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Spatial cue effects in Visual Selection*

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Abstract. The dynamics of cued visual selection (a particular manifestation of "focal attention") were studied in multiple line arrays in which one element (the target to be identified) was marked by a cue; presentation time after cue application was varied. Aim of these experiments was to compare the dynamics of direct and indirect cueing in visual selection and to investigate the influence of spatial parameters, in particular the cue-target distance and the figural connectedness of cue and target locations, on speed and efficiency of the selection process. Performance in direct cueing slowed down with the distance between cue and target (Exp. 1), thus approaching the generally slower dynamics of indirect selection (Exp. 2). This slow-down did not occur when the target location was known beforehand (Exp. 3). Performance was also delayed at small cue-target distances, at which cues interfered with the target both when the target location was known and unknown. In Experiment 4, the tests were repeated with figure-like items in which targets and cues were connected by tentacles. Also in these patterns near cues led to faster performance than far cues. An advantage of the figural connectedness was only seen with distant and ambiguous cue locations where tentacles helped to link cues to the correct bar. Altogether, the data document the importance of cue parameters when single targets must be quickly selected from a large sample.

Key words:
Attention; Visual selection; Cue size; Cue-target distance; Perceptual organization; Figures; Psychophysics

1. INTRODUCTION

When exposed to a complex visual scene, we are able to select single objects while ignoring others, and report their properties. This selection, often referred to as focal attention, is provided by different modes of control (Cheal & Lyon, 1991; Nakayama & Mackeben, 1989; Weichselgartner & Sperling, 1987; Turatto et al., 2000). Extrinsic ("exogenous", "involuntary", "automatic") attention shifts are directly ("bottom-up") driven by visual signals, for example by cues that are briefly flashed at a particular location in the visual field. Intrinsic ("endogenous", "voluntary") shifts of visual attention are made under the observer's control ("top down"); such shifts are often triggered by indirect, symbolic cues (e.g., pointers) that first need to be interpreted before attention can be shifted to the intended location. Stimulus driven, bottom-up control of attention may be followed by top-down control, for example if subjects decide to keep their attention at the cued location or, on the contrary, move it away avoiding that location. In addition, attention can also be directed to objects and then appears to be faster shifted to locations within that object than to locations in other objects in the pattern (Scholl, 2001)[1]. The mechanisms underlying these different modes of control have extensively been studied[2].

The direct control of visual attention has been explored with a variety of cues such as lines, dots, squares, or circles. When the cue is presented at or near the location of a later probe stimulus (valid cues), reaction time of responses to the probe is reduced (e.g., Posner, 1980), and performance in the detection and discrimination of the probe is improved, compared to probes at non-cued locations (absent or invalid cues). By varying the delay between the cue and the probe and the exact location of both, the dynamics of attention shifts and the spatial profile of the focus of

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[1] for a more recent review, see, e.g., Chen (2012)
[2] cf. Carrasco (2011)

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attention can be measured (cf., e.g., Eriksen & St. James, 1986; Kroese & Julesz, 1989; Sagi & Julesz, 1986). In these (and many related) experiments, the cue has been used to pre-select (attend to) a spatial location, at which subsequent targets were then seen faster and better than at non-attended locations (cf. Carrasco, Ling, & Read, 2004).[3]

A different paradigm, in which the *selection* process is even more obvious, has been used to study attention shifts to salient targets (Nothdurft, 2002). From an array of lines all visible to the observer, one (the "target") was singled out by making it salient or by presenting a nearby cue; this target had then to be identified. The dynamics of the selection process and of attention shifts to the target were measured by varying the presentation time of the line array after the cue had occurred. If the pattern was masked too early, the target could not reliably be identified, even though it was presented 500 ms before the cue and must already have been well encoded in many neural processing stages in the brain. Any variations in performance should thus be related to the selection process and not be confounded with target pattern analysis.

Although the two paradigms are different – (a) sequential presentation of the cue and then a single probe vs. (b) continuous presentation of several items one of which is later marked and selected by means of a cue – the introspective percept is similar. In both cases, observers *attend* to the target. In (a), focal attention has the known effects of improving neural representation; targets are seen faster and better. In (b), only the target is recognized, all other items in the pattern are ignored. In the spatial interaction of cues and targets, however, the two paradigms are different. While in (a) the cue may locally enhance the gain for neural processing, thus perhaps fastening and optimizing the analysis of subsequent items, in (b) cues and targets are presented together and may disturb each other. The present study was designed to investigate the spatial and temporal properties of direct and indirect selection processes in paradigm (b).

An important parameter of how quickly attention is deployed to a cued location seems to be the form of the cue. Several studies have reported that large cues are less efficient in attracting attention to a small target or to stimulus details than are small cues (Benso, Turatto, Mascetti, & Umiltà, 1998; Castiello & Umiltà, 1990; Goto, Toriu, & Tanahashi, 2001; Greenwood & Parasuraman, 1999; Maringelli & Umiltà, 1998; see Cave & Bichot, 1999, for a review), but why this is so is not yet clear. It was proposed that the spotlight of attention would, like a zoom lens, adjust to the *size of the cue* (Eriksen & St. James, 1986). Large cues would then produce a more diluted attention effect than small cues (Müller et al., 2003). Thus, if cued attention would modulate gating (Sperling & Reeves, 1980; Reeves & Sperling, 1986) or stimulus permeability (Cheal, Lyon & Gottlob, 1994), large cues should, in general, be less effective than small cues. Instead of size, these data can also be related to distance. If the focus of attention is not sharp but has a gradient-like profile, modulated gating (or permeability) can also explain performance variations with the *distance of the cue* from the target (cf. Downing & Pinker, 1985; Egly & Homa, 1991; Henderson & MacQuistan, 1993); gating from a distant cue would be similarly deteriorated at target location as gating from a large cue.

This kind of size or distance related performance variations was also found in the above mentioned experiments on visual selection from saliency effects (Nothdurft, 2002). When the target itself was made salient from luminance or motion contrast, it was quickly selected and identified. This was also the case when a small cue was presented next to it. For larger cues, however, visual selection was less efficient; targets had to be presented for a longer time after the cue, and even then performance did often not reach the levels obtained with small cues.

All these findings raise the question of how visual selection is encoded in the brain. Is there a separate salience map, as originally proposed by Koch and Ullman (1985), or is salience represented in a distributed manner (Van Rullen, 2003) so that the cues themselves interfere with the encoding and recognition of the target? How does a local cue select a distant target? Is focal attention first directed to the cue and then spreads out from there? The experiments above have shown that efficiency decreases when cues are enlarged and thus located farther away from the target. Is this variation continuous? What would happen in line arrays if the cue-target distance is further enlarged so that parts of the cues are located more closely to neighboring non-targets than to the target itself? Is selection then still visually driven and bottom-up? Or do observers locate these targets mentally, under top-down control, like in indirect cueing?

A related question would be how selection is processed within figures. Several studies have reported a special role of objects in the spatial organization of attention (e.g., Duncan, 1984; Baylis & Driver, 1991; Watson & Kramer, 1999; for reviews see Scholl, 2001[4]) but it is not clear if this would also apply to the *selection* of an object from

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[3] for an overview see, for example, Carrasco (2011)

[4] and Chen (2012)

a large sample. Does a cue on one part of that object automatically select all other parts? Or does the speed of selection and target identification still depend on the distance from the cue?

1.1 Overview of the present work.

The present study was undertaken to investigate some of these questions in detail. Three major issues were addressed in the experiments: (i) Are there variations in speed and efficiency of the selection process with the distance between target and cue? Do cues and targets interfere? (ii) Is there a systematic difference between direct and indirect selection cues, or are distant cues treated like indirect cues? (iii) Do the spatial organization of a pattern and its segmentation into individual objects affect the dynamics of visual selection and subsequent identification processes? All these questions have already been extensively addressed in studies of visual attention, but not systematically yet in studies on visual selection.

The paper is divided in two parts. In part A, subjects saw arrays of oblique bars and were asked to identify the bar that was located in the center of a (briefly presented) cue. Instead of circles, which either change contrast or mean luminance when size is varied, cues were made of fixed little squares at various distances around the target. The data revealed a strong and, from a certain distance on, continuous decrease of cue efficiency with increasing cue-target distance; performance was generally better when the four dots were located near the target than when they were located farther away. Control experiments revealed that this effect was exclusively related to

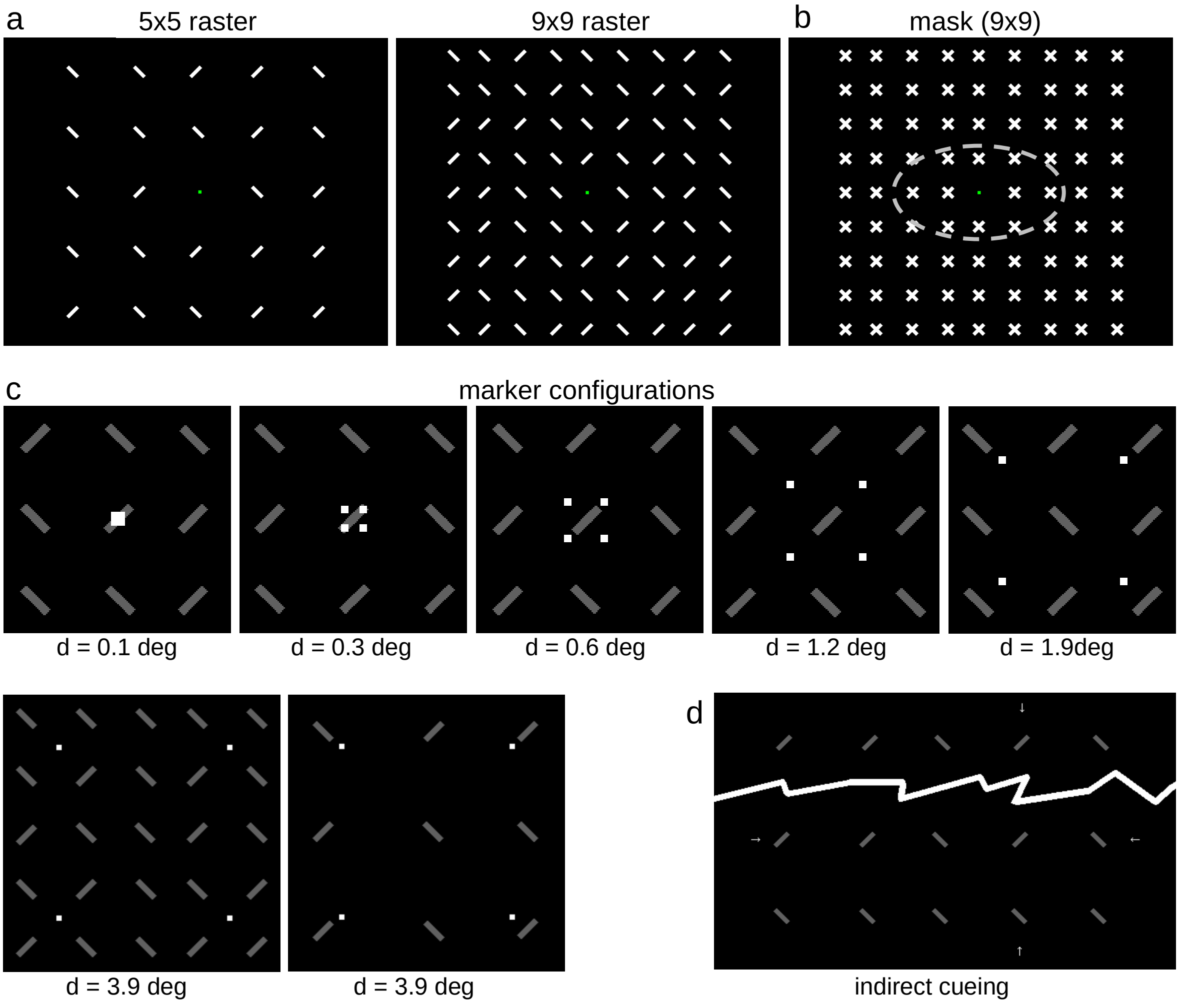


Figure 1. Examples of stimulus patterns used in part A of the study. **(a)** Arrays of 24 (5x5 raster) or 80 (9x9 raster) randomly oriented bars and a central fixation point. During presentation, one of these bars was marked and subjects had to indicate its orientation. **(b)** Mask for the 9x9 raster; possible target locations are sketched (the outline was not shown in experiments). The same raster locations (e.g., one up, one left from the fixation point, etc.), then reaching farther into periphery, served as possible target locations in the 5x5 raster; cf. Fig. 10b. **(c)** Four-dot cues as used in Experiments 1 and 3, here shown on the magnified 9x9 raster. The dots occurred at various distances, d, from the target bar and were symmetrically arranged. The largest distance (d=3.9) is also shown with the 5x5 raster. Cues occurred at one of the locations sketched in (b) thus defining that bar as the target in the actual trial. **(d)** Stimulus pattern with indirect cues, as used in Experiment 2. Row and column of the target were marked by arrows. The example is from a 5x5 test pattern; two rows are omitted.

the visual selection process; no such variations were found when the target location was known beforehand. Very close and overlapping cues, on the other hand, had a generally deteriorating effect on target visibility. This latter observation indicates that cues did not trigger the evaluation of a late and already existing neural representation of the target in the brain but started a new identification process even when the target had already been presented. Thus, there were two deteriorating effects in cued visual selection, (i) a reduced (i.e. slower) performance with too distant cues, and (ii) a reduced target visibility if cues were superimposed on the target. Near (but not too near) cues produced the best results for selection.

In a second series of experiments (part B) these tests were extended to measure figural effects in visual selection. Items were elongated objects so that cue and target locations were connected. Cues were located near to, or far from the part to be identified ("target"). Again, the distance between cue and target had a major influence on the speed and performance of the selection process. Figural effects were only important to ensure the link between cues and targets; like in part A, they could be even disadvantageous if cues were located too near the target and overlapped it.

2. PART A. Visual Selection in line arrays: the effects of cue size and cue location

Aim of the experiments in part A was to measure the efficiency of visual selection when cues were varied in size and thus located close to or farther away from the target. In order to avoid luminance variations with cue size, cues were made of four small squares symmetrically arranged around the target. The section includes three series of experiments based on very similar paradigms. In Experiment 1, the cue-target distance was systematically varied and the performance in target identification was taken as an indicator of cue efficiency for the selection process. In Experiment 2, cues were replaced by arrows pointing to the row and column of the target; this experiment was included to measure performance under indirect control of visual selection. In Experiment 3, the tests of Experiment 1 were repeated but target location was now indicated beforehand so that no visual selection process had to be started by the cue; this experiment measured the target visibility in the presence of the cue. In all experiments, two different densities of line arrays were used (Fig. 1a).

2.1 Methods

2.1.1 Overview

All tests were based on essentially the same paradigm. Subjects saw an array of orthogonal bars (Fig. 1a). One of these bars was later marked by a cue, and subjects had to indicate whether that bar was tilted to the left or to the right. Shortly after presentation of the cue, all bars were masked so that their orientation could not further be evaluated (Fig. 1b).

The three experiments differed in the way of how targets were selected (Fig. 2). In Experiment 1, target selection was visually driven and hence under exogenous control, at least for close cues. Cues were quadruples of dots (small squares) placed around the target (Fig. 1c) and briefly flashed 500 ms after the line pattern had been switched on. Experiment 2 was added as an example of indirect target selection under endogenous, top-down control. Instead of dots, a set of four pointers indicating the row and column of the target was used as cue (Fig. 1d). In Experiment 3, finally, the same cues as in Exp. 1 were used, but target location was indicated beforehand. This experiment was added to measure target visibility and to test for interactions of bars and dot cues independent of the visual selection process.

To distinguish cue-target distance effects from effects associated with the raster width of the line array, each of the three experiments was carried out on a 5x5 and a 9x9 line raster, both made from bars of the same size but arranged at different spacing. Experiment 3 was, in addition, also tested with single bars. All tests were performed under the fixation of a small dot in the center of the screen.

2.1.2 Stimuli

Stimuli were displayed on a computer monitor (100 Hz frame rate) at a viewing distance of 67 cm. Line elements were randomly left- or right-tilted, orthogonal white rectangular bars (0.8 x 0.2 deg size) presented at 9 cd/m^2 on 2.5 cd/m^2 background luminance of the screen. Stimulus patterns were made from regular (jitter free) line arrays with raster widths of 1.8 deg (9x9 raster) or 3.2 deg (5x5 raster) and covered about 15 deg by 15 deg in visual space. Masks were made from both bar orientations superimposed (Fig. 1b).

One of these bars was cued and then considered as the target, the orientation of which had to be reported. To reduce performance variations at different eccentricities, targets occurred at selected locations, on the left or right of the fixation point (as sketched in Fig. 1b; see

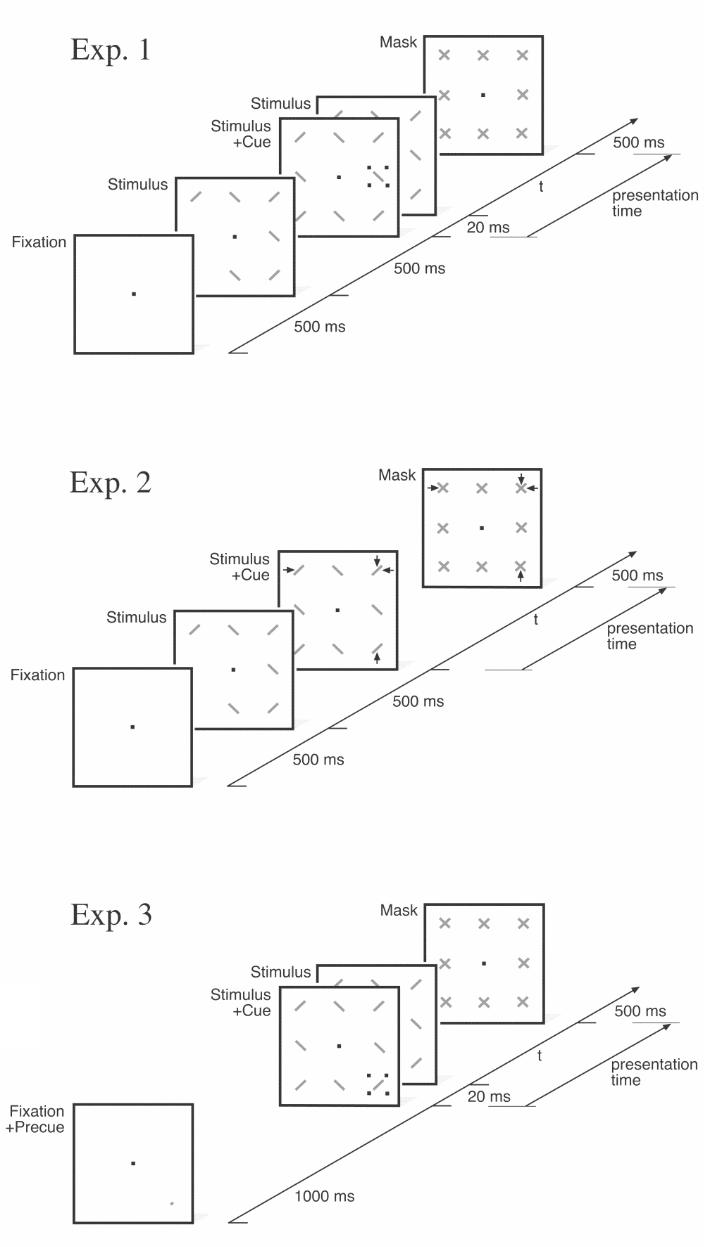


Figure 2. Presentation modes of Experiments 1-3. Performance was measured for direct (Experiment 1) and indirect (Experiment 2) control of visual selection. Experiment 3 measured target visibility in the presence (or absence) of the cues.

Fig. 10b for possible target locations in the 5x5 raster); subjects were not informed about this restriction. Target locations varied between 1.8 deg and 3.6 deg eccentricity (mean 2.5 deg) for the 9x9 raster and between 3.2 deg and 6.4 deg (mean 4.4 deg) for the 5x5 raster.

The cues in Exp. 1 and 3 were four small squares (0.2 deg x 0.2 deg) at 60 cd/m^2 luminance and a cue-target distance (center to center) of 0.1 - 3.9 deg (Fig. 1c). They were onset together with the line pattern (Exp. 3) or 500 ms later (Exp. 1), were shown for 20 ms, and then blanked (Fig. 2). The pointers in Exp. 2 (0.4 deg x 0.2 deg; 60 cd/m^2) were located immediately outside the line array (at ~8 deg eccentricity, depending on row and column; Fig. 1d). They were shown 500 ms after the onset of the line pattern and then remained present until the pattern was blanked. In Exp. 3, target location was indicated before the pattern occurred. This was accomplished by a small white ("indicator") dot (0.1 deg x 0.1 deg; 9 cd/m^2) in the center of the target, which was shown together with the green fixation spot (0.1 x 0.1 deg; 44 cd/m^2) 1 s before the line pattern (cf. Fig. 2) and disappeared when the line pattern was switched on. The same cue configurations as in Exp. 1 were tested in Exp. 3, except that cues were not delayed but already presented with the onset of the bars. Performance in Exp. 3 was also tested with patterns without any cues (but with the indicator dot shown before) and, in addition to targets in 5x5 and 9x9 raster patterns, also on single bars; in this latter test, the possible target locations of the 9x9 raster were used.

2.1.3 Subjects

Four subjects (20, 23, 34, and 54 years old; two female) including the author participated in the experiment. They all had normal or correct-to-normal visual acuity and, except the author, were naïve as to the purpose of the experiment. Two of them had served in similar experiments before. The other two carried out initial training sessions to stabilize performance. All subjects were given several training runs to let them familiarize with the task and with the short presentation times tested.

Subjects were asked to fixate a central green fixation spot while performing the tests; this was controlled for by means of a video camera zoomed in on their eyes. Fixation performance was generally very good; subjects did not shift their gaze to cues (Exp. 1 and 2) or target indicators (Exp. 3). Given the often very short presentation times, gaze shifts had generally not been advantageous to improve performance.

2.1.4 Procedure

Each trial began with the presentation of the fixation spot. Bars were shown 500 ms (Exp. 1 and 2) or 1000 ms later (Exp. 3) and, in Exp. 1 and 2, 500 ms before the cue, so that, in these experiments, stimuli were well represented in the brain before the target was marked for selection.

The independent variable of the tests was presentation time measured from cue onset until onset of the mask. Presentation time was varied between 0 ms (mask occurred simultaneously with the cue) and 2000 ms and was systematically varied over durations that revealed performance variations between chance (short presentation times) and perfect target identification (long presentation times; cf. Fig. 3). In preliminary experiments, this range was found to depend on the spatial configuration of the cue, and presentation times used with different cue conditions were optimized to cover this range.

Subjects indicated the target orientation by pressing specific keys on the left or right side of the keyboard, referring to left or right tilted bar orientations. The next trial began 500-1000 ms after the response. There was no time pressure on responses; only performance, not reaction time was analyzed. Feedback was given in summary form at the end of each run.

Experiments 1 to 3 were blocked for the raster used (5x5, 9x9, and, in Exp. 3, single bars) but otherwise all conditions were intermixed. With 6-8 cue-target distances and 6-10 presentation times for each, this gave 53-80 different test conditions in the blocks of Exp. 1 and 3, and 7-8 conditions in the two blocks of Exp. 2; each condition was tested five times in a single run (10 times in Exp. 2). The altogether seven blocks of Exp. 1-3 were each repeated five to ten times, in an interleaved fashion, so that any long-term variations should have equally affected performance in all tests. Experiments were performed in sessions of up to two hours each.

2.1.5 Data analysis

The performance in target identification for a given stimulus presentation time (after onset of the cue) was taken as an indicator of how quickly subjects could attend to the target. Data were averaged over repeated test conditions for each subject. To condense presentation, the raw data of each subject were fit by cumulative functions (cf. Fig. 3) from which the threshold presentation times (e.g., at 80% correct) for different stimulus conditions were obtained.

Averages across subjects were made using these individual threshold data. Comparisons between test series were statistically evaluated using two-factor repeated-measures ANOVA.

2.2 Results

Experiments 1-3 although here presented in sequence were interleaved in the tests. An outline of these tests is given in Figs. 1 and 2.

Experiment 1: Direct visual selection

Exp. 1 investigated the dynamics of stimulus driven visual selection. In an array of randomly oriented, orthogonal bars, one (the target) was marked (cued) and had to be identified. Aim of the

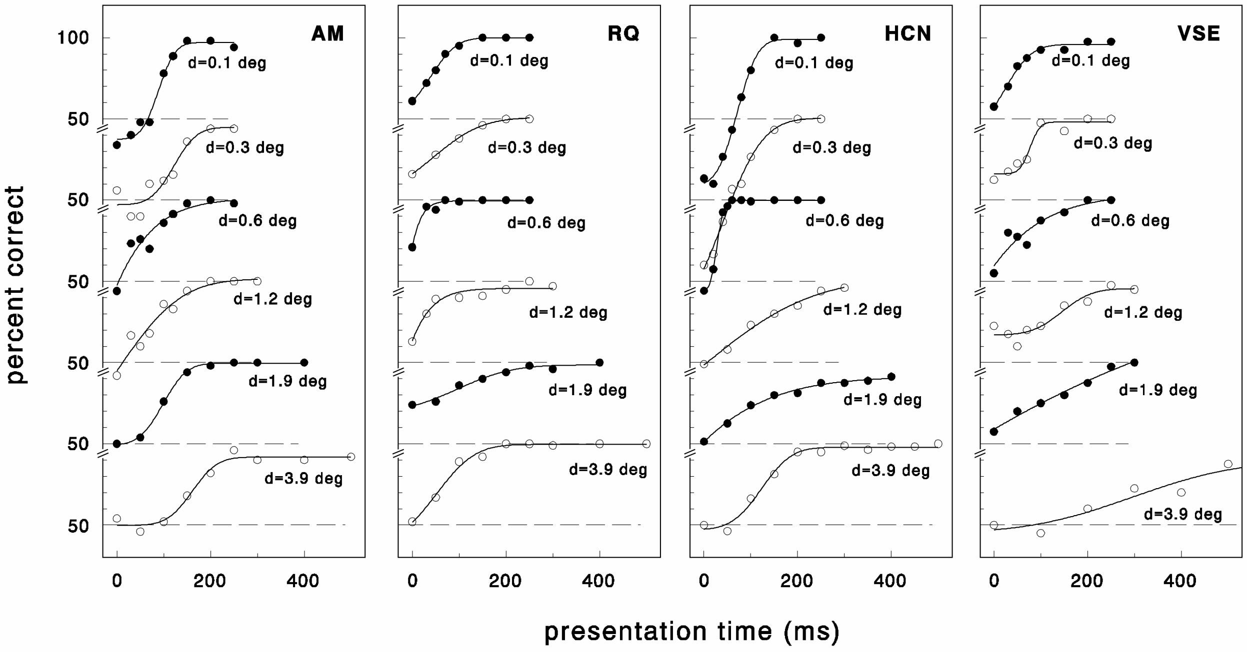


Figure 3. Individual data of four subjects in Experiment 1 (5x5 raster). Each curve plots the performance obtained with one particular cue configuration and one line raster, at different presentation times; curves are shifted by 50% for clarity. Performance generally increased with presentation time but different slopes indicate different efficiency of the various cues. Best (fastest) performance is obtained with the d=0.6 arrangement. Data points were fitted by cumulative functions (as shown) and presentation times at 80% correct were taken to indicate cue efficiency (cf. Fig. 4).

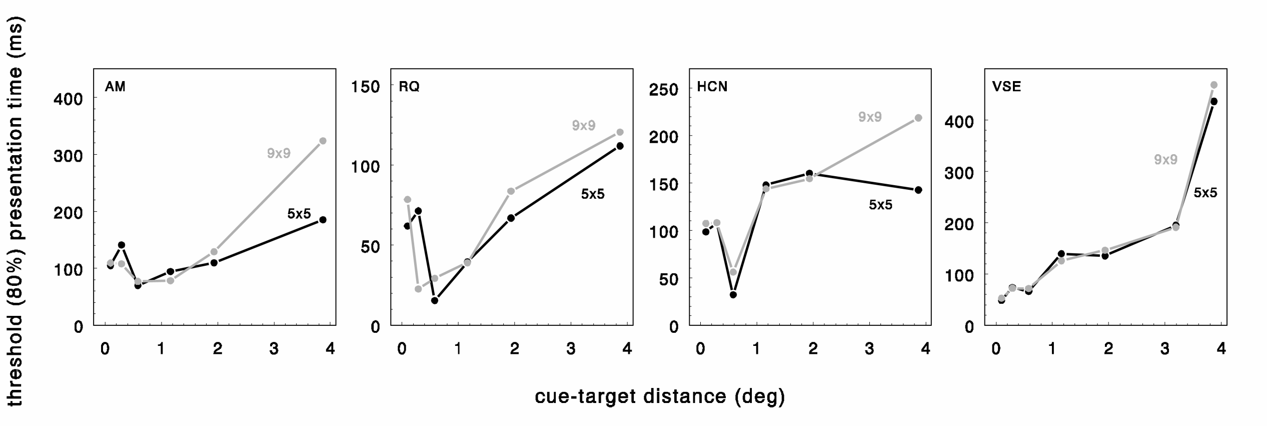


Figure 4. Cue efficiency in Experiment 1; individual data for both raster configurations. Values indicate the presentation times that produced 80% correct target identification (cf. Fig. 3). Despite large differences in performance between the subjects (note the different scales), the characteristic variations are consistent. Performance was best (shortest presentation time required) at a cue-target distance of d=0.6 deg and decreased (threshold presentation time increased) towards smaller and larger distances. In this and the following figures, data from the 5x5 and 9x9 raster are plotted in black and gray, respectively.

experiment was to study the influence of the cue-target distance on the effectiveness of this process. Cues were shown at various distances from the target, and subjects' performance in target discrimination from short presentation times was taken as an indicator of cue efficiency.

In order to keep the overall flux of light constant, all cues were made of the same four dots that were, however, placed in various distances to the target (Fig. 1c). As cueing efficiency may not only depend on the distance between cues and the target but also on the density of lines in the picture, experiments were performed on two patterns (5x5 and 9x9 raster) made of similar bars at different densities. Note that for the largest cue-target distance used, cues fell close to the bars surrounding the target, in the 5x5 raster, and even beyond these, in the 9x9 raster.

Fig. 3 shows the individual data curves of all subjects with the 5x5 raster. Each curve represents the measurements obtained with one particular cue-target distance. Along each curve, performance smoothly increased with presentation time (after cue onset) and subjects could reliably identify targets when presentation time was long enough. However, the various curves differ in important aspects. For every subject, curves changed with the distance of the four dots from the target. The largest distance, d=3.9 deg, produced flatter curves, in which reliable performance was reached at longer presentation times than with small cue-target distances. Note however, that cue efficiency did not monotonously decrease when cue-target distance was increased. Very small distances (0.1 deg and 0.3 deg) and very large distances (1.9 deg and 3.9 deg) produced poorer performance than cues at an intermediate distance (0.6 deg). Performance also varied between subjects (compare, for example, subjects RQ and VSE), but the general characteristics of performance variation with cue-target distance were consistent among subjects.

To visualize these observations, each set of data points was fitted by a cumulative function (already plotted in Fig. 3), from which the presentation time at 80% performance was taken (Fig. 4). These data indicate the cue efficiency of the various test conditions. Except for subject VSE, thresholds first decreased and then increased, when the cue-target distance was enlarged. For three subjects, thresholds were minimal for distances around 0.6 deg; hence, this cue-target distance was the most efficient in the visual selection test. The

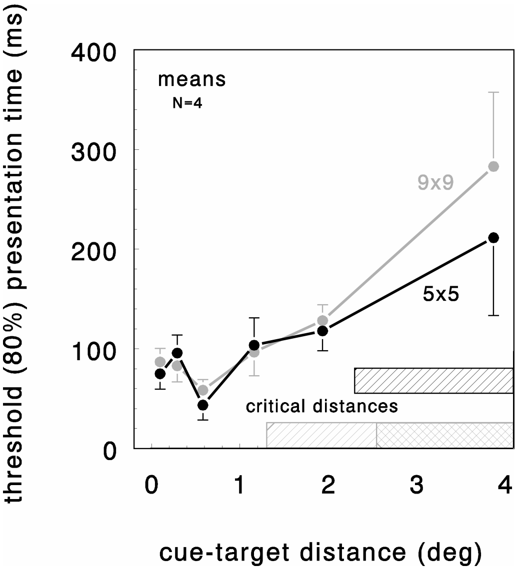


Figure 5. Cue efficiency in Experiment 1; mean data averaged from Fig. 4. Error bars plot SEM. Single-hatched fields indicate the critical distances above which dot cues were closer to neighboring bars than to the target itself. For distances over the cross-hatched field, cues were located even beyond the neighboring bars.

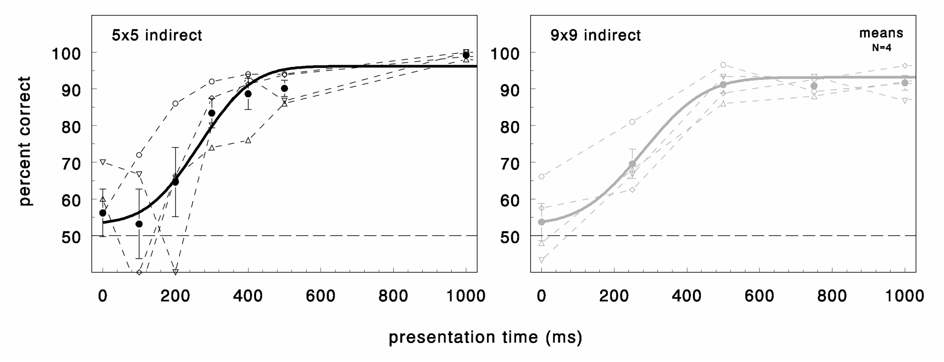


Figure 6. Performance with indirect cueing (Experiment 2). Individual data (dashed-line curves) and means (large symbols) with SEM; mean data are fitted by cumulative functions (continuous thick-line curves).

modulation is also seen in the mean data (Fig. 5). Interestingly, performance with the two raster conditions was fairly similar; only for two subjects did large cue-target distances (3.9 deg) produce different threshold presentation times.

As mentioned above (cf. Fig. 1c), the four dots of distant cues fell closer to the neighboring bars than to the target itself. (The center of all four cues together, however, was still at the selected target.) The critical distances are indicated in Fig. 5. For cue-target distances larger than double this value, cues would even fall beyond the neighboring bars; this was only the case for the largest spacing in the 9x9 raster. Although it might have been more difficult to locate the target in these tests, performance did not change dramatically when the cue arrangement exceeded the critical distance.

Experiment 2: Indirect visual selection

Exp. 2 was designed to measure the efficiency of an indirect cue. In order to use the same patterns as in Exp. 1, target selection was based on pointers located outside the line array. These pointers indicated the row and the column in which the target occurred (cf. Figs. 1 and 2).

Target identification from indirect selection cues required much longer presentation times (Fig. 6) than target identification from direct selection cues by target-near markers. There was considerable variation across subjects, but the general performance properties were consistent. Note that, again, there was only little difference between the 5x5 and the 9x9 raster patterns. Since preliminary experiments had indicated better performance for the 5x5 raster, several short presentation times were only tested in this but not the 9x9 raster (which instead had mainly been tested with longer presentation times). The cumulative fits through the mean data, however, look similar. Compared to performance in Exp. 1, indirect cueing took longer and thus was less efficient than direct cueing with even large cue-target distances (cf. Figs. 4 and 6). Only subject VSE performed slightly better with the indirect cues than with the largest cue-target distance in Exp. 1.

Experiment 3: Reduced target visibility from cue-target interaction

The decreased performance with very small cue-target distances in Exp. 1 suggests that cues did not always facilitate target identification but may have rendered it difficult in some cases. To control for visual interference, Experiment 3 investigated target visibility in the presence and absence of dots cues, using the same stimulus configurations as in Exp. 1.

Since target visibility should be measured without attention shifts, focal attention had to be already directed to the target when the stimulus pattern occurred. This was achieved by small dots indicating the target position 1 s before stimulus onset (Fig. 2). Three test series were performed in Exp. 3, one on each of the two line raster patterns, 5x5 and 9x9, and one on single bars; in all these series, target visibility was tested in the presence and absence of the various four-dot cues.

Target visibility, like target selection, improved with presentation time, and there were differences between the cue configurations and raster widths used. As in Exp. 1, the performance data of each subject were fitted by cumulative functions, from which the threshold presentation times at 80% correct were obtained; these thresholds are plotted in Figs. 7 and 8. The curves are different to those in Figs. 4 and 5. For cue-target distances > 1 deg, threshold presentation time did *not* increase with increasing cue-target distance but remained constant up to the largest distances tested, quite in contrast to the strong increase found with large cue-target distances in Exp. 1. On the other hand, target visibility with small cue-target distances was similarly deteriorated as in Exp. 1. This indicates that stimulus interactions indeed deteriorated the visibility of targets when cues were superimposed (distances 0.1-0.3 deg, cf. Fig. 1d) but that cues did not affect target visibility when the cue-target distance was large. In fact, performances at large distances were similar to those obtained when no cue was presented (indicated by the single bars on the right of each graph in Figs. 7 and 8). Thus, the deteriorated performance at large cue-target

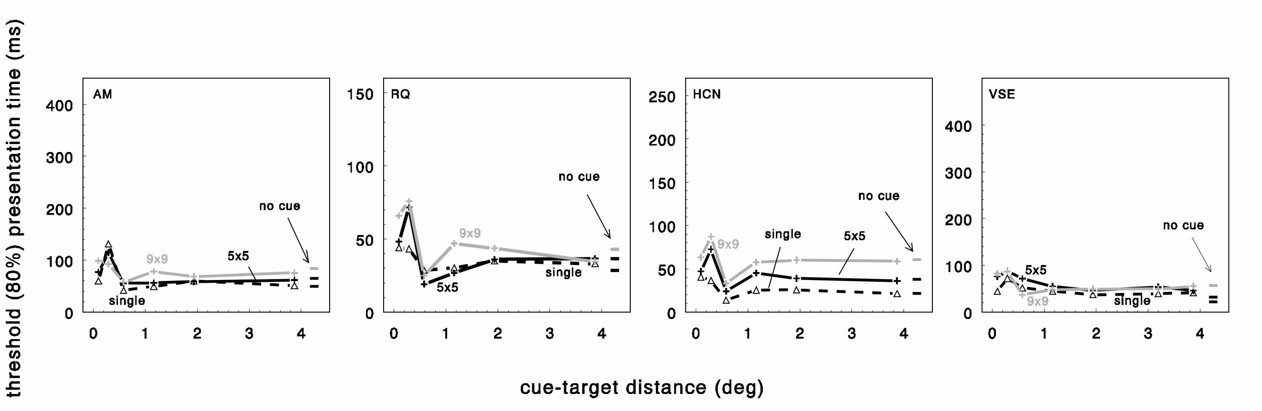


Figure 7. Target visibility in the presence of four-dot cues (Experiment 3); data are plotted at the same scales as in Fig. 4. Target locations were indicated beforehand by pre-cues (cf. Fig. 2). Data curves like in Fig. 3 were fitted by cumulative functions from which presentation times at 80% correct were taken. Tests were performed on the two raster configurations used in Exp. 1 and on single lines, as labeled. The non-connected marks on the right-hand side of each graph indicate performance when only pre-cues but no four-dot cues were shown. Target visibility was deteriorated at small cue-target distances at which the cue was superimposed on the target, but not at large distances.

distances in Exp. 1 is solely due to an inefficient and slower activation of the visual selection process. Best performance was obtained with a cue-target distance of 0.6 deg, at which visual interaction was minimal and cueing inefficiency from cue-target distance not yet pronounced.

Note that target visibility appeared to differ between the raster conditions (Fig. 8). In general, single bars (dashed curves) were seen best, i.e. required the shortest presentation time to be correctly identified, and bars in the 9x9 raster (gray) worst. However, these differences were small.

Comparison of Exp. 1, 2, and 3

Fig. 9 shows the mean data of all experiments in part A. Obviously, target selection suffered from two effects. One is due to the sensory interaction of cue and target, which reduced the target visibility up to cue-target distances of 0.3-0.5 deg. This effect was also seen in the measurements of target visibility when attention was already located at the target position, and thus is not related to visual selection. The second effect is the performance deterioration at large cue-target spacing; this was not observed in the target visibility test. According to the mean data, dot cues 4 deg away from the target were about as (in)efficient as the indirect cues located outside the entire line pattern (dashed lines).

Note that the mean data in Fig. 9 do not indicate strong variations with the raster of the bar pattern. Both the 5x5 and the 9x9 raster produced similar effects (although targets in the 5x5 raster were, on average, presented at larger eccentricities than targets in the 9x9 raster, cf. Methods). Only for the largest cue-target spacing tested (distance 3.9 deg) did cue efficiency deteriorate more strongly with the 9x9 raster than with the 5x5 raster. However, in this condition dot cues were located beyond the neighboring bars (Fig. 1c) which might have rendered direct selection difficult. Here, performance reached that obtained for indirect cueing (horizontal dashed lines). Also for target visibility, there were only small (though consistent) differences between the two raster and the single bar condition.

2.3 Statistical evaluation

Statistical significance of differences was established in two-factors, single or repeated measurements ANOVA. The performance differences with cue-target distance were all reliable and the general variations of threshold

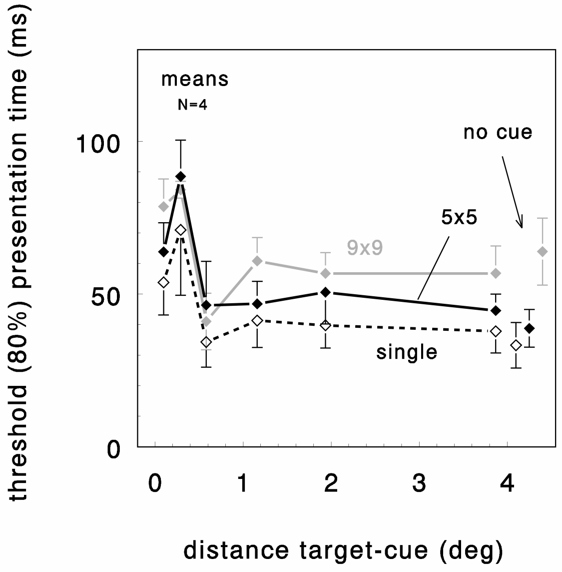


Figure 8. Target visibility in Experiment 3; means and SEM of data in Fig. 7.

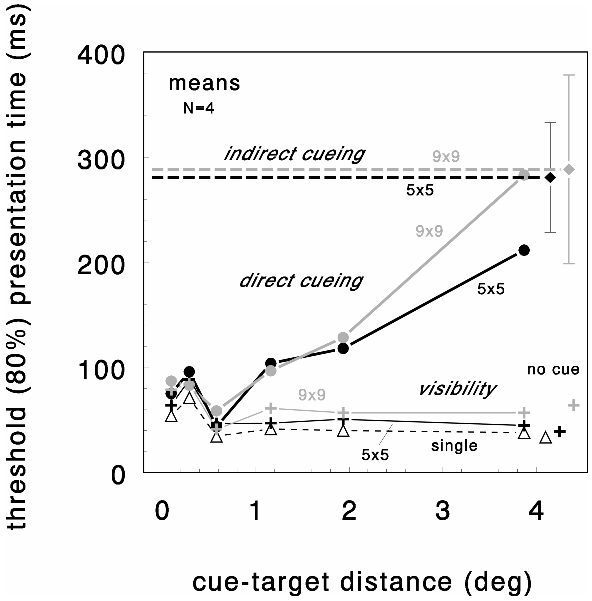


Figure 9. Summary plot of part A of the study (Experiments 1-3). Performance under direct cueing (Experiment 1) was affected by the reduced target visibility at small cue-target distances (Experiment 3) and by an increasing cue inefficiency at larger distances. Indirect cueing (Experiment 2) was similarly delayed as direct cueing with distant cues.

presentation time were significant both for visual selection [Exp. 1; F(5,15)=8.27, p<0.001] and target visibility tasks [Exp. 2; F(6,18)>5.11, p<0.002]. In Exp. 1 (direct visual selection), the performances with the two raster sizes were not significantly different, neither in the pool of data [F(1,3)=0.30, p>0.58] nor in the individual data of single subjects [F(1,1)<1.68, p>0.25]. Also in Exp. 2 (indirect visual selection), threshold presentation times did not differ significantly between the 5x5 and the 9x9 raster [F(1,3)=10.1, p>0.05] and also were not significantly different from the threshold presentation times obtained for the largest cue-target distance in Exp. 1 [F(1,3)=1.40, p>0.25]. In Exp. 3 (target visibility), the differences between the different line configurations (single, 5x5 and 9x9 raster) were generally significant [F(2,6)=8.40, p<0.001]; however, only the extreme differences between single bars (best performance) and the 9x9 raster (worst performance) were large enough to reach statistical significance [F(1,3)=16.5, p<0.001]; the intermediate differences between single bars and the 5x5 raster or between the 5x5 and the 9x9 raster were too small to become significant with the given variation across subjects [F(1,3)<4.68, p>0.03]. Only for one subject were all these differences significant [F(1,1)>15.3, p<0.02].

Most important in the outline of the study are the differences between visual selection and target visibility, i.e. between data from Exp. 1 and 3. These differences were highly significant [F(1,3)>15.0, p<0.001] indicating that the diminished performance with large cue sizes in Exp. 1 is not due to cue-target interferences that should have affected target visibility itself (Exp. 3).

2.4 Discussion

The experiments of part A have revealed three major findings. (1) Cued targets were only quickly selected and discriminated when the cues were located near the target; with increasing distance performance slowed down so that targets had to be presented for a longer time after onset of the cue to have them correctly identified. (2) Cues placed upon targets affected target visibility so that, again, presentation time had to be increased for reliable target identification. This effect was, however, not caused be the visual selection process but was similarly seen when target location was already known. (3) Targets selected by indirect cues (pointers) needed longer presentations for correct identification than targets directly marked by nearby cues. However, the difference between *distant* direct and indirect cues was small and not significant. Although none of these findings is unexpected in the context of partly similar observations in the attention literature, they stress the similarities and certain differences of visual selection and spatial attention.

2.4.1 Cue size, cue-target distance, and visual attention

Several studies have reported that (exogenous) cueing effects are reduced when the *size of the cue* is larger than the size of the test stimulus ("zoom lens" effect; Eriksen & St. James, 1986). Castiello and Umiltà (1990), for example, measured the reaction time to a single imperative stimulus cued by small or large squared boxes. Reaction time was significantly shorter for valid than for invalid cues, but this benefit was reduced when the boxes were enlarged. These results were confirmed in a number of subsequent studies (e.g., Benso et al., 1998; Greenwood & Parasuraman, 1999; Maringelli & Umiltà, 1998). Benso et al. (1998) measured the dynamics of cueing effects with small and large circular cues and found similar differences even when the target location was already known. In the present study, cue size effects disappeared when the target location was known in advance (Exp. 3). Only when the target location was unknown, the differences between small (near) and large (far) cue arrangements were pronounced. Subjects needed, on average, presentation times of 200-280 ms to reach 80% correct performance with the largest cue-target distance, but only 40-60 ms with the 0.6 deg distance. Thus, despite the differences in the task (response to an imperative stimulus in Benso's et al. study vs. target selection and identification in the present study) and in measured parameters (reaction time vs. percent correct), the findings are qualitatively similar; both studies revealed a generally reduced performance with the larger (i.e., more distant) cue. Maringelli and Umiltà (1998) noticed that the size effect disappeared when trials with the same cue size were shown repeatedly, and concluded the presence of top-down interference. Size effects were only observed when cues of different sizes were interleaved in the test. In the present study, all cue-target distances of a given raster were intermixed in a test block, so that adaptation and top-down effects of this sort should not have occurred.

Beside the above mentioned effects of cue size on attention, a number of studies have also reported reduced cueing effects when the *distance between cue and target* was increased. Henderson and MacQuistan (1993) measured both reaction time and accuracy in target discrimination when cues were placed at the target location or at various locations elsewhere in the pattern. They found both benefit and cost effects which, however, varied in a graded manner with the cue-target distance. Similar findings were reported by Egly and Homa (1991), also for both accuracy and reaction time, and by Downing and Pinker (1985) for reaction time. All these studies stress the role of cue-target *distance* rather than cue size for the allocation of attention and thus seem to support a gradient model, different to the zoom lens model mentioned above.

The present work differed in important aspects from these studies in which stimulus patterns comprised only one or two targets, which themselves were salient and thus should have attracted attention even without an additional cue (cf. Nothdurft, 2002; Remington, Johnston, & Yantis, 1992; Theeuwes, 1991). Therefore, the observations above may also reflect interactions between two attractors (although the effect was measured on only one of them). In the present study, the patterns comprised a large number of items (and possible targets), all shown long before the cue. No onset effect after the cue has captured attention; selection was only controlled by the cues [and, likely, by local variations of feature contrast in the line patterns (cf. Nothdurft, 1993) which should have averaged out over repeated trials]. Interestingly, the major findings of both sets of experiments are qualitatively similar; performance deteriorated when the cue-target distance was increased.

2.4.2 Cue-target interaction and masking

Exp. 3 revealed noticeable cue-target interactions; target *visibility* was reduced when the cues were superimposed. This suggests the presence of masking effects, which have extensively been studied in earlier work (Breitmeyer, 1984; Enns & Di Lollo, 2000; Enns, 2004). Large cue-target distances, on the other hand, did not affect target visibility. The reduced performance with these cues in Exp. 1 must thus have been due to a slower and less efficient target *selection* process. Both observations, the reduced target visibility when the cue is superimposed and the reduced efficiency to identify a target that is marked by too far (or too large) cues, underline the need that cue-target interactions must be carefully controlled when attention effects from cueing are investigated. Depending on the task and the form of the target, but also on the size, form, and location of the cue, cueing effects may strongly affect target identification. In particular, cues and targets must not be looked at as independent objects.

The observed interference of cues that are superimposed on the target is particularly interesting. While in Exp. 3 the cues are presented together with the target, which would explain the observed interference, targets in Exp. 1 had already been presented for half a second when the cue occurred, and should thus have been well encoded in the brain, at least in early processing stages. Nevertheless target identification was similarly deteriorated in both experiments (Fig. 9). This indicates that cued selection does not extract the neural representation at higher areas, bypassing earlier processing stages, but interferes with the pattern analysis right from the beginning, in early processing stages. On this basis one may wonder whether cueing effects are indeed encoded in a separate area ("salience map"; cf. Koch & Ullman, 1985) with access to various processing levels simultaneously. Salience may be rather represented in a distributed manner across all levels of processing (Van Rullen, 2003) so that the selection process can not be separated from pattern analysis. With the same argument, the finding can also be taken as evidence against late selection (cf. Yantis & Johnston, 1990).

Enns and Di Lollo (1997; for reviews, see Enns & Di Lollo, 2000, and Enns, 2004) have reported a strong and new masking effect that, on the first view, seems to be closely related to the findings of the present study. It was obtained with four-dot masks similar to the cues in Exp. 1 and strongly depended on *shifts of focal attention*. This should be different from the disturbances at small cue-target distances in the present study, which were also found when no attention shifts occurred (Exp. 3). Enns and Di Lollo (1997) discussed two possible sources for the observed effects, one which they call "camouflage masking" – a degradation of the target through the addition of masking noise – and one to which they refer as "substitution masking" – a competition in object recognition between target and mask when the mask appears before the target has been fully processed. While camouflage masking may indeed be responsible for the deterioration of target visibility at small cue-target distances in the present study, I will argue that that substitution masking cannot account for the degraded performance at large distances.

From Exp. 1 alone it is not evident whether the deterioration of performance at small cue-target distances was due to a noisier target representation or to a weaker cueing signal. Since the luminance contrast of a cue superimposed on the target is smaller than the luminance contrast of a cue presented on the dark background, superimposed cues may be less salient, and hence less effective in attracting attention, than non-superimposed cues. However, this difference should then have disappeared in Exp. 3, where target locations were known in advance. The fact, that target identification in Exp. 3 was similarly affected with superimposed cues, suggests that the target was camouflaged and target visibility itself was disturbed by the cue.

Substitution masking, on the other hand, has several properties which were not found in the present study. (1) It develops over time and is most pronounced when the mask is presented for a long time and, in particular, even after the target is switched off (Di Lollo, Enns, & Rensink, 2000). In the present study, however, cues were only briefly shown (20 ms) and usually disappeared long before the target was “switched off” (i.e., masked by an X; cf. Fig. 1b). In addition, the target (together with all other items) was shown 500 ms before the cue (Exp. 1) so that the paradigm did not resemble a situation in which the mask (here, the cue) “appears before the target has been fully processed" (Enns & Di Lollo, 1997). However, this might have been the case if the target was newly analyzed after application of the cue. (2) It is important to note that Di Lollo et al. (2000) did *not* find a distance effect, which was, however, an essential finding of the present study. In a later study, Jiang and Chun (2001) reported that substitution masking varies with cue-target distance, but the distance effect they found was opposite to the distance effect observed in the present study. They reported substitution masking to decline as the mask moved away from the target, whereas in the present study target identification became more and more difficult when the cue-target distance was increased. (3) As already mentioned, Di Lollo et al. (2000) and Enns and Di Lollo (1997) have reported a strong dependence of substitution masking from set size, whereas set-size variations in the present study (24 items in the 5x5 pattern vs. 80 items in the 9x9 pattern) did not produce largely different effects. Since targets were cued in the present study, a strong set-size effect (believed to reflect sequential shifts of attention) was not to be expected. (4) The main argument for assuming different mechanisms are the different time courses of object substitution masking and of the distance effects in the present study. Substitution masking reduces discrimination performance at and shortly after presentation of the mask (Enns & Di Lollo, 1997) and is strongest when the mask continues to be displayed after the target is switched off (Di Lollo et al., 2000), which was not the case in the present study. Here, an increased cue-target distance *generally* reduced the performance in target discrimination. That is, the rise of performance with presentation time was slower and, for very large cue-target distances, performance did sometimes not reach the level obtained with small distances (cf. Fig. 3, subject VSE). Thus, target discrimination was not decreased for a limited time as reported for substitution masking (Enns & Di Lollo, 1997) but was generally deteriorated.

2.4.3 Direct and indirect cues in visual selection.

There has been long accumulated evidence for different dynamics of exogenous and endogenous control of attention; endogenous control has always been reported to be slower (Chastain & Cheal, 1998; Cheal & Lyon, 1991; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Weichselgartner & Sperling, 1987; Turatto et al., 2000). This was also observed in the present study. A similarly slow performance was only obtained for "direct" cues that were located far away from the target (distance 3.9 deg) and eventually separated from it by other items (cf. Fig. 1; raster 9x9).

This raises the question, however, whether cueing was indeed different in these two particular cases. For directly controlled visual selection (Exp. 1), large cue-target distances required the global evaluation of dot positions to locate the target in the center of that cue. This might have been similar to the situation in Exp. 2, where targets could also be located from the global inspection of the four row and column pointers. The data indicate a continuous increase of the speed of direct visual selection (Exp. 1) between cues close to the target and cues farther away; performance with the farthest cues was similar to that for the particular test of indirect visual selection in Exp. 2. This thus suggests a smooth transition of one mode into the other if cue-target distances become too large. But it is also feasible that other paradigms of indirect cueing might have produced even slower performance, in particular, if the meaning of indirect symbolic cues had been less immediate than the set of pointers used here.

The time courses of direct and indirect visual selection in the present study are in the same order as values of attention shifts reported in the literature. However, detailed reports on the dynamics are rare and different paradigms and measures render direct comparisons difficult. In addition, the exact form and location of cues and targets would be important, as the present study shows. These parameters also differed between studies. In general, direct cueing can produce quite fast attention effects. In a target discrimination task with an exogenous cue under fixation, Gottlob, Cheal, and Lyon (1999) found maximal performance for presentation times around or even below 100 ms. This is similar to the performance with small cue-target distances in the present study. For the optimal distance (d=0.6 deg), 80% performance was already obtained with 40-60 ms presentation time; the value increased towards larger and smaller cue-target distances (cf. Fig. 9).

The time course of attention effects from indirect cueing is slower. Remington and Pierce (1984) found cueing effects (on reaction time) to start at about 100-150 ms and continuously increase up to 200-500 ms, at least. Similar values were reported by Müller, Teder-Sälejärvi & Hillyard (1998) who compared attention shifts in evoked potentials with the performance of subjects in a behavioral task. These values correspond well with the present measurements in Exp. 2 (Fig. 6) which show a beginning increase of target discrimination for presentation times of 100-200 ms and maximal performance around 400-500 ms.

Much of this time, both for indirect and for direct cues, is needed to locate the target (cf. Adam, Ketelaars, Kingma, & Hoek, 1993), i.e. for the visual selection process. When target location was known in advance (Exp. 3), subjects could quickly identify the target, and performance speed was similar to that for the optimal cue-target distance (Fig. 8). This indicates that the process of target identification itself contributes only little to the sometimes long delay until 80% correct performance is achieved.

Altogether, the present findings do not suggest a systematic difference between the frequently studied cueing effects of a single cue upon a single probe and cueing effects when selecting one target from a large sample, as tested in the present work.

3. PART B. Cued Selection of Figures

The second part of the paper investigated distance effects in figural objects. It has been shown that probes on an object are seen faster and better when cued by a mark inside this object than when cued by an equidistant mark upon a different object (Egly, Driver & Rafal, 1994; Goldsmith & Yeari, 2003). Also, attention shifts between different locations within an object are faster than attention shifts from one object to another (Iani, Nicoletti, Rubichi, & Umiltà, 2001). Given the findings of part A that near cues were more efficient than far cues in allocating focal attention to the target, it was studied whether this would also hold when cues and targets are connected to form one single object. Or would distance effects perhaps be compensated for by the figural link?

Experiment 4: Target selection in cued figures

The aim of Experiment 4 was to measure the speed of visual selection of targets that are connected with the cues. The cue-target distance was varied. Performance in this task was compared with performance on similar cue-target configurations in which the figural link was missing.

3.1 Methods

3.1.1 Overview

Stimuli were line arrays similar to those used in Exp. 1-3, except that each bar had a "tentacle", an additional thin line extending into either horizontal or vertical direction (Fig. 10). These tentacles were randomly oriented but care was taken that the tentacles of neighboring bars did not reach into the same free space between neighboring bars. Cues were single dots located on the tentacle at different distances from the bar, or on the bar itself.

The test procedure was similar to that of Exp. 1. Cues occurred half a second after pattern onset, and after a variable delay ("presentation time") the pattern was masked. Subjects were asked to indicate the orientation of the cued bar; performance was taken as a measure of speed and efficiency of the target selection process.

In order to identify specific figural effects from the tentacles, the same set of stimuli but without tentacles was investigated in a second (interleaved) series of tests, for comparison.

All tests were performed under fixation and on the same subjects as in Exp. 1-3.

3.1.2 Details

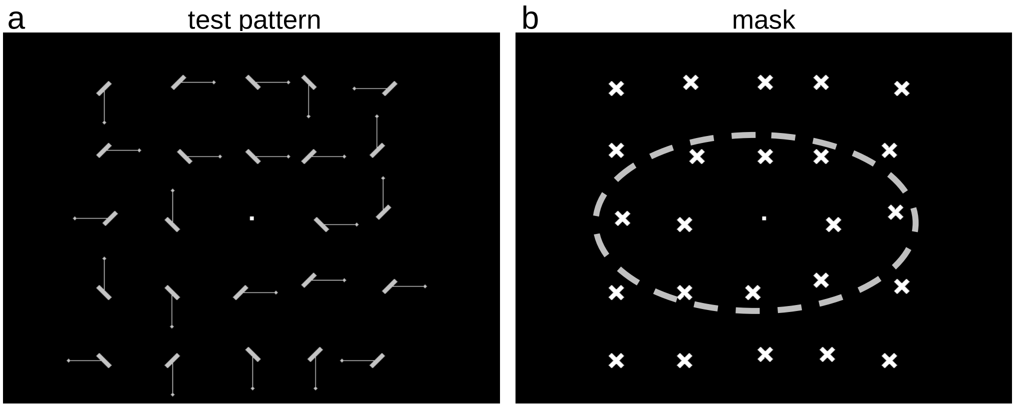
Stimuli and test procedures were identical to those of Exp. 1, with the following deviations.

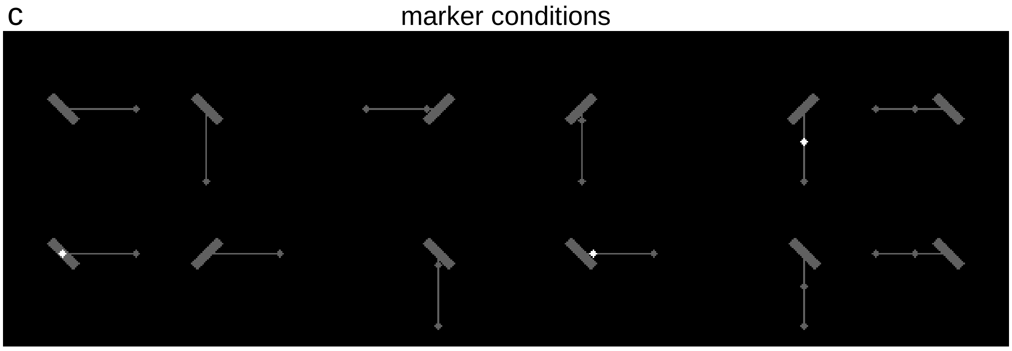
Only the 5x5 raster, now with a raster width of 3.0 deg and a positional jitter of up to ±0.15 deg, was used (Fig. 10a). Tentacles were 1.5 or 2.1 deg long, the longer ones only being used in the "very far distance" condition (Fig. 10c). Bars (and tentacles) had a luminance of 9 cd/m^2 and were masked by slightly brighter crosses (17 cd/m^2;

Fig. 10b). Note that tentacles were not present in the mask patterns to hinder subjects from locating the target once the mask had been switched on.

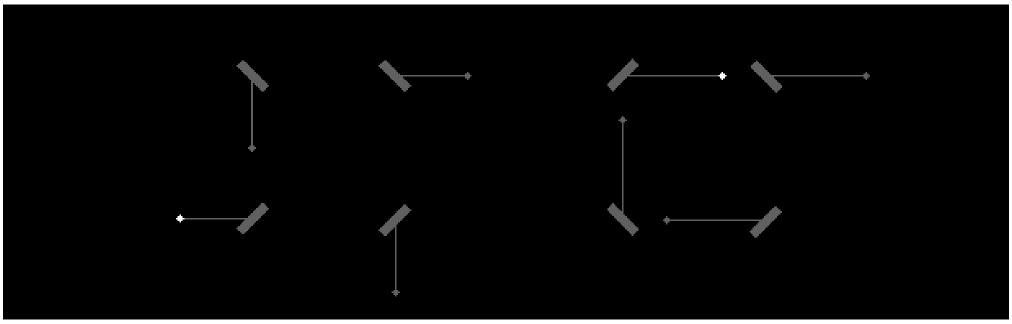
Targets occurred at selected locations at 3-6 deg eccentricity (mean 4.1 deg; cf. Fig. 10b). Cues were single bright dots (60 cd/m^2) located on the bar or the tentacle of the target figure. They were presented 500 ms after onset of the test pattern and were shown for 50 ms. Five cue locations with different cue-target distances, d, were used: *upon line* (d=0 deg), *near* (d=0.25 deg), *medium* (d=0.7 deg), *far* (d=1.5 deg) and *very far* (d=2.1 deg; for this distance, the positional jitter was zero) (cf. Fig. 10c). Presentation time was varied between 0 ms and 500 ms.

In order to identify figural effects in visual selection, the performance in patterns with tentacles was compared with that in patterns from





upon line near line medium distance



far distance very far distance

Figure 10. Stimulus patterns of Experiment 4 for the investigation of figural effects (part B of the study; only 5x5 raster configurations were used in this part). **(a)** Test patterns were line arrays, as in the previous experiments, but each bar was now linked to a thin line (tentacle) upon which one-dot cues were presented. **(b)** Mask; possible target locations are sketched (outline not shown in experiment). **(c)** Enlarged examples of cue configurations; cues were briefly enhanced in luminance (as illustrated). Procedure and task were similar to Experiment 1; i.e., 500 ms after pattern onset (a) one element was marked (and thus selected) by the presentation of a bright dot. Soon thereafter the pattern was masked (b). Subjects had to indicate the orientation of that line. Two sets of stimuli were tested for comparison, patterns with tentacles, as shown, and similar patterns from which the tentacles had been removed.

which the tentacles had been removed so that cues and bars were not connected.

Tests were blocked for cue distance (5 conditions) and tentacles present or absent; each of the 10 blocks contained 20 repetitions of all presentation times intermixed. Every block was repeated five times, in an interleaved fashion, so that each data point from every subject represents an average of 100 repetitions.

All subjects (except the author) were naive as to the purpose of the experiment.

3.2 Results

Fig. 11 compares the data curves of all subjects for cue conditions *upon* and *far* in tentacle patterns. Performance varied between subjects, but all showed a similar difference between these two conditions; patterns in the *far* condition needed longer presentation times than patterns in the *upon* condition to reach the same similar detection rates.

The mean data curves for all tentacle conditions are superimposed in Fig. 12. Curves for cue locations *upon*, *near* and *medium* fell close together; performance quickly increased with presentation time. Curves for the cue locations *far* and *very far* also fell together but with a slower increase of performance (Fig. 12a).

Since tentacles reached out towards neighboring bars, cues in the *far* and *very far* condition might eventually have been falsely linked to the neighboring bar instead of to the target (e.g., to the upper right bar in Fig. 10c, *very far*). To test for such perceptual "mislocations", data were also analyzed for correct responses to the neighboring bar in the direction of the tentacle. For tentacle patterns, this rate remained low (Fig. 12b).

Fig. 13 shows the same data for patterns in which the tentacles had been removed. Again, performances with *near*, *medium* and *upon* cue distances were very good, whereas performances with the *far* and *very far* distances were slow and now even deteriorated, since target detection rates did not reach 100% correct, even not with long presentation times (Fig. 13a). This was due to uncertainties in target selection when cues were located between the intended target and the neighboring bar. Accordingly, hits for neighboring bars notably increased in *far* and *very far* conditions (Fig. 13b). The comparison of Figs. 12 and 13 then shows that tentacles had helped to guide selection but had not entirely compensated for the delay caused by an increased cue-target distance in these patterns.

A closer look into these data (Fig. 14) reveals the major differences between tentacle and tentacle-free stimulus conditions. For *upon* line cues, there was no difference at all. For *near* and *medium* distances, tentacle-free targets were seen slightly *better* than targets with tentacles. For *far* and *very far* distances, the performances with tentacle-free patterns were similar but did not reach 100%.

Fig. 15 summarizes these effects. The curves in Fig. 14 were fit by cumulative functions, from which the threshold presentation times at 75% correct were calculated (the 75% value was taken because some curves did not reach the 80% value used in part A). The partial advantage and disadvantage of adding tentacles to the line patterns is obvious. For *near* and *medium* distances, cues upon tentacles were less effective than cues without tentacles. For *very far* distances, on the other hand, tentacles had helped to select the correct items.

In summary, thus, the figural link between the cue and the target in Exp. 4 did not cancel the distance effect found in part A. Even with tentacle objects, cues located far away from the relevant part of the figure (the bar) produced slower performance than cues that were located close to it.

3.3 Statistical evaluation

For tentacle patterns, the differences between cues upon, near and at medium distance were generally not significant [pair wise two-factors repeated measures ANOVA; F(1,3)<0.04; p>0.85];

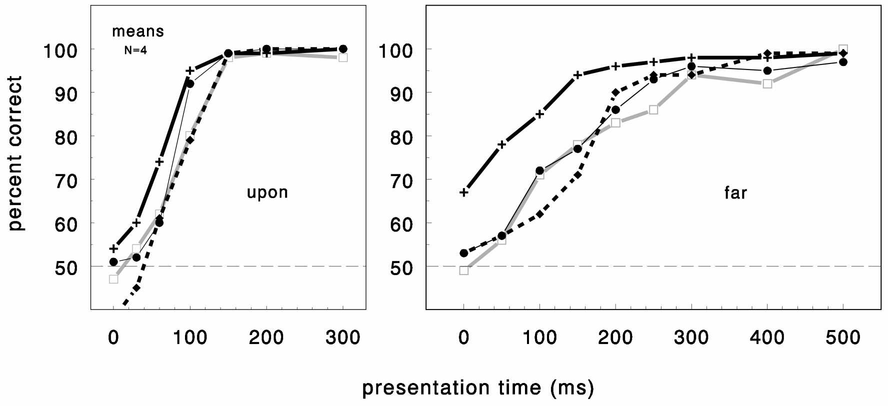


Figure 11. Individual data of all subjects with two cue conditions of Experiment 4; stimulus patterns with tentacles. Despite variations across subjects, there were consistent differences between cues presented upon the target bar (left) and cues presented at far distance (right).

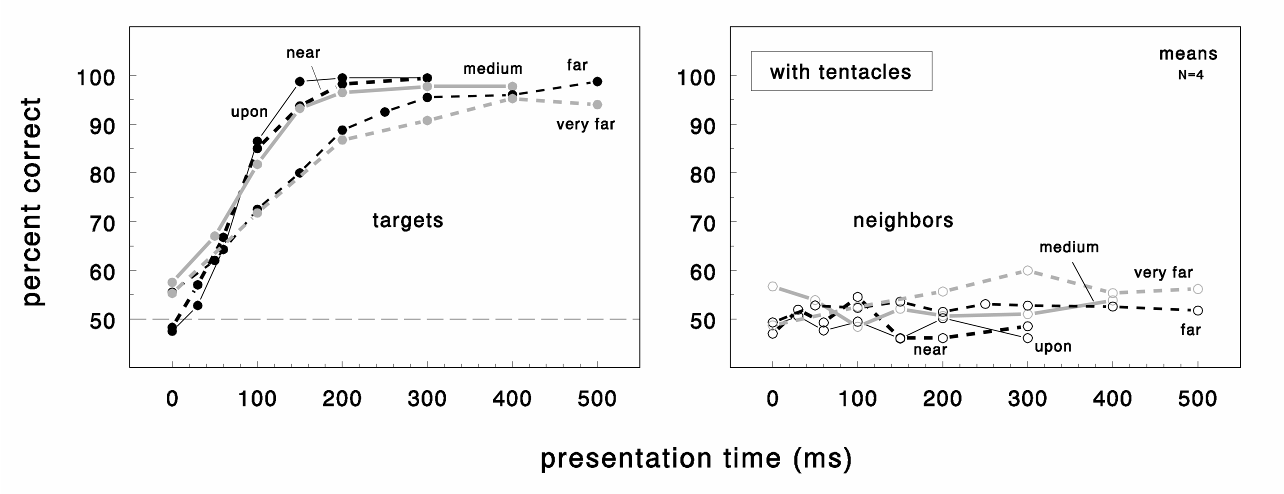


Figure 12. Mean performance curves in Experiment 4, for patterns *with tentacles*. (For readability, error bars are not shown, but see Fig. 14.) **(a)** Data for target identification when cues were located at various distances from it. Performance increased with presentation time; far and very far cue locations were less efficient than cue locations upon or near the bar and at medium distance. **(b)** Same data analyzed for correct identification of the neighboring bar in the direction of the target's tentacle. If neighbors were mistaken as target, then performance should be well above chance. Erroneous selection of neighboring bars was rare, even in the "very far" condition.

the same was true for the tentacle-free patterns [F(1,3)<2.04; p>0.16]. Also, the differences between far and very far conditions were not significant with tentacles [F(1,3)=1.42; p>0.24] and just significant with tentacle-free stimuli [F(1,3)=5.60; p<0.05]. All other pair wise comparisons were highly significant in the tentacle-free conditions [F(1,3)>17.5; p<0.0005] and significant in the tentacle conditions [F(1,3)>6.41; p<0.02].

The differences between patterns with tentacles and patterns without were just not significant for near and medium distance conditions [F(1,3)=3.87; p<0.06 and F(1,3)=2.95; p<0.1], probably because of performance variations among subjects (but see Fig. 14). The differences at far and very far distances, however, were significant [F(1,3)>15.8; p<0.001].

3.4 Discussion

Exp. 4 documented better line discrimination when the selection marker was located near the line than when it was located farther away. This finding is similar to that of Exp. 1 where cues and targets were separated and not embedded in the same figure. Thus, even in the tentacle patterns the cue-target distance effect prevailed and had modulated performance; it was not cancelled by the perceptual organization of the pattern in figural entities. But tentacles were not without any effect, as they it had helped to select the correct target in ambiguous cases. The identification rates of targets with *far* cues and no such figural link were poor, but this was due to an unclear target selection, not to the speed of the selection process itself.

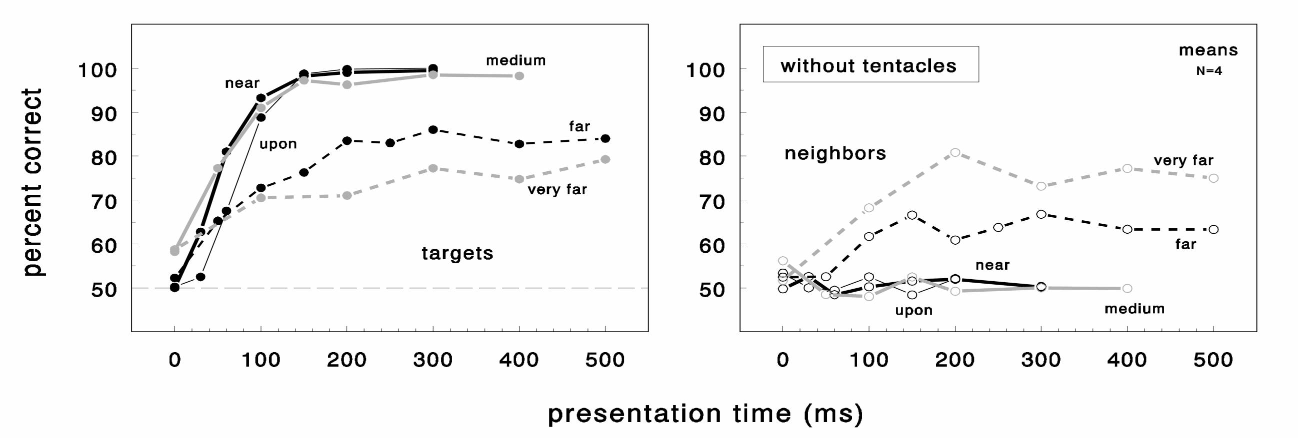


Figure 13. Mean performance curves in Experiment 4, for patterns *without tentacles*. (Error bars in Fig. 14.) **(a)** Data analyzed for target identification and **(b)** for identification of the neighboring bar next to the cue. Performance increased with presentation time, but many errors were obtained for far and very far cues, which were frequently linked to the wrong item.

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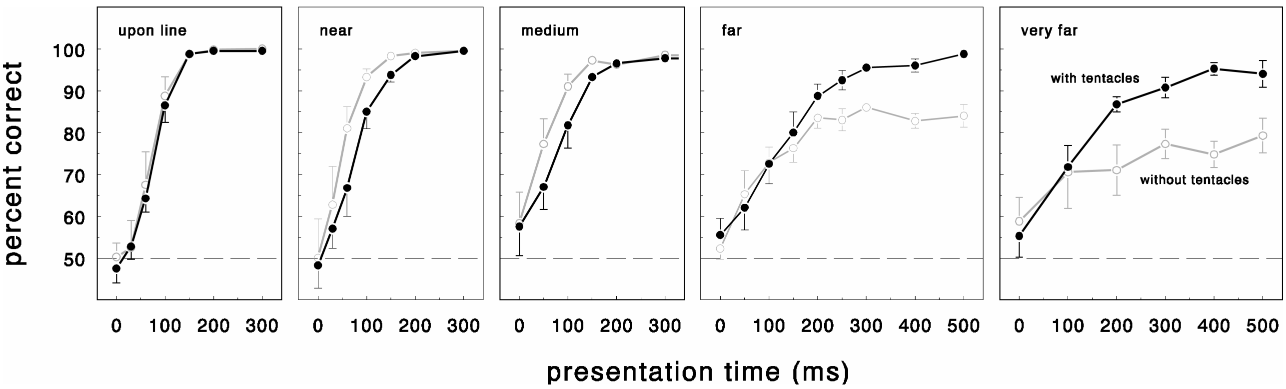

Figure 14. Comparison of cueing effects with tentacle (black) and tentacle-free (gray) patterns; mean data re-plotted from Figs. 12 and 13, now with SEM. There are no differences between the cue-upon-line conditions (left graph). For near and medium cue-target distances, targets were better seen in tentacle-free patterns than in patterns with tentacles. Only for far and very far cue-target distances had tentacles improved performance; however, the similar rise of slopes and the lowered plateaus with tentacle-free patterns indicate that the difference is not based on a faster or slower selection process but on an erroneous target selection when tentacles had been removed.

This interpretation is supported by the observation that long presentation times (up to 500 ms after onset of the cue) did not improve performance above the value that was already reached at 200 ms. Long presentations should have compensated for performance deteriorations caused by a slow selection process but should not have affected the error rate if subjects failed to link the cue to the correct target.

The reduced performance with figural links at near and medium cue-target distances, on the other hand, is likely explained by sensory interactions between the cue and the target and perhaps by a reduced salience of the markers. When cues were superimposed on parts of the figure, the resulting cue contrast, and hence its salience, was reduced. For cues *upon* the *target* there was no difference, and hence performances in tentacle and tentacle-free patterns were identical (Fig. 14). For near and medium distances, however, the target patterns differed. With tentacles the cues remained to be presented upon a part of the figure, and performance remained constant. Without tentacles, however, the cues begin to separate from the target line, and performance was slightly improved.

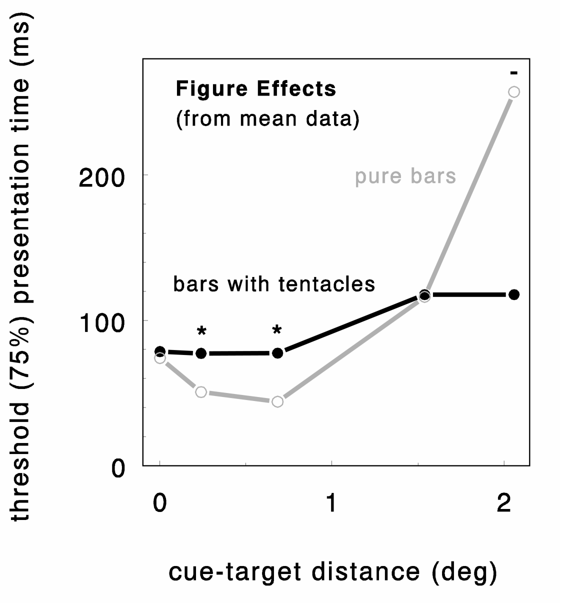

Figure 15. Summary plot of part B of the study (Experiment 4). Data points of Fig. 14 were fitted by cumulative curves; the resulting presentation times at 75% correct performance are plotted against cue-target distance. There were two sorts of differences between tentacle patterns and pure lines: Cues superimposed on the figure (*) are less effective than cues presented on the background. Very far cues without tentacles (-) were frequently linked to the neighboring bar.

Taken together, the differences in Fig. 15 thus are likely due to two effects, (i) a reduced cue efficiency when the cue is superimposed on (parts of) the target (Fig. 15, *) and (ii) a particularly high error rate (for tentacle-free targets) at *very far* cue-target distances when cues and targets could not reliably be linked (Fig. 15, -). Beyond these “artifacts”, the data did not reveal any strong differences between tentacle and tentacle-free patterns in Exp. 4.

This conclusion is particularly interesting, as it stresses the general importance of the cue-target distance for the selection process. Under appropriate stimulus conditions, attention might then be even faster allocated to a near target outside the figure than to a farther target inside, as was indeed found (Nothdurft, unpublished results[5]; cf. Usai, Umiltà, & Nicoletti, 1995). There was no evidence, however, that distance effects could *break* the figural link. Even when cues were closer to the neighboring bar than to the target (*far* and *very far* conditions in Exp. 4; cf. Fig. 10c) were the neighboring bars only rarely selected when the tentacles were present (Fig. 12b).

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[5] now published as *www.vpl-reports.de/5/*

While there has been strong evidence that attention shifts may be object-based and then faster to a target within an attended object than to a target in another object (e.g., Egly, Driver, & Rafal, 1994), a number of studies have recently shown that object-based attention effects may be reduced when priority settings (Shomstein & Yantis, 2002), the interaction with space-based effects (Soto & Blanco, 2004), or the initial and dynamic attention distribution (Goldsmith & Yeari, 2003; Lamy & Egeth, 2002) were not optimal. However, none of these restrictions would strictly apply to the present experiments. Subjects had to keep attention widespread at the beginning of each trial, when the cue location was not yet known, and then focus it down to the target bar to identify its orientation. Far and very far cues were not located on the target; thus selection by location was likely not the primary cue. And subjects looked for targets that were connected with the cue, thus following an object-specific attention prioritization strategy. However, attention shifts within an object are not necessarily instantaneous and without any delay; object-based attention only implies that attention shifts within an object occur faster than shifts across objects. This had not been measured in the present study.

4. GENERAL DISCUSSION

The study has documented important properties, some of which were already discussed above. Interestingly, the visual selection of a cued target from the crowd appears to resemble similar properties as shifting attention to a single target in an otherwise empty field. Although the variety of test conditions in the studies does not allow for an exact comparison of the data, the observations are of the same quality and order as those obtained in the present study (cf. Discussion in section 2.4.3). This similarity suggests that cued visual selection and exogenously controlled shifts of focal attention underlie the same mechanism, the spatial properties of which will here be further discussed.

The study has confirmed the general importance of cue locations for visual selection and for attention effects. For separations of up to almost 4 deg (the range over which cue and target locations were varied in the present experiments) the distance between cue and target affected the speed and efficiency of how the target was selected and attention allocated. Even in figures, attention was not deployed to an object at once but was first allocated to the cue and locations nearby.

It is important to stress the similarity of effects found in Exp. 1 (summarized in Fig. 9) and Exp. 4 (summarized in Fig. 15). In both experiments, cue-target distances of 0.6-0.7 deg were most efficient (if not superimposed on part of the figure) leading to 80% correct target discrimination after only 40-60 ms. For larger cue-target distances (e.g., 2 deg), performance was slowed down and longer presentations (~120 ms) were necessary to reach this level. Larger cue-target distances were not tested in Exp. 4. [In Exp. 1 where larger distances *were* tested, a cue-target distance of nearly 4 deg needed presentation times of 200-280 ms.] This similarity was obtained with quite different cues in the two experiments. In Exp. 1, cues were made of four dots (squares) symmetrically arranged around the target. This allowed subjects to correctly select the target; the error rate was low (provided the presentation time was long enough). In Exp. 4, however, cues were single dots that when located far from the target did not unequivocally select one bar. Error rate was high in this case, but for correctly located targets performance was similar to that in Exp. 1. While performance variations in Exp. 1 could be related to either cue-target distance or cue size, only the distance can account for the variations in Exp. 4.

4.1 Cue size or cue-target distance?

Studies that varied the size of the cue and studies that varied cue-target distance obtained qualitatively similar results, which also were similar to the findings presented here (see section 2.4.1 for discussion). While size might have been important in some of these studies, several aspects point towards a distance effect as an explanation of the present results. (1) The strongest argument is the one just made; the findings of Exp. 4 with a distant and asymmetrically arranged cue cannot be easily explained by cue size. (2) The size of the relevant target was constant in all experiments, and subjects should have tried to keep the focus of attention adjusted to that size to optimize performance. However, if the uncertainty about cue location had forced subjects to keep their attention widely distributed at the beginning of each trial, and had only focused it upon the size of the target when the cue occurred, this would not explain why shifts could be done so much faster with small than with large four-dot cue arrangements. (3) On the other hand, if the focus of attention were automatically adjusted to the size of the cue (which for a large cue would then have been inappropriate to identify the target), the large cues in Exp. 3 (target visibility) should have produced similar effects as the large cues in Exp. 1 (visual selection). This was not the case. (4) Performance was also delayed under indirect cueing, for which the relation to cue size would not be obvious. Indirect cueing produced the same, or slightly stronger, deterioration effects as direct cueing with distant cues.

4.2 Zoom lens or modulated gating?

The strongest support for an interpretation in terms of size effects comes from the "zoom lens" metaphor (Eriksen & St. James, 1986). The decreased efficiency of large cues for the detection and identification of a small test stimulus has often been interpreted as evidence that the "spotlight of attention" was "zoomed" upon the size of the cue, which would then be inappropriate to detect and discriminate details of a smaller target or test stimulus. Indeed, attention to small cues results in a better contrast sensitivity for high spatial frequencies than does attention to large cues (Goto et al., 2001).

But how would the zoom lens metaphor explain the slower performance with large cues in the present experiments? There are two ad-hoc hypotheses why reactions might be delayed and performance rendered more difficult when cues are too large. (1) Focal attention must be zoomed in, and this re-adjustment may take time so that the target cannot be identified when presentation time (after application of the cue) is too short. (2) Large cues activate a larger area than small cues. Therefore, if the amount of (modulated) neural activity evoked by the cue were roughly constant, large cues should be less efficient, at any location within the cue, than would be small cues (cf. Kroese & Julesz, 1989). If we assume that activation by a single-dot cue would spread over several degrees, the latter hypothesis can explain both size and distance effects.

Physiology seems to support the second model according to which attention can be focused to areas of different size, with different levels of activation. Small cues produce stronger activation (of a small area) than large cues, whose activation is distributed over a larger area (Müller et al., 2003). Qualitatively the same is observed for the presumably bottom-up activation reflected in the N1 component of evoked potentials (Luo, Greenwood, & Parasuraman, 2001). It is not conclusive, however, that findings like these would indeed resemble a "zoom lens" effect that would optimize for cue and target sizes and would focus on different spatial frequency channels. Attending to a large cue does not enhance the contrast sensitivity for low spatial frequencies, compared to that obtained with a small cue (Goto et al., 2001), although that should be expected when cues would zoom the "spotlight of attention" to the size of the cue. Even the typical "size" effects discussed above – faster reactions with a small cue, slower reactions with a large cue – may be explained by distributed activation, without the metaphor of focal attention zooming in. If the size of the cue would control the distribution of neural activation (which would be locally reduced when spread over a larger area), with no special reference to target size, pre-activation by a large cue would, on average, be smaller per neuron than pre-activation by a small cue. With the common assumption that strong neural activation leads to faster behavioral responses than weak activation, this distribution would entirely account for the cue size effects discussed in section 2.4.1.

While these arguments are not a strict proof of the prevalence of distance over size effects in visual selection, they provide a plausible interpretation of both. Most of the findings reported and discussed here can be explained with the assumption that the geometry of visual cues would topographically activate the neurons in different areas of the brain and thus modulate stimulus representation, very similar to the model of modulated permeability by Cheal et al. (Cheal, Lyon, & Gottlob, 1984). No static or dynamic "zooming in" would be required in this model.

How can this modulation be linked to neurophysiology? A consistent finding in physiological experiments on attention is the general modulation of neural activity at attended vs. non-attended locations (for reviews, see, for example, Kastner & Ungerleider, 2000; Treue, 2001). Although this modulation may depend on the receptive field size of an individual neuron (Kastner & Ungerleider, 2001; Luck, Chelazzi, Hillyard, & Desimone, 1997), it does, in general, resemble the effect of a spotlight that would gain or enhance the activity of neurons in different areas of the brain at the attended location (e.g., Kastner et al., 1999; Maunsell, 1998; McAdams & Maunsell, 1999, 2000; Treue & Martínez-Trujillo, 1999). Such a modulation of neural activity, particularly (but not only) if based on gain control, may have different effects. It will improve discrimination, as the response differences between two alternative stimulus representations are increased. It will fasten processing and hence reduce reaction time, as activity is increased and responses thus are speeded up. And it will enhance any stimulus representation in the attended region over those at other locations, as if stimuli in this region were enhanced in contrast and their salience was increased (Martínez-Trujillo & Treue, 2002; Nothdurft, Gallant, & Van Essen, 1999; Reynolds & Desimone, 2003).

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REFERENCES

Adam, J.J., Ketelaars, M., Kingma, H. & Hoek, T. (1993). On the time-course and accuracy of spatial localization–basic data and a 2-process model. *Acta Psychologica*, **84**, 135-159.

Baylis, G.C. & Driver, J. (1991). Visual attention and objects: Evidence for hierarchical coding of location. *Journal of Experimental Psychology: Human Perception and Performance*, **19**, 451-470.

Benso, F., Turatto, M., Mascetti, G.G. & Umiltá, C. (1998). The time course of attentional focusing. *European Journal of Cognitive Psychology*, **10**, 373-388.

Breitmeyer, B.G. *Visual masking: an integrative approach.* New York: Exford University Press. (1984).

Carrasco, M. (2011). Visual attention: the past 25 years. *Vision Research*, **51**, 1484-1525.

Carrasco, M., Ling, S., & Read, S. (2004). Attention alters appearance. *Nature Neuroscience*, **7**, 308-313.

Castiello, U. & Umiltà, C. (1990). Size of the attentional focus and efficiency of processing. *Acta Psychologica*, 7**,** 195-209.

Cave, K.R. & Bichot, N.P. (1999). Visuospatial attention: beyond a spotlight model. *Psychonomic Bulletin & Review*, **6**, 204-223.

Chastain, G. & Cheal, M. (1998). Automatic versus directed attention with single-element and multiple-element precues. *Visual Cognition*, **5**, 339-364.

Cheal, M.L. & Lyon, D.R. (1991). Central and peripheral precuing of forced-choice discrimination. *The Quarterly Journal of Experimental Psychology*, **43A**, 859-880.

Cheal, M.L., Lyon, D.R. & Gottlob, L.R. (1994). A framework for understanding the allocation of attention in location-precued discrimination. *The Quarterly Journal of Experimental Psychology*, **47A**, 699-739.

Chen, Z. (2012). Object-based attention: a tutorial review. *Attention, Perception & Psychophysics*, **74**, 784-802.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General,* **113**, 501-517.

Di Lollo, V., Enns, J.T. & Rensink, R.A. (2000). Competition for consciousness among visual events: the psychophysics of reentrant visual processes. *Journal of Experimental Psychology: General,* **129**, 481-507.

Downing, C.J. & Pinker, S. (1985). The spatial structure of visual attention. In M.O. Posner & O.S.M. Marin (Eds.) *Mechanisms of attention: attention and performance XI* (pp. 171-187). Hillsdale, N.J.: Lawrence Erlbaum Associates, Inc.

Egly, R., Driver, J. & Rafal, R.D. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General,* **123**, 161-177.

Egly, R. & Homa, D. (1991). Reallocation of visual attention. *Journal of Experimental Psychology: Human Perception & Performance*, **17**, 142-159.

Enns, J.T. (2004). Object substitution and its relation to other forms of visual masking. *Vision Research*, **44**, 1321-1331.

Enns, J.T. & Di Lollo, V. (1997). Object substitution: a new form of masking in unattended visual locations. *Psychological Science*, **8**, 135-139.

Enns, J.T. & Di Lollo, V. (2000). What's new in visual masking? *Trends in Cognitive Sciences*, **4**, 345-352.

Eriksen, C.W. & St. James, J.D. (1986). Visual attention within and around the field of focal attention: a zoom lens model. *Perception & Psychophysics*, **40**, 225-240.

Goldsmith, M. & Yeari, M. (2003). Modulation of object-based attention by spatial focus under endogenous and exogenous orienting. *Journal of Experimental Psychology: Human perception & Performance*, **29**, 897-918.

Goto, M., Toriu, T., & Tanahashi, J. (2001). Effect of size of attended area on contrast sensitivity function. *Vision Research*, **41**, 1483-1487.

Gottlob, L.R. Cheal, ML., & Lyon, D.R. (1999). Time course of location-cuing effects with a probability manipulation. *The Journal of General Psychology*, **126**, 261-270.

Greenwood, P.M. & Parasuraman, R. (1999). Scale of attentional focus in visual search. *Perception & Psychophysics*, **61**, 837-859.

Henderson, J.M. & MacQuistan, A.D. (1993). The spatial distribution of attention following an exogenous cue. *Perception & Psychophysics*, **53**, 221-230.

Iani, C., Nicoletti, R., Rubichi, S. & Umiltà, C. (2001). Shifting attention between objects. *Cognitive Brain Research*, **11**, 157-164.

Jiang, Y. & Chun, M.M. (2001). The spatial gradient of visual masking by object substitution. *Vision Research*, **41**, 3121-3131.

Kastner, S. & Ungerleider, L.G. (2000). Mechanisms of visual attention in the human cortex. *Annual Review of Neuroscience*, **23**, 315-341.

Kastner, S. & Ungerleider, L.G. (2001). The neural basis of biased competition in human visual cortex. *Neuropsychologia*, **39**, 1263-1276.

Kastner, S., Pinsk, M.A., De Weerd, P., Desimone, R. & Ungerleider, L.G. (1999). Increased activity in human visual cortex during directed attention in the absence of visual stimulation. *Neuron*, **22**, 751-761.

Koch, C. & Ullman, S. (1985). Shifts in selective visual attention: towards the underlying neural circuitry. *Human Neurobiology*, **4**, 219-227.

Kroese, B.J. & Julesz, B. (1989). The control and speed of shifts of attention. *Vision Research*, **29**, 1607-1619.

Lamy, D. & Egeth, H. (2002) Object-based selection: The role of attentional shifts. *Perception & Psychophysics*, **64**, 52-66.

Luck, S.J., Chelazzi, L., Hillyard, S.A. & Desimone, R. (1997). Neural mechanisms of spatial selective attention in areas V1, V2, and V4 of macaque visual cortex. *Journal of Neurophysiology*, **77**, 24-42.

Luo, Y.J., Greenwood, P.M. & Parasuramam, R. (2001). Dynamics of the spatial scale of visual attention revealed by brain event-related potentials. *Cognitive Brain Research*, **12**, 371-381.

Maringelli, F. & Umiltà, C. (1998). The control of the attentional focus. *European Journal of Cognitive Psychology*, **10**, 225-246.

Martínez-Trujillo, J.C. & Treue, S. (2002). Attentional modulation strength in cortical area MT depends on stimulus contrast. *Neuron*, **35**, 365-370.

Maunsell, J. (1998). Effects of attention on visual representations in cerebral cortex. In: *3rd annual vision research conference on pre-attentive and attentive mechanisms in vision*, Abstract book (p.60). Oxford/UK: Elsevier.

McAdams, C.J. & Maunsell, J.H.R. (1999). Effects of attention on orientation-tuning functions of single neurons in macaque cortical area V4. *Journal of Neuroscience*, **19**, 431-441.

McAdams, C.J. & Maunsell, J.H.R. (2000). Attention to both space and feature modulates neuronal responses in macaque area V4. *Journal of Neurophysiology*, **83**, 1751-1755.

Müller, H.J. & Rabbitt, P.M. (1989) Reflexive and voluntary orienting of visual attention: time course of activation and resistance to interruption. *Journal of Experimental Psychology: Human Perception & Performance*, **15**, 315-330.

Müller, M.M., Teder-Sälejärvi, W. & Hillyard, S.A. (1998). The time course of cortical facilitation during cued shifts of spatial attention. *Nature Neuroscience*, **1**, 631-634.

Müller, N.G., Bartielt, O.A., Donner, T.H., Villringer, A. & Brandt, S.A. (2003). A physiological correlate of the "zoom lens" of visual attention. *The Journal of Neuroscience*, **23**, 3561-3565.

Nakayama, K. & Mackeben, M. (1989). Sustained and transient components of focal visual attention. *Vision Research*, **29**, 1631-1647.

Nothdurft, H.C. (1993). The conspicuousness of orientation and motion contrast. *Spatial Vision*, **7**, 341-363.

Nothdurft, H.C. (2002). Attention shifts to salient targets. *Vision Research*, **42**, 1287-1306.

Nothdurft, H.C., Gallant, J.L. & Van Essen, D.C. (1999). Response modulation by texture surround in primate area V1: Correlates of "popout" under anesthesia. *Visual Neuroscience*, **16**, 15-34.

Posner, M.I. Orienting of attention. *Quarterly Journal of Experimental Psychology*, **32**, 3-25. (1980).

Reeves, A. & Sperling, G. (1986). Attention gating in short-term memory. *Psychological Review*, **93**, 47-72.

Remington, R. & Pierce, L. (1984). Moving attention: evidence for time-invariant shifts of visual selective attention. *Perception & Psychophysics*, **35**, 393-399.

Remington, R.W., Johnston, J.C. & Yantis, S. (1992). Involuntary attentional capture by abrupt onsets. *Perception & Psychophysics*, **51**, 279-290.

Reynolds, J.H. & Desimone, R. (2003). Interacting roles of attention and visual salience in V4. *Neuron*, **37**, 853-863.

Sagi, D. & Julesz, B. (1986). Enhanced detection in the aperture of focal attention during simple discrimination tasks. *Nature*, **321**, 693-695.

Scholl, B.J. (2001). Objects and attention: the state of the art. *Cognition*, **80**, 1-46.

Shomstein, S. & Yantis, S. (2002). Object-based attention: Sensory modulation or priority setting? *Perception & Psychophysics*, **64**, 41-51.

Soto, D. & Blanco, M.J. (2004). Spatial attention and object-based attention: a comparison within a single task. *Vision Research*, **44**, 69-81.

Sperling, G. & Reeves, A. (1980). Measuring the reaction time of shift of visual attention. In R. Nickerson (Ed.) *Attention and performance, VIII* (pp. 347-360). Hillsdale, N.J.: Lawrence Earlbaum Associates, Inc.

Theeuwes, J. (1991). Exogenous and endogenous control of attention: the effect of visual onsets and offsets. *Perception & Psychophysics*, **49**, 83-90.

Treue, S. (2001). Neural correlates of attention in primate visual cortex. *Trends in Neurosciences*, **24**, 295-300.

Treue, S. & Martínez-Trujillo, J.C. (1999). Reshaping neuronal representations of visual scenes through attention. *Cahiers de Psychologie Cognitive / Current Psychology of Cognition*, **18**, 951-972.

Turatto, M., Benso, F., Facoetti, A., Galfano, G., Mascetti, G.G. & Umiltà, C. (2000). Automatic and voluntary focusing of attention. *Perception & Psychophysics*, **62**, 935-952.

Usai, M.C. Umiltà, C. & Nicoletti, R. (1995). Limits in controlling the focus of attention. *European Journal of Cognitive Psychology*, **7**, 411-439.

Van Rullen, R. (2003). Visual saliency and spike timing in the ventral visual pathway. *Journal of Physiology Paris*, **97**, 365-377.

Watson, S.E. & Kramer, A. (1999). Object-based visual selective attention and perceptual organization. *Perception & Psychophysics*, **61**, 31-49.

Weichselgartner, E. & Sperling, G. (1987). Dynamics of automatic and controlled visual attention. *Science*, **238**, 778-780.

Yantis, S. & Johnston, J.C. (1990). On the locus of visual selection: evidence from focused attention tasks. *Journal of Experimental Psychology: Human Perception & Performance*, **16**, 135-149.