Does Symmetry Result in a Pop-Out?
Abstract

The previous chapter suggests that symmetry attracts attention. The analyses revealed a correlation between human eye fixation and local symmetry. However, it does not mean that there is a causal relation between the two. To shed more light on this matter, the role of symmetry in attracting visual attention is investigated in more controlled experiments in this chapter. In the first experiment, it is tested to what extent the perception of symmetry is efficient and preattentive in a pop-out experiment. The second experiment examines whether symmetrical figures attract more attention than non-symmetrical figures in a scene-memory task. The results of the first experiment show that symmetry causes a pop out, especially for polygonal figures. For the stacked bar and dot patterns, search for the target is less efficient. However, some elements of a pop-out effect are found. This suggests that the detection of symmetry is preattentive. The second experiment shows no effect of symmetry. This shows that visual attention is mainly object oriented.
4.1 Introduction

The previous chapter has shown that symmetry is a good predictor of human eye fixations. The local symmetry in the image correlates well with the fixation locations. Moreover, the amount of local symmetry is higher at the fixation points, especially for the first fixations. However, this shows a correlation, but not a causal relation between symmetry and visual attention. Does symmetry directly attract attention, or is symmetry a cue for the presence of an object and is visual attention basically object oriented? This is one of the questions that this chapter tries to answer. The other question is whether symmetry is a feature that is processed efficiently and preattentively. The results in the previous chapter suggest that this is the case, since especially the first fixations are on locally symmetrical parts of the image. In this chapter, these questions are addressed in two experiments, a pop-out experiment and a scene-memory task.

4.1.1 Effortless Symmetry Perception

Julesz (1971, 1981) defined perception as efficient and preattentive when important characteristics of a stimulus can be detected when the stimulus is exposed for a very brief period (< 160ms). In this definition, symmetry detection of single presented figures has been found to be preattentive. Humans are able to detect symmetry in simple shapes that are very briefly presented (Carmody, Nodine, & Locher, 1977), as well as in dot patterns (Wagemans, Van Gool, & d’Ydewalle, 1991), line segments (Locher & Wagemans, 1993), and abstract art displays (Locher & Nodine, 1989). Especially symmetry at a coarse scale can be detected very quickly (Barlow & Reeves, 1979; Royer, 1981; Palmer & Hemenway, 1978). It is proposed that symmetry detection takes place in two phases, a quick but coarse first phase, followed by a slower second phase, in which a more detailed investigation of the pattern takes place (Palmer & Hemenway, 1978). Other evidence for preattentive detection of symmetry comes from Baylis & Driver (1994), who demonstrated that the reaction times to detect symmetry are hardly influenced by the complexity of the pattern. This suggests parallel and preattentive perception of symmetry Wagemans (1999).

Another method to investigate preattentive processes is by using visual-search experiments such as discussed in Section 2.3. If the search for an object that differs from the other objects in a search display on a specific feature is efficient, the perception of
that feature is likely to be preattentive. The search for a feature is efficient when the
slope of the reaction time $\times$ set size curve is near zero, in other words when the target
pops out despite the number of distractors. A further indication of preattentive feature
detection is the existence of a search asymmetry (Wolfe, 1998; Treisman & Gormican, 1988).
According to Treisman & Gormican (1988), it is easier to find a deviation
among canonical stimuli than the reverse. It is, for instance, easier to find a tilted bar
among vertical distractors than it is to find a vertical bar among tilted bars, and it is
easier to find an up-side-down elephant among normally oriented elephants than vice versa (Wolfe, 2001).

In Section 2.3.1, we discussed a number of basic features that cause a pop out. These
features include color, intensity, orientation, motion, and shape. Search asymmetries
have been found for these features as well (Wolfe, 1998). Only a few studies focused
on symmetry as a basic feature. Wolfe & Friedman-Hill (1992) showed that symmetry
relations among items in a search display influence the reaction times. If the distractors
are symmetrical to each other, search is easier. If, on the other hand, some of the dis-
tractors are symmetrical with the target, search becomes more difficult. This suggests
that symmetry relations are processed in parallel and preattentively.

Olivers & van der Helm (1998) used more complex symmetrical and non-symmetrical
stimuli in a pop-out experiment. They used dot patterns, polygons, and block-contour
shapes and presented search displays with a symmetrical target among non-symmetrical
distractors and vice versa. Their results showed that symmetry does not result in a
pop-out effect. The reaction times increase when the number of items in the search
display increase. However, in their experiments, the set of distractors was highly het-
erogeneous. All distractors had a completely different shape, with the only common
property that they were either symmetrical among the vertical axis or not. However,
Bauer et al. (1996) showed that search becomes inefficient when the distractors are
sufficiently heterogeneous. This might explain the results of Olivers & van der Helm

In our first experiment, we investigate the preattentive perception of symmetry using
the visual search paradigm. Our experimental setup differs from that of Olivers &
van der Helm (1998) in that we use a homogeneous set of distractors. We furthermore
use set sizes of 4, 8, and 12 items per search display, instead of the 1–4 items used by
Olivers & van der Helm. This is more conform the set sizes used in other visual-search
experiments (see Section 2.3).
4.1.2 Attention for Symmetry

The first experiment presented here studies whether the perception of symmetry is efficient and preattentive. If so, this does not mean that symmetry is also a visual attractor if the task is not to spot the odd-one-out. To investigate whether attention is paid to symmetry outside the visual-search paradigm, we ask the participants to remember a scene consisting of a number of symmetrical and non-symmetrical figures in the second experiment. The question is whether people pay more attention to the symmetrical forms than to the non-symmetrical ones to memorize the scene. If the results confirm this question, symmetry is a stronger visual attractor than the mere presence of an object. If not, it indicates that human visual attention is essentially object oriented.

4.2 Symmetry Pop-Out Experiment

In the symmetry pop-out experiment, the participants have to search for the odd-one-out, a symmetrical figure among non-symmetrical figures or vice versa.

4.2.1 Methods

4.2.1.1 Participants

Eleven undergraduate students participated in the experiment for course credits. The age of the participants ranged from 18 to 25 years. All participants had normal or corrected to normal vision. The data of one participant is discarded, since the mean reaction times exceeded the means of the other participants by three standard deviations.

4.2.1.2 Experimental Design

The participants were shown visual-search displays. The task was to decide as quickly as possible if the search display contained a figure that differed from the rest or not by pushing buttons on a keyboard. The reaction time was recorded.

Three different stimulus types were used, stacked blocks, polygons, and dot patterns (see Figure 4.1a). Figure 4.1b shows the experimental layout. In fifty percent of the
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Figure 4.1: The experimental setup of the pop-out experiments. a) The three different types of stimuli used: blocks, polygons, and dot patterns. b) For each stimulus type, a $3 \times 2 \times 2$ layout was used: three different set sizes, two different conditions (symmetric and non-symmetric), and target presence.

trials, a target was present in the display. In the other cases, the target was absent, and all figures in the display were identical. We used two conditions to investigate search asymmetries. In the symmetric condition, the target was symmetric and the distractors were non-symmetric, and in the non-symmetric condition, the target was non-symmetric and the distractors were symmetric. Three different set sizes were used, 4, 8, and 12. Each unique setting of stimulus type, target presence, symmetry condition, and set size was repeated 20 times, giving a total of $3 \times 3 \times 2 \times 2 \times 20 = 720$ trials. The trials were randomly shuffled. Prior to each trial, the participants were asked to fixate on a cross in the center of the screen.

The experiment started with 20 dummy trials to let the participants get used to the task.
Subsequently, the 720 trials were presented in eight blocks of 90 trials. After each block, the participants got one minute of rest. Halfway the experiment, a five minute break was taken. The number of correct trials was fed back to the participants after every 30 trials, in order to keep them motivated to do the task. In total, the experiment lasted a little less than an hour.

### 4.2.1.3 Stimuli

Three different stimulus types were used, stacked blocks, polygons, and dot patterns, similar to those used in (Olivers & van der Helm, 1998). The figures were presented in a circle with a diameter of two third of the height of the screen (approximately 17°), with the figures uniformly spread out over the circle. The circle was rotated over a random angle, to have different positions for the figures each trial. Each figure had a maximum width and height of 2.9°. All symmetrical figures were mirror symmetric with a vertical symmetry axis. Care was taken that the non-symmetrical figures did not accidentally show symmetry.

The stimuli were presented to the participants at a resolution of 1024 × 768 on an 18” CRT monitor of 36 by 27 cm at a distance of approximately 60 cm from the participants. The visual angle was approximately 33° horizontally by 25° vertically.

The three stimulus types are defined as follows:

**Stacked blocks** A stacked-blocks figure consists of eight filled bars stacked on top of each other. For a non-symmetrical figure, the left and right sides of the bars have randomly appointed lengths, with a minimum of 5% and a maximum of 50% of the height of the figure. For a symmetrical figure, the left and right sides are mirrored copies.

**Polygons** A polygon consists of 16 points. Each point is defined as a vector from the center of the figure, where the angles of the vectors are evenly spread out like a wagon wheel, that is, with intervals of 22.5°. The lengths of the vectors are randomly assigned between 5% and 50% of the maximum width of a figure. For symmetrical figures, the left and right side are mirrored copies. Different from (Olivers & van der Helm, 1998), the polygons are filled to increase their visibility.
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Figure 4.2: Reaction times of the symmetry pop-out experiment for the stacked bars, polygons, and dot patterns. The curves give the mean correct reaction times. The error bars depict the 95% confidence intervals. The dashed lines refer to the target-present trials, whereas the solid lines show the target-absent trials. The circles show results for the non-symmetric condition and the triangles for the symmetric condition. A pop-out effect of symmetry is especially clear for the polygon figures.

Dot patterns Each dot pattern consists of 16 dots randomly placed in a circle with a diameter of 2.9\degree and a minimum distance between two dots of 0.4\degree. The dots have a diameter of approximately 0.3\degree. In the symmetrical case, eight dots are placed and reflected about the vertical symmetry axis.

4.2.2 Results and Discussion

Data for which the reaction times lie outside three standard deviations of the participant’s mean response to that specific set size × condition × target combination is disregarded, since these trials are likely to be false. Figure 4.2 shows the reaction times of the visual search experiment. The lines are the mean correct reaction times, and the error bars depict the 95% confidence intervals on the mean. It can be appreciated from the figure that the slopes of the target-absent curves are steeper than that of the target-present curves. This indicates that there is a symmetry pop-out effect. The pop-
out effect is especially clear for the polygon figures, which show an actual flat curve for the target-present condition. The plots furthermore reveal search asymmetries for all stimulus types. The search for a non-symmetrical target among symmetrical distractors is faster than the search for a symmetrical target. The reaction times greatly differ for the different stimulus types. Search is fastest for the polygon figure, followed by the stacked bars. The search for a dot-pattern target is much slower.

Below, the results of within-subjects repeated measures analysis of variance (ANOVA) on the mean correct reaction times for the different stimulus types are given, followed by an analysis on the slopes of the reaction time × set size curves. This is similar to the analysis done by Olivers & van der Helm (1998).

4.2.2.1 ANOVAs

We performed a three-way within-subjects ANOVA on the mean correct reaction times with the factors set size (4, 8, 12), condition (symmetry / non-symmetry), and target (present / absent) for all stimulus types. There are two effects that we are interested in especially: 1) The ANOVA indicates a pop-out effect when there is a significant set size × target interaction, which indicates that the search efficiency differs between target presence and absence. 2) A significant condition × target interaction hints towards a search asymmetry. We furthermore performed a post-hoc two-way within-subjects ANOVA on the mean correct reaction times with set size and condition as factors. This analysis adds two more effects of interest: 3) This post-hoc ANOVA indicates as pop-out effect when there is a significant main effect of set size in the target-absent case and there is not, or a less strong main effect of set size in the target-present case. 4) A search asymmetry is indicated by a significant main effect of condition in the target-present case. The presence or absence of the four effects of interest are summarized in Table 4.1.

The three-way ANOVA for the stacked blocks shows a significant main effect for target \(F(1,9) = 19.0, p = .002\), and for set size \(F(1,9) = 33.8, p < .001\) and a significant condition × target interaction \(F(1,9) = 24.5, p < .001\). The set size × target interaction is not significant \(F(1,9) = 1.41, p = .27\). The post-hoc two-way ANOVA shows a significant main effect for set size \(F(1,9) = 15.5, p < .01\) and condition \(F(1,9) = 10.8, p < .01\) in the case of target absence. In the target presence case, set size is also a main effect, although less significant \(F(1,9) = 9.53, p = .01\), as is
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condition \((F(1, 9) = 10.4, p = .01)\). In both the target presence and absence case, there is no significant set size \times\ condition interaction.

For the polygons, the three-way ANOVA shows a significant main effect for target \((F(1, 9) = 49.9, p < .001)\) and a significant set size \times\ target interaction \((F(1, 9) = 7.46, p = .02)\). No significant main effect for set size is found, due to the flat slope in the target-present case. The post-hoc two-way ANOVA shows a main effect for set size for target absence \((F(1, 9) = 6.46, p = .03)\), but not for the target-present case \((F(1, 9) = 0.94, p = .36)\). In both cases there are neither significant main effects for condition nor any interaction effects.

For the dot patterns, the three-way ANOVA reveals significant main effects for set size \((F(1, 9) = 67.0, p < .001)\) and target \((F(1, 9) = 34.0, p < .001)\), a significant set size \times\ target interaction \((F(1, 9) = 13.0, p < .01)\), and a significant condition \times\ target interaction \((F(1, 9) = 29.0, p < .001)\). The post-hoc two-way ANOVA shows significant main effects for set size \((F(1, 9) = 41.8, p < .001)\) and condition \((F(1, 9) = 12.8, p < .01)\) in the target-absent case. In the target-presence case, there is also a main effect of set size, though less significant \((F(1, 9) = 17.9, p < .01)\), and for condition \((F(1, 9) = 13.7, p < .01)\). No interaction effects are found.

Table 4.1: Summary of ANOVAs on the mean correct reaction times. The table shows whether the four effects of interest are strongly present (+), mildly present (±), or absent (-). Two effect hint towards a pop-out effect and two indicate a search asymmetry. The reader is referred to the text for the definition of the effects.

<table>
<thead>
<tr>
<th>stimulus type</th>
<th>effect 1</th>
<th>effect 2</th>
<th>effect 3</th>
<th>effect 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>stacked blocks</td>
<td>-</td>
<td>+</td>
<td>±</td>
<td>+</td>
</tr>
<tr>
<td>polygons</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>dot patterns</td>
<td>+</td>
<td>+</td>
<td>±</td>
<td>+</td>
</tr>
</tbody>
</table>

Table 4.1 summarizes the results of the ANOVAs and post-hoc ANOVAs. In general we can conclude that there is a pop-out effect of symmetry. This suggests that the detection of symmetry is efficient and preattentive. The pop-out effect can also be seen in Figure 4.2. The reaction times are slower for the target-absent cases and the slopes of the curves are steeper. Furthermore, the data shows a search asymmetry. It can be seen in
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Figure 4.3: The reaction time \( \times \) set size slopes. The lines give the fitted linear regression models. The dashed lines refer to the target-present trials, whereas the solid lines show the target-absent trials. The circles show result for the non-symmetric condition and the triangles for the symmetric condition. For every line, the slope (ms/item) and a classification of the search efficiency is given.

the plots that the search for a non-symmetrical target among symmetrical distractors is more efficient than the search for a symmetrical target among non-symmetrical distractors. This is in accordance with the search-asymmetry theory of Treisman & Gormican (1988) stating that it is easier to find a deviation among canonical stimuli than the reverse, where canonical here is symmetrical. According to Treisman & Gormican, this indicates preattentive detection of symmetry as well.

4.2.2.2 Slope Analysis

Figure 4.3 shows the regression lines calculated by fitting a linear model to the data. The slopes (ms/item) as well as the classification of slopes are given as well. The classifications are according to Wolfe (1998), who divided the slopes into four different categories: efficient (±0 msec/item), quite efficient (±5-10 msec/item), inefficient (±20-30 msec/item), and very inefficient (> 30 msec/item).

For all stimulus types, the slopes for target absence are steeper than for target presence. This hints towards preattentive detection of the target. There is however a great difference of the efficiency of search for the different stimulus types. Search for the polygon
targets is efficient, whereas search for the stacked blocks is quite efficient, and the
search for a symmetrical dot pattern among non-symmetrical ones is quite inefficient.
Also the slopes for the target-absent cases differ. From quite efficient for polygons to
very inefficient for dot patterns.

In general it can be concluded that the slopes show pop-out effects for all stimulus
types. The effect is strongest for the polygons, followed by the stacked blocks, and
weakest for the dot patterns. This suggests that symmetry can be preattentively de-
tected.

4.3 Scene-Memory Experiment

In the scene-memory experiment, the participants are briefly presented with a scene
containing a number of symmetrical and non-symmetrical figures. When a second
scene is presented, the participants are asked to detect if the two scenes are identical
or if a change occurred. By recording the eye movements and the response times, it
is investigated whether more attention is given to symmetrical figures to remember the
scene. If this turns out to be the case, symmetry is a salient feature and there is a
causal relation between symmetry and eye fixations. If however, the symmetrical and
the non-symmetrical figures receive as much attention, the results of Chapter 3 indicate
that attention is not paid to symmetry per se, but that symmetry is a cue for the presence
of an object, and visual attention is primarily object oriented.

4.3.1 Methods

4.3.1.1 Participants

Twenty undergraduate students from the University of Groningen participated in the
experiment for course credits. The age of the participants ranged from 19 to 30 years.
All participants had normal or corrected to normal vision. Two participants were taken
out of the data set. One because the calibration of the eye tracker failed, the other
because there was a disturbance half way through the experiment.
Figure 4.4: Trial setup of the scene-memory experiment. First, the original scene is presented for 1500ms with 6, 8, or 12 items. Next, a 1000ms blank screen is presented with a fixation cross placed in the center. When the second scene is presented, the participants are asked to respond as quickly as possible whether the two scenes were identical or that a change occurred.

4.3.1.2 Experimental Design

Prior to each trial, a fixation cross was presented in the center of the screen on which the participants had to focus. The setup of a trial is shown in Figure 4.4. The participants are asked to remember the first scene presented. This original scene consists of 6, 8, or 12 polygon figures placed in a circle, identical to the symmetry pop-out experiment. A scene contained symmetrical and non-symmetrical figures. The number of symmetrical figures was either $\frac{1}{2}N$, $\frac{1}{2}N - 1$, or $\frac{1}{2}N + 1$, where $N$ is the total number of items in the scene, with the three cases uniformly distributed. This prevented that the participants could simply count the number of symmetrical figures in the second scene to solve the task. All symmetrical figures per trial were identical as were all non-symmetrical figures. The polygons did change over the trials. The original scene was presented for 1500ms, during which the participants made 5-6 fixations on average. The scenes with 8 and 12 items can therefore not completely be viewed by the participants. If there is a preference for symmetry, it should be visible for these scenes.
Next, a blank screen is presented to prevent an afterimage. A fixation cross was drawn in the center of the blank screen. After 1000ms, a second screen was presented. In 50% of the trials this scene was identical to the original scene. The other changed trials were either in the symmetric or the non-symmetric condition, both in half of the cases. In the symmetric condition, a symmetrical figure was replaced with a non-symmetrical figure. In the non-symmetric condition, a non-symmetrical item was changed into a symmetrical one. The participants were asked to decide as quickly as possible whether the two scenes were identical or not. They responded by a key press.

### 4.3.1.3 Data Acquisition

The reaction times and number of correct trials were recorded. If more attention is paid to symmetrical figures when remembering the scene, we expect to see faster response times and a higher percentage of correct trials in the symmetric condition than in the non-symmetric condition, since it should be more apparent in that a symmetrical figure changed when the participants pay more attention to symmetry.

We also recorded the eye movements of the participants when remembering the first scene. If participants pay more attention to symmetrical forms, the eye-tracking data should reveal this. We used the Eye Link I head-mounted eye tracker (SR Research). Fixations were extracted using the accompanied software. At the beginning of the experiment, the eye tracker was calibrated using the SR-research software. Prior to each trial drift was measured by letting the participants fixated on a cross in the center of the screen. The drift was corrected if necessary.

Based on the eye-fixation data, the *symmetry-fixation score*, $s$ is determined. This is calculated as follows:

\[
\begin{align*}
    v & = \frac{F_s}{F_n} \\
    a & = \frac{N_s}{N} \\
    b & = \log(0.5)/\log(a) \\
    s & = v^b,
\end{align*}
\]

where $F_s$ is the number of symmetrical figures on which a fixation fell, $F_n$ is the total number of figures on which a fixation fell, $N_s$ is the number of symmetrical figures in the scene, and $N$ is the total number of figures in the scene. In the cases that the
4.3. Scene-Memory Experiment

The results of the scene-memory experiment are displayed in Figure 4.5. As expected, the reaction times increase with the number of items in the display, since it takes more time to inspect if any of the figures changed (see Figure 4.5a). The reaction times are faster when there is a change than when the scene is unchanged. This is also expected, since on average, fewer items need to be inspected to notice a change. However, we see no difference between the symmetric and the non-symmetric condition. Figure 4.5b shows the proportion of correct trials. The performance drops as a function of the set size. This correlates with the oral response that the participants gave after the experiment. They reported having difficulties noticing change when there were many items in the display. This is reflected by the scores close to chance for 12 items. The fact that the unchanged scores are higher than the changed scores for larger set sizes shows that the participants have a bias towards responding that there is no change. Also here
there is no difference between the symmetric and the non-symmetric condition. Finally, Figure 4.5c shows the symmetry-fixation scores. The score is 0.5 for all display sizes. This indicates that the participants fixated on symmetrical figures just as much as on non-symmetrical figures.

The fact that there is no difference for reaction times nor for correctness scores between the symmetric and non-symmetric condition suggests that the participants do not pay more attention to symmetry. This is supported by the eye-movement data, which shows that symmetrical and non-symmetrical items are evenly fixated on. The results thus show that participants have no preference for symmetrical objects over non-symmetrical objects when remembering a scene, but instead pay attention to any object that is present in the scene.

When asked after the experiment, some participant reported that they systematically viewed the figures in a clockwise fashion. Via manual inspection of the data, this was confirmed. The used setup and layout of the displays might therefore not be completely appropriate for the study. However, had there been a preference for symmetry, we would expect to have found it, especially for the larger set sizes, since the participants did not have enough time to inspect all figures.

4.4 Discussion

In this chapter, two experiments have been presented that investigate the role of symmetry in attention. The first experiment indicates that there is a pop-out effect for symmetry. The reaction time × set size slopes are less steep for target presence than for target absence for all stimulus types. Especially for the polygonal figures, the search for the target is efficient. The performed statistical tests also indicate pop-out effects. Moreover, they reveal a search asymmetry. Non-symmetrical targets among symmetrical distractors are found faster than vice versa. The presence of a pop-out effect and a search asymmetry suggest that detection of symmetry is preattentive.

The results of the first experiment contradict with the findings of Olivers & van der Helm (1998). They found no pop-out effect of symmetry. However, this might be due to the fact that the distractors used in their experiments were highly heterogeneous. Each distractor had a completely different shape, with only the presence or absence of symmetry in common with the rest. It is known that search becomes inefficient when
the distractors are sufficiently heterogeneous (Bauer et al., 1996). In the experiment presented in this chapter, a homogeneous set of distractors is used. This causes the problem that difference in symmetry coincides with difference in shape. However, an asymmetry in search for the target is observed, which is in accordance with the search-asymmetry of Treisman & Gormican (1988) with symmetry being the canonical case. This is not expected to be found if shape would have been the feature used by the participants. The effects found can therefore be attributed to symmetry.

In the second experiment, the participants are asked to memorize a scene with multiple symmetrical and non-symmetrical figures. The results show that equally much attention is paid to the symmetrical and the non-symmetrical items. The participants paid attention to the objects in the display irrespective of their symmetry. Although this might seem to contradict the results found in Chapter 3 at first sight, this is not the case. The results show that human visual attention is primarily object oriented. If we take this as a basic assumption, the fact that symmetry has been found to be a good predictor of the location of human eye fixations indicates that symmetry is used as a cue for the presence of an object. However, there are more cues for figure-ground segregation. For the stimuli used in the second experiment, closure, for instance, is a strong cue. In fact, the black objects are very easily detectable on the uniform white background. Since this is the case, symmetry has no added value to the segregation of figure and background. The stimuli used in the previous chapter are more complex, with different types of objects on highly cluttered backgrounds. For these kinds of stimuli, symmetry is a valuable cue. We will elaborate on object-oriented visual attention and the role of symmetry as a cue for figure-ground segregation in the next chapter.