The effect of selective spatial attention on peripheral discrimination thresholds

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THE EFFECT OF SELECTIVE SPATIAL ATTENTION ON PERIPHERAL DISCRIMINATION THRESHOLDS

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Abstract

The Effect of Selective Spatial Attention on Peripheral Discrimination Thresholds

Hermann Josef Muller

Experiments were conducted to investigate the role of attention in peripheral detection and discrimination. Advance spatial cues informed subjects about likely target positions; the task required to detect/discriminate plus localise a target briefly presented at cued or uncued locations, with accuracy as the dependent variable ("cost-benefit" analysis).

Spatial cueing produced reliable advantages for cued over uncued locations, in single and in multiple element displays. However, costs plus benefits were less marked for single displays. Thus, advance knowledge of the likely target location enhances performance also when there are no competing stimuli present in the visual field. But costs plus benefits are smaller because single target onsets at uncued locations summon attention in the same "automatic" fashion as peripheral cues.

Peripheral cues trigger a rapid facilitatory component (automatic), fading out within 300 msec after cue onset. Facilitation is then maintained by a less effective mechanism (controlled). Central cues initiate only this second component. Sustained, controlled, orienting in response to central cues is interruptable by automatic orienting in response to uninformative peripheral flashes. Interruption also occurs when irrelevant flashes compete with peripheral cues. However, interference is less marked for the early automatic than for the following controlled orienting component.

Indication of a second position (four-location display) to be most likely resulted in a marked sensitivity gain for this position, relative to uncued locations in a single cue condition. That is, attention could be simultaneously shared between two cued positions. For a luminance detection task (single target), cued locations showed no advantage in sensitivity; but for letter detection tasks (target plus distractors), there was a marked priming effect. That is, letter detection is capacity limited, whereas luminance detection is not. In all tasks, decision criteria are largely preset according to a-priori target probabilities assigned to particular locations, i.e. more liberal for cued and more conservative for uncued locations.

Foreword

This thesis is subdivided into six chapters. Chapter 1 presents a general introduction into the field of spatial attention - by providing a detailed review of methods, findings and theories that are of direct relevance to the experimental work presented in the subsequent chapters. The four experimental chapters - Chapters 2 to 5 - are self-contained units which, like journal articles, present their own introduction and general discussion putting the questions investigated into the context of other work. Although this involves some repetition, the advantage is that Chapters 2 to 5 can be read independently of each other and of the general introduction. The final Chapter 6 provides a link between the experimental chapters by summarising the main findings and the central arguments of this thesis.

Section 1.11. (Chapter 1) and Chapter 6 provide the reader with an overview of the key issues investigated in this thesis. Thus, a reader with an interest in only some of these issues should start with section 1.11. or Chapter 6, providing him/her with a general orientation, and then proceed with the appropriate experimental chapter(s); knowledge of the context can be filled in by going back to the general introduction (Chapter 1) whenever required.

I would like to thank my supervisor, John Findlay, for his invaluable advice and help throughout my postgraduate

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Declaration

I hereby declare that the work in this thesis is entirely my own and that no part has been previously submitted for a degree in this or any other university.

Statement of Copyright

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1986

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CHAPTER 1

Introduction:
Selectivity for Locations in Visual Space

1.1. Spatial Attention

H.L.F. von HELMHOLTZ, in the third volume of his "Handbuch der physiologischen Optik" (1866), reported an experiment suggesting that while ocular fixation is maintained, visual attention can be focused at will on any part of the visual field and enhance the perception of objects, i.e. of the details of complex pictures, in that particular region in comparison with the nonattended parts of the visual field. He pointed out that "... in the development of a theory of attention this is one of the most striking experiments that can be made" (1925, Vol. 3, p. 455). In 1894, HELMHOLTZ published a series of experiments designed to examine these observations further:

> "I refer now to the experiments with a momentary illumination of a previously completely darkened field on which was spread a page with large printed letters. Prior to an electrical discharge (of light) the observer saw nothing but a slightly illuminated pinhole in the paper. He fixed his gaze rigidly upon it, and it served for an appropriate orientation of directions in the dark field. The electrical discharge illuminated the printed page for

an indivisible instant during which its image became visible and remained for a very short while as a positive after-image. Eye movements of a measurable magnitude could not be executed within the duration of the spark, and movements during the brief duration of the after-image could no longer change its position on the retina. Regardless of this, I found it possible to decide in advance which part of the dark field surrounding the continuously fixated pinhole of light I wanted to perceive, and then actually recognized upon the electrical illumination single groups of letters in the region of the field ... the letters of by far the largest part of the field were not perceived, not even in the vicinity of the fixation point. With a subsequent electric discharge I could direct my perception to another section of the field, while always fixating on the pinhole, and then read a group of letters there" (from WARREN and WARREN, 1968).

HELMHOLTZ's experiments can be regarded as the starting point of the more recent research on the effects of spatial attention on performance in a variety of experimental tasks. In this research, as is already evident in the work of HELMHOLTZ, spatial attention is an internal mechanism proposed to account for experimentally induced changes in performance which are difficult to explain in terms of the structure of the visual system. The dissociation between the centre of fixation and the attended region is one of the most striking observations in this context. This makes POSNER (1980) stress the importance of distinguishing "... between overt changes in orienting (the aligning of attention with a source of sensory input) that can be observed in head and eye movements, and the purely covert orienting that may be achieved by the central mechanism alone" (p. 5). Although the close relationship between eye movements and shifts of attention is not disputed, recent research indicates that despite a striking tendency to allocate attention to the target location of a saccade prior to the start of the eye movement - there has been speculation that when attention to a particular location is required an eye movement to that location is prepared ("efference readiness" hypothesis of WURTZ and MOHLER, 1976) - shifts of attention and eye movements can be decoupled by appropriate experimental manipulations (e.g., KLEIN, 1980; REMINGTON, 1980). Thus, the relationship between the attentional mechanism and the eye movement control system appears to be a functional rather than a necessary one (see also POSNER, 1980).

The principal evidence for the dissociation between the line of fixation and the line of attention is provided by studies in which subjects were induced to orient their attention to particular locations in the visual field without changing their ocular fixation. Several techniques have been used to induce attentional orienting, one of the most successful being modelled after the procedure developed by SPERLING (1960) and AVERBACH and CORIELL (1961) to study "iconic" memory. This technique involves the presentation of a spatial cue shortly before presenting the target stimuli, simultaneously with them or afterwards. The task of the subjects is to detect, discriminate or identify a stimulus at the cued location, and their performance under this condition is then compared with that when no spatial cue is provided.

Several experiments employing this technique, in particular the work of ERIKSEN and coworkers (e.g., ERIKSEN and COLEGATE, 1971; ERIKSEN and HOFFMAN, 1972, 1973, 1974; COLEGATE, HOFFMAN and ERIKSEN, 1973), demonstrated enhancement in the recognition of target stimuli at the cued locations. ERIKSEN and COLEGATE (1971) presented circular arrays of eight letters (4 upper-case characters, each presented twice, but not at adjacent locations; size of the letters: 0.2 deg.; diameter of the circle: 1.5 deg.; average exposure duration: 38 msec; no post-display masks) and asked the subjects to report the letter at the location indicated by a bar marker cue at the outer edge of the arrays. There were several cueing and associated response conditions: Single cue presented (1) 250 msec before the display, (2) simultaneously with the display and (3) 700 msec after termination of the display, and report of the letter at the cued location. ERIKSEN and COLEGATE found that advance cues were slightly more effective than simultaneous cues and these were more effective than post-display cues; recognition accuracy was 0.95 for (1), 0.87 for (2) and 0.62 for (3). In a further condition, there were two indicators that occurred simultaneously with the display at any combination of two locations, i.e. adjacent or separate, and both letters at the two cued locations had to be reported. When the two cued locations were adjacent, there was no difference in accuracy (0.80 and 0.83, respectively, for the locations reported first and second); however, when they were separate, accuracy was higher for the location reported first.

ERIKSEN and HOFFMAN (1972) presented circular arrays (diameter: 2 deg.) of 4, 8 and 12 letters and measured the vocal naming latencies for letters at cued locations under high accuracy conditions (error rate: less than 0.02); a bar marker cue appeared either 150 msec before the display or simultaneously with it. ERIKSEN and HOFFMAN found that vocal RTs were faster for cues presented in advance than for simultaneous indicators. Vocal RTs increased with increasing display size, i.e. decreasing inter-letter spacing (1.4, 0.75 and 0.57 deg.), and this increase was more marked for simultaneous than for advance cues. ERIKSEN and HOFFMAN conclude that the "... programming of which stimulus to encode is not completely effective in eliminating ... irrelevant stimuli", and they suggest to "... conceive of the selection as a focusing or narrowing in on the target element that is gradual and requires time"; indicators presented in advance allow "... the precise position in the visual field (to be) focused in upon before the display occurs" (p. 171).

COLEGATE, HOFFMAN and ERIKSEN (1973) investigated the time course of the "focusing" process by varying the interval (SOA) between the onset of the cue and of the display; the SOAs ranged from 0 (simultaneous control) to 250 msec. On trials with a bar marker cue, a dot in the centre appeared with it, and under a control condition a central dot appeared on its own ("warning" signal). Display size (which determined inter-character spacing) was either 8 or 12 letters. COLEGATE et al. found that vocal RTs decreased with increasing SOA and approached an asymptotic level depending on the inter-letter spacing; asymptote was reached at about the 150-msec SOA. In the "warning" control condition, RTs to the target letter were longer than on cued trials and decreased between the 0- and 100-msec SOAs, with the magnitude of the reduction depending on the inter-letter spacing; at the longer SOAs, RTs increased again. COLEGATE et al. conclude "... that the decrease in RT that accompanies the (bar marker) indicator cannot be attributed to a first signal effect upon RT to a following signal", since "... the shape of the function (for the warning signal) is quite dissimilar to that obtained with the (bar marker) indicator and the magnitude of the effect is much smaller". To explain the finding that the SOA at which the warning signal shows maximum facilitation (100 msec) is considerably shorter than previously found (between 200 and 500 msec according to BERTELSON, 1967, and POSNER and BOIES, 1971), COLEGATE et al. suggest that "... Since S initiated each trial by pressing a microswitch, the true warning signal may consist of some internal process associated with his decision to initiate the trial" (p. 220).

ERIKSEN and HOFFMAN (1974) repeated the experiment of COLEGATE et al. (1973), presenting SOAs between 0 and 150 msec. Unlike the previous experiments, however, the display consisted of only a single letter which was to be named. The warning signal condition failed to produce a significant reduction in RT. However, for trials with bar marker cues, RTs decreased significantly; "over half the reduction in RT ... occurs when the indicator leads the letter by only 50 msec". ERIKSEN and HOFFMAN conclude that "... attentional selectivity occurs, at least in part, by some form of signal enhancement rather than solely by noise suppression or filtering. Since the effect occurs with single letter display, there is no noise or irrelevant visual signals to inhibit or attenuate" (p. 589).

In summary, ERIKSEN and his coworkers investigated recognition accuracy and speed mainly for target characters at locations cued simultaneously or in advance by bar marker indicators; with very few exceptions (e.g., some conditions in the study of ERIKSEN and COLEGATE, 1971), performance for uncued locations was ignored. They conceive of spatial attention as a "zoom lens" with a variable focus which is "... characterized by detailed information extraction rather than high sensory resolving power" (ERIKSEN and HOFFMAN, 1973, p. 160). The diameter of the attentional focus is estimated to be about 1 deg., i.e. beyond 1 deg. the physical proximity of noise elements to the target letter has almost no effect.

1.2. Cost-Benefit Analysis

POSNER and SNYDER (1975a, 1975b) have extended this technique to a "cost-benefit" analysis which is based on the assumption of functionally independent processing systems or codes that are brought into relation through the employment of an active, limited capacity attentional mechanism. From priming studies, POSNER (1978) developed the notion of an automatic connection between a stimulus and various separable codes activated by that stimulus. Psychological pathways were defined as the set of internal codes and their connections that are activated automatically when the proper stimulus is presented.

POSNER and SNYDER presented subjects with pairs of letters and required a speeded decision whether they were the same or different. The character pair could be preceded by a prime letter which was sometimes identical to one or both members of the following pair. When the prime was identical to one of the test letters, RTs were faster than when it was not identical. In addition, the gains or "benefits" in response speed were dependent on the probabilistic "informativeness" of the prime: Gains were greater when the prime reliably indicated the following letters than when it was only rarely followed by a test pair containing the same letter. When the prime was (probabilistically) reliable, there were also losses or "costs" in response speed for a prime which was not identical to either test letter, in comparison with a condition in which there was no prime.

From the study of costs and benefits associated with the priming of a pathway, POSNER argues for the following distinction between automatic pathway activation and limited capacity attention processes: Automatic processes produce benefits without costs and occur with unreliable primes; limited capacity attention processes, however, produce both benefits and costs and require reliable primes in order to be employed. That is, automatic activation facilitates the processing of stimuli that share the same pathway without inhibitory consequences on other pathways which are activated in parallel. However, if attention is aligned with an activated pathway, both facilitation for the attended pathway and inhibition for any other pathway occur (because attention is a capacity limited).

In experiments on spatial selective attention (e.g., POSNER, NISSEN and OGDEN, 1978), the priming or cost-benefit procedure is as follows: Displays consist of several spatial locations at one of which a target stimulus can occur. At a certain time before or simultaneously with target onset, subjects are provided with a spatial cue which indicates - with a certain probability - that a target will occur at a particular location. Often, subjects are informed in advance about the frequency with which the target will appear at the cued location, and are instructed to "orient" attention on the basis of this probabilistic information. Often, there are also neutral trials on which the cue presented is only temporally, but not spatially informative, i.e. it provides information as to the time of target presentation, but not about its likely location. Performance on neutral trials provides a baseline measure against which the performance on "valid" trials, on which the target appears at the cued position, and on "invalid" trials, on which the target occurs at an uncued location, can be compared. It is expected that allocation of attention to the cued location produces facilitation ("benefits") on valid trials and inhibition ("costs") on invalid trials, relative to the baseline condition. If there are no neutral trials, the difference in performance between valid and invalid trials is used to index the effect of selective allocation of attention ("cost plus benefit" measure).

In most studies using the cost-benefit procedure the task has been simple detection of change, i.e. the simple RT to suprathreshold luminance increments in an otherwise empty field have been measured (e.g., POSNER, NISSEN and OGDEN, 1978; POSNER, SNYDER and DAVIDSON, 1980), while a few other studies used signal detection tasks with brief, near-threshold luminance increments (e.g., REMINGTON, 1980; BASHINSKI and BACHARACH, 1980). POSNER et al. (1980) state as the reason for their preference for tasks requiring simple RT to the detection of suprathreshold luminance increments: "... Detecting the presence of a clear signal in an otherwise noise-free environment is probably the simplest perceptual act of which the human is capable" and "... may (therefore) serve as an ideal model task for investigating the role of sensory and attentional factors in controlling our awareness of environmental events" (p. 160).

The studies of POSNER and coworkers demonstrated some important properties of the mechanism of spatial attention. POSNER, NISSEN and OGDEN (1978) showed that allocation of attention to the cued location (frequency of target occurrence: p = 0.8) speeds RTs to luminance increments at that position while slowing RTs to targets at the uncued location (p = 0.2), with reference to a neutral baseline condition (p = 0.5).

SHULMAN, REMINGTON and McLEAN (1979) addressed the question whether the "shift" of attention to the cued location proposed to produce this effect is a "digital" process similar to a ballistic eye movement or an "analogue" one in the sense that a shift of attention from one position to another traverses a set of intermediate positions. The display in this experiment was as follows: There were four spatial locations arranged horizontally at distances of 8 deg. (near position) and 18 deg. (far position) to the left and right of a central fixation cross. Each trial began with an arrow in the centre pointing to the left or right which instructed the subjects to shift attention to the far position on the respective side, and at varying intervals after the onset of this cue (SOA) luminance increments could occur at any of the four locations. On trials on which a detection stimulus was presented, it appeared with a probability of 0.7 at the far position of the indicated side and with a probability of 0.1 at each of the three remaining locations. On the assumption that attention is shifted in an analogue fashion across visual space, this shift would be expected to manifest itself in facilitation of simple RTs to target probes at the near position on the cued side prior to any facilitation for the far position (the "target" of the shift). In fact, the RTs for the near and far positions on the cued side, analysed as a function of SOA, showed a divergence at short and a convergence at longer SOAs, i.e. the relative advantage of the near over the far position reached a maximum at about 150 msec after cue onset and was followed by a decrease at longer SOAs (the overall advantage for the near position can be regarded as an eccentricity effect). Thus, SHULMAN et al. conclude that shifts of attention across visual space are analogue in nature.

1.3. Divisibility of Spatial Attention

The result of SHULMAN et al. (1979; see also

POSNER, 1980) suggests that attention cannot be allocated simultaneously to spatially separate locations. This question was specifically addressed by POSNER, SNYDER and DAVIDSON (1980), using the simple RT task (Experiment 5). There were four spatial locations positioned horizontally at distances of 2 deg. and 8 deg. to the left and right of a fixation mark; at the beginning of a trial a warning signal, either a plus sign or a digit from 1 to 4 indicating one of the locations from left to right, appeared in the centre of the fixation square and after variable SOAs the detection stimulus appeared. Prior to each block of trials, subjects were informed about the most likely (p = 0.65) and the second most likely (p = 0.25) target position and instructed to prepare for detection stimuli at these locations on trials (80%) when a digit, indicating the most likely target position once more, appeared as a warning signal. On trials (20%) with the plus sign as the warning signal the detection stimulus appeared equally likely at all four locations. In a further condition there were also blocks of trials on which the most likely position had a probability of target occurence of 0.64 and the three remaining locations each had probabilities of 0.12.

The results of this experiment were (1) that RTs were generally faster for the most likely and second most likely locations in comparison with the least likely positions; (2) but that the second most likely location was only faster than the least likely positions when it was adjacent to the most likely location, not when it was separated from the most likely position by one or more intermediate locations; and (3) that RTs to the detection of the target at the most likely location were not reduced by the introduction of a second most likely position (i.e., the second condition showed no RT differences for the most likely position between blocks which did or did not include a second most likely location).

It is interesting to note that POSNER et al. (1980) state as a limiting condition for their demonstration that attention cannot be effectively divided among spatial locations, the blocking of the second most likely location. In another experiment (Experiment 1), which addressed the question of experimental designs providing spatial cues on each trial versus designs in which the same location is the most likely one throughout a block of trials, POSNER et al. (1980) found that the former condition produced both significant costs and benefits in simple RTs with reference to a neutral baseline condition, whereas there was no evidence of benefits and only reduced costs under the latter condition. POSNER et al. attribute this failure of blocked designs to produce marked costs and benefits to the failure of subjects to "... continue to set themselves for the position in space at which the signal was most expected" (p. 163).

POSNER et al. (1980) conclude that for simple detection of luminance increments (and the blocking of the second most likely target position), there are "... severe limits in the ability of subjects to assign attention to a secondary focus in addition to a primary focus ... Our results suggest an attentional mechanism that cannot be allocated freely to positions in space but appears to have a central focus that may vary in size according to the requirements of the second experiment. These findings are consonant with the idea of attention as an internal eye or spotlight" (p. 171), metaphors previously used, among others, by NORMAN (1968), HOCHBERG (1968) and BROADBENT (1977; see also JONIDES, 1980).

However, there is evidence for a greater flexibility in the division of attention than has been suggested by POSNER et al. (1980). Both SHAW (1978) and JONIDES (1980), requiring a forced choice speeded response to two alternative target letters embedded in an array of distractors, found that decreasing the probabilities of target occurrence for the most likely location(s) and increasing the probabilities for the less likely locations slowed RTs for the former and speeded it for the latter positions. In SHAW's study (no exposure time constraints), error rates were less than 0.05 and did not vary systematically between the most and the less likely locations; in the study of JONIDES (25-msec exposure duration, no post-display masks), error rates were relatively high (0.11 on average) for uncued locations and showed a reduction as the probability of target occurrence increased, while they were low (0.02 on average) and quite invariant for the cued position. Both investigators concluded that, on a given trial, attention is allocated simultaneously (i.e., in parallel) to display locations according to their probabilistic priorities.

SHAW and SHAW (1977), using recognition accuracy as the dependent measure, draw the same conclusion. On a given trial, one of three alternative target letters occurred at one of 8 possible locations arranged around the circumference of an imaginary circle (1-deg. diameter); the target was the only stimulus presented, i.e. nontarget locations remained blank. Target exposure duration was 25 msec and terminated by a noise mask. In the first condition, the target occurred with equal probability at all eight locations; in the second condition, the probability of target occurence was 0.25 for the two opposite positions on the vertical axis, 0.05 for the opposite locations on the horizontal axis and 0.10 for each of the remaining locations. After providing extensive practice with these probability distributions, SHAW and SHAW found that while recognition accuracy did not differ among positions in the first condition, in the second condition accuracy was highest for the most likely, intermediate for the second most likely and lowest for the least likely locations. POSNER et al. (1980), however, point out: "... The results of Shaw and Shaw could also be obtained if subjects sometimes attend to one position in space and sometimes to another, and these probabilities match those assigned to target presentation" (p. 169).

1.4. Externally and Internally Guided Orienting of Spatial Attention

An important property of the mechanism producing shifts of attention concerns POSNER's (1980) distinction between external and internal control over (covert) orienting. That is, similar to eye movements, attention shifts can be guided either by salient stimuli in the peripheral visual field (e.g., the bar marker indicator used by ERIKSEN and coworkers), exercising reflexive, automatic control, or by voluntary control based on an internal search plan (e.g., HELMHOLTZ, 1894; in fact, except for the studies of ERIKSEN and coworkers and of JONIDES, 1980, all other studies reported so far used "symbolic" cues rather than "direct" ones). This distinction of two modes of attentional orienting has been particularly elaborated by JONIDES (1981).

Similar to his 1980-study, JONIDES presented stimulus arrays of 8 letters evenly spaced around the circumference of an imaginary circle (7.5 deg. diameter). One of the 8 stimuli was either an R or an L, the target stimuli, and subjects had to indicate (two-forced choice RT) which of the two target stimuli had been presented on a given trial. 115 msec before display onset, two types of visual cue were be presented: either an arrowhead in the periphery close to the stimulus array or an arrowhead at the fixation point in the centre of the display circle; on neutral trials a simple, spatially uninformative dot appeared in the centre. Introducing an additional memory load task (before initiating a trial subjects had to read a list of 3, 5 or 7 digits and recall them aloud in serial order), JONIDES found a significant interaction between memory load and type of cue for the difference scores ("cost plus benefit") between valid and invalid trials: While the RTs to peripheral cues were relatively unaffected by memory load, there was clear interference for the central cue (the difference scores approached zero, i.e. RT advantages of the valid over the invalid trials decreased).

In another experiment, there were two groups of subjects one of which was instructed to attend to and the other one to ignore the arrow cues (cue validity was at chance; while the "ignore" group knew about that, the "attend" group was told that cue validity was "fairly low"). The "attend" group in this experiment showed clear costs and benefits both for peripheral and for central cues; however, the "ignore" group showed this pattern only for peripheral cues, while there were no differences in RTs between valid and invalid trials for central cues.

In a third experiment, the two types of cue were presented randomly intermixed within blocks of trials. There were two groups, for one of which peripheral cues occurred in 80% of the trials and central cues in 20%; for the other group, the frequencies of central and peripheral cues were reversed (as in the first experiment, cue validity was 0.7); there were also two SOAs: 25 and 100 msec. The results were as follows: In both the 80P-20C and 20P-80C peripheral cueing conditions and, similarly, in the 20P-80C central cueing condition, RTs were faster for valid than for invalid trials and this advantage was quite invariant across SOA. But in the 80P-20C central cueing condition, at the 25-msec SOA RTs for valid and for invalid trials did not differ significantly, while at the 100-msec SOA there was an advantage for valid trials which approached that in the corresponding peripheral cueing condition. JONIDES concludes that at the short SOA, the "unexpectedness" of central cues has striking consequences for the resulting costs and benefits, while the unexpectedness of peripheral cues has no such effect; it is, however, possible to compensate for the unexpectedness of central cues given sufficient time between the cue and display onset.

It is interesting to note that in Experiment 1 and particularly in Experiment 3, RT differences between valid and invalid trials were greater for the peripheral than for the central cues; that is, the former "... are more effective in drawing attention in the sense that they produce greater costs plus benefits in processing time and accuracy than central cues" (JONIDES, 1980, p. 200). The general conclusion to be drawn from JONIDES' study is that the two types of cue differ in the degree of automaticity with which they engage the orienting mechanism; possible reasons for this difference are that (direct) peripheral cues are more precise indicators of locations in the periphery and that (symbolic) central cues require more detailed encoding (i.e., analysis of the direction they are pointing to rather than simple detection of their position).

However, this difference in automaticity appears only a gradual one. This can be concluded from JONIDES (1980) who used a peripheral arrowhead to cue the most likely target location (the cue was presented for 25 msec and followed by a "blank" interval of 50 msec before presentation of the display). The finding that costs and benefits in RTs relative to a neutral baseline decreased to nonsignficant values as cue validity decreased from 0.7 to 0.3, indicates that subjects have at least some control over the extent to which to orient attention in response to a peripheral cue.

It has been suggested (e.g., BREITMEYER and GANZ, 1976) that orienting of attention to the locus of a salient discontinuity in light energy (e.g., of a "direct" peripheral cue) is related to the special status of abrupt onsets in the visual system. It is a well known electrophysiological finding that there are two distinct classes of ganglion cells in the cat's retina: the "Y" or "transient" cells whose rate of firing is enhanced at abrupt onsets and offsets of a stimulus probe, and the "X" or "sustained" cells whose rate of firing is continuously enhanced throughout the duration of the stimulus

(ENROTH-CUGELL and ROBSON, 1966). Subsequent research has shown that transient cells, in comparison with sustained cells, have larger receptive field surrounds, are more senstive to flicker and motion, have a shorter response latency and a higher axonal conduction velocity, and that their receptive fields are more evenly distributed about the retina (while the receptive fields of sustained cells are highly concentrated in the fovea).

Correspondences have been found in studies using psychophysical procedures and human observers. KULIKOWSKI and TOLHURST (1973), measuring contrast sensitivity to sinusoidal gratings, found a marked decline in flicker sensitivity at high spatial and low temporal frequencies, while sensitivity to spatial structure declined at low spatial frequencies and showed little effect of changes in temporal modulation. KULIKOWSKI and TOLHURST concluded that there are (at least) two independent mechanisms in the visual system, one sensitive to rapid flicker and low spatial frequency and the other sensitive to visual detail and high spatial frequency. BREITMEYER and JULESZ (1975) investigated contrast sensitivity to sinusoidal gratings of abrupt or gradual onset and offset (gradual onset: 200-msec linear ramps; constant time-averaged energy of all gratings). BREITMEIER and JULESZ found that sensitivity was enhanced at low spatial frequencies (less than 5 cycles/deg.) when the onset was abrupt as compared to when it was gradual; there was little effect of offset waveform.

BREITMEIER and GANZ (1976) state that the transient system responds to abrupt changes in the periphery and thus forms "... part of an 'early warning system' that orients an organism and directs its attention to locations in visual space that potentially contain novel pattern information" (p. 31). Recently, YANTIS and JONIDES (1984) have provided a detailed investigation of whether "... isolated abrupt stimulus onsets cause a rapid and involuntary deployment of attention to the locus of the temporal discontinuity" (p. 601). YANTIS and JONIDES presented displays of either 2 or 4 letters (display size) positioned 5.7 deg. from fixation at the vertices of an imaginary hexagon. At the beginning of each trial, the target stimulus was specified (varied mapping paradigm, i.e. the letters served equally often as targets and distractors) and it could be either present or absent among the letters of the display. Before the display was presented, three premasks in the form of the digit 8, made up of line segments in right angles, appeared which were arranged in an upward-pointing equilateral triangle. 1000 msec after the onset of the premasks, irrelevant line segments faded gradually within 80 msec ("camouflage offset"). With display size 4, all three premasks changed gradually to letters; with display size 2, one changed to a lettter and the others faded to blanks. At the end of the camouflage offset, one letter was abruptly displayed at a location which had previously been blank. On 50% (display size 2) and 25% (display size 4) of the positive trials the target was the abrupt onset item. The dependent measure was forced-choice RT to the "target present - absent" decision.

YANTIS and JONIDES found that RTs were fastest to abrupt-onset targets, intermediate to gradual-onset targets and slowest to negative decisions (i.e., when the target was absent). Error rates were positively correlated with RT indicating the absence of a speed-accuracy trade-off. Further, the slopes of the functions relating RT to display size were smallest for abrupt onset targets (7.9 msec/item; the 95% confidence interval included zero), intermediate for gradual-onset targets (24.5 msec/item) and largest for negative decisions (35.0 msec/item); all differences were significant at the 0.05 level. YANTIS and JONIDES fitted the mean data to a simple visual search model based on the assumption that search is serial and self-terminating and that the abrupt-onset item is scanned first on every trial. There was a good fit of this model, accounting for 98.7% of the variance with only three parameters (estimates: time for the completion of one comparison: 38.1 msec, additional time required for a negative decision: 33.2 msec; time for all other mental operations: 411.9 msec).

In a second experiment, YANTIS and JONIDES tried to rule out an explanation of the abrupt-onset advantage in terms of perceptual factors; for instance, gradual-onset targets may be more difficult to process than abrupt-onset tagets because of receptor adaptation to the premasks. The display in this experiment consisted of only one letter presented at a location indicated in advance. In gradual-onset blocks the indicator was the "8" pre-mask figure and in abrupt-onset blocks a configuration of six dots at the vertices of the "8". 1000 msec after the presentation of the indicator, irrelevant segments faded within 80 msec revealing the gradual-onset letter; however, the six-dot configuration faded completely and the letter was abruptly displayed. The RT data showed a slight, nonsigificant advantage for gradual-onset (519 msec) over abrupt-onset targets (530 msec) (that is, there was a slight advantage in processing presumably due to the 80-msec preview during the gradual camouflage offset). YANTIS and JONIDES conclude from the absence of a RT advantage for abrupt-onset over gradual-onset targets when attention was directed to the target location in advance, that "... the effect of abrupt onset is to summon attention when it is not already directed to the abrupt onset stimulus location" (p. 610).

1.5. Facilitatory and Inhibititory Components of Spatial Orienting

The interval between the cue and target onset (SOA) is of principal importance for the understanding of the orienting mechanism (e.g., the sudies of ERIKSEN and coworkers; SHULMAN, REMINGTON and McLEAN, 1979; JONIDES

1981, Experiment 3). In the experiment of POSNER, NISSEN and OGDEN (1978; central arrow cue; two spatial locations 5 deg. to the left and right of a central fixation mark; probabilities of target occurrence: 0.8 and 0.2 for cued and uncued locations respectively, and each 0.5 on neutral trials), there were blocks of trials with variable foreperiods: 0 (i.e., no warning signal), 50, 150, 300, 500 and 1000 msec. POSNER et al. found significant costs and benefits in simple RTs, relative to the neutral baseline, even when the cue preceded the detection stimulus by only 50 msec; costs and benefits increased over the first 150 msec, and thereafter costs showed some tendency to decrease while the benefits remained quite invariant.

Recently, there has been much interest in the effect of SOA duration in simple RT tasks with spatially uninformative "cues" (i.e., in tasks without probabilistic relationship between cued and target location). Among others (COHEN, 1981; POSNER and COHEN, 1984), this effect has been described by MAYLOR (1983, 1985). In one of MAYLOR's experiments, there were two peripheral boxes (4.2 deg.) as well as a central box with a fixation dot in its middle. A trial began with a 100-msec brightening of the outline of one of the peripheral boxes (peripheral cue), and after SOAs of 100, 300 or 500 msec a luminance increment occurred in the one or the other peripheral box with equal probability (p = 0.5); the task was simple RT to the detection probe. MAYLOR found that at the 100-msec

SOA, RTs were faster for valid than for invalid trials (facilitation); but at the longer SOAs, RTs were faster for invalid than for valid trials (an effect which MAYLOR and, previously, POSNER and COHEN, referred to as inhibition).

Originally, MAYLOR demonstrated this pattern of "early" facilitation and "later" inhibition for cued locations in an experiment which presented a 100-msec brightening of the central box 200 msec after peripheral cue onset (100-, 300- and 500-msec SOAs between peripheral cue and target). This second brightening served to withdraw attention from the cued to the central box, for salient stimuli such as brief flashes are assumed to summon attention in an imperative fashion (JONIDES, 1981). However, the absence of the second brightening did not eliminate the cross-over between the RT functions for valid and invalid targets, so that MAYLOR concluded that withdrawal of attention from the cued position is not a necessary condition for the inhibition effect.

The basic paradigm in the experiments of COHEN (1981) and POSNER and COHEN (1984) was the same as that of MAYLOR, with one exception: Detection probes could also occur in the central box with a probability of 0.6 as compared to 0.1 for either peripheral box (20% no-target, i.e. catch trials); or the target probe appeared only in the peripheral boxes (equal probability), but the initial brightening of one of these was followed by a brightening of the central box after about 300 msec。 With these paradigms, POSNER and COHEN obtained the early facilitation and the later inhibition for the cued location, provided that the cue was a single brightening or even a dimming of the outline of one of the peripheral boxes。 However, when both peripheral boxes were brightened simultaneously, there was no reliable facilitation at short SOAs, relative to the uncued location on trials when only one box was brightened, but there was significant inhibition at the long SOAs。 In another experiment, POSNER and COHEN used a central arrow to indicate the most likely position (the probabilities were 0。8 for the cued and 0。2 for the uncued location); and then, 600 msec after the onset of the arrow cue, the central box brightened indicating that the target was now most likely to appear at the centre (probabilities of 0。6 for the central box and 0。2 for each of the peripheral boxes)。 In this experiment, POSNER and COHEN obtained "early" facilitation for the location indicated by the arrow cue (450-msec SOA), but no inhibition at the longer SOAs (950 and 1250 msec; at 950 msec, RTs for the cued and uncued sides hardly differed, while the central position showed an advantage)。

Thus, according to POSNER and COHEN (1980), attention must be withdrawn from the cued location, either by an external cue (central brightening) or by appropriate probabilistic manipulations (high probability of target occurrence in the centre at longer SOAs), in order to observe the inhibition effect; otherwise, "... the inhibition may be masked by attention". Second, since no inhibition is obtained with central cues, orienting of attention is not a sufficient condition for this effect. Third, since both a brightening and dimming as well as a double brightening of the peripheral boxes produces inhibition - the double brightening without producing marked facilitation, i.e. without "... attention (being) split to the two sides" (such a "splitting" is not possible according to POSNER et al., 1980) -, inhibition for a location arises from the occurrence of "any" change in light energy; any cue involving such a change in light energy has the effect that "... some part of the pathway from the cued location is reduced in efficiency by the cueing". As to the function of the inhibition effect, POSNER and COHEN suggest "... that the inhibition effect evolved to maximize sampling of the visual environment ... This would reduce the effectiveness of a previous active area in space in summoning attention and serve as a basis for favoring fresh areas at which no previous targets had been presented".

While POSNER and COHEN argue that the inhibition effect is sensory rather than attentional in nature, the results of MAYLOR do not rule out this possibility. MAYLOR (1985; Experiment 2) observed that when a peripheral brightening (cue) occurred at the same time as a discontinuity in a central tracking task (requiring the programming and execution of a small saccadic eye movement), both the early facilitatory and the late inhibitory components were absent. Further, MAYLOR (1983) found that in the case of double cues (simultaneous brightening of both boxes) facilitation is not completely abolished, as suggested by POSNER and COHEN (1984), but only halved in comparison with single cues; subsequent analyses of the RT distributions showed that for trials with double cues variances were not greater than for trials with single cues, suggesting that "... orienting does not occur to one box only, as though the other box had not been cued" (i.e., attention could be divided). MAYLOR (1985; Experiment 3) observed that not only the facilitatory component is approximately halved by double cueing as compared to single cueing, but also the inhibitory component; this is at variance with POSNER and COHEN (1984). MAYLOR concludes that these results argue against the view that the inhibitory component does not arise from attentional orienting but from the sensory information presented at the cued location; rather, "... It appears that the inhibitory component is dependent upon externally controlled orienting."

1.6. Spatial Attention and Visual Acuity

An important question is whether the POSNER's "spotlight" model of spatial attention applies only to simple luminance detection tasks (from which it was mainly derived) or also to tasks requiring visual discrimination and identification. For simple RTs in response to a suprathreshold detection stimuli, POSNER (1978) demonstrated that the costs and benefits were of about the same magnitude for retinal eccentricities varying from 0.5 up to 25 deg. of visual angle, i.e. there was no interaction between cue validity (valid-invalid) and target eccentricity, even though RTs were generally faster for the more central targets. POSNER, SNYDER and DAVIDSON (1980) state that "... when the fovea is not illuminated by attention, its ability to lead to detection is diminished, as would be the case with any other area of the visual system" (p. 173). For tasks requiring visual acuity such a degree of independence between retinal eccentricity and "costs plus benefits" cannot be expected because of the structural limitations of the visual system.

In this context, ENGEL's (1971) distinction between the areas of visibility, attention and conspicuity is of particular interest. According to ENGEL, visual conspicuity is an object factor, "... More precisely, it is an object property in relation to its background ... We define visual conspicuity operationally as that combination of properties of a visible object in its background by which it attracts attention via the visual system, and is seen in consequence" (p. 563). ENGEL, in an attempt at determining the size of the conspicuity area, presented four different test stimuli made up of 1, 2, 3 or 4 0.6-deg. lines in right angles (i.e., test stimulus 1 was a single 0.6-deg. line and test stimulus 4 was a closed square) against a noise background of lines of a length of 1.2 deg. randomly distributed over the display with a density of about 1.4 lines per square deg.; the test stimuli were presented for an exposure time of 75 msec and their distance from fixation was varied in several directions (monocular viewing condition). As could be expected, the higher the similarity between test stimulus and background, the smaller the area in which its presence could be reported correctly (the subject had to report the location and the local orientation of the test stimulus; the diameters of the conspicuity areas ranged from 2 deg. for test stimulus 1 up to to about 20 deg. for test stimulus 4).

In a second experiment designed to determine whether the conspicuity areas for the four test stimuli were identical with their visibility limits (visibility areas), ENGEL preinformed the subjects about the location of the test stimuli by means of a light pen, so that they could direct their attention to the indicated position; the task was to report the local orientation of the test stimulus. ENGEL found that "... with the exception of test stimulus 4, the visibility areas ... were greater than the corresponding conspicuity areas ... The conspicuity area for test object 4 practically equalled the visibility area" (p. 567).

In a third experiment, ENGEL investigated the way in which the preknowledge of the location of the test stimulus modified the area in which it was seen. To do so, he provided an "attention point" in addition to the central fixation dot and there was a "good chance" that the test stimulus appeared at the location of the attention point; he referred to the areas obtained in this experiment as attention areas. As ENGEL reports, "... the attention areas ... obtained were practically equal to the corresponding conspicuity areas, except for an additional extension in the direction of the attention points. The determined extensions were limited by the locus of the corresponding visibility areas" (p. 569). Thus, the results of ENGEL suggest a model in which the central conspicuity area can be extended to the limits of visibility by means of directed attention (it is interesting to note that the distance between central fixation point and peripheral attention point did not seem important for the attention areas obtained).

The finding of ENGEL that the conspicuity area can be elongated by oriented attention suggests that POSNER and SNYDER's cost-benefit analysis can also be applied to tasks requiring visual acuity (at least if the target stimuli are presented outside the conspicuity area). While it is true that attention cannot change the limits of visibility, i.e., as POSNER (1980) puts it, "... it does not provide an increase in retinal grain" or "... it does not provide a substitute for the sensory specific wiring intrinsic to the visual system" (p. 9), there is no a-priori reason to assume that allocation of attention to a position in space does not benefit the discrimination or recognition of information presented at that location, relative to unattended positions, provided that the limits of visibility are not exceeded. POSNER, SNYDER and DAVIDSON's (1980) point that in tasks requiring acuity the magnitudes of costs and benefits may vary with retinal eccentricity cannot be considered as a crucial argument against this position.

POSNER et al. themselves applied a cost-benefit procedure to an identification task. The display in this experiment consisted of four boxes arranged around a central fixation point. The maximum distance between the boxes and the centre was 1.5 deg., i.e. the stimuli, either the digits 4 or 7 or the letters D or Q, appeared foveally (the target was the only stimulus presented). Each trial began with either a neutral warning signal or an arrow cue pointing to one of the four positions. The neutral warning signal indicated that the target was equally likely to occur in any of the four boxes; following an arrow cue, the target appeared with probability 0.79 in the cued and with probability of 0.07 in each of the three remaining boxes. In one condition the target stimulus was presented for 40 msec and terminated by a mask, in another condition it remained present until the subject responded. The task was forced-choice RT to the decision whether the target stimulus was a letter or a digit.

The results of this experiment were that the RTs in the brief exposure condition were somewhat longer than in the condition with unlimited exposure time; and that in both conditions there were benefits and costs for cued and for uncued locations in the RTs, but not in the error rates. However, the magnitude of the costs and benefits were small compared to those typically obtained in simple RT tasks. POSNER et al. (1980) conclude "... that spatial cues are very effective for simple RT to luminance increments because this task does not require determining what the event is before responding, since subjects are required to respond to any event"; in complex tasks, however, the overall effects get smaller because of "... the necessity of the subjects switching attention from the spatial location indicated by the cue to the internal lookup processes that identify ... or determine ... the discriminative response" (p. 168).

In the light of ENGEL's results, the smaller RT effects in this recognition task of POSNER et al. might not be too surprising if one takes into account the near foveal presentation of the target stimuli. Assuming that the "internal lookup processes", i.e. the reorientation of "... attention from spatial position to the area in memory that is available for the analysis of the discrimination" (POSNER, 1980, p. 8), take about the same time on every trial, the rapid availability of attention at the cued location should also benefit choice RT (e.g., because of "prior entry" into the limited capacity system of information at attended positions). Presumably, the target stimuli of POSNER et al. lay within the conspicuity area for which ENGEL could not show effects of directed attention. Possibly, the conspicuity area has to be conceived of as a dynamic region changing its size with stimulus parameters such as exposure time. Thus, one should expect greater effects on choice RT for the condition of POSNER et al. in which the target stimulus was presented for 40 msec and followed by a mask in comparison with the condition with unlimited exposure time. However, this is certainly not the case, a possible explanation being that the 40-msec exposure time was still too long (the error rates did not differ between the conditions with limited and unlimited exposure durations).

Further, there is evidence that the conspicuity area changes its size with practice. Such practice effects have been reported by ENGEL (1971) for a constant 75-msec exposure time: "During a period of training the (conspicuity) areas became larger, after which they remained constant for each subject" (p. 565). Thus, it seems important to control target exposure times individually. This has been done, for instance, by SHAW and SHAW (1977) who determined, in four practice sessions, the exposure times which resulted in stable performance at a level of 68% correct identifications. The exposure times found by SHAW and SHAW for a target eccentricity of 1 deg. (comparable to that of POSNER et al.) were in the order of 25 msec, i.e. 15 msec shorter than the 40 msec used by POSNER et al. With this procedure, SHAW and SHAW demonstrated "benefits" and "costs" in the error rates for highly likely and less likely locations, respectively; however, since they did not provide visual cues (rather, subjects had to learn the probability distributions for eight spatial locations in the practice sessions), it is difficult to interpret their results in terms of POSNER and SNYDER's cost-benefit analyses. Similarly, JONIDES (1980, 1981) demonstrated clear costs and benefits both in choice RTs and error rates for the identification of two alternative target letters presented at locations 3.75 deg. from fixation (characters were 1.2 deg. in height and 0.8 deg. in width) for an exposure time of 25 msec. But unlike SHAW and SHAW as well as POSNER, SNYDER and DAVIDSON, he did not present post-display masks, so that it is unclear whether the costs and benefits obtained reflect "sensory" or "memory" effects (the importance of "iconic storage" for JONIDES' results may also be inferred from the luminance conditions in this experiment: "The testing room was kept dimly illuminated throughout the experiment"; 1981, p. 190).

Another interesting experiment in this context is GRINDLEY and TOWNSEND (1968). In this experiment, the display was divided into the quadrants of the cartesian coordinate system, and the subjects were instructed to fixate on its origin. GRINDLEY and TOWNSEND used two types of display which they referred to as "single" and "multiple". In single displays, the target stimulus was a

T which could be presented in any of the four orthogonal orientations in any of the four quadrants; the eccentricity of the target stimuli was about 13 deg. After each trial, subjects had to report the quadrant in which the target had appeared as well as its orientation. In multiple displays, target stimuli and task were the same; the only difference was that simultaneously with the target, distractor crosses of the same bar size and luminance appeared at the same eccentricities in the three remaining quadrants. In preexperimental trials GRINDLEY and TOWNSEND determined threshold exposure times, separately for single and for multiple displays, "... which would enable the subjects to give answers that were better than chance under each condition but not 100 per cent" (p. 13); these preliminary trials did not involve a location cue. The experiment was run in two blocks, with the first consisting of 16 single display and the second of 16 multiple display trials or vice versa.

The result of this experiment was that in the single display condition, 36 out of 80 (10 subjects) possible responses (joint quadrant plus orientation response) were correct when "foreknowledge" of the quadrant of the target stimulus had been provided as compared to 44 correct responses without foreknowledge (nonsignificant difference). Under the multiple display condition with foreknowledge 66 out of 80 responses were correct, whereas without foreknowledge only 35 (significant difference).

GRINDLEY and TOWNSEND (1968) conclude that "... when attention is directed to one part of the peripheral field it has little or no effect on the visibility of a single test object (tachistoscopically exposed) in that position. If, however, other objects are exposed simultaneously in other parts of the peripheral field the effect of attention is very striking ... it is difficult to believe that the effect of attention to a particular part of the peripheral field is due to any sensitization of the corresponding part of the retina or the visual pathway ... the role of attention in peripheral vision is rather to ensure that when there are competing messages from other parts of the visual field (multiple stimuli) the messages from the part to which attention is directed are given priority of treatment" (p. 18).

This experiment of GRINDLEY and TOWNSEND (1968) is often quoted to support the view that preinformation about a spatial location benefits discrimination or identification of a target presented at that position only if the visual field is cluttered or when there are competing stimuli present in the visual field. However, this experiment is open to criticism. A first point concerns the procedure employed to determine the threshold exposure time: GRINDLEY and TOWNSEND neither state the number of preliminary trials presented ("some preliminary trials"), nor do they state the exact threshold level ("better than chance ... but not 100 per cent"). The only statement they make is that "... it was found that the subject needed a longer exposure time when there were competing objects than when the test object appeared alone" (p. 13). Thus it might be that the threshold level was not the same for the single and the multiple display (see also SPERLING and MELCHNER, 1978).

A second point concerns the verbal indication of the target quadrant which caused a considerable delay between cue and target exposure. On trials with foreknowledge, the procedure was as follows: The experimenter told the subject at the beginning of a trial, for example, "fix 1" indicating that the subject had to fixate on the origin of the coordinate system and to direct attention the quandrant 1; the subject had to say "yes" as soon as he did so and this response was the signal for the experimenter to initiate the display. GRINDLEY and TOWNSEND state that "... as far as we could estimate this procedure ... resulted in a delay of about 1 to 2 sec. between 'fix' and the exposure" (p. 18). In addition, the indication of a quadrant is a rather imprecise cue of the location of the target stimulus presented at a distance of 13 deg. from fixation (see JONIDES, 1981).

A third point is that GRINDLEY and TOWNSEND did not mask the target and distractor stimuli at the end of their exposure, thus leading them to the conclusion that it "... seems most profitable to consider the question of attention in peripheral vision as one of filtering the available information from a short-term information store"

(p. 19). This last point in connection with the first, i.e. the absence of masks together with the generally longer exposure time under the multiple display condition, might provide an explanation for GRINDLEY and TOWNSEND's finding in terms of a longer time course of temporal summation, i.e. a prolonged useful duration of iconic duration in the multiple display which could, in turn, facilitate subsequent read-out processes, provided that attention is quickly available at the "memory location" of the target stimulus.

GRINDLEY and TOWNSEND's finding of no difference between the foreknowledge and no-foreknowledge conditions for the single display is also surprising from a guessing point of view. That is, in the foreknowledge condition the probability of a corrrect guess is 0.25 (since there is no position uncertainty), while in the no-foreknowledge condition it is 0.0625; but with only 8 observations per subject and display/foreknowledge condition, the results are highly liable to random effects (in the single display condition, for instance, the no-foreknowledge condition shows a nonsignificant advantage over the foreknowledge condition).

1.7. Feature Integration Theory of Attention

An important question which GRINDLEY and TOWNSEND fail to discuss concerns the dependency between location and orientation response, i.e. whether the orientation of the target T can only be identified if its position could be detected. In this context, a model which has been recently proposed by TREISMAN, SYKES and GELADE (1977) is of particular interest. TREISMAN, SYKES and GELADE refer to this model as "feature integration theory of attention", since it assumes that "features come first in perception" and have to be integrated into "objects" at some later stage requiring "focal attention".

According to TREISMAN and GELADE (1980), "... the visual scene is initially coded along a number of separable dimensions, such as color, orientation, spatial frequency, brightness, direction of movement (automatic and parallel registration of features). In order to recombine these separate representations and ensure the synthesis of features for each object in a complex display, stimulus locations are processed serially with focal attention. Any features which are present at the same central 'fixation' of attention are combined to form a single object ... Once they have been correctly registered, the compound objects continue to be perceived and stored as such. However, with memory decay and interference, the features may disintegrate and 'float free' once more, or perhaps recombine to form 'illusiory conjunctions'" (p. 98).

This model has important implications for tasks requiring both a location and an identification response: "... if focused attention is prevented, the features of unattended objects may be free floating spatially, as well as unrelated to each other. Thus, we may detect the presence of critical features without knowing exactly where they are located ... Locating a feature would, on this hypothesis, be a separate operation from identifying it, and could logically follow instead of preceding identification. However, the theory predicts that this could not occur with conjunctions of features. If we have correctly detected or identified a particular conjunction, we must first have located it in order to focus attention on it and integrate its features" (p. 100).

TREISMAN and GELADE (1980) tested these predictions in the following experiment: The display consisted of two rows of six coloured letters, with one of the 8 inner letters being the target stimulus and and the remaining 11 the "distractors" O (pink) and X (blue) in approximately equal numbers. There were two conditions, presented in separate blocks of trials, which TREISMAN and GELADE referred to as "disjunctive feature" and "conjunction" conditions. In the feature condition, the two possible targets were the letters H (in pink or blue) and the colour orange (in the shape of an O or X); in the conjunction condition target alternatives were X (pink) and O (blue). The task was both to identify the target and to report its location. Exposure times were individually adjusted for each subject and condition so as to allow an identification accuracy of about 0.8. Each trial started with the presentation of a premask (coloured segments of the target and distractor letters) which was then replaced by a central fixation dot (black); after 1000 msec, the 6 x 2 letter array was presented for the individual exposure times; the display was then terminated by the original masking field.

TREISMAN and GELADE analysed identification accuracy given that the locations reported were (1) correct, (2) incorrect and adjacent to the target position or (3) incorrect and distant from the target position (all other locations). For conjunction trials on which the location reponse was a distant error ((3)), identification accuracy was at chance (0.50); however, in feature trials in which the same error was made, identification accuracy was well above chance (0.68). The identification accuracy given adjacent location errors ((2)) was 0.72 for the conjunction and 0.82 for the feature condition, and localisation accuracy was 0.93 (conjunction) and 0.90 (feature). In both conditions, localisation accuracy was generally at chance when identification was unsuccessful.

TREISMAN and GELADE (1980) conclude that "... at least approximate perception of the location appears to be a necessary condition for identification of conjunction targets. Adjacent errors were, however, associated with better than chance identification of targets. Some of these errors most likely reflect errors of memory ... focused attention is necessary for accurate identification of conjunctions; but it may not be necessary on all trials to narrow the focus down to a single item ... With nonadjacent location errors, identification would have to be at chance, as in fact it proved to be ... The feature condition shows a different pattern which is also consistent with feature integration theory ... target identification is well above chance even when major location errors were made" (p. 130).

NISSEN (1985) proposed to conceive of the integration of multidimensional features (e.g., colour and shape) as a process of "cross-referencing" between separate feature "maps" (the underlying assumption is that the output of parallel feature registration mechanisms is locationally tagged). Suppose, for example, that the spatial layout of colours in a visual display is registered in a colour map and the spatial layout of shapes is registered in a shape map. Then, when the task requires the subject to report the shape and colour of an object at a particular location (i.e., location cue), accuracy of shape and colour identification should be independent (since colour and shape are represented in separate maps, access to shape may succeed while access to colour fails and vice versa). However, reporting the shape of the only "red" object in the display (i.e., colour cue) should require localising the red object within the colour map, selecting its location in the shape map and determining the shape at this location. That is, accuracy of (shape) identification should depend on accuracy of (colour) localisation; restated, when selection (colour) and response (shape) attributes are in different maps, access to the response attribute should require localisation. Both predictions were confirmed by NISSEN (1985; Experiment 2).

NISSEN (1985) further states that in multiple-map situations, "... partial report by location (i.e., location cue) will necessarily be more accurate than partial report by any other physical attribute" (p. 217) because of the required mediation by localisation in the latter conditions. For tasks, however, that are supported by a single map (i.e., without the need for cross-referencing), such as reporting the colour at a particular location (i.e., location cue) and reporting the location with a particular colour (i.e., colour cue), NISSEN (1985; Experiment 1) found no advantage for selection by location. However, NISSEN concedes that in single-map tasks focused attention "... may allow faster or more spatially precise access to information within a map" (p. 218).

1.8. Automatic Detection and Controlled Search

TREISMAN's distinction between tasks requiring simple detection of features and tasks requiring identification of feature conjunctions is reminiscent of SHIFFRIN and SCHNEIDER's distinction between "automatic detection" and "controlled search" (SCHNEIDER and SHIFFRIN, 1977; SHIFFRIN and SCHNEIDER, 1977).

SCHNEIDER and SHIFFRIN demonstrated the difference between automatic and controlled search in the following experiment. Trials consisted of a sequence of 20 frames, each presenting 4 elements arranged in a square around a central fixation dot. The four elements were n characters (digits and/or consonants) and 4 - n random dot masks at noncharacter locations. Frame size N was 1, 2 or 4 and constant for a given trial; character locations varied randomly from frame to frame. The task was to detect any member of the memory set characters, with a different memory set being presented at the beginning of each trial; memory set size ranged from 1 to 4. One half of the trials contained a target, the other half did not. The response required was to indicate presence or absence of a memory set item, with accuracy as the dependent measure.

The most important variable was the "mapping" between memory (target) set and distractor set: "consistent mapping" (CM) and "varied mapping" (VM). In the consistent mapping task, target set elements never appeared as distractors and distractor set elements never appeared as targets (i.e., target numbers had to be detected among distractor letters and vice versa; "number-letter" and "letter-number" conditions). In the varied mapping task, target and distractor set elements changed roles from trial to trial ("number-number" and "letter-letter" conditions).

For the VM task, the results were as follows: (1) For any frame and memory set size condition, detection hit rates increased monotonically with increasing frame time (the frame time axis ranged from 120 msec to 800 msec). (2) Hit rates decreased monotonically with increasing "memory set size x frame size". That is: "Increasing the load on the short-term search process (by increasing the memory set size and/or the frame size) results in a drastic increase in the difficulty of the task. ... the estimated frame time needed to reach a given performance level (say, .70) appears to range from about 60-800 msec, depending on the load placed on the serach process ... The fact that performance is monotonically related to M x F (i.e., memory set size x frame size) suggests a search process that takes longer to complete as the total number of comparisons increases". (3) Hit rates were lower for the condition with memory set size 4 and frame size 1 than for the condition with memory set size 1 and frame size 4. (4) False alarm rates were consistently low across conditions (i.e., most errors were misses rather than false alarms). "The low-false alarm rate in all conditions suggests that the processing of the features of the individual characters is quite accurate", for "... Inaccurate processing would lead to confusions among characters" (SCHNEIDER and SHIFFRIN, 1977, p. 12).

For the CM task, however, the results were radically different: (1) Performance levels were much higher than for the corresponding VM conditions; even for the VM condition with memory set and frame size 1, performance was lower than for the CM condition with memory set and frame size 4. (2) Performance also increased monotonically with increasing frame time; however, the frame times needed to reach a given performance level, e.g. 0.7, were of the order of 40-80 msec (as compared to 60-800 msec). (3) The effects of memory set and of frame size were very small, and the direction of effects were not monotonic with load (i.e., with the product of memory set and frame size). (4) False alarms were most marked at the 40-msec frame duration and decreased at longer frame times.

These fundamental differences between VM and CM tasks, in particular the finding the VM performance is dependent on load while CM perfomance is not, led SCHNEIDER and SHIFFRIN to refer to the first search process as "controlled search" and to the second as "automatic detection".

In a second experiment, SCHNEIDER and SHIFFRIN attempted to develop a direct link between accuracy and reaction time measures. Displays were the same as in Experiment 1, except that only five frames were presented on each trial with the middle frame containing a combination of characters and masks and the other frames containing masks only. Frame time in all conditions was kept constant at 160 msec. The dependent measure was two-forced choice RT to the presence and absence of a target element in frame 3. For the CM conditions, there was almost no change in mean RT as a function of either memory set or frame size (RTs were faster for positive than for negative trials, but there were no differences in the slopes of the functions relating RT to frame and to memory set size). For the VM conditions, however, there were large effects of memory set size and frame size; the functions were approximately linear and the slopes were about twice as large for negative as for positive trials.

SCHNEIDER and SHIFFRIN fitted a quantitative model to the RT data for the VM condition. This model was based on the following assumptions: (1) Controlled search is a serial, self-terminating comparison process; (2) the search order is to compare first a memory set element to all display elements in turn and then choose a new memory set element and continue; (3) a certain amount of time is needed to choose each new memory set element. This model was also fitted to the VM accuracy data of Experiment 1. For both sets of data, "... The fit was good enough to suggest that the same search and detection mechanisms underly performance in the two paradigms" (p. 52).

In a further series of experiments, SHIFFRIN and SCHNEIDER (1977) investigated the following questions: ""To what degree can the subject focus attention on a specified subset of the inputs without distraction from the remaining (irrelevant) inputs" (p. 145). That is, unlike the previous "divided attention" experiments, these experiments addressed the question of "focused attention".

The first experiment was designed to show that "VM foils", i.e. characters at invalid (irrelevant) display locations which previously served both as targets and as distractors in a VM task, can be ignored and that search can be carried out through the valid (relevant) locations without performance decrement produced by the presence of the foils.

There were three main conditions: (1) memory set size 2, frame size 2; (2) memory set size 2, frame size 4; (3) memory set size 2, frame size 4, "diagonal". In the "diagonal" condition ((3)), one of the diagonals in the display was always to be attended (valid) and the other diagonal was always to be ignored (invalid). As in Experiment 1, each trial consisted of 20 frames. There were "target absent" (0.25) and "target present" trials; on "target present" trials, the display could contain one (0.25) or two targets (0.50). Double targets could appear in the same frame (spacing 0), in directly successive frames (spacing 1) and in successive frames with one or three intervening frames (spacing 2 and 4). In the spacing-0 condition all double targets were identical, and in the spacing 1, 2 and 4 conditions they were nonidentical. The dependent measure was accuracy in the detection of multiple targets (i.e., subjects had to report the number of targets detected).

For double targets, performance was generally lower than for single targets and improved with spacing. There was no difference in performance between the "frame size

2" and the "frame size 4, diagonal" condition, but performance was clearly lower for the condition with frame size 4. SHIFFRIN and SCHNEIDER conclude that search in VM tasks can be controlled "... at least to the degree that comparisons can be limited to a specified diagonal. It is possible that characters in the invalid diagonal are sometimes compared, but not until the valid diagonal is searched first (if time were taken to compare foils during the search of the valid diagonal, then performance would be worse)" (p. 147).

A further experiment was designed to establish whether VM target foils (in contrast to VM distractor foils) at invalid display locations can be ignored. The procedure was similar to the previous experiment, with the following differences: There was only one condition with memory set size 2 and frame size 4. Either no target or else one target appeared on the valid diagonal, and a binary yes/no response was required. The foils in the invalid diagonal were chosen from the VM distractor set, except for exactly one foil on each trial which was a member of the memory set (VM target foil). On 1/3 of the trials, only a VM target foil occurred (in frames 8-13), and on 2/3 both a target foil and a target appeared; target foil and target could be identical or nonidentical (equal probability). The target foil appeared equally often in frames -4, -1, +1 and +4 with respect to the target frame. The result was that the VM target foil had no effect on hit rates, except when it directly preceded the target and was nonidentical; in this condition, detection accuracy was reduced by 0.11.

In a similar "divided attention" experiment (i.e., all locations were equally "valid") with multiple targets, SCHNEIDER and SHIFFRIN (1977) found a comparatively large decrement in VM detection for double targets when they occurred in directly successive frames. SCHNEIDER and SHIFFRIN explain this decrement in the following way: "It may be that the subject spends extra time processing a frame on which a target is found, borrowing the additional time from the following frame. Alternatively, the detection of a target may be associated with a somewhat delayed, time-demanding, ... registration response, in which the subject notes and counts the occurrence of a target" (p. 47). (In the CM search condition of this experiment, there was no effect of spacing on double target detection and performance was higher than for VM search.)

SHIFFRIN and SCHNEIDER suggest a similar explanation for the "VM target foil" experiment: "The pattern of findings (i.e., that there is a decrement when VM target foils directly precede the VM targets, but that this is small compared to search for double VM targets) would be explicable if the valid diagonal would always be searched first and then, whenever the search finished early, one or more characters on the invalid diagonal were inadvertedly checked in addition. In this event, target foils would occasionally be noticed and might harm subsequent detection in a fashion similar to that caused by true target detection" (p. 148).

In a third experiment, SHIFFRIN and SCHNEIDER asked to what extent a CM target foil would interfere with automatic target detection on the valid diagonal. Memory set and frame size were both 2; each frame contained one mask and one character in the valid and the invalid diagonal. The CM target foil occurred either in the same frame as the CM target or four frames before or after the target frame. The only effect was a slight (but significant) performance decrement of about 4% when an identical CM target foil appeared simultaneously with the CM target.

In a fourth experiment, SHIFFRIN and SCHNEIDER tested the hypothesis that the serial process of controlled search "... should easily be disturbed if an automatic-attention response occurs that draws attention to an invalid location" (p. 150). Memory set size was 2 and frame size was 4. Search in the valid diagonal was for consonants among consonants or digits among digits. VM foils on the invalid diagonal were chosen from the distractor set. CM foils were digits for consonant-consonant search and consonants for digit-digit search; the CM foils were chosen from the CM memory set used for a particular subject in all his/her previous experiments. On 1/2 of the trials, both a target and a CM foil appeared with spacing -1, 0 or 1 between target and CM foil frames; on each 1/6 of the trials there was either a target or a CM foil or neither a target nor a CM foil. Frame time was 200 msec.

The hit rate on trials without CM foils was 0.84. When a CM foil preceded the target by one frame, the hit rate was not significantly lower than the 0.84-baseline (0.82); when target and CM foil were presented in the same frame, the hit rate was 0.62; and when a CM foil followed the target by one frame, the hit rate was 0.77 (significantly lower than the baseline). SHIFFRIN and SCHNEIDER conclude "... when (a CM stimulus) appears on a to-be-ignored display diagonal, it apparantly causes an (automatic) attention response that interrupts processing along the valid diagonal and directs attention to the invalid diagonal. The time lost before attention is returned to the valid diagonal and search is resumed causes a considerable decrement in performance if the target is in fact on the valid diagonal during that frame" (p. 151).

In summary, according to SHIFFRIN and SCHNEIDER, attention can be "divided" among display locations without deficit when automatic detection is utilized; however, it cannot be "divided" without deficit when controlled search is utilized. "Focused attention" deficits are substantial when caused by automatic detection responses to invalid display elements, but are less severe when caused by controlled processing of invalid items.

SHIFFRIN and SCHNEIDER (1977) propose the following theoretical framework for their findings: They conceive of memory as a permanent collection of nodes which become increasingly interassociated by learning. Most nodes are normally inactive, and they are termed "long-term store" (LTS; passive store of information); the set of temporarily active nodes is termed "short-term store" (STS). Information in STS is lost when it reverts from an active to an inactive state. Control of information processing is carried out through manipulation of the flow of information into and out of STS.

An automatic process within this system is conceived of as a sequence of nodes that nearly always becomes active in response to a particular input configuration (i.e., activation occurs without the necessity of active control or attention); this sequence is a relatively permanent set of associative connections in LTS developed by extensive training and, once initiated by the proper input configuration, it is difficult to suppress or to alter. When the sequence is initiated its nodes are activated, i.e. the associative information enters STS. Unless attention is directed to the process or unless it includes an automatic attention response, the information may be immediately lost from STS without leading to awareness of the occurrence of the process. The probability that an automatic process runs to completion is assumed to depend on the strength of the initiating stimulation (this stimulation can be provided by external or internal input or by a control process). Some indirect control of automatic processes is possible by manipulation of the activation thresholds (a lowering of the threshold, however, does not imply that the quality of processing is improved; rather, the automatic process would be triggered by inputs that normally would not do so) and further by manipulation of the contents of STS at the time of the initiating input. Automatic processes are not hindered by the capacity limitations of STS; they appear to act in parallel with and independent of each other.

A control process utilizes a temporary sequence of nodes activated through active control and attention; since active attention is required, only one such sequence may be controlled without interference. Controlled processes are thus capacity limited, but they have the advantage of being easy to set up and altered. Since contolled processes utilize STS, the nature of their limitation is determined by the capacity limitation of STS, e.g. limited comparison rate of items and limited amount of information that can be maintained without loss. (Although a large amount of information may be present in STS at any one moment, only a small amount will persist for a sufficient period of time. The rate of loss of any element in STS is assumed to depend on the number of "similar" elements simultaneously active; similarity not only in terms of physical form but also of features at comparable levels of processing.) Because capacity limitations prevent multiple control processes from occurring simultaneously, these processes are often strung together in time to form a series of operations controlled singly. Not all control processes are available to consciousness (e.g., the serial comparison of items in STS which is carried out too quickly to be accessible).

In visual search and attention tasks, when a set of inputs is presented, each input undergoes automatic processing. "The system automatically encodes each input stimulus in a series of stages and activates a series of features in the process. For example, the letter 'M' may first be encoded in features indicating contrast, color, and position; the curvature, convexity, and angles; then a visual letter code and a verbal, acoustic-articulatory code, then the codes 'letter', 'consonant', 'capital'; and finally, perhaps, semantic and conceptual codes ... to the extent that internally generated information can alter the context in STS, the subject will have at least some indirect control over automatic sensory encoding." Some of the features automatically activated may initiate a response which will direct subsequent processing. For instance, an attention response may be activated which "... direct(s) controlled processing to the corresponding set of features representing that input stimulus, so long as other competing attention responses do not occur simultaneously ... If the set of inputs contains a target stimulus that gives rise to a relevant nonconflicting attention response, then we say that automatic detection is operating." The attention response can be "called" by features at any level of processing and by more than one feature (e.g., if the input stimulus is the character "8", attention responses can be called by the feature "8" and the feature "number"). If more than one input stimulus gives rise to an automatic attention response, the various responses will conflict and cancel each other since "... it is impossible to direct attention to every item in the display at once". In this case, a controlled search must be utilized employing strategies as efficient as possible.

Accordingly, in most studies which do not show "divided attention" deficits, automatic detection is operating (CM paradigm, extensive practice). "An exception to this general rule (of automatic detection, in parallel with and independently of other stimuli) may apply when two ... targets are presented simultaneously ... Even if both targets generate attention responses, there may be a difficulty in discriminating a double from a single occurrence. In such an event, the controlled comparison system may have to be called into play to count the targets." In most tasks requiring controlled search, an increase in the number of relevant inputs impairs performance; firstly because "... some of the features in STS may decay and revert to LTS before the comparison process reaches them", and second because "... new inputs may arrive and require processing, forcing the comparison process to switch away from the previous inputs." In "focused attention" studies, if controlled search is utilized, the search order determined so that the relevant locations are searched first; thus, there are hardly any performance deficits. Such deficits will occur only if "... irrelevant items give rise to attention responses during automatic encoding" and "... a loss of time will occur before the controlled search can be redirected to the relevant inputs" (all quotations from SHIFFRIN and SCHNEIDER, 1977, pp. 162-165).

In the light of the SHIFFRIN and SCHNEIDER's (1977) distinction between "automatic detection" and "controlled search", some previous findings of SHIFFRIN and his coworkers (SHIFFRIN, GARDNER and ALLMEYER, 1973; SHIFFRIN and GARDNER, 1972) become more explicable.

SHIFFRIN et al. (1973) presented, on each trial, a target dot pattern, either a vertical or a horizontal "line" consisting of two dots at the end points, at one spatial location and distractor dot patterns at three other locations; distractors consisted of either a single dot (low confusability) or a double-dot "line" tilted diagonally (high confusability). Display locations were arranged at the corners of an imaginary square separated by a minimum angle of 1.5 deg. The main independent variable was the temporal mode of presentation of the display elements: Either all elements appeared in the same frame (simultaneous condition; termination of the frame by masking patterns); or the elements at the locations on diagonal A appeared in one frame with masking patterns at the positions on diagonal B (termination of the display elements by masks presented for 500 msec between the display array frames) and the elements of diagonal B appeared in the following frame with masking patterns on diagonal A (sequential condition; termination of the second frame by masking patterns); subjects were preinformed about the order of the "diagonals". Frame time was set so for each subject that it allowed a detection accuracy of 80% for targets in the low confusable, simultaneous condition (frame times varied between 48 and 80 msec with a mean of 70 msec). Subjects had to indicate both the identity (vertical or horizontal line) and the location of the target.

SHIFFRIN et al. found no advantage of sequential over simultaneous presentation, in any of three dependent measures (recognition, localisation and joint recognition plus localisation). Such an advantage would have been expected on the assumption that under the sequential condition, attention is "switched" between successive diagonals; the time between frames was 500 msec, i.e., according to SHIFFRIN et al., sufficient for attention switching to occur. (Confusability had some effect on recognition and localisation accuracy, but not on joint target detection plus localisation). SHIFFRIN et al. (1973) conclude "... that information on four visual channels can be encoded and evaluated as efficiently when all four channels occur simultaneously as when only two at a time occur simultaneously. If attention was operative, it could have been switched between successive diagonals, leading to superior performance in the (sequential) condition. Hence, we conclude that attention was not operative in that situation" (p. 236).

SHIFFRIN and GARDNER (1972) conducted a similar experiment. Instead of dot patterns, they presented either an upper case T or an F as targets; distractors were either three Os (low confusability) or three stimuli consisting of a T superimposed on an F with the right hand part of the horizontal bar of the T, i.e. the upper horizontal bar of the F, missing (high confusability). The mode of presentation was either simultaneous or sequential; under the sequential condition, all four stimuli were presented in known clockwise order, with each element being preceded and followed by masks. As expected, higher confusability resulted in lower performance. However, sequential presentation was not superior to simultaneous presentation. Since the time between successive frames (50 msec) may have been too short in this experiment to allow attention switching to occur, SHIFFRIN and GARDNER repeated this experiment introducing a 500-msec interval; further, display elements were not presented a single one per frame, but rather two elements per frame at diagonally opposite locations with the order of diagonals known in advance (as in the experiment of SHIFFRIN et al., 1973). Again, there was no difference between sequential and simultaneous presentation.

In the light of the distinction between "automatic detection" and "controlled search", one could interpret these results of SHIFFRIN and coworkers in terms of "automatic detection", since all experiments used a consistent mapping paradigm and well practised targets. This could be taken to conflict with the studies already reported which found superior performance both in RT and in accuracy measures for targets presented at locations known in advance (e.g., POSNER, SNYDER and DAVIDSON, 1980; JONIDES, 1980, 1981; SHAW and SHAW, 1977; SHAW, 1978; ERIKSEN and COLEGATE, 1971; ERIKSEN and HOFFMAN, 1974). All these studies employed CM paradigms, i.e. target and distractors never changed roles; detection of a single luminance increment in an otherwise empty field, used by POSNER et al., can be regarded as the most simple consistent mapping task.

However, there are reasons to question the generality of the result of SHIFFRIN and coworkers. As DUNCAN (1980a) points out, the comparison between simultaneous and successive modes of presentation "... ignore(s) the importance of comparing evidence from the four corners. In 'successive' evidence from the first observation interval could not have been compared with that from the second, without an intervening period of storage. Memory losses may have seriously weakened performance in this condition" (p. 84).

Further, in the experiments of SHIFFRIN et al. (1973) and SHIFFRIN and GARDNER (1972) in which the target could appear at the opposite locations of a known diagonal (successive presentation), the target location was not known exactly; in other words, the contrast is between two alternative and four alternative locations. The target position was known precisely only in the first experiment of SHIFFRIN and GARDNER in which, however, the time between successive frames allowed for attention switching to occur may have been too short (e.g., SPERLING and REEVES, 1980).

Further, with respect to the diagonal presentation, it seems an open question whether attention can be effectively divided between two locations. According SHAW and SHAW (1977), attention can be "split" among multiple locations according to probabilistic priorities; but according to POSNER et al. (1980), this ability is severely limited. If attention can be divided between two locations, one should assume that this ability is based on a slow, controlled process. That is, the "attention reaction time" needed might be longer than the time allowed in the experiments of SHIFFRIN and his coworkers, since preparing for two possible locations is a more complex process than preparing for one exactly known position.

Thus, there are several possible factors which might have acted together to reduce performance in the sequential condition.

1.9. Spatial Attention and Preattentive Processing

HOFFMAN (1978, 1979) reinvestigated SHIFFRIN and SCHNEIDER's proposal that in varied mapping paradigms, search is a serial-serial process, i.e. that "... comparisons ... took place in an order that cycled through the frame for a given memory-set item before switching to a new memory-set item, and a matching decision was made after every comparison" (1977, p. 164).

HOFFMAN argues that SCHNEIDER and SHIFFRIN's (1977) finding of increasing detection accuracy with decreasing presentation rates of multiple frames (sequential condition) may have occurred because successive characters were presented to the same retinal locations and because the elements in one frame were continuously displayed until the onset of the next frame. In other words, the increase in frame time may have reduced forward and backward masking (as well as increased display energy because of temporal integration). (Note that there was also an effect of presentation rate on accuracy in the consistent mapping paradigm which is not supposed to be sensitive to processing load.)

In order to avoid this confounding factor, HOFFMAN (1978) presented 8 letters on a given trial, a single letter per frame, at locations around the circumference of an imaginary circle (2.1 deg. diameter; the letter presented in a given frame was the only letter in the display; i.e., presentation rate could be varied without variation in exposure duration or visual masking; displays were not refreshed). The spatial order of the letters was random, as was the location of the target on positive trials (50% positive and 50% negative trials). Presentation rates (SOA, i.e. onset asynchrony between successive frames) varied between 0 msec and 100 msec. The task required varied mapping (letter-letter search) with memory set size being set to 1, 2 or 4. Dependent measures were detection accuracy and forced-choice RT to the "target present - absent" decision (positive latencies were measured from the onset of the target and negative latencies from the onset of the last element in the sequence).

As expected (varied mapping), HOFFMAN found increased detection accuracy with slower presentation rates and smaller memory sets, with the effects of presentation rate and memory set size being additive. False alarm rates were relatively low and showed little effect of presentation rate and memory set size at SOAs longer than 25 msec. These findings argue against an independent-channels model. (ERIKSEN and SPENCER, 1969, using a similar presentation technique and requiring consistent mapping, found presentation rate to be ineffective; they suggested that each character was classified as target or nontarget in parallel and independently.) Latencies of correct decisions, both positive and negative, increased with memory set size; positive latencies showed little effect of presentation rate, while negative latencies showed a substantial reduction as presentation rate decreased (if the presentation rate is slow enough, negative RTs measure the time to classify a single character, i.e. the last one of the sequence, as compared to 8 characters in the simultaneous condition).

The main finding was that while negative latencies were generally longer for larger memory sets, the decrease with lower presentation rates approached asymptote at the 100-msec SOA independently of memory set size. Since the asymptotic SOA can be interpreted as the time required to process a single character (i.e., a further increase of SOA does not result in a further decrease in RT), HOFFMAN concludes "... that the time to process a display character is independent of memory set size" (1978, p. 4).

STERNBERG and SCARBOROUGH (1969) found a similar result. In their experiment, subjects searched a sequentially presented array for any one of five characters; letters were presented at a rate of 1/75 msec. If letters are compared to the target set in a serial, exhaustive process with a rate of approximately one comparison per 40 msec (e.g, STERNBERG, 1966), the comparison process would require 200 msec in the case of a five-letter memory set. However, STERNBERG and SCARBOROUGH found that search was much faster than attention; according to HOFFMAN, this process is the "limiting" factor since transfer time is assumed to have a rectangular distribution in the range of 0-200 msec (this assumption is based on the "leading cue" experiments of ERIKSEN and his coworkers). Once transfer of one character is completed, transfer of another one may begin, i.e. the transfer can be carried out in parallel with memory comparison. However, if the transfer of a character is completed while a preceding character is still in the memory comparison stage, the second charactor must queue. HOFFMAN (1978) points out that "... the asymptotic SOA value will depend on the slower of two processes: the attention mechanism or Stage 2 comparison" (p. 8), i.e. the attention (transfer) mechanism. The memory comparison stage is assumed to be free of errors; that is, the main source of errors (misses) is the failure of display elements to gain admission to the transfer list in the preattentive stage of processing as well as the queueing time exceeding iconic memory duration (i.e., "... the process limitation affected by presentation rate is the ability to transfer items from a rapidly fading trace (iconic memory) to a more permanent store (STM)", HOFFMAN, 1979, p. 324).

In a further study, HOFFMAN (1979) tested some consequences of this two-stage model. According to this model, the transfer of elements from iconic memory to short term memory is not a random process, but guided by the initial parallel processing. HOFFMAN predicted that

"... If the signal/noise ratio is high, the target item will be the first element transferred, leading to small effects of presentation rate on positive trials" (1979, p. 325). In an experiment designed to test this prediction, target letters were embedded in two types of context: The letter context used in the previous experiments (varied mapping) and a symbol context with the character "$" presented at nontarget locations (consistent mapping); on negative trials in the symbol context condition, either a single, nonmemory set element letter was presented among 7 $-characters or all eight characters were $s. Array presentation was either simultaneous (0-msec SOA) or sequential (75-msec SOA between successive frames). Memory set size varied from 1 to 4.

The detection accuracy results for the letter context replicated the previous experiments, i.e. accuracy was lower for simultaneous than for sequential presentation and decreased with increasing memory set size. Accuracy in the symbol context did not show an effect of presentation mode and memory set size.

The RT results for the letter context also replicated those of the previous experiments. The prediction for the symbol context (with a single nontarget letter among $s on negative trials) was that there would be no advantage of sequential over simultaneous presentation, but an effect of memory set size (since a memory comparison would be required to determine whether the single letter was a target or nontarget set element). As expected, there was an effect of memory set size, and RTs in the sequential condition were not faster than in the simultaneous condition. However, unexpectedly, RTs were faster for simultaneous than for sequential presentation, both for positive and for negative trials. There was also such an advantage for simultaneous presentation in the symbol context condition with only $s on negative trials; there was no effect of memory set size.

To explain the advantage of simultaneous over sequential presentation in the symbol context, HOFFMAN (1979) suggests that in addition to the parallel (preattentive) memory comparisons in the first stage "... there must be a prior, parallel stage which is sensitive to 'global' features of the pattern, those features not depending on memory comparison. This stage is more efficient with more simultaneous identical patterns" (p. 326). This accounts also the absence of an effect of memory size in the symbol context with $-characters only on negative trials, for "... Memory comparison is not required when a prior parallel analysis can efficiently provide information on the presence or absence of a target" (p. 326).

In summary, HOFFMAN suggests, in analogy with the model of NEISSER (1967), that there is a parallel, preattentive stage of processing accomplishing the detection of spatial periodicity and/or carrying out memory comparisons independently for each input element. If periodicity detection is not sufficient and if a single one of several memory set elements must be detected, "... the outputs of several filters (i.e., memory set elements represented as filters) are integrated, which increases the noise in the detection process and lowers the signal/noise ratio" - the more, the larger the memory set. A subject making a desicion at this point (the optimal decision procedure is to sum the similarity values corresponding to each display element and compare the sum to a criterion), behaves as a CM subject. However, when signal and noise elements are similar or in VM tasks, responding on the basis of preattentive processing would result in high error rates. To reduce error rates, display elements can be submitted to a second discrimination process which is slower, but more accurate. The transfer of display elements can either be controlled internally (preattentive processing; order of transfer according to similarity values) or externally (spatial cues, e.g. the bar marker used by ERIKSEN and his coworkers).

In a further series of experiments, HOFFMAN, NELSON and HOUCK (1983) investigated the role of attention in CM tasks. The basic technique was to pair a CM task with a variety of concurrent visual discrimination tasks and examine the pattern of dual-task interference.

In the first experiment, the search task required a decision as to whether or not a single target digit was present in a display of distractor letters (3 letters on positive and 4 on negative trials; elements appeared at four locations in a circular array with a diameter of 4.27 deg.), and the second task, flicker localisation, required the subject to determine which one of four small lights, adjacent to letter elements, was briefly interrupted. Subjects were instructed, in different conditions, to emphasize the one or the other task (e.g., "give 90% of your attention to the search task and 10% to the flicker task"), and the POC (Performance Operating Characteristic) curves were generated. The rationale of the POC technique is that if two task do not share a common resource, dual-task performance should be equal to single-task performance; the degree of the deviation from the "independence point" provides a measure of dual-task interference.

HOFFMAN et al. found that for flicker localisation, accuracy (d') showed dual-task interference in all instruction conditions (90/10, 50/50 and 10/90), while the search task showed interference only when major emphasis was placed on the flicker detection task. Search task RTs (i.e., the latencies for correct decisions, related to performance in the flicker task) showed dual-task interference even with partial attention to the flicker task; increasing attention to the flicker task produced a linear trade-off in performance. Performance (i.e., accuracy and RT) was higher for memory set size 1 than for memory set size 4; dual-task interference was independent of memory set size. Accuracy of flicker localisation was impaired on positive trials, in all instructional conditions ("intrusion effect"). Further, accuracy of CM target detection was improved by 0.08 if the target digit appeared adjacent to the flicker, also in all instructional conditions ("adjacency effect").

Performance in the CM task met several criteria presumed to indicate "automatic detection": (1) RT slopes for positive and negative trials did not differ; (2) effects of memory load were small, i.e. 0.5 as compared to 0.8 d'-units in a comparable CM condition of SCHNEIDER and SHIFFRIN (1977); (3) the intrusion effect occurred in the first sessions and did not change in magnitude with practice, i.e. the "automatic target" could not be ignored even when less emphasis was placed on letter detection; (4) stable performance was reached after sessions 3 and 4, i.e. RTs did not improve over the subsequent 16 sessions of practice; however, dual-task interference was independent of practice.

The finding of impaired "automatic detection" (RT and accuracy measures) in dual-task conditions lead HOFFMAN et al. (1983) to conclude that "... both the motor output as well as earlier discrimination processes associated with automatic detection depend on a limited-capacity process"; further, the finding that detection of "automatic targets" is improved when they occur adjacent to a transient stimulus suggests that "... detection of CM targets is affected by the location of visual attention" (p. 391).

In the second experiment, HOFFMAN et al. further investigated the role of spatial attention by increasing the spatial separation between the two tasks, i.e. by locating the concurrent task, which required determination of the direction of a 0.22-deg. displacement of a dot, at the centre of fixation. HOFFMAN et al. found that even partial attention to the dot-displacement task was associated with a large decrement in search performance. Unlike the first experiment, performance in the dot displacement task was independent of the presence or absence of the target digit, i.e. the intrusion effect was eliminated.

HOFFMAN et al. suggest that after determining the dot displacement in the centre (the displacement information was presented for only 7 msec and masked about 48 msec after the onset of the character array), attention is switched to the periphery to encode the search information. Attention switching, however, is a time consuming process which had to be completed before the onset of the post-display masks about 126 msec after array onset. The finding that the intrusive effect of automatic targets was absent with a spatially disparate, attention demanding task in the centre indicates, according to HOFFMAN et al. (1983), that "... spatial attention affects the activation of internal target templates" (p. 396).

The third experiment of HOFFMAN et al. attempted to trace the shifts of attention to automatic targets more directly. A single acuity symbol, a small U-shaped character, could appear adjacent to the location of one of the display elements, either in the "same" frame or in the "successive" (i.e., subsequent) frame which presented the masks. The concurrent task was to report the orientation of the U-shaped symbol (symbol exposure time was about 67 msec and duration of the display array was about 116 msec).

HOFFMAN et al. found that when the symbol occurred in the same frame, accuracy was reduced for both tasks in dual task conditions. However, when the symbol occurred in the subsequent frame, digit search accuracy showed little impairment. Both in same and successive frame conditions, increasing the emphasis placed on the symbol orientation task improved performance (however, without loss in search accuracy for the successive frame condition). Further, both in same and successive frame conditions, performance in the symbol orientation task was impaired on (positive) CM target trials; on (negative) no-target trials or, less marked, when the CM target was not detected ("misses"), performance in the symbol orientation task was enhanced (intrusion effect). When the symbol occurred adjacent to a CM target, there was a substantial improvement in orientation accuracy for the successive frame condition, but no improvement for the same frame condition (adjacency effect).

This suggests that "... correct detection of a CM target is accompanied by a shift of attention to the target's area"; this shift enhanced performance in the symbol-orientation task when the symbol occurred in close spatial proximity to the CM target on the subsequent frame (but not on the same frame since the shift requires a substantial time). Further, "... This experiment also verified that the ability of automatic targets to interfere with other concurrent discriminations depends on information for both tasks sharing the same field of attention" (HOFFMAN et al., 1983, p. 400).

HOFFMAN et al. (1983) conclude that "... detecting or locating consistently mapped targets, a task thought to be 'automatic' ..., makes extensive use of one or more limited-capacity processes". Their findings are consistent with the two-stage model proposed by HOFFMAN (1978, 1979). However, HOFFMAN et al. emphasize the role of the second stage which is conceived of as "... an episodic representation which can support the awareness and report of the target's occurrence and location". Establishing this second representation is directly dependent on the role of spatial attention "... in controlling the transfer of information from the first to the second stage". In other words, "... spatial attention is a fairly late process that is guided by information derived in the first stage".

In the third experiment, only correct detections of automatic targets resulted in a shift of attention to the target area, improving discrimination of another character when it occurred spatially adjacent to the target and followed in time. But the (automatic) intrusion effect in this experiment was almost independent of whether or not the target was actually detected; further, it was rapid enough to impair discrimination of a shape presented in the same frame as the automatic target; that is, even though the ability to report the presence of the target was dependent on the instructional emphasis placed on the search task, the intrusion effect was independent of instructional variations. Thus, the allocation of attention to the target location "... seems to determine whether information extracted in the first stage is preserved long enough to be the basis for report".

It cannot be ruled out that "... spatial attention also plays some role in establishing the quality of Stage 1 representation". For example, the finding in the second experiment that the intrusive effect of automatic targets is eliminated when they occur outside the narrow focus of attention (at the centre of the display) could be taken as evidence for this possibility.

That intructions to emphasize a concurrent task impair detection of automatic targets might suggest "...

the presence of a second limited-capacity process (in addition to and independent of spatial attention) ... we interpret this second limited-capacity process as reflecting differential activation of internal representations prior to each trial (which) may provide the 'mapping' between a stimulus and the task-relevant information that must be retained in memory in order to perform the task" (all quotations from HOFFMAN et al., 1983, pp. 404-407).

Very similar notions of a first, parallel stage of processing and a second, limited capacity stage have been proposed by DUNCAN (1980a, 1981, 1985).

According to DUNCAN (1980a), at the first level simultaneous stimuli are fully identified in parallel without effects of divided attention; information derived at this level includes form, colour, size, position and also aspects of meaning (e.g., letter-digit classification). However, "... though all this information is derived (so that the further action of the system can depend on it), none can yet serve as the basis for response. No reportable perception of any sort has been formed".

Information at the first level is susceptible to visual masking and decay, so that it must be passed on to the second level in order to be preserved. This transfer is accomplished by a limited capacity system which cannot deal efficiently with simultaneous stimuli (i.e, not all elements from a single brief exposure can be passed on). "Thus some selection schedule is needed to define which stimuli should be taken. Potentially any information derived at the first level could serve as the basis for selection".

In search tasks, only targets, i.e. stimuli with the attribute(s) defining the "target", "... will usually pass into and compete for the limited-capacity system". "... Emergence of a stimulus at the second level creates a reportable perception" (i.e., it "pops out" from the array into awareness) and can be stored and acted upon by "conscious" operations. Since the stimulus at the second level is a percept based on first-level processing, "... There is no way ... for the second level to know whether information received from the first level is accurate or inaccurate" (all quotations from DUNCAN, 1980a, pp. 284-285).

DUNCAN supports this model mainly by studies which required search for multiple targets. DUNCAN (1980a) presented brief displays of four characters arranged to form a plus sign (vertical and horizontal limb) centred on fixation (character eccentricity was 1.75 deg.). Displays consisted of digit targets (0, 1 or 2 digits) among letter nontargets (consistent mapping); each limb could contain either none or one target. There were two presentation conditions: simultaneous and successive. In the successive condition, characters at the opposite locations in limb A, indicated in advance by bar markers, were presented first (with the positions of limb B filled by masks); and 500 msec after termination of the limb A characters, the characters at the opposite locations in limb B, also indicated in advance, were displayed. Bar marker indicators were presented for 250 msec. There were two tasks: combined and separated. In the "combined task", a single response key was to be depressed if any target was detected. In the "separated task", there was one key for targets detected in the first limb and another key for the second limb; the limb designated "first" for a given subject in the successive condition was also designated "first" in the simultaneous condition, both for key assignment and for data analysis. Target exposure duration was 15-20 msec.

For the combined task, DUNCAN found a slight, but reliable effect of divided attention, i.e. accuracy was higher by approximately 0.3 d'-units for successive than for simultaneous presentation. Further, detection probabilities were consistent with the assumption that the two limbs were examined separately and independently as well as with equal accuracy. For the separated task, the effect of divided attention was more marked, i.e. the advantage for successive over simultaneous presentation was of the order of 0.7 d'-units. In the simultaneous condition, performance for the two limbs was far from independent: For each limb, accuracy was much lower when the other limb contained a correctly detected target (a "hit") than when it contained correctly rejected nontargets (a "correct rejection"). The difference between successive and simultaneous presentations was approximately 1.0 d'-unit with concurrent hits, but only 0.3 d'-units with concurrent correct rejections.

In a second experiment, DUNCAN (1980a) showed that the requirement in the separated task of Experiment 1 to report both the presence of a target and its location (limb) was not responsible for the interference effect of simultaneous targets. (In this experiment, the task was to indicate only whether the display contained "0 versus 1" targets or "1 versus 2" targets.)

DUNCAN (1985) repeated Experiment 1 requiring subjects to detect targets defined by a simple feature: tilt. Targets were tilted by 45 deg., either clockwise or anticlockwise, with the direction of the tilt determined randomly; nontargets were vertical lines (separated task). DUNCAN found essentially the same results as in Experiment 1. Again, DUNCAN could show in a further experiment (simultaneous presentation only) that the requirement to report the presence and location (limb) of the targets was not responsible for the finding that in the simultaneous condition, performance on each limb was markedly impaired when the concurrent event (i.e., the event of the other limb) was a hit than when it was a correct rejection.

The fact that DUNCAN found consistent advantages of successive over the simultaneous presentations (divided attention effect) is at variance with SHIFFRIN and his coworkers (e.g., SHIFFRIN and GARDNER, 1972; SHIFFRIN, GARDNER and ALLMEYER, 1973). DUNCAN discusses several reasons for this. However, an important reason not mentioned by DUNCAN might be that he used bar marker indicators which might be more effective in guiding reorientation of spatial attention than preknowledge of the sequence of the limbs on its own.

The most important finding of these experiments is, according to DUNCAN, that an increase the number of targets in the display produces a substantial decrease in performance. "... Nontargets can be rejected in parallel after preselective processing; hence the number of nontargets in the display has little effect. Targets, however, must pass on to the limited capacity system" (DUNCAN, 1985, p. 91). And: "... the distinction between a preselective stage, at which nontargets are rejected and a limited capacity stage to which targets must gain access if they are to be reported, is as important for the detection of simple feature targets as for the detection of digits and letters" (p. 94). Thus, DUNCAN's "late selection" theory of target search is similar to those theories (e.g., SHIFFRIN and SCHNEIDER, 1977; HOFFMAN, 1978) which propose that "... targets 'draw' attention or limited-capacity processing to themselves" (DUNCAN, 1980a, p. 292); elsewhere he states: "The experience is that the target is only 'seen' when it 'draws attention' to itself" (1985, p. 91).

However, DUNCAN's theory disagrees with the view that only simple physical stimulus characteristics are extracted at the first level of processing so that only these can serve as the basis for selective access to the limited capacity system. According to HOFFMAN's (1978, 1979), preselective processing is inaccurate and serves to direct the "best candidates" to the second stage where a more accurate decision is made. Restated, "... access to the second stage is probabilistic: Access probability is greater for targets than for nontargets, but nonzero for both" (DUNCAN, 1985, p. 94).

DUNCAN (1985) attempted to test this suggestion, reasoning that "... If it sometimes happened, in the simultaneous condition, that nontargets from one limb B gained access to the limited capacity system but were then (on more careful analysis) correctly rejected, performance on limb A, for all trials with a concurrent correct rejection, could not be as good as performance in the successive condition, in which the limited capacity system was never occupied by material from limb B during the time that limb A was presented" (p. 94). The data from the line-tilt experiment showed that with concurrent correct rejections of limb B, performance for limb A was not lower in the simultaneous condition than in the successive condition; however, in the digit-search task (DUNCAN, 1980a) there was a slight loss for the simultaneous relative to the successive condition (of the order of 0.3 d' units). DUNCAN (1985) concludes that the process of keeping nontargets out of the limited capacity system is perfect if the defining/reported attribute of the target is a simple feature, but a "little inaccurate" if the defining/reported attribute is more complex.

An important aspect of DUNCAN's theory is the notion of a "selection schedule" (1980a, 1981) which is responsible for choosing a first-level stimulus representation and passing it through the limited capacity system to the second level. This is a process which "... Phenomenally ... would correspond to directing attention to the stimulus" (1981, p. 91). According to DUNCAN, many different schedules can be implemented, amongst other stimulus properties (e.g., colour, size, form) selection based on advance knowledge of spatial position and adjacency to a bar marker (e.g., POSNER, NISSEN and OGDEN, 1981; ERIKSEN and HOFFMAN, 1973).

Although first-level processing is assumed to be parallel across stimuli simultaneously present in the visual field, this does not imply that different stimulus properties are all derived with equal speed and/or accuracy and that all are equally effective in guiding access to the limited capacity system. Rather: "Selection schedules will vary in efficiency" (1981, p. 91). Thus, the question of the relative efficiency of different selection schedules is purely an empirical one.

For instance, the finding that even when the target is the only stimulus presented in an otherwise blank field, selection based on advance knowledge of spatial location is more effective than selection based on stimulus properties which have to be derived after arrival of the target relates to the question of the relative efficiency of selection schedules. However, it has no bearing on the question of an "early" perceptual role for attention. In other words, any finding that selection based on advance knowledge of spatial location is more efficient than other selection schedules cannot be taken as support for the idea that attention can facilitate the very "early" stages of perceptual analysis. DUNCAN (1981) concludes that "... If (a limit to the completeness or accuracy of preattentive perceptual analysis) is, in fact, to be found, it cannot be by experiments on the improvement of performance by advance knowledge of target position" (p. 93).

1.10. Spatial Attention and Signal Detection Theory

Recently, SHAW (1980, 1982, 1984; SHAW, MULLIGAN and STONE, 1983) has developed "attention theory", which appears to differ from the approaches discussed so far. In accordance with signal detection theory (GREEN and SWETS, 1966), attention theory assumes that there are (at least) two successive functional stages between stimulus and response: coding and decision. In the coding stage, each stimulus is converted into an internal representation (this stage may consist of a number of substages); and in the decision stage, the internal representation is used to determine the response. The decisive question which attention theory attempts to address is whether attention influences the quality of the stimulus representation generated by the coding process and/or whether it influences the decision stage.

SHAW (1980, 1982, 1984) has been mainly concerned with the dispay size effect, i.e. the decrease in the probability of correct decisions (e.g., target present - target absent) that results from an increase in the number of separate input sources containing nontarget information (SHAW, 1984, extended attention theory also to the effect of probabilistic priming). Assuming that there is a strength associated with the stimulus (target or nontarget) at each location representing the degree of similarity between the internal stimulus representation and the target, and assuming further that the strength (probability) distributions for targets and nontargets overlap, then with an increase in the number of nontargets there is also an increase in the probability that the strength of at least one nontarget exceeds the strength associated with the target. Thus, for instance, if the task requires detection and localisation of a target and the observer chooses the location with the largest strength, there is an increase in error rate with increasing display size even if the strength distributions remain unchanged.

The basic approach of attention theory to account for the increase in error rates with increasing display size is to generate predictions as to the magnitude of the performance decrement expected on the assumption that the losses were entirely due to decision errors. If the observed decrement exceeds the predicted losses, then attention theory concludes that the increase in display size (also) reduces the quality of the internal representations generated by the coding process; the reduced quality of the internal representation is conceived of as greater overlap between the strength distributions of target and nontarget.

SHAW (1982) discusses a number of decision models for integrating separate sources of information to form a simple "target present - absent" response. There are two basic classes of decision model: "first order integration models" and "second order integration models", with the "order" of a model being determined by the number of independent internal codes postulated prior to the integrated code.

The "order 1 code" X for a given source of information is a sensory (or iconic) representation of the stimulus which may be influenced by the amount of attention allocated to this source, the energy level of the stimulus and the type of stimulus presented (e.g., target or nontarget). In first order integration models, the code at the next level is the "integrated code" Y, e.g. a weighted average of the Xs associated with the separate sources of information. The third code, the "response code" R is conceived of as a binary decision (e.g., target present - target absent) requiring a comparison of the integrated code Y to a criterion beta; it is assumed that if Y is equal to or greater than beta a positive response is given, and if Y less than beta a negative response. Second order integration models differ from the first-order models in that they postulate an additional "order 2 code" X' between the "order 1 code" X and the "integrated code" Y. The "order 2 code" X' is considered as a binary categorization of the "order 1 code" X requiring a comparison of the separate Xs associated with each source to a decision criterion beta (e.g., "detect state" X' = 1 or "nondetect state" X' = 0). The beta criterion (i.e., the "category boundary") may be different for the different sources of information and is assumed to be under subject control. The "integrated code" Y is typically assumed to be the sum of the X's, and the response code R is a binary decision requiring a comparison of Y to a criterion beta.

In first order integration models the "order 1 code" X (i.e., the internal stimulus representation) may be considered as discrete (e.g., two-state, three-state, integer-state) or continuous. An example of a two-state model is LUCE's (1963) "low-threshold" model which assumes that the internal representation of a stimulus is in either a detect or a nondetect state; in contrast to "high-threshold" models, low-threshold models allow a detect state to occur when no target is present (in high-threshold models a detect state never occurs when no target is present; in both classes of model, a detect state may or may not occur when a target is present). SHAW (1982) generalized LUCE's two-state model to multiple sources of information, assuming that a positive response is given whenever a criterion number of sources is in a detect state (otherwise, a negative response is given; "low-threshold independent decisions model"). An example of continuous-state model is the Gaussian integration model of GREEN and SWETS (1966) which considers the "order 1 code" X as a random variable; the set of possible values for such a random variable forms a onedimensional continuum, and the probability of a particular value is nonzero both for targets and for nontargets. Target and nontarget probability distributions have Gaussian functions, with the target distribution being displaced to the right of the nontarget distribution. In tasks involving multiple sources of information, it is assumed that the random variables associated with the individual codes Xs are independent and identically distributed. These codes are then summed to form the integrated code.

In second-order integration models, the "order 1 code" X (i.e., the internal stimulus representation) may also be considered as discrete (integer-state) or continuous. An example of a continuous-state second order integration model is SHAW's (1980) "independent decisions model". The assumptions underlying this model are similar to those of the Gaussian integration model, except that the probability distributions of the independent random variables associated with the stimulus representations may or may not be Gaussian and may or may not be identical (i.e., in contrast to the Gaussian integration model, attention may influence the stimulus representation).

SHAW (1982) suggests that there are several possible strategies for allocating limited capacity attention to separate sources of information. The "fixed-sharing" model assumes that attention is divided among locations (sources) within a given trial and that the allocation of attention does not change from trial to trial. A second model, the "all-or-none mixture model", assumes that on a given trial attention is exclusively allocated to one location, and the location from which information is obtained varies in a probabilistic manner across trials ("mixture" of rules for attention allocation).

SHAW (1984) investigated the display size effect, i.e. the magnitude of the increase in error rates with an increase of the display size from two locations (sources of information) to four locations (the target could appear at only one location on a given trial). Both a consistent mapping and a varied mapping letter detection task and a simple luminance detection task were investigated. The task required judging the location of the target. The probability of target occurrence at each location was 0.5;

displays were of size n = 2 or n = 4 and could contain 0, 1, ..., or n targets, with the presence of a target at one location being independent of its presence at any other location. The four locations were arranged at the corners of an imaginary square (1.75 deg. diagonal separation); for n = 2, trials were blocked by the positive and negative diagonal. For the consistent mapping task, the exposure time needed for a performance level between 0.80 and 0.95 correct location judgements (n = 2) was 10 msec; the corresponding duration for the varied mapping task was 75 msec. In the luminance detection task, two (n = 2) or four (n = 4) lights at the corners of the square were continuously illuminated; the target was a luminance increment (brightening) of a particular light over the baseline level.

The decisive question was as to when it is possible to reject the null hypothesis that attention has no effect on the quality of the internal stimulus representation. To answer this question, SHAW (1980) derived a theoretical "boundary" function relating the (decrement in the) probability of a correct location judgement in the four-location task to the probability of a correct location judgement in the two-location task. This boundary function represents the maximum performance decrement attributable to the decision process alone (i.e., without an effect of display size on the parameters of the strength distribution of the internal stimulus representation; the "maximum" is taken over all possible strength distributions, since the expected decrement attributable to the decision process varies from distribution to distribution). The boundary function was based on the following assumptions:

(1) "... the signal location chosen is the one evoking the strongest impression of the target's presence" (i.e., the "order 1 code" random variable with the largest value);

(2) the mean and variance of the target and distractor strength distributions remain unchanged with increases in set size (p. 291).

On the basis of these assumptions, the probability P(N) that the target random variable is larger than any of the N - 1 distractor variables is always equal to or greater than the result of raising P(2), i.e. the probability of a correct location judgement in the two-location case, to the power of N - 1.

The (first-order) Gaussian model (which is based on the assumptions of normally distributed random variables, equal variance for the target and distractor distributions and no effect of display size on the mean and variance of these distributions) predicts a performance decrement with the increase in display size from 2 to 4 which is lower than the maximum decrement represented by the boundary function. SHAW (1984) found that this model provided a good fit for the data of the simple luminance detection experiment. SHAW (1984) concludes that for simple luminance detection the entire, display size effect can be accounted for in terms of the decision process and the detection of luminance increments is not capacity limited.

However, for the letter detection data (both consistent and varied mapping) the actual performance decrement exceeded the maximum decrement represented by the boundary function. Two models provided a good fit for the data of the letter detection tasks: A two-state model and a continuous-state model, both assuming that attention does influence the parameters of the two-valued or, respectively, continuous-valued random variables. SHAW (1984) concludes from the fact that the performance decrement exceeded the boundary function not only for the varied mapping, but also for the consistent mapping task, that both controlled search and automatic detection use limited capacity attention resources and that "... training with a consistent-mapping (task) produces an increase in the efficiency with which processing capacity is used (shorter exposure duration in comparison with the varied mapping task), but not the bypassing of limited-capacity processes" (p. 117).

SHAW (1984) refers to the two-state model also as "capacity allocation" model (see also SHAW and SHAW, 1977, and KINCHLA, 1980). Attention is assumed to be a finite quantity phi which may be partitioned among locations without changing the total amount available. The probability of a detect state for a particular location given that it contains the target and a certain amount of attention phi(k) has been allocated there is assumed to be b(phi(k)) = 1 - e**-phi(k). And the probability of a nondetect state for a particular location given that it contains a nontarget and phi(k) has been allocated there is q(phi(k)) (q(phi(k)) is assumed to be nonzero). Both b(phi(k)) and q(phi(k)) are assumed to be continuous and increasing (concave).

SHAW (1984) refers to the continuous-state model also as "sample size" model (see also LUCE, 1977). The sample size model, which treats sample strength as a continuous Gaussian random variable, is based on the assumption that there is a fixed number N of strength samples (observations) available to be divided among all locations. The internal random variable X for a particular location k given presence of a target or of a distractor there is then the sample mean based on a subset of N(k) observations (since the total number N of observations over all locations remains constant), and the variance of each sample depends directly on the size of this subset: The variance for a particular location is equal to the variance of a single observation of the random variable (a constant that depends on the stimulus conditions) over the number of samples allocated to this location. With an increase in the number of locations, fewer samples can be allocated to each one, resulting in an increased variability in any sample strength statistic, e.g. the sample mean. Restated, with increasing display size the discriminability between target and nontarget at each location would decrease and the reduced discriminability would, in turn, produce an increase in the probability that a nontarget strength at one location exceeds a target strength at another. (The number of strength samples N is a discrete, integer-state quantity; the argument does not change if N is replaced by the continuous attention quantity phi.)

As SHAW, MULLIGAN and STONE (1983) point out, "... the real difference between two-state and continuous-state models ... is whether a subject's criterion or threshold is fixed or can be varied"; they assume that "... the (two-state) model applies whenever an initial stimulus code involves categorization of a stimulus into one of two possible states for the purpose of making a decision. Our particular tests of the model do not address the question of whether this is the only code, but only whether the threshold is fixed" (p. 348).

The letter detection data of SHAW (1984) favoured the sample size and the capacity allocation model, but did not allow her to distinguish between them. The study of SHAW et al. (1983) was an attempt to separate these models. This study involved three conditions (varied mapping letter detection): Display size was either 2 or 4; when it was 4, subjects were instructed either to "divide attention" between all four locations or to "focus attention" on only two locations (i.e., the locations on the positive or negative diagonal of an imaginary square).

With display size 2, there were no targets on a given trial, one target in the one or the other location, or two targets in both locations; with display size 4, there were either no targets, one target in one diagonal but none in the other, or one target in each diagonal. The task required indication of the target location (n = 2) or the target diagonal (n = 4).

For the two-state (capacity allocation) model, the decision making assumptions were as follows: With n = 2, the location chosen is that for which there is a detect state; if neither or both locations are in a detect state, one location is chosen at random. With n = 4 and the focused attention instruction, the attended diagonal is chosen if either location on this diagonal results in a detect state; otherwise, the nonattended diagonal is chosen. With the divided attention instruction, the diagonal with the greatest number of detect states is chosen; if the diagonals have the same number of detect states, selection is random.

For the continuous-state (sample size) model, the following assumptions were made: The location chosen is that for which the associated random variable is the maximum. With n = 4 and the focused attention instruction, the attended diagonal is chosen whenever one of the associated random variables exceeds its criterion; otherwise, the unattended diagonal is selected. With the divided attention instruction, the diagonal chosen is that for which the associated random variable is the maximum.

SHAW et al. formally demonstrated that the two-state and the continuous-state model lead to different predictions for the accuracy of the location judgement under the divided and the focused attention instruction (n = 4). The two-state model predicts that localisation accuracy is lower for the divided than for the focused attention instruction (single target trials only), while the continuous-state models predicts that localisation accuracy for the focused attention instruction is lower than or equal to that for the divided attention instruction.

The prediction for the two-state model, however, depends upon whether the subjects followed the instruction to focus attention on one diagonal. To test this, the data for the focused attention condition (n = 4) was compared with the n = 2 condition: If subjects focus attention one diagonal, detection accuracy for the n = 4 condition without targets in the attended diagonal should not differ from that in the n = 2 condition with no targets; this should hold whether targets are present or absent in the ignored diagonal. Further, detection performance for a diagonal with one target should be identical for the n = 2 and n = 4 condition.

SHAW et al. found that the magnitude of the display size effect (i.e., the decrement in localisation accuracy in the n = 4 divided attention condition as a function of localisation accuracy in the n = 2 condition) could be equally well accounted for by the two-state and the continuous-state model. This replicates the findings of SHAW (1984) and suggests that "... as the number of display locations (independent sources of information) is increased from two to four, the noisiness of information obtained from each location increases" (p. 348).

As to the comparison between the focused and the divided attention instruction (n = 4), the important finding was that for all four subjects, localisation accuracy for the divided attention condition equalled or exceeded that for the focused attention condition; this result favours the continuous-state model over the two-state model. However, the generality of this conclusion was weakened by the fact that only two of the four subjects were completely successful in following the focused attention instruction. (A further finding was that in the n = 2 condition, all subjects used an attention sharing strategy, i.e. none used an all-or-none mixture strategy).

In summary, in terms of SHAW's "attention theory", attention is "... a limited resource (..., processing capacity, search effort, search time) available for processing" (SHAW et al., 1983, p. 340). The allocation of the finite-quantity attention capacity phi is assumed to be under the control of the subject. That is, the total processing capacity available cannot be altered, for instance, by changing the luminance level of the display since this is "... analogous, in a real-world search problem, to altering visibility (e.g., the effect of fog) and not the total search effort" (SHAW et al., 1983, p. 350; however, changing the total duration of the display may be viewed as changing phi). The processing capacity allocated to a particular source of information can influence the internal stimulus representation (at least in letter detection tasks). That is, the more limited capacity attention is allocated to a particular source, the higher the discriminability between target and nontarget and vice versa; and preferential allocation of limited capacity attention to one source necessarily increases the "noisiness" for other sources.

The difference between attention theory on the one hand and the models of HOFFMAN and of DUNCAN on the other seems to be that attention theory allows the "coding stage" to be influenced by attention, whereas the models of HOFFMAN and of DUNCAN assume that stimulus coding is more or less complete (i.e., capacity- and error-free), but that the information derived in this stage is only reportable if it is passed on to a second stage through a limited capacity process. In terms of attention theory, however, access to the coding stage information does not appear to be the limiting factor, although the quality of this information may be more or less affected by "noise".

1.11. Overview

The following four experimental chapters address a variety of questions arising from the work reviewed thus far. Chapters 2 to 5 start with their own introduction, focusing on the specific questions investigated. This involves some repetition of the material presented in the preceding sections, but it allows the reader to read chapters independently of each other (and of the general introduction). The following paragraph presents an outline of the questions investigated in Chapters 2 to 5, together with a "guide" to other work providing the context for the present experiments. Thus, readers can go straight to the experimental chapters of particular interest to them; if they require more detailed contextual information than provided in the introduction to each experimental chapter, they could go back to the relevant sections in Chapter 1 whenever necessary.

All experiments applied POSNER and SNYDER's (1975a, b) cost-benefit analysis to a discrimination or detection plus localisation task. Chapter 2 (Experiments 1 to 4) is concerned with GRINDLEY and TOWNSEND's (1968) question of the differential advantage produced by spatial cueing in single and multiple element displays. Effects of SOA, i.e. of the interval between cue and target onset, in Experiments 1 to 4 led to the proposal of a model of spatial attention that postulates an automatic and a controlled orienting component. This model is tested in

Chapter 3 (Experiments 5 to 7) which relates, most directly, to the work of JONIDES (1981; YANTIS and JONIDES, 1984) and SHIFFRIN and SCHNEIDER (1977; SCHNEIDER and SHIFFRIN, 1977). Chapter 4 (Experiments 8 to 10) analyses the relationship between discrimination and localisation accuracy in single and multiple element displays, intending to reveal the search and decision processes underlying performance in Experiments 1 to 4. Search models discussed include TREISMAN's feature integration theory (TREISMAN, SYKES and GELADE, 1977; TREISMAN and GELADE, 1980), HOFFMAN's (1978, 1979; HOFFMAN, NELSON and HOUCK, 1983) and DUNCAN's (1980a, 1981, 1985) late selection theories of attention and SHAW's (1980, 1982, 1984; SHAW, MULLIGAN and STONE, 1983) sample size model. Chapter 5 (Experiments 11 and 12) is concerned with the question of how effectively attention can be divided among display locations, within a single brief exposure, and whether attention affects sensitivity parameters and/or decision criteria. Thus, Chapter 5 relates to the divided attention studies of, amongst others, SHAW and SHAW (1977) and POSNER, SNYDER and DAVIDSON (1980), and it also has important implications for the visual search theories of SHAW, HOFFMAN, DUNCAN and SHIFFRIN and SCHNEIDER.

Chapter 2

The Effect of Visual Attention on Peripheral Discrimination Thresholds in Single and Multiple Element Displays

2.1. Introduction

In many studies on visual selective attention, subjects are induced to "orient" attention to particular locations in the visual field without moving their eyes. One of the most successful techniques for inducing attentional orienting is modelled after a procedure developed by SPERLING (1960) and AVERBACH and CORIELL (1961) to study "iconic memory". A "spatial cue" is presented either shortly before or just as the target appears. These conditions are then compared with that when no spatial cue is provided. Several studies using this technique, in particular the experiments of ERIKSEN and coworkers (e.g., ERIKSEN and HOFFMAN, 1972, 1973, 1974; COLEGATE, HOFFMAN and ERIKSEN, 1974; VAN DER HEIJDEN and EERLAND, 1973) have demonstrated facilitation in accuracy and latency measures for targets at cued locations.

POSNER and SNYDER's (1975a, 1975b) extension of this method to a "cost-benefit" analysis is based on the assumption that alignment of attention with one input necessarily decreases the amount of attention available for other inputs. In studies using this analysis, subjects were provided with a spatial cue indicating that a target would be presented at a particular location with a certain probability. Selective allocation of attention was expected to produce "benefits" on "valid" trials on which the target appeared at cued and "costs" on "invalid" trials on which the target occured at uncued locations.

The predicted costs and benefits have been found in many studies (e.g., POSNER, NISSEN and OGDEN, 1978; POSNER, SNYDER and DAVIDSON, 1980; POSNER and COHEN, 1984; BASHINSKI and BACHARACH, 1980; MAYLOR, 1983). With only one exception, the task in these studies required a simple speeded response to the detection of a suprathreshold luminance increment in an otherwise empty field (BASHINSKI and BACHARACH measured detection accuracy for a near-threshold luminance increment). One reason for preferring a simple detection task seems to be POSNER, SNYDER and DAVIDSON's (1980) observation that in more complex tasks requiring visual acuity (e.g., discrimination or identification) the magnitudes of costs and benefits are reduced. POSNER et al. (1980) concluded that "... spatial cues are very effective for simple RT to luminance increments because this task does not require determining what the event is before responding"; in complex tasks, however, the overall effects get smaller because of "... the necessity of the subjects switching attention from the spatial location indicated by the cue to the internal look-up processes which identify ... or determine the discriminative response" (p. 168).

Another reason for the preference for simple detection stimuli in an otherwise empty field is, again to quote POSNER (1980), the "... usual observation that knowledge of spatial position only helps complex tasks when the field is cluttered" (p. 8) or when there are competing stimuli present in the visual field. The strongest support for this statement comes from GRINDLEY and TOWNSEND's (1968) finding that advance knowledge of target location facilitated recognition only in their "multiple display" (four spatial locations one of them containing the target stimulus, the other three containing distractors), but not in their "single display" (in which the three remaining positions were blank). The task in GRINDLEY and TOWNSEND's experiment (Experiment 1) required subjects to indicate both the location and the orientation of the symbol T (four orthogonal orientations) presented for a limited exposure duration; the distractor stimuli in multiple displays were crosses of the same size and luminance as the target. GRINDLEY and TOWNSEND concluded that "... the role of attention in peripheral vision is rather to ensure that when there are competing messages from other parts of the visual field (multiple stimuli) the messages from the part to which attention is directed are given priority of treatment" (p. 18); it "... seems most profitable to consider the question of attention in peripheral vision as one of filtering the available information from a short-term information store" (p. 19).

However, GRINDLEY and TOWNSEND's experiment is open to criticism. (1) They failed to specify the precise threshold exposure times; they only state that the exposure durations needed to reach the threshold criterion were longer for multiple than for single displays. Thus, the threshold levels may have been incomparable between the two display conditions (e.g., SPERLING and MELCHNER, 1978). (2) Their verbal indication of the target location on foreknowledge trials caused a considerable delay between "cue" and target onset (i.e., a delay in the order of 1-2 seconds according to GRINDLEY and TOWNSEND). In addition, the indication of a quadrant is a rather imprecise location cue for a target presented at an eccentricity of 13 deg. (e.g., JONIDES, 1981). (3) GRINDLEY and TOWNSEND did not mask the display after exposure. Thus, for multiple displays, absence of masks and generally longer exposure times could have allowed a longer build-up of temporal summation, i.e. a prolonged useful duration of iconic storage which could, in turn, have facilitated subsequent read-out processes. (4) The fact that GRINDLEY and TOWNSEND found no "benefit" of foreknowledge in single displays (there is actually a nonsignificant advantage for the condition without foreknowledge) is also puzzling: In their foreknowledge condition the probability of a corrrect orientation guess was 1/4 (no location uncertainty), while in the condition without foreknowledge the probability of a correct location plus orientation guess was 1/16. However, with only 8 observations per display/foreknowledge condition and subject, their results were highly susceptible to random effects.

Thus, it may not be too surprising that later studies of single element displays have demonstrated enhancement both of recognition latency (ERIKSEN and HOFFMAN, 1974) and accuracy measures (SHAW and SHAW, 1977; VAN DER HEIJDEN, SCHREUDER and WOLTERS, 1985) when target locations were known in advance. However, VAN DER HEIJDEN at al. found advantages for the cued location relative to a control condition with a spatially uninformative warning signal of less than 0.05 (probability correct), i.e. considerably less than the advantage GRINDLAY and TOWNSEND (1968) found for their multiple displays. That is, despite the fact that single element displays may benefit from spatial cueing, these studies do not rule out the possibility that the benefits for multiple displays are more pronounced. In fact, a recent RT study by ERIKSEN and YEH (1985; comparison between Experiment 1 and 2) seems to support this. Thus, the findings of GRINDLEY and TOWNSEND merit a more elaborate reinvestigation.

In a pilot study, MULLER (1984) applied POSNER and SNYDER's (1975) cost-benefit analysis to a discrimination plus localisation task adapted from GRINDLEY and TOWNSEND (1968). Single and multiple element displays were presented for their respective 0.75-threshold exposure times. The median exposure times needed to reach the

0.75-level were about 60 msec for the single and 80 msec for the multiple display condition; this difference is in accordance with GRINDLEY and TOWNSEND (1968). The target display was terminated by contour masks. MULLER found significant "benefits" and "costs" in performance for cued and uncued locations. That is, the task proved sensitive to the spatial cueing procedure, a result not demonstrated previously with accuracy as dependent measure. The advantage of cued over uncued locations did not differ reliably between single and multiple displays, a finding which is at variance with GRINDLEY and TOWNSEND. However, there was a tendency for performance in the multiple display condition, in comparison with the single display condition, to be lower for uncued locations and higher for the cued position.

This pilot study did not reveal any reliable effects of SOA (varying cue-target onset intervals) on performance for the cued location (valid trials). When the cue was a transient change in light energy at the indicated position (peripheral cue), there was neither a consistent improvement nor a decline in performance with increasing SOA, such as have been found in choice and simple RT paradigms (e.g., COLEGATE et al., 1973; ERIKSEN and HOFFMAN, 1974; POSNER and COHEN, 1984; MAYLOR, 1983). According to ERIKSEN and coworkers, one should have expected some improvement in accuracy with SOA durations up to 150 msec, reflecting the orientation of attention to the cued position (i.e., in terms of ERIKSEN and coworkers, the focusing of the attentional "zoom lens"). According to POSNER and COHEN, at even longer SOAs there should have been a decline in accuracy, reflecting what they refer to as "inhibition" effect; that is, "... Some part of the pathway from the cued location is reduced in efficiency by the cuing" (p. 537), thus favouring the sampling of areas of the visual field at which there was no previous change in light energy. This decline in performance for the cued location, however, may not occur with "informative" spatial cues, i.e. when the cue reliably indicates the actual target location, since inhibition may then be suppressed by attention. For uncued locations (invalid trials), MULLER's pilot study found a reliable improvement in accuracy with increasing SOA for single, but relatively invariant performance for multiple displays.

2.2. Experiment 1

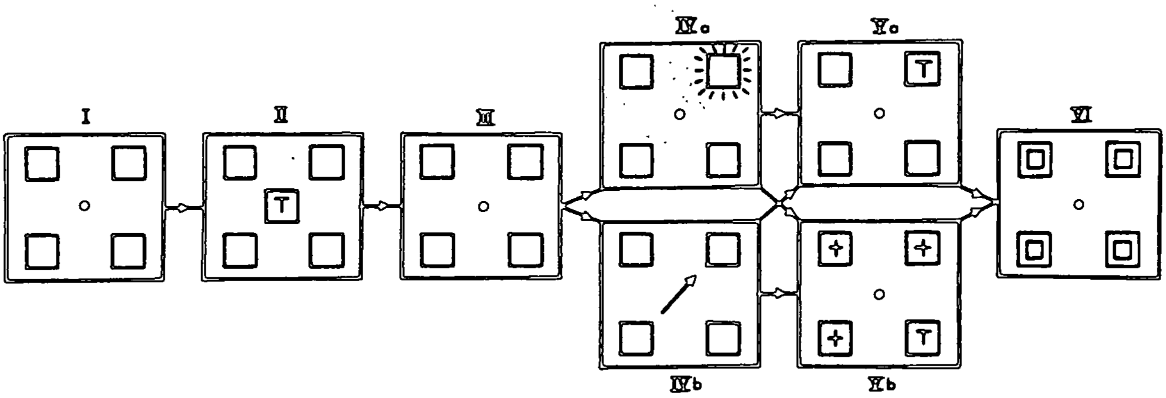
Experiment 1 was designed to investigate three questions raised by this pilot study. The first question concerned the tendency for the performance difference between valid and invalid trials to be greater for multiple than for single displays. That is, might a two-way interaction between display type and cue validity be established under more controlled conditions? The second and third questions of Experiment 1 concerned the effects of SOA on performance for cued and uncued locations; that is, whether the SOA effects found in RT studies (ERIKSEN et al., POSNER and COHEN) and the pilot experiment could be established (valid trials) or replicated (invalid trials). The expectations were as follows: For valid trials, an early improvement in performance and either no change (sustained preparation) or only a modest decrease (inhibition) in accuracy at longer SOAs; for invalid trials, an improvement in performance with increasing SOA for single, but not (or less marked) for multiple displays.

Experiment 1 basically introduced the same factors as the pilot study: display type (single and multiple), cue validity (valid and invalid) and SOA. There was only one type of cue: a brief brightening of the outline of one of the peripheral boxes marking the possible target locations (peripheral cue). In order to map performance as a function of SOA for valid and invalid trials, the SOAs presented ranged between 50 and 200 msec. The experimental design was devised to allow a comparison between single and multiple displays within the limitations of GRINDLEY and TOWNSEND's (1968) procedure; e.g., blocked design and separate determination of the 0.75-threshold exposure durations for the two display conditions.

2.2.1. Method

Apparatus and Materials: Stimuli were presented on a Hewlett Packard 1321A X-Y display with a P 31 phosphor. The CRT was controlled by a CED Alpha (LSI 2/20G) computer through a CED 502 Interface; the display program used was the EMDISP system developed by SHEPHERD (1984). The laboratory was dimly illuminated by an incandescent lamp placed behind the screen and shielded from direct view. The luminance of the stimuli was 0.1 ftL and the luminance of the background of the screen was 0.01 ftL. Observers viewed the CRT from a distance of 115 cm with their heads resting on a chin rest.

Diagram 2.1.: Sequence of frames (I - VI) presented on a given trial



Display and Timing: Diagram 2.1. illustrates the sequence of frames presented on a given trial. Frame I displayed a central fixation dot and four boxes in the periphery. The target stimulus, a T in any of the four orthogonal orientations, appeared later in one of these (frame V). After 500 msec, the central fixation dot was replaced by a central box containing one of the four possible Ts (frame II); this T, displayed for 1500 msec, indicated the comparison stimulus for a given trial. Then, 1000 msec after the reappearance of the fixation dot (frame III), a spatial cue was presented indicating the most likely target location (frame IV). The cue was a 50-msec brightening of the outline of one of the peripheral boxes (frame IVa). There were also baseline trials on which all four boxes were brightened simultaneously; this event indicated that the target was equally likely to appear at all four locations. After variable delays following the onset of the cue (SOA), the target stimulus, a T in the same or a different orientation as the comparison T, was presented in one of the four boxes for a limited exposure duration (frame V). In single displays (frame Va), the three nontarget locations remained empty. In multiple displays (frame Vb), the three nontarget locations contained distractor crosses of the same size and luminance as the target. On valid trials (frame Va), the target appeared at the cued location. On invalid trials (frame Vb), the target occurred at one of the uncued locations. The eccentricity of the target stimuli was 4.4 deg. and their size was 0.25 deg. In frame VI, the exposure of target and distractors was terminated by contour masks; the masks, which were composed of lines of the same size as target and distractors, appeared simultaneously at all locations, independently of the display condition.

Task: After termination of the target display (frame VI), the subjects had to give two responses on a hand-held keypad: First, a same-different response indicating whether the orientation of the target T was the same as or different from that of the comparison T previously presented in the centre, and, second, a position response indicating in which of the four boxes the target T had appeared. The position response immediately triggered the the next trial.

Design and Procedure: The three factors in Experiment 1 were (1) S/M - single/multiple display, (2) V/I - valid/invalid trials, and (3) SOA (6 levels: 50, 75, 100, 125, 150, and 200 msec). Experiment 1 was divided into two sessions, each consisting of two blocks of trials: one block of single and one block of multiple display trials, with their order counterbalanced across sessions and subjects. Each session lasted about four hours. The number of trials totalled 2880, i.e. 1440 single and 1440 multiple display trials (6 x (96 + 96 + 48); SOAs x (valid + invalid + baseline trials)) which were presented in random order. The four orientations of the target T were presented with equal frequency. In half the trials the target T was the same as the memory T, in the other half it was different. The target appeared with equal frequency at each of the four locations. The spatial cue was valid on half the trials and invalid on the other half. The cued location was three times as likely to contain the target as any one of the three uncued locations.

Determination of the Threshold Exposure Durations: At the beginning of each block of trials, target exposure times were determined individually for each subject for the respective display condition. The estimation procedure used was a modified PEST adaptive staircase (FINDLAY, 1978) which aimed at a threshold level of 0.75 on the baseline trials (the threshold trials presented a "neutral" warning signal followed by the target at delays randomly drawn from the set of SOAs in Experiment 1). This procedure was based on joint correct same-different plus correct position responses (i.e., an error was counted if one or both responses on a given trial were incorrect). As a rule, the threshold criterion was reached between the 48th and the 96th trial. In the experiment there were also concurrent baseline trials (fixed exposure duration) in order to provide a check on the validity and stability of the threshold estimates.

Instruction: The subjects were asked to respond as accurately as possible. They were informed that the target stimulus would appear equally often in each of the four boxes, but three times as often at the cued as at one of the uncued locations; further, that the target T would be equally often the same as and different from the memory

T. The subjects were instructed to "attend" to the cued location. They were told to fixate on the central dot during the sequence of frames on a given trial. If they accidentally pressed a wrong response key, they had a later opportunity to correct the response.

Subjects: Four subjects participated in Experiment 1 and also in the subsequent experiments: I.P., N.A., D.C. and H.M. (males; ages 20-28; one with normal and three with corrected-to-normal vision). I.P., N.A. and D.C. were paid 4.0 pounds for each four-hour session; payment was the same in the later experiments. I.P. and N.A. had taken part in the pilot study (MULLER, 1984); D.C. and H.M. received a similar amount of practice in two preexperimental sessions. All four subjects participated in another training session in which the 0.75-threshold exposure durations were estimated repeatedly until they were stable. The following 0.75-threshold exposure times were introduced in Experiment 1 for I.P., N.A., D.C. and H.M., respectively (means of the two sessions): 31, 30, 33.5 and 29 msec in the single and 45, 47.5, 49.5 and 42 msec in the multiple display condition.

2.2.2. Results

The main performance measure analysed in Chapter 2 is the joint probability of a correct position plus a correct same-different response - p(CP,CSD). Section 2.7. (appendix) provides a detailed justification for this measure.

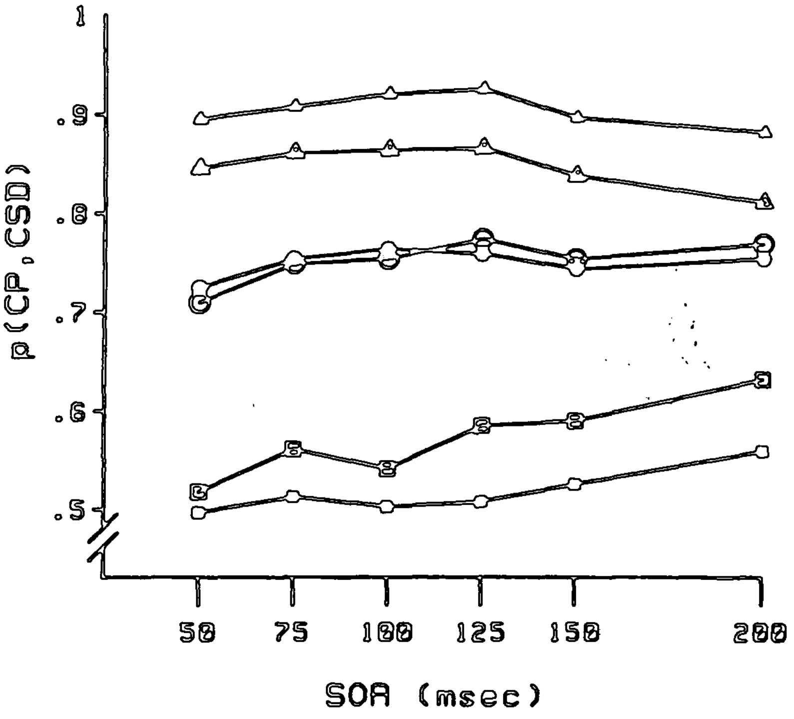
Further, "costs plus benefits", i.e. differences in p(CP,CSD) between valid and invalid trials, were analysed rather than benefits and costs with reference to the ("neutral") baseline condition. This was done because baseline trials were far less frequent than cued, i.e. valid and invalid trials, so that they were relatively unexpected; in addition, the simultaneous brightening of the outline of all four peripheral boxes on baseline trials produced a greater energy change in the display than did a peripheral cue on its own. Thus, performance on baseline trials may be affected by factors (e.g., warning signal and alerting effects, etc.) which may have no (or less) influence on cued trials and make an analysis in terms of costs and benefits problematic (see JONIDES and MACK, 1984).

Figure 2.1. presents the mean values of p(CP,CSD) as a function of SOA, separately for single and multiple display valid and invalid trials; figure 2.1. also presents p(CP,CSD) for single and multiple display baseline trials. (See figure 2.5. in section 2.7. for the corrected values of p(CP,CSD).)

The values of p(CP,CSD) were arcsin-transformed (WINER, 1971) and evaluated in a three-way ANOVA involving the factors S/M (single/multiple), V/I (valid/invalid) and SOA. This ANOVA revealed the following effects to be significant: (1) V/I: $F(1,3) = 325.29$, $p < 0.001$; (2) SOA: $F(5,15) = 14.98$, $p < 0.001$; (3) S/M x V/I:

$F(1,3) = 18.07$, $p < 0.025$; (4) V/I x SOA: $F(5,15) = 40.62$, $p < 0.001$; (5) S/M x V/I x SOA: $F(5,15) = 3.10$, $p < 0.05$. (A separate ANOVA of arcsin p(CP,CSD) for the baseline trials, with the factors S/M and SOA, revealed no significant effects.)

Figure 2.1.: p(CP,CSD) as a function of SOA, separately for single (S: open symbols) and multiple (M: closed symbols) displays and for valid, baseline and invalid trials (V: triangles; B: circles; I: squares)



The significant main effect of V/I is due to the fact that p(CP,CSD) is generally higher when the target appeared at the cued rather than at an uncued location. The significant S/M x V/I interaction agrees with the prediction derived from GRINDLEY and TOWNSEND (1968): The overall difference in p(CP,CSD) between valid and invalid trials (V-I difference) is greater for multiple than for single displays. This is due to the fact that performance is higher for multiple than for single displays on valid trials ($p < 0.001$) and lower for multiple than for single displays on invalid trials ($p < 0.05$; all comparisons are based on the TUKEY-test, unless stated otherwise). As can be seen from figure 2.1., the advantage of multiple over single display valid trials appears quite invariant over the entire range of SOAs.

With regard to the effect of SOA on valid trials, it was expected that p(CP,CSD) would increase initially and reach its optimum at a SOA of the order of 150 msec; thereafter, either remaining constant at optimum or decreasing to some extent. As figure 2.1. shows, there is some improvement between the 50 and 125-msec SOAs (at the 50-msec SOA, p(CP,CSD) is significantly lower than at the SOAs of 100 and 125 msec: $p < 0.01$). However, this initial increase is small, i.e. the advantage for the cued position is already present at the very short SOAs and does not improve substantially. After the SOA of 125 msec, p(CP,CSD) shows a tendency to decrease (at the 200-msec SOA, p(CP,CSD) is significantly lower than at all shorter SOAs: $p < 0.025$ and beyond). This pattern of early improvement and later decline in performance on valid trials is apparent in both single and multiple display conditions.

For invalid trials, the expectation was for a general (i.e., combined across display conditions) improvement in performance with increasing SOA. As can be seen from figure 2.1., p(CP,CSD) on invalid trials shows the expected improvement (at the 50-msec SOA p(CP,CSD) is significantly lower than at the SOAs longer than 100 msec, and at the 200-msec SOA p(CP,CSD) is significantly higher than at all shorter SOAs: $p < 0.001$). Thus, the significant V/I x SOA interaction occurs because performance for valid and for invalid trials converges at longer SOAs.

An additional prediction was that SOA would have different effects on single and multiple display invalid trials: no change in performance for multiple, and improvement with increasing SOA for single display invalid trials. If the advantage of multiple over single display valid trials is independent of SOA, this differential effect on invalid trials should manifest itself as a significant three-way interaction between S/M, V/I and SOA. This interaction actually turned out significant. As can be seen from figure 2.1., for single display invalid trials there is a marked improvement in p(CP,CSD) as SOA gets longer. However, p(CP,CSD) for multiple display invalid trials trials also shows a tendency to improve, though this is less pronounced than on single display invalid trials. Linear regression analyses of arcsin p(CP,CSD) revealed the increase to be significant for both single ($F(1,22) = 33.77$, $p < 0.001$) and for multiple displays ($F(1,22) = 6.94$, $p < 0.025$). Thus, the

S/M x V/I x SOA interaction occurs because the convergence between valid and invalid trials at longer SOAs is more pronounced for single than for multiple displays, mainly due to a more marked increase with SOA for single display invalid trials.

The increase in performance at very short SOAs, in particular between 50 and 75 msec, for valid and invalid trials may be partly attributable to a nonspatial (i.e., warning signal) effect, since baseline trials also show some (nonsignificant) increase.

2.2.3. Discussion

With regard to the three questions investigated in Experiment 1, the results can be summarized as follows:

Performance differences between valid and invalid trials are greater for multiple than for single displays, due to a superiority for multiple displays on valid trials and a disadvantage on invalid trials. The superior performance in MV relative to SV trials appears independent of SOA. This result at least points in the direction of GRINDLEY and TOWNSEND's (1968) finding. Note, however, that performance for the cued position is clearly enhanced in single displays, in comparison with uncued locations as well as the baseline condition; further, that multiple displays required an additional exposure duration of about 15 msec in order to reach the 0.75-threshold which may have contributed to the superior performance on valid trials (longer build-up of temporal summation).

For valid trials, perfomance shows a slight but reliable improvement between the SOAs of 50 and 125 msec, followed by a tendency to decline. For invalid trials, performance improves with SOA over the whole range. The magnitude of the improvement on invalid trials appears dependent on the display condition: While there is a significant increase with SOA on both single and multiple display invalid trials, the improvement is more pronounced for single displays.

The large advantage for valid trials, relative both to baseline and to invalid trials, at very short SOAs appears surprising when compared to the size of the effects obtained in other studies (e.g., ERIKSEN and HOFFMAN, 1972, 1974; COLEGATE, HOFFMAN and ERIKSEN, 1973; POSNER, SNYDER and DAVIDSON, 1980). The greater advantage of spatial cueing in the present experiment may be attributable to three factors: (1) A bias to localise the target at the cued position (see section 2.7.), (2) greater spatial separation between display locations and (3) greater target eccentricity together with the complexity of the task (localisation plus discrimination).

The greater separation between locations eliminates effects of lateral masking and "intrusions", into the "focus" of attention, of display elements adjacent to the indicated target item (see ERIKSEN and HOFFMAN, 1972, for the effects of inter-element spacing)。 This factor is important, above all, for multiple displays。

The second factor, 4。5 deg。 target eccentricity, is important for both display conditions。 For complex tasks requiring stimulus discrimination rather than simple detection of change, benefits and costs associated with spatial cueing are dependent on the availability of (sustained) channels responsible for visual resolution。 These are highly concentrated in the fovea, while (transient) channels responding to abrupt visual chance are more evenly distributed about the retina (FUKADA and STONE, 1974; STONE and FUKADA, 1974)。 That is, even though direct cues at the target location may summon attention rapidly and effectively both with foveal and with extrafoveal displays (possibly through transient channel activation), costs associated with orienting may be less marked for small eccenticities because high spatial resolution channels are available。

This is consistent with ENGEL's (1971) finding that for a task requiring a difficult target-background discrimination, the area within which the discrimination could be performed without advance knowledge of target location ("conspicuity area") is limited to the foveal region。 For extrafoveal targets, advance knowledge of their whereabouts can expand the conspicuity area in the direction of the target location。 Restated, spatial cueing of attention has little effect for targets falling inside the area of high visual conspicuity, but a greater effect for targets outside this area. Note that large "costs plus benefits" were also found in other studies which used similar eccenticities as the present experiment. JONIDES (1981, Experiment 3), for example, found RT differences between valid and invalid trials as large as 300 msec with peripheral cues, target eccentricities of 3.75 deg. and SOAs of 25 and 100 msec; SOA had no effect on RTs for valid trials.

Further, the finding that the advantage for the cued position exists already at the 50-msec SOA and improves only little thereafter (particularly when warning signal effects are allowed for) appears in agreement with TSAL's (1983a) estimate of the time it takes to shift attention to the location of a peripheral cue. According to TSAL, latencies of attention shifts are about 50 msec and shift velocity is about 1 deg. per 8 msec. Thus, executing an attention shift in the present display could be estimated to take about 85 msec (50 msec plus 4.4 * 8 msec), i.e. a time about equal to the duration of the shortest SOA (50 msec) plus the target exposure time (38.5 msec on average).

Although valid trials show some initial increase and later decrease in performance, as expected, it appears premature to interpret this in terms of the hypotheses underlying the predictions. Two alternative explanations seem available. First, that the pattern of initial improvement and later decline, approximately symmetric around the performance peak at the 125-msec SOA, is an expression of a range effect, i.e. a tendency to prepare optimally for SOAs in the middle of the series. Second, that the later decrease on valid trials reflects a limitation to the period for which optimal preparation for the cued position can be maintained or, alternatively, a "trade-off" with the corresponding increase for invalid trials (i.e., reallocation of attention away from the cued position to the uncued locations). Thus, before the second and third questions asked by Experiment 1 can be answered in a satisfactory way, two further problems must be addressed: (1) whether the SOA function of performance for valid trials is produced by a range effect, and (2) whether the improvement in performance with SOA for invalid trials reflects a trade-off against the corresponding decrease for valid trials.

2.3. Experiment 2

According to the range-effect explanation of the early improvement and later decline in performance on valid trials, as observed in Experiment 1, extending the upper limit of the range of SOAs should shift the performance peak towards the long SOAs. If, however, such a shift of the performance peak does not occur, a range effect cannot explain the SOA function of performance on valid trials. Thus, Experiment 2 basically replicated Experiment 1, except that SOAs varied from 100 to

500 msec. Experiment 2 also added further evidence relating to the question of the relative performance difference between valid and invalid trials in single and multiple displays and to the question of the differential effect of SOA on single and multiple display invalid trials.

2.3.1. Method

Experiment 2 presented 6 SOAs ranging from 100 to 500 msec: 100, 150, 200, 300, 400 and 500 msec. Note that Experiment 1 and 2 had three common SOAs: 100, 150 and 200 msec. The following 0.75-threshold exposure times were introduced in Experiment 2 for I.P., N.A., D.C. and H.M., respectively (means of the two sessions): 30.5, 29.5, 32 and 27 msec for single and 42, 43.5, 45.5 and 38 msec for multiple displays.

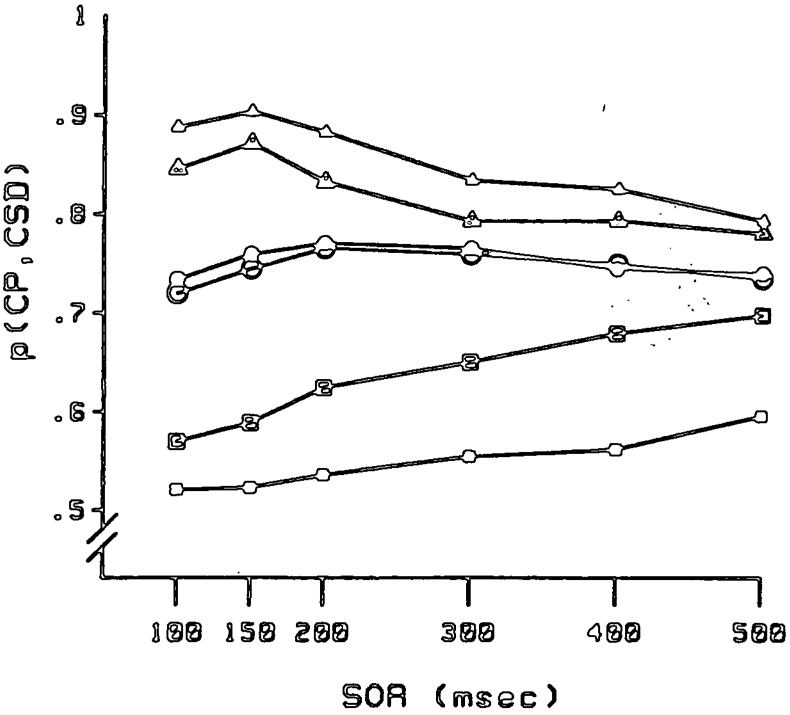
2.3.2. Results

Figure 2.2. presents the mean values of p(CP,CSD) as a function of SOA, separately for single and multiple display valid and invalid trials; figure 2.2. also presents p(CP,CSD) for single and multiple display baseline trials. (See figure 2.6. in section 2.7. for the corrected values of p(CP,CSD).)

The values of p(CP,CSD) were arcsin-transformed and subjected to a three-way ANOVA involving the factors S/M, V/I and SOA. This ANOVA revealed the following significant effects: (1) V/I: $F(1,3) = 136.66$ $p < 0.005$;

(2) SOA: $F(5,15) = 19.99$, $p < 0.001$; (3) S/M x V/I: $F(1,3) = 12.75$, $p < 0.05$; (4) V/I x SOA: $F(5,15) = 71.19$, $p < 0.001$; (5) S/M x SOA: $F(5,15) = 2.86$, $0.10 < p < 0.05$. (A separate ANOVA of arcsin p(CP,CSD) for the baseline trials, with the factors S/M and SOA, revealed no significant effects.)

Figure 2.2.: p(CP,CSD) as a function of SOA, separately for single (S: open symbols) and multiple (M: closed symbols) displays and for valid, baseline and invalid trials (V: triangles; B: circles; I: squares)



The results of Experiment 2 basically replicate the findings of the previous experiment, as can be seen from figure 2.2. However, the decline in performance on valid trials and the improvement on invalid trials appear more pronounced.

P(CP,CSD) is higher for valid than for invalid trials (significant main effect of V/I). The S/M x V/I interaction is significant, i.e. V-I differences are greater for multiple than for single displays. P(CP,CSD) tends to be higher for multiple than for single display valid trials ($0.10 > p > 0.05$) and is significantly lower for multiple than for single display invalid trials ($p < 0.005$).

For valid trials, p(CP,CSD) tends to increase slightly from the 100- to the 150-msec SOA, and thereafter to decrease towards the SOA of 500 msec (while the initial increase is not significant, p(CP,CSD) at SOAs longer than 200 msec is significantly lower than at shorter SOAs: $p < 0.001$). Most of this decline occurs between the SOAs of 150 and 300 msec (i.e., there are no significant differences among SOAs longer than 200 msec). With regard to the range-effect question, the crucial finding is that the performance peak occurs at the SOA of 100/150 msec, i.e. at the short extreme of the range of SOAs presented and not in the middle of the series. That is, a range effect cannot explain the SOA function of performance on valid trials. P(CP,CSD) for the invalid trials shows a tendency to increase as SOA gets longer, thus contributing to the significant V/I x SOA interaction. This interaction occurs because V-I differences show a marked decrease after the 150-msec SOA.

In contrast to Experiment 1, the three-way interaction between S/M, V/I and SOA is not significant even though the increase on invalid trials appears more pronounced for single than for multiple displays. To test whether the slopes of the increase in single and multiple display invalid trials differ, the values of arcsin p(CP,CSD) were subjected to separate linear regression analyses. The analysis for single displays revealed a highly significant linear regression ($F(1,22) = 39.96$, $p < 0.001$), and the linear regression for multiple displays also reached significance ($F(1,22) = 4.48$, $p < 0.05$). Slopes do not differ significantly ($p > 0.05$; t-test).

The increase in performance between the 100- and 150-msec for valid and invalid trials may be partly attributable to a nonspatial (i.e., warning signal effect), since baseline trials also show some non-significant increase.

2.3.3. Discussion

With regard to the three questions of Experiment 2, the results can be summarized as follows:

Performance differences between valid and invalid trials are greater for multiple than for single displays. Performance on valid trials reaches an early peak at the 150-msec SOA, followed by a declining trend. Performance on both single and multiple display invalid trials shows a significant improvement with increasing SOA. The rate of improvement does not differ reliably between the two display conditions; there is, however, some evidence for a stronger increase for single display invalid trials.

Extending the range of SOAs in Experiment 2 had no marked effect on the performance peak for valid trials: The difference between the SOAs at which the performance peak occurred in Experiment 1 and 2 is only 25 msec (note that the series of SOAs in Experiment 2 did not include a 125-msec SOA). Thus, it seems justified to reject the range effect explanantion for the performance function on valid trials. The rapid build-up of performance for the cued location seems a genuine effect associated with the transient change in light energy (peripheral cue) which may produce an "automatic" attention response (JONIDES, 1981).

However, the question of the interpretation of the declining trend in performance after the early performance peak remains unanswered. Experiment 2 demonstrated that this decrease is quite substantial and that it occurs under both display conditions. This raises the question whether the decline in performance for valid trials with increasing SOA is due to a trade-off with performance for invalid trials which shows a marked tendency to improve in correspondence.

The combined results of Experiment 1 and 2 suggest that the magnitude of improvement for invalid trials is dependent on the display condition. Although the three-way interaction between S/M, V/I and SOA was not significant in Experiment 2, the pattern is similar to that found in Experiment 1. (For multiple displays the decline on valid trials at longer SOAs appears slightly stronger than for single displays, thus compensating for the less marked improvement on invalid trials). The differential improvement for invalid trials between single and multiple displays is related to the finding that V-I differences are generally greater for the multiple display condition. That is, spatial cueing produces less marked benefits and costs for single displays, in particular at long SOA durations.

2.4. Experiment 3

The main question of Experiment 3 was whether the improvement in performance on invalid trials is separable from the decline on valid trials. If this is the case, the performance loss for the cued location, which occurs after the early peak, may be caused by an "inhibitory" effect of the change in light energy associated with the peripheral cue, as described by POSNER and COHEN (1984). According to POSNER and COHEN, the inhibition effect can be overcome if the cue is spatially informative, i.e. if the cued position is more likely to contain the target than the uncued locations, since inhibition may then be "masked" by attention. However, it may well be questionable to regard the inhibition effect as an all-or-none process. If the decline in performance for the cued location observed in the previous experiments indeed reflects an inhibition effect, this effect is certainly weaker than that which POSNER and COHEN (1984) and MAYLOR (1985) observed in simple RT experiments. In these experiments, RT functions for valid and invalid trials typically intersect between the SOAs of 200 and 300 msec.

Note that in Experiments 1 and 2 functions for valid and invalid trials are closer to intersection in the single display condition, because of the differential improvement with SOA between single and multiple display invalid trials. The simple RT experiments resemble the single display condition in that they present a suprathreshold luminance increment in an otherwise empty field. That is, as SOA duration gets longer, single luminance increments at uncued locations may become increasingly powerful in summoning attention away from the cued position (to which it has been allocated by the advance cue), thus contributing markedly to the intersection of the RT functions.

According to POSNER and COHEN (1984), the inhibition effect is due to a change in light energy preceding the target at the cued position. If so, a possible test for the inhibition effect explanation of the performance loss on valid trials in Experiment 1 and 2 (direct peripheral cue) would be whether or not this loss fails to occur when the likely target location is indicated by a symolic cue in the centre of the display (i.e., without a prior change in light energy at the cued position). If there is no performance loss for valid trials but an improvement for invalid trials, the loss for valid trials that is associated with the peripheral cue cannot be explained in terms of a trade-off with the improvement for invalid trials.

Thus, Experiment 3 replicated the previous experiments, with two differences: The most likely target location was indicated by a central arrow cue; and the SOAs were longer than in Experiment 2 (by 250 msec), since production of a spatial expectancy in response to symbolic cues is regarded as a time consuming, "controlled" process (e.g., JONIDES, 1981; see also SHULMAN and McLEAN, 1978).

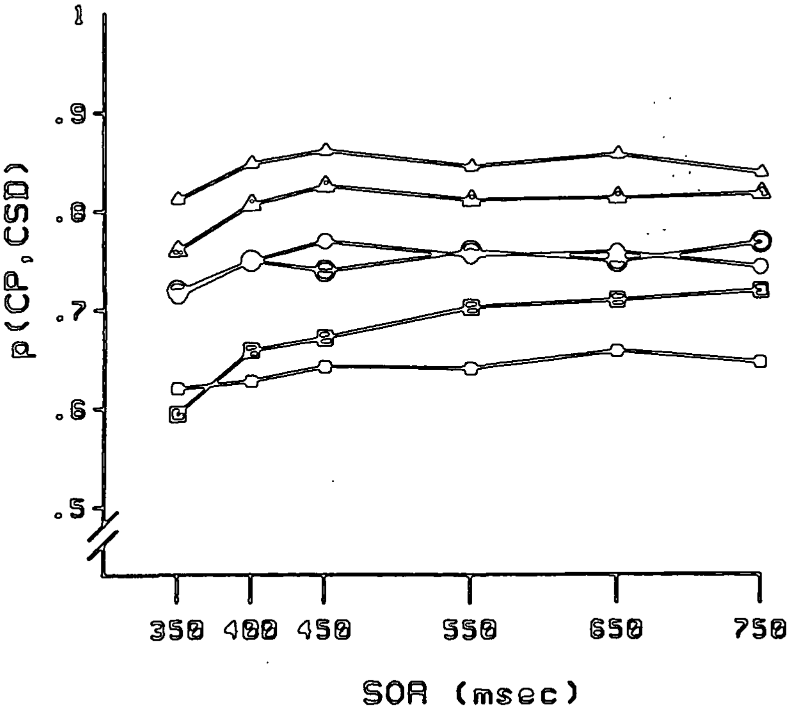
2.4.1. Method

The methodological details were the same as in the previous experiments, with the exception of the type of cue and the range of SOAs. The 6 SOAs were 350, 400, 450, 550, 650 and 750 msec. The spatial cue was a 300-msec central arrow (see frame IVb in diagram 2.1.). The warning signal presented on baseline trials was a central cross (instead of the arrow). The following 0.75-threshold exposure times introduced in Experiment 3 for I.P., N.A., D.C. and H.M., respectively (means of two sessions): 33, 32.5, 35 and 30.5 msec for single and 45, 46.5, 48 and 42.5 msec for multiple displays.

2.4.2. Results

Figure 2.3. presents the mean values of p(CP,CSD) as a function of SOA, separately for single and multiple display valid and invalid trials; figure 2.3. also presents p(CP,CSD) for the two baseline conditions. (See figure 2.7. in section 2.7. for the corrected values of p(CP,CSD).)

Figure 2.3.: p(CP,CSD) as a function of SOA, separately for single (S: open symbols) and multiple (M: closed symbols) displays and for valid, baseline and invalid trials (V: triangles; B: circles; I: squares)



The values of p(CP,CSD) were arcsin-transformed and evaluated in a three-way ANOVA involving the factors S/M, V/I and SOA. This ANOVA revealed the following effects to be significant: (1) V/I: $F(1,3) = 400.54$, $p < 0.001$;

(2) SOA: $F(5,15) = 9.68$, $p < 0.001$; (3) V/I x S/M: $F(1,3) = 19.33$, $p < 0.025$; (4) S/M x SOA: $F(5,15) = 3.85$, $p < 0.025$. (A separate ANOVA of arcsin p(CP,CSD) for the baseline trials, with the factors S/M and SOA, revealed no significant effects.)

As in the previous experiments, performance for single display invalid trials improves with increasing SOA. However, in contrast with Experiments 1 and 2, there is no decrease in performance for valid trials at longer SOAs; rather, performance stays quite invariant after an initial build-up.

In accordance with the previous experiments, the overall V-I difference is greater for multiple than for single displays (significant S/M x V/I interaction). For invalid trials p(CP,CSD) is relatively lower for multiple displays ($p < 0.01$), and for valid trials it is higher ($p < 0.005$).

In contrast with Experiments 1 and 2, there is no significant V/I x SOA interaction. For valid trials, performance improves significantly between the SOAs of 350 and 400 msec (at the 350-msec SOA p(CP,CSD) is significantly lower than at longer SOAs: $p < 0.005$ and beyond) and then remains quite invariant at optimum. As can be seen from figure 2.3., there is no apparent difference in this pattern between single and multiple displays. For invalid trials, performance shows a trend to improve with increasing SOA (at the 350-msec SOA p(CP,CSD) is significantly lower than at SOAs longer than 400 msec: $p < 0.001$). Thus, the convergence between valid and invalid trials at longer SOAs is much weaker than in the previous experiments, since no decline on valid trials contributes to it.

The increase in performance on invalid trials appears more pronounced for single than for multiple displays (however, the three-way interaction between S/M, V/I and SOA failed to reach significance). To test this effect, arcsin p(CP,CSD) for single and multiple display invalid trials were subjected to separate linear regression analyses. The tendency for p(CP,CSD) in the multiple display condition to increase did not prove reliable ($F(1,22) = 2.28$, n.s.), while there was a significant linear regression for the single display condition ($F(1,22) = 23.21$, $p < 001$). Thus, combined over valid and invalid trials, single displays show a more marked improvement with SOA than do multiple displays (significant S/M x SOA interaction).

The increase in performance between the 350- and 400-msec SOAs for valid and invalid trials may be partly attributable to a nonspatial (i.e., warning signal) effect, for baseline trials also show some nonsignificant increase.

2.4.3. Discussion

Experiment 3 confirms two findings of the previous experiments. For valid trials, performance is superior for multiple than for single displays; for invalid trials, however, performance is lower for multiple than for single displays. As a result, V-I differences are greater for multiple displays. Further, there is a differential improvement with increasing SOA between single and multiple display invalid trials.

Experiment 3 demonstrates that when the likely target location is indicated by a central arrow cue, there is no decline in performance for valid trials after optimum level has been reached. However, even in the absence of a decline for valid trials, performance for invalid trials can improve as SOA duration increases. Thus, the loss in performance for the likely target location following a peripheral cue (i.e., a change in light energy at this position; Experiments 1 and 2) cannot be explained in terms of a trade-off in attention allocation between cued and uncued locations.

This pattern of results is in accordance with that described by POSNER and COHEN (1984) for simple RT tasks, so that the performance loss for valid trials observed in Experiments 1 and 2 might be attributable to "inhibition". If so, the present experiment would suggest that "inhibition" is not an all-or-none, but rather a graded effect which also occurs with spatially informative direct cues; in other words, attention allocated to the likely target location might partly, but not completely suppress inhibition. However, if suppression is complete, this would indicate that spatial orienting is more effective immediately after occurrence of a peripheral cue than at long SOA durations following presentation of either a central or a peripheral cue. In other words, with peripheral cues optimum advantage for the cued location at very short SOAs might be superior to the optimum level which can be maintained with central (and with peripheral) cues at longer SOA durations.

The finding that performance for invalid trials increases with SOA might indicate that search for targets at uncued locations is inhibited, initially, when attention is "automatically" summoned to the likely target location by a peripheral cue and/or during "controlled" production of a spatial expectancy based on the information (about the likely location) provided by a central or by a peripheral cue. With completion of these processes, attention can be reallocated to a target at an "unattended" position calling an attention response, and performance for uncued locations can improve.

The differential improvement for invalid trials between single and multiple displays points to a basic difference in the search for targets at uncued locations. In single displays, search presumably utilises the luminance change associated with the onset of the single target to detect it. In multiple displays, however, this information is not available since distractors of the same size and luminance appear simultaneously with the target.

Thus, for single displays, the improvement is more pronounced since the luminance change associated with target onset acts as a direct "cue" to its position; indeed, a target at an uncued location may produce an "automatic" attention response in the same way as a peripheral cue if attention is no longer engaged by the cued position. In multiple displays, however, target detection is based on some attribute which discriminates a T from a cross. Derivation of this information is more time consuming and liable to errors than is the detection of a single luminance change, so that any attention response to the target is delayed. Thus, because of the limited exposure time, the improvement in performance with SOA is less pronounced.

With peripheral cues (Experiment 1 and 2), both single and multiple display invalid trials show a significant improvement with increasing SOA; with central cues (Experiment 3), however, only single display invalid trials improve reliably. Thus, it appears that the "early" inhibitory effect on uncued locations is stronger when the likely target location is indicated by a direct change in light energy rather than by a symbolic cue in the centre. (Note, however, that the present experiments are not entirely conclusive, since the shortest SOA durations in Experiment 3 were longer than those in Experiments 1 and 2).

2.5. Experiment 4

The three previous experiments established that performance differences between the valid and invalid trials are greater for multiple than for single displays, due to a relative advantage for multiple displays on valid trials and a disadvantage on invalid trials. Although V-I differences are highly reliable in both display conditions, this pattern at least points in the direction of GRINDLEY and TOWNSEND's (1968) finding.

However, any conclusions about the relative strength of the effects associated with spatial cueing in the two display conditions seem problematic, since the longer threshold exposure durations for multiple displays in GRINDLEY and TOWNSEND's study and in Experiments 1, 2 and 3 presumably favour the multiple display condition (SPERLING and MELCHNER, 1978). On the assumption that the cued position is assigned search priority, there is relatively less time available in the single display condition to discriminate the target if it appears there. That is, the advantage for multiple over single display valid trials may be compensated for or even reversed when the two display conditions are presented with the same exposure durations. Thus, Experiment 4 aimed at a direct comparison between the two display conditions by presenting them with the same exposure duration and in randomized order.

The finding that performance on invalid trials is generally superior for single relative to multiple displays may be due to the fact that target detection is based on the luminance change produced by single target onset. To test this, a third display condition was introduced in Experiment 4 which was a "hybrid" of the single and multiple display conditions: In the first half of target exposure, the target appeared on its own, as in single displays, and in the second half distractors appeared at nontarget locations, as in multiple displays. Thus, if the luminance change associated with the onset of a single target is a "pointer" to its location, performance on hybrid display invalid trials should be intermediate between single and multiple display invalid trials.

It has been proposed (see section 2.4.3.) that the transient change in light energy produced by direct cues is associated with a strong ("early") inhibitory component for uncued locations. As the effect of peripheral cues to summon attention fades out and production of an expectancy, based on the spatial information provided by the cues, is completed, attention becomes available for reallocation and performance for uncued locations can increase. Thus, rather than being linear, the increase for invalid trials should be more marked at short SOA durations and then reach an asymptotic level that depends on the display condition. To obtain further information about this increase, the range of SOAs in Experiment 4 was extended to 700 msec (peripheral cue).

2.5.1. Method

The basic method of Experiment 4 was the same as in the previous experiments. The variations were as follows:

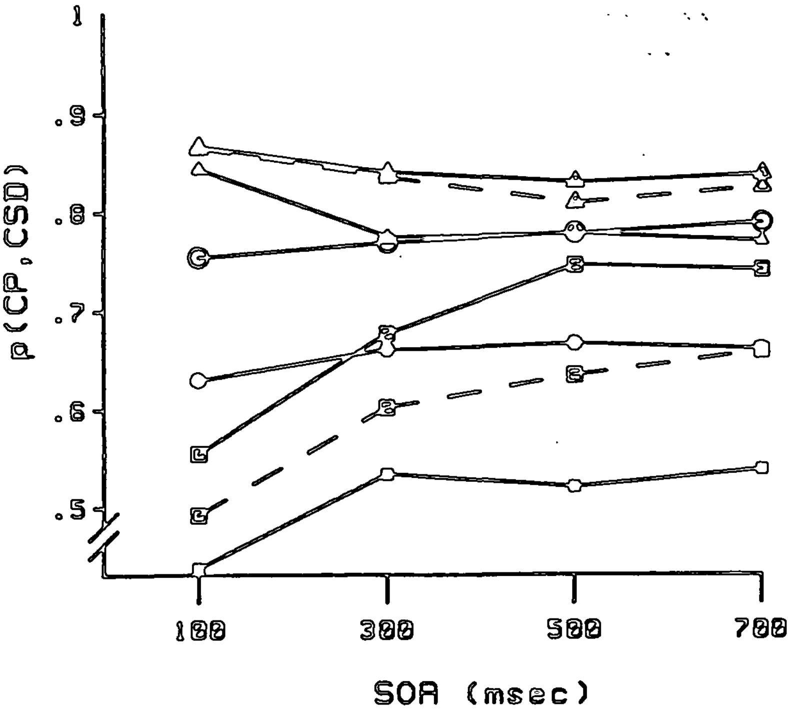
Design and Procedure: Experiment 4 involved the factors S/H/M - single/hybrid/multiple display, V/I and SOA (4 levels: 100, 300, 500 and 700 msec). In hybrid displays, there was a delay between target and distractor onset which was half the exposure time estimated individually for each subject. The spatial cue was a 50-msec peripheral brightening. Experiment 4 consisted of 2688 trials, including single and multiple display baseline trials. The three display conditions were presented in randomized order (within the same block) and with the same target exposure duration. The exposure duration was the mean of the 0.75-threshold estimates obtained separately for single and multiple displays at the beginning of each session (the order of single and multiple display threshold trials was counterbalanced across sessions and subjects). The subjects were not informed about the presentation of the hybrid display (except for H.M.).

Subjects: By the time Experiment 4 was conducted, all four subjects had taken part in a different series of experiments (see Chapters 3 and 5), with the consequence that the 0.75-threshold times were reduced (practice effect). The average 0.75-threshold exposure times (average of single and multiple displays) were, for I.P., N.A., D.C. and H.M., respectively (means of two sessions): 32.75, 33, 35.25 and 29 msec.

2.5.2. Results

Figure 2.4. presents the mean values of p(CP,CSD) as a function of SOA, separately for single, hybrid and multiple display valid and invalid trials and also for single and multiple display baseline trials. (See figure 2.8. in section 2.7. for the corrected values of p(CP,CSD).)

Figure 2.4.: p(CP,CSD) as a function of SOA, separately for single (S: open symbols), hybrid (H: dashed line) and multiple (M: closed symbols) displays and for valid, baseline and invalid trials (V: triangles; B: circles; I: squares)



The arcsin-transformed values of p(CP,CSD) were subjected to a three-way ANOVA involving the factors S/H/M, V/I and SOA. All effects were significant: (1) S/H/M: $F(2,6) = 46.01$, $p < 0.001$; (2) V/I: $F(1,3) = 720.75$, $p < 0.001$; (3) SOA: $F(3,9) = 20.24$, $p < 0.005$; (4) S/H/M x V/I: $F(2,6) = 26.56$, $p < 0.005$; (5) S/H/M x SOA: $F(6,18) = 7.41$, $p < 0.001$; (6) V/I x SOA: $F(3,9) = 596.34$, $p < 0.001$; (7) S/H/M x V/I x SOA: $F(6,18) = 6.13$, $p < 0.025$. (A separate ANOVA of arcsin p(CP,CSD) for the baseline trials, with the factors S/M and SOA, revealed a significant effect of S/M: $F(1,3) = 12.04$, $p < 05$).

Unlike the previous experiments, overall performance is higher for single than for multiple and for hybrid displays (significant main effect of S/H/M). This holds for both the comparisons between invalid trials (SI-MI and SI-HI: $p < 0.001$), but only for the S-M comparison between valid trials (SV-MV: $p < 0.001$). Performance for hybrid displays is superior to multiple displays (HV-MV and HI-MI: $p < 0.001$). V-I differences are smallest for single displays (S-H and S-M: $p < 0.001$), intermediate for hybrid displays (H-M: $p < 0.005$) and greatest for multiple displays (significant S/H/M x V/I interaction).

The effect of SOA on valid trials does not differ much among the three display conditions. Performance is highest at the 100-msec SOA and then declines as SOA increases to 300/500 msec; thereafter, performance remains relatively constant (combined over the three display conditions, only the differences between the 100-msec and the longer SOAs are reliable: $p < 0.001$).

For invalid trials, performance in all display conditions improves substantially between the 100 and 300-msec SOAs (at the 100-msec SOA p(CP,CSD) is significantly lower than at the longer SOAs: $p < 0.001$). This initial increase appears comparatively more marked for single, intermediate for hybrid and less marked for multiple displays. Single and hybrid, but not so much multiple, displays show some further improvement after the 300-msec SOA.

The significant three-way interaction between S/H/M, V/I and SOA occurs mainly because of the differential effect of SOA on invalid trials. That is, V-I differences generally decrease between the 100- and 700-msec SOAs, but the total magnitude of this decrease is greater for single than for multiple ($p < 0.005$) and tends to be greater for hybrid than for multiple displays ($p < 0.05$); it does not differ between single and hybrid displays.

2.5.3. Discussion

In summary, the results are as follows:

For valid trials, performance is superior for single and for hybrid in comparison with multiple displays when all display conditions are presented with the same exposure time. This is consistent with the idea that when attention is already available at the cued location at target onset, processing demands in single and hybrid displays are largely reduced to target discrimination since the target appears on its own (at least initially in hybrid displays). The absence of a significant performance loss for hybrid displays suggests that the luminance change associated with (single) target onset at the cued position is detected early during target exposure and that the later arrival of distractors at uncued locations does not interfere with target discrimination. The poorer performance for multiple displays can be attributed to the additional requirement of distinguishing the target T from a distractor cross.

The finding that on invalid trials performance for hybrid displays trials is superior to multiple displays indicates that target search is in fact utilising the information provided by the (initially single) luminance change produced by target onset at one of the uncued locations. However, reduced performance for hybrid relative to single displays points to some interference from delayed distractors (one of them occurring at the cued position).

For invalid trials, there is a general, i.e. largely display-condition independent, increase in performance between the 100- and 300-msec SOAs; after the 300-msec SOA, hybrid and single displays show a further, asymptotic, improvement. For valid trials, there is no indication of a differential effect of SOA between the three display conditions. They all show optimum performance at the 100-msec SOA; thereafter, performance declines to some extent and then stabilizes at the lower level.

The substantial impairment of performance for uncued locations at the 100-msec SOA reflects, presumably, an early inhibitory effect associated with transient changes in light energy in peripheral vision, such as the peripheral cues presented in Experiment 4. Peripheral cues rapidly and inadvertently summon attention to the cued position, thereby reducing the amount of attention available for the uncued locations. As this passive effect of the peripheral brightening fades out and attention for the cued location is actively maintained, through production of a spatial expectancy based on the information of the cue, attention becomes available for reallocation, thus allowing enhancement for uncued locations to occur in all display conditions.

However, the magnitude of the enhancement depends on the type of display: It is greater when the target appears on its own (single and, at least initially, hybrid displays). This suggests that the luminance change associated with the onset of a single target summons attention in a similar "automatic" fashion as previously a peripheral cue. In multiple displays, however, target search cannot take advantage of the luminance change associated with target onset since distractors appear simultaneously (one of them at the cued position).

The finding of Experiments 1, 2 and 3 that performance differences between valid and invalid trials are less marked for single than for multiple displays also holds when targets are presented for the same exposure duration in both display conditions. Further, V-I differences decrease as SOA increases and this effect is more pronounced for single displays (because of the substantial improvement on invalid trials). Thus, for single displays, the advantages associated with spatial cueing are small, in particular at long SOAs. But performance stays superior for valid trials even at the longest cue-target intervals, despite the marked improvement for "unattended" locations, so that there is no justification for the conclusion that single displays do not benefit from spatial cueing of attention.

2.6. General Discussion

In summary, there is clear evidence that the difference in performance between valid and invalid trials is greater for multiple than for single displays (see also the RT study of ERIKSEN and YEH, 1985). This finding is independent of whether single and multiple displays are presented for their respective 0.75-threshold exposure durations (resulting in a relatively longer duration for multiple displays; Experiment 1, 2 and 3) or whether they are presented for the same exposure time (Experiment 4). In the first case, the greater V-I difference for multiple displays is due to superior performance in valid trials and reduced performance in invalid trials. In the second case, it is due to a more pronounced disadvantage, compared to single displays, for invalid than for valid trials.

Note that the superior performance for valid trials in comparison with invalid (and baseline) trials cannot be accounted for in terms of guessing. When corrected for guessing (see figures 2.5. to 2.8. in section 2.7. for the corrected values of p(CP,CSD)), the magnitudes of the overall V-I differences, collapsed over display conditions and SOA durations, are reduced by up to 0.05. Even at the longest SOAs (200, 500, 750 and 700 msec), V-I differences in single displays are 0.18, 0.09, 0.09 and 0.13 for Experiment 1, 2, 3 and 4, respectively, with performance for valid trials (0.77, 0.75, 0.77 and 0.82) never falling below the uncorrected 0.75-baseline level.

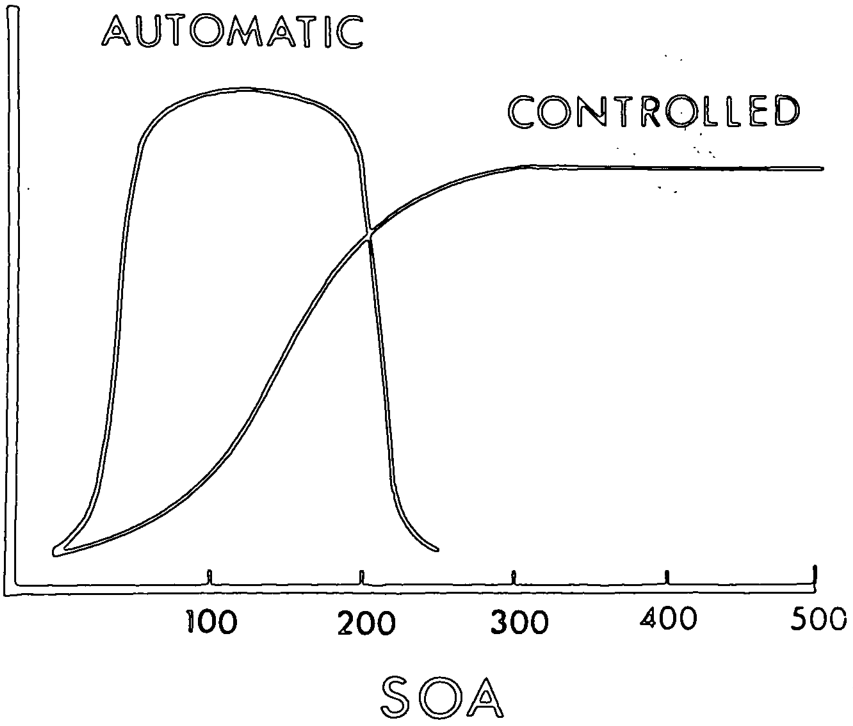
A further reliable finding is that for valid trials, performance differences between single and multiple displays, whatever their direction, are largely independent of SOA. For both display conditions, when the likely target location is indicated by a direct change in light energy (Experiment 1, 2 and 4), performance is "boosted" almost instantly, with the SOA at which performance reaches its peak (125/150 msec) being almost unaffected by the presented range; after having reached optimum, performance shows a marked decline, in particular between the SOAs of 125/150 and 300/500 msec, followed by sustained performance at the lower level. When the likely location is indicated by a symbolic cue in the centre (Experiment 3), performance is maintained at optimum after an initial build-up.

For invalid trials, performance differences between single and multiple displays are not independent of SOA; rather, they increase as SOA gets longer, for both types of cue. However, when the cue is a peripheral change in light energy (Experiment 1, 2 and 4) performance for both single and multiple displays increases, in particular between the SOAs of 100/200 and 300 msec, while in the case of the central cue (Experiment 3) there is a reliable improvement only for single displays and this increase appears less pronounced. The finding that with a central cue, improvement on invalid trials can occur (single displays) without a loss in performance for valid trials suggests that the decline in performance for the likely target location following a change in light energy at this position is a separate effect from the improvement for the uncued locations and cannot be explained in terms of a trade-off relationship.

It seems possible to provide an explanation for these results by extending POSNER's (1980) theoretical framework into a two-component model of spatial orienting. This model is illustrated in diagram 2.2.

A transient change in light energy preceding the target at the cued location (i.e., a direct peripheral cue) triggers an automatic attention response (JONIDES, 1981), producing a rapid performance boost for this position. This early facilitatory effect for the cued position is associated with a concurrent inhibitory effect for uncued locations. This early inhibitory effect reflects an impairment in the ability of targets at unattended locations to call an attention response, presumably caused by the rapid engagement of attention by the peripheral cue.

Diagram 2.2.: Hypothetical two-component model of spatial orienting (see text for detail)



The early, automatic, facilitation for the cued position produced by the preceding change in light energy is transitory, passing over into a component of actively sustained attention for the cued position. This component is initiated through a controlled process of producing an expectancy for the likely target location. Production of a spatial expectancy, based on the information provided by the cue, is relatively delayed and occurs while the automatic orienting component is active. The duration of the early inhibitory effect on uncued locations is time-locked to the automatic orienting component. Thus, with the fading of automatic facilitation, attention can be disengaged from the cued position. This enhances the ability of targets at uncued locations to call an attention response.

With a symbolic cue in the display centre, the early facilitatory effect is absent, i.e. build-up of performance for the cued position is more gradual. That is, central cues seem to initiate only the second component of actively maintained attention for the cued position, through production of an expectancy for the likely target location.

There is evidence that with central cues the early inhibitory effect on uncued locations is not absent, but only reduced (i.e., performance for uncued locations appears less impaired, initially, than with peripheral cues). McLEAN and SHULMAN (1978) suggest that "... construction of an expectancy requires the involvement of attention demanding processes"; but "... once that expectancy has been constructed it can persist for brief periods of time independent of the direction of attention" (p. 453). That is, attention may be diverted into production of an expectancy, so that inhibition for unexpected locations may build up rapidly, while facilitation for the likely position may be delayed; this early inhibitory effect may be compensated for, to some extent, once production of the expectancy is completed and attention becomes available again.

This two-component model makes a basic distinction between "external" and "internal" spatial orienting (POSNER, 1980): With peripheral cues, orienting of attention initially responds to external, i.e. physical properties of the cue (activation of transient channels through abrupt changes in light energy). However, as the delay between cue and target increases, orienting is guided by internal processes which respond to the spatial information provided by the cue (production and maintenance of a spatial expectancy). Note that external and internal orienting processes may interact: Production of a spatial expectancy may enhance the magnitudes of the early facilitatory and inhibitory effects of peripheral cues on cued and on uncued locations. This suggestion is consistent with JONIDES' (1980) finding that even with peripheral cues and very short SOAs, the magnitudes of benefits and costs vary with cue validity.

Presumably, the internal processes which enable attention for the cued position to be maintained (at long SOAs) are the same for central and for peripheral cues. However, the present experiments are not conclusive as to the extent to which POSNER and COHEN's (1984) inhibition effect (i.e., the inhibitory effect following a preceding change in light energy at the cued position) is suppressed by sustained attention. That is, a direct comparison between central and peripheral cueing experiments is limited by the fact that they were not conducted at the same time and with the same 0.75-threshold exposure durations. In the present data, suppression appears fairly strong (i.e., performance on valid trials at longer SOAs does not differ substantially between central and peripheral cueing experiments). If confirmed, this result would suggest that the early facilitatory component associated with peripheral cues is more powerful than the component of sustained facilitation associated both with central and with peripheral cues.

It is interesting to note that there is no indication of POSNER and COHEN's inhibition effect in the baseline condition of Experiments 1, 2 and 4, although there was a change in light energy occurring at each location and this warning signal was spatially uninformative (i.e., inhibition should not be masked by attention). The absence of this effect in the baseline trials may indicate that inhibition occurs only for a particular location when there was a prior, externally triggered attention response to this position (see also MAYLOR, 1985). For the present experiments, however, it seems unlikely that such an attention response could be made to four different locations simultaneously.

The present data suggest that the early inhibitory effect on uncued locations is stronger when the likely target location is indicated by a direct change in light energy rather than by a symbolic cue in the centre. But again, this conclusion is limited by the fact that the shortest SOA durations in Experiment 3 (central cueing) were longer than those in Experiments 1, 2 and 4 (peripheral cueing). This makes it difficult to assess to what extent production of a spatial expectancy inhibits performance for uncued locations.

However, it seems well established that the enhancement following the early inhibitory effect is more marked for single than for multiple displays. This differential SOA effect points to a basic difference in target search between the two display conditions.

In single displays, the luminance change associated with target onset at one of the uncued locations is a direct pointer to its position. As attention is no longer passively engaged by the cued location (automatic process) and/or active production of an expectancy for the cued position is completed (controlled process), a single luminance increment occurring at an unattended uncued location can elicit an "automatic" attention response in the same way as previously a change in light energy at the cued location.

In multiple displays, however, the luminance change associated with target onset provides only temporal but no spatial information since distractors of the same size and energy appear simultaneously. Rather, target search must be based on some "higher level" attribute which discriminates a T from a cross. Extraction of this information is a relatively time consuming and error-prone process (i.e., distractors may erroneously call attention and have to be rejected), so that any attention response to the target is delayed. Thus, because of the limited exposure time, unattended targets receive less advantage from the increasing availability of attention.

Presumably, the more demanding nature of the search for "unattended" targets in multiple element displays is the cause for the longer 0.75-threshold exposure duration (since for the cued location the longer exposure time produces an advantage in comparison with the single display). In other words, the 0.75-threshold time may be shorter for the single display since targets at unattended locations may automatically call attention. If restated in this way, the finding of GRINDLEY and TOWNSEND (1968) can claim support.

2.7. Appendix

Choice of the joint probability of correct position plus correct same-different responses - p(CP,CSD) - as the main performance measure needs justification since any bias inherent in one measure could call into question whether effects observed are attentional in nature (see KINCHLA, 1977 and 1980, for a detailed discussion of this problem). Note that the problem of separating effects of attention and decision making (biases) is not confined to the present task (see DUNCAN, 1980b, SHAW, 1984, and SPERLING, 1984, for a discussion of "response threshold" effects in POSNER's simple RT paradigm).

The localisation task is the most likely source of bias, since targets occurred more frequently at cued than at uncued positions. That is, if subjects do not perceive the target location, they may guess the cued position. This would inflate localisation accuracy for the cued position at the expense of the uncued locations, and any advantage for valid over invalid trials may be partly or entirely an artefact of this guessing strategy.

One possible way to resolve this problem would be to analyse localisation and discrimination responses separately. If the discrimination data by themselves show an advantage for valid over invalid trials, this would be a more convincing demonstration of attentional (rather than bias) effects (since the discrimination task is not confounded with cue validity).

However, although subjects show cued position biases, as could be expected, localisation and discrimination data were analysed jointly (rather than in separation). The reason for this will be given in Chapter 4 which provides detailed analyses of the relationship between localisation and discrimination accuracy in the single and multiple elements presented in Experiments 1 to 4. However, it is necessary to anticipate the main results of these analyses to justify the choice of p(CP,CSD) performance measure:

Discrimination accuracy is well above chance only when localisation is successful. With localisation failures, discrimination accuracy is close to chance; that is, the conditional probability of correct target discrimination given localisation failure, i.e. p(CSD/IP), is close to 0.5. Further, p(CSD/IP) does not differ between valid and invalid trials and does not differ between cued and uncued location errors. Restated, successful discrimination depends on sucessfull localisation; if localisation fails, the choice of the discrimination response is more or less at random and independent of cue validity. Thus, analysing the discrimination data on their own would not add any new information to a joint analysis with the localisation data.

Another solution to the bias problem inherent in the localisation task is to correct for cued position biases. A model devised to accomplish this is formally set out in Chapter 4 (see section 4.2. for detail). Table 2.1. presents the estimates, derived for Experiments 1 to 4, of the probabilities of (joint) correct location plus discrimination guesses, separately for single and multiple displays and for valid and invalid trials and their difference.

Table 2.1.: Estimated probabilities of correct position plus same-different guesses, separately for single and multiple displays and for valid and invalid trials and their difference

	Single			Multiple		
	Val.	Inval.	Diff.	Val.	Inval.	Diff.
Exp. 1	.052	.028	.024	.057	.025	.032
Exp. 2	.054	.031	.023	.081	.030	.051
Exp. 3	.047	.032	.015	.057	.035	.022
Exp. 4	.032	.022	.010	.108	.029	.079
Mean	.046	.028	.018	.076	.030	.046

As can be seen, correct guesses occur with a probability of 0.045 (combined across display and cue validity conditions) and are about twice as likely for valid than for invalid trials (combined across display conditions). Further, correct guesses on valid trials are more likely for multiple than for single displays. The effect of cue validity occurs because subjects show biases towards giving a cued position response (both in single and in multiple displays). And the effect of display condition occurs because these biases are more pronounced for multiple than for single displays.

As a result, differences in p(CP,CSD) between valid and invalid trials are also inflated by correct guesses, and more markedly so for multiple than for single displays (see the "Diff." values in table 2.1.). However, correct guesses account for only about 10% (single displays: .018/.183) to 15% (multiple displays: .046/.295) of the observed differences between valid and invalid trials. In other words, 90% to 85% of these differences can be attributed to attentional effects.

Figures 2.5. to 2.8. present, for Experiments 1, 2, 3 and 4, respectively, the values of p(CP,CSD) corrected for guessing as a function of SOA, separately for the display and cue validity conditions. As can be seen from these figures, all the important effects found in the uncorrected data are also apparent in the data corrected for guessing.

Figure 2.5.: Experiment 1: cor. p(CP,CSD) as a function of SOA, separately for single (S: open symbols) and multiple (M: closed symbols) displays and for valid and invalid trials (V: triangles; I: squares)

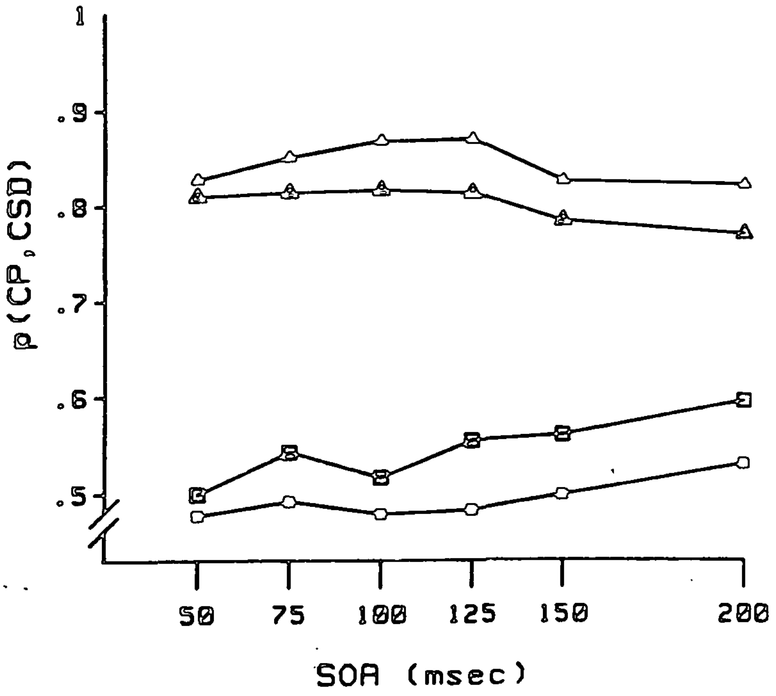


Figure 2.6.: Experiment 2: cor. p(CP,CSD) as a function of SOA, separately for single (S: open symbols) and multiple (M: closed symbols) displays and for valid and invalid trials (V: triangles; I: squares)

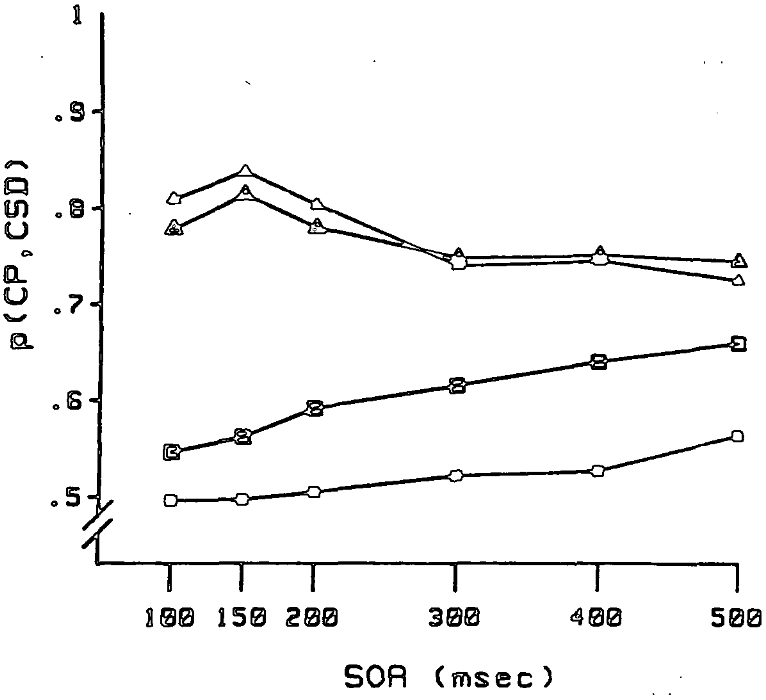


Figure 2.7.: Experiment 3: cor. p(CP,CSD) as a function of SOA, separately for single (S: open symbols) and multiple (M: closed symbols) displays and for valid and invalid trials (V: triangles; I: squares)

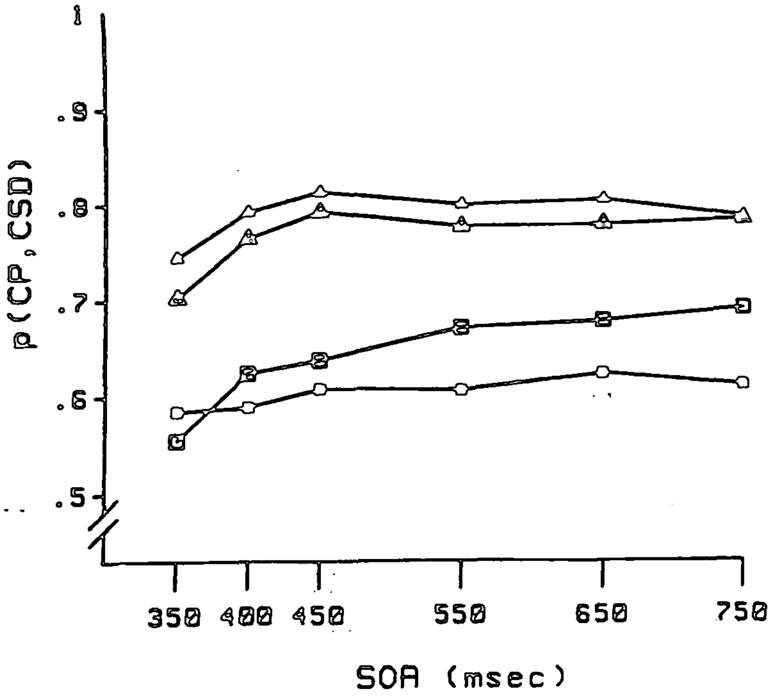
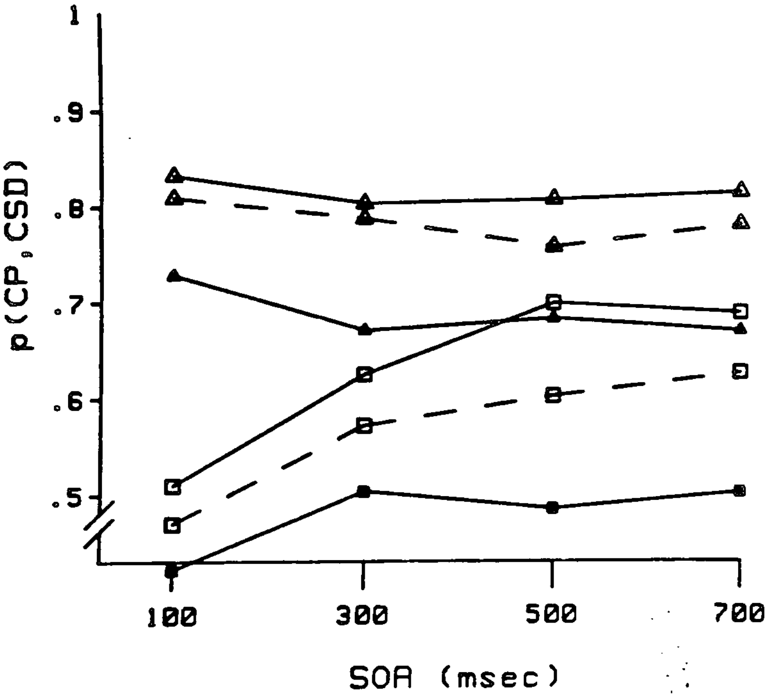


Figure 2.8.: Experiment 4: cor. p(CP,CSD) as a function of SOA, separately for single (S: open symbols), hybrid (H: dashed lines) and multiple (M: closed symbols) displays and for valid and invalid trials (V: triangles; I: squares)



Chapter 3

Internally and Externally Guided Orienting of Visual Attention: Time Course of Activation and Resistance to Interruption

3.1. Introduction

POSNER (1980) proposed that orientation of attention, while maintaining ocular fixation, can be achieved by two mechanisms: The first mechanism is "automatic" orienting triggered externally by salient stimuli in the visual field, such as a peripheral flash (peripheral cue), and the second mechanism is internally "controlled" orienting in response to symbolic indicators, such as a central arrow (central cue). The question of the differing degrees of automaticity associated with internal and external orienting has been investigated recently by JONIDES (1981) who applied POSNER and SNYDER's (1975a, 1975b) "cost-benefit" technique to a spatial cueing task.

SHIFFRIN and SCHNEIDER (1977; SCHNEIDER and SHIFFRIN, 1977) regard the degree to which a particular visual search process can be interrupted or suppressed, given its initiating condition, as one of the main criteria of its degree of automaticity. Experiment 2 of JONIDES' study was designed to test the relative ability to suppress orienting of attention in response to central and peripheral cues. One of two experimental groups was instructed to "attend" to the cue and the other to "ignore" it. Cues were spatially uninformative, i.e. the cued and the actual target location were probabilistically unrelated. Note that subjects in the "ignore" group were informed about this, while subjects in the "attend" group were told that cue validity was "fairly low". JONIDES found that under the "attend" instruction RTs to targets occurring at the cued position were faster than those to targets appearing at uncued locations, both for the peripheral and the central cueing condition. However, under the "ignore" instruction RTs were faster only for the peripheral but not for the central cueing condition. JONIDES concluded that it is possible to supress orienting in response to central cues, but not in response to peripheral cues.

It seems, however, problematic to conclude from this finding that the orienting process is per se less automatic when induced by central rather than peripheral cues, for the following reasons.

The instruction to "ignore" the cue may have different effects for the two cue types, due to a basic difference in the way in which the spatial information is encoded. Peripheral cues provide spatial information "directly" through their presence at one of the possible target locations, whereas the indirect spatial information of central (symbolic) cues requires decoding before it can be acted upon. Decoding requires use of rules which define cue "directionality" and is, itself, prone to errors.

MULLER (1984) found that the direction of 300-msec central arrow cues may be confused, thus leading to an attention response to an uncued location (i.e., there was evidence for confusions between cued and diagonally opposite locations; there was no evidence for confusions with 50-msec peripheral cues). Such problems may also have occurred in JONIDES' study in which central cueing produced generally less marked "benefits" and "costs" in comparison with peripheral cueing (e.g., "attend" group in Experiment 2; "80C-20P" group in Experiment 3). This may be due to the fact that central cues were presented for only 25 msec, i.e. not long enough to allow decoding to be successful on every trial.

Further effects on cue analysis may have have been induced by the "ignore" instruction since subjects knew that cues were spatially uninformative. If a cue is spatially informative, "ignoring" the cue would be detrimental to overall performance. However, "attending" to the cue may not be detrimental if a cue is uninformative. That is, when the target is equally likely to occur at any possible location it may make no difference to overall performance if one position is searched first or allocated more search effort. Thus, in the central cueing "ignore" condition, some subjects may have attended to the cued position and some to one of the uncued locations (this is suggested by the between-subject standard deviations of the mean RTs for cued and uncued locations; see JONIDES, 1981, p. 195). However, to attend to an uncued rather than the cued location implies redefinition of the information (i.e., directionality) of the cue.

Thus, it cannot be ruled out that what JONIDES measured was the degree to which the decoding of the spatial information provided by symbolic cues can be changed by the instruction to ignore it, but not the degree to which the orienting mechanism itself can be interrupted after being triggered. That is, it does not necessarily follow from the absence of costs and benefits in the central cueing "ignore" condition that the mechanism guiding allocation of attention is per se different from that in the peripheral cueing condition (nonautomatic versus automatic). For it is conceivable that once analysis of a symbolic cue is completed, the same mechanism is initiated as in the case of a direct peripheral cue which requires no intermediate translation.

Another approach to the question of differing degrees of automaticity associated with internal and external orienting of attention has been to compare the time course of the orienting process in response to the two types of cue. Peripheral cues seem to produce an almost instantaneous enhancement of detection and recognition performance for targets at the location at which they occur (e.g., ERIKSEN and HOFFMAN, 1972; COLEGATE, HOFFMAN and ERIKSEN, 1973; ERIKSEN and HOFFMAN, 1974), while the advantage produced by central cues appears to build up more gradually to optimum (e.g., POSNER, NISSEN and OGDEN, 1978; see also Experiment 3 in Chapter 2.).

Experiment 3 of JONIDES (1981) aimed at a direct comparison of the time course of spatial orienting in response to (informative) central and peripheral cues under two cue "expectancy" conditions: Either peripheral cueing trials were more frequent than central cueing trials ("80P-20C" group) or the frequencies were reversed ("20P-80C" group). The two cue-target SOAs were 25 msec and 100 msec. In both the 80P-20C and the 20P-80C peripheral cueing conditions and, likewise, in the 20P-80C central cueing condition, RTs were faster for cued than for uncued locations and this advantage was quite invariant across SOA. But in the 80P-20C central cueing condition, at the 25-msec SOA RTs for cued and for uncued locations did not differ significantly, while at the 100-msec SOA there was an advantage for cued positions which approached that under the "80P-20C" peripheral cueing condition. That is, when central cues are rare, the facilitatory effect of spatial cueing takes time to build up, and this build-up is associated with a corresponding loss in response speed for uncued locations. (However, again it cannot be ruled out that unexpectedness of central cues affects the process of decoding rather than orienting itself; the same applies to the effect of memory load in Experiment 1 of JONIDES, 1981).

It is interesting to compare JONIDES' results with the data from Experiment 2 (peripheral cue; range of SOAs: 100 - 500 msec) and Experiment 3 (central cue; range of SOAs: 350 - 750 msec) in Chapter 2. In the peripheral cueing experiment, peak performance for the cued position was reached almost instantly (100/150-msec SOA), followed by a decline (between the SOAs of 150 and 300 msec) and sustained performance at the lower level; performance for uncued locations was impaired at short SOAs and then showed a marked improvement towards the 300-msec SOA. In the central cueing experiment, performance for the cued position showed a more delayed build-up (reaching its peak at the 450-msec SOA) and was then maintained at optimum; performance for uncued locations also showed an initial improvement which was, however, less marked.

In section 2.6. a two-component model was proposed to explain these results: Peripheral cues trigger a fast, "automatic" orienting mechanism which responds to physical (external) properties of the cue and produces an early facilitatory effect for cued and a concurrent inhibitory effect for uncued locations. This component is transitory, and as it fades out control is taken over by a second, slower, orienting mechanism which responds to the (internal) spatial information of the cue (cue analysis is performed while the first mechanism is active). This second component may be less powerful than the earlier "automatic" component, but it enables facilitation for the cued location to be maintained and suppresses, to some extent, the inhibition effect which would otherwise occur because of the preceding change in light energy at this position (POSNER and COHEN, 1984; MAYLOR, 1985). Central cues initiate only this second orienting mechanism.

However, a direct comparison between the central and peripheral cueing experiments was limited by the fact that they were conducted one after the other and the ranges of SOAs and target exposure times (0.75-thresholds) were different. Thus, no decision was possible as to the degree to which POSNER and COHEN's inhibition for the cued position can be suppressed by sustained attention and whether the second "controlled" component is less effective than the earlier "automatic" one (the results of JONIDES', 1981, third experiment point in this direction; however, central cues may have been at a disadvantage since the 25-msec exposure of the cue may have been to short for it to be decoded on every trial).

Therefore, Experiment 5 aimed at establishing the time course of both orienting components, using a design which allowed a direct comparison between central and peripheral cueing conditions: Both types of cue were presented with equal frequencies and in random order, and 0.75-threshold exposure durations and SOAs were the same for both cueing conditions. Experiment 5 can thus be regarded as "50P-50C" condition in terms of JONIDES' (1981) third experiment.

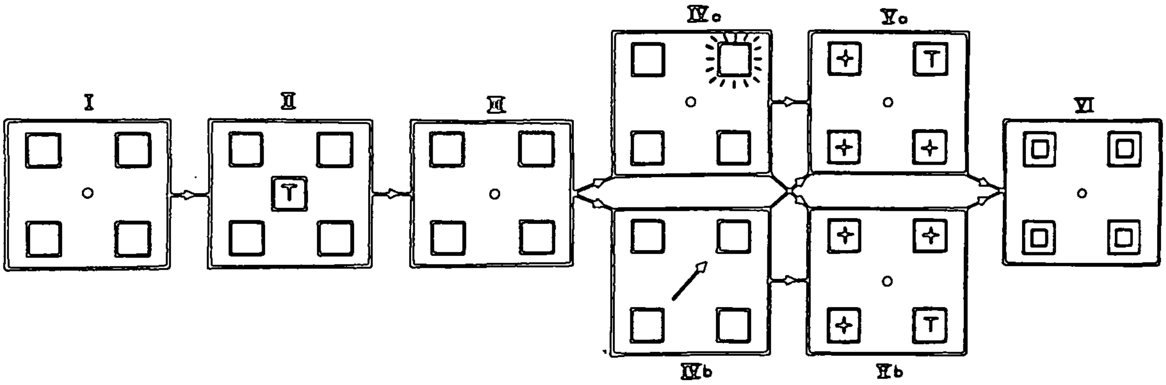
Experiments 6 and 7 were designed to test the degree to which early (peripheral cue) and delayed orienting components (central and peripheral cue) in response to informative cues can be interrupted by task-irrelevant (uninformative) peripheral flashes. That is, unlike JONIDES' (1981) second experiment, Experiment 6 and 7 did not measure "resistance to suppression" of orienting but rather "resistance to competetion" (informative cues and uninformative flashes compete when flashes occur at uncued locations; flashes are expected to produce "automatic" orienting). If the early component of orienting in response to peripheral cues is indeed an "automatic" process, it should be fairly resistant to the competition of peripheral flashes at uncued locations; if the delayed component of orienting in response to central and peripheral cues is a "controlled" process, it should be less resistant to competition. Thus, the experimental situations in Experiment 6 (central cues compete with flashes) and Experiment 7 (peripheral cues compete with flashes) were analogous to those used by SHIFFRIN and SCHNEIDER (1977) in their Experiments 4d and 4c to test the distractive effect of consistent-mapping foils on focusing attention in controlled (varied mapping) and in automatic (consistent mapping) search.

3.2. Experiment 5

3.2.1. Method

Apparatus and Materials: Stimuli were presented on a Hewlett Packard 1321A X-Y display with a P 31 phosphor. The CRT was controlled by a CED Alpha (LSI 2/20G) computer through a CED 502 Interface; the display system used was the EMDISP program developed by SHEPHERD (1984). The laboratory was dimly illuminated by an incandescent lamp placed behind the screen and shielded from direct view. The luminance of the stimuli was 0.1 ftL and the luminance of the screen background was 0.01 ftL. Subjects viewed the CRT from a distance of 115 cm with their heads resting on a chin rest.

Diagram 3.1.: Sequence of frames (I - VI) presented on a trial



Display and Timing: Diagram 3.1. illustrates the sequence of frames presented on a given trial. Frame I displayed a central fixation dot and four boxes in the display periphery. The target stimulus, a T in any of the four orthogonal orientations, appeared later in one of these (frame V). After 500 msec, the central fixation dot was replaced by a central box containing a T in one of the four possible orientations (frame II); this T, displayed for 1500 msec, indicated the comparison stimulus for a given trial. Then, 1000 msec after the reappearance of the fixation dot (frame III), a spatial cue was presented indicating the most likely target location (frame IV). This was either a 50-msec brightening of the outline of one of the peripheral boxes (periperal cue; frame IVa) or an arrow indicator in the centre (central cue; frame IVb); the arrow cue was presented throughout a central cueing trial, i.e. for 900 msec, since there was evidence (MULLER, 1984) that durations of less than 300 msec may be too short to allow arrow direction to be analysed accurately on every trial. There were also baseline trials on which either all four boxes were brightened simultaneously (peripheral cue) or a cross appeared in the centre (central cue); these events indicated that the target was equally likely to appear at all four locations. After variable delays following cue onset (SOA), the target stimulus, a T in the same or a different orientation as the comparison T, was presented in one of the four boxes for a limited exposure duration (frame V);

the three nontarget locations contained distractor crosses of the same size and luminance as the target. On valid trials (frame Va), the target appeared at the cued location. On invalid trials (frame Vb), the target occurred at one of the uncued locations. The eccentricity of the target was 4.4 deg. and its size was 0.25 deg. In frame VI, the exposure of target and distractors was terminated by contour masks.

Task: After termination of the target display (frame VI), subjects had to give two responses on a hand-held keypad: First, a same-different response indicating whether the orientation of the target T was the same as or different from that of the comparison T previously presented in the centre, and, second, a position response indicating in which of the four boxes the target T had appeared. The position response immediately triggered the the next trial.

Design and Procedure: The three factors in Experiment 5 were (1) P/C - peripheral/central cueing, (2) V/I - valid/invalid trials, and (3) SOA (6 levels: 100, 175, 275, 400, 550 and 725 msec). Experiment 5 was divided into two sessions, each lasting about four hours and consisting of two blocks of 720 trials. The number of trials totalled 2880, i.e. 1440 central and 1440 peripheral cueing trials (6 x (96 + 96 + 48); SOAs x (valid + invalid + baseline trials)). All conditions were presented in random order within a block of trials. The four orientations of the target T were presented with equal frequency. In half the trials the target T was the same as the comparison T, in the other half it was different. Targets appeared with equal frequencies at each of the four locations. Spatial cues were valid on half the trials and invalid on the other half. The cued position was three times as likely to contain the target as any one of the three uncued locations.

Determination of the Threshold Exposure Durations: At the beginning of each session, target exposure times were determined individually for each subject and separately for each cueing condition (with the order of conditions counterbalanced across sessions and subjects). The estimation procedure used was a modified PEST adaptive staircase (FINDLAY, 1978) which aimed at a threshold level of 0.75 on baseline trials (threshold trials presented "neutral" warning signals, either a central cross or four simultaneous peripheral flashes, followed by the target at delays randomly drawn from the set of SOAs in Experiment 5). This procedure was based on joint correct same-different plus correct position responses (i.e., an error was counted if one or both responses on a given trial were incorrect). As a rule, the threshold criterion was reached between the 48th and the 95th trial. The target exposure times introduced in Experiment 5 were the average values of the 0.75-thresholds estimated for the two cueing conditions. Experiment 5 also included concurrent central and peripheral cueing baseline trials (fixed exposure duration) to provide a check on the validity and stability of the threshold estimate.

Instruction: The subjects were asked to respond as accurately as possible. They were informed that the target stimulus would appear equally often in each of the four boxes, but three times as often at the cued as at one of the uncued locations; further, that the target T would be equally often the same as and different from the comparison T. The subjects were instructed to "attend" to the cued location. They were told to fixate on the central dot during the sequence of frames on a given trial. When they had accidentally pressed a wrong response key, they had a later opportunity to correct the response.

Subjects: Four subjects participated in Experiment 5 and also in the second experiment: D.C., H.M., L.S. and S.C. (ages 20-28; two with normal and two with corrected-to-normal vision). D.C., L.S. and S.C. were paid 4.0 pounds for each four-hour session; payment was the same in the later experiments. D.C. and H.M. had taken part in Experiments 1 to 4; L.S. and S.C. received a similar amount of practice in 4 - 6 preexperimental sessions. All four subjects participated in another training session in which the 0.75-threshold exposure durations were estimated repeatedly until they were stable. The following 0.75-threshold exposure times were introduced in Experiment 5 for D.C., H.M., L.S. and

S.C., respectively (means of two sessions): 35.5, 31.5, 39.0 and 37.0 msec. These times were based on the following threshold estimates: 37.5, 34.0, 42.0 and 39.5 msec for the central and 33.5, 29.0, 36.0 and 34.50 msec for the peripheral cueing condition.

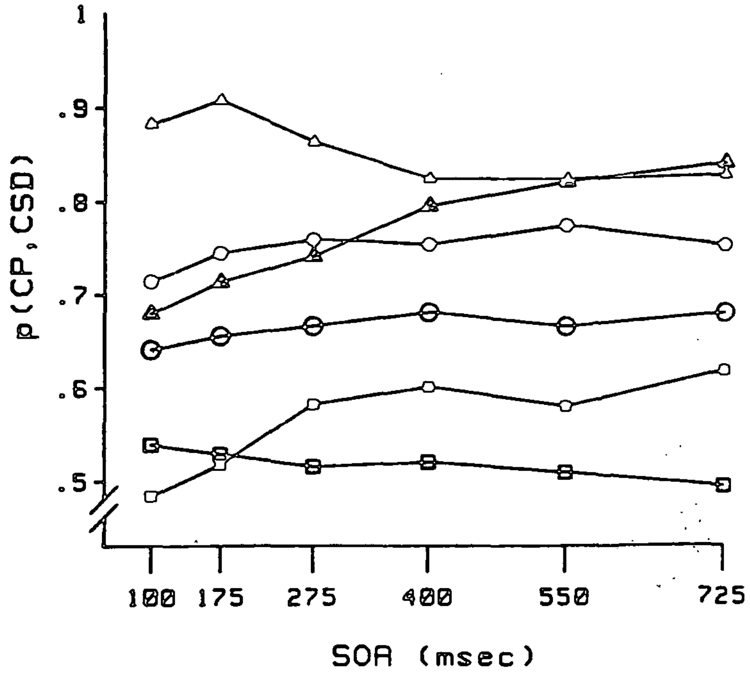
3.2.2. Results

The main performance measure analysed is the joint probability of a correct position plus a correct same-different response - p(CP,CSD). (See section 2.7. for a justification of this performance measure).

Figure 3.1. presents the mean values of p(CP,CSD) as a function of SOA, separately for central and for peripheral cueing valid and invalid trials, and also for central and for peripheral cueing baseline trials. The values of p(CP,CSD) were arcsin-transformed (WINER, 1971) and evaluated in a three-way ANOVA involving the factors C/P (central/peripheral cueing), V/I (valid/invalid trials) and SOA. This ANOVA revealed all effects to be significant: (1) C/P: $F(1,3) = 131.82$, $p < 0.005$; (2) V/I: $F(1,3) = 2192.72$, $p < 0.001$; (3) SOA: $F(5,15) = 7.07$, $p < 0.005$; (4) C/P x V/I: $F(1,3) = 27.74$, $p < 0.025$; (5) C/P x SOA: $F(5,15) = 15.28$, $p < 0.005$; (6) V/I x SOA: $F(5,15) = 3.43$, $p < 0.05$; (7) C/P x V/I x SOA: $F(5,15) = 91.88$, $p < 0.001$. (A separate ANOVA of arcsin p(CP,CSD) for baseline trials, involving the factors C/P and SOA, revealed the main effect of C/P to be

significant: F(1,3) = 16.97, $p < 0.025$).

Figure 3.1.: p(CP,CSD) as a function of SOA, separately for central (C: open symbols) and peripheral cues (P: filled symbols) and for valid, baseline and invalid trials (V: triangles; B: circles; I: squares)



As can be seen from figure 3.1., performance is generally higher for the peripheral than for the central cueing condition (main effect of C/P). This holds both for valid and for invalid trials (CV - PV, CI - PI: $p < 0.001$; note that these contrasts as well as all comparisons reported below are based on the TUKEY method). However, differences in performance between valid and invalid trials (V-I differences), combined across SOA, are greater for peripheral than for central cues, mainly because of superior performance in peripheral cueing valid trials (significant C/P x V/I interaction).

The SOA function for peripheral cueing valid trials shows an initial performance boost reaching its peak at the 175-msec SOA; thereafter, performance declines towards the SOA of 400 msec and then remains fairly constant (the decrease between the 175- and 400-msec SOAs is highly significant: $p < 0.001$ for all comparisons between SOAs shorter and longer than 275 msec). Peripheral cueing invalid trials show an improvement between the 100 and 275-msec SOAs and then remain quite invariant at the higher level (100 and 175-msec SOAs differ reliably from longer SOAs: $p < 0.001$).

Unlike peripheral cueing valid trials, the SOA function for central cueing valid trials shows monotonic improvement over the entire range of SOAs, particularly marked between the SOAs of 100 and 400 msec (SOAs equal to and longer than 400 msec differ significantly from shorter SOAs: $p < 0.001$). Performance for central cueing invalid trials does not vary much with SOA; however, there appears to be a slight tendency for performance to decrease as SOA gets longer.

Performance is significantly higher for peripheral than for central cueing valid trials within the 100 - 275 msec range of SOAs ($p < 0.001$); there are no reliable differences at longer SOAs. Performance is significantly lower for peripheral than for central cueing invalid trials at the 100-msec SOA ($p < 0.005$) and higher at SOAs longer than 275 msec ($p < 0.005$). That is, functions for central and peripheral cueing valid trials converge at longer SOAs, whereas those for central and peripheral cueing invalid trials diverge. The significant three-way interaction between C/P, V/I and SOA occurs mainly because V-I differences at short SOAs are greater for the peripheral than for the central cueing condition.

3.2.3. Discussion

The results of Experiment 5 are consistent with the two-component model of spatial orienting proposed in section 2.6.

The main finding is that peripheral cues almost instantly produce large gains in performance for the cued position, followed by a decrease and then sustained performance at the lower level. Gains produced by central cues, however, are delayed and build up only gradually within about 400 msec after cue onset. (Note that the onset of an arrow cue in the display centre may be itself an event which summons attention and thus reduces performance gains at short SOAs.) At very short SOAs (100 to 175 msec), there is a marked advantage for peripheral over central cues. This, however, decreases as the early facilitatory effect of peripheral cues fades out and as central cues become increasingly effective.

On valid trials, optimum performance for peripheral cues (100- to 175-msec SOAs) is higher than optimum for central cues (550- to 725-msec SOAs); but there are no differences between central and peripheral cues at SOAs longer than 400 msec. This suggests, first, that the early facilitatory component associated with peripheral cues ("automatic") is indeed more powerful than the following component of sustained orienting ("controlled"); second, that this second component is the same for central and for peripheral cues; and third, that sustained orienting for the cued position completely suppresses POSNER and COHEN's (1984) inhibition effect which would otherwise (i.e., without sustained attention) follow a preceding peripheral, but not a central cue.

The two-component model receives further support from the SOA functions for invalid trials. With peripheral cues, early ("automatic") facilitation for the cued position (100 to 175-msec SOAs) is associated with a concurrent inhibitory effect, i.e. markedly reduced performance for uncued locations, which can be compensated for only as the "automatic" orienting component fades out and attention is actively maintained for the cued position. It has been suggested (see section 2.6.) that this early inhibitory effect occurs because peripheral cues rapidly summon attention to the cued position; that is, there is a "refractory" period, associated with "automatic" orienting, during which attention is engaged by the cue, so that the ability of targets at uncued locations to call an attention response is reduced.

With central cues, however, there is a slight tendency for performance in uncued locations to decrease as internal preparation for the indicated position gains in efficiency. This agrees with JONIDES' (1981, Experiment 3) results for the 80P-20C condition; and it suggests that decoding of the cue and production of an expectancy for the likely target location are themselves capacity demanding processes (see also McLEAN and SHULMAN, 1978) which divert attention and produce inhibition for uncued locations at short SOAs. Indeed, inhibition is almost as strong as with peripheral cues at the 100- and 175-msec SOAs. This suggests that production of a spatial expectancy is at least a contributory factor to the early inhibitory effect.

However, the finding that the early inhibitory effect is not followed by enhancement at longer SOA durations (i.e., that performance for uncued locations stays below that for peripheral cues at SOAs of 275-msec and longer) appears inconsistent with the two-component model of spatial orienting. Such an enhancement should occur within a period of about 400 msec after cue onset during which internal orienting processes are largely completed.

The absence of any enhancement might have two causes: First, trials with central and with peripheral cues were presented in a randomized order (50C-50P). That is, when central cues are not always expected, internal production and maintenace of a spatial expectancy might demand more attention than when central cues are blocked; this might delay facilitation for cued (i.e., the build-up has not yet reached asymptote at the 400-msec SOA; see figure 3.1.) and recovery from early inhibition for uncued locations. (Note that Experiment 3 of JONIDES, 1981, demonstrated that cue frequency influences orienting with central, but not with peripheral cues). Second, the arrow cue remained present in the display centre throughout a given trial. That is, informative stimuli in the centre might distract attention, in particular for unexpected locations.

The finding that for ("neutral") baseline trials, performance for central cues is below that for peripheral cues across SOA is also puzzling, in particular because the 0.75-threshold exposure times for central and for peripheral cues, estimated separately at the beginning of each session, differed by only 5 msec on average (see section 3.2.1.; i.e., since the target exposure times introduced in Experiment 5 were the means of the separate threshold estimates, exposure times were 2.5 msec above 0.75-thresholds for peripheral and 2.5 msec below for central cues). Again, the continuous presence of a central cross on central cueing baseline trials may have caused some distraction, and/or the general attentiveness was raised on peripheral cueing baseline trials because the four simultaneous peripheral flashes produced a greater energy change in the display than a cross in the centre. That such baseline shifts can occur lends support to JONIDES and MACK's (1984) view that it is preferable to analyse differences between valid and invalid trials rather than benefits and costs with reference to a supposedly "neutral" condition.

3.3. Experiment 6

If attention for the cued position is maintained, at long SOA durations, by a "controlled" process, as suggested, orienting should be interruptable by a competing "automatic" process. Thus, Experiment 6 was designed to measure the degree to which the component of sustained orienting, initiated through informative central cues, can be interrupted by task-irrelevant (uninformative) peripheral flashes.

On every trial, a 300-msec central arrow was presented which indicated the likely target location (frame IV of a given display cycle), and this cue was followed by the target after varying intervals (600, 900 and 1200 msec). In 1/3 of the trials the central cue only was presented. In the other 2/3 there was an additional 50-msec brightening of the outline of one of the peripheral boxes which occurred at a fixed interval of 500 msec after central cue onset (i.e., the SOAs between flash and target were 100, 400 and 700 msec). Cue-target SOAs of 600 msec and longer were introduced to allow sustained preparation for the cued location to be reached at flash onset (Experiment 5 had shown that this takes up to 400/550 msec). The flash was spatially uninformative, i.e. it did not alter the probability with which the target occurred at the location indicated by the arrow cue. Thus, in order to maximise overall performance, subjects had to maintain preparation for the cued position, independently of the position of the flash; there was competition between cue and flash whenever the flash occurred at an uncued location.

In summary, Experiment 6 involved three conditions: (1) The C condition ("central cue only") providing a baseline measure for valid and invalid trials (CV and CI); (2) the F condition ("flashed") in which the target occurred at the flashed location (cued position and uncued locations, i.e. FV and FI); (3) the -F condition ("unflashed") in which the target appeared at an unflashed location (cued position and uncued locations, i.e. -FV and -FI).

The expectations were as follows: When flash and cue compete (i.e., when the flash occurs at an uncued location), there would be a performance loss for the cued position (-FV), relative to the central cue only condition (CV), at short SOAs, because of attention being instantly summoned by the flash; at longer SOAs, performance for the cued position would build up again, as attention is reoriented to the cued location. For the flashed location (FI), it was expected that there would be a performance gain, relative to the central cue only condition (CI), at short SOAs; at longer SOAs, this advantage would be lost again because of the reorientation of attention to the cued position.

When flash and cue do not compete (i.e., when the flash occurs at the cued position), performance for the cued position (FV) would be superior to the central cue only condition (CV) at short SOAs, since the automatic orienting component associated with the flash "adds" to the component of sustained attention (see Experiment 5); at longer SOAs, as the effect of the flash fades out, performance would converge with the central cue only condition (CV). For uncued unflashed locations (-FI), there would be a performance loss, relative to the central cue only condition (CI), at short SOAs, due to the early inhibitory effect of the flash; with the fading of this effect, performance would improve again.

3.3.1. Method

Design and Procedure: Experiment 6 involved three main factors: (1) C/F/-F, (2) V/I and (3) SOA (600, 900 and 1200 msec between cue and target onset; 100, 400 and 700 between flash and target onset). Baseline trials (B), presenting a spatially uninformative cross instead of an arrow cue, were combined with the C, F and -F conditons in the same way as valid and invalid trials. The uncued unflashed (-FI) condition can be broken down further according to the relation between the cued and the flashed position: The target could occur at one of the uncued unflashed locations with cued and flashed positions being either identical or not (-FIc: the flash occurred at the 'c'ued position; -FIu: the flash occurred at an 'u'ncued location).

Table 3.1.: Design of Experiment 6 (C: central cue only; F: target position = flashed; -F: target position = unflashed; V, B and I: valid, baseline and invalid trials; c: cued position = flashed; u: uncued position = flashed; number of trials in brackets)

C	x	V	x SOA	(3 x 96)
	x	B	x SOA	(3 x 48)
	x	I	x SOA	(3 x 96)
F	x	V	x SOA	(3 x 48)
	x	B	x SOA	(3 x 24)
	x	I	x SOA	(3 x 48)
-F	x	V	x SOA	(3 x 144)
	x	B	x SOA	(3 x 72)
	x	I	x SOA	(3 x 144)
-FI	x	c	x SOA	(3 x 48)
	x	u	x SOA	(3 x 96)

The design of Experiment 6 is summarized in table 3.1. The ratio between flashed (F) and unflashed (-F) trials was 1/3, i.e. the probability with which the target occurred at the flashed location was 1/4 (i.e., flashed location and target position were probabilistically unrelated). The peripheral flash did not change the information about the likely target location provided by the arrow cue, i.e. in flashed (F) and in unflashed (-F) conditions the target appeared with probability 3/6 at the cued position and with probability

3 x 1/6 at the three uncued locations. Further, each of the four locations was equally likely to contain the target, equally likely to be cued and equally likely to be flashed. The total number of trials was 2160 which were presented in two four-hour sessions each of 1080 trials. All conditions were presented in randomized order.

Determination of the Target Exposure Times: At the beginning of each session, the 0.75-threshold exposure durations for CB trials (baseline trials without flash) were determined individually for each subject. The 0.75-exposure durations introduced in Experiment 6 were as follows for subjects D.C., H.M., L.S. and S.C., respectively (means of two sessions): 34.0, 30.0, 36.5 and 35.5 msec.

Instruction: The subjects were told that on the "cue plus flash" trials the flash would not alter the information about the most likely target location provided by the central arrow. In order to maximise overall performance, they should therefore "ignore" the flash and "attend" to the cued location.

3.3.2. Results

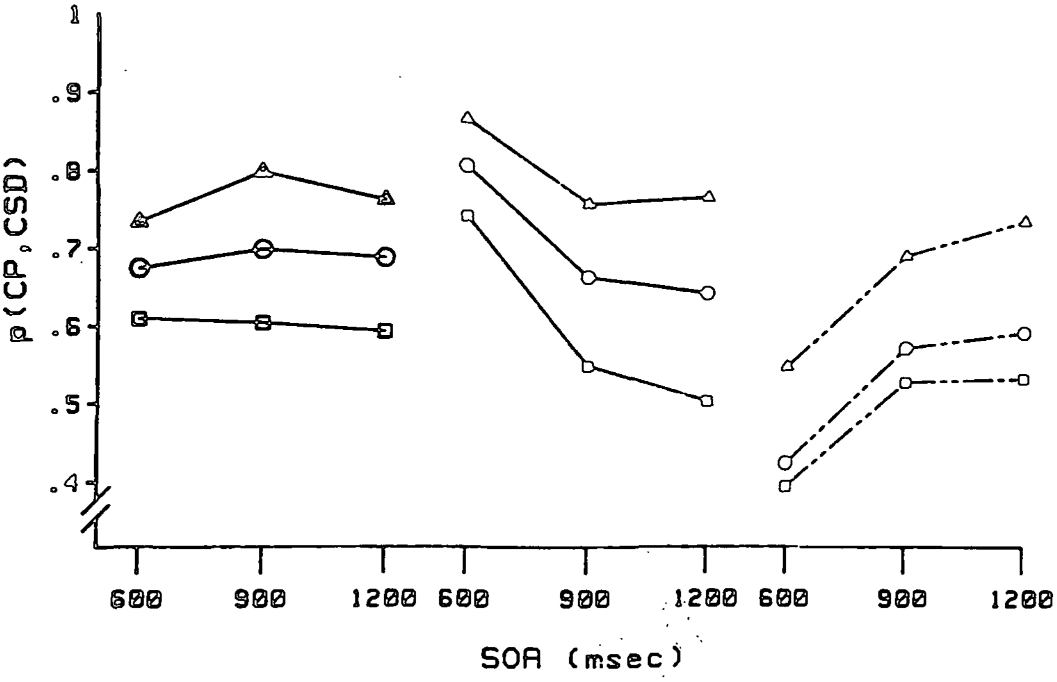
Figure 3.2.a. presents the mean values of p(CP,CSD) as a function of SOA, separately for C, F and -F conditions and for valid, baseline and invalid trials. Figure 3.2.b. (page 190) presents p(CP,CSD) for CI, FI, -FIc and -FIu trials (i.e., for central cue only and

flashed invalid trials and for unflashed invalid trials broken down according to whether the flash occured at the cued or at an uncued position). And figure 3.2.c. (page 191) illustrates the comparison between the -FV, FI and -FIu trials (i.e., for the critical condition when flash and cue compete and the target occurs at the unflashed cued, at the flashed uncued or at an unflashed uncued location).

The arcsin-transformed values of p(CP,CSD) were evaluated in a three-way ANOVA involving the factors C/F/-F, V/I and SOA. This ANOVA revealed the following effects to be significant: (1) main effect C/F/-F: $F(2,6) = 83.04$, $p < 0.001$; (2) main effect V/I: $F(1,3) = 276.11$, $p < 0.001$; (3) C/F/-F x V/I interaction: $F(2,6) = 8.76$, $p < 0.025$; (4) C/F/-F x SOA interaction: $F(4,12) = 218.72$, $p < 0.001$; (5) V/I x SOA interaction: $F(2,6) = 21.89$, $p < 0.005$; (6) C/F/-F x V/I x SOA interaction: $F(4,12) = 4.66$, $p < 0.025$.

To examine whether the location of the flash (cued position or uncued location) had an effect on performance for unflashed invalid (-FI) trials, the values of arcsin p(CP,CSD) for invalid trials was subjected to a separate ANOVA involving the factors C/F/-Fc/-Fu and SOA. This ANOVA revealed all effects to be significant: (1) main effect C/F/-Fc/-Fu: $F(3,9) = 45.17$, $p < 0.001$; (2) main effect SOA: $F(2,6) = 6.55$, $p < 0.05$; (3) C/F/-Fc/-Fu x SOA interaction: $F(6,18) = 77.04$, $p < 0.001$.

Figure 3.2.a.: p(CP,CSD) as a function of SOA, separately for central cue only (C: left), for flashed (F: middle) and for unflashed (-F: right) conditions and for valid, baseline and invalid trials (V: triangles; B: circles; I: squares)



As can be seen from figure 3.2.a., under the unflashed (-F) condition performance is generally lower than in the central cue only (C) and flashed (F) conditions (C - -F, F - -F: $p < 0.001$; main effect of C/F/-F). Differences in performance between valid and invalid trials (V-I differences), combined across SOA, differ between the C, F and -F conditions (significant C/F/-F x V/I interaction): They are greatest for the F condition (C - F, F - -F: $p < 0.001$). Further, V-I differences in the C, F, and -F conditions are dependent on SOA (significant C/F/-F x V/I x SOA interaction).

For valid central cue only (CV) trials, performance increases between the 600- and 900-msec SOAs ($p < 0.001$) and then tends to fall slightly. For invalid central cue only trials, performance is quite invariant across SOA (see left hand side of figure 3.2.a.).

For valid and invalid flashed (FV and FI) trials, performance is highest at the 600-msec SOA, i.e. 100 msec after flash onset, and then declines towards the 900- (FV: 600-900: $p < 0.001$) and 1200-msec SOAs (FI: 600-900: $p < 0.001$; 900-1200: $p < 0.025$). (See middle of figure 3.2.a.).

For valid and invalid unflashed (-FV and -FI) trials, performance is lowest at the 600-msec SOA, i.e. 100 msec after the flash, and then improves towards the 900- (-FI: 600-900: $p < 0.001$) and 1200-msec SOAs (-FV: 600-900: $p < 0.001$; 900-1200: $p < 0.025$; most of the improvement occurs between the 600 and 900-msec SOAs). (See right hand side of figure 3.2.a.).

At the 600-msec SOA, performance is significantly higher for flashed (FV and FI) than for central cue only (CV and CI) trials (CV - FV, CI - FI: $p < 0.001$; performance for FI trials is as high as performance for CV trials). At longer SOAs, there are no reliable differences between flashed and central cue only conditions for valid trials (FV and CV; note that optimum performance for FV trials at 600 msec is above optimum performance for CV trials at 900 msec). For invalid trials, however, performance for flashed trials (FI) is below that for central cue only (CI) trials (900: $p < 0.005$; 1200: $p < 0.001$).

At the 600-msec SOA, performance is significantly lower for unflashed (-FV and -FI) than for central cue only (CV and CI) trials ($p < 0.001$; performance for -FV trials is also lower in comparison with CI trials). For invalid trials, performance for unflashed trials (-FI) stays below that for central cue only (CI) trials at longer SOAs (900, 1200: $p < 0.001$). For valid trials, however, the difference between unflashed (-FV) and central cue only (CV) trials is no longer reliable at the 1200-msec SOA (900: $p < 0.001$).

The significant three-way interaction between C/F/-F, V/I and SOA occurs because of a tendency for V-I differences in the flashed (F) condition to increase more markedly between the 600- and 1200-msec SOAs than in the central cue only (C) and unflashed (-F) conditions.

As can be seen from figure 3.2.b., for invalid unflashed (-FIc and -FIu) trials, performance is lowest at the 600-msec SOA, i.e. 100 msec after the flash, and increases towards the 900-msec SOA (600-900: $p < 0.001$). However, when the flash occurred at an uncued location (-FIu) performance is generally below ($p < 0.001$) that when it occurred at the cued position (-FIc), and also lower than in the central cue only (CI) and flashed (FI) conditions. When the flash occurred at the cued position, performance for invalid unflashed trials (-FIc) is lower than in the central cue only condition (CI) at the 600-msec SOA ($p < 0.001$), but as high at the 900- and 1200-msec SOAs; further, it (-FIc) is above performance in the flashed (FI) condition at long SOAs ($p < 0.001$).

Figure 3.2.b.: p(CP,CSD) as a function of SOA, separately for central cue only (CI: open sqares, solid line) and for flashed (FI: filled squares, solid line) invalid trials and also for unflashed invalid trials with a flash at the cued position (-FIc: filled squares, dashed line) or with a flash at an uncued location (-FIu: filled squares, dotted line)

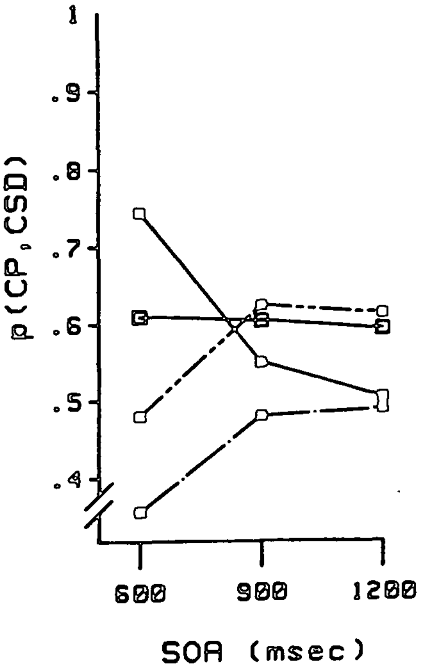


Figure 3.2.c.: p(CP,CSD) as a function of SOA, separately for unflashed valid (-FV: filled triangles, dashed line), for flashed invalid (FI: filled squares, solid line) and for unflashed invalid trials with a flash at an uncued location (-FIu: filled squares, dashed line)

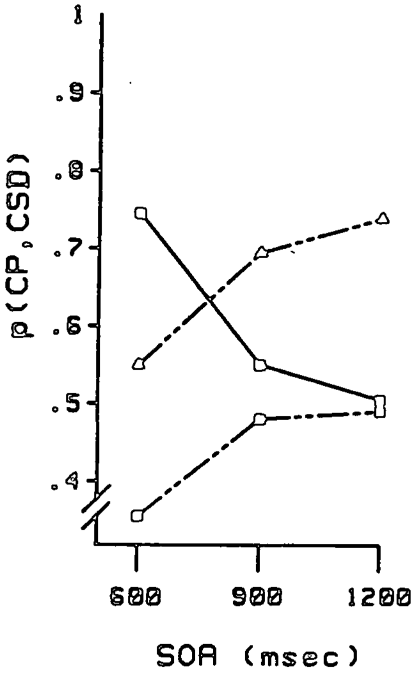


Figure 3.2.c. summarizes the results for -FV, FI and -FIu trials, i.e. for the critical conditions in which a flash occurred at an uncued position and the target appeared at the cued (-FV), at the flashed (FI) or at an uncued unflashed (-FIu) location. At the 600-msec SOA, i.e. 100 msec after flash onset, there are performance gains for targets at uncued flashed (FI) and losses for targets at cued unflashed (-FV) and uncued unflashed (-FIu) locations. As SOA duration increases, functions

for uncued flashed (FI) and cued unflashed (-FV) locations intersect as performance improves for cued (-FV) and declines for flashed (FI) positions. And functions for flashed (FI) and unflashed (-FIu) uncued locations converge, because of the decline for flashed (FI) and an initial improvement for unflashed (-FIu) uncued locations.

3.3.3. Discussion

The central cue only condition generally agrees with the central cueing condition of Experiment 5. For valid trials, performance increases slightly from the 600- to the 900-msec SOA. This might indicate that internal preparation processes are not yet fully completed 600 msec after cue onset. For invalid trials, performance is quite invariant across SOA. Note that differences between valid and invalid trials appear less marked than in Experiment 5 (mainly because of higher performance for invalid trials).

With reference to the central cue only condition, the effect of the flash is rather stereotyped: For flashed positions (FV and FI), performance is enhanced 100 msec after flash onset (i.e., at the 600-msec SOA); for unflashed locations (-FV and -FI), performance is impaired. Magnitudes of enhancement and impairment are largely independent of whether targets appeared at the cued (FV and -FV) or at an uncued (FI and -FI) location (note, however, that the magnitude of the impairment is greater than that of the enhancement: 0.20 on average as compared to 0.13). Restated, the flash, 100 msec after its onset, does not influence the advantage for valid over invalid trials.

This indicates that the effect of peripheral flashes is not completely automatic; rather, it can be attenuated or enhanced, to some degree, by a controlled process based on cue validity (i.e., production and maintenance of an expectancy based on the spatial information provided by the cue; see also JONIDES, 1980, 1981). Attenuation occurs when cue and flash compete: When the flash occurs at an uncued position, performance for the likely target location (-FV) is less inhibited, 100 msec after flash onset, than is performance for uncued unflashed locations (-FI). Enhancement occurs when cue and flash agree: When the flash occurs at the cued position (FV), performance for this position is more facilitated, shortly after the flash, than in the condition with only the central cue (CV); further, facilitation for flashed locations is more marked when a flash occurs at the cued position (FV) rather than at an uncued location (FI). In other words, facilitatory effects produced by uninformative flashes can "add" to the facilitation associated with the maintenance of a spatial expectancy, while maintenance of a spatial expectancy can "subtract" from inhibitory effects of flashes.

The most important finding of Experiment 6 is that when cue and flash compete (i.e., when the flash occurs at an uncued location), performance for the cued position

(-FV) is markedly reduced, 100 msec after flash onset, while performance for the flashed location (FI) is enhanced (see figure 3.2.c.). This indicates that the "controlled" process of sustained orienting, initiated through production of a spatial expectancy based on central cue information, is interrupted by an "automatic" orienting response triggered by a competing peripheral flash. The abrupt peripheral change in light energy rapidly summons attention away from the high (i.e., the cued) to a low priority (i.e., the flashed) location, inhibiting performance for the former and facilitating performance for the latter position. This is detrimental to overall performance because gains for the flashed location (probability of target occurrence: p = 1/3) cannot compensate for losses for the cued position (p = 3/6). This stereotyped effect of the flash indicates that an abrupt discontinuity in light energy in peripheral vision is a "proper" initiating condition for an "automatic" orienting response that is not interruptable (though modifiable to some degree) by voluntary control.

After attention has been rapidly summoned away to the location of the flash, performance for the cued position (-FV) recovers as the interval between flash and target onset increases and attention is reoriented; this recovery is particularly marked within 100 - 400 msec after flash onset and is associated with marked losses in performance for the flashed location (FI; see figure 3.2.c.). This trade-off in attention between flashed and cued positions suggests that the period for which the automatic orienting mechanism is active is transitory. That is, within 100 to 400 msec after its onset, external orienting in response to the flash becomes increasingly interruptable by voluntary control, i.e. a controlled process which is guided by the expectancy for the likely target location previously indicated by the central cue. It is interesting to note the similarity of the time course of recovery for the cued position (-FV) with that of the performance build-up for the indicated location in the central cueing condition of Experiment 5. This suggests that same internal orienting mechanism is involved.

100 msec after flash onset, performance for unflashed positions is markedly reduced: both for the cued (-FV) and for the two uncued unflashed locations (-FIu) with a flash at an uncued position, and for the three uncued unflashed locations (-FIc) with a flash at the cued position. That is, the automatic orienting response triggered by the flash is associated with a rapid build-up of inhibition for unflashed locations.

This inhibitory effect which rapidly follows flash onset shows a remarkable difference for uncued unflashed locations between the condition with a flash at the cued position (-FIc) and the condition with a flash at an uncued location (-FIu): In the first condition (-FIc) inhibition is less marked than in the second condition

(-FIu)。 Further, both conditions improve within 100 to 400 msec after flash onset; however, performance for uncued unflashed locations reaches a comparable level as on invalid trials without flash (CI) only for the condition with a flash at the cued position (-FIc; i.e., there are no differences between -FIc and CI at the 900- and 1200-msec SOAs), while in the condition with a flash at an uncued location (-FIu) performance stays well below this level. (See figure 3.2.b.)

This finding indicates that two factors contribute to the inhibitory component for unflashed locations: Early inhibition caused by the rapid summoning of attention by the flash, no matter whether it occurs at the cued (-FIc) or at an uncued location (-FIu); this "passive" inhibition can be compensated for as the power of the flash to summon attention fades out, within 100 to 400 msec after its onset, and attention becomes available for reorientation. And "active" inhibition which occurs only with a flash at an uncued location; that is, it is caused by the additional capacity demands of the controlled process which guides reorientation of attention to the cued position. Since active inhibition is time-locked to the reorienting process, it can outlast "passive" inhibition which is time-locked to the transitory automatic orienting process. The additional capacity demands with a flash at an uncued location might arise because the spatial expectancy for the likely target locations needs to be renewed or consolidated. With a flash at the cued position, no additional demands arise because the flash may itself "refresh" the spatial expectancy and there is no need to reorient attention.

The suggestion that two sources contribute to inhibition for uncued unflashed locations could also account for the finding in Experiment 5 that with unexpected central cues (50C-50P), performance for uncued locations is not enhanced within 400 msec after cue onset (i.e., there is no recovery from early inhibition as with peripheral cues). That is, if central cues are not always expected, additional demands on production of a spatial expectancy might cause active inhibition which outlasts passive inhibition produced by peripheral cues.

Note that at the 900- and 1200-msec SOAs, performance for invalid central cue only (CI) trials does not differ from performance for invalid unflashed trials with a flash at the cued position (-FIc; -FIc trials can be regarded as equivalent to peripheral cueing invalid, PI, trials in Experiment 5; recall that PI trials showed superior performance to CI trials at SOAs longer than 275 msec; see figure 3.1.). This might indicate that when central cues are always expected, active inhibition for uncued locations (CI) is compensated for within 600 msec after cue onset; that is, performance for uncued locations might have been reduced at very short SOAs and might have recovered before the 600-msec SOA (i.e., the shortest SOA duration in the present experiment).

3.4. Experiment 7

Experiment 7 was designed to measure the degree to which the early automatic and the later controlled component of orienting in response to informative peripheral cues can be diverted by task-irrelevant (uninformative) peripheral flashes. If external orienting is indeed an "automatic" process, as suggested, it should be less interruptable by a competing flash than internal orienting.

A trial began with the presentation of a peripheral cue, i.e. a 50-msec brightening of the outline of one of the four boxes indicating the likely target location, which was then followed by the target after varying delays. In one condition only the peripheral cue was presented, and in the other conditions an additional flash ocurred at varying delays after the onset of the peripheral cue (cue-flash onset asynchronies, CFOAs). This flash was spatially uninformative, i.e. it was necessary to maintain preparation for the cued location, whether the flash appeared at the cued (no competition) or at an uncued location (competition).

Thus, Experiment 7 involved three conditions: (1) The "peripheral cue only" (P) condition; (2) the "flashed" (F) condition in which the target occurred at the flashed position; and (3) the "unflashed" (-F) condition in which the target appeared at an unflashed location. The SOAs between cue and target onset (P condition) and between flash and target onset (F and -F conditions) were 100, 300 or 500 msec so that the time course of orienting in response to peripheral cues and flashes could be traced. The CFOAs were 100, 300 or 500 msec, i.e. the flash occurred during the components of automatic (100- to 300-msec CFOAs) and of sustained (300- to 500-msec CFOAs) facilitation for the cued position so that resistance to competition for these could be tested. The 100-msec CFOA was just long enough to avoid apparent movement when the flash occurred at an uncued location and to allow the cued and flashed positions to be clearly distinguished. (Although originally planned, shorter CFOAs could not be introduced because of these difficulties.)

For flashes occurring at uncued locations, it was expected that there would be a performance loss for the cued position (-FV) at the 100-msec SOA, with the magnitude of this loss depending on CFOA: At the 100-msec CFOA this performance loss would be less marked than at longer CFOAs, because the early automatic orienting component triggered by a peripheral cue is more powerful in resisting the competition of a flash than the later controlled component. That is, automatic orienting is characterized by a "refractory" period during which attention is engaged by the peripheral cue so that a second flash at an uncued location is less powerful in eliciting an attention response. At longer SOAs, priority for the cued location would be reestablished (controlled reorienting of attention).

Likewise, it was expected that there would be a performance gain for the uncued flashed location (FI) at the SOA of 100 msec, with the magnitude of this gain depending on CFOA: At the 100-msec CFOA this gain would be less marked than at the longer CFOAs, because attention is initially engaged by the peripheral cue. At longer SOAs, this advantage for the flashed location would be lost again, because attention is reoriented to the cued position.

3.4.1. Method

The general method of Experiment 7 was the same as in Experiment 6. The variations in methodology were as follows.

Apparatus and Materials: Stimuli were presented on a Tektronix 608 X-Y display with a P 31 phosphor. The CRT was controlled by a LSI-11/23 computer system through a CED 502 Interface. Subjects viewed the CRT from a distance of 50 cm, resulting in the same angular sizes and eccentricities of the stimuli as in the previous experiments.

Design and Procedure: Experiment 7 involved four main factors: (1) CFOA (100, 300 and 500 msec), (2) P/F/-F, (3) V/I and (4) SOA (100, 300 and 500 msec). Note that the term "SOA" refers to the delay between the onset of the peripheral cue (P) or of the peripheral flash (F and -F) and target onset. Baseline trials (B) which presented a spatially uninformative, simultaneous brightening of all four boxes were combined with the F/-F conditons in the same way as valid and invalid trials. Further, in the PB condition ("warning signal only") the target occurred not only at the SOAs of 100, 300 and 500 msec but also at delays of 700 and 900 msec to provide a baseline measure without flash for the F and -F conditions. The design of Experiment 7 is summarized in table 3.2. The total number of trials was 2976 which were presented in four two-hour sessions each of 744 trials.

Table 3.2.: Design of Experiment 7 (P: peripheral cue only; F: target position = flashed; -F: target position = unflashed; V, B and I: valid, baseline and invalid trials; c: cued position = flashed; u: uncued position = flashed; number of trials in brackets)

	x	V	x			SOA	(3 x 96)
P	x	B	x			SOA	(5 x 48)
	x	I	x			SOA	(3 x 96)
	x	V	x	CFOA	x	SOA	(3 x 3 x 24)
F	x	B	x	CFOA	x	SOA	(3 x 3 x 12)
	x	I	x	CFOA	x	SOA	(3 x 3 x 24)
	x	V	x	CFOA	x	SOA	(3 x 3 x 72)
-F	x	B	x	CFOA	x	SOA	(3 x 3 x 36)
	x	I	x	CFOA	x	SOA	(3 x 3 x 72)
-FI	x	c	x	CFOA	x	SOA	(3 x 3 x 24)
	x	u	x	CFOA	x	SOA	(3 x 3 x 48)

Subjects: Seven subjects participated in Experiment 7: A.N., P.P., S.M., L.G., C.W., T.L. and H.H. (ages 19-29; four with normal and three with corrected-to-normal vision). Payment was 5.0 pounds for each two-hour session. Subjects having no prior experience with the task (all except for H.M.) participated in 4 - 6 practice sessions until they reached stable and comparable 0.75-threshold exposure durations. The following exposure times were introduced in Experiment 4 for A.N., P.P., S.M., L.G., C.W., T.L. and H.M., respectively (means of four sessions, based on threshold estimates for PB trials, i.e. baseline trials without flash): 45, 53.5, 50, 47.5, 51.5, 50.5 and 39 msec.

3.4.2. Results

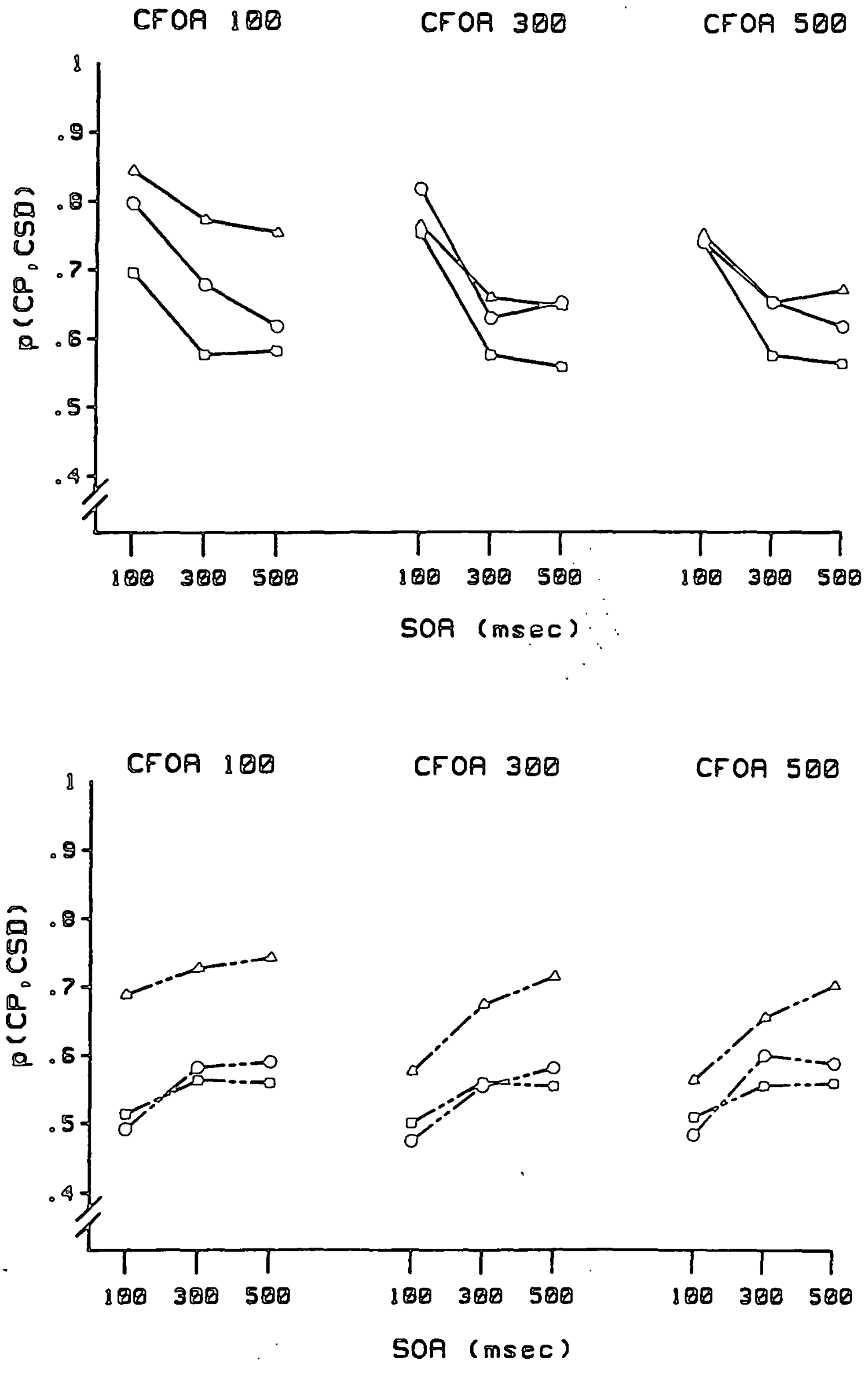
Figures 3.3.a. and 3.3.b. present the mean values of p(CP,CSD) as a function of CFOA and of SCA, separately for flashed (F; figure 3.3.a.) and for unflashed (-F; figure 3.3.b.) valid, baseline and invalid trials. Figure 3.3.c. (page 208) presents the comparison between flashed (FI) and unflashed (-FI) invalid trials, with the -FI trials broken down according to whether the flash occurred at the cued (-FIc) or at an uncued (-FIu) location. Figure 3.3.d. (page 210) illustrates the comparison between valid unflashed (-FV), invalid flashed (FI) and invalid unflashed (-FIu) trials with a flash at an uncued location. And figure 3.3.e. (page 211) presents the comparison between valid flashed (FV), peripheral cue only baseline (PB) and invalid unflashed (-FIc) trials with a flash at the cued position.

The arcsin-transformed values of p(CP,CSD) were evaluated in a four-way ANOVA involving the CFOA, F/-F, V/I and SOA. This ANOVA revealed the following effects to be significant: (1) main effect CFOA: $F(2,12) = 26.51$, $p < 0.001$; (2) main effect F/-F: $F(1,6) = 114.53$, $p < 0.001$; (3) main effect V/I: $F(1,3) = 81.13$, $p < 0.001$; (4) main effect SOA: $F(2,12) = 28.36$, $p < 0.001$; (5) CFOA x V/I interaction: $F(2,12) = 18.61$, $p < 0.001$; (6) F/-F x SOA interaction: $F(2,12) = 131.81$, $p < 0.001$; (7) V/I x SOA interaction: $F(2,12) = 5.04$, $p < 0.05$; (8) CFOA x F/-F x V/I interaction: $F(2,12) = 3.53$, $0.05 < p < 0.075$; (9) CFOA x F/-F x SOA interaction: $F(4,24) = 2.65$, $0.05 < p < 0.075$.

To examine whether the location of the flash (cued position or uncued location) has an effect on performance for unflashed invalid (-FI) trials, the values of arcsin p(CP,CSD) for invalid trials were subjected to a separate ANOVA involving the factors CFOA, F/-Fc/-Fu and SOA. This ANOVA revealed the following effects to be significant: (1) main effect F/-Fc/-Fu: $F(2,12) = 30.27$; $p < 0.001$; (2) main effect SOA: $F(2,6) = 4.77$, $p < 0.05$; (3) F/-Fc/-Fu x SOA interaction: $F(4,24) = 41.97$, $p < 0.001$; (4) CFOA x F/-Fc/-Fu x SOA interaction: $F(8,48) = 2.12$, $0.05 < p < 0.075$.

As can be seen from figures 3.3.a. and 3.3.b., overall performance is higher for flashed (F) than for unflashed (-F) trials (main effect of F/-F), and also higher for valid than for invalid trials (main effect of V/I).

Figures 3.3.a. and 3.3.b.: p(CP,CSD) as a function of CFOA and SOA, separately for flashed (F; top figure) and unflashed (-F; bottom figure) conditions and for valid, baseline and invalid trials (V: triangles; B: circles; I: squares)



For flashed (F) trials (figure 3.3.a.), performance is highest at the 100-msec SOA and then declines significantly towards the 300-msec SOA (100-300: $p < 0.001$), both for valid and for invalid trials and for all CFOAs. This decline appears more marked for invalid than for valid trials. For unflashed (-F) trials (figure 3.3.b.), performance is lowest at the 100-msec SOA and then improves significantly towards the 300-msec SOA (100-300: $p < 0.001$). This improvement appears more marked for valid than for invalid trials; for valid trials, it continues after the 300-msec SOA.

At the 100-msec SOA, performance is higher for valid and invalid flashed (FV and FI) trials than for valid and invalid unflashed (-FV and -FI) trials (FI - -FV: $p < 0.001$). At longer SOAs, performance does not differ reliably between flashed and unflashed valid (FV and -FV) and between flashed and unflashed invalid (FI and -FI) trials.

Combined across flashed (F) and unflashed (-F) conditions, performance for valid trials does not vary as a function of SOA (i.e., the relatively strong improvement for -FV trials between the 100- and 300-msec SOAs compensates for the decrease for FV trials). However, performance for invalid trials, combined across flashed (F) and unflashed (-F) conditions, decreases between the 100- and 300-msec SOAs (i.e., the relatively strong decline for FI trials is not compensated for by the initial increase for -FI trials). As a result, overall performance decreases significantly (100-300: $p < 0.001$; main effect of SOA) and V-I differences increase between the SOAs of 100 and 300 msec (significant V/I x SOA interaction).

As can be seen from figures 3.3.a. and 3.3.b., V-I differences, combined across SOA, are significantly smaller for the CFOAs of 300- and 500-msec than for the 100-msec CFOA. This difference occurs because of an initial performance loss for valid (100-300, 100-500: $p < 0.001$) and invariant performance for invalid trials (CFOA x V/I interaction).

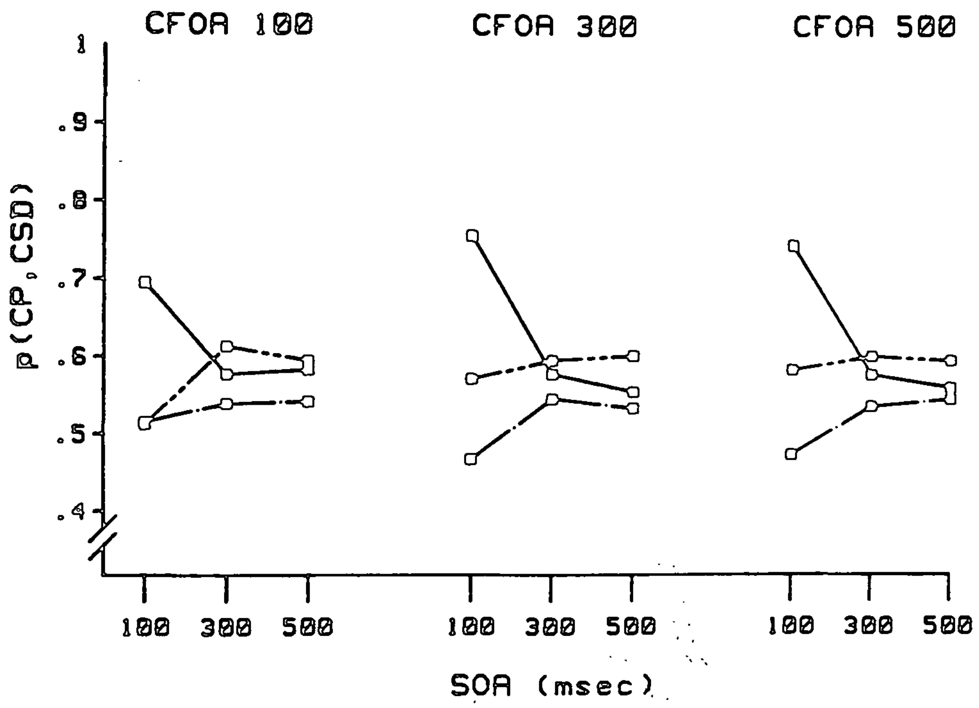
Further, for the 100-msec CFOA, V-I differences do not differ between flashed (F) and unflashed (-F) conditions; however, for the CFOAs of 300 and 500 msec, V-I differences tend to be smaller for the flashed (F) than for the unflashed (-F) condition (marginally significant CFOA x F/-F x V/I interaction). This occurs because performance losses for valid trials between the CFOA of 100 msec and the 300- and 500-msec CFOAs are more marked for the flashed (F) than the unflashed (-F) condition.

Performance differences between the F and -F conditions, combined across valid and invalid trials, vary little with SOA for the 100-msec CFOA; however, for the CFOAs of 300 and 500 msec differences tend to increase between the SOA of 100 msec and the 300- and 500-msec SOAs (marginally significant CFOA x F/-F x SOA interaction). This occurs because at the 100-msec SOA, there is a performance loss for unflashed valid (-FV) trials between the CFOA of 100 msec and the 300- and 500-msec CFOAs (100-300, 100-500: $p < 0.001$; see also figure 3.3.d.), in addition to the SOA independent loss for flashed valid (FV) trials.

Thus, the reduced overall performance for the CFOAs of 300 and 500 msec in comparison with the 100-msec CFOA (main effect of CFOA) is due to a largely SOA independent loss in performance for flashed valid (FV) trials and a specific loss for unflashed valid (-FV) trials at the 100-msec SOA (note that performance for these conditions is below the peripheral cue only baseline PB; see figure 3.3.e.). Performance for flashed and unflashed (FI and -FI) invalid trials is relatively unaffected by CFOA (except for the FI condition at 100-msec SOA, which shows a slight increase between the CFOA of 100 msec and the 300- and 500-msec CFOAs; see figure 3.3.d.).

As can be seen from figure 3.3.c., for unflashed invalid trials (-FIc and -FIu), performance is lowest at the SOA of 100 msec and increases significantly towards the 300-msec SOA (100-300: -FIc: $p < 0.025$; -FIu: $p < 0.005$). General performance for unflashed invalid trials is significantly lower with a flash at an uncued location (-FIu) than with a flash at the cued (-FIc) position ($p < 0.001$ for all SOAs).

Figure 3.3.c.: p(CP,CSD) as a function of CFOA and SOA, separately for flashed invalid trials (FI: solid lines) and also for unflashed invalid trials with a flash at the cued position (-FIc: dashed lines) and with a flash at an uncued location (-FIc: dotted lines)



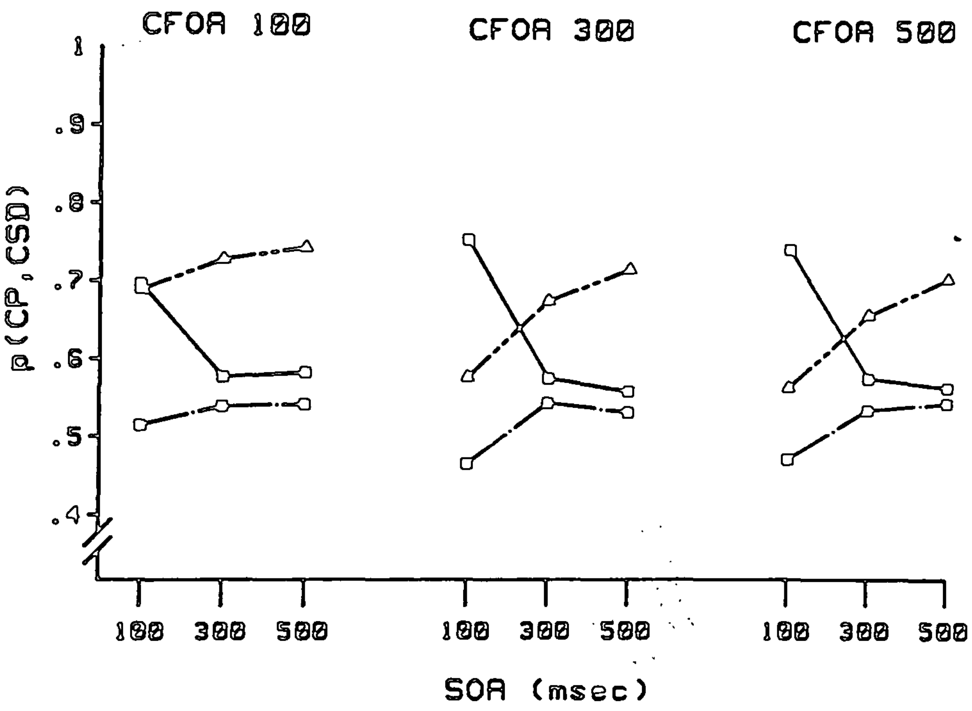
At the 100-msec SOA, performance for unflashed invalid (both for -FIc and for -FIu) trials is significantly lower than for flashed invalid (FI) trials ($p < 0.001$). However, at the 300- and 500-msec SOAs, performance tends to be higher for unflashed invalid trials with a flash at the cued position (-FIc) and lower for unflashed invalid trials with a flash at an uncued location (-FIu) in comparison with flashed invalid trials (FI). (Significant F/-Fc/-Fu x SOA interaction.)

At the SOAs of 300 and 500 msec, performance for flashed (FI) and unflashed (-FIc and -FIu) invalid trials does not differ significantly among CFOAs. However, at the 100-msec SOA, performance both for flashed invalid trials (FI) and for unflashed invalid trials with a flash at the cued position (-FIc) is lower for the 100-msec CFOA than for the CFOAs of 300 and 500 msec (FI: 100-300: $p < 0.025$, 100-500: $0.10 > p > 0.05$; -FIc: 100-300: $p < 0.05$, 100-500: $p < 0.01$); but performance for unflashed invalid trials with a flash at an uncued location (-FIu) tends to be higher.

In other words, when the flash occurs at an uncued location, performance (100-msec SOA) is slightly increased for the flashed position (FI) and reduced for unflashed locations (-FIu) at the CFOAs of 300 and 500 msec relative to the 100-msec CFOA. However, when the flash occurs at the cued position, performance (100-msec SOA) is reduced for unflashed locations (-FIc) at the 100-msec CFOA relative to the CFOAs of 300 and 500 msec (marginally significant interaction between CFOA, F/-Fc/-Fu and SOA).

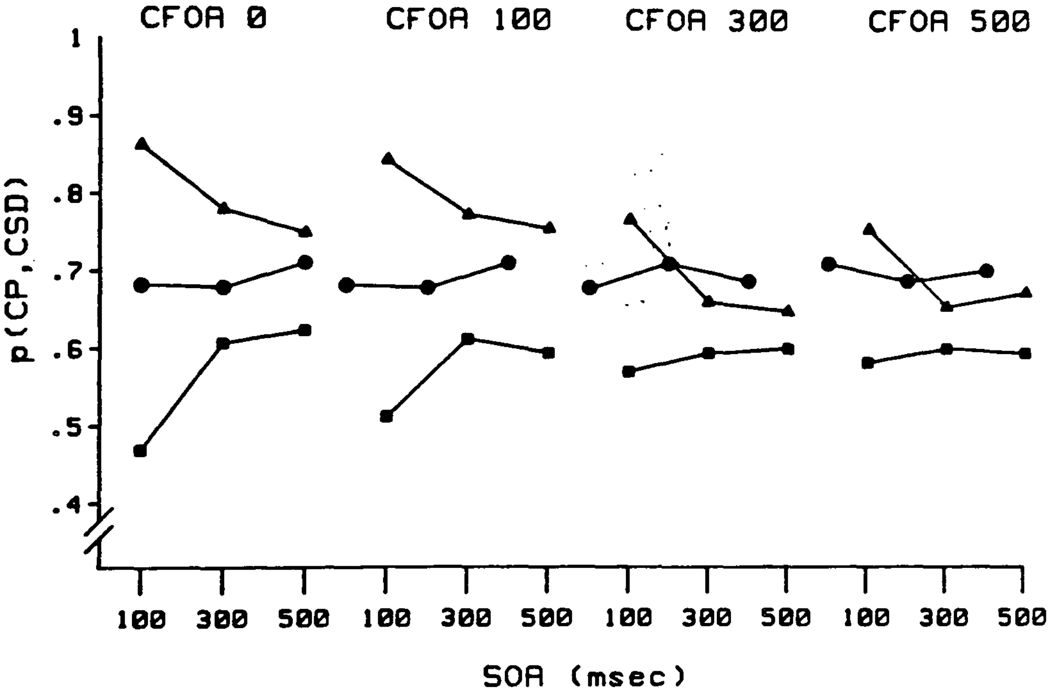
Figure 3.3.d. summarizes the results for -FV, FI and -FIu trials, i.e. for the critical conditions in which a flash occurred at an uncued position and the target appeared at the cued, at the flashed or at an uncued unflashed location.

Figure 3.3.d.: p(CP,CSD) as a function of CFOA and SOA, separately for unflashed valid (-FV: filled triangles, dashed lines), for flashed invalid (FI: filled squares, solid lines) and for unflashed invalid trials with a flash at an uncued location (-FIu: filled squares, dotted lines)



At 100-msec SOAs, there are performance gains for flashed invalid (FI) trials and losses for unflashed valid (-FV) and unflashed invalid (-FIu) trials. Note that at the CFOAs of 300 and 500 msec gains and losses for flashed and unflashed locations are more marked than at the 100-msec CFOA. At longer SOAs, SOA functions for invalid flashed (FI) and valid unflashed (-FV) trials intersect, in particular for the 300- and 500-msec CFOAs, as performance improves for valid (-FV) trials and declines for invalid (FI) trials; and SOA functions for flashed (FI) and unflashed (-FIu) invalid trials converge, because of performance losses for flashed (FI) and improvements for unflashed (-FIu) trials.

Figure 3.3.e.: p(CP,CSD) as a function of CFOA and SOA, separately for flashed valid (FV: triangles), for peripheral cue only baseline (PB: circles) and for invalid trials with a flash at the cued position (-FIc: squares)



Valid and invalid trials with a flash at the cued position (FV and -FIc) are comparable to the "peripheral cueing" conditions of Experiments 5 and 6. As can be seen from figure 3.3.e., flashed valid (FV) and unflashed invalid trials (-FIc) in Experiment 7 show a pattern which is very similar to PV and PI trials in Experiment 5 and, respectively, to FV and -FIc trials in Experiment 6; note that the "peripheral cue only" (P) condition, presented at the left of figure 3.3.e., can be regarded as a "flashed" condition with identity between cued and flashed location and a CFOA of 0 msec.

There is no difference in performance between the 0- and 100-msec CFOAs and between the 300- and 500-msec CFOAs. For the 0/100-msec CFOAs, performance at the 100-msec SOA is highest for valid and lowest for invalid trials. For the 300/500-msec CFOAs, however, performance for invalid trials remains invariant across SOA at a level comparable to the 300- and 500-msec SOAs with the 0/100-msec CFOAs (i.e., performance is not reduced at the 100-msec in comparison with the longer SOAs). In contrast, performance for valid trials is generally reduced in comparsion with the 0/100 msec CFOAs. Thus, V-I differences decrease between the 100- and 300-msec SOAs, for all CFOAs, and also between the 0/100- and the 300/500-msec CFOAs. A separate ANOVA of arcsin p(CP,CSD), involving the factors CFOA (0, 100, 300 and 500 msec), FV/-FIc and SOA, revealed the corresponding three-way interaction to be significant ($F(6,36) = 2.45$, $p < 0.05$).

3.4.3. Discussion

100 msec after the onset of a flash at an uncued

location, there are substantial performance losses for the unflashed cued position (-FV) and marked gains for the flashed uncued location (FI); there are also losses for unflashed uncued locations (-FIu) (see figure 3.3.d.). That is, a flash at an uncued location rapidly summons attention away from the cued position, enhancing performance for the flashed location and reducing it for the cued position and also for uncued unflashed locations.

However, the magnitudes of the performance losses for cued and of the gains for flashed positions are dependent on the interval between cue and flash onset (CFOA): The trade-offs are less marked for the CFOA of 100 msec than for the 300- and 500-msec CFOAs; and, likewise, the losses for uncued unflashed locations are less for the 100-msec than for the longer CFOAs. In other words, when a flash occurs at an uncued position during the early orienting component triggered externally by a peripheral cue (i.e., 100 msec after cue onset), its ability to summon attention and to cause inhibition for unflashed locations is reduced, in comparison with flashes occurring during the later component that is guided internally by the spatial information of the cue (i.e., 300 to 500 msec after cue onset).

That is, the early, "automatic", orienting process is more powerful in resisting the competition of a flash than the later, "controlled", process of sustained orienting. This differential resistance against a competing ("automatic") process indicates that orienting in response to a peripheral cue is indeed characterised by a higher degree of automaticity than orienting based solely on production of a spatial expectancy in response to the information of the cue; note, however, that the difference is only a gradual one, i.e. there is a substantial trade-off even for the 100-msec CFOA (but this is less marked than for the 300- and 500-msec CFOAs). The differential trade-offs between the 100-msec and the longer CFOAs support the notion of a "refractory" period during which attention is engaged by the peripheral cue, so that a second flash or a target at an uncued location is less likely to call an attention response; note that this idea of a refractory period could also provide an explanation for the early, "passive", inhibitory effect of peripheral cues on uncued locations.

With increasing time between flash and target (300- and 500-msec SOAs), as the power of the flash to engage attention fades out and attention can be actively withdrawn from the flashed location, priority for the cued position is reestablished through an internal orienting process guided by the spatial expectancy induced by the preceding cue. This reorientation of attention to the likely target location (-FV) shows a similar time course and is associated with a similar, substantial, decline in performance for the flashed position (FI) as in Experiment 6. With the fading of the power of the flash to summon attention, some enhancement, i.e. recovery from early, passive, inhibition, can also occur for uncued unflashed locations (-FIu; i.e., targets at these positions become more likely to call an attention response).

As in Experiment 6, performance for uncued unflashed locations is generally lower with a flash at an uncued (-FIu) than with a flash at the cued position (-FIc; see figure 3.3.c.). That is, with a flash at a less likely target location, uncued unflashed positions (-FIu) are affected by lasting, "active", inhibition (in addition to the transitory, passive, inhibition) associated with the additional capacity demands of reorienting attention to the cued position.

The peripheral cue only (P) condition shows the typical pattern associated with peripheral cueing (see CFOA = 0 condition in figure 3.3.e.). For the cued position, there is a powerful ("automatic") facilitatory effect at the 100-msec SOA, followed by a decline and sustained ("controlled") facilitation at the 300- and 500-msec SOAs. For uncued locations, there is an early inhibitory effect followed by some enhancement within 300 msec after cue onset. With a flash at the cued position (FV and -FIc), the pattern is essentially the same for the 100-msec interval between cue and flash onset (100-msec CFOA; note that at the 100-msec SOA, the flash does not improve performance for the cued position above that for the peripheral cue only, i.e. 0-msec CFOA condition).

However, there is a change in this pattern for the longer intervals (300- and 500-msec CFOAs). For the cued position, the early enhancement produced by the flash (100-msec SOA) does not improve upon the sustained level of facilitation for CFOAs of 0 and 100 msec CFOAs at the 300- and 500-msec SOAs, and at the SOAs of 300 and 500 msec performance falls even below this level (note the intersection between valid flashed, FV, and peripheral cue only baseline, PB, trials in figure 3.3.e.). For uncued locations, the early inhibitory effect is reduced or absent (in contrast with unflashed trials with a flash at an uncued position, i.e. -FIu) and performance at the 300- and 500-msec SOAs is as high as that for the CFOAs of 0 and 100 msec. That is, the reduced strength of the early facilitatory component for the cued position is associated with a less powerful inhibitory component for uncued locations; but the reduced level of sustained facilitation for the cued position at the 300- and 500-msec SOAs does not enhance performance for uncued locations.

Presumably, POSNER and COHEN's (1984) inhibition effect is the cause for the reduced facilitation (of both the early and the sustained component) for the 300- and 500-msec CFOAs. That inhibition for the cued position cannot be completely suppressed by attention when it is flashed repeatedly (cue plus flash) and with intervals between cue and flash onset of 300 to 500 msec, appears in accordance with POSNER, COHEN, CHOATE, HOCKEY and MAYLOR

(1984). POSNER et al. observed that simple RTs to suprathreshold luminance increments were slowed when the target probe appeared twice or more often at the same location than when it did not (inhibition was most pronounced at the 300-msec interval between response to target N and presentation of target N + 1, i.e. at inter-target intervals of 600 to 700 msec). Although POSNER et al. found that inhibition was at its maximum after only one repetition, this does not rule out the possibility that inhibition may build up with more repetitions when the inter-stimulus interval is shorter than 600 to 700 msec. Such a build-up might have occurred in the present experiment with a maximum inter-stimulus interval of 500 msec in the cue-flash-target sequence (i.e., two repetitions).

POSNER and COHEN's inhibition results in failure of a second flash at the cued position to reactivate fully the early (100-msec SOA), automatic, orienting component following activation by a peripheral cue, and this is associated with reduced strength of early, "passive", inhibition for uncued locations. ("Active" inhibition should not be involved, for a noncompeting flash should not influence the spatial expectancy based on the information provided by the advance cue.) But POSNER and COHEN's inhibition effect is not associated with enhanced performance for uncued locations at 300- and 500-msec SOAs, indicating that this effect is not a trade-off phenomenon (see also POSNER and COHEN, 1984).

3.5. General Discussion

The results of the present experiments are largely consistent with the two-component model of spatial orienting proposed in Chapter 2 (section 2.6.; see also JONIDES, 1981).

Experiment 5 showed that at short SOAs, central cues are less effective than peripheral cues in orienting attention to the indicated location; however, at longer SOAs, the two types of cue are equally effective in sustaining attention for the cued position.

This suggests that there are two different processes associated with central and peripheral cueing: Direct cues in the display periphery trigger a rapid and powerful orienting response ("summoning" of attention); presumably, this process is activated by external properties of the cue (abrupt temporal discontinuity in light energy). Symbolic indicators in the centre initiate a delayed orienting process (production of an expectancy) which is guided by the spatial information provided by the cue. Production of a spatial expectancy demands time and capacity, but it may enhance the effect of peripheral cues.

The early facilitatory component produced by peripheral cues is followed by a less effective component of sustained facilitation; however, this component is powerful enough to supress POSNER and COHEN's inhibition effect which would otherwise, i.e. without actively sustained attention, follow the preceding peripheral cue (POSNER and COHEN, 1984; MAYLOR, 1985). The transition from the first to the second component with peripheral cues and the asymptotic build-up of facilitation with central cues suggest that the component which enables attention to be maintained for the indicated location is the same for the two types of cue.

The build-up of facilitation for the cued position is associated with a concurrent inhibitory effect for uncued locations. This effect appears to have two sources: "Passive" inhibition which is transitory and caused by the summoning of attention to the locus of a peripheral cue; and "active" inhibition which can last longer and is caused by the capacity demands of producing a spatial expectancy for the indicated position. Early inhibition can be compensated for only as the "passive" effect of a peripheral cue to engange attention fades out and/or "active" production of a spatial expectancy is completed. Maintenance of a spatial expectancy for the cued position is associated with reduced inhibition for uncued locations.

The differential time course of spatial orienting in response to peripheral and to central indicators (Experiment 5) suggested that the early facilitatory component associated with peripheral cues and the component of sustained facilitation associated both with central and with peripheral cues are based on separate processes which differ in their degree of automaticity ("automatic" versus "controlled"). Experiments 6 and 7 were designed to test this by measuring the degree to which these processes could resist the competition of an uninformative peripheral flash (i.e., of an "automatic" stimulus itself).

Experiment 6 showed that sustained orienting initiated through central cues ("controlled" process) is not powerful enough to resist the competition of ("automatic") orienting in response to a peripheral flash: With a flash at an uncued location, performance is initially impaired for the cued (-FV) and enhanced for the flashed position (FI), because the flash rapidly summons attention away from the high to a low priority location. Presumably, the ability of the orienting process initiated by central cues to resist interruption would not be greater at shorter intervals between cue and flash (i.e., shorter than the 500-msec CFOA used in Experiment 5).

As the automatic effect of the flash to engage attention fades out, within 100-400 msec after its onset, attention can be actively reoriented to the high priority location indicated by the advance cue and facilitation for this position (-FV) is built up again. The time course of this recovery resembles the asymptotic build-up of facilitation in the central cueing condition of Experiment 5, suggesting that reorientation of attention is guided by the same process which enables orienting in response to central indicators. Reorientation of attention to the cued position involves a trade-off with the flashed location (FI) which loses its early advantage as the interval between flash and target gets longer.

With the fading of early, passive, inhibition produced by the flash, performance for uncued unflashed locations improves initially, whether the flash occured at the cued (-FIc) or at an uncued position (-FIu). However, with a flash at an uncued location, the capacity demands associated with the reorientation of attention to the cued position involve lasting, active, inhibition for uncued unflashed locations.

Experiment 7 showed that similar trade-offs occur when the likely target location is indicated by a peripheral cue which is then followed by a spatially uninformative peripheral flash.

However, with a flash at an uncued position, the tradeoff between the cued (-FV; early performance loss) and the flashed (FI; early performnace gain) location is less marked for the 100-msec interval between cue and flash than for the 300- and 500-msec intervals. That is, the early orienting component triggered by peripheral cues (100-msec CFOA) shows greater resistance against the competition of a peripheral flash than the later component of sustained orienting (300- and 500-msec CFOAs); the trade-off for this second component is as large as that in

Experiment 6 with central cues and a 500-msec CFOA. This indicates that external orienting triggered by peripheral cues is indeed an "automatic" process, while sustained (internal) orienting initiated both through central and through peripheral cues is a "controlled" process.

With a flash at the cued position (FV and -FIc; PV and PI trials are regarded as "flashed" conditions with a CFOA of 0 msec), there is a further differential effect between the 0- and 100-msec intervals between cue and flash onset and the 300- and 500-msec intervals: When long CFOAs are compared with short ones, the early (100-msec SOA) facilitatory component for the cued position is reduced in magnitude, as is the component of sustained facilitation (300- and 500-msec SOAs). This reduction is presumably caused by POSNER and COHEN's (1984) inhibition effect. This would suggest that inhibition may build up, and reach a strength which cannot be compensated for by sustained attention, when the cued position is repeatedly stimulated with a maximum inter-stimulus interval of 500 msec in the cue-flash-target sequence (see also POSNER et al., 1984).

Both Experiments 6 and 7 provide evidence that the effect of peripheral flashes is not completely "automatic"; rather, it can be attenuated or enhanced, to some degree, by a controlled process based on a spatial expectancy (see also JONIDES, 1980, 1981). Attenuation occurs when cue and flash compete; enhancement can occur when they agree. Restated, facilitatory effects produced by uninformative flashes can "add" to the facilitation associated with the production and maintenance of a spatial expectancy (note that with a flash at the cued position, enhancement occurs only with central but not with peripheral cues); and maintenance of a spatial expectancy can "reduce" inhibitory effects of flashes.

YANTIS and JONIDES (1984) have recently demonstrated that single abrupt stimulus onsets in multielement displays with gradual stimulus onsets produce "... a rapid and involuntary deployment of attention to the locus of temporal discontinuity" (p. 601). The present experiments, using single salient discontinuities in light energy in peripheral vision (peripheral cues and flashes), agree with this. They are consistent with two of YANTIS and JONIDES' (1984) predictions for "onset" and "no-onset" stimuli (see pp. 618 - 619): First, if an attended location contains a target, an abrupt onset nontarget at some other location is more likely to interfere with target processing than a no-onset nontarget; second, performance for a target with abrupt onset should be quite high even if it appears at an unattended location.

That is, targets with abrupt onsets "... should be efficiently processed regardless of the subject's intentional allocation of attention" (p. 619). The reason for this is the involuntary nature of the automatic orienting process triggered by abrupt changes in light energy. Such changes are "imperative", summoning attention possibly without subjective effort, intention and awareness. Presumably, they are encoded at some early, preselective (parallel and capacity-free), stage in the visual system and guide access of immediately following stimuli to a limited capacity system (e.g., DUNCAN, 1980a).

YANTIS and JONIDES linked the effect of direct peripheral cues to the special status of abrupt onsets in the transient visual system (e.g., KULIKOWSKI and TOLHURST, 1973; BREITMEYER and JULESZ, 1975; TODD and VAN GELDER, 1979). In responding to abrupt changes in the periphery, this system can be regarded as "... part of an 'early warning system' that orients an organism and directs its attention to locations in visual space that potentially contain novel pattern information" (BREITMEYER and GANZ, 1976, p. 31).

The differential trade-off functions in Experiment 7 for the 100-msec and the 300- and 500-msec intervals between cue and flash onset suggest that the transition from the early automatic to the later controlled orienting component occurs at some point between 100 and 300 msec after the onset of a peripheral cue, i.e. at a time characteristic for the latencies of saccadic eye movements in response to peripheral target stimuli. This appears to be more than a coincidence, suggesting that "automatic" shifts of attention (covert) precede saccadic changes of ocular fixation (overt).

There has been some controversy about the nature of the relationship between attention shifts and saccadic eye movements.

When presenting monkeys with a peripheral stimulus which was to be the target of a saccade, GOLDBERG and WURTZ (1972) found increased activity, about 50 msec after stimulus onset, of single cells in the intermediate layers of the superior colliculus whose receptive field included the eye movement target. The latency of this enhancement is consistent with the findings of NISSEN, POSNER and SNYDER (1978) and of REMINGTON (1980; Experiments 1 and 2) that when a luminance increment occurs at the location of a peripheral eye movement target, simple RT to and sensitivity for the detection probe is enhanced, 50 to 100 msec after the onset of the saccade target, in comparison with the locations at the centre and on the opposite side of the eye movement target. However, WURTZ and MOHLER (1976; MOHLER and WURTZ, 1976) found no increased discharge rate of collicular cells when monkeys made spontaneous saccades either in the dark or in the light, or when they were trained to make hand movements to the onset of a peripheral target light or to detect a dimming of this light while maintaining fixation. That is, the attentional mechanism associated with the enhanced activity of collicular cells appeared related to the "intention" to make a saccade to a peripheral target probe.

This led WURTZ and MOHLER to propose their "efference readiness" hypothesis that when attention to a peripheral stimulus is required, a "program" for an eye movement to its location is prepared; the oculomotor readiness, "... via as yet unknown feedforward pathways, has the effect of enhancing processing in or from sensory pathways dealing with information from the target location" (KLEIN, 1980, p. 262).

However, KLEIN (1980) argues against this position on the basis of a study which was designed to decouple attention shifts and eye movements. The first experiment consisted of eye movement (75%) and of simple manual RT (25%) trials which were presented in randomized order (dual condition). On eye movement trials, subjects had to make a saccade to a prespecified location (left or right) which was fixed throughout a block; the signal for the eye movement was a peripheral asterisk which could occur either at the target position of the saccade (compatible) or on the opposite side (incompatible). On manual RT trials, subjects had to give a simple speeded response to a luminance increment which could occur either at the prespecified (eye movement) location (50%) or on the opposite side (50%).

KLEIN found that saccade latencies were shorter when the asterisk signal occurred at the eye movement target (compatible) than when it did not (incompatible); but manual RTs showed no advantage for luminance increments occurring at the (blocked) location of the eye movement target. KLEIN concluded that "... shifts of visual attention do not necessarily occur when subjects get ready to move their eyes to a target location" (p. 268).

On manual response trials, the location of the detection probe is probabilistically unrelated with the location of the eye movement target, so that, indeed, no attention shift should occur. However, it is questionable whether the advantage in saccade latencies for compatible trials is caused by "readiness", prior to the asterisk signal, to make an eye movement to a position known in advance. Rather, saccade latencies may be faster on compatible trials because an asterisk signal precedes the eye movement at its target location. That is, the asterisk is an imperative stimulus for an automatic orienting process. This process may be intrinsically related to oculomotor "programming" (possibly, it is associated with enhanced activity of collicular cells), so that on compatible trials saccades can be readily executed. On incompatible trials, however, eye movements to the asterik must be actively suppressed and saccades in the opposite direction must be generated. This may require internally controlled reorienting of attention and is responsible for the increased saccade latencies. In other words, there is no need to assume that eye movements in KLEIN's Experiment 1 were programmed in advance of the asterisk signal.

In KLEIN's second experiment, 80% of trials required a manual response (simple RT to the onset of a luminance increment) and 20% of trials required an eye movement (saccade latency to the onset of an asterisk signal). Both types of trial started with the presentation of a central arrow cue pointing to the likely location of the luminance increment. On manual response trials, the luminance increment occurred, 1000 msec after cue onset, either at the cued (88%) or at the uncued location (12%). On eye movement trials, subjects of one experimental group had to make a saccade to the location of the asterisk signal (compatible), and subjects of a second group had to make a saccade to the opposite location (incompatible). The asterisk occurred with equal frequency at cued and at uncued locations.

KLEIN found that simple RTs were faster for cued than for uncued locations, for both the compatible and the incompatible eye movement group. However, saccade latencies did not differ between trials with asterisk signals at cued and those with asterisk signals at uncued locations, neither for the compatible nor for the incompatible eye movement group. The manual RT advantages for cued locations indeed indicate that subjects used the advance cue to orient attention. However, KLEIN's conclusion that "... oculomotor readiness does not accompany shifts of visual attention" (p. 272) is again questionable. On eye movement trials, an asterisk occurred 1000 msec after cue onset. This asterisk automatically summons attention, whether it occurs at the cued or at the uncued location. Thus, the absence of an advantage in saccade latencies for asterisk signals at cued locations only indicates that internal orienting guided by the cue (controlled process) can be effectively interrupted by external orienting in response to an asterisk at an uncued location (automatic process).

On the basis of this interpretation, one should expect saccade latencies to be shorter for compatible than for incompatible eye movement trials. (For if external orienting in response to an asterisk signal is intrinsically related to oculomotor programming, saccades can be readily executed on a compatible trials; but on incompatible trials, an eye movement to the asterik must be actively suppressed and a saccade in the opposite direction must be generated, a process which may require internal reorienting of attention). Although the main effect of compatibility on saccade latencies is not significant in KLEIN's Experiment 2, latencies are consistently faster for compatible than for incompatible eye movements; that is, consistently across saccade directions (left and right) and across cue validity conditions (valid, neutral and invalid). (The reason why this effect failed to reach significance may be that this contrast involves different groups of subjects; in KLEIN's Experiment 1, the within-subject comparison between compatibility conditions turned out significant.)

Thus, it may be premature to discard the "efference readiness" hypothesis, at least as far as "automatic" orienting in response to peripheral stimuli is concerned. This view seems consistent with REMINGTON's (1980; Experiment 3) finding that shifts of attention, prior to the onset of an eye movement, "... do not seem to accompany saccades that are initiated by a central cue" (p. 738). But "... whenever a peripheral event is used to trigger an eye movement, clear shifts of attention occur" (p. 742), whether or not subjects "intend" to move attention with their eyes (Experiment 4). This might indicate that there are two types of oculomotor readiness: "readiness" externally imposed by a salient peripheral stimulus and "readiness" internally generated in advance of some target event. It seems plausible to suggest that the first type of readiness is characterised by a closer intrinsic link to the saccadic control system than the second type.

This does not rule out the possibility, of course, that there is a common mechanism (e.g., the transient visual system) that links both attention and eye movements to the onset of peripheral events, but that the control systems for attention and for eye movements are separate mechanisms. That is, the onset of a stimulus may "attract" both the eye movement system and the automatic attention mechanism, without any intrinsic physiological relationship between the two systems being implicated.

Chapter 4

The Relationship between Target Localisation and Target Discrimination in Single and Multiple Element Displays

4.1. Introduction

What is the relationship between localisation and discrimination accuracy in the single and multiple element displays presented in Experiments 1 to 4? Analyses of (1) p(CP,CSD), i.e. the joint probabilities of correct position plus correct same-different responses have already been presented in Chapter 2. This chapter will also present analyses of the three remaining combinations between correct and incorrect localisation and discrimination responses: (2) p(CP,ISD): correct position plus incorrect same-different response; (3) p(IP,CSD): incorrect position plus correct same-different response; and (4) p(IP,ISD): incorrect position plus incorrect same-different response. These analyses will be guided by a model which allows the correction for effects of guessing on localisation and discrimination accuracy. This, in turn, will allow a decision among several alternative hypotheses about the relationship between target localisation and target discrimination.

There are five logically distinct alternatives:

(1) Localisation and discrimination accuracy are completely independent.

(2) Target localisation and target discrimination are completely interdependent: Localisation accuracy is at chance when discrimination fails and discrimination accuracy is at chance when localisation fails.

(3) Target discrimination is completely dependent on target localisation: Discrimination accuracy is at chance when localisation fails; however, localisation accuracy may be above chance when discrimination fails.

(4) Target localisation is completely dependent on target discrimination: Localisation accuracy is at chance when discrimination fails; however, discrimination accuracy may be above chance when localisation fails.

(5) Mixture between (3) and (4): Both localisation and discrimination accuracy may be above chance when discrimination or, respectively, localisation fails.

What are the positions of current models of visual search about these alternatives? Four influential models will be reviewed in some detail: The models of TREISMAN (TREISMAN, SYKES and GELADE, 1977; TREISMAN and GELADE, 1980), of HOFFMAN (1978, 1979), of DUNCAN (1980a, 1981, 1985) and of SHAW (1980, 1982, 1984; SHAW, MULLIGAN and STONE, 1983).

TREISMAN's "feature integration theory" assumes that there is an initial, parallel and capacity-free ("automatic") stage of "feature registration" in which the visual display is coded along a number of separable "dimensions" (e.g., brightness, colour, spatial frequency, orientation, etc.). In a second stage of "feature integration" these separate first-stage representations are then synthesized into compound object representations, i.e. object "perceptions", which can be stored and reported as such. Feature integration is assumed to be serial and capacity-limited ("controlled") in nature, requiring "focused attention".

This theory makes a basic distinction between two types of search task: (1) Tasks in which targets are defined by single features ("feature tasks"; e.g., search for a red or blue square among red circles and blue triangles; i.e., the defining attribute is shape); and (2) tasks in which targets are defined by conjunctions of features ("conjunction tasks"; e.g., search for a red triangle among red circles and blue triangles; i.e., the defining attributes are shape plus colour). If exhaustive search of display elements is prevented (limited exposure times), feature integration theory makes different predictions for localisation and identification accuracy in single feature and in feature conjunction tasks.

In feature tasks, the presence of the defining attribute may be detected without being localised. That is, feature identification may be based on the first-stage registration of the critical feature (i.e., square shape in the above example); but feature localisation, which "... could logically follow instead of preceding identification" (TREISMAN and GELADE, p. 100), may fail because of the prevention of exhaustive (serial) search. That is, "... focused attention may be necessary not only to ensure correct identification of conjunctions, but also to localize single features accurately" (TREISMAN and GELADE, 1980, p. 130).

In conjunction tasks, however, a compound target cannot be identified without being localised. That is, first-stage registration of the critical features (i.e., red colour and triangle shape in the above example) is not sufficient to determine the presence of the target (since there are "red" objects and coloured "triangles" as distractors); rather, localisation is a necessary precondition for the integration of separate features into a (correct) second-stage representation of the target (i.e., a red triangle). Note, that when focused attention is prevented, "... the registration of unlocalised features in separate maps permits illusory conjunctions to be formed from incorrectly integrated features" (TREISMAN and GELADE, 1980, p. 131).

Further, in both tasks localisation accuracy should be at chance when identification failed. That is, "... one cannot normally locate an item which differs from a field of distractors without also knowing at least on which dimension (color or shape) that difference exists" (TREISMAN and GELADE, 1980, p. 131). That is, first-stage representations (of colour and shape) are separate and detection of one odd item must be specific to one such representation.

However, successful localisation without successful identification might still be possible if a sufficient number of display elements can be searched by serially focusing attention on them. Suppose, for example, that three out of a total of four display locations, one of them containing the target, can be searched successfully; then, if none of the searched positions contains the target, the unsearched location can be correctly guessed (see, KADANE, 1971, and STONE, 1975, for a formal treatment of "optimal whereabouts search"). But identification could fail because of the prevention of focused attention for the target location.

HOFFMAN suggested the following two-stage model (to counter SHIFFRIN and SCHNEIDER's, 1977, proposal that memory comparisons in "varied mapping" search, i.e. when target and distractor stimuli change roles from trial to trial, occur in a "serial-serial" order that cycles through a frame of display elements for a given memory set item k before switching to the next item k + 1).

In a first, preattentive stage, each display element is compared in parallel to all memory set items, computing independent values of the similarity between display and memory set elements. Display items are then transferred, in order of decreasing similarity, to a second stage of serial, exhaustive memory comparisons (transfer from a rapidly fading trace (iconic memory) to a more permanent store (short term memory). Transfer is a serial, limited capacity process of selective attention. When transfer of display element k is complete, transfer of item k + 1 can begin, i.e. transfer can be carried out in parallel with memory comparison. However, if transfer of element k + 1 is completed while item k is still in the memory comparison stage, element k + 1 must queue. The memory comparison stage is assumed to be error-free; the main sources of errors (misses) is that display elements fail to gain admission to the transfer list and that queueing time exceeds "iconic" memory duration.

This model allows a matching decision (i.e., response) to be made based on first-stage representations. The optimal decision strategy involves summing of the output of several "filters" (i.e., of the independent similarity values for each display element) and comparing the sum to a criterion. This may be a successful strategy for consistent mapping search or when signal/noise discriminability is high. However, for varied mapping search or when signal/noise discriminability is low, responding on the basis of first-stage representations would result in high error rates. To reduce error rates, display elements can be submitted to a second stage whose output is more accurate.

Thus, HOFFMAN's model predicts that identification accuracy may be above chance even when localisation failes, because of the possible integration of the output of several filters. Further, localisation accuracy may be above chance when identification failed, for the following reason: Suppose, for example, that "distractor" element k gains access to second-stage memory comparison before "target" item k + 1 on the transfer list; then, second-stage processing may succeed in correctly rejecting element k as a distractor, but may not be able to complete memory comparison for item k + 1; then, item k + 1 should be chosen for the position response and the identity response should be based on the integrated similarity values for all the remaining elements on the transfer list.

Similar ideas of a first, parallel stage of processing and a second, limited capacity stage have been proposed by DUNCAN (1980a, 1981, 1985). In DUNCAN's model, display elements are fully identified (position, colour, size, form and aspects of meaning) at the first stage, and the further action of the system can depend on this information. However, first-stage representations cannot serve as the basis for response, i.e. "no reportable perception of any sort has been formed". Since first-stage representations are susceptible to visual masking and decay, they must gain access to a limited capacity system which accomplishes the transfer to the second stage. Since transfer is capacity-limited, some "selection schedule" is needed to define which elements to pass on. As DUNCAN states, "... Potentially any information derived at the first level could serve as the basis for selection". In search tasks, only targets, i.e. stimuli with the attribute(s) defining the target, "... will usually pass into and compete for the limited-capacity system".

The main feature which distinguishes DUNCAN's model from that of HOFFMAN seems to be that only emergence of an element at the second stage creates a reportable perception and that the second stage of processing cannot be more accurate than the first stage. Since second-stage representations are percepts based on first-stage representations, "... There is no way ... for the second level to know whether information received from the first level is accurate or inaccurate" (DUNCAN, 1980a, p. 285).

Thus, since only targets will usually pass into the limited capacity system, identification accuracy should be at chance when localisation failed and localisation accuracy should be at chance when identification failed. However, DUNCAN (1981, 1985) seems to imply that these predictions hold only if location and identity information are derived equally efficiently (i.e., equally fast) at the first stage of processing, so that neither could serve as the basis for selecting the other. Suppose, for example, that position information is derived faster than identity information; it could occur then that the position information gains access to the second stage while the identity information does not. That is, localisation accuracy could be above chance when identification failed. Similarly, if identity information is derived faster than position information, identification accuracy could be above chance when localisation failed. Note, however, that identification and localisation accuracy could not be both above chance when localisation or, respectively, identification failed.

SHAW's "attention theory", based on signal detection theory (SDT; GREEN and SWETS, 1966), distinguishes between a first stage of stimulus coding and a second stage of decision making: In the coding stage stimuli are converted into internal representations, and in the decision stage the internal representations are used to determine the response (note that the coding stage may consist of substages which are, however, considered together).

The basic assumption of SHAW's model is that a finite resource (attention, processing capacity, search effort) is divided among display elements and that the processing capacity allocated to a particular element can influence its internal representation. Suppose, for instance, that there is a fixed number of "strength samples" N available to be divided among display elements (note that SHAW conceives of the finite attention resource not as an integer-state quatitity N, but as a continuous-state quantity phi). The value of the internal random variable for a particular input k, given that it is a target or a distractor, is then the mean of the subset of N(k) samples and its variance is the variance of a single sample (a constant depending on stimulus conditions) divided by N(k). With an increase in display elements, fewer samples could be allocated to each one and target-distractor discriminability for each input would decrease. That is, the probability would increase that the value for a distractor at one location would exceed the value for a target at another position.

The decision making assumptions of SHAW's model are then as follows: The display element chosen for the position response is that for which the associated random variable is the maximum of the n random variables associated with the n elements. The value of the random variable associated with the element chosen for the position response should usually also determine the identity response. However, it is also possible that for the identity response the values of independent random variables are integrated (e.g., averaged) and compared to a criterion. This allows identification accuracy to exceed chance even when localisation failed. However, localisation should be at chance when identification failed.

But, as with feature integration theory, successful localisation without successful identification might still be possible if the finite attention resource is completely allocated to a subset of display locations, while the other elements are ignored. Suppose, for example, that one out of four display locations, one of them containing the target, receives no search effort. This improves target-distractor discriminability for the three attended locations, and if none of the associated random variables exceeds the criterion, it is more likely that the unattended location contains the target. Thus, guessing the ignored position would optimize target localisation without improving target discrimination (see SHAW, MULLIGAN and STONE, 1983).

The explanations for successful localisation without successful identification given by SHAW's attention theory and by TREISMAN's feature integration theory resemble each other in that both assume a strategy of "excluding" one or more locations from search to which guesses are allocated if no target was found at searched locations. Note, however, that SHAW conceives of attention as a continuous quantity rather than a discrete resource applied serially to discrete locations.

4.2. Analysis

None of the current model of visual search predicts complete independence between localisation and identification, i.e., in the context of the present task, discrimination accuracy. This hypothesis can be easily tested. Assuming independence, the observed values of p(CP,CSD), p(CP,ISD), p(IP,CSD) and p(IP,ISD) should be predictable in the following way:

p(CP,CSD) = p(CP) * p(CSD);

p(CP,ISD) = p(CP) * (1-p(CSD));

p(IP,CSD) = (1-p(CP)) * p(CSD);

p(IP,ISD) = (1-p(CP)) * (1-p(CSD)),

where p(CP) and p(CSD) are the observed probabilities of correct position and correct same-different responses. However, the values calculated in this way consistently (i.e., across subjects and conditions) underestimate p(CP,CSD) and p(IP,ISD) and overestimate p(CP,ISD) and p(IP,CSD), so that the hypothesis of complete independence between target localisation and target discrimination can be refuted.

To decide among the remaining hypotheses requires establishing that either localisation accuracy (hypothesis (3)) or discrimination accuracy (hypotheis (4)) or both (hypothesis (5)) are above chance when discrimination or localisation, respectively, failes. Hypothesis (2) can be refuted if either p(CP,ISD) or p(IP,CSD) or both are above chance.

p(IP,CSD), i.e. correct discrimination with localisation failure, is at chance when:

p(IP,CSD) = p(IP,ISD);

that is, when p(CSD/IP), the probability of a correct same-different response given an incorrect position response, is 0.5 (two-alternative forced choice discrimination):

$$p(CSD/IP) = p(IP,CSD)/p(IP) = 0.5,$$

where p(IP) is the sum of p(IP,CSD) and p(IP,ISD).

It is more difficult to determine whether p(CP,ISD), i.e. correct localisation with discrimination failure, exceeds chance, for the cued position (i.e., the likely target location) might be more or less frequently "guessed" to contain the target than any one of the three uncued locations and this "cued position bias" has to be taken into account. It is possible, however, to derive a model which resolves this problem. This model is designed to estimate the value of p(CP,ISD) expected on the "guessing assumption" (see (1) and (2) below) and to compare it with the observed value. This model is based on the following assumptions and definitions:

(1) If insufficient location information is acquired on a given trial, the position response is a guess.

(2a) The three uncued locations are guessed with equal probability. (2b) The cued position, however, may be more or less likely guessed than any particular uncued location.

(3a) For invalid trials, the probability with which the two uncued nontarget locations are guessed is estimated by inval. p(IP=u) (observed probability of 'u'ncued position errors). (3b) And the probability with which the cued position is guessed is estimated by inval. p(IP=c) (observed probability of 'c'ued position errors). (3c) For valid trials, the probability with which the three uncued locations are, erroneously, chosen is estimated by val. p(IP=u) (observed probability of 'u'ncued position errors).

(4a) For invalid trials, the probability of a correct same-different response given an uncued position guess is estimated by inval. p(CSD/IP=u) and val. p(CSD/IP=u); that is, p(CSD/IP=u) on invalid trials (observed probability) is equal to p(CSD/IP=u) on valid trials (observed probability). (4b) For valid trials, the probability of a correct same-different response given a correct position guess is estimated by inval. p(CSD/IP=c); that is, p(CSD/IP=c) on valid trials (not observable) is equal to p(CSD/IP=c) on invalid trials (observed probability). Note that while (4a) is a testable assumption, (4b) is not.

(5a) The "cued position bias", henceforth p(cb), is defined as the probability (invalid trials) of a cued position guess given a position guess. (5b) p(cb) is the same for invalid and for valid trials.

The following deductions can be made from these assumptions:

(6) It follows that, for invalid trials, the

probability with which any particular uncued location, including the target position, is guessed is given by inval. p(IP=u)/2, i.e. half the probability with which the two uncued nontarget locations together are guessed (consequence of (2a) and (3a)).

(7) It follows further that the probability of position guesses on invalid trials is given by inval. p(IP=c)+3*p(IP=u)/2, i.e. the sum of the probability with which the cued position is guessed and three times the probability with which any particular uncued location is guessed (consequence of (2a), (3a), (3b) and (6)).

(8) The cued position bias p(cb) is then given by inval. p(IP=c)/[p(IP=c)+3/2*p(IP=u)] (consequence of (5a) and (7)).

(9) It follows further that, for valid trials, the probability with which the cued position is, correctly, guessed to contain the target is given by val. p(IP=u)*p(cb)/[1-p(cb)] (consequence of (3c), (5b) and (8)).

(10) The expected value of p(CP,ISD) is then given by:

(10a) invalid trials (consequence of (3a) and (4a)):

[1-p(CSD/IP=u)] * p(IP=u)/2;

(10b) valid trials (consequence of (4b) and (9)):

[1-p(CSD/IP=c)] * p(IP=u)*p(cb)/[1-p(cb)].

This model allows one to correct the observed values of p(CP) and of p(CP,CSD) for correct guessing. P(CP) corrected for guessing is given by:

(11a) invalid trials:

p(CP) - p(IP=u)/2;

(11b) valid trials:

p(CP) - p(IP)*p(cb)/[1-p(cb)].

And p(CP,CSD) corrected for guessing is given by:

(12) cor. p(CP) - cor. p(CP,ISD),

where cor. p(CP) is p(CP) corrected for correct guessing and cor. p(CP,ISD) is the difference between the observed values of p(CP,ISD) and the values expected on the guessing assumption (see note on page 246A).

The data obtained in Experiments 1 to 4 were analysed in this way in order to decide whether localisation or discrimination accuracy or both are above chance even when discrimination or, respectively, localisation failed. Analyses were performed on pooled data, i.e. data pooled for each subject across corresponding conditions in Experiments 1 to 4 (i.e., not across display and cue validity conditions and the whole SOA range), in order to provide enough data for reliable parameter estimates. Data pooling seemed permissible, for the following

Note: The guessing model assumes four underlying perceptual states:

W - location seen, same-different seen;
X - location seen, same-different guessed;
Y - location guessed, same-different seen;
Z - location guessed, same-different guessed.

In correcting p(CP,CSD), one wishes to estimate p(W). But cor. p(CP,CSD) is p(W) + (f * p(X)), where f is the conditional probability of a correct same-different guess given location seen. One possible assumption is that f is 1/2, i.e. the expected probability for a correct same-different guess. Alternatively, the probability of a correct same-different guess given location seen (not observable) might be equal to the probability of a correct same-different guess given location guessed (observable). However, when the location is seen, the way the same-different guess is made may be different from when the location is guessed. That is, one cannot extrapolate from the situation when the location was not seen. It is possible to show that what one can estimate from observed parameters is cor. p(CP,CSD), but that one cannot estimate p(X) without knowing the conditional probability of a correct same-different guess given location seen. All what one can savely say is that p(W) is (equal to or) less than cor. p(CP,CSD).

Assuming that the conditional probability of a correct same-different guess given location seen is the same for targets at cued and uncued locations, the difference in p(W) between valid and invalid trials is greater than the difference in cor. p(CP) - cor. p(CP,ISD) - because, as will be seen in section 4.3., cor. p(CP,ISD) is smaller for targets at the cued location. Restated, the difference in cor. p(CP) - cor. p(CP,ISD) between valid and invalid trials provides a conservative estimate of joint localisation plus discrimination costs plus benefits.

reasons:

(1) The same subjects participated in all four experiments, and the order in which experiments were carried out was the same for each subject.

(2) The design of all four experiments was three-factorial: single/multiple displays (S/M), valid and invalid trials (V/I) and SOA. Note, however, that Experiments 1, 2 and 4 presented peripheral and Experiment 1 presented central cues; further, SOA durations differed among experiments (see (4) below).

(3) Target exposure times were determined individually for each subject and separately for each display condition (except for Experiment 4) at the beginning of each block of trials, so as to allow a joint localisation plus discrimination accuracy of 0.75 on baseline trials. Note, however, that in Experiment 4 baseline performance for multiple displays was below 0.75 (since display conditions were presented for the same exposure time and in randomized order). Thus, only the single display condition of Experiment 4 was used in the data pooling. To provide a corresponding multiple display condition, the same subjects participated in a further experiment in which threshold exposure times were set to the 0.75-level (Experiment 4a: multiple display condition only; otherwise same methodological details as in Experiment 4).

(4) Pooling of individual SOA durations across peripheral (Experiments 1, 2 and 4) and central (Experiment 3) cueing experiments seemed permissible since Experiment 3 presented only "long" SOAs (i.e., SOA durations of 350 msec and longer) and since the experiments reported in Chapter 3 had shown that there are no reliable differences between central and peripheral cueing conditions at long SOAs. The way in which data obtained for individual SOAs in separate experiments were combined for each subject can be seen from table 4.1. Note that data were pooled across experiments only when there were no consistent within-subject differences between SOA durations. For convenience, the resulting SOAs are labelled 50, 100, 150, 200, 300, 400, 500 and 700 msec even though average durations may be slightly shorter (50- and 150-msec SOAs) or longer (300-msec SOA). Data pooling ensured that the number of observations available per SOA, display (S/M) and cue validity (V/I) condition for each subject was at least 192. Combined across SOA durations, cue validity (including baseline trials) and display conditions, the total number of observations available for each subject was 12672.

The analyses presented below are subdivided into three parts: (1) Localisation accuracy with discrimination failures (section 4.3.); (2) discrimination accuracy with localisation failures (section 4.4.); and (3) cued position biases (section 4.5.). Sections 4.3. and 4.4. aim to establish whether target localisation and target discrimination are above chance even with discrimination and, respectively localisation failures. Section 4.5. examines response biases for the likely target location in order to reveal to what degree spatial cueing influences "stimulus coding" and "decision making" processes.

Table 4.1.: Pooling of SOA durations (msec) across experiments (No.: number of observations per display and cue validity condition for each subject; see text for further details)

SOA	50	100	150	200	300	400	500	700
Exp. 1	50	100	125	200				
Exp. 1	75		150					
Exp. 2		100	150	200	300	400	500	
Exp. 3					350	400	450	650
Exp. 3							550	750
Exp. 4		100			300		500	700
No.	192	288	288	192	288	192	384	288

4.3. Localisation Accuracy With Discrimination Failures

4.3.1. Results

This section will present analyses of p(CSD/CP), i.e. the probability of correct same-different responses given correct position responses, and of p(CP,CSD) (see Chapter 2 for separate analyses of this measure for Experiments 1 to 4) and p(CP) on which p(CSD/CP) is based. Effects on p(CSD/CP), i.e. the ratio between p(CP,CSD) and p(CP), involve changes in p(CP,ISD), i.e. the joint probability of correct position plus an incorrect same-different responses (p(CP,ISD) is the difference between p(CP) and p(CP,CSD)). To evaluate whether effects on p(CSD/CP) can be accounted for by correct position guesses, the values of p(CP,ISD) expected on the guessing assumption (see section 4.2.) will be estimated and compared with the observed values.

Figures 4.1. and 4.2. present mean values of p(CP,CSD) and of p(CP) as a function of SOA, separately for single and for multiple display valid and invalid trials; figure 4.3. presents mean values of p(CSD/CP), i.e. the ratio between p(CP,CSD) and p(CP).

The arcsin-transformed values of p(CP,CSD), of p(CP) and of p(CSD/CP) were evaluated in separate three-way ANOVAs involving the factors display type, cue validity and SOA. These ANOVAs revealed the following effects to be significant or marginally significant:

ANOVA of p(CP,CSD): (1) V/I: $F(1,3) = 695.34$, $p < 0.001$; (2) SOA: $F(7,21) = 11.80$, $p < 0.001$; (3) S/M x V/I: $F(1,3) = 44.73$, $p < 0.01$; (4) S/M x SOA: $F(7,21) = 3.16$, $p < 0.025$; (5) V/I x SOA: $F(7,21) = 71.00$, $p < 0.001$.

ANOVA of p(CP): (1) S/M: $F(1,3) = 25.16$, $p < 0.025$; (2) V/I: $F(1,3) = 1118.87$, $p < 0.001$; (3) SOA: $F(7,21) = 4.33$, $p < 0.005$; (4) S/M x V/I: $F(1,3) = 40.30$, $p < 0.01$; (5) S/M x SOA: $F(7,21) = 2.56$, $p < 0.05$; (6) V/I x SOA: $F(7,21) = 92.21$, $p < 0.001$.

ANOVA of p(CSD/CP): (1) S/M: $F(1,3) = 181.32$, $p < 0.001$; (2) V/I: $F(1,3) = 188.56$, $p < 0.001$; (3) SOA: $F(7,21) = 9.67$, $p < 0.001$; (4) S/M x SOA: $F(7,21) = 3.06$, $p < 0.025$; (5) V/I x SOA: $F(7,21) = 10.50$, $p < 0.001$.

The effects obtained for p(CP,CSD) and for p(CP) are very similar (see figures 4.1. and 4.2.).

P(CP,CSD) and p(CP) are significantly higher for valid than for invalid trials (main effects of V/I).

Figure 4.1.: p(CP,CSD) as a function of SOA, separately for single and multiple displays (S: open symbols; M: closed symbols) and for valid, baseline and invalid trials (V: triangles; B: circles; I: squares)

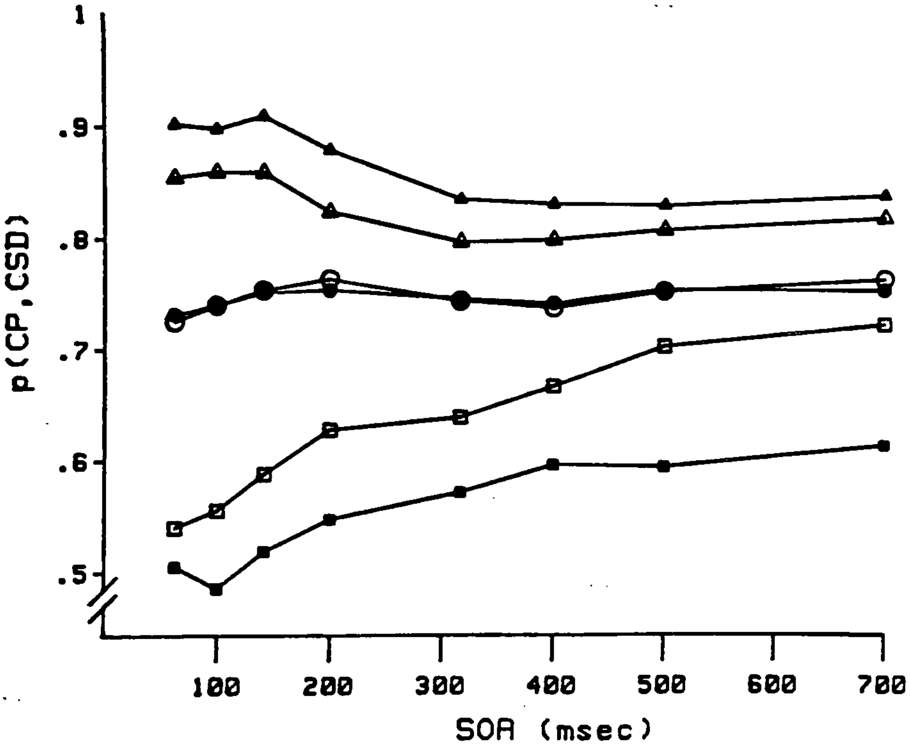
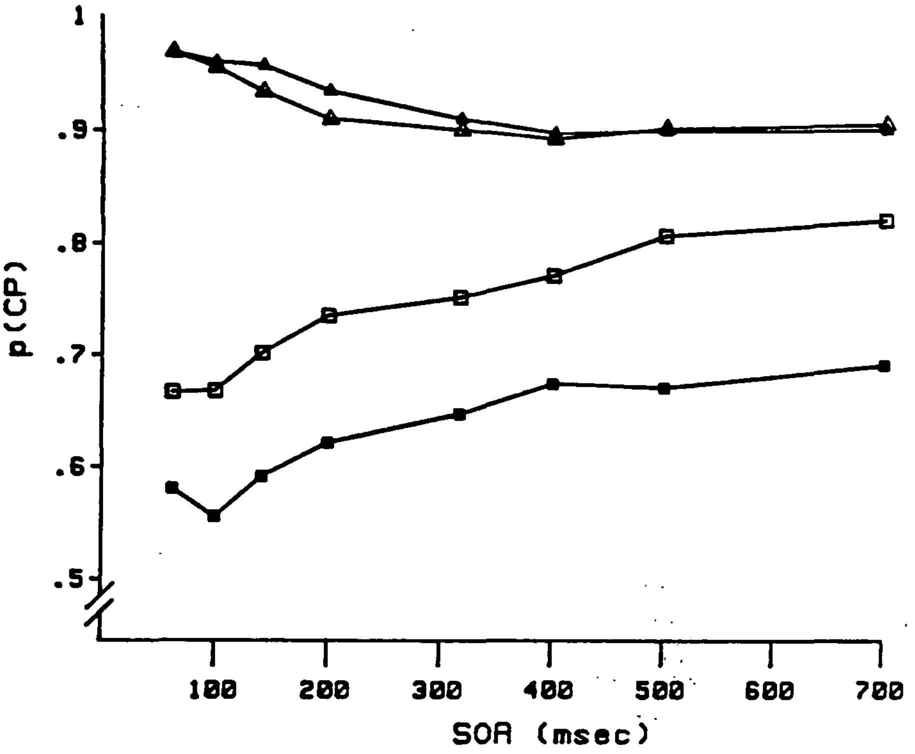


Figure 4.2.: p(CP) as a function of SOA, separately for single and multiple displays (S: open symbols; M: closed symbols) and for valid and invalid trials (V: triangles; I: squares)



For valid trials, p(CP,CSD) and p(CP) are highest at short SOA durations (50 to 150/200 msec), decrease significantly between the 150- and 300-msec SOAs and thereafter remain constant at the lower level ($p < 0.001$ for all comparisons between SOAs shorter and longer than 200 msec).

For invalid trials, p(CP,CSD) and p(CP) increase as SOA gets longer. The increase is particularly marked between the 50/100- and 300/400-msec SOAs and then reaches asymptote at SOA durations of the order of 500 msec ($p < 0.005$ and beyond for all comparisons between SOAs shorter and longer than 300 msec).

Thus, functions of p(CP,CSD) and of p(CP) for valid and invalid trials converge, i.e. V-I differences decrease at longer SOAs (significant V/I x SOA interactions).

For valid trials, the SOA effect on p(CP,CSD) and on p(CP) (i.e., the decrease between SOA durations of 150 and 300 msec) does not differ much between display conditions. For invalid trials, however, the increase with SOA is more pronounced for single than for multiple displays. Thus, functions of p(CP,CSD) and of p(CP) for valid and invalid trials converge more markedly for single than for multiple displays (however, S/M x V/I x SOA interactions failed to reach significance). This is reflected in significant S/M x SOA interactions, i.e. p(CP,CSD) and p(CP), combined across valid and invalid trials, increase with SOA for single, but not for multiple displays. Further, while linear regression analyses of arcsin p(CP,CSD) and of arcsin p(CP) for invalid trials revealed highly significant effects for both display conditions (p(CP,CSD): S: $F(1,30) = 82.69$ and M: $F(1,30) = 99.14$, $p < 0.001$; p(CP): S: $F(1,30) = 83.14$ and M: $F(1,30) = 82.58$, $p < 0.001$), slopes are greater for single than for multiple displays ($p < 0.05$, t-test).

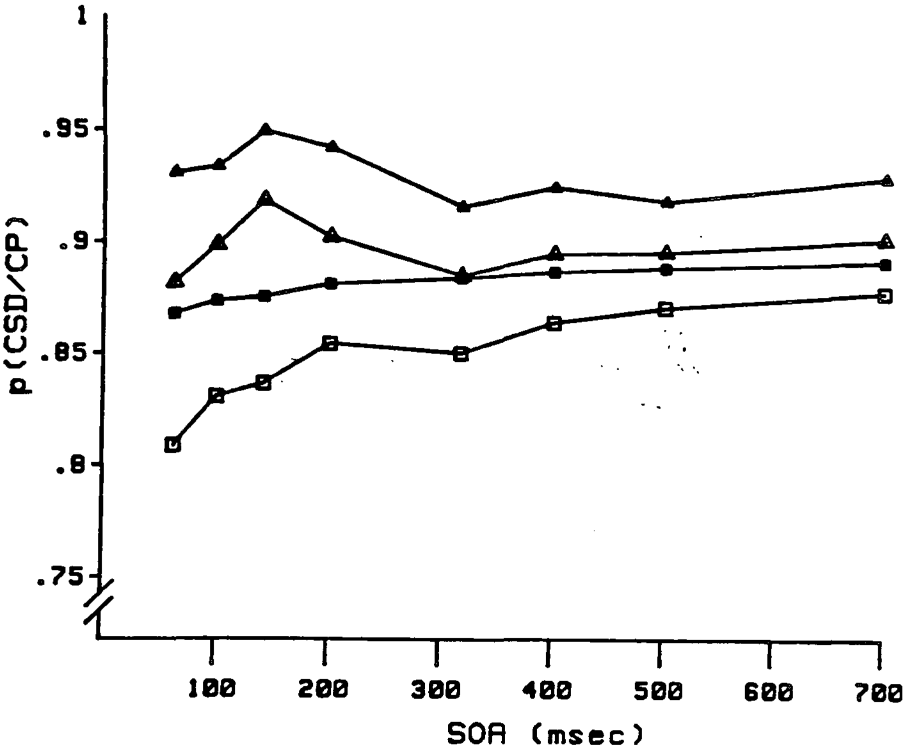
Combined across valid and invalid trials and across

SOAs, p(CP,CSD) does not differ between display conditions (no main effect of S/M), whereas p(CP) is significantly higher for single than for multiple displays (main effect of S/M). A main effect of S/M on p(CP,CSD) is absent because single displays, relative to multiple displays, show a significant ($p < 0.001$) advantage on invalid and a significant ($p < 0.001$) disadvantage on valid trials (S/M x V/I interaction). The main effect of S/M on p(CP) occurs, however, because there is no reliable difference between display conditions on valid trials, while on invalid trials p(CP) is higher ($p < 0.001$) for single than for multiple displays (S/M x V/I interaction).

Examining p(CSD/CP) (see figure 4.3), there are highly significant main effects of S/M and V/I: p(CSD/CP) is higher for multiple than for single displays and higher for valid than for invalid trials. That is, p(ISD/CP) is greater for single than for multiple displays and greater for invalid than for valid trials.

Further, for valid trials, p(CSD/CP) shows a significant increase between the 50- and 150-msec SOAs (50-150: $p < 0.001$), followed by a decrease and invariant values at longer SOA durations ($p < 0.001$ for the comparisons between the 150- and the 300-, 400- and 500-msec SOAs). That is, p(ISD/CP) decreases initially and then increases again. For invalid trials, p(CSD/CP) shows a trend to increase, i.e. p(ISD/CP) decreases, as SOA gets longer ($p < 0.005$ and beyond for the comparisons between the 50/100-msec and 500/700-msec SOAs). Thus, functions of p(CP/CSD) for valid and invalid trials converge at long SOAs (V/I x SOA interaction).

Figure 4.3.: p(CSD/CP) as a function of SOA, separately for single and multiple displays (S: open symbols; M: closed symbols) and for valid and invalid trials (V: triangles; I: squares)

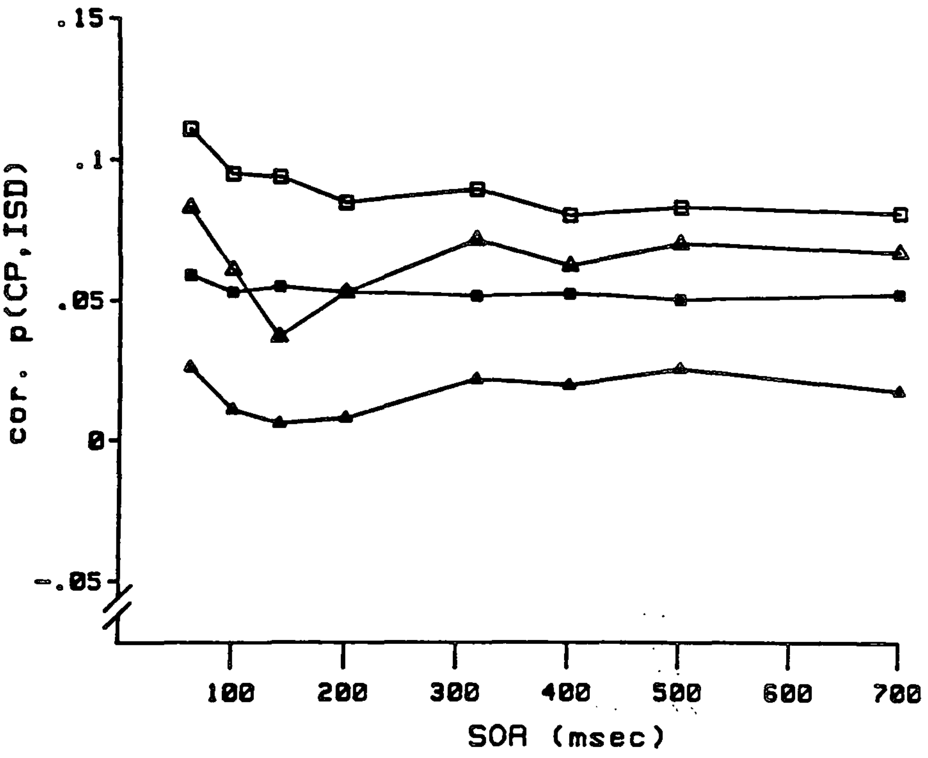


The convergence of the functions of p(CP/CSD) for valid and invalid trials appears more pronounced for single than for multiple displays, mainly because of a more marked increase for single than for multiple display invalid trials. (However, the S/M x V/I x SOA interaction failed to reach significance.) This is reflected in a significant S/M x SOA interaction, i.e. p(CSD/CP), combined across valid and invalid trials, increases with SOA for single, but not for multiple displays. The greater increase on invalid trials for single than for multiple displays is confirmed by linear regression analyses of arcsin p(CSD/CP): There are significant effects for both display conditions (S: $F(1,30) = 50.55$, $p < 0.001$; M: $F(1,30) = 12.63$, $p < 0.005$), but regression slopes are significantly greater for single than for multiple displays ($p < 0.025$; t-test).

In order to decide whether these effects can be accounted for by (correct) position guesses, the values of p(CP,ISD) expected on the guessing assumption were calculated (see section 4.2.) and then subtracted from the observed values. Figure 4.4. illustrates the mean differences between obs. and exp., i.e. cor. p(CP,ISD) as a function of SOA, separately for single and multiple display valid andinvalid trials.

The values of cor. p(CP,ISD) were subjected to a three-way ANOVA involving the factors display type, cue validity and SOA. This ANOVA revealed the following effects to be significant: (1) S/M: $F(1,3) = 1081.10$, $p < 0.001$ (2) V/I: $F(1,3) = 1158.15$, $p < 0.005$; (3) SOA: $F(7,21) = 4.14$, $p < 0.01$; (4) V/I x SOA: $F(7,21) = 3.12$, $p < 0.025$.

Figure 4.4.: cor. p(CP,ISD) as a function of SOA, separately for single and multiple displays (S: open symbols; M: closed symbols) and for valid and invalid trials (V: triangles; I: squares)



As can be seen from figure 4.4., cor. p(CP,ISD) is significantly greater for single than for multiple displays (main effect of S/M; S-M differences are 0.042 on average) and greater for invalid than for valid trials (main effect of V/I; V-I differences are 0.032 on average). For multiple display valid trials, cor. p(CP,ISD) is about 0.017, i.e. obs. p(CP,ISD) is hardly different from chance. For single display valid trials, trials, however, cor. p(CP,ISD) is about 0.063, i.e.

clearly above chance. This is also true for multiple and single display invalid trails for which cor. p(CP,ISD) is about 0.054 and 0.090, respectively.

For valid trials, cor. p(CP,ISD) decreases between the 50- and 150-msec SOAs ($p < 0.01$) and then tends to increase again ($p < 0.025$ and beyond for the comparisons between the 150- and the 300- and 500-msec SOAs). For invalid trials, cor. p(CP,ISD) shows a slight tendency to decrease with increasing SOA (no significant comparisons). Thus, functions of cor. p(CP,ISD) for valid and invalid trials converge at long SOAs (significant V/I x SOA interaction). For invalid trials, the decrease in cor. p(CP,ISD) with increasing SOA appears more marked for single than for multiple displays. This is confirmed by linear regression analyses: There is a significant effect for single ($F(1,30) = 23.97$, $p < 0.001$), but not for multiple ($F(1,30) = 0.78$, n.s.) displays.

Unlike p(CP,ISD) corrected for guessing (i.e., cor. p(CP,ISD)), p(CP,ISD) accounted for by guessing (i.e., exp. p(CP,ISD)) does not differ much between single and multiple displays and between valid and invalid trials (SV: 0.030; SI 0.020; MV: 0.046; MI: 0.021; the apparent V-I differences - V: 0.038; I: 0.021 - are due to "cued position biases", i.e. tendencies to "guess" the cued position to contain the target; see section 4.5.). Table 4.2. presents S-M and V-I comparisons between the values of p(CSD/CP) expected and corrected for guessing;

that is:

$$\text{exp. } p(CP,CSD/CP) = p(CP,CSD)/(p(CP,CSD) + \text{exp. } p(CP/ISD))$$

and

$$\text{cor. } p(CSD/CP) = p(CP,CSD)/(p(CP,CSD) + \text{cor. } p(CP/ISD)),$$

where p(CP,CSD) is the value of p(CP,CSD) corrected for guessing (see section 4.5.). The expected values of p(CSD/CP) hardly differ between display and between cue validity conditions, while the corrected values are higher for multiple than for single displays and higher for valid than for invalid trials, as are the observed values of p(CP/CSD). Thus, the main effects of S/M and of V/I on p(CSD/CP) cannot be accounted for by (correct) position guesses.

Table 4.2.: S-M and V-I comparisons between p(CSD/CP) expected and corrected for guessing (see text for detail)

p(CSD/CP)	M	S	V	I
exp.	.954	.965	.954	.965
cor.	.943	.897	.952	.888

Similarly, the effects of SOA on p(CSD/CP) for valid and invalid trials cannt be accounted for by guessing: The expected values of p(CSD/CP) do not vary as a function of SOA and are uncorrelated with the observed values (correlations between mean observed and mean expected p(CSD/CP) for valid and invalid trials, respectively:

-0.37 and 0.18, F(1,6) = 0.04 and 0.75, ns). However, correlations between mean observed and mean corrected p(CSD/CP) are positive and highly significant (correlations for valid and for invalid trials, respectively: 0.93 and 0.99, F(1,6) = 55.28 and 666.00, $p < 0.001$).

Thus, in valid trials, the initial decrease and later increase in cor. p(CP,ISD) (see figure 4.4.), together with the initially high performance and the later decrease of p(CP,CSD), produce the SOA effect on p(CSD/CP). That is, as performance for the cued location approaches optimum at very short SOAs (50-150 msec), the probability decreases that successful localisation is not associated with correct discrimination; and at longer SOAs, with the reduction in performance for the cued position, this probability increases again.

Invalid trials show a trend for p(CSD/CP) to increase with SOA. This increase is caused by a decrease of cor. p(CP,ISD), together with an increase of p(CP,CSD) (neither the increase in p(CP,CSD) nor the decrease in cor. p(CP,ISD) on their own could account for more than about half the increase in p(CSD/CP)). Both single and multiple displays show an increase of p(CSD/CP); however, the increase is more pronounced for single displays because of more marked SOA effects on p(CP,CSD) (increase) and on p(CP,ISD) (decrease).

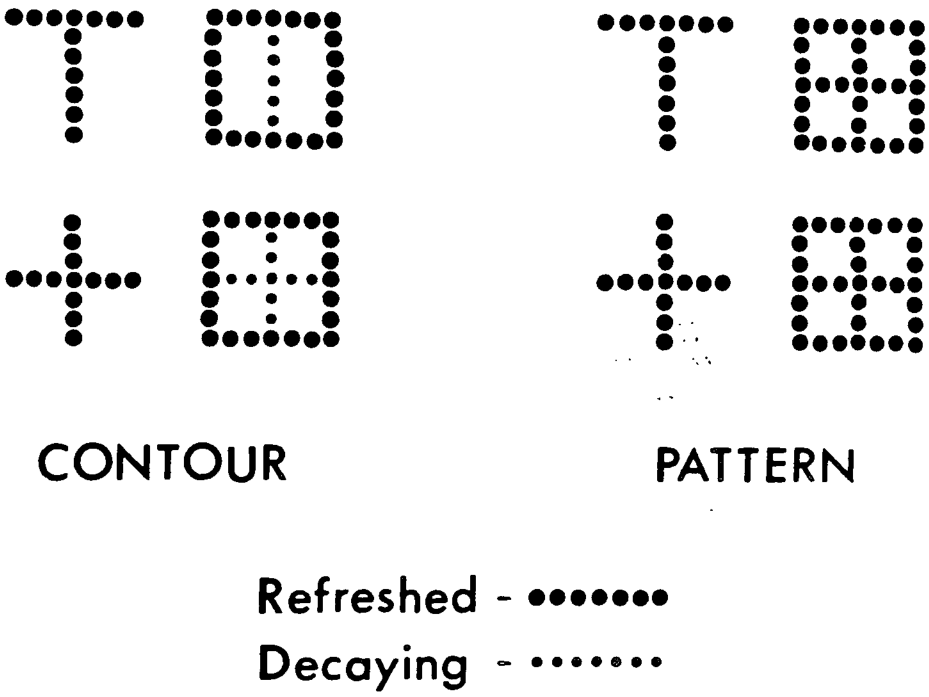
4.3.2. Discussion

In summary, localisation accuracy is generally above chance even with discrimination failures; that is, cor. p(CP,ISD) exceeds the expected value of 0.0. There seem to be several possible explanations for this finding. Firstly, it may be attributable to a post-display factor, namely prolonged access, after mask onset, to information useful for target localisation but not so much for discrimination. Secondly, it may reflect a serial search process based on rejection of searched locations as containing the target and allocation of guesses to unsearched positions. Thirdly, it may indicate a preselective mechanism which ensures that only those display elements are searched which are likely to be target items.

The first possibility is that some information on which target localisation, but not so much discrimination, is based was accessible after onset of the masking contours. This might have been so because the visible persistence of the P31 phosphor, with which the CRT was equipped, is rather long when the laboratory is dimly illuminated. (P31 phosphor decay below the 0.5%-level takes in excess of 400 microseconds; note that the 1%-level is clearly visible in a dimly lit room.) That is, the finding that localisation accuracy is above chance even with discrimination failures may be an artefact associated with inadequate masking.

A closer look at some display characteristics provides a hypothesis about the stimulus attributes which might persist after mask onset and which might, thus, serve as the basis for successful target localisation (but less so for target discrimination).

Diagram 4.1.: Contour (left) and pattern masks (right) at target and nontarget locations



Countour masks in the present experiments were squares of the same size as the target Ts and distractor crosses. As can be seen from diagram 4.1., target Ts and distractor crosses were composed of two "bars", each of which consisted of seven illuminated spots (i.e., the two bars shared one spot at their intersection). Similarly, the bars which contour masks were composed of consisted of seven spots (i.e., they shared one spot at each corner). Thus, at display offset and mask onset, the outer spots which target Ts and distractor crosses were composed of were superseded by the masking contours, while the spots inside the masks decayed.

However, the number of spots decaying inside the masking contours, differed between target and nontarget locations and also, concerning nontarget locations, between display conditions: The number of spots decaying inside masks at nontarget locations was 0 for single displays (since nontarget locations were "blank" before mask onset) and 9 for multiple displays. The number of spots decaying at target locations was 5, both for single and for multiple displays.

Thus, target localisation could have been successful, after display "termination" by the masking contours, to the degree to which any existing luminance differences between target and nontarget locations could be detected. However, the ability to detect these luminance differences should have less influence on target discrimination, since the masking contour at the target position completely supersedes the outer line of the target T; one possible effect could be an increase in the probability of confusions between Ts of opposite (i.e., for example, "normal" and "upside down") orientation. (Note, however, this it is not testable with the present data since erroneous "different" responses on "same" trials leave the "perceived" orientation of target Ts unspecified; see section 4.4.)

Experiment 8

Thus, detection of post-mask luminance differences between target and nontarget locations could explain the finding that localisation accuracy is "generally" above chance even with discrimination failures. (Note, however, that it is difficult for this explanation to account for the differences in p(CP,ISD) found between display (S/M) and between cue validity (V/I) conditions.) Since the present data do not rule out this explanation, a control experiment (Experiment 8) was carried out which eliminated, under one masking condition, any post-mask luminance differences between display locations. The critical masking condition presented "pattern" masks which were composed of an outer square (like contour masks) plus an inner cross (see diagram 4.1.). That is, with target masks, one bar of the square superseded the outer bar of the T, and one bar of the cross superseded the inner bar of the T (note that in multiple displays the luminance increment, i.e. the additional number of spots illuminated at pattern mask onset was the same for target and nontarget locations). The second masking condition presented "contour" masks, as in the previous experiments.

In summary, Experiment 8 comprised four factors: S/M - single/multiple displays, V/I- valid/invalid trials (peripheral cue), SOAs (100, 300, 500 and 700 msec) and C/P - contour/pattern masks. Trials with contour and with pattern masks were presented in randomized order (within a given block), as were valid and invalid trials and SOAs. Presentation of display conditions was blocked, with their order counterbalanced across sessions and subjects. At the beginning of each block, 0.75-threshold exposure durations were determined for contour mask baseline trials under the respective display condition. Trials with contour and trials with pattern masks were then presented with the (same) threshold exposure time estimated for contour mask baseline trials. All other methodological details were the same as in the previous experiments.

Four subjects (L.G., C.W., S.M. and H.M.), all highly practised with the present task, participated in Experiment 8 which presented a total of 3840 trials (including baseline trials) over four two-hour sessions; payment was 2.50 pounds per hour. The following 0.75-threshold exposure durations were estimated for L.G., C.W., S.M. and H.M., respectively (average of four sessions): 43.75, 53.75, 40.75 and 32.50 for single displays and 61.25, 63.75, 57.50 and 52.50 for multiple displays.

Figures 4.5., 4.6., 4.7. and 4.8. present mean values of p(CP,CSD), p(CP), p(CSD/CP) and cor. p(CP,ISD), respectively, as a function of SOA, separately for contour and pattern masks, for single and multiple displays and for valid and invalid trials. The arcsin-transformed values of p(CP,CSD), p(CP) and p(CSD/CP) and the values of cor. p(CP,ISD) were subjected to separate four-way ANOVAs involving the factors C/P, S/M, V/I and SOA. These ANOVAs revealed the following effects to be significant:

ANOVA of p(CP,CSD): (1) C/P: $F(1,3) = 11.33$, $p < 0.05$; (2) V/I: $F(1,3) = 36.33$, $p < 0.01$; (3) S/M x V/I: $F(1,3) = 44.58$, $p < 0.01$; (4) S/M x SOA: $F(3,9) = 5.67$, $p < 0.025$; (5) V/I x SOA: $F(3,9) = 127.29$, $p < 0.001$.

ANOVA of p(CP): (1) V/I: $F(1,3) = 40.46$, $p < 0.01$; (2) S/M x V/I: $F(1,3) = 23.79$, $p < 0.025$; (3) S/M x SOA: $F(3,9) = 5.37$, $p < 0.025$; (5) V/I x SOA: $F(3,9) = 77.52$, $p < 0.001$.

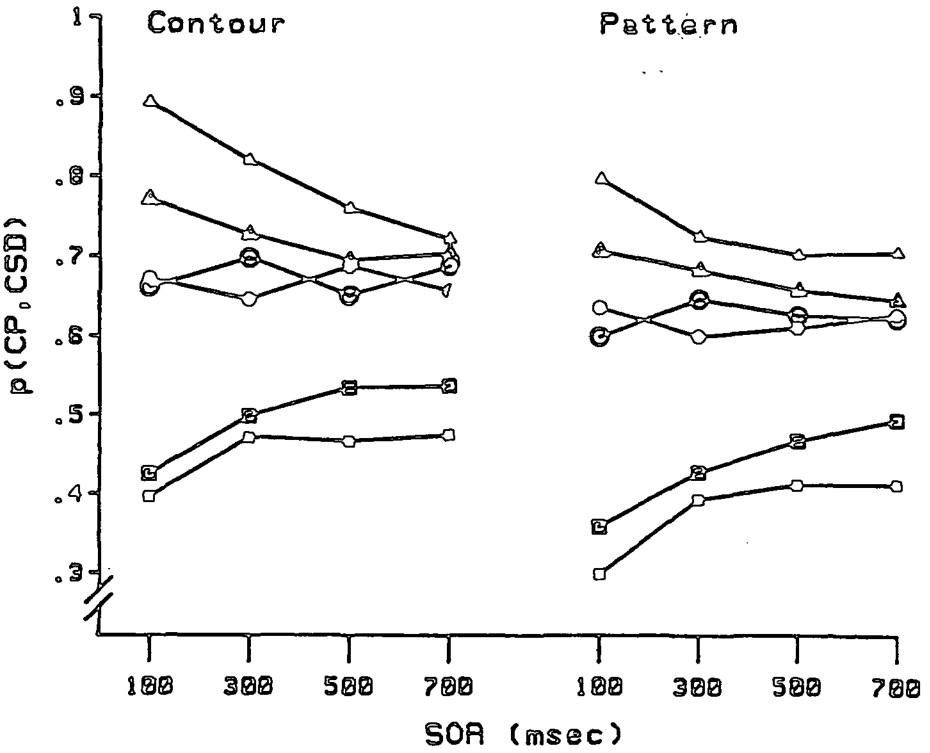
ANOVA of p(CSD/CP): (1) C/P: $F(1,3) = 78.07$, $p < 0.005$; (2) S/M: $F(1,3) = 25.34$, $p < 0.025$; (3) V/I: $F(1,3) = 18.60$, $p < 0.025$; (4) V/I x SOA: $F(3,9) = 15.98$, $p < 0.001$.

ANOVA of cor. p(CP,ISD): (1) C/P: $F(1,3) = 17.34$, $p < 0.025$; (2) S/M: $F(1,3) = 171.24$, $p < 0.001$ (3) V/I: $F(1,3) = 927.70$, $p < 0.001$; (4) SOA: $F(3,9) = 7.63$, $p < 0.01$.

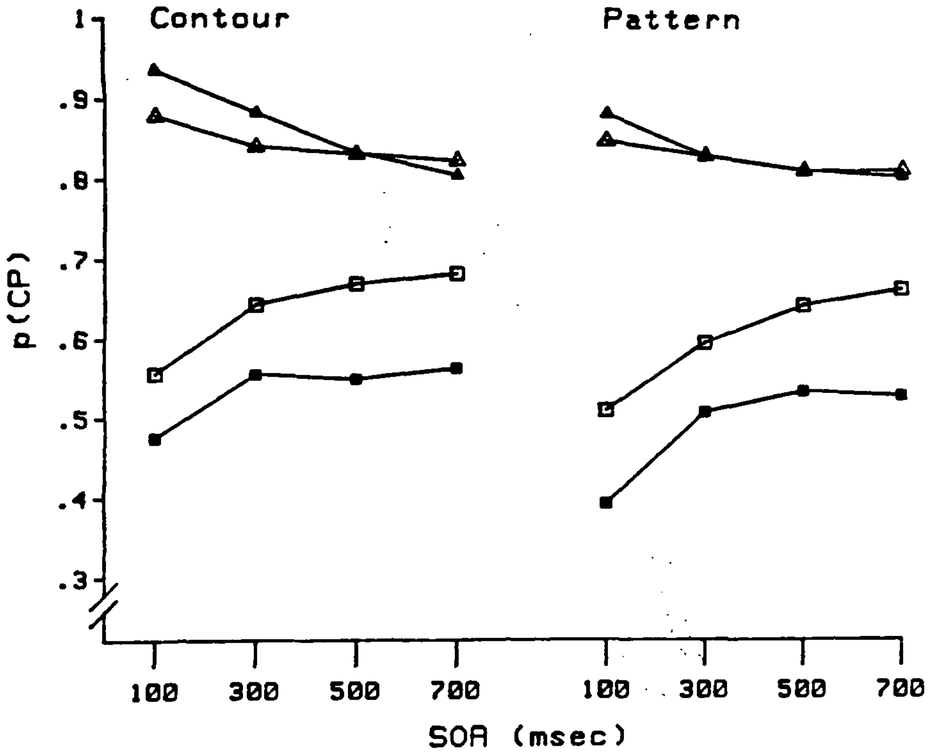
As can be seen from figures 4.5. and 4.6., Experiment 8 replicates the effects of S/M, V/I and SOA obtained in the previous experiments.

p(CP,CSD) and p(CP) are significantly higher for valid than for invalid trials (main effects of V/I). For valid trials, p(CP) does not differ reliably between display conditions, whereas p(CP,CSD) is lower for single than for multiple displays. For invalid trials, however, both p(CP,CSD) and p(CP) are higher for single than for multiple displays (significant S/M x V/I interactions).

Figures 4.5.: p(CP,CSD) as a function of SOA, separately for contour and pattern masks (C: left; P: right), for single and multiple displays (S: open symbols; M: closed symbols) and for valid, baseline and invalid trials (V: triangles; B: circles; I: squares)



Figures 4.6.: p(CP) as a function of SOA, separately for contour and pattern masks (C: left; P: right), for single and multiple displays (S: open symbols; M: closed symbols) and for valid and invalid trials (V: triangles; I: squares)

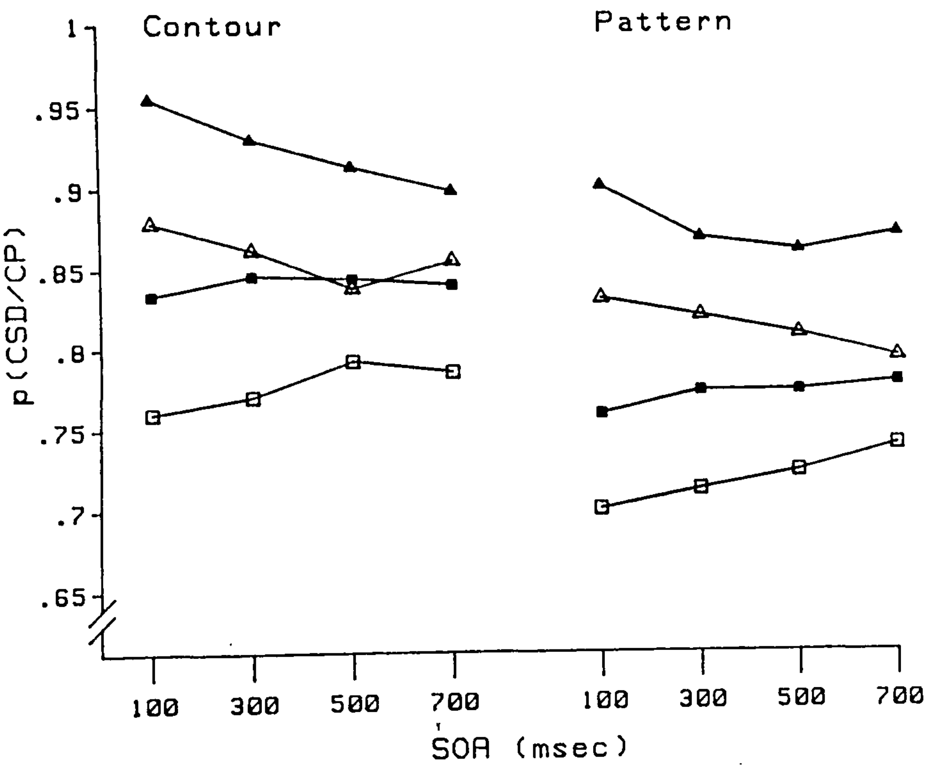


Further, for valid trials, p(CP,CSD) and p(CP) are highest at the 100-msec SOA, decrease towards the 300/500-msec SOAs and then remain constant at the lower level. For invalid trials, p(CP,CSD) and p(CP) increase as SOA durations get longer, in particular between the 100- and 300-msec SOAs. Thus, functions of p(CP,CSD) and of p(CP) for valid and invalid trials converge with increasing SOA (significant V/I x SOA interactions). The increase with SOA for invalid trials appears more pronounced for single than for multiple displays. As a consequence, p(CP,CSD) and p(CP), combined across valid and invalid trials, increase with SOA for single, but not for multiple displays (significant S/M x SOA interactions).

The main effects of C/P occur because of losses in p(CP,CSD) and p(CP) for pattern in comparison with contour mask trials (p(CP,CSD) for contour and pattern mask trials, respectively: 0.618 - 0.555; p(CP): 0.795 - 0.720). These losses are largely independent of display type, cue validity and SOA. However, losses appear more pronounced for p(CP,CSD) than for p(CP). Thus, p(CSD/CP) is lower for pattern than for contour mask trials (significant main effect of C/P; see figure 4.7.).

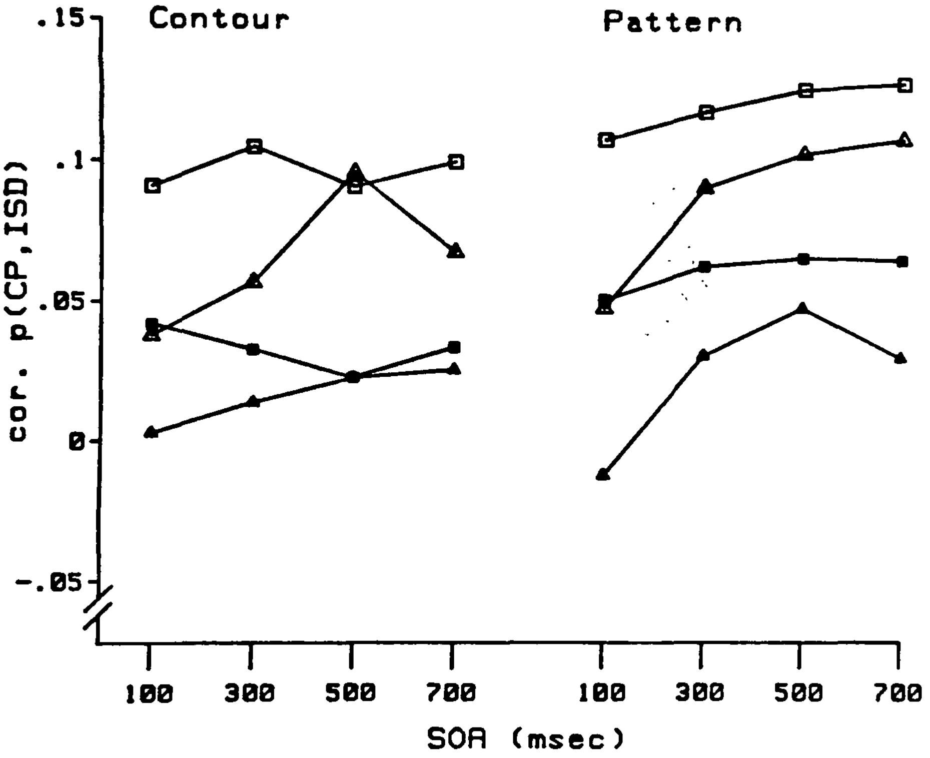
As in the previous experiments, p(CSD/CP) is higher for multiple than for single displays (significant main effect of S/M) and higher for valid than for invalid trials (significant main effect of V/I). Further, for valid trials, p(CSD/CP) shows a decrease between the 100- and 300/500-msec SOAs, as p(CP,CSD) decreases relatively more than p(CP); and for invalid trials, p(CSD/CP) tends to increase with SOA, as p(CP,CSD) increases relatively more than p(CP). Thus, functions of p(CP/CSD) for valid and invalid trials show a trend for convergence at longer SOAs (significant V/I x SOA interaction).

Figure 4.7.: p(CSD/CP) as a function of SOA, separately for contour and pattern trials (C: left; P: right), for single and multiple displays (S: open symbols; M: closed symbols) and for valid and invalid trials (V: triangles; I: squares)



As can be seen from figure 4.8., cor. p(CP,ISD) is higher for single than for multiple displays and higher for invalid than for valid trials (significant main effects of S/M and of V/I). Further, cor. p(CSD/IP) increases between the 100- and 500-msec SOAs (significant main effect of SOA), and this effect is mainly produced by an increase for valid trials (marginally significant V/I x SOA interaction: $F(1,3) = 2.89$, $0.10 > p > 0.05$). This pattern agrees with the previous experiments and accounts for the observed effects of S/M, V/I and SOA on p(CSD/CP). The main finding of Experiment 8, however, is the significant main effect of C/P: cor. p(CP,ISD) is slightly higher, rather than lower and close to zero, for pattern (0.073) than for contour mask trials (0.053)

Figure 4.8.: cor. p(CP,ISD) as a function of SOA, separately for contour and pattern masks (C: left; P: right), for single and for multiple displays (S: open symbols; M: closed symbols) and for valid and invalid trials (V: triangles; I: squares)



In summary, Experiment 8 replicates the main findings of the previous experiments. And, most importantly, it shows that eliminating any post-mask luminance differences between target and nontarget locations in the pattern mask condition failed to eliminate the higher than chance values of cor. p(CP,ISD). Thus, detection of post-mask luminance differences between target and nontarget locations does not appear to be an adequate explanation for the previous finding that localisation accuracy generally exceeds chance even with discrimination failures.

A second possible explanation for this finding is that higher than chance values of cor. p(CP,ISD) reflect a search strategy which is based on rejection of display locations to contain the target. That is, if target presence cannot be ascertained for a subset of searched locations, one of the remaining locations is chosen by default.

Suppose, for instance, that search of display locations is "serial" and self-terminating, with the cued position being searched first on every trial because spatial cues are probabilistically informative. Note that these assumptions resemble those of SHIFFRIN and SCHNEIDER's (1977) model 1a for varied mapping tasks and of TREISMAN's model for conjunction tasks. (In terms of feature integration theory, the present task can be regarded as requiring the conjunction of features which differ on one stimulus dimension.) Suppose further that, because of limited exposure times, only three (i.e., the cued and two uncued) locations can be searched successfully. Thus, if the searched locations can be rejected, as not containing the target, the unsearched (i.e., the third uncued) position containing the target would be correctly accepted by default. That is, localisation accuracy should be as high for unsearched as for searched positions. However, the localisation accuracy with concurrent discrimination failures would be lower for unsearched locations, since discrimination accuracy should be close to chance for target positions chosen by default.

The decisive question for this explanation appears to be whether target exposure times in the present experiments were long enough to allow serial memory comparisons and switching of attention between display locations to occur. Single memory comparisons take about 40 msec (e.g., STERNBERG, 1966; YANTIS and JONIDES, 1984), and attention shifts from one location to another take about 8 msec per degree of visual angle (TSAL, 1983a; see also SHULMAN, REMINGTON and McLEAN, 1979). Thus, it seems unlikely, with the present target exposure times (between 30 and 45 msec), that displays could be searched in a (near-exhaustive) serial fashion. With matching decisions requiring at least one memory comparison and with visual angles between display locations of 6.2 deg., serial search of just two locations would take much in excess of target exposure durations.

Appendix 4.7. presents more direct arguments, based on the available data, against serial search. In particular, the serial search model outlined above fails to account for the actual localisation accuracy observed for invalid trials and, further, it overestimates and, respectively, underestimates cor. p(CP,ISD) observed for cued and for uncued locations. Over- and underestimations are the more marked the lower the number of display locations which can be searched successfully.

This and other recent findings (e.g., PASHLER and BADGIO, 1985; HOUCK and HOFFMAN, 1986) raise a question concerning TREISMAN and GELADE's (1980) assumption that search for conjunctive targets is serial and self-terminating. PASHLER and BADGIO (1985) used a conjunction task requiring detection of the letter E among Fs and Ls; in addition, they varied the quality of the display elements by manipulating stimulus contrast. Instead of the 2:1 slope ratio of RTs as a function of display size for "target absent" versus "target present" trials, PASHLER and BADGIO found a ratio of about 1.5:1, which is contrary to a self-terminating model. Further, the effect of display quality was additive with display size, suggesting "... that the stages retarded by the intensity reduction are not executed serially" (p. 111). A serial strategy would predict that "... the visual quality effect on the encoding of each item would be added to the overall RT, once for each additional item in the display (presuming exhaustive processing" (p. 108), resulting in an interaction between display quality and display size.

Thus, if a serial exclusion strategy fails to explain the finding that localisation accuracy is generally above chance even with discrimination failures, this finding would indicate that search is not a "blind" process, based on a fixed search order or on random selection of uncued locations. Rather, it could be taken as evidence for a mechanism, at an early stage of processing, which ensures that only those elements (i.e., display locations) are selected (i.e., "searched") which are likely to be target items.

Both the models of HOFFMAN (1978, 1979) and of DUNCAN (1980a, 1981, 1985) explicitly propose such a preattentive selection mechanism, so that they could provide a framework for the explanation for the finding that p(CP,ISD) exceeds chance. However, any explanation which aims to account for the effects of cue validity and of display type on p(CP,ISD) must make the following assumptions.

(1) The stimulus attributes on which target localisation is based are derived faster than the information on which target discrimination is based.

(2) Information from the cued position becomes available faster than information from uncued locations.

(3) The stimulus attributes required for target localisation are derived faster for single than for

multiple displays.

(1) Suppose that stimulus attributes indicating target presence at a given location are derived faster than information required for target discrimination, and may thus serve as the basis for selection of information for discrimination (DUNCAN) or may determine the transfer order of display elements (HOFFMAN). Thus, because of exposure time constraints, derivation of the attibutes required for target localisation is more likely to be completed than derivation of the information necessary for target discrimination, no matter whether the target occurs at the cued or at an uncued location.

This does not imply that the stimulus attributes on which target localisation is based are necessarily different from those required for target discrimination (although they may be in different display conditions; see section 4.6. below). It is also conceivable that target localisation and target discrimination are based on the same information, but that discrimination requires more detailed processing.

(2) Suppose further that information from the cued position becomes available faster than information from uncued locations because of the informative spatial cueing. That is, a selection schedule is set up in advance which assigns priority to the likely target location (DUNCAN), or the cued position is placed first on the transfer list (HOFFMAN). (Note that for uncued

locations no selection schedule can be set up prior to display onset; otherwise, selection of uncued locations would be at random or based on a fixed search order; see section 4.7.) Thus, information from the cued position can be passed on, through the limited capacity system (DUNCAN) or to the memory comparison stage (HOFFMAN), as soon as it is derived. Although location attributes are derived faster than discriminative information (see above), priority for the cued location makes it less likely that discriminative information is lost (limited target exposure times) when a target occurs there.

When a target occurs at an uncued (rather than at the cued) location, it may be possible to reject the cued position on the basis of location information on its own. It may occur, however, that both location and discriminative information are passed on, causing delays in the availability of the limited capacity system. While information from the cued position occupies the limited capacity stage, location attributes derived from uncued locations serve to set up a selection schedule determining order of passage for low priority (i.e., uncued) display elements. However, selection may involve further delays because more than one item may compete for access to the limited capacity system. Thus, even if the uncued location containing the target is successfully selected, exposure time constraints are more likely to prevent discriminative information to be passed on successfully.

(3) The information for target localisation is derived faster in single than in multiple display conditions. For single displays, simple detection of the luminance change produced by single target onset is sufficient for localisation (see Experiment 4 in Chapter 2). That is, target localisation and target discrimination are based on different stimulus attributes. With multiple displays, however, luminance changes of the same energy occur simultaneously at target and at nontarget locations, so that localisation is based on more complex (shape) information, i.e. on attributes which discriminate a target T from distractor crosses. Localisation may involve preselective "filtering" of locations for any "odd" element in the display. (As a result, there may be more competition of uncued display elements for the limited capacity system than in single displays.) Discrimination may then determine the precise shape of the odd element (see section 4.6. below for a more detailed discussion of the "primitive" visual coding in single and multiple element displays).

Since target localisation is based on a more effective mechanism in single displays, localisation accuracy is as high as for multiple displays on valid trials and higher than for multiple displays on invalid trials, despite shorter 0.75-threshold exposure durations for single displays. However, since exposure time constraints affect target discrimination relatively more than target localisation, successful localisation with discrimination failures is more likely for single displays.

Compared to the effects of cue validity and display type, the effects of SOA on p(CP,ISD) are small and should be interpreted with caution (in particular, since the estimates of exp. p(CP,ISD) are based on pooled data obtained in experiments with different ranges of SOA durations).

According to the two-component model of spatial orienting (see Chapters 2 and 3 for detail), the "early" facilitatory effect for cued and the "early" inhibitory effect for uncued locations are associated with a "fast", automatic, orienting process which is triggered by external properties of peripheral cues. This component is transitory, and as its power to engage attention fades out orienting is guided by a "slower", controlled process which is based on the spatial information provided by the cue. This second component is less effective than the prior automatic component; however, it maintains facilitation for the cued position (but at some lower level), while inhibition for uncued locations can be compensated for to some extent.

For valid trials, p(CP,ISD) tends to increase at SOA durations longer than 100 to 150 msec, because of relatively greater losses in discrimination than in localisation accuracy. (Note that at very short SOAs, p(CP,ISD) tends to decrease. However, this tendency should be interpreted with caution, since the estimate of exp. p(CP,ISD) for the 50-msec SOA is based on data from one experiment only.)

The increase in p(CP,CSD) for valid trials 100- to 150-msec after cue onset is expected on the basis of the assumption that the components of automatic and controlled facilitation are characterised by lower and, respectively, higher interruptability of the priority of selection assigned in advance to the display element at the cued position. That is, at longer SOAs distractor stimuli at uncued locations are more likely to claim precedence, causing delays in the availability of the limited capacity system for the target item at the cued position. This affects target discrimination relatively more than target localisation, since location attributes are derived faster than discriminative information.

For invalid trials, both localisation and discrimination accuracy are reduced at very short SOAs and then show an asymptotic increase as SOA duration gets longer. This increase, however, is greater for discrimination than for localisation accuracy, i.e. p(CP,ISD) tends to decrease.

This is again expected on the basis of the assumption that interruptability of the priority of selection for the cued position increases as the automatic orienting component fades out. That is, a target stimulus at an uncued location is more likely to claim precedence, so that the probability increases that both location and discriminative information are passed on successfully.

The tendency for p(CP,ISD) to decrease more markedly, with increasing SOA, for single than for multiple displays (invalid trials) can be explained along similar lines.

With multiple displays, it is a more frequent event that an interruption to the priority of selection for the cued position is caused by a distractor (rather than by the target) at an uncued location. With single displays, however, it is more likely that the target stimulus itself, i.e. the single luminance change associated with its onset, causes an interruption (rather than some "illusory" target at an uncued location). Thus, since it occurs more frequently with single displays that precedence is claimed by the actual target stimulus at an uncued location, there is a more marked increase in the probability that both location and discriminative information are passed on successfully.

Note that these assumptions imply, in DUNCAN's words, that "... access to the second stage is probabilistic: Access probability is greater for targets than for nontargets, but nonzero for both" (DUNCAN, 1985, p. 94). This assumption agrees with HOFFMAN's model. According to HOFFMAN, preselective processing is inaccurate and serves to direct the "best candidates" to a more accurate checking stage. But according to DUNCAN, keeping nontargets out of the limited capicity system is perfect (that is, at least when the defining/reported target attribute is a simple feature; it may be a "little inaccurate" with more complex attributes). However, the present data would question the position that full-scale pattern recognition occurs in parallel, at an early stage of stimulus encoding.

Note further that SHAW's attention theory (1980, 1982, 1984; SHAW, MULLIGAN and STONE, 1983) could also account for the finding that p(CP,ISD) exceeds chance.

One possibility would be that attention, which is conceived of as a finite continuous resource, is concentrated on a subset of display locations, while the others are ignored. However, SHAW et al. (1983) found no consistent evidence that subjects "... do, indeed, ignore information in the unattended diagonal" (p. 347) of a four-location display when instructed to do so. In the present experiments, no "ignore" instruction was given, and none of the subjects agreed to having applied such a strategy spontaneously. Thus, it seems questionable whether allocation of guesses to ignored locations can account for the the finding that p(CP,ISD) exceeds chance.

However, there is an alternative way for SHAW's model to explain the present findings. All that this requires is to make the same basic assumptions outlined above: (1) That the cued position is allocated more of the finite attention "samples" than uncued locations and (2) that target localisation requires less "sampling" than target discrimination and (3) less "sampling" in single than in multiple element displays. (Note that for single displays, assumptions (2) and (3) are consistent with SHAW's, 1984, claim that detection of luminance changes is not capacity limited.)

In SHAW's attention theory, the amount of samples allocated to display locations influences the quality of "first stage" representations, i.e. of the final outputs of the initial "coding" stage on which further decision making is based. However, since SHAW leaves the substages which stimulus coding may be composed of unspecified, the output of the coding stage might correspond to "second stage" (i.e., post-selective) representations in terms of HOFFMAN's or of DUNCAN's model. Thus, SHAW's attention theory may not be incompatible with HOFFMAN's and DUNCAN's "late selection" theories of attention.

4.4. Discrimination Accuracy With Localisation Failures

4.4.1. Results

This section will present analyses of p(CSD/IP), the probability of a correct same-different response given an incorrect position response (i.e., ratio between p(IP,CSD) and p(IP)). Assuming that when localisation fails the discrimination response is randomly chosen (two-forced choice), the expected value of p(CSD/IP) is 0.5.

The main finding is that, p(CSD/IP), combined across experimental conditions, is 0.594 and significantly above chance ($p < 0.001$ for each subject; binomial tests).

The guessing model predicts that p(CSD/IP) for uncued position errors (i.e., IP=u) does not differ between valid and invalid trials; in both cases, the cued position is, erroneously (valid trials) or correctly (invalid trials), rejected and one out of three (valid trials) or two (invalid trials) uncued nontarget locations is chosen for the position response. Invalid trials on which the target location is correctly "guessed" are treated as uncued position "errors", and p(CSD/IP) is assumed to be the same for correct and incorrect position guesses. That is, the guessing model predicts that the actual target location (whether cued or uncued) does not affect p(CSD/IP) for uncued position guesses.

However, p(CSD/IP) may differ between cued (i.e., IP=c) and uncued (i.e., IP=u) position errors. Correct position "guesses" on valid trials are treated as cued position "errors", and it is assumed that p(CSD/IP) is the same for correct (valid trials) and incorrect (invalid trials) cued position guesses. This assumption, however, is not directly testable.

To test whether p(CSD/IP) for uncued position errors differs between valid and invalid trials, the arcsin transformed values of p(CSD/IP) were subjected to a three-way ANOVA involving the factors display type, cue validity and SOA. This ANOVA revealed only a significant main effect of S/M ($F(1,3) = 10.90$, $p < 0.05$): p(CSD/IP) is slightly higher for single than for multiple displays.

However, when p(CSD/IP) for single and for multiple displays is weighted (z-transformation) by the corresponding values of p(IP), i.e. probability with which uncued position errors occur, the difference between display conditions does not turn out to be reliable ($F(1,3) = 1.70$, ns). That is, the degree of confidence that p(CSD/IP) differs from chance does not differ reliably between single and multiple displays. (Note that the z-transformation - [p(IP,CSD)-p(IP)*0.5]/SQRT[p(IP)*0.5**2] - weights a given value of p(CSD/IP) the more, the higher p(IP) on which it is based).

The absence of cue validity (V/I) effects on p(CSD/IP) is consistent with the guessing model: The actual target location (cued or uncued) does not affect p(CSD/IP) for uncued position guesses.

A second ANOVA tested whether there are any differences in p(CSD/IP) between cued and uncued position errors (three-way ANOVA of arcsin p(CSD/IP), involving the factors S/M, c/u, i.e. IP=c and IP=u, and SOA). Again, only the main effect of S/M was significant ($F(1,3) = 24.64$, $p < 0.025$): p(CSD/IP) is higher for single than for multiple displays. However, the difference between display conditions is small (0.012), and the degree of confidence that p(CSD/IP) differs from chance is actually lower for single displays (ANOVA of z-transformed values: S/M: $F(1,3) = 15.74$, $p < 0.05$)

because position errors are less likely; that is, a random effect cannot be ruled out.

The absence of any differences between cued and uncued position guesses indicates that p(CSD,IP) is a constant fraction of p(IP), i.e. of the probability of position errors, no matter whether the cued or an uncued location is (erroneously) chosen for the position response.

The last question examined was whether p(CSD/IP) differs between "same" and "different" trials, i.e. trials with and without matching comparison and target Ts. Unlike same responses on same trials, different responses on different trials leave it unspecified whether target "identification" is actually correct. That is, a correct different response may refer to an illusory "target" which happens to be different from the comparison T, but is not the same as the actual target T. Imagine, for example, that the orientation of the comparison T is "normal" and that of the target T "upside down"; a correct different response on such a trial would fail to specify whether the target was correctly "identified" as "upside down" or incorrectly as tilted to the "right" or to the "left". Thus, p(CSD/IP) should be higher for different than for same trials because an illusory T may have been seen at the reported (nontarget) location.

To test this, the values of arcsin p(CSD/IP) were subjected to a four-way ANOVA involving the factors S/M, c/u (i.e., cued/uncued position errors), s/d (i.e., same/different trials) and SOA. This ANOVA revealed the main effect of s/d to be significant ($F(1,3) = 33.42$, $p < 0.01$): p(CSD/IP) at chance for same trials (0.497), but well above chance for different trials (0.684). This difference cannot be attributed to a random effect (ANOVA of z-transformed values: s/d: $F(1,3) = 34.90$, $p < 0.01$).

Table 4.3. presents the probabilities with which p(CSD,IP) exceeds chance (i.e., (p(CSD,IP)-p(ISD,IP))*0.5), separately for single and multiple displays, for cued and uncued position errors and for same and different trials. The upper half of table 4.3. presents the observed values and the lower half presents the corrected values which take into account (p(CSD,IP)-p(ISD,IP))*0.5 for correct position guesses (i.e., correct position "guesses" are treated as localisation "errors"; see above).

Table 4.3.: (p(CSD,IP)-p(ISD,IP))*0.5 for single and multiple displays, for cued and uncued position errors and for same and different trials (upper half: observed values; lower half: corrected values; see text for details)

	Single		Multiple	
	Same	Diff.	Same	Diff.
Cued	0.001	0.015	-0.001	0.025
Uncued	-0.001	0.016	-0.001	0.015
Cued	0.002	0.023	-0.002	0.036
Uncued	-0.001	0.021	-0.001	0.020

As can be seen from table 4.3., the probabilities that p(CSD,IP) exceeds chance are low, even for different trials. The apparent differences between single and multiple displays and between cued and uncued position errors occur because localisation errors are more likely for multiple displays and more likely to be cued position responses (see section 4.5.).

4.4.2. Discussion

In summary, p(CSD/IP) exceeds the expected value of 0.5, i.e. discrimination accuracy appears to be above chance even when localisation failed.

However, p(CSD/IP) exceeds chance only for different, but not for same trials. The probability with which p(CSD,IP) exceeds the expected value is about -0.001 for same and 0.025 for different trials (corrected for correct position guesses). That is, even for different trials correct discrimination with a localisation failure is a very rare event.

p(CSD/IP) does not differ between display conditions, between types of localisation error and among SOA durations. That is, choice of discrimination responses is determined by the same factors when localisation failed ("guessing"). However, the probability with which p(CSD,IP) exceeds chance is dependent on these variables, because they determine the probability of localisation errors.

The finding that p(CSD/IP) exceeds chance on different trials, but not on same trials, appears to result from two factors:

Firstly, three of the four subjects show a tendency towards responding different (probabilities of different responses: 0.536, 0.545 and 0.544, respectively); and one subject shows a slight same tendency (0.483). The tendency of three subjects towards responding different increases p(CSD/IP) for different and decreases it for same trials. Their average values of p(CSD/IP) are 0.485 (same) and 0.701 (different), respectively. However, for the subject with a same tendency, p(CSD/IP) is greater than 0.5 both for same (0.533) and for different (0.656) trials. But even for this subject, p(CSD/IP) is smaller for same than for different trials, although the difference is less marked than for the subjects with a different tendency. Thus, discrimination response tendencies modify p(CSD/IP) to some extent; but they cannot account for the finding that, with localisation failures, discrimination accuracy exceeds chance reliably only for different and not for same trials.

That is, there must be another factor which produces this asymmetry. As already pointed out, different responses on different trials leave it unspecified whether target identification is actually correct. Same responses on same trials indicate that the reported target matched the comparison stimulus and the actual target. However, different responses on different trials only indicate a mismatch between perceived target and comparison stimulus, but not whether the perceived target matched the actual target. Thus, different trials are at an advantage in comparison with same trials in that different responses are not required to indicate identity between perceived and actual target in order to be counted as "correct".

This should inflate discrimination accuracy for different trials, no matter whether target localisation is successful. With localisation failures, however, discrimination accuracy for different trials should be more inflated, for Ts perceived (i.e., reported) at nontarget locations are more likely to be "illusions" which happen to be different from comparison Ts without being identical with target Ts.

With successful localisation, p(CP,CSD), p(CP), p(CSD/CP) and cor. p(CP,ISD) do not differ significantly between same and different trials (see upper third of table 4.4. for the overall values). However, there are strong trends for differences in p(CSD,CP) and obs. and cor. p(CP,ISD), the directions of which depend on subjects' discrimination response tendencies (see middle and lower thirds of table 4.4.): For the three subjects with a different response tendency p(CP,CSD) is higher for different trials, while for the subject with a same response tendency p(CP,CSD) is higher for same trials. And, since p(CP) hardly differs between same and different trials, p(CP,ISD) is higher on same trials for the subjects with a different tendency and higher for different trials for the subject with a same tendency (this is true both for obs. p(CP,ISD) and for cor. p(CP,ISD)). Thus, p(CSD/CP) is higher on different trials for the subjects with a different tendency and higher on same trials for the subject with a same tendency. This contrasts with p(CSD/IP) which is higher on different than on same trials, irrespective of subjects' individual response tendencies.

Table 4.4.: Observed values of p(CP,CSD), p(CP) and p(CSD/CP) and corrected value of p(CP,ISD) for all four subjects together (Overall) and separately for the subject with a "same" and for the three subjects with a "different" response bias.

		obs. p(CP,CSD)	obs. p(CP)	obs. p(CSD/CP)	cor. p(CP,ISD)
Overall	Same	0.715	0.813	0.879	0.060
	Diff.	0.730	0.803	0.909	0.048
"Same"	Same	0.739	0.809	0.913	0.032
	Diff.	0.676	0.793	0.852	0.085
"Diff."	Same	0.707	0.815	0.867	0.069
	Diff.	0.748	0.806	0.928	0.035

Restated, when localisation is successful, the predominant type of discrimination error (same or different) for individual subjects can be accounted for by their respective response tendencies. However, when localisation fails, response tendencies only modify, but do not cause the predominance of different decisions. Thus, the factor responsible for the asymmetry in p(CSD/IP) between same and different trials has a stronger effect on the discrimination decision when target localisation fails rather than when it is successful. (Note that as a result, different responses are more likely for invalid than for valid trials, since localisation accuracy is lower: p(diff.) for valid and invalid trials, respectively: 0.516 and 0.538; V/I: $F(1,3) = 8.59$, $0.10 > p > 0.05$.)

If discrimination accuracy for different trials, given localisation failures, is inflated (predominance of different responses) because different responses are not required to indicate "identity" between perceived and actual target in order to be counted as "correct", then requiring an identification instead of a discrimination response should reduce this asymmetry. Experiment 9 was designed to test this prediction.

Experiment 9

The task in Experiment 9 was basically the same as the localisation plus discrimination task in the previous experiments. However, instead of giving a same-different response, subjects had to report the precise orientation of the target (four-forced choice recognition). Subjects were informed that the "comparison" T in the display centre (frame II) indicated that the orientation of the target (frame V) would be same on half the trials and different on the other half. The spatial cue presented was a 50-msec peripheral brightening; the type of display was "multiple" (i.e., target T plus distractor crosses); and the SOA between cue and target was 150 msec (only one display condition and one SOA were tested since p(CSD/IP) did not show any effects of display type and SOA duration in the previous experiments).

Experiment 9 consisted of 1440 trials (576 valid, 576 invalid and 288 baseline trials) which were presented in randomized order (two two-hour sessions of each 720 trials). Four subjects (L.G., C.W., P.P. and H.M), all experienced with the previous localisation plus discrimination task, participated in Experiment 9; payment was 2.50 pounds per hour. The following 0.75-threshold exposure durations were estimated at the beginning of each session for subjects L.G., C.W., P.P. and H.M, respectively (average of two sessions): 45.5, 52.5, 47.0 and 36.0 msec. Note that the threshold determination routine counted a given recognition response as correct if it correctly indicated whether comparison and target T were the same or different, no matter whether reported and actual target orientation were identical.

The data were analysed in two stages. In the first stage, a given recognition response was counted as correct if it correctly indicated whether comparison and target T were the same or different, no matter whether reported and actual target orientation were identical on different trials. That is, the identification response was "reduced" to a same-different discrimination response (notation for a correct discrimination response: CSD). In the second stage, reported and actual target orientation had to match in order for the recognition response to be counted as correct (notation for a correct recognition response: CR).

For correct localisation responses, these analyses showed performance to be significantly higher for valid than for invalid trials. That is, two-way ANOVAs involving the factors V/I and s/d (i.e., same and different trials) revealed significant main effects of V/I for arcsin p(CP) (i.e., localisation accuracy: 0.887 - 0.501; $F(1,3) = 436.33$, $p < 0.001$), for arcsin p(CP,CSD) (i.e., joint localisation plus discrimination accuracy: 0.778 - 0.414; $F(1,3) = 574.01$, $p < 0.001$) and for arcsin p(CP,CR) (i.e., joint localisation plus recognition accuracy: 0.745 - 0.392; $F(1,3) = 391.28$, $p < 0.001$).

However, only p(CP,CR) showed an effect of s/d: joint localisation plus recognition accuracy is higher for same than for different trials (0.604 - 0.533: $F(1,3) = 111.08$, $p < 0.005$). Note that the absence of s/d effects on p(CP) and p(CP,CSD) is consistent with the previous experiments.

With incorrect localisation responses, p(CSD/IP) is 0.459 for same and 0.611 for different trials (however, a two-way ANOVA of arcsin p(CSD/IP) involving the factors c/u, i.e. cued and uncued position errors, and s/d revealed the main effect of s/d to be only marginally significant: $F(1,3) = 9.51$, $0.10 > p > 0.05$). This agrees with the previous experiments. Note that all four subjects show this asymmetry; however, the magnitude of s-d differences depends on subjects' different response biases: For unbiased subjects (L.G. and C.W.; average p(diff.) = 0.499), p(CSD/IP) is 0.486 on same and 0.556 on different trials, while for subjects with a different bias (P.P. and H.M.; average p(diff.) = 0.529), p(CSD/CP) is 0.433 on same and 0.666 on different trials.

p(CR/IP) is unchanged - 0.459 - for same trials (since recognition is correct whenever discrimination is correct), but 0.196 for different trials (ANOVA of arcsin p(CR/IP): $F(1,3) = 118.63$, $p < 0.005$). That is, on different trials, target orientation is correctly recognized in only about one out of every five trials on which localisation failed. Incorrect recognition responses (about 4 out of every 5 trials) include same responses and nontarget orientation different responses in about equal numbers (each about 2 out of every 4 trials). That is, on different trials, p(CR/IP) for incorrect same responses and p(CR/IP) for incorrect different responses are 0.332 and 0.325, respectively. The second figure indicates that with localisation failures, the choice of a "different" orientation response is at chance; that is, when subjects make a different decision on a different trial, chance expectancy for a correct orientation response is 1/3.

Thus, with localisation failures, recognition accuracy (i.e., orientation response) is at chance, both for same and for different trials; however, discrimination accuracy (i.e., same-different response) is above chance for different trials, no matter whether or not subjects are biased towards responding different. One consequence of this is that, when localisation failed, p(same) is higher for same than for different trials and p(diff.) is higher for different than for same trials (with localisation failures, the probabilities that a same response is given on a same rather than a different trial and that a different response is given on a different rather than a same trial are 0.545 and 0.528, respectively, for Experiment 9 and 0.597 and 0.588, respectively for the previous experiments).

In terms of feature integration theory (TREISMAN et al., 1980), the finding that recognition accuracy is at chance when localisation failed would suggest that target recognition requires the "conjunction" of independent target features; that is, the integration of the orientation of the horizontal and vertical bars, i.e. of the constituent parts of target Ts, into correct target representations. However, the finding that discrimination accuracy can be above chance when localisation failed (as is the case for different trials) would suggest that target discrimination requires simple feature "detection". How can these findings be reconciled?

There appears to be an alternative explanation for the finding that discrimination accuracy can be above chance when localisation failed. It is based on the assumption that a same-different (s-d) value is "computed" in parallel and independently for each display location; that is, a value indicating the degree to which the stimulus at a particular location matches the comparison T. If there is no s-d value associated with a particular location that clearly exceeds the values associated with all or a subset of the other positions, thus favouring selection of this location for the position response, the position response may be a (pseudo-)random choice (taking into account "strategic" information such as the a-priori probability of target occurrence at alternative locations, etc.) and the independent s-d values may be summed to determine the discrimination response. In this way, the s-d value associated with the actual target position might play a decisive role in determining the discrimination response, although it may not be strong enough to determine the position response.

Suppose, for example, that on a different trial the target location and one other position are in different "states" and one location is in a same "state" (the fourth location may have created a "neutral" impression). The discrimination response chosen in this case would then be different (and the localisation response would involve a decision between positions in different states). In this way, the different state associated with the actual target location would shift the balance towards a different decision. Note that the same and different impressions associated with the nontarget locations are "illusions", while the different state for the target position may or may not be an illusion.

It is easy to imagine the analogous situation for a same trial. In this case, however, the orientation of one illusory target at one nontarget location and the orientation of the impression for the target position would have to be the same and both impressions would have to match the comparison T. If the orientation of illusory targets at nontarget locations is more or less randomly determined (1 out of 4 orientations), such a situation would be less likely to occur. This could explain why p(CSD/IP) is lower for same than for different trials.

Note that this proposal of same-different response integration across display locations agrees with the visual search theories of HOFFMAN (1978, 1979) and of SHAW (1982). The basic assumption of this explanation is that target discrimination involves a "choice" among real and/or illusory target impressions which are accessible to the decision process; they may, however, not be accessible for report because impressions may be lost from memory while others are reported. This assumption also receives some support from subjects' experience that on "many" trials they had "seen" not only one, but two or more "targets" of different orientations at different display locations.

4.5. Cued Position Biases

4.5.1. Results

This section will present analyses of p(cb), i.e. of cued position biases. p(cb) was introduced in section 4.2. as the probability, on invalid trials, to localise a target in the cued position given that the position response is a "guess", where the probability of a position guess is estimated by p(IP=c)+p(IP=u)*3/2. That is, the probability of a position guess is the sum of the probability of cued position errors (i.e., p(IP=c)) plus 3/2 times the probability of uncued position errors (i.e., p(IP=u)). The factor 3/2 takes into account that if the position response is a random guess on invalid trials, all three uncued locations, including the target position, should be guessed with equal probability (that is, the uncued target position should be "guessed" with half the probability with which the two uncued nontarget locations together are guessed).

Figure 4.9. presents p(cb) as a function of SOA, separately for single and multiple display conditions. Figure 4.9. also presents the probabilities of a cued position error - p(IP=c) - and of an uncued nontarget position error - p(IP=u) - on which p(cb) is based, separately for single and multiple display invalid trials.

The values of p(cb) and those of p(IP), i.e. p(IP=c) and p(IP=u), were arcsin-transformed and evaluated in separate ANOVAs. The ANOVA of p(cb) involved the factors S/M and SOA, and the ANOVA of p(IP) involved the factors S/M, c/u (i.e., IP=c/IP=u) and SOA. These ANOVAs revealed the following effects to be significant or marginally significant.

ANOVA of p(IP): (1) S/M: $F(1,3) = 39.29$, $p > 0.01$; (2) c/u: $F(1,3) = 992.54$, $p < 0.001$; (3) SOA: $F(7,21) = 27.94$, $p < 0.001$; (4) S/M x c/u: $F(1,3) = 50.76$, $p < 0.005$; (5) c/u x SOA: $F(7,21) = 67.26$, $p < 0.001$.

ANOVA of p(cb): (1) S/M: $F(1,3) = 49.56$, $p < 0.005$; (2) SOA: $F(7,21) = 69.74$, $p < 0.001$; (3) S/M x SOA: $F(7,21) = 2.83$, $p < 0.05$.

As can be seen from figure 4.9., the probability of cued position errors (IP=c) exceeds that of uncued position errors (IP=u) (significant main effect of c/u). Further, c-u differences are greater for multiple than for single displays (significant S/M x c/u interaction). This effect occurs because p(IP=c) is higher for multiple than for single displays, while there are no apparent differences in p(IP=u). Thus, the difference in p(IP=c) between display conditions accounts for the significant main effect of S/M.

Figure 4.9.: p(cb) (circles), p(IP=c) (triangles) and p(IP=u) (squares) as a function of SOA, separately for single and multiple display invalid trials (S: open symbols; M: closed symbols)

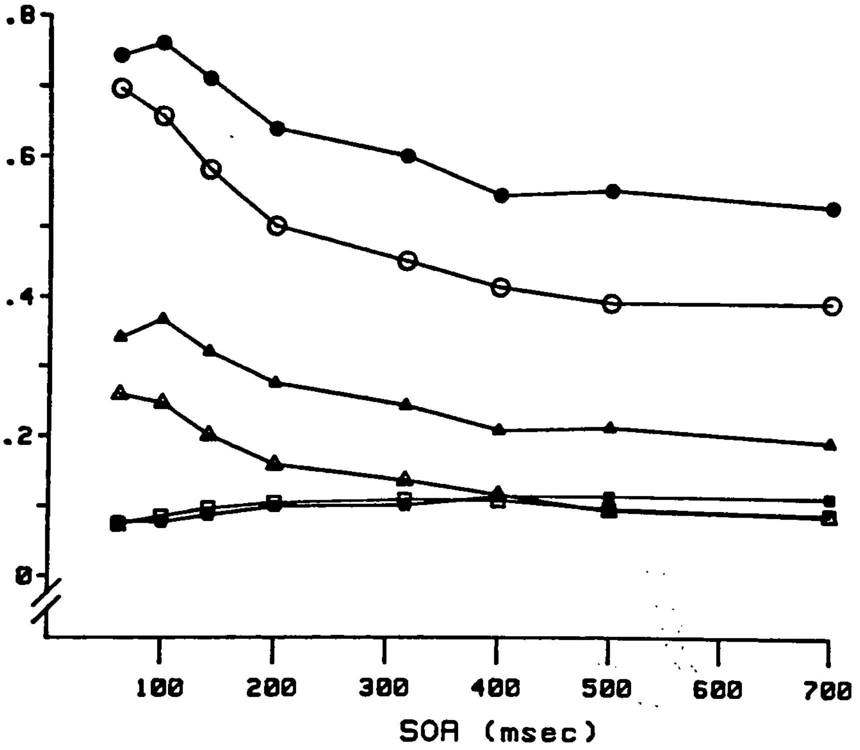


Figure 4.9. shows further that p(IP) decreases as SOA gets longer (significant main effect of SOA). This effect is caused by a decrease in p(IP=c), most of which occurs after the 150-msec SOA (at SOAs equal to and shorter than 150 msec, p(IP=c) is significantly higher than at longer SOAs: $p < 0.005$ and beyond; there are no reliable differences between SOAs longer than 300 msec). Unlike p(IP=c), p(IP=u) shows some tendency to increase with SOA (at SOAs shorter than 150 msec, p(IP=u) is

significantly lower than at longer SOAs: $p < 0.01$ and beyond; there are no reliable differences between SOAs longer than 150 msec). Thus, SOA functions for p(IP=c) and p(IP=u) converge at longer SOAs (significant c/u x SOA interaction). The degree of convergence does not differ much between display conditions.

As can be seen from figure 4.9., cued position biases are stronger for multiple (0.637, i.e. above the expected value) than for single (0.512, i.e. at about the expected value) displays (the expected value is 0.5, i.e. the probability with which targets occur at the cued position). This significant main effect of display type results from p(IP=c) being higher for multiple than for single displays, while there are no reliable differences in p(IP=u).

Further, p(cb) shows a trend to decrease with increasing SOA durations (significant main effects of SOA), with most of the decrease occurring between the 150- and 300-msec SOAs (at SOAs shorter than 200 msec, p(cb) is significantly higher than at longer SOAs: $p < 0.001$; there are no reliable differences between SOAs longer than 200 msec). The rate of decrease in p(cb) appears somewhat greater for for single than for multiple displays (significant S/M x SOA interaction).

4.5.2. Discussion

In summary, the probability of cued position errors is generally higher than that of uncued position errors (IP=u). Further, p(IP=c) is higher for multiple than for single displays, while p(IP=u) does not differ between display conditions. p(IP=c) shows a trend to decrease and p(IP=u) shows some tendency to increase between 150- and 300-msec SOAs. Likewise, p(cb) is higher for multiple than for single displays and shows a trend to decrease, in particular between SOA durations of 150 and 300 msec.

The finding that p(cb) tends to exceed the expected value of 0.5 could reflect a response strategy to choose preferably the cued location in the case of uncertainty (and, thus, reliance on guessing). Such a strategy can contribute to optimizing overall performance, as can be seen from the following example: If the cued position is guessed to contain the target with p = 1.0, the likelihood of a correct position guess is 1/2; if, however, the cued position is chosen with p = 1/2, the likelihood of a correct position guess is 5/12. Thus, adopting a value of p(cb) greater than 0.5 can result in an advantage in correct position guesses of up to 1/12 or 0.083. It may therefore not be surprising that p(cb) tends to be greater than 0.5, in particular since the task in the present experiments did not discourage "false alarms" for the cued position.

In addition to such a response strategy, the value of p(cb) should depend on how efficiently the cued position can be rejected as the target location and on how efficiently targets can be localised at uncued positions. That is, it should be easier (and be associated with a higher degree of certainty) to "decide" whether the cued position is empty (single displays) than whether it contains a distractor cross (multiple displays). And localisation of targets at uncued positions is based on a more effective mechanism in single than in multiple displays. The finding that p(cb) is lower for single than for multiple displays may then be explicable along the following lines.

(1) The advantage for single displays in rejecting the cued location as the target position results primarily in a reduction in p(IP=c) and a corresponding increase in p(IP=u), i.e. in an increase of correct uncued position guesses. That is, it does not per se affect localisation accuracy for uncued locations. (2) The more effective localisation mechanism in single displays results in greater localisation accuracy for uncued locations, with corresponding reductions in both p(IP=c) and p(IP=u). Note that there is no reason to assume this affects the ratio between p(IP=c) and p(IP=u) and, thus, p(cb).

Thus, p(IP=c) should be lower for single than for multiple displays, for both (1) and (2) reduce p(IP=c) for single relative to multiple displays. However, p(IP=u) may not differ between display conditions, since (1) results in an increase and (2) in a decrease in p(IP=u) for single relative to multiple displays. This is consistent with the finding that p(IP=c) is lower for single than for multiple displays, without reliable differences in p(IP=u). With regard to the cued position bias, this explanation implies that the lower value of p(cb) for single than for multiple displays is caused by the differential efficiency in rejecting the cued location as the target position.

Cued position biases decrease with increasing SOA durations, in particular between 150 and 300 msec, because of a decrease in p(IP=c) and a slight increase in p(IP=u).

This change in biases appears to be too systematic and consistent across subjects to be based on a conscious strategy. Rather, it may be attributable to a factor which is not under subject control and which produces a genuine change in subjects' perception of the target location. It is interesting to note that this bias change occurs within 150 and 300 msec after cue onset, i.e. it coincides with a decline in localisation accuracy for valid trials and an improvement for invalid trials.

It has been suggested (see Chapters 2 and 3 for detail) that the loss in localisation accuracy for the cued position and the gain for uncued locations are caused by the fade-out of an initial, automatic, orienting component triggered by peripheral cues and the transition to a second, controlled, component of sustained attention.

Automatic and controlled orienting components are characterised by lower and, respectively, higher interruptability of attention, i.e. of priority of selection, for the cued position. That is, as the (automatic) effect of peripheral cues to engage attention fades out, stimuli at uncued locations are more likely to cause an interruption and claim precedence. Interruptions may be produced both by targets or by nontargets (i.e., illusory targets) at uncued locations; but interruption probability is higher for targets than for nontargets and higher for single than for multiple displays.

Thus, as the (automatic) effect of peripheral cues to engage attention fades out and targets at uncued positions become more likely to claim priority, localisation accuracy for uncued locations improves (while that for the cued position declines); restated, position guesses for uncued locations decrease. If biases were to remain constant, this should result in a decrease both in cued (p(IP=c)) and in uncued (p(IP=u)) location errors in such a way that their ratio remains invariant.

However, not only targets, but also nontargets at uncued locations become more likely, within 300 msec after cue onset, to cause an interruption to the priority for the cued position. When this occurs and a nontarget (i.e., an illusory target) claims precedence, it may not be always possible, because of exposure time constraints, to reject it and it may be accepted as the most likely target candidate. Thus, the probability increases within 300-msec after cue onset that an uncued nontarget location is chosen for the position response.

However, this increase in uncued location errors (p(IP=u) can only occur at the expense of cued position errors (p(IP=c)). That is, there is a trade-off which changes the bias by subtracting from cued and adding to uncued location errors. As a result, p(IP=c) shows a more marked decrease and p(IP=u) shows a slight increase rather than a decrease which would be expected if biases were constant.

Thus, the bias change which occurs within 300 msec after cue onset does might be completely "automatic", involving a simple change in subjects' perception of the whereabout of targets rather than conscious monitoring of SOA duration and readjustment of decision processes.

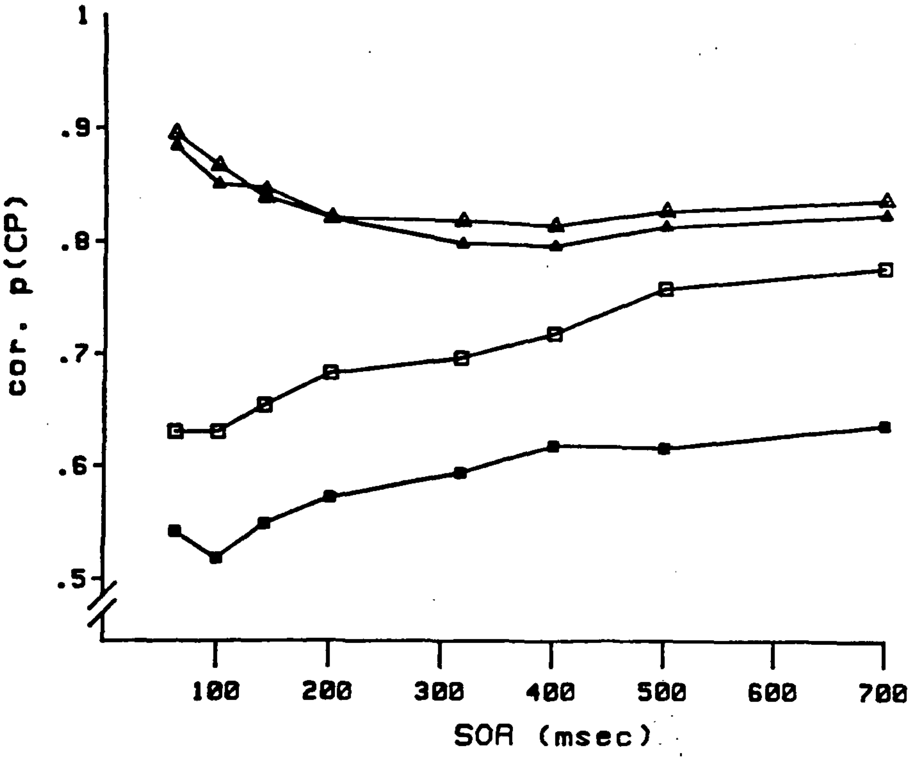
In summary, the localisation task in the present experiments is a source of bias, since targets are more likely to occur at cued than at uncued locations. This bias inflates localisation accuracy for the cued position at the expense of the uncued locations, and advantages for valid over invalid trials are at least in part an artefact of this guessing strategy. (Note that this problem of separating effects of "attention" and of "decision making" (biases) is not confined to the present task; see, for instance, DUNCAN, 1980b, SHAW, 1984, and SPERLING, 1984, for a discussion of "response threshold" effects in

POSNER's simple RT task).

In order to assess to what extent biases towards giving cued position responses inflate advantages for valid over invalid trials, the values of p(CP) and of p(CP,CSD) were corrected for (correct) guessing (see section 4.2. for the correction procedure). Figures 4.10. and 4.11. present cor. p(CP) and cor. p(CP,CSD), i.e. the corrected values, as a function of SOA, separately for single and multiple displays and for valid and invalid trials. (Note that cor. p(CP,ISD), shown in figure 4.4., is the difference between cor. p(CP) and cor. p(CP,CSD).)

Figures 4.10. and 4.11. show that differences between valid and invalid trials are reduced in comparison with the uncorrected data (see figures 4.1. and 4.2.). The contribution of correct guesses to V-I differences can be seen from table 4.5. which presents the estimates of the probabilities of correct position guesses (p(CP)) and of (jointly) correct localisation plus discrimination guesses (p(CP,CSD)).

Figures 4.10. and 4.11.: cor. p(CP) and cor. p(CP,CSD) as a function of SOA, separately for single and multiple displays (S: open symbols; M: closed symbols) displays and for valid and invalid trials (V: triangles; I: squares)



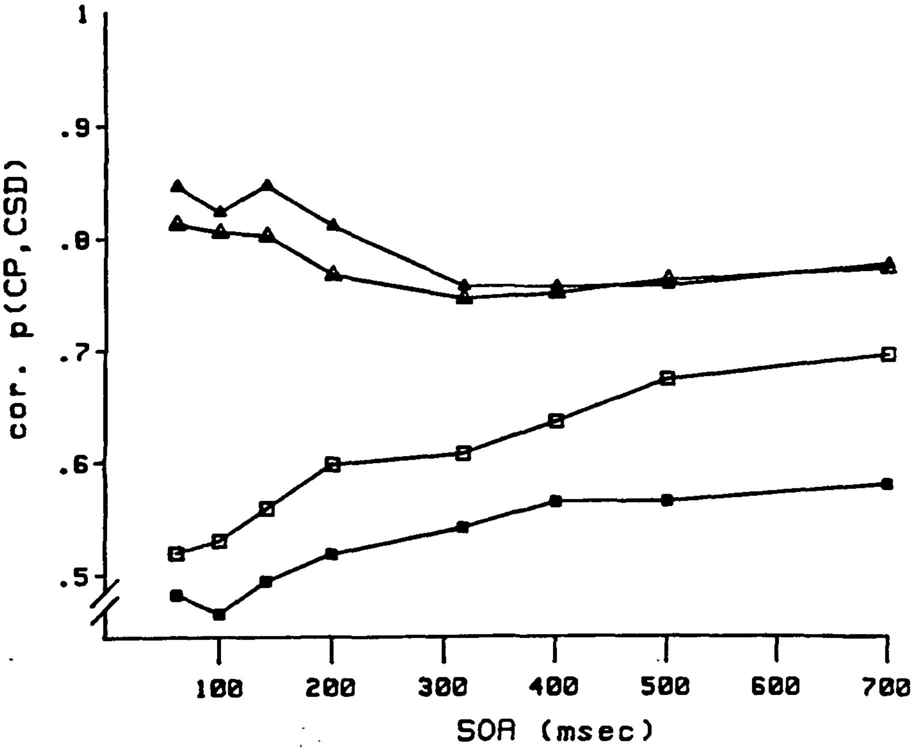


Table 4.5.: Estimated probabilities of correct position guesses (p(CP)) and of correct position plus same-different guesses (exp. p(CP,CSD), separately for single and multiple displays and for valid and invalid trials and their difference

Single Val.	 Inval.	 Diff.	Multiple Val.	 Inval.	 Diff.
p(CP)					
.078	.047	.031	.115	.049	.066
p(CP,CSD)					
.047	.029	.018	.069	.028	.041

Correct position guesses occur with a probability of 0.072, and correct position plus correct same-different guesses occur with a probability of 0.043 (combined across display and cue validity conditions). Correct guesses are about twice as likely for valid than for invalid trials (combined across display conditions) because subjects show biases towards giving a cued position response. For valid trials, correct guesses are more likely for multiple than for single displays, because biases are more marked for multiple than for single displays.

However, the contribution of correct guesses to V-I differences in localisation and in joint localisation plus discrimination accuracy are limited (see the "Diff." values in table 4.5.): About 15 (single displays) to 20 (multiple displays) percent of the observed differences in p(CP) between valid and invalid trials, and about 10 (single displays) to 15 (multiple displays) percent of the observed differences in p(CP,CSD) can be accounted for by correct guessing. In other words, at least 80 percent of these differences cannot be attributed to guessing strategies.

Further, guessing strategies cannot account for the effects of display conditions and of SOA duration on performance in valid and invalid trials. All the effects found in the uncorrected data are largely unchanged in the data corrected for guessing (see figures 4.10. and 4.11).

With the present task, the bias consciously adopted by subjects appears quite strong, i.e. as strong as that observed for very short SOAs (average values of p(cb) for 50- and 100-msec SOAs: 0.68 for single and 0.75 for multiple displays). This may in part be attributable to the present task which did not discourage "false alarms" for the cued position.

This has important consequences for the question to what extent "costs plus benefits" can be attributed to attentional factors (see also KINCHLA, 1977). Suppose, for instance, that on a given invalid trial the subjective probability that a target has appeared at the uncued location containing the target is 0.8, and the probability for the cued (nontarget) position 0.7. Thus, if subjects responded on the basis of these probabilities, they would decide in favour of the information from the uncued location. However, because the cued position has a higher a-priori probability, observers might give preferential weight to the evidence from this location. Thus, if subjects were biased towards accepting any information available from the cued position as target information, the result would be a large advantage for valid over invalid trials.

One prediction arising from such a strategy of assigning preferential weight to any evidence available from the cued location would be that not only hit rates, but also false alarm rates should be higher for valid than for invalid trials. Thus, it seemed necessary to replicate the present findings in a further experiment (Experiment 10) which used a task, based on signal detection theory, that allowed the measurement of false alarm rates for cued and uncued locations.

Experiment 10

Hit rates in this experiment should behave in the same way as with the previous task, i.e. they should decrease, with increasing SOA duration, for the cued position and increase for uncued locations. False alarm rates, however, should behave in the same way as cued and uncued location errors with the previous task, i.e. they should decrease for the cued position and increase slightly for uncued locations (because cued location biases are more marked at short SOAs).

The methodology used in Experiment 10 was based on signal detection theory (SDT; GREEN and SWETS, 1966); in particular, it employed the joint ROC technique previously used by BASHINSKI and BACHARACH (1980). With the exception of the type of spatial cue presented and of the varying SOA durations, the methodological details of Experiment 10 are the same as in Experiments 11 and 12 (see Chapter 5). Thus, only the basic design and procedure will be outlined in this section and all other details will be presented in Chapter 5.

The target stimulus in Experiment 10 was the symbol T which could appear in any of the four orthogonal orientations. The T presented in the display centre (frame II) prior to target exposure (frame V) indicated the particular orientation to be expected on a given trial; that is, on signal (i.e., target) trials, the target T presented in one of the four peripheral boxes was always the same as the T previously displayed in the centre. On signal trials, the target T appeared at one of the peripheral locations and distractor crosses of the same size and luminance appeared at the remaining three positions; on noise (i.e., no-target) trials, distractor crosses appeared at all four locations ("multiple" displays). The spatial cue presented in frame IV was a 50-msec brightening of the outline of one of the four boxes (peripheral cue) which might (valid trials) or might not (invalid trials) correctly prime the cued position. There were also baseline (neutral) trials in which all four boxes were brightened simultaneously. SOA durations between spatial cue and target were 150 and 700 msec, so that hit and false alarm rates could be measured for the early automatic and the later controlled orienting components (see Chapter 3 for detail). Experiment 10 consisted of 2784 trials ("single cue" condition; 288 valid plus 3 x 128 invalid signal trials and 336 cued noise trials and, in addition, 256 baseline signal and 128 baseline noise trials per SOA). SOA durations, signal and noise trials and cue validity conditions were presented in randomized order.

After target display termination (frame VI), subjects gave three responses: First, a yes-no response to indicate whether or not they had detected a target. Second, they rated their degree of certainty of this response (i.e., in the case of a positive response according to the categories "very certain", "certain" and "uncertain" and in the case of a negative response according to the categories "uncertain" and "certain"). Third, they made a response to indicate at which of the four locations they had detected a target. The localisation response was also required in the case of a no-target response. Subjects were instructed to avoid false alarms for a given location if they could reject it to contain the target, since this would improve their overall performance.

Three subjects (I.P., N.A. and H.M.) participated in Experiment 10 (two four-hour sessions of each 1392 trials). Payment was 2.50 pounds per hour. Since Experiment 10 was conducted after Experiment 11 (see Chapter 5), all subjects were highly experienced with the present task. At the beginning of each session, threshold exposure times were determined according to a modified PEST adaptive staircase procedure (see section 5.2. for detail) which aimed at a "detection" sensitivity of P(A) = 0.75 on baseline (neutral) trials. The following times were estimated for I.P., N.A. and H.M., respectively (average of two sessions): 32.5, 31.5 and 28.5 msec.

The data were subjected to a SDT analysis which accepted a detection response as a hit only if both the detection and the joint localisation response were correct. This analysis allowed the assignment of false alarms to individual (i.e., cued or uncued) positions since the localisation response specified whether a target stimulus had been - erroneously - detected at the cued or at an uncued location. Restated, this analysis took into account the cue validity condition under which a particular noise trial would fall if it had been a signal trial, as indicated by the positive detection response. (Note that this analysis corresponds to "detection plus localisation II" analysis in terms of BASHINSKI and BACHARACH, 1980; see section 5.5. Appendix A).

In addition to hit and false alarm rate measures, computer-determined estimates were obtained for the sensitivity parameter P(A). These estimates are based on the maximum likelihood approach developed by DORFMAN and ALF (1969; SDT rating method data) and calculated for each subject under each experimental condition. Table 4.6. presents the hit and false alarm rates and the P(A) estimates, individually for each subject and separately for the two SOAs and for valid, baseline (neutral) and invalid trials.

Table 4.6.: Joint detection plus localisation hit (HR) and false alarm rates (FAR) and joint detection plus localisation sensitivity: Summary of HR, FAR and P(A) for each subject under each experimental condition.

	SOA 150			SOA 700		
Ss	V	N	I	V	N	I
HR						
I.P.	.778	.660	.542	.674	.656	.596
N.A.	.774	.672	.542	.719	.676	.607
H.M.	.868	.742	.552	.792	.676	.641
Mean	.807	.691	.545	.728	.669	.615
FAR						
I.P.	.146	.117	.089	.060	.102	.080
N.A.	.143	.132	.077	.068	.117	.083
H.M.	.119	.109	.068	.065	.094	.074
Mean	.136	.119	.078	.064	.104	.079
P(A)						
I.P.	.896	.865	.802	.890	.878	.856
N.A.	.896	.865	.815	.880	.881	.854
H.M.	.947	.915	.864	.926	.908	.890
Mean	.913	.882	.827	.899	.889	.867

As can be seen from table 4.6., hit rates are higher for valid than for invalid trials (ANOVA of arcsin HR: main effect of V/I: $F(1,2) = 45.60$, $p < 0.025$), and V-I differences for HR are less marked at the 700- than at the 150-msec SOA (V/I x SOA interaction: $F(1,2) = 77.47$, $p < 0.01$). This interaction occurs because hit rates decrease between SOAs for valid trials and increase for invalid trials. This is consistent with hit rates in the previous experiments.

False alarm rates are higher for valid than for invalid trials (ANOVA of arcsin FAR: main effect of V/I: $F(1,2) = 60.96$, $p < 0.025$), and V-I differences for FAR are more marked at the 150- than at the 700-msec SOA (V/I x SOA interaction: $F(1,2) = 197.78$, $p < 0.005$). This interaction is caused by a false alarm rate decrease between SOAs for valid trials, while for invalid trials false alarm rates remain constant. Note that FAR for invalid trials remain unchanged despite of a "general" tendency for FAR to decrease, i.e. despite a decreasing tendency for baseline trials. That is, relative to baseline trials, FAR for invalid trials show an increase across SOAs, while FAR for valid trials show a decrease. Thus, the false alarm rate pattern agrees with that of cued and uncued location errors for invalid trials in the previous experiments.

The pattern of cued and uncued position errors for invalid (signal) trials in the present task also agrees with the previous experiments (note that localisation errors in the present task, i.e. when the cued position or an uncued nontarget location was erroneously chosen, are treated as "misses"). Cued position errors show a marked decrease between the 150- and 700-msec SOAs, and uncued location errors remain constant (cued position errors are 0.220 at the 150- as compared to 0.106 at the 700-msec SOA, and uncued position errors are 0.182 as compared to 0.164; an ANOVA of arcsin p(IP) with the factors cued/uncued position errors and SOA revealed the following effects to be significant: main effect of c/u: $F(1,2) = 23.72$, $p < 0.05$; and c/u x SOA interaction: $F(1,2) = 33.05$, $p < 0.05$).

Thus, cued position biases decrease between the 150- and 700-msec SOAs, both for (invalid) signal and for noise trials. (Combined across signal and noise trials, the decrease is from 0.423 to 0.257; an ANOVA of arcsin p(cb) with the factors signal/noise trials revealed a significant main effet of SOA: $F(1,2) = 171.73$, $p < 0.005$.) Cued position biases do not differ between (invalid) signal and noise trials (as indicated by the absence of signal/noise trial effects).

Thus, the factor which is responsible for the reduction in hit rate for the cued position between SOAs does not only change the ratio between cued and uncued position "guesses" for (invalid) signal trials, but also that for noise trials. The effect of this factor is to decrease cued and to increase uncued location guesses.

As a result, reduced hit rates for the cued position at the 700- as compared to the 150-msec SOA are accompanied by reduced false alarm rates. The reduction in false alarm rates almost compensates for that in hit rates, so that there are only slight losses in "sensitivity" for the cued position between the 150- and 700-msec SOAs. As can be seen from table 4.6., the sensitivity parameter P(A) for valid trials differs by 0.014 between SOAs; but although small, this difference is consistent across subjects. (See note on page 319A.)

For invalid trials, there is a more marked increase in P(A), i.e. sensitivity tends to converge towards that for valid trials at the 700-msec SOA. (See note on page 319A.) (An ANOVA of P(A) with the factors V/I and SOA revealed to following significant effects: main effect of V/I: $F(1,2) = 376.32$, $p < 0.005$; V/I x SOA interaction: $F(1,2) = 203.44$, $p < 0.005$).

In summary, Experiment 10 replicates the findings obtained with the previous task. However, it also shows that higher hit rates for cued than for uncued locations are not accompanied by lower false alarm rates (i.e., at least not at short SOAs). In other words, while detection probability is higher when the cued position contains a target, rejection probability may not be higher when it does not contain a target. Thus, advantages in hit rate for the cued position are at least in part the result of a strategy to assign preferential weight to evidence available from the cued location. (See Chapter 5. for a more detailed discussion.)

It has been proposed (see above) that the SOA effects on hit and false alarm rates and on sensitivity occur because spatial orienting (peripheral cues) is based on two different processes at short and at long SOAs: an early automatic and a later controlled process which are characterised by lower and, respectively, higher

Note: This pattern indicates that automatic orienting is characterised by a marked cue validity effect both on sensitivity and on bias, while controlled orienting is mainly characterised by an effect on bias.

interruptability of attention for the cued position.

In terms of SDT, the major difference between the components of automatic and controlled orienting appears to be a shift to the right of the yes-no cutoff point on the decision axis (i.e., internal strength variable), as indicated by reductions both in hit and in false alarm rates. Restated, the early, automatic orienting component seems to maximise hit rates at the cost of increased false alarm rates, while the later, controlled component appears to minimise false alarm rates at the cost of reduced hit rates.

While the yes-no cutoff point is further to the right of the mean of the noise distribution for long than for short SOAs, it is questionable whether a "rightwards shift" of the yes-no cutoff point indeed occurs. It appears more likely that subjects do not adopt different cutoffs for short and for long SOAs, but that distribution parameters change relative to each other; that is, the absolute value of the cutoff on the internal strength variable may be constant across SOA, but the noise distribution may be shifted to the left.

Such a leftwards shift would occur if, as suggested, the likelihood increases between SOAs that distractor elements at uncued locations cause an interruption to the priority for the cued position. As it is not always possible, because of exposure time constraints, to reject such a nontarget stimulus claiming precedence, the probability increases that it is accepted as the most likely target candidate. Thus, on noise trials false alarm rates increase for uncued locations and decrease for the cued position, in the same way as uncued and cued localisation errors on (invalid) signal trials.

4.6. General Discussion

In summary, detailed analyses for the single and multiple element displays presented in Experiments 1 to 4 revealed that both localisation and discrimination accuracy are above chance even with failures to discriminate and, respectively, to localise. Thus, it appears discrimination is not a necessary condition for target localisation and that localisation is not a necessary condition for target discrimination (mixture of hypotheses (3) and (4) outlined in section 4.1.). However, in terms of the processes which, plausibly, underly search in the present task, the principal route to successful discrimination is through localisation. Only when this fails is there a second, inefficient, route of integrating target impressions across display locations.

The finding that localisation accuracy is above chance even with discrimination failures cannot be explained by inadequate masking, i.e. detection of "post-mask" luminance differences between target and nontarget locations (see Experiment 8). Nor can it be explained in terms of a serial search strategy which aims at ascertaining target presence for a subset of display locations and, if it fails to do so, chooses one of the unsearched locations at random (see appendix 4.7.).

This supports the idea that search in the present task is not a "blind" (random selection) process, but rather based on a mechanism, at an early stage of processing, which ensures that only those elements (i.e., display locations) are selected (i.e., "searched") which are likely to be target items. Both the models of HOFFMAN (1978, 1979) and of DUNCAN (1980a, 1981, 1985) explicitly propose such a preattentive selection mechanism and can, thus, provide a framework for the explanation of the finding that localisation accuracy is above chance even with failures to discriminate.

Note that SHAW's attention theory (1980, 1982, 1984), which distinguishes between an initial "coding" and a later "decision" stage, could also provide such a framework. However, SHAW's model may not be incompatible with HOFFMAN's and DUNCAN's "late selection" theories of attention, since SHAW leaves the substages which stimulus coding may be composed of unspecified.

It appears that any feasible explanation for the effects of display condition, cue validity and SOA duration on localisation accuracy with discrimination failures has to make at least three assumptions:

(1) Stimulus attributes required for target

localisation are derived faster than, and may thus serve as the basis of selection of, information required for target discrimination. Thus, exposure time constraints are more likely to limit target discrimination than target localisation.

(2) Information from the cued position becomes available faster than information from uncued locations. That is, the likely target position is assigned priority of selection in advance, so that information can gain access to the limited capacity system as soon as it is derived. The order of selection for elements at less likely locations must be determined by (localisation) attributes derived after display onset. However, selection is subject to delays if more than one element competes for access to and if information from the cued position occupies the limited capacity system. Thus, exposure times constraints cause more information losses for uncued locations.

(3) Information for target localisation is derived faster in single than in multiple element displays. For single displays, simple detection of the luminance change produced by single target onset is sufficient for localisation, and localisation and discrimination are based on separate attributes. However, for multiple displays, with luminance changes occurring simultaneously at target and nontarget locations, localisation must be based on a more complex attribute which discriminates a T

from a cross. Since target localisation is based on a more effective mechanism in single displays, localisation accuracy is at least as high as for multiple displays, despite shorter exposure durations. However, since exposure time constraints affect target discrimination more than target localisation, successful localisation with discrimination failures is more likely for single displays.

One additional assumptions is needed to explain the SOA effects: Spatial orienting is guided by two different processes at short and at long SOAs: an early automatic and a later controlled process which are characterised by lower and, respectively, higher interruptability of the priority (of selection) assigned in advance to the cued position.

Thus, within about 300 msec after (peripheral) cue onset, elements at uncued locations become more likely to claim precedence, causing delays in the availability of the limited capacity system for a target at the cued position. As a result, both localisation and discrimination accuracy decrease for the cued location. However, this is less marked for localisation, since location attributes are derived faster than information required for discrimination.

Interruptions to the priority for the cued position may be caused both by target and by nontarget elements at uncued locations; but interruption probability is higher for targets than for nontargets and higher for targets in single than in multiple element displays (note that "nontargets" may also "arise" in single displays, because of noise in the visual system and confusion between mask and target information).

Thus, as interruptability of the priority for the cued position increases within 300 msec of cue onset, targets at uncued locations become more likely to claim precedence. As a result, the probability increases that not only whereabout, but also and discriminative information is passed on successfully. This increase is less marked for multiple than for single displays, because distractors in multiple displays are more likely to claim precedence than "nontargets" in single displays (that is, with multiple displays, there may not be a "second" chance if the "first" interruption is caused by a distractor; with single displays, however, it is more likely that the target takes the first chance).

The same assumption can explain the SOA effect on cued location biases. That is, not only targets, but also nontargets at uncued locations become more likely, within 300 msec after cue onset, to cause an interruption to the priority for the cued position. However, it may not always be possible, because of exposure time constraints, to reject a nontarget claiming precedence. Thus, the probability increases that an uncued nontarget location is chosen for the position response. This increase in uncued location errors can only occur at the expense of cued position errors. As a result, the ratio between cued and uncued location errors changes.

Thus, the bias change which occurs within 300 msec after cue onset might be completely "automatic", involving a simple change in subjects' perception of the whereabout of targets rather than conscious monitoring of SOA duration and readjustment of decision processes.

The explanation suggested for the present findings makes one or two critical assumptions which HOFFMAN (1978, 1979) and, more so, DUNCAN (1980a, 1981, 1985) might have reservations about.

First, access to the limited capacity system is probabilistic: "Access probability is greater for targets than for nontargets, but nonzero for both" (DUNCAN, 1985, p. 94). This is consistent with HOFFMAN's model; but according to DUNCAN, keeping nontargets out of the limited capicity system is nearly perfect, at least when the defining/reported target attributes are simple features.

Second, location attributes not only serve as the basis for selection of information required for discrimination (because they are derived faster at the preselective stage of processing), but also gain prior access to the limited capacity system. That is, location information can become available for report, while discriminative information fails to do so. (In terms of

HOFFMAN's model, this assumption might imply that the order of display elements on a transfer is accessible for report).

This assumption should be less disputable for single element displays, target since localisation is based on detection of a single luminance increment, i.e. on an attribute that is separate from the form information required for discrimination. In other words, detection of the luminance increment associated with single target onset can be regarded as a task in itself. For the multiple element displays, however, there appears to be no clear-cut separation between localisation and discrimination components.

However, recent research on the primitive coding of the (1D) spatial distribution of luminance changes suggests that such a separation may also exist for multiple displays. According to the MIRAGE model of WATT and MORGAN (1985), there is a number of filters of different spatial scales (i.e., space constants) for every point in the retinal image. Line terminations, line intersections and line curvature maxima produce small peaks in the convolutions between the summed outputs of these filters and a distal stimulus, at which visual images are segmented into simple features prior to shape analysis (WATT, 1985, and WATT and CAMPBELL, 1985).

Thus, in terms of the MIRAGE algorithm, target (T) stimuli would characterised by four convolution peaks (three line terminations plus one intersection), and distractor (+) stimuli by five peaks (four line terminations plus one intersection) peaks. Thus, any system based on counting the number of convolution peaks would allow an initial grouping of display elements into target and distractor stimuli prior to shape analysis (i.e., target discrimination).

In other words, there is, in principle, only a quantitative, but not a qualitative, difference between single (4 peaks for target as compared to nought for "nontarget" locations) and multiple displays. This quantitative difference could account for the assumptions that localisation, i.e. grouping of display elements into targets and distractors is less error-prone (i.e., less liable to noise) and faster (i.e., based on the output of filters of the largest spatial scale which show transient properties) for single displays.

Thus, for both display conditions, location information may be derived prior to information for discrimination. In terms of MIRAGE, discrimination requires a "scaling down" process in which a likely target candidate is subjected to geometrical (i.e., topological) analysis of stimulus segments in terms of "above ...", "right of ..." etc. This involves a time consuming, extra, step of finding the appropriate spatial scale. According to WATT (1986), this scale is found by switching filters off, starting with the largest scale filters and proceeding "downwards" in an orderly manner, until the output of the MIRAGE algorithm changes topologically.

Note that there are alternatives to WATT and MORGAN's MIRAGE model, such as JULESZ's (1981, 1984; JULESZ and BERGEN, 1983) "texton" theory which is based on research on patterns composed of many randomly repeated texture elements. JULESZ used the immediacy of texture segregation as a criterion for identifying the basic elements, or "textons", of preattentive vision. Differences in the density of textons serve to mark areas that will be analysed by "focal" attention. However, it apppears difficult to generalize beyond this research since the visual system may deal with redundant patterns in a special manner.

Thus, the main route to target discrimination is through target localisation. However, there appears to be a second route available when localisation failed. This is suggested by the finding that discrimination accuracy can exceed chance even with failure to localise. However, this holds only for different, but not for same trials (i.e., for trials with no rather than with matching target and comparison Ts). And it holds only for (two-forced choice same-different) discrimination, but not for (four-forced choice orientation) recognition (Experiment 9). This second route to target discrimination is very unreliable, i.e. successful discrimination with localisation failures is a very rare event exceeding chance by not more than 0.025 (different trials).

This route is presumably based on integration of independent target "impressions", i.e. real and/or illusory ones, across display locations. Integration can contribute to optimising discrimination accuracy for different trials, but not so much recognition accuracy for same and for different trials.

For "different" discrimination to be successful, it would be sufficient if two target impressions, e.g. one for a nontarget and one for the target location, are both different from the comparison T, no matter whether they are identical with each other or whether they match the actual target. However, for "same" and "different" recognition to be successful, the orientation of one illusory impression at a nontarget location and the orientation of the impression for the target position would have to be identical and, and for "same" recognition, both impressions would have to match the comparison T. That is, integration is much less likely to be successful for "same" and "different" recognition if the orientation of illusory target impressions for nontarget locations is more or less randomly determined (one out of four orientations).

This proposal of same-different "response" integration across display locations agrees with the theories of HOFFMAN (1978, 1979) and of SHAW (1982). The basic assumption of this explanation is that target discrimination involves a choice among real and/or illusory target impressions which are accessible to the decision process (they may, however, not be accessible for report because impressions may be lost from memory while others are reported).

In summary, the visual search theories of HOFFMAN (1978, 1979), of SHAW (1980, 1982, 1984) and, with some qualifications, of DUNCAN (1980a, 1981, 1985) can provide consistent explanations for the effects of attention and decision making in the present localisation plus discrimination task. The present data, however, do not allow (and Experiments 1 to 4 were not designed) a decision among them. The most important conclusion is that target discrimination is largely dependent on target localisation, and that differences in localisation between single and multiple element displays are more quantitative rather than qualitative in nature.

4.7. Appendix

If target search in the present task is a serial, self-terminating process, one should assume that the cued position is searched first and that selection of an uncued location to be searched next is either random or based on a search "rule". While the assumed priority for the cued position could explain the superior performance for the cued position, there is no evidence in the present data for any fixed search order among uncued locations.

One rule, for example, would be to search the cued position first and the adjacent locations next. This rule would predict that performance on invalid trials would be higher for locations adjacent rather than opposite to the cued position. However, the present data do not show any advantages for adjacent over opposite locations. There is also no evidence for alternative search rules such as, for instance, to search in clockwise or anticlockwise order (see also JONIDES, 1980). Thus, any serial model remaining would have to assume random choice.

(Note that the absence of advantages for adjacent over opposite locations also provides evidence that the superior performance for the cued position is not produced by strategic eye movements in the direction of spatially informative cues; see section 5.6. in Chapter 5 for a more detailed discussion of the possible role of eye movements in the explanation of "sensitivity" advantages for cued over uncued locations.)

In the following paragraphs, a serial, random choice, search model will be derived which aims to predict maximum localisation accuracy for uncued locations. Model predictions, based on parameter estimates taken from the available data, will then be compared with the observed values in order to decide whether the serial search assumption is consistent with actual localisation accuracy.

(1) Assumptions: (1a) Target search is a serial process, starting with the cued location. (1b) Target search is self-terminating, i.e. search is terminated when a target is, correctly or erroneously, localised. (1c) Because of limited target exposure times, only a subset of display locations, including the cued position, can be searched; if the target cannot be localised in a searched position, an unsearched location is chosen by "default". (1d) Selection of uncued locations to be searched is random.

(2) On invalid trials, the probabilities that the uncued position searched first, second and third contain the target - i.e., $p(T/i)$, $i = 1,2,3$ - are 1/3, 1/2 and 1, respectively. The probabilities that the uncued location searched first, second and third contain a distractor - i.e., $p(D/i)$, $i = 1,2,3$ - are $1 - p(T/i)$.

(3) It follows from (1b) that uncued locations are searched only on invalid trials if a target has not been erroneously localised in the cued position; thus, the probability with which the first uncued location is searched is $p(i=1) = 1 - p(IP=c)$.

(4) Assumptions: (4a) The probability with which the target is localised in a searched position given that it is present there - i.e., max. $p(t/T)$ (T for target present, t for target response) - does not decrease as the number of searched locations increases. (4b) The probability with which a searched position is rejected

as not containing the target given that it is not present there - i.e., max. p(d/D) (D for distractor present, d for distractor response) - does not decrease as the number of searched locations increases.

(5) p(i) is the probability with which search is not terminated after searching location i-1; the initial value of p(i=1) is 1 - p(IP=c); if search continues from uncued location i-1 to uncued location i, p(i) is p(d/D) obtained when searching location i-1 (i.e., the probability that search is not terminated is the sum of the probabilities of correct rejections when searching i-1).

(6) The conditional probabilities of p(t/T) - i.e. target response given target present -, p(d/T), p(d/D), p(t/D) can then be derived as follows:

$p(t/T) = p(i) * p(T/i) * \max.\ p(t/T);$

$p(d/T) = p(i) * p(T/i) * [1 - \max.\ p(t/T)];$

$p(d/D) = p(i) * p(D/i) * \max.\ p(d/D);$

$p(t/D) = p(i) * p(D/i) * [1 - \max.\ p(d/D)].$

The left hand side of table 4.7. shows p(CP) - i.e., p(t/T) - and p(IP=u) - i.e., p(t/D) - for uncued locations expected on the basis of this model when 3, 2 or 1 display locations (i.e., 2, 1 or 0 uncued locations) can be searched successfully. The expected values are based on the following parameter estimates: p(t/T) = 0.926, p(d/D)

= 0.782 and p(i=1) = 0.782; these are the empirical values obtained for the cued position (combined across display conditions and SOA durations). The right hand side of table 4.7. shows cor. p(CP,ISD), i.e. the values of p(CP,ISD) corrected for guessing (see guessing model in section 4.1.), expected for cued (left) and uncued (right) locations when 3, 2 or 1 display locations can be searched successfully. These values are based on the following further estimates: p(CSD/CP) is 0.915 and 0.594 and for searched and unsearched locations, respectively, and p(CSD/IP) is 0.594 (that is, p(CSD/CP) for unsearched locations is assumed to be equal to p(CSD/IP)); p(CSD/CP) = 0.915 and p(CSD/IP) = 0.594 are the actual values observed for cued position and for incorrect localisation decisions in general.

Table 4.7.: Observed and expected values of p(CP) and p(IP=u) for uncued locations and of cor. p(CP,ISD) for cued (left) and uncued (right) locations (expected values are based on the assumption that 3, 2 or 1 display locations, including the cued position can be searched; see text for further details)

	p(CP)	p(IP=u)	cor. p(CP,ISD)	
obs.	0.686	0.097	0.034	0.073
exp. 3	0.590	0.192	0.057	0.066
exp. 2	0.445	0.337	0.066	0.035
exp. 1	0.261	0.521	0.071	0.000

As can be seen from table 4.7., the expected values of p(CP) underestimate and the expected values of p(IP=u) overestimate the values actually observed; further, the expected values of cor. p(CP,ISD) overestimate the value obtained for the cued position and understimate the value observed for uncued locations. Over- and underestimations are the more marked the fewer display locations can be searched successfully. Thus, it seems unlikely that search in the present task is based on a serial (random choice) model.

Chapter 5

Sensitivity and Criterion Effects in the Spatial Cueing of Visual Attention

5.1. Introduction

How does the focusing and dividing of attention influence perception? Recent research on this question has been concerned with two effects: that of "display N", i.e. the number of nontargets in the display, and that of "probabilistic priming", i.e. the relative frequencies of target occurrence assigned to individual locations. Experiments with accuracy as the dependent measure and with high error rates have established that an increase in the number of nontargets, without an increase in the number of targets, reduces target detectability (e.g., ESTES and TAYLOR, 1964), and that variations in the probabilities with which the target occurs at particular locations enhance target detectability for the more likely positions relative to the less likely locations (e.g., SHAW and SHAW 1977). Equivalent effects have been demonstrated in RT experiments (e.g., ESTES and WESSEL, 1966; SHAW, 1978).

For the explanation of these effects, it seems useful to assume that there are at least two functional stages between stimulus and response: In the first "coding" stage, which may consist of a number of substages, each stimulus is converted into an internal representation. In the second "decision" stage, the internal representation is used to determine a response, for example a "target present - absent" decision. According to signal detection theory (SDT; GREEN and SWETS, 1966), the internal stimulus representation is characterized by a one-dimensional strength variable and the observer makes decisions about the presence of a target by comparing the strength of a representation against a criterion. Thus, the decisive question is whether the variations in the number of nontargets in a display and in frequencies of target occurrence at particular locations influence the quality of the stimulus representations generated by the coding process or whether the resulting effects are due to errors and criterion shifts in the decision process.

SHAW (1980, 1984) has developed a model for the prediction of the maximum performance decrement which can be produced by an increase in display N on the assumption that the losses are entirely due to decision errors. This model assumes that there is a strength value associated with the stimulus (target or nontarget) at each location which represents the degree of similarity between the internal representation and the target and, further, that the strength distributions for targets and nontargets overlap. It follows that an increase in display N increases the probability that the strength of at least one nontarget will exceed the strength associated with the target. Thus, if the observer chooses the location with the greatest strength value, error rate will increase with display N even if the strength distributions remain unchanged.

SHAW (1984) found that in tasks requiring the detection and localisation of letters (consistent and varied mapping), the actual performance decrement exceeded the maximum amount expected on the basis of the decision process explanation. SHAW concluded that dividing of attention among an increased number of locations results in greater overlap of the strength distributions for target and nontarget, i.e. in reduced quality of the internal stimulus representations. While SHAW (1984) thus found capacity limitation in the coding process for the detection of letter stimuli, for the detection of luminance increments her results were "radically" (sic) different: Here the entire display N effect could be accounted for in terms of the decision process. SHAW claims that the same qualitative difference also holds for the effect of probabilistic priming.

Most studies investigating this effect have used simple detection of change, i.e. simple RTs to suprathreshold luminance increments (e.g. POSNER, NISSEN and OGDEN, 1978; POSNER, SNYDER and DAVIDSON, 1980). However, DUNCAN (1980b), SPERLING (1984) and SHAW (1984) have recently argued that it does not necessarily follow from the mere presence of the priming effect that stimulus coding at the more likely positions is enhanced by allocation of limited attention resources. RT advantages for the more likely relative to the less likely locations can equally well be explained by a simple response bias, i.e. a tendency of the processing system to reduce the amount of evidence it requires to decide whether a change has occurred at the more frequent positions (and, possibly, to raise the criterion for the less frequent locations). As is apparent, the response bias explanation presupposes that the observer can adopt independent criteria (i.e., response thresholds) for positions with high and low probabilities of target occurrence.

However, SHAW's (1984) conclusion about the priming effect for the detection of luminance increments contrasts with the results of BASHINSKI and BACHARACH (1980) who combined a "cost-benefit" analysis (POSNER and SNYDER, 1975) with a SDT rating procedure. This task required detection plus localisation of a single target probe briefly flashed at either of two locations on signal trials (on noise trials both locations remained blank). On cued trials, an arrow indicator primed the more ($p = 0.8$) and the less ($p = 0.2$) likely location. There were also trials with a neutral prime (i.e., $p = 0.50$ for each location). BASHINSKI and BACHARACH found benefits in the sensitivity parameter P(A) for the more likely position (relative to the neutral condition). When the localisation response was taken into account, there were also costs for the less likely location. The likelihood ratios (betas) at the yes-no cutoff point were near-optimal and independent of the frequency with which the target occurred at a particular location. (Note, however, that there is a major problem with the joint detection plus localisation analysis used by BASHINSKI and BACHARACH which renders their conclusions questionable; see section 5.5. Appendix A for details.) Thus, while according to SHAW (1984) focusing attention produces criterion shifts without sensitivity changes, according to BASHINSKI and BACHARACH (1980) there are sensitivity effects without criterion changes.

A further question on which there is conflicting evidence concerns the limit to the divisibility of attention among spatial locations according to their assigned probabilities. SHAW and SHAW (1977) argue in favour of a flexible attention sharing mechanism. They compared one condition in which a single letter appeared equally often at one of eight locations with another in which the frequencies of target occurrence assigned to individual locations were varied ($p = 0.25$ and $p = 0.05$ for each two positions and $p = 0.10$ for four locations). SHAW and SHAW found that after providing extensive practice with these frequency distributions, recognition accuracy did not differ between locations in the first condition, while in the second condition it varied as a function of the probability with which the target occurred at any particular location.

POSNER et al. (1980) question whether attention can be allocated freely over the visual field within a given trial and argue that SHAW and SHAW's finding may be due to averaging across trials, i.e. "... subjects (may) sometimes attend to one position ... and sometimes to another, and these probabilities match those assigned to target presentation" (p. 169; see also ERIKSEN and YEH, 1985). POSNER et al. investigated this possibility employing a simple RT task (Experiment 5). They used four signal locations arranged horizontally to the left and right of a fixation mark. One location, indicated to be the most likely ($p = 0.65$) target position, varied across trials, while another location, the second most likely ($p = 0.25$) position, remained fixed throughout a block of trials. Posner et al. found that RTs for the second most likely position were faster than those for the uncued locations when it was adjacent to the most likely position, but not when it was separated from it. POSNER et al. (1980) concluded that for luminance detection, there are "... severe limits in the ability of subjects to assign attention to a secondary focus in addition to a primary focus"; however, the focus of attention "... may vary in size according to the requirements of the experiment" (p. 171).

Thus, two questions seem open: whether luminance detection is "radically" different from letter detection; and what the "limits" are to the ability to divide attention among spatial locations according to probabilistically defined priorities. These questions were investigated in two experiments. Both employed a task amenable to SDT analysis which required the detection plus localisation of a target stimulus.

Experiment 11 investigated the limits to the divisibility of attention among spatial locations. The target stimulus was the symbol T which could appear in any of the four orthogonal orientations; nontargets were crosses of the same size and luminance. On every trial, a "single arrow" or a "double arrow" was presented to indicate the likely target position(s) in a display of four locations; that is, the cued positions numbered either one (single arrow) or two (double arrow) and the uncued locations either three or two. The probability of target occurrence for the "cued 1" position was the same in single and double cue conditions. The probability of target occurrence for the "cued 2" location in double cue conditions was either the same as that for "cued 1" (i.e., both arrow arms were equally long) or it was reduced (i.e., the second arm was shorter). Estimates of the sensitivity parameter P(A) and the bias parameter beta were obtained independently for indicated and nonindicated locations and compared within and between cueing conditions.

Experiment 12 investigated differences between luminance increment and symbol detection tasks. There were three display conditions: The first was similar to that used by BASHINSKI and BACHARACH (1980), i.e.

although the target was a T, the task required only detection of the luminance change produced by its arrival in the display; the second display condition was the same as in Experiment 1 (consistent mapping); and the third was a varied mapping task in which Ts in different orientations changed roles as targets and nontargets from trial to trial.

5.2. Experiment 11

5.2.1. Method

Observers: Three subjects (I.P., N.A. and H.M.; males; ages 20 - 30; each with corrected-to-normal vision) participated in Experiment 11 which lasted 30 hours inclusive of two practice sessions. They were all experienced psychophysical observers who had taken part in previous experiments involving the localisation plus discrimination task. Payment was 1.50 Pounds per hour plus a bonus of 10.0 Pounds for completion of the experiment. H.M. also participated in a repetition of Experiment 11 involving the monitoring of eye movements (Experiment 11a).

Apparatus and Materials: Stimuli were presented on a Hewlett Packard 1321A X-Y monitor with P31 phosphor, driven by a CED Alpha (LSI 2/20G) computer via a CED 502 Interface. Refreshing of the display and sampling of digital and analogue (Experiment 11a) inputs were controlled by a software system developed by SHEPHERD

(1984). Observers viewed the screen from a distance of 115 cm with their heads resting on a chin rest. The laboratory was dimly illuminated by an incandescent lamp placed behind the screen and shielded from direct view (to eliminate reflections from the observer). The luminance of the stimuli was 0.1 ftL and the luminance of the background of the screen was 0.01 ftL.

Display and Timing: Diagram 5.1. illustrates the sequence of frames presented on a given trial. Frame I displayed a central fixation dot and four boxes in the periphery in one of which the target stimulus, a T in any of the four orthogonal orientations, could appear later (frame V). After 500 msec, the central fixation dot was replaced by a central box containing one of the four Ts (frame II); this T, displayed for 1500 msec, indicated the target stimulus for a given trial. Then, 1000 msec after the reappearence of the fixation dot (frame III), an arrow cue appeared in the display centre for 350 msec indicating the most likely target position(s) (frame IV). There were also neutral ("baseline") trials on which a cross (instead of the arrow) was displayed in the centre; this cross indicated that the target was equally likely to appear at any of the four locations. 750 msec after the onset of the cue, the target display appeared for a limited exposure duration (frame V). On signal trials, the target stimulus occurred in one of the four boxes and distractor crosses of the same size and luminance appeared in the remaining three boxes. On noise trials, distractor crosses appeared in all four boxes. The eccentricity of the target stimulus was 4.4 deg. and the size of its constituent lines was 0.25 deg. In frame VI the exposure of the target and distractors was terminated by contour masks (squares of 0.25-deg. line size).

Diagram 5.1.: Sequence of frames (I - VI) presented on a given trial

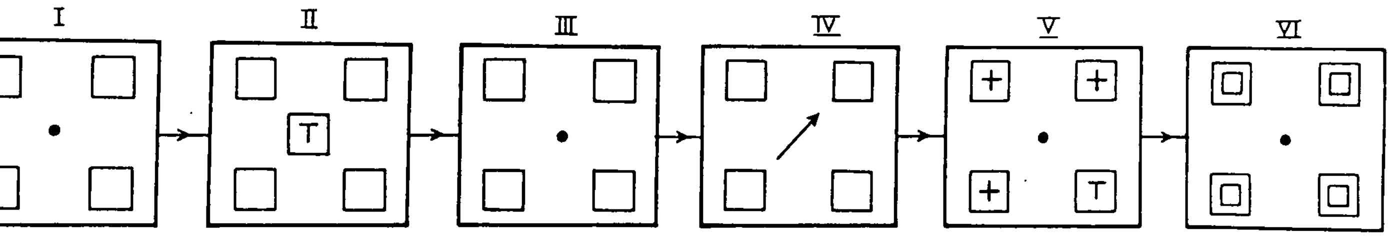
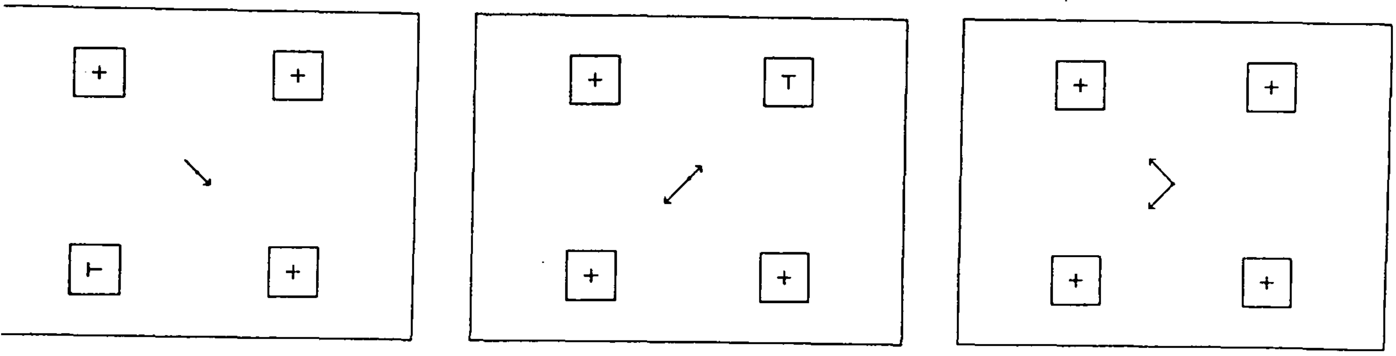


Diagram 5.2. illustrates the three cueing conditions used in Experiment 11. In the first condition (left), the cue in frame IV was a single arrow which might or might not correctly prime the cued position (single cue). However, on this trial the target (in frame V) did not appear at the most likely position indicated by the arrow (valid 1), but rather at one of the uncued locations

Diagram 5.2.: Cueing conditions: Single cue (left), double cue 1 (middle) and double cue 2 (right)



(invalid). In the second condition (middle), the cue in frame IV was a double arrow with two arms of unequal length (double cue 1). The long arm indicated the most likely position (valid 1) and the short arm indicated the second most likely location (valid 2). Note that the central fixation dot remained in the display while the cues were presented in order to allow the long and short arrow arms to be discriminated when they formed a straight line. In the third condition (right), the cue was a double arrow consisting of two arms of equal length (double cue 2). This two arms indicated that the target might appear with equal probability at either of the two cued locations. Over the whole experiment, all four locations were indicated with equal frequencies and under the double arrow conditions all configurations of the two arms occurred equally often.

Task: After the target display terminated (frame VI), the observers made three responses, in succession, on a hand-held keypad: First, a yes-no response indicating whether or not a target had been detected. Second, a rating of the certainty of the yes-no response; in the case of a positive response according to the categories "very certain", "certain" and "uncertain" and in the case of a negative response according to the categories "uncertain" and "certain". Third, a position response indicating in which of the four boxes a target had been detected; this response was also required in the case of a "no-target" response.

Design: Table 5.1. shows the frequencies of signal and noise trials and the frequencies with which, on signal trials, the target appeared at the cued and uncued locations. Table 5.1. shows that the frequency of the most likely location (valid 1) was the same for all three cueing conditions. The introduction of the second cued location (valid 2) in the double arrow conditions reduced the frequencies of target occurrence at the two remaining uncued locations (invalid). Note that signal and noise trials were presented in the ratio of 2:1. Adding the cell entries over the cueing and cue validity conditions, Experiment 11 consisted of 7200 trials in all. Each observer was presented with these 7200 trials, in 6 experimental sessions of 1200 trials. Each session was subdivided into three blocks of 400 trials in which one of the three cueing conditions was presented. While the design was thus blocked with regard to the cueing conditions, valid, neutral and invalid trials were presented in randomized order. (The positions indicated by the arrow cues were also randomized across trials.) The order of presentation of single cue, double cue 1 and double cue 2 blocks within a given session was counterbalanced across observers and sessions.

Table 5.1.: Summary of the frequencies of signal trials (valid I, valid II and invalid, neutral) and of noise trials for each cueing condition (number of invalid locations in brackets)

Condition	Single	Double I	Double II
Valid 1	576	576	576
Valid 2	---	384	576
Invalid	256(3)	192(2)	96(2)
Noise	672	672	672
Neutral	256	256	256
Noise	128	128	128
Total	2400	2400	2400

Table 5.2.: 0.75-target exposure times in msec for each observer and session

Session	1	2	3	4	5	6	Mean
I.P.	38	34	35	31	29	27	32.3
N.A.	41	34	30	32	30	27	32.3
H.M.	34	30	27	25	26	24	27.7
Mean	37.7	32.7	30.7	29.3	28.3	26.0	30.8

Determination of the Threshold Exposure Durations: At the beginning of each session the threshold exposure times for target detection were determined individually for each subject according to a modified PEST adaptive staircase procedure (FINDLAY, 1978) which aimed at a detection sensitivity of P(A) = 0.75 on neutral trials. Ratings of the certainty of the yes-no response and position responses were also required on threshold trials to give the observers practice at the task, but only detection hits and false alarms were used to home in on the intended threshold level. Preexperimental estimations had shown that the 0.75-thresholds corresponded to a ratio between the average detection hit and false alarm rates of about 2:1. Table 5.2. presents, individually for each subject and session, the 0.75-threshold exposure durations estimated in this way. As can be seen from table 5.2., the times varied between 20 and 40 msec and showed a reduction as the number of sessions increased.

Instruction: In two practice sessions, the observers were familiarized with the task. After an initial outline of SDT and the instruction to maximise the number of hits and minimise the number of false alarms, repeated threshold determinations were carried out until the estimated times stabilised. After each threshold determination, the observers were shown their hit and false alarm rates for each rating category; they were then given specific instructions how to improve performance. In the next stage, the observers were introduced to the three cueing conditions. They were told the frequencies of target occurrence at individual locations and instructed to divide their attention accordingly. Again, they practised the task over several blocks of trials. The observers experienced no difficulty in making the position response even in the case of a "no-target" response. They were instructed to avoid responding to a given location if they were certain that it did not contain the target since this would improve their overall performance. The observers were told to fixate on the central dot throughout the display cycle.

SDT-Analysis: The data were subjected to a two-stage SDT analysis: In the first stage, localisation responses were ignored, i.e. detection responses were accepted as hits if the yes-no responses were correct. In this stage, false alarm rates were the same (i.e., pooled) for valid and invalid trials, but different for the neutral condition (since they were estimated from trials with neutral warning signals).

In the second stage, detection responses were accepted as a hit only if both the detection and the localisation responses were correct. In this stage, it was possible to assign false alarms to individual display locations since the localisation responses specified whether a target stimulus had been - erroneously - detected at a cued or at an uncued position. Restated, this analysis stage took into account the cue validity condition (valid 1, valid 2, invalid) under which a particular noise trial would have fallen if it had been a signal trial (as indicated by the positive detection response). Accordingly, false alarm rates differ between valid and invalid trials. For neutral trials, however, this conditional classification of false alarms was not possible. Thus, false alarm rates are the same for the two analysis stages; note, however, that hit rates can vary, since correct detections may not always be associated with correct localisations.

This hierarchical STD analysis is similar to BASHINSKI and BACHARACH (1980). Note, however, that false alarm rates in the joint detection plus localisation analysis were calculated according to a solution which avoids the problem in the procedure used by BASHINSKI and BACHARACH (see 5.5. Appendix A for further details.)

The sensitivity parameter P(A), i.e. the area under the ROC curve, was the principal performance measure (since it has the advantage of being relatively independent of the shapes and variances of the underlying distributions of noise and signal plus noise; see GREEN and SWETS, 1966; SIMPSON and FITTER, 1973). In both stages of analysis, computer-determined estimates were obtained for the P(A) parameter and its variance and for the likelihood ratio beta at the yes-no cutoff point. These estimates were based on the maximum-likelihood (ML) approach developed by DORFMAN and ALF (1969) and calculated for each observer under each experimental condition. The P(A) values obtained for the cue validity conditions under the three cueing conditions were tested for statistical significance (one-tailed within-subject G-tests; GOUREVITCH and GALANTER, 1967).

Eye Movement Monitoring: Since eye movements were not monitored in Experiment 11, effects of attention on sensitivity might be confounded with effects of retinal eccentricity (i.e., saccades to cued locations could be executed because of the 700-msec delay between cue and target onset). To rule out this possibility, Experiment 11 was repeated for one observer, H.M., involving the monitoring of his ocular fixation (Experiment 1a). Design and procedure of Experiment 11a were the same as in Experiment 11, except that the numbers of trials under each cueing and cue validity condition were only half the values reported in table 5.1. (3 four-hour sessions of each 3 blocks of 400 trials). Target exposure time was 45 msec (average of the three sessions). Room lighting was normal (fluorescent overhead light). Head movements were eliminated by providing a dental bite bar. Eye movements, i.e. the horizontal movement components, were monitored by a photoelectric method (ACS eye movement system EM 130, developed by R. ABADI at the University of Manchester Institute of Science and Technology). Output from the eye movement recorder was sampled every 10 msec, starting at cue onset and ending 150 msec after target onset. The eye movement record for each trial was analysed at the end of the trial. If a pre- or post-stimulus saccade was detected, the trial was rejected and rerun later in the block. Saccade detection was based on comparing the differences between successive samples with a velocity criterion (two successive differences, both in the same direction, exceeding approximately 30 deg./sec). To detect slow fixation drifts on accepted trials, mean (and variance) differences between the first 25 samples after cue onset and the last 25 samples before target offset of each eye movement record were analysed at the end of the experiment (see table 5.10. in section 5.6. Appendix B).

5.2.2. Results

Table 5.3. presents the P(A) values for the detection data (D) and the joint detection plus localisation data (D+L), individually for each observer and separately for the three cueing conditions and for the valid, neutral and invalid trials. Note that the values for H.M. in Experiment 11a (eye movement monitoring) are indicated by an asterisk; H.M.'s values for Experiments 1 and 1a were averaged before calculating the group means. Data were pooled over the neutral trials under the three cueing conditions since an initial analysis did not reveal any significant differences depending upon which cue (single or double) was presented during a given block of trials.

Table 5.3.: detection and joint detection plus localisation sensitivity: Summary of P(A) values for each observer under each experimental condition (V = valid, N = neutral, I = invalid; * - eye movements monitored)

	Detection				Detection + Localisation			
Os	V 1	V 2	N	I	V 1	V 2	N	I
Single Cue								
I.P.	.909	----	.784	.779	.948	----	.900	.897
N.A.	.923	----	.788	.783	.946	----	.913	.912
H.M.	.951	----	.780	.784	.970	----	.909	.891
H.M.*	.892	----	.780	.770	.936	----	.897	.902
Mean	.918	----	.784	.780	.949	----	.905	.902
Double Cue 1								
I.P.	.894	.865	.784	.777	.926	.918	.900	.902
N.A.	.908	.894	.788	.783	.932	.935	.913	.891
H.M.	.940	.911	.780	.770	.953	.927	.909	.901
H.M.*	.882	.864	.780	.762	.917	.900	.897	.882
Mean	.904	.882	.784	.775	.931	.922	.905	.895
Double Cue 2								
I.P.	.868	.871	.784	.775	.920	.920	.900	.893
N.A.	.904	.910	.788	.768	.924	.935	.913	.875
H.M.	.922	.922	.780	.766	.923	.934	.909	.905
H.M.*	.880	.870	.780	.755	.914	.902	.897	.871
Mean	.891	.892	.784	.768	.921	.924	.905	.885

Note that the P(A) values for observer H.M. show no substantial differences between conditions with (H.M.*) and without (H.M.) eye movement monitoring. This indicates that eye movements cannot account for the pattern of sensitivity effects found in Experiment 11. Further evidence for this is provided by the absence of P(A) differences between "adjacent" and "opposite" cues (see 5.6. Appendix B, in particular tables 5.12. and 5.13., for details). That eye movement would produce such differences is shown in a further experiment (Experiment 11b) reported in section 5.6. Appendix B. In this Experiment, varying the retinal eccentricity of cued and uncued positions (single cue) resulted in systematic sensitivity differences between uncued locations adjacent and opposite to the cued position.

P(A) values are generally higher and differences in P(A) between cue validity conditions are generally smaller for the joint detection plus localisation analysis than for the analysis of the detection responses on their own. Note that all comparisons reported below are based on G-tests between D+L data pooled over observers.

In the single cue condition, P(A) is higher for the most likely position (V 1) than for the neutral condition and the uncued locations ($p < 0.001$ for all comparisons). In the double cue 1 condition, P(A) tends to be higher for the more likely one of the two cued positions; but note the exception of N.A. (D+L data). And P(A) not only shows a reliable difference between the most likely position and the neutral and invalid trials (V 1-N: $p < 0.005$; V 1-I: $p < 0.001$), but also between the second most likely position and the latter conditions (V 2-N: $0.10 > p > 0.05$; V 2-I: $p < 0.025$). In the double cue 2 condition, there are no differences in P(A) between the two indicated positions (V 1 and V 2) which are equally likely. Of course, from the point of view of the observer, the two locations (as defined in the computer program) are not distinguishable. Further, P(A) is significantly higher for these positions than for the neutral condition and the two uncued locations (V 1-N:

$0.10 > p > 0.05$; V 1-I: $p < 0.05$; V 1-N: $p < 0.05$; V 1-I: $p < 0.025$). There are no reliable differences between the neutral and invalid trials under any of the cueing conditions. Note, however, that for all observers P(A) appears lower for invalid than for neutral trials, except for H.M.* in the single and I.P. in the double cue 1 condition (D+L data).

In the single cue condition, P(A) for the most likely position (V 1) is higher than P(A) for the most and second most likely locations in the double cue 1 and 2 conditions ($p < 0.01$ and beyond for all comparisons between the single cue and the double cue conditions in D+L data). P(A) does not differ among the invalid trials in the single cue, the double cue 1 and the double cue 2 conditions.

Table 5.4.: Detection and joint detection plus localisation hit (HR) and false alarm (FAR) rates: Summary of mean HR and mean FAR under each experimental condition (V = valid, N = neutral, I = invalid)

	Detection				Detection + Localisation			
	V 1	V 2	N	I	V 1	V 2	N	I
				Single Cue				
HR	.918	----	.769	.768	.877	----	.699	.663
FAR	.361	----	.379	.361	.108	----	.095	.084
				Double Cue 1				
HR	.893	.872	.769	.753	.847	.802	.699	.640
FAR	.354	.354	.379	.354	.107	.093	.095	.078
				Double Cue 2				
HR	.887	.886	.769	.732	.833	.848	.699	.604
FAR	.351	.351	.379	.351	.120	.128	.095	.052

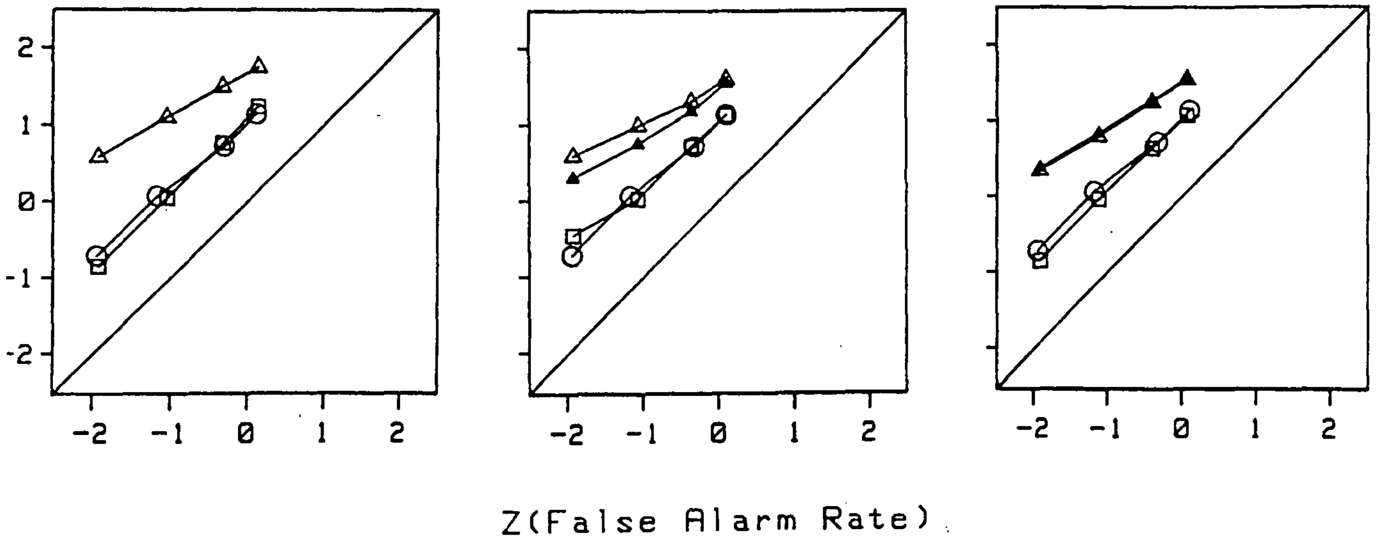
In the detection data, the differences in P(A) between valid and invalid trials occur because hit rates are higher for cued than for uncued locations (see table 5.4. for the mean hit and false alarm rates). Since noise trials were pooled across cue validity conditions (valid and invalid) within a given cueing condition (single or double), there are no differences between false alarm rates. Such differences could occur between cueing conditions. However, total false alarm rates do not vary much (the average false alarm rates are 0.361, 0.354, 0.351 and 0.379 for the single cue, the double cue 1, the double cue 2 and the neutral condition, respectively).

For the joint detection plus localisation responses, hit rates are lower than for the detection responses since on some trials correct detections were associated with localisation failures. Reductions in hit rates are more than twice as marked for uncued than for cued locations. False alarm rates are higher for cued than for uncued locations. That is, on noise trials, cued locations were about 1.5 times more likely to be accepted as the target position than any particular one of the uncued locations.

Thus, the general increase in P(A) from the detection to the joint detection plus localisation analysis is due to the partitioning of the total (i.e., detection) false alarm rates into cue validity conditions (see 5.5. Appendix A). But this increase is less marked for valid than for invalid trials because more false alarms are assigned to cued than to any particular one of the uncued locations. The result is a decrease in costs plus benefits in P(A) from the detection to the joint detection plus localisation analysis.

Figure 5.1. presents the normal-normal detection ROC curves, based on the certainty ratings, for each experimental condition; the values plotted are the means of the three subjects (excluding H.M.*). Detection plus localisation ROC curves are not presented because P(A) differences between cue validity conditions are rather small (i.e., ROC curves are not clearly discernible).

Figure 5.1.: Detection ROC curves for the single cue (left), double cue 1 (middle) and double cue 2 (right) conditions and for the valid 1 (open triangles), valid 2 (filled triangles), neutral (open circles) and invalid trials (open squares)



As can be seen from figure 5.1., the ROC curves show a linear relationship between the z-transformed rates of hits and of false alarms; this is also true for the detection plus localisation ROC curves (i.e., none of the chi**2s based on the final ML slope estimates is significant). The linear ROC curves suggest that the underlying distributions of noise and signal plus noise are Gaussian. The slopes of the ROC curves vary systematically: For valid trials, the average slopes are 0.57 and 0.60 for the detection and the joint detection plus localisation ROC curves, respectively; for neutral trials they are 0.87 and 1.09; and for invalid trials 0.98 and 1.01. That is, while for invalid and neutral trials the variances of the noise and signal plus noise distributions are approximately equal, for valid trials the variance of the signal plus noise distribution is greater than that of the noise distribution. The slope differences between the valid trials on the one hand and the neutral and invalid trials on the other are generally significant ($p < 0.001$, except for $p < 0.025$ for the comparisons between V 1-I and V 2-I in the double cue 2 condition; G-tests based on the ML estimates for the slopes and their variances for D+L pooled data).

In order to test whether the instruction to maximize hits and minimize false alarms was successful, the likelihood ratios (betas) at the yes-no cutoff were estimated (ML estimates) for each subject under each experimental condition. The individual beta values are presented in table 5.5., separately for the detection and the joint detection plus localisation data. The values for H.M. in Experiment 11a (eye movement monitoring) are indicated by an asterisk; H.M.'s values for Experiments 1 and 1a were averaged before calculating the group means. These beta estimates take into account the fact of the unequal variances of the noise and signal plus noise distributions.

Table 5.5.: Detection and joint detection plus localisation bias: Summary of the likelihood ratios (beta) at the yes-no cutoff for each observer under each experimental condition (V = valid, N = neutral, I = invalid; * - eye movements monitored)

	Detection				Detection + Localisation			
Os	V 1	V 2	N	I	V 1	V 2	N	I
				Single Cue				
I.P.	.233	----	.614	.722	.629	----	1.722	2.205
N.A.	.211	----	.735	.795	.581	----	2.467	2.777
H.M.	.145	----	.746	.860	.515	----	2.690	2.538
H.M.*	.384	----	.770	.770	1.201	----	2.460	2.662
Mean	.236	----	.702	.777	.689	----	2.255	2.527
				Double Cue 1				
I.P.	.252	.391	.614	.667	.579	1.114	1.722	2.329
N.A.	.223	.298	.735	.749	.666	.998	2.467	2.147
H.M.	.156	.234	.746	.976	.425	.681	2.690	3.037
H.M.*	.455	.575	.770	.974	1.101	1.447	2.460	3.283
Mean	.260	.365	.702	.797	.669	1.059	2.255	2.545
				Double Cue 2				
I.P.	.355	.339	.614	.725	.910	.812	1.722	2.729
N.A.	.304	.288	.735	.850	.737	.771	2.467	2.542
H.M.	.236	.221	.746	.962	.559	.547	2.690	3.661
H.M.*	.485	.470	.770	.946	.938	.941	2.460	3.421
Mean	.340	.324	.702	.843	.799	.776	2.255	2.937

The beta values are higher for the joint detection plus localisation responses than for the detection responses on their own. Further, the beta values vary as a function of the probability with which the target occurs at a particular location: They are lower for valid than for neutral and invalid trials, for all observers. In other words, the lower the probability with which a target occurs at a particular location, the more evidence is required for a positive decision, and vice versa. This also applies to the comparison between the most likely and the second most likely location in the double cue 1 condition.

5.2.3. Discussion

In general, the results of Experiment 11 agree with those of BASHINSKI and BACHARACH (1980). There are sensitivity gains for cued position(s); there are only slight sensitivity losses for uncued locations relative to the neutral baseline (however, even if the position response is taken into account); slopes of ROC curves for a particular location decrease to follow the assigned probability of target occurrence.

The asymmetric relationship between the sensitivity gains for cued position(s) and the losses for uncued locations, relative to the neutral condition, may occur because the neutral trials underestimate baseline performance. Since neutral trials were far less frequent than cued trials (the ratio is 1/5.25), they were comparatively unexpected. JONIDES (1981) found reduced efficiency of unexpected symbolic cues; this might as well apply to the neutral warning signal presented in

Experiment 11 (see also Experiment 5 in Chapter 3). Comparisons between cued (valid and invalid) and neutral trials should therefore be interpreted with caution (see JONIDES and MACK, 1984).

The finding that the slopes of the ROC curves are close to 1.0 for uncued locations and in the neutral condition, but significantly lower for cued positions is expected if one assumes that the uncued, the neutral and the cued conditions represent increasing levels of signal strength. That is, there is a positive relationship between the frequency of target occurrence at a particular location and the confidence associated with positive decisions (signal trials) for this location. Note, however, that this relationship involves a trade-off in terms of slightly higher false alarm rates for the increased certainty associated with the more likely locations.

The most important result of Experiment 11 (for which the "actual" neutral baseline appears irrelevant) is that there are substantial sensitivity gains for a second cued position, in comparison with the uncued locations in the single cue condition. This finding suggests that for letter detection and for trial-by-trial cueing of the second most likely position, attention can be more effectively divided between two indicated locations than has been proposed by POSNER et al. (1980). However, although division of attention appears posssible, the available processing capacity cannot be increased. This can be concluded from the finding that P(A) for the position cued to be most likely and, less reliably, for the uncued locations decreases from the single to the double cue conditions. That is, the total processing capacity is fixed.

On the basis of the estimates of the time it takes to shift attention from one location to another (e.g., SPERLING and REEVES, 1980; TSAL, 1983a; TSAL estimates the velocity of attention shifts in response to peripheral cues to be about 1 deg. per 8 msec), it seems unlikely that the division of attention between the cued locations in Experiment 11 is based on "attention switching". An "attention sharing" model which assumes that a fraction of the total processing capacity is allocated simultaneously to each of the input sources appears more appropriate (e.g., the "sample size" model of SHAW, 1980, 1984, and SHAW et al., 1983; see also GREEN and LUCE, 1973, and LUCE, 1977). (Note that this argument depends on effective control of target exposure times, i.e. effective display termination by the masking contours. Experiment 11c, reported in section 5.7. Appendix C, shows that sensitivity gains for a second cued position cannot be explained in terms of inadequate masking.)

Suppose, for instance, that a fixed number of samples is available to be divided among the input locations and that more samples are allocated to the more likely and less to the less likely locations. The greater number of samples allocated to cued positions reduces the variability associated with the sample mean and thus improves discriminability between target and distractor, and vice versa for uncued locations.

One should expect that the higher variability for uncued locations produces an increase in the probability that nontargets presented at them will exceed the criterion, whereas this is less likely for nontargets presented at cued positions. That is, on noise trials, a target should be more likely to be - erroneously - detected and localised at one of the uncued locations. However, the observed false alarm rates are slightly higher, rather than lower, for cued locations.

This suggests that observers give preferential weight to evidence from cued locations, in accordance with the higher a-priori signal probabilities assigned to them. Suppose that on a noise trial, both the stimulus at a cued and that at an uncued position produce a target impression, but that the evidence is stronger for the uncued location. Thus, if the observer decided on the basis of the strength of "sensory" impressions, he would allocate a false alarm to the uncued position. However, if he assigns preferential weight to the evidence from the likely target location, he would - erroneously - decide in favour of the cued position.

Thus, the slightly higher false alarm rates for cued than for uncued locations can be taken as indicating some bias towards accepting information available from cued positions as target information. Thus, the summing of false alarm rates over cue validity conditions in the analysis of the detection responses on their own exaggerates the advantage in sensitivity for valid over invalid trials since it "reduces" the false alarm rates for cued positions and "increases" them for uncued locations. Note that any bias towards accepting information from cued positions as target evidence would inflate not only false alarm rates but also hit rates for cued positions, and vice versa for uncued locations. However, in the joint detection plus localisation analysis, inflated hit rates for cued locations are counterbalanced by higher false rates, and vice versa for uncued locations. That is, joint detection plus localisation P(A) values give a less "biased" estimate of costs plus benefits in sensitivity than detection P(A) values.

The suggestion that the observer assigns weights to display locations according to their probabilistic priorities is consistent with a class of models which can be referred to as "weighted integration" (KINCHLA, 1977) or "first order integration" (SHAW, 1982) models. The "order 1 code" X for a given location is a "sensory" representation of the stimulus which is influenced by the type of stimulus presented (target or nontarget), its energy etc. and, possibly, by the amount of attention allocated to this source. (Note that in SHAW's sample size model, X is the strength of a continuous-state random variable and that the strength values are derived independently for each input source.)

For the localisation decision, the observer might then weight the Xs according to the a-priori probabilities assigned to their locations and choose that position for which the weighted X is the maximum (SHAW et al., 1983). For the detection response, however, the (weighted) Xs might be be summed and compared to a criterion (SHAW, 1982). Thus, in the integration process, the strength value associated with the actual target position may play a decisive role in determining the detection response. Target localisation, however, may fail if the strength values associated with one or more of the nontarget locations exceed the value of the target position, because of sample strength variability and/or differential weighting.

The finding of a more positive response bias for cued positions and a more negative bias for uncued locations and the neutral condition does not agree with BASHINSKI and BACHARACH (1980) who failed to find any bias effects (but see 5.5. Appendix A). This result shows, in accordance with SHAW (1984; SHAW et al., 1983), that observers can and do adopt independent criteria at different locations. Further, this finding is consistent with the weighted integration model; that is, assigning more weight to strength values for cued and less weight to strength values for uncued locations is equivalent to lowering and, respectively, raising the decision criteria for cued and for uncued positions.

It seems reasonable to suggest that the decision criteria (i.e., the "weights") are largely set "a priori", before display onset, on the basis of the probabilistic information provided by the spatial cue; that is, more liberal for more likely and more conservative for less likely locations. Note, for instance, that as the a-priori probability assigned to uncued locations decreases from the single through the double cue 1 to the double cue 2 condition, beta tends to increase (see table 5.5.). However, there might also be some "a-posteriori" adjustment of decision criteria on the basis of the perceived competition among independent input sources for the detection and localisation response. Suppose, for example, that the strength values of two or more equally likely positions favour a positive response. Thus, in order to decide optimally among these locations, the decision criterion might be raised. Note, for instance, that beta for cued locations tends to be higher in the double cue 2 than in the single cue condition, although the a-priori probabilities are equal (see table 5.5.).

5.3. Experiment 12

Experiment 12 was designed to test this by presenting three display conditions with varying degrees of target-distractor similarity (i.e., target-distractor discriminability). It seems a reasonable assumption that the degree of response competition among locations being in a detect "state" depends on the similarity between target and distractor. Thus, increasing the degree of target-distractor similarity should lead to a raise of criteria for optimal decision making.

On this hypothesis, the fact that BASHINSKI and BACHARACH (1980) did not find any bias effects (not even in the detection data on their own) may be due to their display condition. In their study, the target was the only stimulus presented and the "nontarget" was a "blank" location. That is, target-nontarget discriminability was high (see DUNCAN, 1981) and the task required detection of a single luminance increment. Thus, the first display condition in Experiment 12, termed single display, was the same as that presented by BASHINSKI and BACHARACH.

The second display condition, termed multiple display 1, was the same as in Experiment 11. In order to detect the target T, it had to be discriminated from distractor crosses of the same size and luminance appearing simultaneously with it. The third condition, termed multiple display 2, required the discrimination of the target T from distractor Ts in different, i.e. nontarget orientations. The order of presentation of the three display conditions was randomized within blocks of trials so that the "a priori" decision criteria would be the same.

5.3.1. Method

Display: The only cueing condition presented in Experiment 2 was double cue 1 (double arrow with unequal arm lengths). On a signal trial in the single display, the target T appeared in one of the peripheral boxes and the other locations remained blank; on noise trials, all four boxes remained empty. On signal trials in the multiple display 1, the target T appeared in one of the boxes and distractor crosses of the same size and luminance at the remaining locations; on noise trials, all four boxes contained distractor crosses. On signal trials in the multiple display 2, the target T appeared in one of the four peripheral boxes and three Ts in nontarget orientation at the other locations; on noise trials, four nontarget Ts appeared in the periphery (one of the three possible nontarget Ts was randomly chosen and presented twice, i.e. at two locations). The single display and the multiple display 1 are consistent mapping tasks in terms of SCHNEIDER and SHIFFRIN (1977; SHIFFRIN and SCHNEIDER, 1977). The multiple display 2, however, is a varied mapping task since target and distractors Ts changed roles from trial to trial. Unlike Experiment 11, the arrow cue in the centre was displayed for 500 msec and the onset of the target display immediately followed the offset of the cue.

Design and Procedure: The probabilities of signal and noise trials and the probabilities with which, on signal trials, the target occurred at the cued (valid 1 and valid 2) and uncued locations (invalid) were the same as in the double cue 1 condition of Experiment 11. The three display conditions were presented in randomized order (i.e., randomized within the same blocks of trials). The threshold exposure times were determined on threshold trials presenting the multiple display 1 neutral condition. The threshold exposure times introduced in the main experiment were the same for the three display conditions.

Observers: N.A. and H.M. participated in this experiment (I.P. was not available). Payment was 25 Pounds for completion of the experiment. N.A. was presented with 1200 trials under each display condition (in three sessions), i.e. the frequencies listed under the double cue 1 condition in table 5.1. are halved for a given display condition. H.M. completed 6 sessions, i.e. 2400 trials under each display condition. The average threshold exposure duration was 26.33 msec for N.A. and 21.67 msec for H.M.

5.3.2. Results

The data from Experiment 12 were analysed in the same hierarchical fashion as in Experiment 11. Table 5.6. presents the P(A) values for the detection data (D) and the joint detection plus localisation data (D+L), individually for each subject and separately for the three display conditions and for the valid, neutral and invalid trials.

Table 5.6.: Detection and joint detection plus localisation sensitivity: Summary of P(A) values for each observer under each experimental condition (V = valid, N = neutral, I = invalid)

	Detection				Detection + Localisation			
Os	V 1	V 2	N	I	V 1	V 2	N	I
				Single Display				
N.A.	.883	.876	.845	.844	.930	.918	.928	.928
H.M.	.892	.892	.847	.848	.926	.939	.922	.924
Mean	.887	.884	.846	.846	.928	.929	.925	.926
				Multiple Display 1				
N.A.	.846	.836	.775	.776	.931	.895	.890	.881
H.M.	.861	.840	.782	.766	.921	.912	.900	.891
Mean	.854	.838	.779	.771	.926	.904	.895	.886
				Multiple Display 2				
N.A.	.856	.810	.746	.728	.904	.896	.851	.825
H.M.	.844	.816	.759	.733	.903	.875	.865	.828
Mean	.850	.813	.753	.730	.904	.889	.858	.827

As in the previous experiment, P(A) values are generally higher and differences in P(A) between cue validity conditions are generally smaller for the joint detection plus localisation data than for the detection data on their own. Note that all comparisons reported below are based on the joint detection plus localisation (G-tests between D+L data pooled over observers).

In the single display condition, there are no differences in P(A) between cue validity conditions (D+L data). In the multiple display 1 condition, P(A) is slightly higher for the more likely one of the cued locations (i.e., for V 1 than for V 2) and higher for cued positions than for uncued locations and for the neutral condition. However, only the difference between the most likely position and the uncued locations is reliable (V 1-I: $p < 0.05$). In the multiple display 2 condition, the pattern is very similar. However, the difference between the most likely position and the uncued locations and that between the second most likely position and the uncued locations are more pronounced (V 1-I: $p < 0.01$; V 2-I: $p < 0.05$).

In the single display condition, P(A) (for all cue validity conditions) is significantly higher than for uncued locations in the multiple display 1 condition ($p < 0.05$ and beyond) and for the second most likely position, the uncued locations and the neutral condition in the multiple display 2 condition ($p < 0.05$ and beyond). Further, P(A) for uncued locations is higher in the multiple display 1 than in the multiple display 2 condition ($p < 0.05$). That is, in the multiple display 2 condition, there is a marked loss in sensitivity for uncued locations relative to both the single and the multiple display 1 condition. And the magnitude of P(A) differences between cued and uncued locations tends to increase with decreasing target-distractor discriminability (i.e., from single display through multiple display 1 to multiple display 2).

Table 5.7.: Detection and joint detection plus localisation hit (HR) and false alarm (FAR) rates: Summary of mean HR and mean FAR under each experimental condition (V = valid, N = neutral, I = invalid)

	Detection				Detection + Localisation			
	V 1	V 2	N	I	V 1	V 2	N	I
Single Display								
HR	.832	.827	.770	.764	.805	.787	.758	.733
FAR	.231	.231	.258	.231	.072	.064	.065	.048
Multiple Display 1								
HR	.816	.802	.742	.671	.759	.721	.656	.590
FAR	.296	.296	.328	.296	.077	.089	.082	.066
Multiple Display 2								
HR	.810	.760	.707	.603	.736	.655	.594	.474
FAR	.292	.292	.375	.292	.071	.085	.094	.069

In the detection data, the observed P(A) differences between valid and invalid trials within a given display condition occur because hit rates are higher for cued than for uncued locations; there are no false alarm differences between valid and invalid trials since noise trials were pooled across cue validity conditions (see table 5.7. for the mean hit and false alarm rates). Among display conditions, however, false alarm rates are lower for single than for multiple displays. For the most likely location, hit rates hardly differ among display conditions. For the remaining cue validity conditions, however, hit rates decline with frequency of target occurrence and with target-distractor similarity.

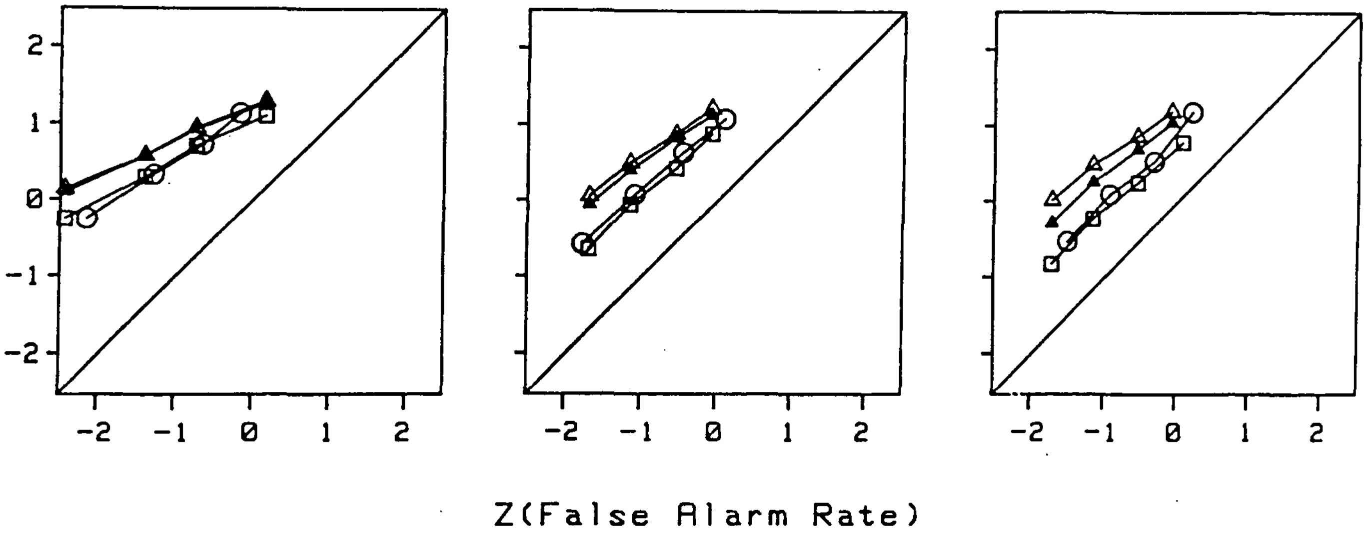
In the joint detection plus localisation data, hit rates are reduced relative to the detection data. The losses, due to correct detections associated with localisation failures, appear dependent on both cue validity and display condition: They increase from the most likely through the second most likely to the uncued locations and from the single display through the multiple display 1 to the multiple display 2 condition. False alarm rates are slightly higher for valid than for invalid trials; that is, on noise trials, cued positions are about 1.25 times more likely to receive erroneous responses than any particular one of the uncued locations.

Thus, partitioning of the total (i.e., detection) false alarm rates into cue validity conditions (see 5.5. Appendix A) produces a general increase in P(A) from the detection to the joint detection plus localisation analysis. This increase is more marked for invalid than for valid trials because less false alarms are assigned to uncued locations. As a result, costs plus benefits in sensitivity decrease from the detection to the joint detection plus localisation analysis. Note that for the single display conditon, sensitivity differences between cue validity conditions in the joint detection plus localisation analysis.

Figure 5.2. presents the normal-normal detection ROC curves, based on the certainty ratings, for each experimental condition; the values plotted are the means of the two observers. Again, detection plus localisation ROC curves are not presented because P(A) differences between cue validity conditions are too small for ROC

curves to be clearly discernible.

Figure 5.2.: Detection ROC curves for the single display (left), multiple display 1 (middle) and multiple display 2 (right) conditions and for the valid 1 (open triangles), valid 2 (filled triangles), neutral (open circles) and invalid trials (open squares)



The ROC curves show a linear relationship between the z-transformed hit and false alarm rates (i.e., none of the chi**2s based on the final ML slope estimates is significant). Slopes of the ROC curves vary systematically: For valid trials, the average slopes are about 0.67 and 0.70 for the detection and for the joint detection plus localisation ROC curves, respectively; for neutral trials they are 0.82 and 1.02 and for invalid trials 0.84 and 0.85. Further, slopes appear dependent on display condition: They are lower for single than for multiple displays (0.61 as compared to 0.81 in the D+L data). In the single display condition, there are no significant slope differences between cue validity conditions. In the multiple display conditions, slope differences between valid 1 and invalid trials are reliable (D+L: $p < 0.05$).

Table 5.8.: Detection and joint detection plus localisation bias: Summary of the likelihood ratios (beta) at the yes-no cutoff for each observer under each experimental condition (V = valid, N = neutral, I = invalid)

	Detection				Detection + Localisation			
Os	V 1	V 2	N	I	V 1	V 2	N	I
				Single Display				
N.A.	.414	.416	.657	.555	1.185	1.219	1.949	2.132
H.M.	.459	.453	.695	.662	1.073	1.661	1.744	2.373
Mean	.436	.434	.676	.608	1.129	1.440	1.847	2.253
				Multiple Display 1				
N.A.	.541	.589	.817	1.005	1.716	1.514	2.793	2.875
H.M.	.547	.596	.736	.934	1.643	1.855	2.143	3.087
Mean	.544	.593	.777	.969	1.680	1.685	2.468	2.981
				Multiple Display 2				
N.A.	.537	.741	.868	1.096	1.332	2.207	2.175	2.591
H.M.	.571	.699	.932	1.082	1.571	1.986	2.293	2.760
Mean	.554	.720	.900	1.089	1.452	2.097	2.234	2.680

The ML estimates of the likelihood ratios (betas) for the yes-no cutoff are shown in table 5.8., individually for each observer and separately for the detection and the joint detection plus localisation data. The beta values are higher for the joint detection plus localisation responses than for the detection responses on their own. Further, the beta values (in particular the D+L values) are lower for valid than for neutral and invalid trials, both in the multiple and in the single display conditions. The beta values are consistently (i.e., across observers and cue validity conditions) higher for multiple than for single displays, but do not differ much between the multiple display 1 and 2 conditions (D+L data).

5.3.3. Discussion

With regard to the sensitivity parameter P(A), the results of Experiment 12 for the multiple display 1 and 2 conditions replicate the findings for the double cue 1 condition in Experiment 11. Both multiple display conditions show gains and losses associated with the preferential allocation of attention to the cued locations. For the cued positions, there are no reliable differences in P(A) between the multiple display conditions; for the uncued locations, P(A) is reduced in the multiple display 2 in comparison with the multiple display 1 condition.

In the single display condition, P(A) is generally higher than in the multiple display conditions. However, there are no differences between cue validity conditions (D+L data); that is, there are no costs plus benefits associated with the preferential allocation of attention to the cued positions.

The fact that there are gains and losses in sensitivity for cued and uncued locations in the multiple display conditions indicates that letter detection is a limited capacity process. In this respect consistent (i.e., multiple 1) and varied (i.e., multiple 2) mapping tasks do not differ essentially. However, the magnitude of costs plus benefits differs between multiple display conditions. In other words, there are differences between consistent and varied mapping tasks in the efficiency with which the limited processing capacity is used (see also SHAW, 1984).

However, the failure to find costs plus benefits in sensitivity for cued and uncued locations in the single display condition indicates that detection of a luminance increment in an otherwise empty field is not capacity limited. That is, luminance detection appears "radically" different from letter detection. This agrees with SHAW's (1984) findings for the display size effect (see also COHN and LASLEY, 1974).

Note that there appears to be a discrepancy between the present study, and that of SHAW (1984), on the one hand and BASHINSKI and BACHARACH's (1980) experiment on the other. Using only two locations, BASHINSKI and BACHARACH reported P(A) differences between valid and invalid trials of 0.168 for detection and 0.263 for joint detection plus localisation. In the present experiment the corresponding values are 0.039 and 0.002 (average differences between V 1 and I in the single display condition). In BASHINSKI and BACHARACH's study, the increase in P(A) between the detection and the joint detection plus localisation analysis is an artefact of their method of calculating detection plus localisation false alarm rates (see 5.5. Appendix A for details). It is possible that one might fail to find costs plus benefits in BASHINSKI and BACHARACH's luminance detection data if they were analysed according to the joint detection plus localisation ROC procedure suggested in section 5.5. Appendix A.

For the most likely location (V 1), the slight loss in P(A) for multiple relative to single displays is due to localisation failures (i.e., misses). Similarly, the more marked losses for the less likely positions (V 2 and I) are largely accounted for by localisation failures, but somewhat higher false alarm rates associated with these positions in multiple in comparison with single displays contribute to the reduction in sensitivity. (Note that in the D+L data, the proportion of localisation failures among misses, i.e. of targets erroneously "detected" at nontarget locations, is 12.9 percent for the single and 23.8 and 27.1 percent for the multiple display 1 and 2 conditions, respectively; these differences between display conditions are the more marked the less likely a particular location.)

This pattern indicates greater sample strength variability for less likely locations in multiple displays. That is, the strength value associated with one of the less likely locations (V 2 and I) is more likely to exceed the value associated with the most likely position (V 1), resulting in a failure to choose that position for the localisation response. The same argument provides an explanation for the finding that false alarm rates for the most likely position are not higher for multiple than for single displays. Differences between the multiple display 1 and 2 conditions can be explained along similar lines.

With regard to the bias effects, the likelihood ratios increase with decreasing cue validity, in the single display condition as well as in the the multiple display 1 and 2 conditions. The more positive and, respectively, negative biases for cued and for uncued locations in the single display condition (especially in the D+L data) are at variance with BASHINSKI and BACHARACH (1980) who reported costs plus benefits in sensitivity without bias changes. However, BASHINSKI and BACHARACH's beta estimates are based on a flawed calculation of false alarm rates (D+L analysis; see 5.5. Appendix A); and, further, they do not take into account variance differences between noise and signal plus noise distributions (i.e., the fact that the slopes of the normal-normal ROC curves for cued locations were different from 1.0).

In the multiple display conditions, response biases are generally (i.e., across cue validity conditons) more conservative than in the single display condition. Since the three display conditions were presented in randomized order (within blocks of trials), decision criteria could not be differentially preset. Thus, decision criteria set "a priori" according to the probabilistic information provided by the arrow cue must have been readjusted on the basis of the information obtained during the presentation of the target display.

The more conservative biases in the multiple display conditions are consistent with the assumption that target-distractor discriminability for a particular location is a function of both the similarity between target and nontarget and the amount of processing capacity allocated to this position. The single luminance increment on which the discrimination between target and nontarget is based in the single display condition can be picked up more efficiently, i.e. presumably without capacity limitation, than the information required for target-distractor discrimination in the multiple display conditions. Thus, in the multiple display conditions, there is greater variability in sample strength for the less likely locations, i.e. an increase in the probability that the strength values associated with nontarget locations equal or exceed the value of the actual target position (signal trials) or exceed some criterion value (noise trials). The resulting response competition requires decision criteria to be raised for optimal decision making.

The same argument predicts more conservative decision criteria for the multiple display 2 (varied mapping) than for the multiple display 1 (consistent mapping) condition. But note that the difference does not appear reliable (at least in the D+L data). This indicates that the increase in target-nontarget similarity from consistent to varied mapping multiple displays is less fundamental than that from single to multiple displays.

5.4. General Discussion

With regard to the question raised by POSNER et al. (1980), Experiment 11 demonstrates that attention can be effectively divided between two likely target locations. Recently, ERIKSEN and YEH (1985) have argued against such a position on the basis of a letter detection experiment in which the most likely position was directly cued by a bar marker and the second most likely location was always diagonally opposite to the cued position. ERIKSEN and YEH found benefits in response speed only for the cued position; for the second most likely location, RTs were slower than in neutral control conditions, but faster than for the uncued locations. When the probability of target occurrence at the cued position was increased, at the expense of the second most likely and uncued locations, there was a further divergence of RT functions. This pattern of results led ERIKSEN and YEH to suggest that search strategies alternated, across trials, between a focused (serial) and a diffuse (parallel) mode of processing, with their mixture being determined by cue validity.

However, the type of spatial cue presented in this experiment may have interfered with effective attention sharing. JONIDES (1981; see also YANTIS and JONIDES, 1984) and Experiments 6 and 7 (see Chapter 3) have shown that direct (peripheral) cues produce rapid and involuntary deployment of attention to the cued position and that this process cannot be suppressed substantially even when cue validity is neutral. Thus, the failure of ERIKSEN and YEH to find benefits in RT for the location diagonally opposite to the bar marker may be attributable to the dominance of "automatic" processes triggered by external properties of the cue over "controlled" processes, i.e. attention sharing, based on its implicit spatial information.

With regard to the question raised by SHAW (1984), Experiment 12 does support the conclusion that the explanation of the priming effect differs "radically" between tasks requiring the detection of letters and those requiring the detection of luminance increments; the differences appear more qualitative than just quantitative in nature. This conclusion is at variance with BASHINSKI and BACHARACH (1980).

Thus, for spatial cueing experiments measuring simple RT to luminance increments (e.g., POSNER, SNYDER and DAVIDSON, 1980), the present data (as well as those of SHAW, 1984) would suggest that the benefits and costs in response speed typically found for cued and uncued locations are produced by differential setting of response thresholds, i.e. lowered for cued and raised for uncued locations. But note that the present experiments do not rule out that costs and benefits in simple RT at very short intervals (about 100 msec) following the onset of peripheral cues ("automatic" orienting) are caused by "sensitivity" rather than (mere) "bias" changes (see also Experiment 10 in Chapter 4). However, it seems at least questionable whether the simple luminance detection task is an "ideal model task" (POSNER et al., 1980) for investigating the effects of spatial attention.

Given that costs plus benefits in simple RT to luminance increments reflect the differential setting of response thresholds for cued and uncued locations, the question arises why POSNER et al. (1980; Experiment 5) failed to find consistent RT advantages for the second most likely location. Possibly, this is due to the fact that this position was not cued on every trial (but rather fixed throughout a block).

To test this, MULLER, ASTELL and FINDLAY (1985) repeated Experiment 11 with the simple RT task used by POSNER et al. That is, the task required a simple speeded response to a suprathreshold luminance increment; this was the only stimulus presented, i.e. nontarget locations remained blank (2/3 target trials and 1/3 catch trials). Table 5.9. presents the mean RTs and their standard deviations (6 subjects). MULLER et al. found reliable benefits, relative to the neutral baseline, for cued positions and significant costs for the uncued locations, both under single and double cueing conditions (main effect of cue validity: $F(2,10) = 10.64$, $p < 0.005$). Thus, it appears that consistent benefits for a second cued location can be obtained in a simple RT task when this position is cued on every trial (rather than blocked). This is consistent with POSNER et al.'s (1980; Experiment 11) own finding that with blocked designs the subjects apparently "... (did) not continue to set themselves for the position in space at which the target was most expected" (p. 163).

Table 5.9.: Simple RTs in msec: Summary of mean values and their standard deviations (S.D.) under each experimental condition (V = valid, N = neutral, I = invalid)

	V 1	V 2	N	I
	Single Cue			
Mean	246	---	257	263
S.D.	33	---	31	39
	Double Cue 1			
Mean	248	255	260	269
S.D.	22	21	32	28
	Double Cue 2			
Mean	251		264	274
S.D.	24		27	30

The results of the present experiments have some implications for the notion of "automatic detection" (SCHNEIDER and SHIFFRIN, 1977; SHIFFRIN and SCHNEIDER, 1977). According to SHIFFRIN and SCHNEIDER, one should expect that extensive practice with consistent mapping multiple displays (multiple display 1 condition) reduces the size of the priming effect as the demands on the limited processing capacity are reduced and finally bypassed. Experiment 11 and 12, however, demonstrate capacity limitation for consistent mapping multiple displays despite the fact the observers had all undergone extensive training. As can be seen from table 5.2. (0.75-threshold exposure times for Experiment 11), display duration decreased from about 38 msec in the fist session to 26 msec in the sixth session; i.e., exposure durations had to be continuously readjusted in order to compensate for practice (automatization) effects (see also PRINZMETAL and BANKS, 1983, and KLEISS and LANE, 1986). However, the decrease in exposure durations was not associated with reductions of benefits and costs associated with the preferential allocation of attention to the cued locations. Thus, training with a consistent mapping task appears to produce an increase in the efficiency with which the available processing capacity is used rather than a bypassing of limited capacity processes.

SHAW's (1980, 1984; SHAW et al., 1983) "sample size" model provides a good account for the priming effects found in the present experiments. This model is based on the assumption that a finite resource (attention, processing capacity, search effort) is divided among the input locations. The processing capacity allocated to a particular source can influence the internal stimulus representation generated in the coding stage. Since this model considers the substages which the coding stage may be composed of together, it may not be incompatible with "late selection" theories of attention (e.g., HOFFMAN, 1978, 1979; DUNCAN, 1980a, 1981, 1985).

These theories generally assume that there is a preselective, parallel and relatively capacity-free stage of processing deriving simple stimulus features and also aspects of meaning which must be passed on to a second stage in order to be preserved and form a reportable perception. The transfer from the first to the second stage is accomplished by a limited capacity system which involves an "attention response" to the attributes defining the the stimulus to be selected; this transfer is generally presumed to be serial in nature. DUNCAN (1981) argues that the finding of enhanced "sensitivity" for spatial locations known in advance cannot be taken as evidence for the idea that attention has a facilitatory effect on the "early" stages of perceptual analysis. Rather, selection of first-stage representations on the basis of spatial location is but one of several possible "selection schedules" which may, however, differ in efficiency.

For the double cue conditions in the present experiments the selection schedule implemented might have been one of transferring first-stage representations in a spatial order determined by the arrow cue until they were terminated by masking. However, such a selection schedule would not predict the decrease in sensitivity for lower priority locations (i.e., the second cued and the uncued locations) from the multiple display 1 to the multiple display 2 condition, as observed in Experiment 12 (see also TSAL, 1983b). This decrease is expected on the basis of the assumption that reduced target-distractor discriminability increases the likelihood that nontarget stimuli compete for and gain access to a limited capacity system. This finding appears incompatible with the assumption that display elements are fully identified in parallel and without capacity limitation at a first stage of encoding, and it may point to at least some role of attention for influencing the "quality" of information extracted in simultaneous processing of multiple input sources.

5.5. Appendix A

It is not immediately clear from BASHINSKI and BACHARACH (1980) how they calculated the false alarm rates for the joint analysis of detection plus localisation responses. BASHINSKI and BACHARACH agree (DUNCAN, personal communication) that their procedure was as follows:

(1) Let the total number of "noise", i.e. nontarget, trials be N.

(2) Across these N trials, let the number of false

alarms assigned to, i.e. erroneously localised at, the cued position be a and the number assigned to the uncued location be b.

(3) For "signal", i.e. target, trials with an arrow cue, let the probability that the target occurred at the cued position be p and the probability that the target occurred at the uncued location be q = 1-p.

(4) BASHINSKI and BACHARACH then took the false alarm rate for the cued position to be a/(pN) and the false alarm rate for the uncued location to b/(qN).

Restated, BASHINSKI and BACHARACH performed an imaginary division of the noise trials into a proportion p for the cued position and a proportion 1-p for the uncued location. That BASHINSKI and BACHARACH (1980) performed such a division is also evident from their article: The false alarm rates reported for the joint detection plus localisation analysis - 0.17 for the cued and 0.37 for the uncued position (p. 245) - add up to a higher total false alarm rate than that reported for the detection analysis - 0.22 collapsed across cued and uncued locations (p. 244).

This procedure has one problem: It produces an advantage in the sensitivity parameter P(A) for cued over uncued locations. Suppose, for example, that the a-priori probabilities of a signal occurring at the cued and at the uncued location are 0.8 and 0.2, respectively - as in BASHINSKI and BACHARACH's experiment. Then, on the basis of BASHINSKI and BACHARACH's procedure, the expected ratio between hit and false alarm rates is 0.4/0.5 for the cued and 0.1/0.5 for the uncued position. That is, the ROC curves for the cued and the uncued location based on the expected hit and false alarm rates lie beneath, rather than on, the main diagonal (chance performance), and P(A) is smaller for uncued than for cued locations.

There is a simple solution to this problem: The numbers a and b, i.e. the false alarms assigned to the cued and the uncued location, should both be divided by N since they are based on the total N trials. (Otherwise, false alarm rates could exceed 1.0!) And further, if there is more than one uncued location, b must be divided by the number of uncued positions to give the false alarm rate per location. Thus, for example, in the single cue condition of Experiment 11, the false alarm rate for the cued position is given by a/N and that for the three uncued location by (b/3)/N.

Note that there is another solution: To count as a false alarm any response on signal trials on which the observer erroneously detects and localises a target in a nontarget position. This is problematic, however, since any advantage in detection plus localisation hit rates for cued positions would result in reduced false alarm rates for uncued locations.

It is important to note that recalculation of the false alarm rates in BASHINSKI and BACHARACH's experiment according to the solution set out above radically changes their conclusion concerning the relative accuracy for cued and uncued locations. Working backwards from the joint detection plus localisation false alarm rates reported by BASHINSKI and BACHARACH, the false alarm rates recalculated for cued and uncued locations are 0.14 and 0.07, respectively. That is, the false alarm rate is twice, rather than half, as high for cued than for uncued locations. And, as a result, costs plus benefits in joint detection plus localisation sensitivity are smaller, rather than greater, in comparison with detection sensitivity on its own. It is not possible to recalculate P(A), since BASHINSKI and BACHARACH do not report joint detection plus localisation hit rates for cued and uncued locations. It cannot be ruled out, however, that the recalculated P(A) values do not differ between valid and invalid trials.

Note that in the present experiments, joint detection plus localisation false alarm rates were calculated according to the solution proposed above. Note further that for the joint detection plus localisation ROC curves, frequencies of misses and of correct rejections were pooled across "no - uncertain" and "no - certain" response categories.

5.6. Appendix B

There is evidence that eye movements cannot account for the pattern of sensitivity effects in Experiment 11.

Experiment 11a showed that when trials on which saccadic eye movements occurred are excluded, the pattern of results is very similar to Experiment 11 in which eye movements were not monitored. Out of 3600 trials in Experiment 11a, the number of saccades detected was 16, all occurring before display onset (i.e., there was no evidence of post-display saccades within 150 msec after display onset). Thus, saccade probability was less than 0.005. However, there was evidence of slow fixation drifts prior to display onset.

Table 5.10.: Size (in deg. of visual angle) and direction (left-right) of slow fixation drifts: Frequencies separately for "neutral" trials (central cross), for double cue trials with arrows pointing to "different" sides and for single cue and double cue trials with arrows pointing to the "same" side

			Left			Centre			Right		
deg.	1.25	1.00	0.75	0.50	0.25	0.00	0.25	0.50	0.75	1.00	1.25
Neutral		4	14	66	122	186	119	52	9	4	
Different	5	8	62	133	285	390	282	115	51	10	3
Same/Left		11	20	108	218	274	156	46	7		
Same/Right			11	54	143	263	221	107	29	10	2

Table 5.10. presents the size and direction of these drifts, separately for neutral trials, for double cueing trials with arrows pointing to different sides and for single cueing and double cueing trials with arrows pointing to the "same" side. Table 5.10. shows that for "neutral" and "different" trials, the distributions are approximately symmetric. However, for "same" trials the distributions are skewed to the side (left or right) of

the location(s) to which the single arrow (single cueing condition) or both arrows (double cueing conditions) were pointing; that is, approximately 60 percent of the shifts were in the cued, i.e. "attended" direction. The mean and variance of the combined "same/left" and "same/right" distribution are about equal to those of the "neutral" and "different" distributions. This suggests that fixation drifts in some attended direction also occurred on neutral trials and on trials with double arrows pointing to locations on different sides. Note, however, the size of these drifts (horizontal components) was small: Approximately 75 percent were smaller than 0.375 deg. and approximately 95 percent smaller than 0.625 deg. These findings appear consistent with KOWLER and STEINMAN's (1979a, 1979b) work on slow fixation drifts in the attended direction in tasks which required eye tracking of repetitive target steps: Drifts occurred as early as 350 msec before expected target steps and with velocities up to 0.5 deg./sec.

Thus, even though it seems certain that such drifts occurred in Experiment 11, because of their small size they should have had little influence on sensitivity parameters. Shifts of greater size towards the most likely position(s) should show up in contrasts between equally likely display locations adjacent and opposite to the eye position in the same way as outright saccadic eye movements. Suppose, for instance, that in the single cueing condition an observer moved his eyes towards the cued location before target onset. This would have decreased the retinal eccentricity of the cued position and increased it for the uncued locations. However, the increase would have been relatively greater for the diagonally opposite position than for the adjacent locations. For example, if the distance of the eye from the cued position decreases from 4.4 to 2.0 deg., that for the opposite position increases from 4.4 to 6.8 deg. while that for the two adjacent locations increases from 4.4 to only 5.0 deg. To assess the effect of such changes in retinal eccentricity, an experiment (Experiment 11b) was conducted which varied the distances of cued and (adjacent and opposite) uncued locations systematically.

In Experiment 11b, the observer viewed the fixation dot in the centre of the display, expecting the target event to occur at some location on the positive or negative diagonal. Unlike Experiment 11, however, display locations were not marked by boxes and their distances from the display centre were not fixed, but varied from trial to trial. Three seconds after the beginning of a trial, a single box (i.e., single peripheral cue) appeared for 50 msec marking the likely target position (uncued locations were not marked). On neutral trials, 50-msec boxes occurred at all four display locations. The distance of the cued location from the display centre could take the following values: 4.4, 4.0, 3.0 or 2.0 deg. Thus, the distance of the diagonally opposite position was 4.4, 4.8, 5.8 or 6.8 deg. and that of the adjacent locations 4.4, 4.4, 4.6 or 5.0 deg. On neutral trials, display locations were equidistant from the centre (4.4 deg.). The interval between cue and target onset (SOA) was 75 msec, i.e. too short for eye movements to occur. Target and distractor exposure was terminated by contour masks.

One observer, H.M., was presented with 2008 cued (i.e., valid, invalid and noise) trials under each of the four eccentricity conditions plus 768 neutral (signal and noise) trials, i.e. 8800 trials in all (8 four-hour sessions). Eccentricity conditions were presented in randomized order (within the same block of trials). The average target exposure time, determined at the beginning of each sessions for neutral threshold trials, was 35.5 msec. The experiment was conducted under normal room lighting (fluorescent overhead light). All other methodological details were the same as in Experiment 11.

Table 5.11. presents the P(A) values for cued and for adjacent and opposite uncued locations and for each retinal eccentricity condition. P(A) for the neutral condition (4.4 deg.) was 0.765 for the detection and 0.888 for the joint detection plus localisation data. Costs plus benefits in sensitivity explicable in terms of "attention", rather than retinal eccentricity, appear small in Experiment 11b (see P(A) for the 4.4-deg. eccentricity in the D+L data). Presumably, this is due to forward masking produced by the peripheral cue. Forward

masking reduces gains for the cued position, and for the neutral condition, relative to the uncued locations.

Table 5.11.: Detection and detection plus localisation sensitivity: Summary of P(A) values for cued and for ajacent and opposite uncued locations under each retinal eccentricity condition (distance of central fixation dot from cued location in deg. of visual angle)

	Detection			Detection + Localisation		
deg.	Cued	Adj.	Opp.	Cued	Adj.	Opp.
4.4	.825	.702	.705	.903	.888	.886
4.0	.842	.708	.702	.911	.884	.878
3.0	.865	.695	.667	.936	.878	.849
2.0	.896	.688	.637	.959	.864	.813

Note that the size of the attentional effect in Experiment 11b is irrelevant with respect to the comparison between adjacent and opposite uncued locations as a function of retinal eccentricity. Table 5.11. shows that when the eye is equidistant from all four display locations, there are no P(A) differences between adjacent and opposite uncued locations. However, such differences occur when the eye "moves" closer to the cued location. At an eye-cued location distance of 2.0 deg., P(A) for opposite locations (6.8-deg. distance) is 0.051 (D+L data) lower than P(A) for adjacent locations (5.0-deg. distance). Linear regression analyses for cued and opposite locations showed the retinal eccentricity effect to be approximately 0.03 P(A)-units per degree of visual angle.

Thus, if observers in Experiment 11 had made eye movements in the direction of the cued position larger than about 1 deg., this should show up in differences, in the single cue condition, between adjacent and opposite uncued locations. However, as can be seen from tables 5.12. and 5.13. which present the corresponding "adjacent-opposite" contrasts individually for each observer in Experiment 11, there is no evidence for such differences. (Note that the values for H.M. in Experiment 11a (eye movement monitoring) are indicated by an asterisk; H.M.'s values for Experiments 1 and 1a were averaged before calculating the group means.)

Table 5.12.: Detection sensitivity: Summary of P(A) values for each observer under each experimental condition (V = valid, I = invalid; * - eye movements monitored)

	Adjacent			Opposite		
	V 1	V 2	I	V 1	V 2	I
			Single Cue			
I.P.	----	----	.780	----	----	.776
N.A.	----	----	.788	----	----	.774
H.M.	----	----	.773	----	----	.790
H.M.*	----	----	.769	----	----	.774
Mean	----	----	.780	----	----	.777
			Double Cue 1			
I.P.	.886	.867	.786	.911	.861	.758
N.A.	.914	.896	.777	.898	.890	.795
H.M.	.934	.906	.764	.951	.922	.784
H.M.*	.880	.867	.762	.885	.857	.762
Mean	.902	.883	.775	.909	.880	.775
			Double Cue 2			
I.P.	.866	.874	.790	.871	.865	.744
N.A.	.902	.915	.767	.910	.902	.771
H.M.	.913	.922	.749	.938	.923	.802
H.M.*	.882	.868	.758	.877	.874	.750
Mean	.889	.895	.770	.896	.889	.764

Table 5.13.: Joint detection plus localisation sensitivity: Summary of P(A) values for each subject under each experimental condition (V = valid, I = invalid; * - eye movements monitored)

	Adjacent			Opposite		
	V 1	V 2	I	V 1	V 2	I
Single Cue						
I.P.	----	----	.898	----	----	.896
N.A.	----	----	.915	----	----	.901
H.M.	----	----	.888	----	----	.890
H.M.*	----	----	.901	----	----	.902
Mean	----	----	.903	----	----	.898
Double Cue 1						
I.P.	.923	.914	.898	.939	.921	.911
N.A.	.935	.930	.894	.925	.940	.886
H.M.	.947	.922	.904	.963	.935	.894
H.M.*	.920	.905	.890	.910	.891	.864
Mean	.931	.919	.896	.934	.925	.892
Double Cue 2						
I.P.	.917	.925	.901	.925	.911	.868
N.A.	.924	.938	.863	.924	.930	.891
H.M.	.920	.937	.899	.932	.927	.910
H.M.*	.896	.903	.870	.899	.901	.869
Mean	.916	.928	.883	.922	.918	.883

Similar arguments apply to the double cueing conditions. Suppose that observers made an eye movement to the (potentially) most informative region of the display. Thus, with double arrows pointing to adjacent locations (90-deg. angle between arrows), the optimal strategy would have been to move to the point in the middle between the cued positions. However, with double arrow indicators pointing to opposite locations (180-deg. angle between arrows), the optimal strategy would have been to maintain fixation at the display centre. Thus, the distance from eye fixation of the uncued locations would have been 6.9 deg. for adjacent cues as compared to 4.4 deg. for opposite cues. That is, sensitivity for uncued locations should be lower for adjacent than for opposite cues and sensitivity for cued locations should be lower for opposite than for adjacent cues. However, neither in the double cue 1 nor in the double cue 2 condition of Experiment 11 are there any such differences in the P(A) data (see tables 5.12. and 5.13.).

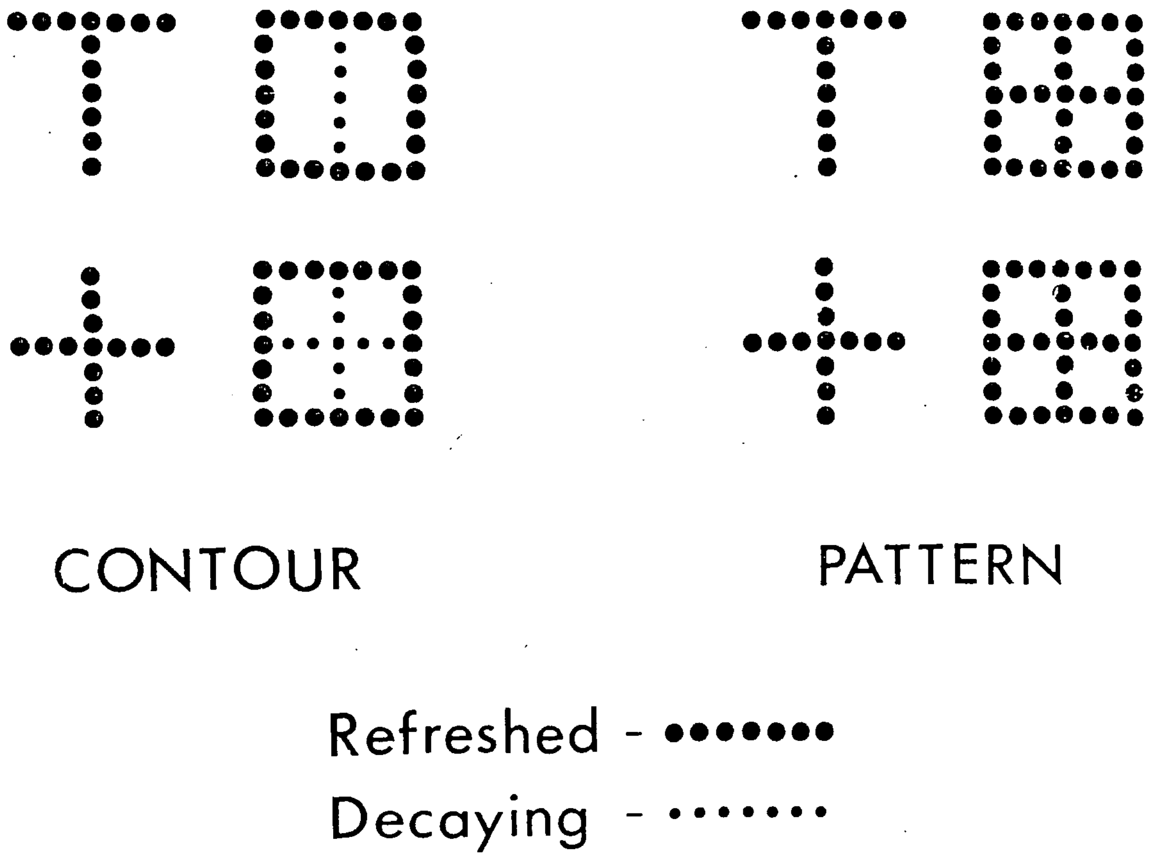
Alternatively, subjects could have made an eye movement to the most likely location (i.e., to one of the two equally likely signal locations in the double cue 2 condition). One should expect then that in the double cue 1 condition (with different signal probabilities assigned to cued locations), sensitivity for the second most likely position would be lower for opposite than for adjacent cues (8.8 as compared to 6.2 deg. distance from eye fixation of most likely location). And that in the double cue 2 condition (with equal signal probabilities assigned to cued locations), sensitivity for both cued positions would be lower for opposite than for adjacent cues. However, again there is no evidence for such differences in the P(A) data of Experiment 11 (see tables 5.12. and 5.13.).

Rather, sensitivity parameters are quite independent of the angle between arrow indicators (double cueing conditions) and of the relation of uncued locations with respect to the cued position (single cueing condition). In other words, there is no evidence for large and strategic eye movements in the data of Experiment 11.

5.7. Appendix C

The effectiveness of the contour masks to terminate the display was tested in a further experiment (Experiment 11c). Contour masks might leave some useful information accessible even after display offset since the visible persistence of the P31 phosphor, with which the monitor was equipped, is rather long when the laboratory is dimly illuminated. A closer look at some display characteristics provides a hypothesis about the stimulus attributes which might persist after mask onset. Contour masks were squares of the same size as that of target Ts and distractor crosses (0.25 deg.). As can be seen from figure 5.3., target Ts and distractor crosses were composed of two bars each of which consisted of 7 illuminated spots (i.e., they shared one spot at their intersection). Similarly, the bars of which contour masks were composed consisted of 7 spots (i.e., they shared one spot at each corner). Thus, at display offset and mask onset, the outer spots of which target Ts and distractor crosses were composed were superseded by the masking contours, while the spots inside the masks decayed. However, the number of spots decaying inside the masking contours differed between target (5 spots) and nontarget (9 spots) locations. Thus, target detection and localisation could have been successful, after display "termination" by the masking contours, to the degree to which any existing luminance differences between target and nontarget locations could be detected.

Figure 5.3.: Contour (left) and pattern (right) masks at target and nontarget locations



Experiment 11c was designed to eliminate, under one masking condition, any post-mask luminance differences between display locations. The critical masking condition presented "pattern" masks which were composed of an outer square (like contour masks) plus an inner cross (see figure 5.3.). Note that the additional number of spots illuminated at pattern mask onset was the same for target and nontarget locations; further, that the pattern masks appeared like continuously filled squares (i.e., the gaps could not be resolved) with fixation at the display centre. The second masking condition presented contour masks, as in Experiment 1. The cueing condition was double cue 1 (double arrows indicating different signal probabilities for V 1 and V 2). Target exposure durations, estimated at the beginning of each session for contour mask threshold (neutral) trials, were the same for contour and pattern mask trials which were presented in randomized order (i.e., randomized within the same block). Room lighting was the same as in Experiment 11. One observer, H.M., completed 2400 trials under each masking condition (4 four-hour sessions). His target exposure duration was 27.75 msec (mean of the four sessions).

Table 5.14.: Detection and joint detection plus localisation sensitivity: Summary of P(A) values under each experimental condition (V = valid, N = neutral, I = invalid)

Detection				Detection + Localisation			
V 1	V 2	N	I	V 1	V 2	N	I
Contour Masks							
.895	.874	.794	.776	.931	.900	.898	.878
Pattern Masks							
.891	.869	.783	.758	.924	.901	.896	.879

Table 5.14. presents the P(A) values for each cue validity condition (V 1, V 2, N and I) and stage of analysis (D and D+L), separately for contour and for pattern mask trials. P(A) values show the same pattern as in Experiment 11 (double cue 1 condition) and the same pattern for contour and for pattern mask trials. That is, the sensitivity gains for the second most likely position relative to the uncued location cannot be a post-display effect.

CHAPTER 6

Conclusions

Experiments 1 to 4, which investigated the effects of spatial orienting in single and in multiple element displays, provide clear evidence that performance differences between valid and invalid trials are indeed greater for multiple than for single displays, as suggested by GRINDLEY and TOWNSEND (1968).

For valid trials, performance differences between single and multiple displays are largely independent of SOA. In both display conditions, when the likely target location is indicated by a direct change in light energy (peripheral cue), performance is enhanced very rapidly; after having reached optimum (150-msec SOA), performance shows a marked decline (300- to 500-msec SOAs), followed by sustained performance at the lower level. When the most likely location is indicated by a symbolic cue in the centre (central cue), performance is maintained at optimum after an initial build-up.

For invalid trials, performance differences between single and multiple displays increase with SOA duration, for both types of cue. However, with peripheral cues performance increases both for single and for multiple displays, in particular between the SOAs of 100/200 and 300 msec, while with central cues there is a reliable increase only for single displays and this increase appears less pronounced.

To explain these results, a two-component theory of spatial orienting was proposed:

A transient change in light energy preceding the target at the cued location (i.e., a direct peripheral cue) triggers an "automatic" attention response. This response produces both an "early" facilitatory effect (i.e., an "instant" performance gain) for the cued position and an early inhibitory effect (i.e., an immediate performance loss) for uncued locations. Presumably, this inhibitory component reflects a loss in the ability of targets at uncued locations to call attention, caused by the rapid engagement of attention by the peripheral cue.

The early, automatic, facilitation for the cued location produced by a preceding peripheral cue is transitory and passes over into a second component of actively sustained attention for the cued position. This component is initiated through a "controlled" process of producing an expectancy for the likely target location. Production of a spatial expectancy is relatively delayed and occurs while the automatic orienting component is active; it may also enhance the magnitude of the early facilitatory and inhibitory effects of peripheral cues on cued and on uncued locations.

The duration of the early inhibitory effect on uncued locations is time-locked to the automatic orienting component, so that with the fading of this component (during which attention is "summoned" and engaged by the preceding change in light energy), attention can be disengaged from the cued position. This enhances the ability of targets at uncued locations to call an attention response.

With a symbolic cue in the display centre, the early facilitatory component is absent (i.e., the performance build-up for the cued position appears more gradual) and the early inhibitory component is reduced (i.e., performance for uncued locations appears less impaired initially). That is, central cues initiate only the second component of actively sustained preparation for the cued position, through production of an expectancy for the likely target location.

For uncued locations, the magnitude of the enhancement following the initial inhibitory effect is more marked for single than for multiple displays. This differential SOA effect points to a basic difference in target search between the two display conditions.

For single displays, the luminance change associated with target onset at an uncued location is a direct pointer to its position. As attention is no longer automatically engaged by the (peripheral) cue and/or production of an expectancy for the cued position is completed, a single luminance increment occurring at an unattended (i.e., uncued) location may elicit an automatic attention response in the same way as a previous change in light energy at the cued position.

In multiple displays, however, the luminance change associated with target onset at an uncued location provides only temporal but no spatial information, since distractors of the same size and energy appear simultaneously, one of them at the cued position. That is, rejecting the cued position as not containing the target is more demanding than when it is blank; and search requires extraction of some "higher level" attribute which discriminates a T from a cross, a more time consuming and error-prone process. Thus, search for targets at uncued locations is less enhanced when automatic engagement of attention by the (peripheral) cue fades out and/or controlled production of an expectancy for the cued position is completed. This more demanding nature of the search for "unattended" targets appears to be the main cause for the finding that performance differences between valid and invalid trials are more pronounced for multiple than for single element displays.

This two-component model makes an important distinction between "external" and "internal" spatial orienting. With peripheral cues, orienting of attention initially responds to external, i.e. physical properties of the cue (transient change in light energy). With increasing SOA duration, however, control is taken over by an internal process of producing and maintaining an expectancy, guided by the spatial information of the indicators. With central cues, only this second process is initiated.

The two-component model suggests that external orienting, together with the production of a spatial expectancy, is more effective than internal orienting on its own; that is, that the "early" facilitatory component associated with peripheral cues is more powerful than the "late" facilitation associated both with central and with peripheral indicators. (Note, however, that the internal processes which produce a spatial expectancy may not only enhance, but also attenuate the external orienting processes responding to peripheral changes in light energy; enhancement and attenuation depend on the compatibility between expectancy and external trigger stimulus.)

However, Experiments 1 to 4 did not allow a direct comparison to be made between central and peripheral cueing conditions, so that it could not be decided whether peripheral cues show a special advantage for the cued position at short SOAs (shorter than about 300 msec) in comparison with central cues at long SOAs (longer than 300 msec) and whether performance levels at long SOAs are the same for both types of cue.

Experiment 5, which was designed to allow a direct comparison between central and peripheral cueing conditions, revealed this to be the case: Peripheral cues produce a powerful early facilitatory component, i.e., at short SOAs, performance for the cued position shows an advantage relative to long SOAs and relative to all (particularly, however, to short) SOAs in the central cueing condition. At long SOAs, however, the two types of cue are equally effective in maintaining facilitation for the cued position (but at a lower level than the early facilitatory component produced by peripheral cues).

This suggests that the external orienting mechanism, responding to an temporal discontinuity in light energy, combined with the production of an expectancy, based on the spatial information of the cue, indeed produces a special advantage; further, that the internal orienting mechanism, i.e. (production and) maintenance of a spatial expectancy, is the same for the two types of cue and is powerful enough to supress POSNER and COHEN's (1984) inhibition for the cued position which would otherwise, i.e. without actively sustained attention, follow a preceding change in light energy (i.e., a peripheral cue).

To explain the special advantage associated with peripheral cues, it was proposed that external orienting is based on an "automatic" and internal orienting on a "controlled" process. Experiments 6 and 7 were designed to test this. The rationale of these experiments was as follows:

A peripheral cue produces rapid facilitation for the cued position which is associated with an inhibitory effect for uncued locations. This effect can be compensated for only as the power of the cue to engage attention fades out and facilitation for the cued position is maintained by an internal orienting process. This indicates that external orienting, triggered by a peripheral cue, is characterised by a "refractory" period during which attention cannot be disengaged from the cued position; as a result, a stimulus at an uncued location is less likely to call an attention response. However, disengagement can occur as an internal orienting process takes over at longer SOA durations.

In other words, the external orienting process runs to completion without being interruptable, for instance by a target at an uncued location; the internal orienting process, however, is interruptable. SHIFFRIN and SCHNEIDER (1977) regard the extent to which a given process can be interrupted, after its initiation, as one of the main criteria of its automaticity. Thus, Experiments 6 and 7 investigated the degree to which automatic and controlled orienting components could resist the competition (i.e., the interrupting effect) of a spatially uninformative peripheral flash at an uncued location, i.e. of a stimulus which is itself a trigger for an "automatic" orienting response.

Experiment 6 showed that sustained ("controlled") orienting in response to central cues is not powerful enough to resist the competition of ("automatic") orienting in response to the flash: A flash occurring at an uncued position, well after production of an expectancy for the likely target location, produces an immediate performance loss for the cued and an immediate gain for the flashed (uncued) position. That is, the flash rapidly summons attention away from the high to a low priority location.

As the power of the flash to engage attention fades out, within 100-400 msec after its onset, an internal process based on the spatial expectancy induced by the preceding cue can take over again and reorient attention back to the high priority location. That is, performance for the cued position recovers as the interval between flash and target increases. This build-up of the advantage for the cued position is accompanied by a performance loss for the flashed (uncued) location, caused by the trade-off in attention distribution.

Experiment 7 showed that effects are not essentially different when the likely target location is indicated by a peripheral (rather than a central) cue which is then followed by a spatially uninformative peripheral flash. However, Experiment 7 revealed that when a flash occurs at an uncued location, the magnitude of the rapid inhibition for the cued position and the magnitude of the rapid enhancement for the flashed (uncued) location is less pronounced for a short (100-msec) than for long (300- and 500-msec) intervals between cue and flash onset. That is, when a competing flash occurs during the (early) external orienting response triggered by the peripheral cue, the trade-off between the cued (unflashed) and the flashed (uncued) location is less marked than when a flash occurs during the (later) sustained orienting process.

Thus, Experiments 6 and 7 demonstrated that the external orienting mechanism triggered by peripheral cues is characterised by greater resistance against interruption than the internal orienting mechanism initiated by production of a spatial expectation. This suggests that external orienting is indeed "automatic", while internal orienting is "controlled" (that is, that external and internal orienting are characterised by different degrees of automaticity).

Experiments 6 and 7 also provided evidence that production of a spatial expectancy can enhance or attenuate external orienting processes. Enhancement: When an uninformative flash occurs at the likely target location, performance for this position is rapidly facilitated in comparison with the "cue only" condition; and this facilitation is relatively greater than that for a less likely flashed location (for which the spatial expectancy is low). Attenuation: When an uninformative flash occurs at an uncued location, performance for the cued position is less inhibited than performance for uncued unflashed locations (with a low spatial expectancy).

Experiments 1 to 7 established the general orienting components underlying localisation and discrimination performance. But the two-component model of spatial orienting leaves the nature of the basic search and decision processes unspecified. However, some insight into these processes could be gained by detailed analyses of the relationship between localisation and discrimination performance in the single and multiple element displays presented in Experiments 1 to 4. These analyses revealed that both localisation and discrimination accuracy are above chance even when discrimination or, respectively, localisation failed.

The finding that localisation accuracy exceeds chance even with discrimination failures is not a post-display effect, caused by inadequate masking (see Experiment 8). If it were, it would have provided little information about the nature of the underlying search process. And, further, it cannot be explained in terms of a strategy to search only a subset of display locations in a serial fashion and to choose one of the unsearched positions at random if target presence could not be ascertained for the searched locations. That is, search does not appear to be a "blind" process, but rather based on some selection mechanism, at an early stage of processing, that ensures that only those display elements are passed on which are likely to be targets.

The parallel-serial "hybrid" model of HOFFMAN (1978, 1979) and that of DUNCAN (1980a, 1981, 1985) explicitly propose such a preattentive selection mechanism, and both models can explain the finding that localisation accuracy is above chance, even with discrimination failures, if they are extended by three assumptions. SHAW's (1980, 1982, 1984) parallel model can also provide an explanation if it makes the same basic three assumptions. These assumtions are needed to account for the effects of display condition and cue validity.

(1) Stimulus attributes required for target localisation are derived faster than, and may thus serve as the basis for selection of, information required for target discrimination. Thus, exposure time constraints are more likely to limit target discrimination than target localisation.

(2) Information from the cued position becomes available faster than information from uncued locations. That is, the likely target position is assigned priority of selection in advance, so that information can gain access to the limited capacity system as soon as it is derived. The order of selection for elements at less likely locations must be determined by (localisation) attributes derived after display onset. However, selection is delayed if more than one element competes for access to and if information from the cued position

occupies the limited capacity system. Thus, exposure times constraints cause more information losses for uncued locations.

(3) Information for target localisation is derived faster in single than in multiple element displays. For single displays, simple detection of the luminance change produced by single target onset is sufficient for localisation, and localisation and discrimination are based on separate attributes. However, for multiple displays, with luminance changes occurring simultaneously at target and nontarget locations, localisation must be based on a more complex attribute which discriminates a T from a cross. Since target localisation is based on a more effective mechanism in single displays, localisation accuracy is at least as high as for multiple displays, despite shorter exposure durations. However, since exposure time constraints affect target discrimination more than target localisation, successful localisation with discrimination failures is more likely for single displays.

The effects of SOA can be explained along similar lines if the additional assumption is made that automatic and controlled orienting components are characterised by lower and, respectively, higher interruptability of the priority of selection for the cued position.

Thus, as the power of the (peripheral) cue to engage attention fades out, elements at uncued locations become more likely to claim precedence, causing delays in the availability of the limited capacity system for a target at the cued position. As a result, both localisation and discrimination accuracy decrease for the cued location. However, the decrease is less marked for localisation, since whereabout attributes are derived faster than information required for discrimination.

Interruptions to the priority for the cued position may be caused both by targets and by nontargets at uncued locations; but the probability is higher for targets than for nontargets and higher for targets in single than in multiple displays.

Thus, as interruptability of the priority for the cued position increases, targets at uncued locations become more likely to claim precedence. As a result, the probability increases that not only whereabout, but also discriminative information is passed on successfully. This increase is less marked for multiple than for single displays, because distractors in multiple displays are more likely to claim precedence than "nontargets" in single displays.

This explanation presupposes that whereabout information may become accessible for report, while information required for discrimination fails to do so. This is a position which HOFFMAN and, and more so, DUNCAN might have reservations about, in particular for multiple displays for which the separation between localisation and discrimination processes appears less clear-cut. However, research on the primitive coding of the spatial distribution of luminance changes suggests that there is, in principle, only a quantitative, but not a qualitative, difference between single and multiple elements displays.

In WATT and MORGAN's (1985) MIRAGE model, for example, line terminations and intersections produce small peaks in the convolutions between the summed outputs of filters of different spatial scales and a distal stimulus. Any system based on counting these peaks would allow grouping of display elements into target and distractor stimuli prior to shape analysis, which is a time consuming process requiring geometrical analysis of stimulus segments in terms of "above ...", "right of ..." etc. For multiple displays, the difference in convolution peaks between target and nontarget locations is 1. For single displays, however, it is 5 and grouping can be based on the output of filters of the largest spatial scale which show transient properties, so that target localisation is less liable to noise and faster. But there is no need to assume that preselective "grouping" of display elements is essentially different for single and for multiple displays.

Thus, in terms of the processes which plausibly underly search in the present task, target discrimination is generally dependent on prior target localisation, both for single and for multiple element displays.

When localisation fails, there appears to be a second, ineffective, way to successful discrimination through (same-different) response integration across display locations, a suggestion which is in accordance with HOFFMAN (1978, 1979) and with SHAW (1982). Two findings provide evidence for this possibility: Firstly, discrimination accuracy exceeds chance, when localisation failed, only for "different" (no match between target and comparison T) but not for "same" (matching target and comparison T) trials; and secondly, recognition accuracy is at chance both for "different" and for "same" trials (see Experiment 9).

The integration explanation is based on the assumption that there are illusory target impressions (in particular for nontarget locations). If the orientation of illusory targets is more or less randomly determined (one out of four orientations), integration of "impressions", i.e. real and/or illusory ones, across display locations can be successful for "different" discrimination, but not so much for ("same" and "different") orientation recognition.

A decisive question for any spatial priming task is whether performance gains and losses for cued and uncued locations are attributable to "sensitivity" or to "bias" changes. For the discrimination plus localisation task used in Experiments 1 to 4, sensitivity and bias effects could be separated by correcting for a response tendency to localise the target preferably at the cued position. However, this task involves a second source of bias: Assigning preferential weight to "any" information available from the likely target location. Such a strategy is likely since priming appears to increase not only hit rates, but also false alarm rates for cued in comparison with uncued locations (see Experiment 10).

Experiments 11 and 12 investigated this question of criterion versus sensitivity effects further, together with the question of whether or not attention can be effectively divided between two cued (i.e., likely) target locations.

Experiment 11 demonstrated that observers can attend to a second cued position without incurring marked losses in sensitivity for the location cued as most likely. There are significant sensitivity gains for the second most likely position, in comparison both with a neutral baseline condition and with uncued locations in a single cue condition. This indicates that attention can be more effectively divided between two indicated locations than has been suggested, amongst others, by POSNER, SNYDER and DAVIDSON (1980).

However, although division of attention is possible, the available processing capacity is fixed. This is suggested by the finding that sensitivity for the position cued to be most likely and, less reliably, for the uncued locations decreases from the single cue to the double cue conditions.

However, spatial priming produces not only sensitivity, but also criterion changes: Uncued locations require more evidence for a positive (i.e., a "target present") decision than cued positions. This could have two explanations: Decision criteria may be set "a priori", i.e. before display onset, on the basis of the probabilistic information provided by the spatial cue; that is, more liberal for more likely and more conservative for less likely locations. Or decision criteria may be set (or changed) "a posteriori" on the basis of the perceived competition among independent input sources for the detection and localisation response; that is, the decision criterion is raised in order to decide optimally among competing display elements.

Experiment 12 was designed to decide between these explanations. The rationale was as follows: The perceived competition among independent input sources should depend on target-distractor discriminability. Thus, when displays with varying degrees of target-distractor discriminability, such as single and consistent and varied mapping multiple element displays, are presented in randomized order, bias differences between display conditions cannot be caused by differential pre-setting of decision criteria (for observers cannot know in advance which type of display to expect on a given trial).

Experiment 12 showed that for single displays, there are no sensitivity gains and losses associated with the preferential allocation of attention to two cued locations. For multiple displays, however, there are gains and losses, and these are more pronounced for varied than for consistent mapping displays.

The decision criteria adopted are more liberal for cued and more conservative for uncued locations, in all display conditions. However, negative biases for the less likely locations are more marked for multiple than for single displays and, less reliably, for varied than for consistent mapping multiple displays.

Since decision criteria could not be differentially preset, the bias differences between display condition suggest that decision criteria, which are largely set "a priori" according to the probabilistic information provided by the cue, are readjusted on the basis of the information derived during display presentation.

The bias changes indicate that target-distractor discriminability for a particular location depends on both the similarity between target and nontarget and the amount of processing capacity allocated to this position. In single displays, discrimination between target and nontarget is based on detection of a single luminance increment. In multiple displays, however, derivation of the information required for target-distractor discrimination is capacity demanding. Thus, there is greater noise for less likely locations, and the resulting response competition requires criteria to be raised for optimal decision making.

SHAW's (1980, 1984; SHAW et al., 1983) "sample size" model provides a good account for the priming and bias effects found in Experiments 11 and 12. This model is based on the assumption that a finite resource (attention, processing capacity, search effort) is divided among input locations, and the amount of capacity allocated to a particular source can influence the internal stimulus representation generated in the coding stage.

However, since this model considers the substages which the coding stage may be composed of together, it may not be incompatible with "late selection" theories of attention (e.g., HOFFMAN, 1978, 1979; DUNCAN, 1980a, 1981). These theories assume that there is an "early", parallel and capacity-free stage of stimulus encoding; representations generated in this stage must be passed on to a second stage in order to be preserved and form a reportable perception. Transfer from the first to the second stage, which is accomplished by a limited capacity attention process, is presumed to be serial in nature.

DUNCAN (1981) argues that the finding of enhanced "sensitivity" for spatial locations known in advance cannot be taken as evidence for the idea that attention facilitates the "early" stages of perceptual analysis. Rather, selection of first-stage representations on the basis of spatial location is only one of several possible "selection schedules". Thus, in the double cue conditions of Experiments 11 and 12, first-stage representations might have been transferred in an order determined by the arrow cue. However, such a selection schedule would not predict the decrease in sensitivity for low priority locations from the multiple display 1 to the multiple display 2 condition in Experiment 12. This appears to be incompatible with the assumption that display elements are fully identified in parallel and without capacity limitations at a first stage of stimulus encoding, and it may point to at least some role of attention for influencing the "quality" of information extracted in simultaneous processing of multiple elements.

In summary, the findings presented in this thesis should contribute to the understanding of the mechanisms underlying selectivity for locations in visual space. However, the experiments reported do not allow a decision amongst alternative theories of visual search. The difficulty is that examination of accuracy in data limited situations appears a suitable approach to detecting capacity limitations, but provides little information as to the question of the locus of any information loss that may be found. Chronometric analyses seem better suited to addressing this question. What is needed is, in the words of PASHLER and BADGIO (1985), "... A unified theory (that) will ultimately need to address both issues and possible processing differences between speeded and data-limited tasks" (p. 118).

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