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"Spatial Constraints on the Distribution of Selective Attention in the Visual Field"

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SPATIAL CONSTRAINTS ON THE DISTRIBUTION OF SELECTIVE ATTENTION IN THE VISUAL FIELD

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INTRODUCTION

The term selective attention refers to those intrinsic mechanisms by which an animal becomes temporarily more reactive to some aspects of its sensory environment while at the same time its responsiveness to other components of the same environment diminishes. These opposite changes in reactivity occur both between and within sensory modalities. Selective attention is traditionally distinguished from arousal, which alludes to the modulation of the overall reactivity of the organism without selection between stimuli, and with intention, defined as the preparation to move (see Heilman, Watson, Valenstein and Goldberg, 1987). While the distinction between selective attention and arousal is necessary and feasible in both physiological and behavioral terms, the usefulness and the legitimacy of a complete conceptual separation between selective attention and intention are more questionable. Normal behavior undoubtedly suggests that in any situation the brain can choose one or more among many of its sensory inputs for further processing, as well as select one of several possible motor outputs for appropriate action. However, since the selection of a sensory input will ultimately become manifest in behavior through a motor output, one wonders whether the selection process involves a specific increase in the response of the brain sensory systems to the selected stimulus, or rather a facilitated access of the sensory activity evoked by that stimulus to the motor systems for translation into action. In the latter case the differentiation between selective attention and intention would become difficult if not downright impossible.

Inspired by an action-based view of cerebral organization for perception proposed by Sperry (1952), we have recently suggested that selective attention may be regarded as an operational adjustment of the brain which primes or facilitates all motor responses potentially triggered or guided by the selected stimulus (although the degree of facilitation may vary from one response to another), to the disadvantage or exclusion of motor reactions to other stimuli (Tassinari, Aglioti, Chelazzi, Marzi and Berlucchi, 1987). Which response is eventually emitted to the attended stimulus depends on a variety of internal and external conditions which are relevant to the responder's goals at that moment and which are too numerous and heterogeneous to be jointly categorized as "intention". For present purposes it is sufficient to say that under otherwise identical conditions the same motor response will be elicited more promptly and easily by an attended than an unattended stimulus, mainly if not exclusively because of a facilitated linkage between the sensory input representing the attended stimulus and the motor output controlling the response.

From the physiological point of view this suggestion is consonant with the notion that the limited and specific changes in neuronal activities required by a process of selective attention are seen not in primary sensory areas of the cortex, but rather in areas such as the posterior parietal cortex which can more directly channel sensory input into a variety of motor outputs (see Wurtz, Goldberg and Robinson, 1980; Heilman et al., 1987). By contrast, attention (or intention?) can be focussed at will on a single muscle by facilitation processes which are likely to occur in the primary motor cortex or even more peripherally (Gandevia and Rothwell, 1987). From the psychological point of view our suggestion is compatible with late-selection theories of attention (see e.g.Duncan, 1981), according to which attention acts not on the first level representation of the stimuli, but rather on their capacity-limited (and therefore selective) entry into a second-level representation which makes them available for conscious awareness and behavioral output.

In the following we describe and discuss the results of some experiments which bear on this issue. We will deal with a much studied form of selective attention, e.g.attention to a specific visual field location (visuospatial attention). In ordinary photopic human vision, targets of selective attention are normally processed faster and more accurately than non-attended targets mainly because they are positioned on the region of highest acuity of the retina (the fovea) by appropriate saccadic or pursuit eye movements. However, it has long been known from everyday experience, as well as from ingenious but non-systematic experimental observations made in the past century (Helmholtz, 1867), that by a conscious and voluntary effort it is possible to turn attention to any chosen portion of the entire visual field without moving the eyes to it. These anecdotal claims of a possibility to dissociate selective visuospatial attention from the direction of gaze have recently been validated with quantitative methods that allow a precise cost-benefit analysis of the effects of directed attention. The employment of the reaction time (RT) method in investigating attentional influences on both detection and discrimination of targets presented in different locations of the visual field has been particularly useful for this purpose

(Ericksen and Hoffman, 1972; Posner, 1978; Jonides, 1980). We shall concern ourselves chiefly with the attentional modulation of RT for the detection of a simple suprathreshold luminous target presented alone in a nearly empty visual field.

SPEED OF RESPONSE TO LIGHT TARGETS AS A FUNCTION OF SPATIALLY ALLOCATED ATTENTION

The pioneering experiments on this topic are those of Posner and his colleagues (see Posner, 1978, 1980; Posner, Cohen and Rafal, 1982). While maintaining fixation, subjects show decreases in reaction time (RT) for detecting targets at deliberately attended extrafoveal positions, and RT increases for targets at unattended extrafoveal positions, compared with a neutral or baseline condition in which there is no motivation or instruction to allocate attention to any specific target position. Spatial allocation of attention is controlled in these experiments by a central cue (e.g. an arrow) that precedes the target and provides valid or invalid information about the probability of target occurrence at each possible location. The probability of target occurrence is high for the cued position (e.g.80% probability of target occurrence at the position indicated by the arrow) and low for the other positions (e.g.20% altogether). The condition in which the target appears at the cued position is called valid, whereas the condition in which the target appears at non-cued positions is called invalid. In additional trials the cue is replaced by a signal (e.g. a cross) that indicates an equal probability of stimulus occurrence at all positions (neutral condition).

These findings have suggested the existence of a covert orienting mechanism that can shift the focus of attention over the visual field independent of ocular movements and can be metaphorically described as a continuously orientable spotlight (Posner, 1978, 1980). According to this view benefits from valid cues result from the spotlight being correctly aimed at the target location before the presentation of the target itself, whereas costs from invalid cues are linked with the necessary reorientation of a misdirected spotlight after target appearance. Other interpretations have instead supported the notion that spatially directed visual attention involves the total or partial concentration of processing resources at the selected visual field location, as opposed to the even distribution of resources among all possible target locations which is thought to be typical of the neutral, attentionally uncommitted state (Jonides, 1983; Eriksen and Murphy, 1987; Murphy and Eriksen, 1987). These accounts stress the advantage that directed attention may confer to performance by improving the extraction of information from the attended position, but do not consider the possibility that enhanced performance may derive from facilitated sensory-motor integration. We shall examine this possibility by assessing the spatial distribution of the costs and benefits of directed attention.

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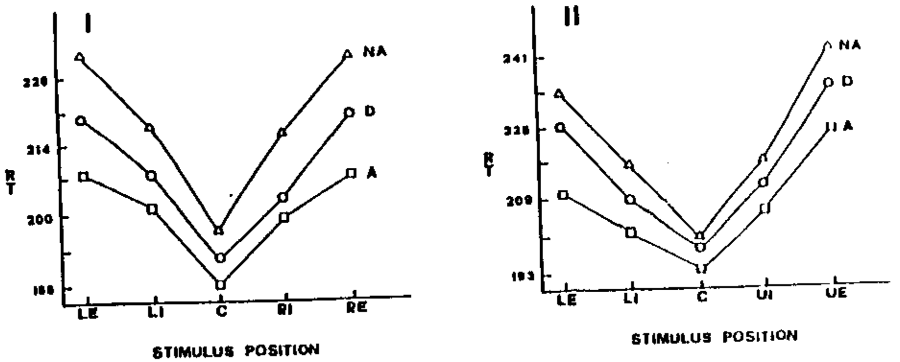
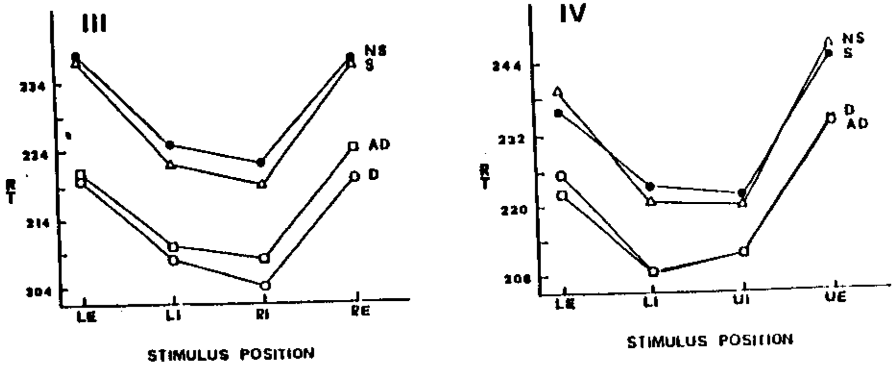


Figure 1. Benefits and costs of voluntary selective attention. Reaction time (RT, msec) is shown as a function of stimulus position and attentional condition. In I and III the stimulus array was horizontal (LE = left external position; LI = left internal position; C = central position; RI = right internal position; RE = right external position) while in II and IV it was vertical (LE = lower external position; LI = lower internal position; C = central position; UI = upper internal position; UE = upper external position). I and II show both benefits and costs of directed attention (A = attention directed to stimulated position; NA = attention directed to positions other than the stimulated position; D = diffuse attention, i.e. attention distributed among all possible positions); III and IV show a break-down of costs as a function of the positional relationship between locus of attention and target location (AD = attended location and target location are within the same hemifield; S = attended location and target location are symmetrically placed across the vertical or horizontal meridian; NS = attended location and target location are non-symmetrically placed across the vertical or horizontal meridian; D = diffuse attention). RT for the central position is not shown in III and IV. The increase in RT associated with the eccentricity of the target and the difference in RT between upper and lower fields are explained by retinal factors. Note the similarity of the patterns of costs and benefits of directed attention between horizontal and vertical arrays, and the limitation of costs to the hemifield opposite the one containing the attended location in both conditions.



SPATIAL PATTERNS OF THE EFFECTS OF DIRECTED ATTENTION

Our method for analyzing the costs and benefits of the voluntary allocation of attention to a visual field location differs in important respects from the precuing paradigm typically employed by Posner and coworkers. Their paradigm may be unnecessarily complicated, first, because on each trial the subject must interpret the cue before responding to the target, second, because sampling errors may arise from the fact that there are many more responses to attended than to unattended locations, and third, because the performance of the subject may be guided more by probabilistic operant conditioning than by a voluntary control of attention.

We studied RT for detecting small flashes of light under conditions of equal probability of stimulus occurrence at all possible locations, in the complete absence of pre-stimulus cues. There were five possible stimulus positions, aligned along either the horizontal or the vertical meridian of the visual field. One position coincided with the fixation point, while the other positions lay 10 and 30 degrees of visual angle on either side of the fixation point. The constant response task involved a speeded manual key-press to a flash of light appearing at any position; the variable attentional task changed from one block of trials to the next, with five blocks of trials requiring a deliberate and sustained allocation of attention to each of the five positions in turn, one position per block, and another block destined for an even distribution of attention among the five positions (diffuse-attention condition). Fixation of the central position was maintained troughout each trial. For each stimulus position benefits were measured as differences between median RT in the diffuse-attention condition and median RT in the attended condition; costs were measured as differences between median RT in the non-attended condition (that is when attention was directed elsewhere) and median RT in the diffuse-attention condition.

Figure 1 illustrates the main aspects of the outcome of this experiment and shows that the overall pattern of results did not depend on the horizontal or vertical alignment of the stimuli. With both stimulus arrangements we found the following:
1) all positions showed significant benefits from directed attention. These were smallest for the central position, intermediate for the intermediate position, and largest for the most peripheral position, with no significant differences in benefits between the right and left fields, and between the upper and lower fields. There was however an overall RT superiority of the lower field over the upper field;
2) when attention was allocated to an extrafoveal position (e.g. right internal or low internal), there were significant and equal costs for both positions in the opposite field (i.e. both left or both upper positions), but not for the other position in the same visual hemifield (i.e. right external or upper external);
3) paying attention to the central stimulus induced costs in all

other positions, and these were significantly greater for the more peripheral positions.

Possibly because of the elimination of the aforementioned complications implicit in the precuing technique these results compound partially contrasting findings from other cost-benefit analyses of directed attention using that technique. Thus our finding of benefits limited to the attended position agrees with Downing and Pinker (1985) and Rizzolatti, Riggio, Dascola and Umilta' (1987), but not with Hughes and Zimba (1985, 1987) who found virtually no benefits from directed attention. The finding that costs affect locations in the hemifield contralateral to the hemifield containing the attended location, but not unattended positions in the ipsilateral hemifield is in agreement with the results of Downing and Pinker (1985) and Hughes and Zimba (1985, 1987), but not with those of Rizzolatti et al. (1987) who found ipsilateral costs which however were vastly smaller than contralateral costs. Taken together all these investigations concur in supporting the claim that the main meridians of the visual field act as dividers between a homogeneous cost area and a dishomogeneous benefit area where benefits affect a restricted location rather than the entire hemifield. When cost areas and benefit areas are separated by the vertical meridian one might surmise that this spatial pattern is the result of interactions and differentiations between the activities of the two cerebral hemispheres, each of which receives its primary visual input from the contralateral visual field. However, the fact that the description of this spatial pattern applies to the right and left hemifields as much as to the upper and lower visual fields rules out the possibility of an exclusive hemispheric interpretation, since the upper and lower visual fields are represented in both hemispheres (Hughes and Zimba, 1985, 1987; Rizzolatti et al., 1987; Tassinari et al., 1987).

Our explanation of these results is as follows. When attention is selectively turned to a location, the head-start afforded to motor reactions to stimuli from that location is associated with widespread contrasting effects on allied and opposed response tendencies. Even if the response under examination is not directed in space (such as, for example, a key-press), it will nonetheless be planned and executed within a general motor set whose spatial frame of reference is the location of the attended stimulus. Responses to stimuli in non-attended locations will require a readjustment of the motor set and will be delayed in proportion to the degree of difference or incompatibility between the required motor set and the preexisting set. If for example one attends to a location in the upper visual field and a stimulus occurs at an unattended location in the lower field, the emission of a response to this stimulus will call for a time-consuming reversal of the preexisting upward directional motor bias. However, responses to stimuli at unattended locations within the upper visual field should require no directional respecification and only a vastly less time-consuming amplitude respecification of the preexisting motor set. Respecification of amplitude is indeed known to be much faster than direction respecification in programs for saccadic movements of the eyes (Hou and Fender, 1979) as well as for rapid movements of the hands (Rosenbaum, 1980). According to this view, the horizontal and vertical meridians of the visual field would serve as dividers between cost areas and benefit areas of directed attention simply because they are the main polar axes for specifying direction. This view can be examined further by analyzing the spatial distribution of the inhibitory after-effects of covert orienting.

INHIBITORY AFTER-EFFECTS OF EXTERNALLY CONTROLLED COVERT ORIENTING

In the precuing studies cited in the previous section, positional expectancies for extrafoveal target positions were induced by foveal cues that were remote from the cued positions and therefore where apt to signal them solely by reference to a predetermined system of symbolic relations connecting each cue to a specific position. Positional expectancies thus generated are thought to produce corresponding attentional shifts by a conscious and voluntary effort. The "symbolic" cues resulting in voluntary control of attention allocation have been contrasted with "spatial" cues engendering positional expectancies because of their spatial coincidence or contiguity with the cued position. It has been suggested that under these conditions attention is attracted automatically to the cued position without requiring a conscious effort of the will, and that these automatic attentional shifts can occur either overtly as orienting movements of the eyes, or covertly when eye position remains fixed. In the latter case attentional shifts should be revealed by improved detection or discrimination performance at the cued position (Jonides, 1983). Discrimination or detection of structured visual targets is indeed facilitated by spatial cues (Ericksen and Hoffman, 1972; Jonides, 1983).

However Posner and Cohen (1984), Maylor (1985) and Maylor and Hockey (1985) have reported an apparently paradoxical increase in RT (inhibition) for detecting simple luminous targets at the cued position. We have extended their results by studying the spatial spread of this inhibition in the visual field (Tassinari et al., 1987; Berlucchi, Tassinari, Marzi and Di Stefano,1988). In our experiments subjects made a speeded manual key-pressing response to the second of two successive light flashes in a pair, the cue and the target, while maintaining fixation. Each of the two flashes could appear at random in one of four positions, two in the right and two in the left visual field, or two in the upper and two in the lower visual fields. The stimulus-onset-asynchrony (SOA) between cue and target was varied randomly between 0.2 and 4 or 5 sec.

Our results confirmed the increase in RT to targets preceded by

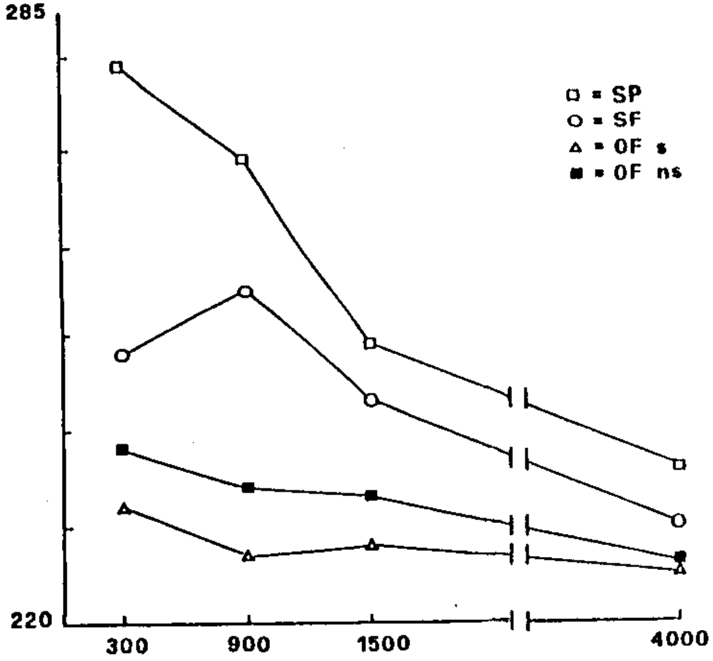


Figure 2. Reaction-time (RT, msec) to targets preceded by cues at the same position (SP), by cues at a different position within the same visual hemifield (SF) and by cues in the opposite hemifield, at a symmetrical (OF s) or non-symmetrical position (OF ns), at different cue-target SOAs (msec). Cues and targets appeared 10 or 20 degrees from the fixation point, in the right and left hemifield. At the first three SOAs RT on SP combination is significantly longer than RT for SF combinations, and this in turn is significantly longer than the RTs for the two OF combinations which do not differ from one another. From Berlucchi et al., Neuropsychologia, 1988.

a cue in the same position relative to RT to targets preceded by cues at other positions. However, our results additionally showed that inhibition affected not only targets presented at cued locations, but also targets occurring in the visual half field containing the cue. Inhibition from ipsilateral cues was long lasting since it was seen with cue-targets asynchronies ranging from 0.2 to 1.5 sec or more (Figure 2). Inhibition from ipsilateral cues occurred between right and left fields as well as between upper and lower fields, both across fixation and across points of the vertical and horizontal meridians away from fixation, and independently of the eccentricity of target and cue positions over the explored range (from 1 to 30 degrees from the main meridians). We have described this inhibition as an effect which irradiates from the cued location and arrives at the horizontal and vertical meridians without crossing them (Tassinari et al., 1987; Berlucchi et al., 1988). Thus, as in the case of deliberately allocated attention, the spatial spread of these RT effects appears to be limited by the main meridians of the visual field.

We have interpreted these effects in accord with the previously described concept of directed attention as a mechanism acting at the sensory-motor interface. Suddenly appearing extrafoveal luminous signals are strong stimuli for eliciting saccades toward their location, but this oculomotor tendency must be suppressed in experiments on covert orienting because fixation must be maintained. This suppressive action is bound to have consequences for more general motor adjustments. Important for our purposes is the directional conflict between the command that inhibits the natural ocular reaction toward a cue and the manual response to a subsequent target occurring in the same hemifield. It is conceivable that by a process of generalization in the overall motor set the oculomotor command opposing movements toward the cue can also retard manual responses to closely following targets from that same direction. Ipsilateral inhibition is a toll to be paid for being allowed to dissociate the direction of attention from the direction of gaze.

INFLUENCE OF EYE MOVEMENTS ON THE DISTRIBUTION OF ATTENTION

The essential functional significance of ocular motility is that of aligning the fovea with the focus of visuospatial attention. While, as we have seen in the foregoing, the focus of attention can shift over visual space in spite of a complete stillness of the eyes, it would seem reasonable that ocular movements cannot occur without corresponding attentional shifts. There is considerable evidence to support this association. For example, according to Posner at al. (1987) and Rafal et al. (1988) brain lesions that impair the ability to move the eyes to a target also slow down covert shifts of attention toward that target; and Shepherd, Findlay and Hockey (1986) have shown that in neurally intact subjects the preparation to make a voluntary saccadic eye movement inevitably involves the allocation of attention to the target for the saccade. In fact by facilitating motor reactions to the attended stimulus directed attention is likely to be a factor in the control of eye movements to that stimulus.

On the above assumption that attending to a stimulus at a location on, say, the right tends to facilitate responses to stimuli from other right locations as well and to inhibit responses to stimuli from the left, it can be suggested that a voluntary movement of the eyes to an extrafoveal stimulus is preceded by an attentional shift that may expedite motor responses not only toward that specific stimulus, but also toward regions of the visual space in the general direction of both stimulus and related ocular movement. Stated differently, the directional (hemifield) patterns of the spatial distribution of the costs and benefits of directed visual attention should also be apparent upon an attentional shift causing a corresponding eye movement. The development of a similar directional pattern during the programming of a saccade would strongly argue for a cause-effect link between the attentional shift and the ocular movement. This suggestion was tested in studies carried out in our laboratory on normal subjects according to the following experimental paradigm.

The task required that a voluntary saccade be made from a central fixation point toward a continuously present visual target upon hearing a 1000 Hz binaural tone delivered through earphones. In two experiments the target was to the right of the fixation point in half experimental sessions, and to the left in the other sessions. In another experiment the saccade was made to a target positioned above or below the fixation point, again in separate experimental sessions. In all cases the distance between the fixation point and the saccade target was 10 degrees of visual angle. The task also required a manual key-press immediately after seeing a small flash of light, presented at different time intervals after the auditory tone, either ipsiversively or contraversively to the direction of the saccade. Ipsiversive and contraversive were defined by reference to the current fixation point and the direction of the intended ocular movement. The eyes were to remain on the target for the saccade until after making the key-press response. The SOA between each auditory tone and the subsequent flash could randomly take one of five values: 0.1, 0.3, 0.5, 0,7 (or 0.9) and 1 (or 1.5) sec. These values were chosen on the expectation that at the first SOA (0.1 sec) the flash would appear at a time when the saccade was being programmed but had not yet begun, whereas at the other SOAs the flash would appear after the saccade had been terminated. The occurrence of ipsiversive and contraversive flashes was equiprobable, and the flash position was expected to be such that on each trial the two types of flashes would occur equidistantly from the current fixation point, i.e. the initial fixation point on the before-saccade trials and the final fixation point on the after-saccade trials. Electrophysiological monitoring of saccadic time-course through electro-oculographic recordings confirmed these expectations save for the 0.3 sec SOA at which in a non-negligible number of cases the saccadic movement had not yet been completed and thus the eyes were not yet on target. When equidistancy of ipsiversive and contraversive flashes from current fixation point was ensured, in all trials with long SOAs and in some trials with a 0.1 sec SOA the distance between the current fixation point and the flash was set at 20 degrees, so that ipsiversive flashes occurred well beyond the target for saccade; in some other trials with a 0.1 sec SOA this distance was set at 10 degrees, in which cases the position of ipsiversive flashes coincided with that of the actual saccade target.

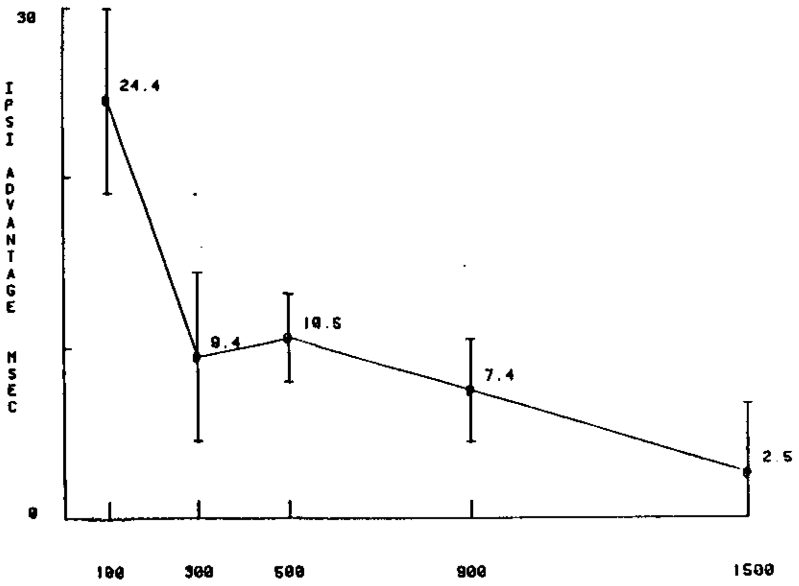


Figure 3. Advantage for ipsiversive over contraversive manual RT as a function of SOA between the command for making a saccade and target. RT and SOA in msec; vertical bars indicate standard deviations. The advantage becomes insignificant at the 900 msec SOA.

Our working hypothesis predicted that ipsiversive flashes would be consistently responded to faster than contraversive flashes, thus indicating a shift of the focus of attention in the general direction of the saccade before and after the saccade itself. The results presented in Figure 3 generally corroborate this prediction. There was a highly significant ipsiversive advantage which depended on SOA, since it was maximal at the 0.1 sec SOA and declined with increasing SOA to disappear completely at the 0.7 sec SOA in one experiment and at the 0.9 sec SOA in another. The following features of the results are most relevant to our purposes: 1) the ipsilateral advantage seen when the flash position coincided with the position of the saccade target was comparable to that seen when the flash occurred in the direction of the saccade, but well beyond its target; and 2) the pattern of results was the same regardless of the horizontal or vertical arrangement of the target array.

The fact that voluntary saccades are preceded and accompanied by changes in speed of manual responses to stimuli as a function of their position in the visual field is consistent with the idea that saccades cannot occur without a rearrangement of the spatial allocation of attention. Our results show that attention is allocated not only to the location which is the target for the saccade, but also to other locations in the general direction of the target. To the extent that an upward saccade speeds up manual responses to stimuli in the upper visual field, and a rightward saccade speeds up manual responses in the right visual field, these effects are comparable to those observed in our experiments on voluntary and externally controlled covert orienting. Our account of these effects is that an allocation of attention to a point in space - i.e. a facilitation of motor responses to stimuli from that location - precedes and plays a causal role in the generation of a voluntary saccade to that location. Both the actual eye movement and the facilitation of manual responses to stimuli in the attended location (and from points in its general direction) are expressions of the motor set which is essential to directed attention. Oculomotor readiness does not precede directed attention (see e.g.Klein, 1980) but rather is a component of it.

REFERENCES

Berlucchi, G., Tassinari, G., Marzi, C.A., and Di Stefano, M. (1988). Spatial distribution of the inhibitory effect of peripheral non-informative cues on simple reaction time to non-fixated visual targets. Neuropsychologia 26, in press.

Duncan, J. (1981). Directing attention in the visual field. Percept.Psychophys. 30 90-93.

Ericksen, C.W., and Hoffman, J.E. (1972). Some characteristics of selective attention in visual perception determined by vocal reaction time. Percept.Psychophys. 11, 169-171.

Ericksen, C.W., and Murphy, T. (1987). Movement of the attentional focus across the visual field: a critical look at the evidence. Percept.Psychophys. 42, 299-305.

Gandevia, S.C., and Rothwell, J.C. (1987). Knowledge of motor commands and the recruitment of human motoneurons. Brain 110, 1117-1130.

Heilman, K.M., Watson, R.T., Valenstein, E., and Goldberg, M.E. (1987). Attention: behavior and neural mechanisms. In Handbook of Physiology Section 1, Volume V, Part 1 (V.B.Mountcastle, F.Plum, S.R.Geiger Eds.). American Physiological Society, Bethesda.

Helmholtz, H. (1867). Handbuch der Physiologischen Optik. Voss, Leipzig.

Hou, R.L., and Fender, D.H. (1979). Processing of direction and magnitude by the saccadic eye-movement system. Vision Res. 18, 1421-1426.

Hughes, H.C., and Zimba, L.D. (1985). Spatial maps of directed visual attention. J.Exp.Psychol.: Human Percept.Perform. 11, 409-430.

Hughes, H.C., and Zimba, L.D. (1987). Natural boundaries for the spatial spread of directed visual attention. Neuropsychologia 25, 5-18.

Jonides, J. (1980). Towards a model of the mind's eye 's movements. Can.J.Psychol. 34 103-112.

Jonides, J. (1983). Voluntary versus automatic control over the mind's eye's movement. In Attention and Performance IX (J.Long and A.Baddeley Eds.). Erlbaum, Hillsdale N.J.

Klein, R. (1980). Does oculomotor readiness mediate cognitive control of visual attention? In Attention and Performance VIII (R.S.Nickerson Ed.). Erlbaum, Hillsdale N.J.

Maylor, E.A. (1985). Facilitatory and inhibitory components of orienting in visual space. In Attention and Performance XI (M.I.Posner and O.F.Marin Eds). Erlbaum, Hillsdale N.J.

Maylor, E.A. and Hockey, R. (1985). Inhibitory component of externally controlled orienting in visual space. J.Exp.Psychol.: Human Percept.Perform. 11, 777-787.

Murphy, T.D., and Ericksen, C.W. (1987). Temporal changes in the distribution of attention in the visual field in response to precues. Percept.Psychophys. 42 576-586.

Posner, M.I. (1978). Chronometric Explorations of Mind. Erlbaum, Hillsdale N.J.

Posner, M.I. (1980). Orienting of attention. Q.J.Exp.Psychol. 32, 3-25.

Posner, M.I., and Cohen,Y. Components of visual orienting. In Attention and Performance X (H.Bouma and G.G.Bouwhuis Eds.). Erlbaum, Hillsdale N.J.

Posner, M.I., Cohen, Y., and Rafal, R.D. (1982). Neural systems control of spatial orienting. Phil.Trans.R.Soc.B 298, 187-198.

Posner, M.I., Inhoff, A.W., Friedrich, F.J., and Cohen, A. (1987). Isolating attentional systems: a cognitive-anatomical analysis. Psychobiology 15 107-121.

Rafal, R.D., Posner, M.I., Friedman, J.H., Inhoff, A.W., and Bernstein, E. (1988). Orienting of attention in progressive supranuclear palsy. Brain 111 267-280.

Rizzolatti, G., Riggio, L., Dascola, I., and Umilta' C. (1987). Reorienting attention across the horizontal and vertical meridians: evidence in favor of a premotor theory of attention. Neuropsychologia 25, 31-40.

Rosenbaum, D.A. (1980). Human movement initiation: specification of arm, direction and extent. J.Exp.Psychol.: Gen. 109, 475-495.

Shepherd, M., Findlay, J.M., and Hockey, R.J. (1986). The relationship between eye movements and spatial attention. Q.J.Exp.Psychol. 38A 475-491.

Sperry, R.W. (1952). Neurology and the mind-brain problem. Am.Sci. 40, 291-312.

Tassinari, G., Aglioti, S., Chelazzi, L., Marzi, C.A., and 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.

Wurtz, R.H., Goldberg, M.E., and Robinson, D.L. (1980). Behavioral modulation of visual responses in the monkey. Progr. Psychobiol.Physiol.Psychol. 9, 43-83.