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Investigating metrical and structural aspects of visual completion: Priming versus searching

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Earlier research on visual occlusion showed some flexibility in the formation of visual completions, as long as the structural aspects (e.g., symmetry) of the visible part of the partly occluded shape were preserved in the completion (de Wit & van Lier, 2002). In this study, we examined whether changing the overall size of the occluded shape would preserve the overall structure. In Experiment 1, using the primed-matching paradigm, we found evidence for relative size invariance in the completion process. To investigate whether changes in the structural aspects of shape are generally more salient than those of size, we employed the same stimuli in visual search and change detection paradigms. Experiment 2 demonstrated effects of completion in both paradigms. Experiment 3 showed that the metrical aspects of the shapes used in Experiment 1 are nevertheless detected faster than the structural aspects under search conditions. Because the variation in structural aspects is not more salient than in metrical aspects, we conclude that for these shapes, visual completion is indeed size-invariant. The relations between performances in the three paradigms are discussed.

In our visual experience, partly occluded objects give rise to sensations of whole objects. This phenomenon, called visual completion, is particularly important in situations where a specific action requires a good representation of the whole of a partly occluded object. When we move around in the world and pick up an object, some representation of the whole object is needed to be able to act on the object. This dynamic situation poses the brain with several problems, two of which will be focused on here. The first deals with the structure of the partly

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occluded object; to what extend does the visible object structure determine the perceptual interpretation? The second deals with the size of the visible object part, which depends on the actual distance between perceiver and object.

With regard to the first difficulty concerning how object structure is recovered under conditions of occlusion, there are two main theories on shape or object completion, the so-called local and global theories. Simply put, local theories state that only information at the boundary of two crossing objects is used in the completion process (e.g., Boselie, 1994; Kellman & Shipley, 1991). Global theories state that completions are formed by continuing the pattern of overall regularity of the visible part in the completion (e.g., Sekuler, Palmer, & Flynn, 1994; van Lier, van der Helm, & Leeuwenberg, 1994, 1995b; van Lier & Wagemans, 1999). However, most natural objects are not completely regular, and most theories ignore the remaining quasi-regularities by proposing simple local completions for these objects. In Figure 1A, a shape that is not perfectly regular is partly occluded by a rectangle. However, there is some quasi-regularity in that there is a pattern of similar protrusions. In a primed-matching experiment, in which facilitation from a prime occurs for representationally similar test pairs, we showed these partly occluded shapes as primes. Going against the local predictions for more natural objects (Figure 1B), we found evidence for fuzzy, global completions in quasi-regular shapes in previous studies, in that the partly occluded primes facilitated global completions (de Wit & van Lier, 2002; van Lier, 1999). In the global completions all information from the partly occluded object is used to form a completion that adds to an overall regularity of the partly occluded object, in this case by continuing the pattern of protrusions in the completion (Figure 1C). The lack of perfect regularity in the shape also implies an absence of a single ''perfect'' global completion. Indeed, these studies provide evidence not only for global completions, but also for flexibility in the outcome of the completion process. After seeing a quasi-regular partly occluded shape, instead of one particular completion being primed, there appeared to be a range of plausible completions with the same fuzzy properties, belonging to some structural class, becoming activated. In the case of Figure 1A this means that the completion has certain protrusions, but the length of these protrusions can be variable, as long as it is within a certain range as reflected in the priming effect for different completions with different protrusion lengths (this range depends on the visible part of the occluded shape; see de Wit & van Lier, 2002).

The second difficulty for the formation of completions lies in movement to or from an object, which causes size changes in the retinal projection of the object. In spite of these metrical variations, we perceive one object that remains the same. For partly occluded objects this implies a necessity for the formation of size-independent visual completions. This idea of size-independent visual completions fits with the aforementioned flexibility in the completion process. In this study, we will investigate the occurrence of these size-independent

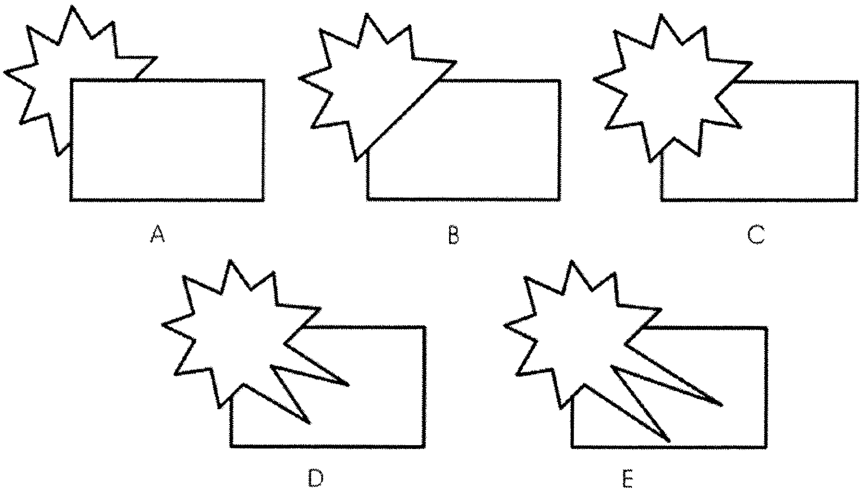


Figure 1. **(A)** The shape on the left is partly occluded by the rectangle. **(B)** Completion of the partly occluded shape as predicted by local theories. **(C)** A possible global completion. **(D)** Increasing the length of the protrusions in the completed part results in a less plausible completion. **(E)** Increasing protrusion length even more resulted in an even less plausible completion.

completions and then compare structural and metrical flexibilities using the primed-matching paradigm, which was also used in former experiments (de Wit & van Lier, 2002). In the second and third experiment, the same variables are examined using visual search and change detection paradigm, to assess the contribution of structural and metrical aspects to selection, across a range of procedures. It is known from several studies that stimuli do not have to be identical to generate visual priming; visual priming occurs under many conditions (Fiser & Biederman, 2001; Stankiewicz & Hummel, 2002). For example, Fiser and Biederman (1995) showed that a priming effect still occurs under conditions in which the stimulus size had changed, when participants had to name objects that had already been seen and named previously.

We will use the primed-matching paradigm in the present studies, where the task is not to name an object, after seeing the prime, but to decide if two shapes presented after the prime are the same or not. On trials where the to-be-matched stimuli are the same, reaction times should be faster if the prime and the shapes in the test pair are representationally similar (Beller, 1971). We want to see if such priming effects still occur when primes and test pairs have different sizes, but are structurally identical. Going one step further, we want to see if visual completion is independent of size, by using partly occluded shapes as primes (an occlusion prime). In this paradigm, there should be priming of test pairs that are similar to a visually completed form of the partly occluded shape (de Wit & van Lier, 2002; Sekuler & Palmer, 1992; van Lier, Leeuwenberg, & van der Helm, 1995a). For this, we will use the same shapes as in our previous experiments (de Wit & van Lier, 2002), but here size will be manipulated between prime and test pair. As mentioned, several different completions may be computed for a given occluded object. In de Wit and van Lier, the metrical flexibility of the completion was tested by varying the length of the protrusions in the completed part of the to-be-matched shapes or test pair (Figure 1C–E). Gradually increasing the length of these protrusions resulted in a less and less plausible completion, and less priming (Figure 1D and 1E). In the present experiment, we again manipulated the metrical properties of the shape, but now instead of just changing size in the completed part of the shape, we induced a size change in the whole shape, without distorting the overall structure of the shapes. Figure 2A shows the two types of metrical occlusion primes (small and large) and examples of the matching and nonmatching test pairs. Figure 2B shows the foreground primes, primes that are completed globally or locally, and these are also depicted as a small and a large variant. In the four right columns of Figure 2B the test shapes are depicted that form the matching test pairs, where in each cell, one shape of each test pair is shown. If visual completion is size-independent, the occluded prime should also facilitate decisions to different as well as same-sized completion (global) test pairs, compared to the condition in which matching shapes differ from the prime (local test pairs). After Experiment 1, we will also look at structural and size aspects using the same shapes in visual search and change detection paradigms; in Experiment 2 we will restrict the variability of the shapes to the structural aspects. In Experiment 3 we will compare structural and metrical aspects of the shapes in the two search paradigms, and we will compare results on the two paradigms.

EXPERIMENT 1. PRIMED-MATCHING: STRUCTURAL AND METRICAL ASPECTS

Method

Participants. Twenty participants took part in this experiment. All had normal or corrected-to-normal vision. Participants were students at the University of Nijmegen and received either payment or course credit.

Stimuli. Two sets of stimuli were used that originated from the experiments by de Wit and van Lier (2002), see Figure 2A–B for the first set. The second set was derived from the shape that is shown as the prime in Figure 3. In each trial a prime was given consisting of a shape that could either be occluded by a rectangle (the occlusion prime, see left column of Figure 2A) or completed and shown in front of the rectangle (the foreground prime, see left column of Figure 2B); or a no-prime, in which only a dot was presented. Three variants of foreground primes were used: A global prime, a local prime, and a filler prime. The latter was added to make the experiment somewhat harder by having more

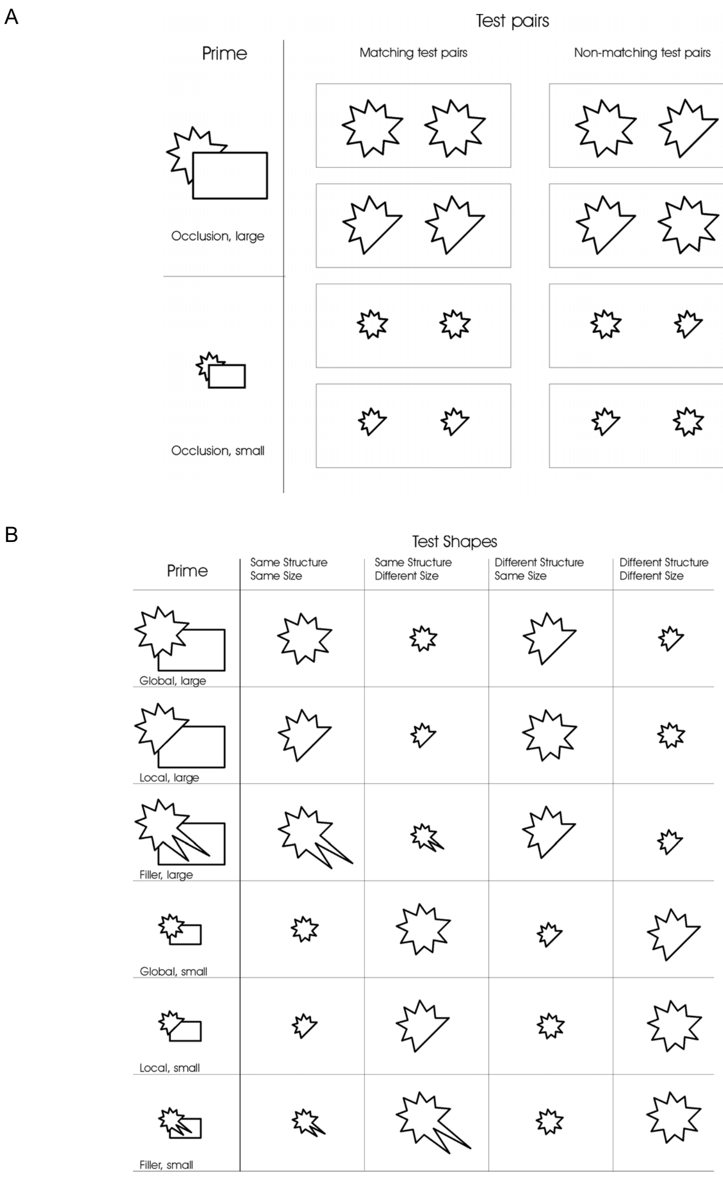


Figure 2. (A) In the left column are the occluded primes in a large and a small size. In the right column are the matching and nonmatching test pairs for the local and global sets, from set 1. **(B)** Examples of the different forms of the primes and test shapes that were used. In the left column, two types of occlusion primes are shown: small and large primes. Besides these variations in size, also the structural variations are depicted: Globally completed shapes and locally completed shapes. The test shapes depicted in the four right columns are all from the possible matching test pairs, having either the same size as the prime, or having a different size as the prime. Note that in each cell, one shape of each test pair from set 1 is shown.

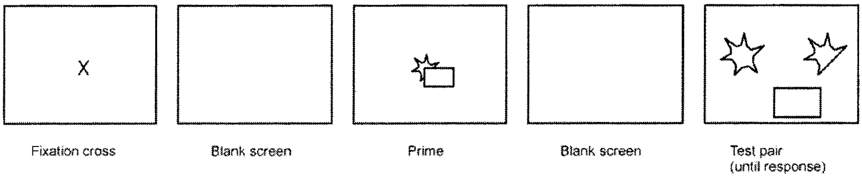


Figure 3. Procedure of the primed-matching paradigm as used in Experiment 1, using stimuli from set 2.

variation in the stimulus material. In the global completion, the same kind of protrusion, as available in the pattern of the visible part, was continued in the completion (see the first shape in the second column of Figure 2B). In the local completion, the contours that meet the occluder in the occluded version were continued until the lines would meet (see the second shape in the second column of Figure 2B). The filler completion for the first set was similar to the global completion in that the pattern of protrusions was continued, but now protrusions in the completion were longer than the protrusions in the visible part (see the third shape in the second column of Figure 2B). In the filler completion for the second set, the lengths of the protrusions were similar to those in the visible part, but here a different kind of protrusion appeared in the completion. In the left column of Figure 2B all foreground primes are depicted for the first set and it can be seen that there were two size variants: Small primes (0.71°) and large primes (1.52°).

After each prime, a test display was shown that consisted of two full shapes of the same set as the prime, which could be matching or nonmatching and could have a small or a large size (see Figure 2A for examples of matching and nonmatching test pairs of global and local test pairs). The matching test pairs were formed by having two global, two local, or two filler shapes, see the four right columns of Figure 2B for the shapes that are same or different to the primes in terms of structure and size. The nonmatching test pair could be a combination of all completed shapes from the same set, and were controlled for left–right position. The two shapes that formed the test pair were always of the same size. All combinations of completions were shown equally often. Matching test pairs were shown as often as nonmatching test pairs. The test pairs appeared on both sides of the prime, to reduce masking by the prime (Sekuler & Palmer, 1992). The rectangle appeared on the lower part of the screen, preventing the illusion that the rectangle was perceived as moving and changing into one shape of the test pair, thereby hindering any priming effect (Sekuler & Palmer, 1992). The size of the rectangle was the same in the prime display and the test pair display. Practice shapes differed from the shapes used in the actual experiment.

Procedure. Participants sat in a dimly lit room with their head stabilized by a chin rest approximately 2 m from the screen. First, a fixation cross was presented in the middle of the screen for 500 ms. After a blank was shown for 50 ms, a prime appeared on the screen for 500 ms. After a 17 ms interstimulus interval, the test display was shown until the participant responded with a button press (Figure 3). The order of the presentation was randomized for each subject and the reaction time (RT) was measured to the nearest millisecond. The trials were presented continuously, but the participants could pause by pressing a specific button. To respond to a matching or a nonmatching test pair, 11 participants used their dominant hand for ''same'' responses and their nondominant hand for ''different'' responses. This was reversed for the nine other participants. The experiment was run with SuperLab Pro, version 2.0 (Cedrus Corporation).

Participants were instructed to pay extra attention to the left shape of the prime and to respond as accurately and as quickly as possible. Participants received 20 practice trials in which they received feedback on the speed of their response to encourage them to respond as quickly as possible. There were 480 experimental trials: Set (2) × Prime (5) × Test pair (9) × Prime size (2) × Test pair size (2) = 360, where due to the left–right variation in the nonmatching trials, an extra 1/3 matching trials had to be added to get an equal number of matching and nonmatching trials.

Results

Table 1 depicts the mean RTs and mean error rates for each condition. Only correct responses to matching test pairs (93.4%) were analysed, because priming effects only seem to occur for identical test pairs (Beller, 1971). The priming effect (PE) is defined as the difference in reaction time (RT) between a prime condition and a no-prime condition:

$$PE\ (TP \mid P) = RT\ (TP \mid NP) - RT\ (TP \mid P)$$

where TP is any test pair, NP is the no prime, and P stands for any prime. In Figure 4, the mean priming effects are plotted for global, local, and occlusion test pairs as a function of the global and local primes and same size and different size prime–test pair combinations. A repeated-measures ANOVA was performed for priming effect with set (2), prime type (3), prime size (2), test shape (2), and test pair size (2). This revealed a main effect for test pair size, $F(1, 19) = 5.34$, $p < .05$, with a larger priming effect for small test pairs. An interaction effect was found for Prime size × Prime type, $F(2, 18) = 3.88$, $p < .05$, and for Prime type × Test shape, $F(2, 18) = 16.86$, $p < .001$. Planned comparisons were performed to investigate the effect of the primes on test pairs that were structurally identical to the prime, compared to the no-prime condition (taking

TABLE 1
RTs (ms) for the different primes and test pairs, for the same and different size conditions (mean error rates for each condition in brackets)

	Test pairs					
	Same size			*Different size*		
	Global	*Local*	*Nonmatching*	*Global*	*Local*	*Nonmatching*
Occluded	602.51 (3.1%)	636.8 (4.3%)	650.61 (7.5%)	621.16 (3.8%)	637.28 (7.5%)	648.15 (6.5%)
Global	591.13 (3.8%)	640.16 (10.0%)	657.08 (7.7%)	599.41 (3.1%)	644.28 (11.3%)	643.19 (9.0%)
Local	642.58 (3.1%)	591.31 (8.1%)	657.68 (7.3%)	642.48 (6.3%)	589.68 (4.4%)	643.03 (6.3%)
No-prime	644.02 (1.9%)	634.45 (6.3%)	669.02 (5.9%)			

together the data for the two test shapes). This showed that the global prime facilitated the global test pair, PE(global | global), $F(1, 19) = 24.17$, $p < .001$, and the local prime facilitated the local test pair, PE(local | local), $F(1, 19) = 20.46$, $p < .001$. The occlusion prime facilitated the global test pair, PE(global | occlusion), $F(1, 19) = 18.27$, $p < .001$, but it did not facilitate the local test pair, PE(local | occlusion), $F(1, 19) < 1$, n.s.

To examine the role of size differences on priming, global, local, and occlusion primes were compared in the same size condition and in the different size condition. No differences were found for the priming effects: the priming

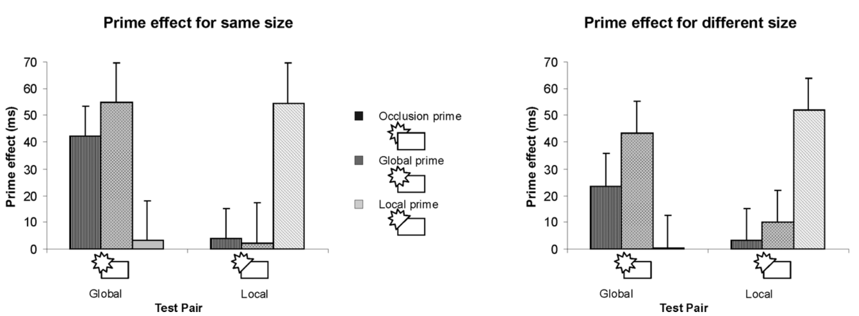


Figure 4. **(A)** Mean priming effects and error bars for global and local test pairs as a function of occlusion, global, and local primes for same size conditions. **(B)** Mean priming effects and error bars for global and local test pairs as a function of occlusion, global, and local primes for different size conditions. Note only one of the two sets is shown to exemplify the stimuli.

effect for the global prime on the global test pair did not differ in the same or different size conditions, $F(1, 19) < 1$, n.s., and the same and the different size conditions also did not differ for the effect of the local prime on the local test pair, $F(1, 19) < 1$, n.s. More importantly, the priming effect from the occlusion prime on the global test pair was not different in the two conditions, $F(1, 19) = 1.73$, n.s. To check if there was a trend for a diminishing priming effect for an occlusion prime on global test pairs under different size conditions, compared to the effect of a global prime under the same conditions, we tested for an interaction on the size of the priming effect between occlusion and global primes under same size and different size conditions, for global test shapes. This interaction was not significant, $F(2, 18) = 0.081$, n.s.

Discussion

Replicating our earlier study (de Wit & van Lier, 2002), the functionality of the paradigm was again shown in the effect of the primes on identical test pairs. That is, global primes facilitated RTs to global test pairs and local primes had a facilitating effect on local test pairs. Also, the occluded prime had a facilitating effect on the global test pair, but not on the local test pair. This implies that, for the shapes used here, the occluded prime was representationally much more similar to global completions compared to local completions. The local completions distort the overall regularity apparent in the occluded prime so that the priming effect disappears (this was also found in the earlier study). So again, global influences dominated in the completion process of these forms, not local influences.

The issue in our study was what effect a size difference has on priming and more specifically on the process of visual completion. The priming effect did not disappear when the prime and the test pair were structurally identical but the sizes were different, supporting earlier research that factors such as change in position, scale (bandwidth), or mirror reflection, do not prevent priming effects from occurring (Biederman & Cooper, 1991a, 1991b, 1992; Biederman & Gerhardstein, 1993; Cooper, Biederman, & Hummel, 1992; Fiser & Biederman, 1995, 2001; Stankiewicz & Hummel, 2002; Stankiewicz, Hummel, & Cooper, 1998). Importantly, the present finding shows that size invariance applies to visual completion. When primes disappear from our view, the representation of these primes seems to be based more on structural aspects of the shapes than on metrical aspects, such as their specific size.

The main conclusion, that overall size differences do not strongly influence visual completion, fits with results from our earlier study (de Wit & van Lier, 2002) where we also found evidence for metrical flexibility in the completed part of a partly occluded shape, as long as the overall structure was preserved. Taken together, these data suggest that, priming can be insensitive to global size differences between prime and test pairs, whilst being sensitive to structural differences. However, one could argue that this finding can be explained by a difference in saliency between the size and structural differences used here. Compared to structural differences, the size differences might simply have been less salient, and so had less impact on performance. To test this possibility, visual search was used in Experiment 2. In this paradigm, a target has to be found among distractors, and the more similar the target and the distractors are, the longer it takes to detect the target. When a target has to be found among distractors that sufficiently differ in size, the search is fast (e.g., Treisman & Gelade, 1980), which provides us with a way of seeing if the size difference used in Experiment 1 was sufficient for efficient detection. We also employed change detection (Rensink, O'Regan, & Clark, 1997). In a change detection procedure, two alternating displays are shown, separated by a blank screen (to eliminate transients when a change takes place). The task for the participant is to detect the difference between the two screens. This intervening screen demands, at least for the attended object (Rensink, 2000), visual short-term memory. Compared to visual search, this paradigm is more similar to the primed-matching paradigm, in that the partly occluded shape is not constantly available to the eye. As a consequence, the nature of the representations used in performing change detection might be more similar to those in the primed-matching paradigm. The main finding from the change detection experiments is that it is surprisingly difficult to detect even large changes in images. Here we compared visual search and change detection paradigms, in relation to the manipulations previously used in primed-matching. Effects of occlusion have not previously been studied in change detection. If occluded objects are completed, then changes from partial occlusion to a completed shape should prove relatively difficult to detect. The question is whether such a shape change would be more difficult to detect than the size change manipulated in Experiment 1.

EXPERIMENT 2. VISUAL SEARCH AND CHANGE DETECTION: STRUCTURAL PROPERTIES

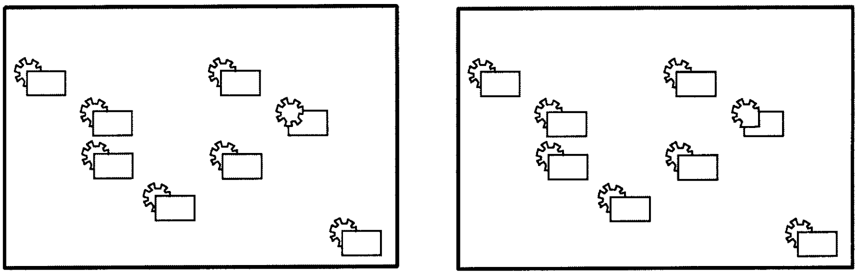
Rensink and Enns (1998) have previously used visual search (Treisman & Gelade, 1980) to study early vision and amodal completion. In their experiments, search rates for targets were used as an indication of the target–distractor similarity, slow search indicating high similarity. When simple, partly occluded shapes served as targets among whole object distractors, search was slow. On the basis of this finding, Rensink and Enns argued that there was high target–distractor similarity between the partly occluded objects and the whole objects, indicating a rapid completion for the occluded objects. Surprisingly, partly occluded objects were also hard to detect among notched objects, where notched objects are similar to a ''mosaic'' interpretation of an object (i.e., where the occluded object is not completed). This was taken to suggest that partly occluded objects and notched objects are fairly similar, indicating that contours are not perceptually filled in as complete objects; it is therefore argued for a more functional (higher level) kind of filling in (see Rensink & Enns, 1998).

In the visual search paradigm, a display with partly occluded shapes will be shown in which one completed form of the partly occluded shapes served as the target. The completion in this target could be either local or global. The search rates for these differently completed shapes will be compared to each other. In the change detection paradigm, the same display as in the visual search paradigm will be used, but in alternation with a display with partly occluded shapes only, and between these displays a briefly presented white display will appear. For both paradigms it is expected that the completion that is most salient will be detected faster (and a plausible completion should take longer to detect). Using the same stimuli, for which we found global completion in our previous experiment, we expect the local completions to be detected faster than the global completions. Another important matter is the difference in sensitivity between these tasks. We expect the change detection paradigm to be more sensitive to the structural aspects as found in the primed-matching paradigm than the visual search paradigm, due to the assumed higher similarity between the two paradigms.

Method

Participants. Eighteen participants took part in this experiment. All had normal or corrected-to-normal vision. Participants were students at the University of Nijmegen and received either payment or course credit.

Stimuli. Two sets of shapes from the previous experiment were used, plus one extra that also originated from a previous study (de Wit & van Lier, 2002). The shapes in the third set were constructed by superimposing a pattern of two concave angles alternating with two convex angles on a virtual circle (see Figure 5, in which this shape is used to exemplify the stimulus display). The shapes from each set could appear in three forms: partly occluded by a square, or completed in either a global or a local way (thereby partly occluding the square). In each display, the partly occluded shapes served as distractors and a completed shape served as a target. The shapes were used to create two sorts of displays: One sort comprised of distractors and a target (i.e., the target display; see Figure 5) and the other sort of displays comprised of distractors only (i.e., the distractor display). The target displays were used in both the visual search paradigm and the change detection paradigm. Displays consisted of 4, 8, 12, or 16 shapes, always drawn from the same set of shapes. The shapes were distributed equally over four (3×3) quadrants, in an imaginary 6×6 grid on a 900×700 display. The target (a completed shape) was displayed equally often in each quadrant and in each of the target positions both a local and a global solution could be shown. In the change detection paradigm, displays were added where a



A B

Figure 5. Structural-target displays for the visual search paradigm and the change detection paradigm. **(A)** Display with a global target. **(B)** Display with a local target.

partly occluded shape substituted the target, thereby creating displays with distractors only.

Procedure. Half of the participants first performed the visual search block followed by the change detection block, while the other half performed the tasks in the reversed order. In the visual search paradigm, first a fixation cross was shown, and then (in all cases) a target display was shown until the participant signalled with a button press that the target had been seen. As soon as the participant responded, a brief black display appeared followed by the distractor display, so that the participant could no longer search for the target (as the target changed into a distractor). Also, a red rectangle appeared that the participant had to navigate through the distractors in order to localize the position of the target, thereby proving that the target was detected. The change detection paradigm differed from the visual search paradigm in that the distractor display was shown for 500 ms, which was followed by a briefly presented blank screen for 120 ms, followed by the target display, which was also shown for 500 ms, and again followed by the blank display for 120 ms, and so on. The distractor display, the blank display, and the target display kept alternating until the participant pressed a button to signal the detection of the change (i.e., the target). Again, the distractor display appeared and the participant had to show that the target had been seen, by navigating a red rectangle to the right location. Before each experimental block of 192 trials started, the participants received eight practice trials.

Results

The results for both paradigms are shown in Figure 6. Data were analysed for both the visual search paradigm and the change detection paradigm together, over all correct trials (93.77%). On the right side of the graph, search rates are shown, calculated by means of a best fit on the slope of the correct RT over

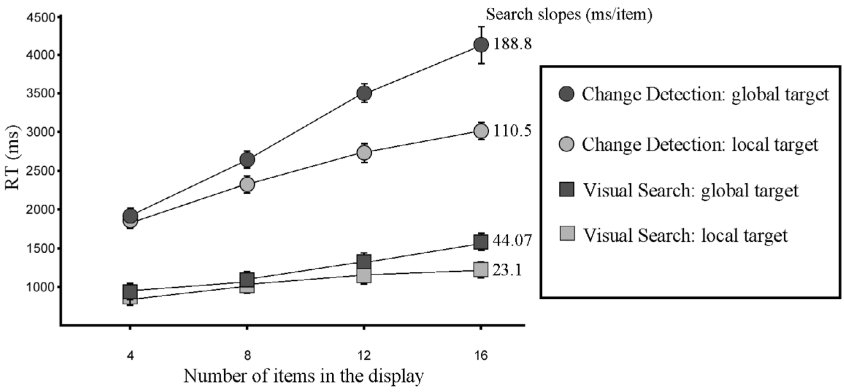


Figure 6. RTs and error bars for global and local targets as a function of number of items in the display for the visual search paradigm and the change detection paradigm.

display size. If the index finger was not lifted properly from the response button after responding to a trial, the computer recorded this also as a response to the next trial. To be on the conservative side, we have excluded the data points that showed identical RTs (in ms) as their predecessors. A repeated-measures ANOVA was performed with paradigm (2), target (2), and number of items (4) as independent variables, and RT as the dependent variable. This revealed main effects for all independent variables. First, a main effect was found for paradigm, $F(1, 17) = 183.57$, $p < .001$. The mean RT for the visual search paradigm was lower than for the change detection paradigm. Second, a main effect was found for target, $F(1, 17) = 47.30$, $p < .001$. The mean RT for local targets was lower than for global targets. Third, a main effect was found for number of items, $F(3, 15) = 39.35$, $p < .001$. A significant linear contrast, $F(1, 17) = 112.58$, $p < .001$, showed that mean RT increased linearly with number of items.

All three two-way interactions were found to be significant. First, the Paradigm $\times$ Target is significant, $F(1, 17) = 23.89$, $p < .001$, indicating that the difference between global and local targets is larger in the change detection paradigm. A second interaction was found for Paradigm $\times$ Number of items, $F(3, 15) = 27.23$, $p < .001$, indicating that the increase in RT that accompanied an increasing number of items was stronger for the change detection paradigm. A third interaction was found for Target $\times$ Number of items, $F(3, 15) = 16.80$, $p < .001$. The RT advantage for local targets increases with the number of items. Finally, a significant three-way interaction was found for Paradigm $\times$ Target $\times$ Number of items, $F(3, 15) = 5.87$ $p < .01$, indicating that the RT difference for global and local targets, which was enlarged by an increasing number of items, was stronger in the change detection paradigm.

Discussion

A number of expected effects were found. One finding was that task difficulty increased with number of items. A well-known result is that task difficulty in detecting targets increases as a function of increasing number of distractors. This was also found in the present experiments for both the local and the global targets. Also expected are some of the contrasts between the paradigms. First, for the present stimuli, the change detection task appears to be more difficult than the visual search task. This is not surprising given the ''flicker'' present in the change detection task, and the fact that participants may have to wait until the next presentation of a display to confirm that a change has taken place. The main finding, however, was that a global completion indeed resulted in higher RTs among the partly occluded shapes than a local completion and this held across both search and change detection paradigms. This confirms the findings on the global influences on completion from our previous primed-matching experiment (de Wit & van Lier, 2002). Second, the effect of global completion was larger in the change detection paradigm. This interaction between paradigm and target might be explained by the additional memory component introduced by the change detection task. For example, the representation that is stored may be similar to the global completion. Third, the more items there are, the more difficult the change detection task gets as compared to the visual search task. A similar finding concerning the number of items was found for the kind of completion: The effect of an increasing number of distractors was larger for the global compared to the local completions. This suggests that local completions are less likely to take place, and so local completion distractors are likely to compete less with the completed target. The final finding can be seen in the same light. The change detection paradigm magnifies the effect of an increasing number of items, which further impairs the detection of global completions because of the increased competition for selection, when more items are present.

Now that we have results on visual search and change detection that are compatible with results of the primed-matching paradigm, we return to the issue that was raised after Experiment 1 with respect to the detectability of the metric and structural aspects of occluded shapes. Whether the size changes examined in Experiment 1 were less salient than the shape changes was examined by evaluating the effects of these changes in a combined search and change detection paradigm.

EXPERIMENT 3. VISUAL SEARCH AND CHANGE DETECTION: STRUCTURAL AND METRICAL PROPERTIES

To compare the saliency of size aspects and structural aspects of shapes in both paradigms, we looked at two possible targets: Shapes differing either in size or structure. The distractors were locally or globally completed shapes, as used in our previous experiments, and they were large or small. If structure is indeed a more salient feature than size, the structural targets should be detected much faster than the size-defined targets.

Method

Participants. Fourteen participants took part in this experiment. All had normal or corrected-to-normal vision. Participants were students at the University of Nijmegen and received either payment or course credit.

Stimuli. The same three sets of shapes as in Experiment 2 were used. However, now, there were four forms in which the shapes could appear: a completed shape in either a global or a local way, with a size that was either small or large, identical to Experiment 1. Figure 7 shows examples for each type of target. All shapes could serve as distractors and as targets, resulting in eight sorts of displays, where the target always differed from the distractors in one aspect: size or structure.

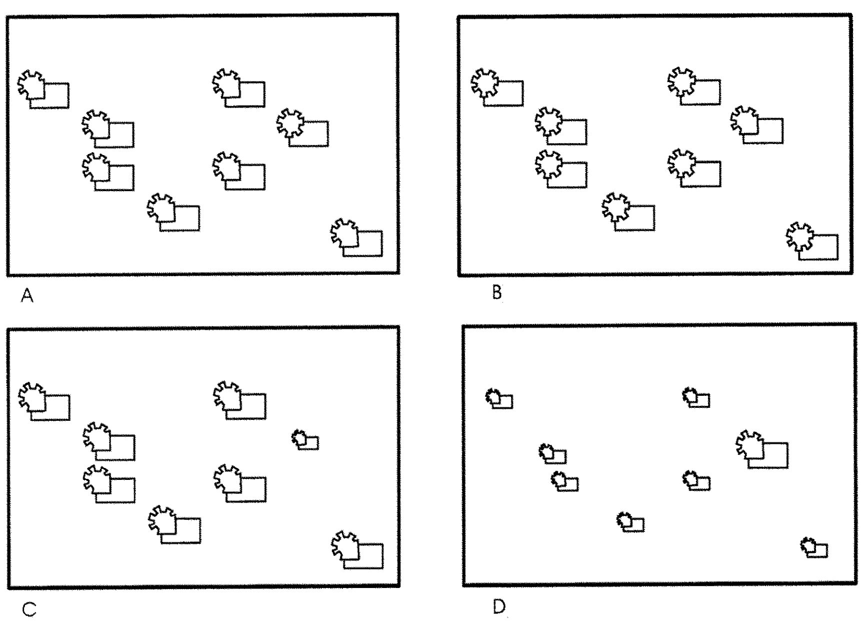


Figure 7. Examples of displays for the visual search paradigm and the change detection paradigm. **(A)** Example of a structural target display with a global target. **(B)** Example of a structural target display with a local target. **(C)** Example of a size target display with a small target. **(D)** Example of a size target display with a large target. Note that in the experiment, all possible structural and size combinations are used.

Procedure. The procedure was the same as that used in Experiment 2, there were 384 experimental trials per block (paradigm).

Results

Figure 8 shows the results for both paradigms. The data were analysed over all correct trials (97.13%), combined for the visual search paradigm and the change detection paradigm. A repeated-measures ANOVA was performed with paradigm (2), target (4), and number of items (4) as independent variables, and RT as the dependent variable. This analysis revealed main effects for all independent variables. First, an effect of paradigm, $F(1, 13) = 188.84$, $p < .001$, reflecting lower RTs for visual search than for change detection. Second, a main effect was found for target, $F(3, 11) = 105.45$, $p < .001$. Planned comparisons show that large targets had lower RTs than small targets, $F(1, 13) = 138.17$, $p < .001$, the RTs for local targets were lower than for global targets, $F(1, 13) = 8.37$, $p < .05$, and RTs for size differences were lower than for structural differences, $F(1, 13) = 364.87$, $p < .001$. Third, a main effect was found for number of items, $F(3, 11) = 67.99$, $p < .001$. Planned comparisons for the different pairs showed that RTs increased with number of items, $F(1, 13) = 196.47$, $p < .001$, $F(1, 13) = 155.97$, $p < .001$, $F(1, 13) = 19.16$, $p < .005$.

All interactions were significant. An interaction effect was found for Paradigm × Number of items, $F(3, 11) = 39.43$, $p < .001$, indicating that the increase in RT that accompanied an increasing number of items was stronger for the change detection paradigm. An interaction effect was also found for Paradigm × Target, $F(3, 11) = 25.39$, $p < .001$. A planned comparison showed that the difference between large and small targets was larger in the change detection paradigm, $F(1, 13) = 19.18$, $p < .005$, yet the difference between local and global

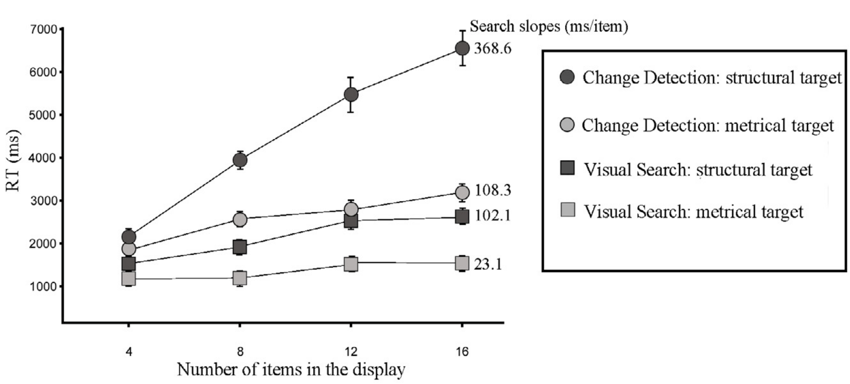


Figure 8. RTs and error bars for structural and size targets as a function of number of items in the display for the visual search paradigm and the change detection paradigm.

targets was not significantly different for the two paradigms, $F(1, 13) < 1$, n.s. Taking together all size targets and structural targets for the different paradigms, size targets were easier to detect than structural targets, $F(1, 13) = 79.17$, $p < .001$. Furthermore, an interaction effect was found for Target × Number of items, $F(9, 5) = 31.75$, $p < .005$: the RT advantage for size over structural targets increased with the number of items. Finally, a significant three-way interaction was found for Paradigm × Target × Number of items, $F(9, 5) = 36.11$, $p < .005$, indicating that the RT difference for structural and size targets, which is enlarged by an increasing number of items, was stronger in the change detection paradigm.

Discussion

The results from this experiment were straightforward. All the basic effects were found again: Change detection was harder than visual search, and the difficulty of detection increased as a function of the number of distractors. Also, global targets were harder to detect than local targets. Additionally, large targets are easier to detect than small targets. The most important finding, with regard to our question on the detectability of structural versus size aspects as used in Experiment 1, was that structural targets were much harder to detect than size targets. The interaction effects are consistent with the findings from Experiment 2, the effect of the number of items is magnified in the change detection paradigm, compared to the visual search paradigm, and the effect of number of items is also larger for structural targets. The difference in RTs between structural and size targets is larger in the change detection paradigm compared to the visual search paradigm. Finally, the three-way interaction shows that the difference in RTs between structural and size targets increases with the number of items and that this effect is larger in the change detection paradigm. Taken together, the results show the relatively higher saliency of size differences as compared to the structural differences in our stimuli. This is surprising when we compare this to the effects we found earlier in Experiment 1, where structural aspects were found to be more important for the priming effect than size aspects. That is, having a size change between primes and test pairs did not prevent a priming effect, but having primes and test pairs with different structures did prevent priming. Taken together, we find that structure is important in representing shapes as pointed out by Experiment 1, even though structural changes are not necessarily more salient (Experiment 3).

GENERAL DISCUSSION

These experiments provide us with information on the relative effects of structural and metrical (overall size) variations in completion, and also on the relations between completion effects in three different paradigms. Experiment 1 examined priming from a partly occluded prime on a completed different-sized test pair, as measured in the primed-matching paradigm. This showed that the completion process is hardly sensitive to overall size differences. The results fit nicely with earlier experiments showing the flexibility of the completion process for the completed part itself (de Wit & van Lier, 2002); a variation in the metrical aspects of the completed part did not disrupt performance as long as the overall structure was not distorted. As mentioned in the introduction, this flexibility can easily be understood in the light of problems that are posed on the visual system by our dynamic world.

One aspect of these studies that shows the relations between the three experimental paradigms with regard to visual completion is the similar pattern of findings for the change detection paradigm and the visual search paradigm, although performing a change detection paradigm is harder. The larger difference between conditions for the change detection paradigm might suggest that this paradigm has better discriminating abilities. This pattern of results does not have to be surprising: It takes longer to go over each shape, due to the intervening blank screen and the disappearance of the target in the change detection paradigm. Moreover, participants have to wait for the re-presentation of a display before confirming that an object has disappeared. This difficulty increases RTs differentially for the more difficult tasks.

In Experiment 3, however, we showed that metrical aspects of the stimuli were more salient than structural aspects in searching and detecting. This is in contrast to findings from the primed-matching paradigm, where the reversed pattern was found. In experiments using a similar procedure to the primed-matching paradigm, Biederman and Bar (1999) manipulated objects so that these could have a change in a structural property or in a metric property. Biederman and Bar used the term structural properties to refer to properties that are not affected by rotation in depth, and metric properties to refer to properties that are affected by rotation in depth. In the tasks, participants had to decide whether objects, that were shown sequentially, were the same or different. They found that objects that differed structurally were easier to discriminate, pointing at the higher relevance of these structural aspects for stimulus representation. Although their terms refer to different aspects of shapes than ours, these findings are similar to our findings from the primed-matching paradigm. The reason for this might lie in the similarity of the tasks. In both the priming paradigm used by Biederman and Bar and the primed-matching paradigm used in Experiment 1, stimuli are shown sequentially and explicitly or implicitly compared, respectively. In contrast, in the search paradigms, a target has to be detected among different shapes, which probably results in different strategies, in turn resulting in different representations of shapes. Also, search and change detection are more dependent on peripheral vision, where detailed structural aspects of shape may not be well presented.

For metrical aspects of shapes it was found in the search paradigms that large targets were easier to detect among small distractors. Generally, distractors can be seen as context, similar to the prime in the primed-matching paradigm serving as context. A post hoc test shows that for a different-sized prime–test pair combination, the priming effect was larger for a small prime, large test pair, rather than the other way around, $F(1, 19) = 26.49$, $p < .001$. Thus within these metrical aspects, the same pattern of effects was found for all paradigms. For structural variations, one could argue for the same pattern of effects for the paradigms, although the underlying cause could be different. Experiment 2 showed that global targets are harder to detect than local targets, a result that was strongest in the change detection paradigm, and we speculated that this could be due to a larger memory contribution in the nature of the change detection paradigm. The results of Experiment 3 seem to disprove this idea, however, because metrical aspects were then more important in performing the task. In contrast, the pattern of findings for structural changes is similar across the three paradigms, and all show the presence of global relative to local completion. However, in the primed-matching paradigm there is no context to signal metrical differences, but in the search paradigms there is always a context (the distractors) that can signal metrical differences.

Whatever the explanation for the difference in results between the primed-matching paradigm and the search paradigms, the finding of size invariance for visual completions in Experiment 1 is even more striking in the light of Experiment 3, where it is shown that metrical aspects of shapes are very salient. A possible lack of saliency cannot explain the priming effect across size changes. What is more, this priming effect thus provides us with a glimpse at the nature of representations, which are based more on structural than on metrical aspects of a shape.

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