar analysis of the results of Experiment 2. It is conceivable that the difference between the results of the two experiments is entirely due to the difference between the corresponding neutral conditions, the same-modality neutral condition of Experiment 2 being probably more suited to the purposes of the analysis than the different-modality neutral condition of Experiment 1. The possibility to ascertain the operation of a dual attentional mechanism, with facilitation of some channels and inhibition of other channels, in double-stimulation paradigms with non-informative but biasing cues will ultimately depend on the availability of appropriate non-informative and non-biasing cues (Jonides & Mack, 1984). For the moment, it seems safe to conclude that by comparison with central non-informative visual cues, lateralized non-informative visual cues inhibit RT to ipsilateral visual targets and facilitate RT to contralateral visual targets.

The above pattern of results is not consistent with the assumption implicit in the arguments of Posner and Cohen (1984), Maylor (1985) and Maylor and Hockey (1986) that reduced reactivity to a recently stimulated visual field location must go along with a relative enhancement of responsiveness to all other visual field locations. While the focal limitation of inhibition to the locus of stimulation has already been ruled out by our finding of an extension of the inhibitory effect to a whole hemifield (Tassinari et al., 1987; Berlucchi et al., 1988), the present results point to a concomitant facilitation affecting the opposite hemifield. This hemifield separation between facilitation and inhibition from non-informative cues bears an at least partial resemblance with the spatial distribution of the costs and benefits resulting from the deliberately cued allocation of attention to an extrafoveal location (Hughes & Zimba, 1985, 1987; Tassinari et al., 1987; Rizzolatti et al., 1987). We believe that the attentional mechanisms underlying all these phenomena are better explained by the interaction of response tendencies aroused by cues and targets (Tassinari et al., 1987) than by the hypothesis of an orientable attentional spotlight enhancing the intake of information from locations within its circumscribed field of action (Posner, 1980). Certainly visual spatial attention must involve the selection of stimuli from the environment for detailed analysis as well as of motor preparations for emitting appropriate responses (Goldberg & Segraves, 1987). Our present understanding of the shifts of attention in visual space is at best of a very crude nature, and further examinations of the attentional control of visuomotor behavior in different experimental contexts are undoubtedly required for arriving at firmer conclusions (Eriksen & Murphy, 1987).

Experiment 1 - Differences between RTs to S2 after a response to S1 for different cue-target combinations at each SOA. In brackets: number of subjects (out of 8) showing the difference.

SOA (seconds)

	.2	.6	1.5	5.0	Mean
	Difference in milliseconds				
SP RT minus SF RT	34.8**	36.2**	12.0*	.2	21.7**
	(7)	(8)	(7)	(4)	(8)
SF RT minus AV RT	5.2	-1.4	.4	3.7	2.0
	(5)	(3)	(5)	(6)	(4)
AV RT minus OF RT#	.3	19.1	5.8	.3	6.3
	(3)	(5)	(4)	(5)	(5)
SP RT minus AV RT	43.6**	34.8**	12.4	3.9	23.7**
	(8)	(8)	(6)	(4)	(8)
SF RT minus OF RT#	5.5	17.7*	6.2*	4.0	8.3**
	(5)	(8)	(7)	(6)	(8)
SP RT minus OF RT#	43.9**	53.9**	10.2**	4.2	30.0**
	(8)	(8)	(8)	(4)	(8)

SP = same position; SF = same field; OF = opposite field; AV = audio-visual sequences; SOA = stimulus onset asynchrony

* significantly different from 0 at p<.05 (one-sample t-test)

** significantly different from 0 at p<.01 (one-sample t-test)

mean of the two OF combinations

Experiment 1 - Differences between RTs to S2 in absence of a response to S1 for different cue-target combinations at each SOA. In brackets: number of subjects (out of 8) showing the difference.

SOA (seconds)

	.2	.6	1.5	5.0	Mean
	Difference in milliseconds				
SP RT minus SF RT	31.5**	33.7*	22.0*	-3.3	20.9**
	(7)	(7)	(8)	(3)	(8)
SF RT minus AV RT	44.8**	51.1**	58.1**	34.1**	47.0**
	(8)	(8)	(8)	(8)	(8)
AV RT minus OF RT#	-34.9*	-28.9*	-32.6**	-28.6**	-31.2**
	(1)	(2)	(0)	(0)	(0)
SP RT minus AV RT	76.2**	84.8**	80.1**	30.8**	68.0**
	(8)	(8)	(8)	(7)	(8)
SF RT minus OF RT#	9.9	22.2**	25.5**	5.6	15.8**
	(5)	(8)	(7)	(5)	(8)
SP RT minus OF RT#	41.4**	55.9**	47.5**	2.3	36.7**
	(8)	(8)	(8)	(4)	(8)

SP = same position; SF = same field; OF = opposite field; AV = audio-visual sequences; SOA = stimulus onset asynchrony

* significantly different from 0 at p<.05 (one-sample t-test)

** significantly different from 0 at p<.01 (one-sample t-test)

mean of the two OF combinations

Table 3

Experiment 2 - Differences between RTs to S2 for different cue-target combinations at each SOA. In brackets: number of subjects (out of 8) showing the difference.

	SOA (seconds)				
	.2	.6	1.5	5.0	Mean
	Difference in milliseconds				
SP RT minus SF RT	38.5**	23.5**	16.9*	5.9	21.3**
	(8)	(8)	(7)	(5)	(8)
SF RT minus CE RT	9.0	10.3	4.5	4.7	7.1**
	(6)	(6)	(5)	(6)	(8)
CE RT minus OF RT	7.4	6.7	10.4*	1.5	6.5**
	(6)	(6)	(8)	(5)	(8)
SP RT minus CE RT	47.5**	33.8**	21.4*	10.6*	28.4**
	(8)	(8)	(7)	(7)	(8)
SF RT minus OF RT	16.4**	17.0*	14.9*	6.2	13.6**
	(8)	(7)	(7)	(6)	(8)
SP RT minus OF RT	54.9**	40.5**	31.8**	12.1*	34.9**
	(8)	(7)	(7)	(6)	(8)

SP = same position; SF = same field; OF = opposite field; CE = central-eccentric sequences; SOA = stimulus onset asynchrony

* significantly different from 0 at $p<.05$ (one-sample t-test)

** significantly different from 0 at $p<.01$ (one-sample t-test)

Table 4

Experiment 2 - Reaction time (averaged across SOAs) to targets in medial (above) and lateral positions (below) as a function of the positional relation between cue and target.

Targets in medial positions (means between right and left)

RT (ms)	Statistical significance of difference		
SP 272.4	SP vs SF =.02 (8)	SP vs OF <.001 (8)	SP vs CE <.001 (8)
SF 252.1	SF vs OF =.002 (8)	SF vs CE =.07 (5)	
CE 248.2	CE vs OF =.02 (6)		
OF 242.1	[in brackets: number of subjects (out of 8) showing the difference]		

Targets in lateral positions (means between right and left)

RT (ms)	Statistical significance of difference		
SP 301.3	SP vs SF =.001 (8)	SP vs OF <.001 (8)	SP vs CE <.001 (8)
SF 279.2	SF vs OF <.001 (8)	SF vs CE =.003 (7)	
CE 268.8	CE vs OF =.005 (8)		
OF 261.9	[in brackets: number of subjects (out of 8) showing the difference]		

SP = same position; SF = same field; CE = central-eccentric sequences; OF = opposite field.

Table 5

Experiment 2 - Differences between RTs to central S2s as a function of different cue-target combinations at each SOA. In brackets: number of subjects (out of 8) showing the difference.

SOA (seconds)

	.2	.6	1.5	5.0	Mean
	Difference in milliseconds				
CC RT minus EC RT	47.5**	25.9*	12.4*	14.2#	25.0**
	(8)	(8)	(7)	(7)	(8)

CC = central-central sequences; EC = eccentric-central sequences; SOA = stimulus onset asynchrony

* significantly different from 0 at p<.05 (one-sample t-test)

** significantly different from 0 at p<.01 (one-sample t-test)

# p < .06

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Figure captions

Figure 1. - Experiment 1: Reaction-time (RT) to S2 for same-position (SP), same-field (SF), pooled opposite-field (OF) and auditory-visual (AV) combinations as a function of S1-S2 SOA in absence of a response to S1.

Figure 2. - Experiment 1: Reaction-time (RT) to S2 (continuous lines) and to S1 (broken lines) as a function of S1-S2 SOA. RT to S2 (RT2) is divided into same-position (SP), same-field (SF), pooled opposite-field (OF) and auditory-visual (AV) combinations. RT to S1 (RT1) is divided into auditory-visual (AV) and visual-visual (VV) combinations.

Figure 3. - Experiment 2: Reaction-time (RT) to S2 as a function of S1-S2 SOA and positional relation between S1 and S2. The four panels correspond to the four SOAs. In each panel the five groups of bars correspond to the five positions of S2: left external (left ext.), left internal (left int.), central, right internal (right int.) and right external (right ext.). In each group of bars, the numbers 1-5 indicate the position of S1: 1=left ext., 2=left int., 3=central, 4=right int., 5=right ext. The dark bars indicate RT to S2s following S1s at the central location for each of the five locations.

Figure 4. - Experiment 2: Reaction-time (RT) to S2 for same-position (SP), same-field (SF), pooled opposite-field (OF) and central-extrafoveal (CE) combinations as a function of S1-S2 SOA.

Fig 1

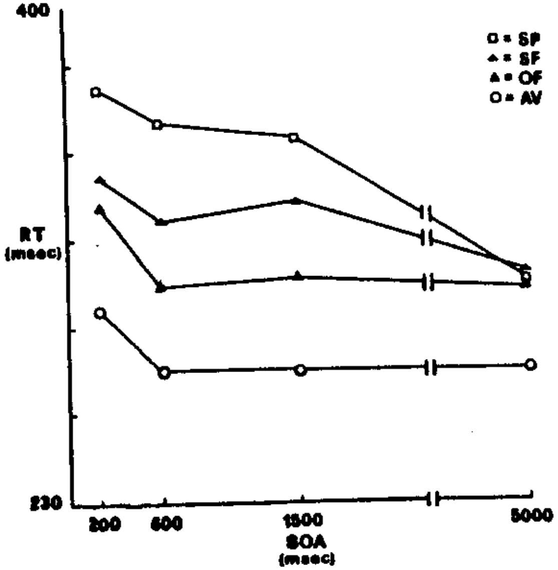


Fig 2

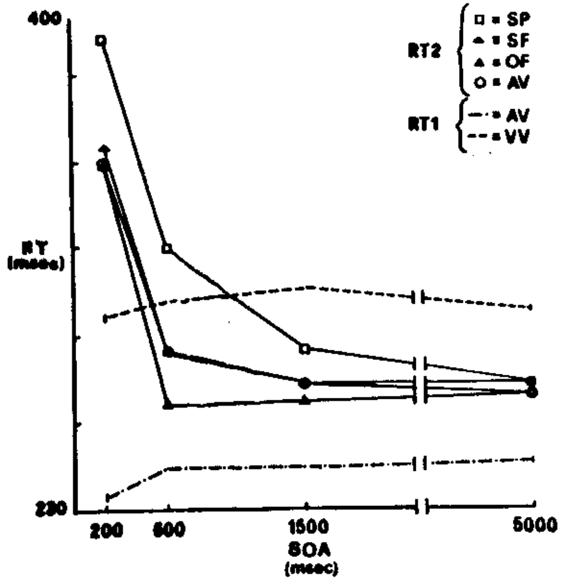


FIG 3

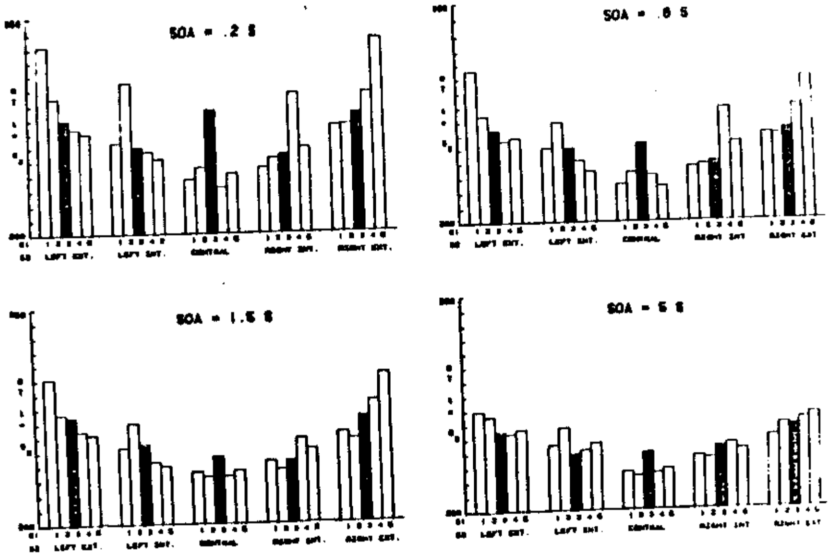
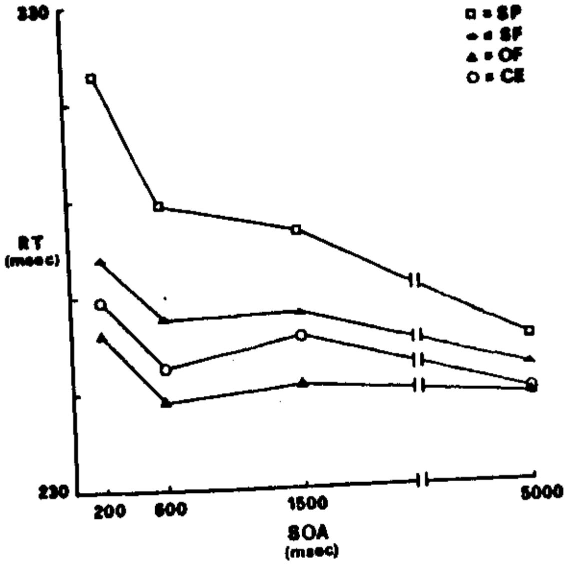

SOA = .2 S
SOA = .6 S
SOA = 1.5 S
SOA = 5 S
1 2 3 4 5
LEFT EXT.
LEFT INT.
CENTRAL
RIGHT INT.
RIGHT EXT.

FIG 4


□ = SP
◆ = SF
▲ = OF
○ = CE
330
RT
(msec)
230
200
600
1500
5000
SOA
(msec)