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Fast identification of salient objects depends on cue location*

Hans-Christoph Nothdurft

Visual Perception Laboratory (VPL) Göttingen, Germany

Abstract. How fast can you identify a salient object? Are all its features immediately present, or are features near a saliency-marker seen faster than features farther away? The present study shows that local salience markers enhance the representation of nearby locations. Depending on stimulus geometry, items outside an object (but close to the marker) may then be faster discriminated than features of the object itself. This suggests a low-level component in visual attention that modulates neural representation according to cue location, yet without cognitive processing of object identity.

Key words:
Visual selection; Object-based attention; Cue-target distance; Perceptual organization; Figures

1. INTRODUCTION

Imagine yourself surfing through the internet and having just loaded one of those busy sites with lots of icons and boxes. You are searching for information about a new printer, and, indeed, after some while, you have found the right box. In one corner, there is a flashing star, which has probably attracted your gaze, and there is an icon of the printer you have been searching for, in another corner of the box. When you click on the icon to download additional information, you have activated several processes in your brain that are related to the many features of "directed attention". You have selected one of the many icons (visual selection) and ignored all other pictures on the screen (shift of focal attention), and you have moved the mouse to this location (orienting response). How have all these processes been started? Maybe the blinking star had attracted your attention. But did it really guide you to the whole box including the printer icon inside? Or did it first guide you to the star itself? To rephrase the question with another picture: Does a turn-signal of a car guide your attention to the car, or to the turn-light?

The role of visual attention and how it is shifted over a scene has extensively been studied in the last decades (see Carrasco, 2011, for an overview). In many attention studies, however, the visual scenes were rather special; a single cue (or instruction) was given to direct attention, and often only one or two test targets were shown to measure the effects. In daily life the guidance of attention to objects may be far more complicated, as was frequently addressed in studies of visual search (cf. Wolfe, 1994, 1998; Nothdurft, 2002). Targets that are particularly salient are found much faster than non-salient targets (Nothdurft, 2006). But it has not always been clear that finding the target was indeed associated with a shift of focal attention to that target (Joseph, Chun, & Nakayama, 1997; Nothdurft, 1999); some targets were originally even claimed to be found “pre-attentively” (Treisman, 1985). In the present paper, I used a different paradigm. The patterns included many items (here, 24) which all were seen right from the beginning of a presentation and were designed so that none of them was particularly salient and would have attracted attention. Only

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Address for correspondence: <christoph.nothdurft@vpl-goettingen.de>

after a while (here, 500 ms) one of these items was marked and thus selected, and it was measured how fast observers could then detect details of this target. In earlier experiments, I have selected targets by changing some of their features thus making them salient, or by adding a cue (Nothdurft, 2002). Here, selection was exclusively provided by salience-markers applied directly to a part of the item.

Obviously, the process of “visual selection” described here shares many features with processes that have regularly been referred to as “shifts of focal visual attention”. Targets must be located and identified; certain neural resources are competitively applied to the selected part of the scene (all other items are ignored); and applying (shifting) these resources to the indicated location requires time (Nothdurft, 2002, 2016). But since, after 500 ms presentation, the target (and other items) must already be well presented in the brain, at least in the early (“bottom-up”) processing stages of the visual system, the late application of salience-markers might help to distinguish selection and identification processes. Aim of the present paper is to enlighten the similarities and eventual dissimilarities between visual selection and focal attention.

Attention is guided in two ways (Chastain & Cheal, 1998; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Turatto et al., 2000; Weichselgartner & Sperling, 1987), either voluntarily (indirect, "top-down") at the observer's will (often triggered by an external command or symbolic signal), or automatically (direct, "bottom-up") by stimuli that mark an object or location in the visual field. Salient targets such as stimuli reflecting discontinuities in luminance, color, or form (Joseph & Optican, 1996; Nothdurft, 2002; Turatto & Galfano, 2000) and the onset of new items in a display (Jonides & Yantis, 1988; Remington, Johnston & Yantis, 1992; Theeuwes, 1991, 1994; Yantis, 1993, reviewed in Yantis, 1998) are effective guides for the direct control of attention.

Objects play a special role in visual perception, and in visual attention, too (Duncan, 1984; Baylis & Driver, 1991; for reviews see, e.g., Wolfe, 2000; Scholl, 2001). One can shift attention faster between different locations on the same object than between locations on different objects (Egly, Driver & Rafal, 1994; Iani, Nicoletti, Rubichi & Umiltà, 2001). Similarly, it is easier, and faster, to attend to different features of one object than to the features of two distinct objects (Duncan, 1984; Baylis & Driver, 1991; Lavie & Driver, 1996; Law & Abrams, 2002). This suggests that objects are treated as entities in visual perception, not only in recognition processes but also in the control of attention and visual selection. Subjects can covertly (that is, without eye movements) attend to an object that moves (Pylyshyn & Storm, 1988; Yantis, 1992), and can even keep track of it if the appearance of its surface changes (Blaser, Pylyshyn & Holcombe, 2000). This should be very helpful in a world of moving objects under variable illumination.

However, the direct control of visual attention is a bottom-up process that may not have immediate access to the cognitive analysis of object identities. For example, large cues automatically draw attention to a large area, and small cues to a small area (Benso, Turatto, Mascetti, & Umiltá, 1998; Castiello & Umiltà, 1990; Eriksen & St. James, 1986; Greenwood & Parasuraman, 1999; Maringelli & Umiltà, 1998), an effect referred to as the "zoom lens" of focal attention (Eriksen & St. James, 1986), and both accordingly modulate the neural activity in the brain (Müller, Bartelt, Donner, Villringer & Brandt, 2003; Luo, Greenwood & Parasuraman, 2001). Cueing effects, i.e. the modification of perceptual and behavioral performance on a test stimulus after attention has been "cued" to its location, are modulated by the distance of the cue to the target (Downing & Pinker, 1985; Egly & Homa, 1991; Henderson & MacQuistan, 1993; Nothdurft, 2016). This suggests a gating or enhancement mechanism that is primarily controlled by stimulus geometry. Cognitive aspects concerned with the gestalt and prägnanz of an object might not be important at this level.

To solve this apparent controversy I studied distance effects of cued attention in patterns like that illustrated in Fig. 1A. The objects were elongated horizontal or vertical boxes each with an oblique test bar inside. Twenty-four such boxes were shown on every trial, and half a second later one of them was selected by application of a cue. The subjects' task was to identify the bar within this box as being tilted to the right or to the left. In order to measure the speed of selection processes and attention shifts, the bars were masked soon after application of the cue. In a second experiment, squared boxes were used and test bars were located inside or outside these boxes (Fig. 2A). All tests were carried out under fixation of a small dot in the center of the screen.

EXPERIMENT 1: The role of cue-target distances within objects

Experiment 1 searched for distance effects between salience markers on the frame of a selected box, and targets within that box to be identified. Three different sorts of markers were used (in separate tests); luminance enhancement of a dot, an edge, or half of the box (Fig. 1B).

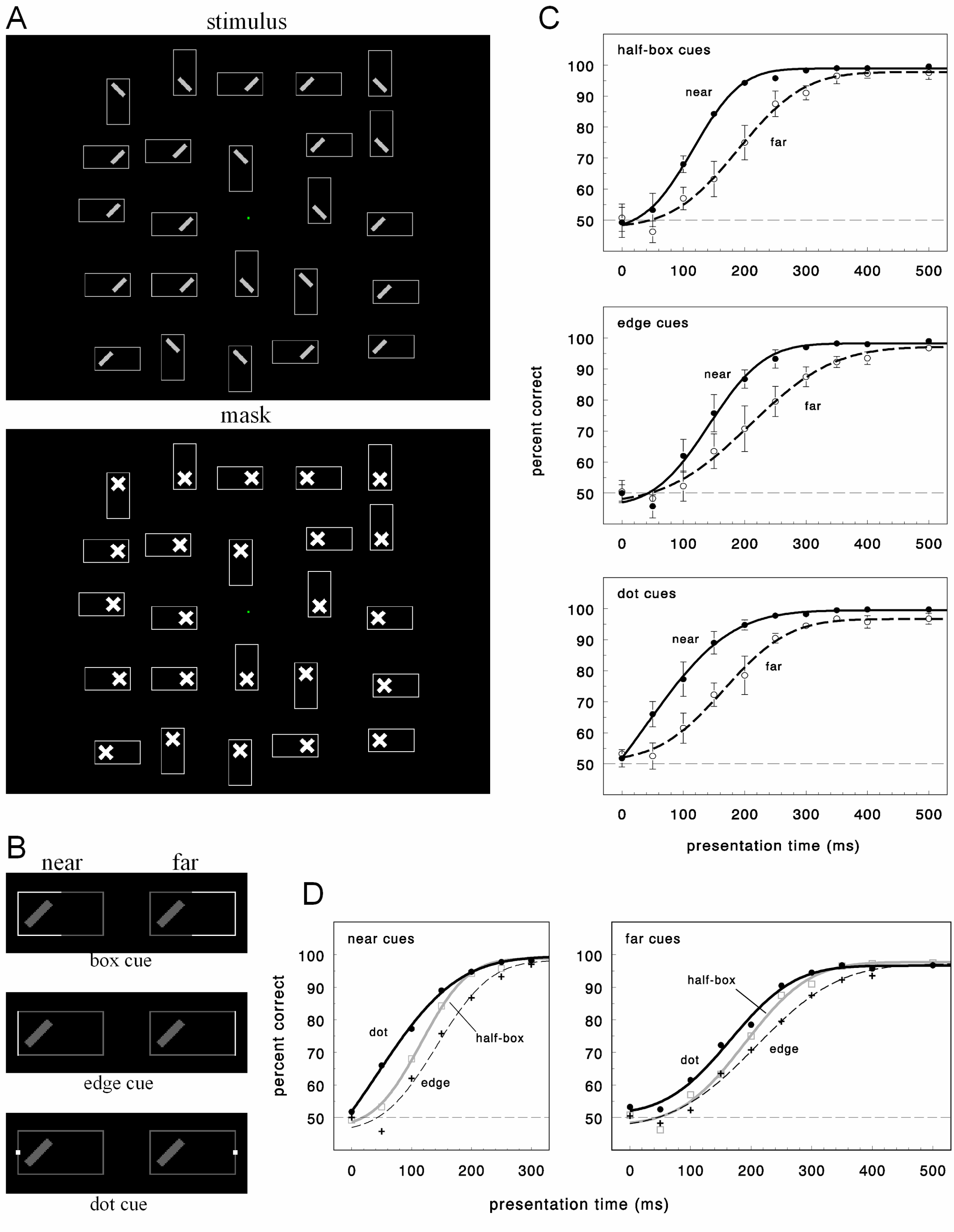

Figure 1. *Experiment 1: Visual selection of objects.* Aim of the experiment was to measure the efficiency of near and far cues upon target identification. **(A)** In an array of elongated boxes (upper graph) one was marked by the brief enhancement of a cue; the observer's task was to indicate the orientation of the bar inside this box (target). After the "presentation time", all lines in the pattern were masked (lower graph). **(B)** Three kinds of cues were tested, each presented at locations near to or far from the bar. Every trial began with 500 ms presentation of the fixation point, before the stimulus pattern occurred (A, top). After another 500 ms, the cue was shown for 50 ms. The following "presentation time" (measured from cue onset) varied from 0 ms to 700 ms. Performance in target identification was measured in a 2AFC task. **(C)** Mean performance data from 4 subjects were fitted by cumulative functions. The curves show the increase of target identification rates with presentation time; the corresponding cue conditions are sketched next to each curve. With all cues, performance increased faster when boxes were cued on the side near the test bar than when cued on the far side. Bars give the S.E.M. **(D)** Data re-plotted from (C) to illustrate performance variations with the form of the cue. For both near and far cue locations, dot cues were most, and edge cues least efficient. Performance variations with different cues were generally smaller than performance differences between cue locations.

These markers were applied to the near or far side of the box with respect to the bar that had to be identified.

Methods

Overview. All stimuli were shown on a PC monitor (100 Hz frame rate) at a viewing distance of 67 cm. Figures were boxes with a test bar; 24 of those boxes were arranged in a 5x5 irregular raster, leaving out the central location. Boxes could be horizontal or vertical; test bars were left or right tilted oblique lines. In the course of a trial, 500 ms after the onset of the pattern one of these figures was selected ("cued") by increasing the luminance of part of the box frame, and subjects were asked to report the orientation of the corresponding test bar. After a variable delay ("presentation time") all test bars in the pattern were masked (cf. Fig. 1A). Note that the total presentation time of each bar was 500 ms longer, as the whole pattern was already shown before the cue application. The rate of correctly identified bars for a given presentation time was taken as a measure of cue efficiency.

Stimuli. The spatial arrangement of the figures was made in such a way that test bars were separated from each other by 3.0 deg ± 0.15 deg jitter. Boxes were randomly arranged around these bars avoiding that neighboring boxes extend into the same free space between bars. Bars were 0.8 deg x 0.2 deg in size and presented at 9 cd/m^2 on 2.5 cd/m^2 background luminance. Boxes were rectangular (2.1 deg x 1.0 deg) and placed around or near the test bars as illustrated in Fig. 1A and B. They were shown at the same luminance as test bars. Cues (markers) were brighter (60 cd/m^2) and covered either three edges of a square (half-box cue), one short edge of the box (edge cue) or a dot located in the center of one of the short edges (dot cue; Fig. 1B). Different configurations of cues and test bars in a figure gave cue-target distances (center short edge to bar center) of 0.5 deg (near cues), and 1.5 deg (far cues). The total size of a stimulus pattern was about 15 deg by 15 deg with a central fixation point of 0.1 deg x 0.1 deg.

Subjects. Three paid students (ages 20, 23, 34 years; two female) and the author (54 years; male) served as subjects in the experiments. They all had normal or corrected-to-normal visual acuity.

Procedure. Each trial started with a 500 ms presentation of the fixation point, before the stimulus pattern was shown. After another 500 ms, one of the figures was marked by onset of the brighter cue that remained visible for 50 ms and then turned back into normal box luminance. Subjects had to detect the cue and, in a 2AFC task, to indicate the orientation of the bar inside the cued figure. After a variable delay from the onset of the cue ("presentation time"), all test bars of the pattern were masked by the superimposition of two orthogonal bars as illustrated in Fig. 1A. Presentation time was systematically varied from 0 ms to 500-700 ms to include durations in which subjects performed at chance, and durations in which they performed nearly 100% correctly. The late presentation of the cue (500 ms after onset of the pattern) ensured that all test bars and boxes were well represented in the brain before the selection process was started. To minimize performance variations with eccentricity, only 10 boxes served as possible cue locations in the experiment; subjects were, however, not informed about this restriction. These locations were (columns/rows from top left) 1/3, 2/2, 2/3, 2/4, 3/2, 3/4, 4/2, 4/3, 4/4, 5/3, resulting in target eccentricities of 3.0-6.0 deg (mean 4.1 deg). All tests were made under fixation which was regularly controlled for by means of a camera zoomed in on the observer's eyes.

Tests were blocked for the different cues and for near or far cue-target arrangements; the resulting 6 blocks were tested in a pseudo-random sequence so that all data were obtained in an interleaved manner. Within each block, all conditions (9-12 presentation times) were intermixed and each repeated 10 or 20 times. Every block was repeated five or ten times so that altogether 100 responses on every condition were obtained from each subject. Subjects worked, as long as they felt concentrated and motivated, in sessions of maximally 2 hours. The tests were interleaved with other tests on visual selection; usually 2-3 sessions were carried out per week.

Data analysis and statistics. Performance is measured as the percentage of correct test bar identifications over presentation time (after cue onset); the individual data of the four subjects were averaged. The mean data were then fitted with cumulative functions to obtain the presentation times at 75% correct; these are plotted in Fig. 3. Statistical comparisons of different test conditions are based on two-factor repeated measures ANOVA.

Results and Discussion

The mean data of four subjects in Exp. 1 are plotted in Fig. 1C. Presentation time (from application of the cue until masking of the bars) was systematically varied and performance was taken as a measure of speed and efficiency of the selection process. Patterns were shown 500 ms before the cue, so that all stimuli should have been well encoded in the brain when the selection process started. Performance was at chance when the bars were masked immediately on cue occurrence, but quickly increased with presentation time. This quick increase, beside the regular fixation controls, confirms that subjects had not performed the task by gaze shifts to the targets, which had been possible only 250-300 ms after appearance of the cue.

For all cues, there was a systematic difference in performance between cues located next to the test bar (black line curves) and cues located farther away on the opposite side of the box (gray line curves); subjects needed, on average, 70-100 ms longer presentations with cues on the far side to reach similar performance. Thus, in terms of attention shifts, cues at one part of an object did not immediately attract attention to the whole object but first to locations near the cue.

Interestingly, the three different cues did not produce identical results (Fig. 1D). The dot cue was the most efficient one, leading to almost 100% correct performance in only 200 ms when located near the bar. Least efficient was the edge cue, while the half-box cue lay in between. This is probably due to masking effects between the cue and the test bar (Breitmeyer, 1984; Enns & Di Lollo, 2000) and to the different salience of these cues. From the amount of light added by each cue (all cues had the same luminance but different sizes), the half-box cue should have been most salient and attracted attention best, whereas dot cues should have been least salient. This effect is counteracted by masking effects, which were probably strong with edge and half-box cues but negligible with the dot cue. The combination of these two effects, salience and masking, produced the differences illustrated in Fig. 1C. The smaller interference of dot cues with the target made them the most efficient cues, although their size was smaller than that of the other cues.

EXPERIMENT 2: Cueing effects at locations near an object

Exp. 2 was designed to measure cue efficiency for bars located outside the frame box. This time, figure boxes were squares, but otherwise the experiment was similar to the previous one; only edge cues were tested (Fig. 2A).

Methods

Experiments were identical to those in Exp. 1 except that boxes were squared rather than rectangular and bars were located inside or outside the box, at same distance from the (near) edge (Fig. 2A). Three conditions with different cue-target distances were tested in separate but interleaved blocks: outside near, outside far and inside (near).

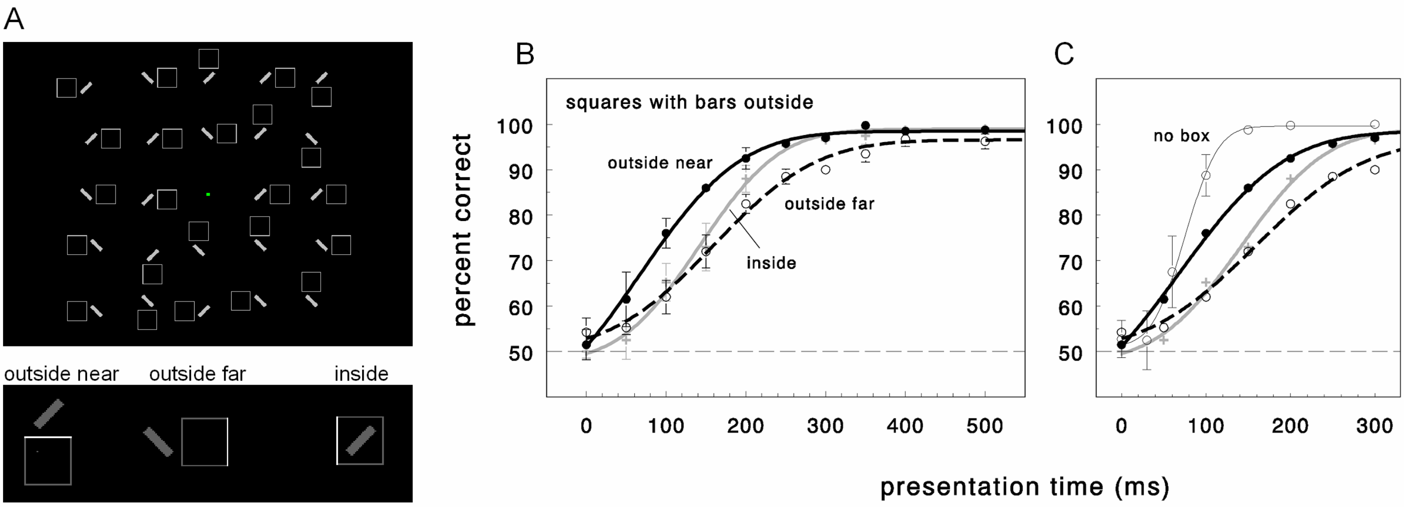

Figure 2. *Experiment 2: Identification of test bars inside and outside the selected box.* The experiment was similar to Exp. 1 (Fig. 1) except that figures were squared boxes and test bars were located inside or outside these boxes. **(A)** Examples of a stimulus pattern (top) and of the various cueing conditions (below); stimulus presentation as described in Fig. 1. After "presentation time", the bars were masked. **(B)** Mean performance curves and S.E.M. from Exp. 2. Test bars outside the boxes and cued on the near side were seen best, but least well when cued on the far side. This indicates that the cue-target geometry modulates initial performance across, and independent of, object borders. **(C)** Data re-plotted and completed by data from a similar experiment with no boxes and cues upon the selected bars (thin lines; *from Nothdurft, 2016*).

The data of Exp. 2 are compared with those of an experiment of another study on cueing effects (Nothdurft, 2016), performed by the same subjects in tests interleaved to those of the present study. Stimulus patterns in this additional experiment were similar to those used here, but bars were shown without boxes and cues were single dots located in the center of the target bar.

Results and Discussion

Again, there were clear differences in cue efficiency (Fig. 2B). Test bars outside the square were seen best when cued at the near edge, and least well when cued at the far edge, similar to the findings of Exp. 1 (black line curves in Fig. 2B). Thus, the cue-target distance modulates attention even beyond the boxes. Test bars within the box were seen less well than the near bars outside. Since cues for bars inside were exactly as close or far as those for (near) bars outside, this difference cannot be explained by the cue-target distance alone but does probably reflect additional masking effects from the frame around the inside bars. This becomes obvious when the data are compared with performance in another experiment, in which the same bars were presented without boxes and the target was marked with a dot cue in the center of the bar (Nothdurft, 2016). In this case, with no masking from boxes, performance was much better (thin line curve in Fig. 2C). Note however, that performance with the bar inside was less deteriorated than performance with the far cued bar outside; thus, the masking effects were smaller than the performance shifts associated with an increased cue-target distance.

ANALYSIS: Statistical evaluation, and comparison of Exp. 1 and 2

Statistical comparisons of different test conditions were made using two-factor repeated measures ANOVA. All distance effects (near vs. far cue) are significant ($F>18.1$; $p<0.0001$), as are most of the masking and saliency effects with the different cue types in Exp. 1 (near cues, dot vs. edge: $F>25.8$, $p<0.0001$; dot vs. half-box: $F>8.0$, $p<0.01$; half-box vs. edge: $F>6.98$, $p<0.02$; far cues, dot vs. edge: $F>11.9$, $p<0.001$; dot vs. half-box: $F<3.72$, n.s.; half-box vs. edge: $F<2.37$, n.s.). In Exp. 2, near bars outside were better seen than near bars inside ($F>11.6$; $p<0.002$) and near bars inside better than far bars outside ($F>4.37$; $p<0.05$).

Fig. 3 summarizes the findings of Exp. 1 and 2. From the data curves in Figs. 1 and 2 the presentation times for 75% correct performance were taken and plotted against the cue-target distance in the individual tests; data points obtained with similar stimulus configurations are connected. The different masking effects of the various cues and boxes produced noticeable differences in performance; on top of these differences, however, there is a consistent shift towards longer presentation times when the cue-target distance was enlarged. This shift was identical when lines inside or outside the boxes had to be identified.

Note that the centers of the various cues in Exp. 1 were not identical when defined as the center of gravity of the cue's luminance distribution. If this is taken into account, cue-target distances of half-box cues are slightly reduced. A re-plot of the data (Fig. 3B) shows that, in this

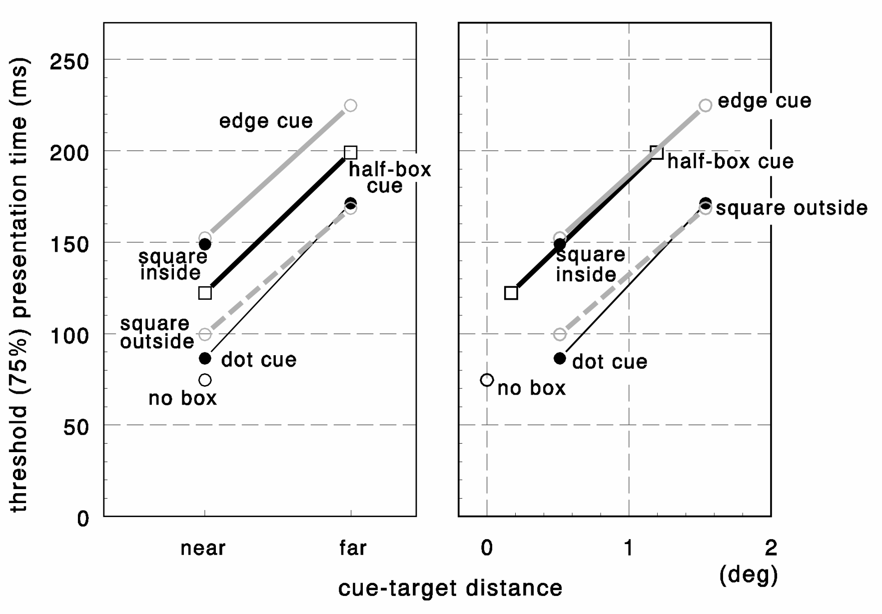

Figure 3. *Summarized findings of Exp. 1 and Exp. 2.* **(A)** Data in Figs. 1 and 2 were fitted by cumulative functions (as plotted) and threshold presentation times at 75% correct performance were taken from these fits. These values are plotted here; data from the same cue type and target locations inside or outside are connected. There was a consistent shift of performance between near and far cues (slopes); with far cues presentation time had to be increased by 70-86 ms to reach 75% correct (differences within each curve). There also was some variation with the different types of cues (curves displacement); edge cues required 56-66 ms longer presentations than dot cues. **(B)** Data re-plotted against the cue-target distance in deg. When the cue-target distance for half-box cues is measured from the center of luminance distribution in the cue, the curve closely matches that for edge cues, indicating that edge and half-box cues had a similarly deteriorating effect on target identification (curve displacement), which was, however, smaller than the difference between near and far cues along each curve.

case, data from half-box cues and data from edge cues fall upon the same line. This indicates that edge cues, whether made of one or three line segments of the box, had a similarly deteriorating (masking) effect on the identification of targets located inside the box (upper curves); no such masking effect was found with dot cues or targets located outside (lower curves). Under both conditions, however, with and without masking, cue efficiency is similarly modulated by the distance between the cue and the place where attention effects were measured.

DISCUSSION

Distance effects with cued "attention" (to use this terminology) have frequently been reported in studies measuring reaction time or performance in distant cue-target configurations (Downing & Pinker, 1985; Egly & Homa, 1991; Henderson & MacQuistan, 1993). However, it is important here that distance effects also occur for cue and target locations *within* a figure. This has also been reported for *attention shifts* within objects (Egly, Driver, & Rafal, 1994; Shomstein & Yantis, 2002; Lamy & Egeth, 2002; Goldsmith & Yeari, 2003; Soto & Blanco, 2004; cf. Chen, 2012, for a more recent review) but the present data suggest that such differences may be independent of the perceptual organization of a pattern into objects. The observed differences with near and far cues and, in particular, the similar performance shifts for bars inside and outside the boxes indicate that the direct control of attention is modulated by cue geometry and initially ignores figural aspects[1].

This does, of course, not exclude that the deployment of attention is later refined and modified by the recognition of figures and of what is cognitively perceived as belonging together. However, these processes take time (Law & Abrams, 2002), in agreement with several reports of a slower time-course of voluntary attention shifts (Chastain & Cheal, 1998; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Turatto et al, 2000; Weichselgartner & Sperling, 1987), and may not show up in the very early control of cued attention. Even if attention is later voluntarily deployed to a figure as a whole, the automatic deployment by local cues is first modulated by cue-target geometry. Thus, the first control of attentional gating in a cued visual selection process seems to be low-level, rather than a higher-level cognitive process.

Back to the printer box on that internet website. The present data indicate that the required information would probably have been found faster if the printer and not the star in the box had been flashing. Depending on the distance between these two icons, the true difference in speed of selection might be larger than the 70-100 ms found in the present study. However, for fast reactions in time-critical situations, even a 100 ms delay can be critical.

[1] One cannot exclude that even the boxes with "outside" test bars in Fig. 2A are seen as figural entities and compact "objects" (as a referee had correctly pointed out on an earlier draft of the paper). However, a test bar within the box would obviously form a better gestalt than the same bar outside–but would still be identified more slowly if the cue was farther away; cf. Exp. 1

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