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Symmetry is less than meets the eye

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Symmetry is a ubiquitous feature in the visual environment and can be detected by a variety of species, ranging from insects through to humans [1,2]. Here we show it can also bias estimates of basic scene properties. Mirror (reflective) symmetry can be detected in as little as 50 ms, in both natural and artificial visual scenes, and even when embedded within cluttered backgrounds [1]. In terms of its biological relevance, symmetry is a key determinant in mate selection; the degree of symmetry in a face is positively associated with perceived healthiness and attractiveness ratings [3]. In short, symmetry processing mechanisms are an important part of the neural machinery of vision. We reveal that the importance of symmetry extends beyond the processing of shape and objects. Mirror symmetry biases our perception of scene content, with symmetrical patterns appearing to have fewer components than their asymmetric counterparts. This demonstrates an interaction between two fundamental dimensions of visual analysis: symmetry [1] and number [4]. We propose that this numerical underestimation results from a processing bias away from the redundant information within mirror symmetrical displays, extending existing theories regarding redundancy in visual analysis [5,6].

Participants performed a perceptual discrimination in which they were asked to estimate the relative number of items in mirror symmetrical compared to asymmetrical dot displays (Figure 1A, top). Both displays were composed of non-overlapping luminance-defined dots. For asymmetric patterns, dots were placed at random locations within a circular aperture. For mirror symmetric patterns we randomly assigned items to individual locations in one half of the aperture and placed a counterpart in the corresponding location across the axis of symmetry. Inter-dot separations were equivalent across display types (see Supplemental Information for details). In the first set of data we chose vertical symmetry — the most salient axis [1]. Reference displays contained 50, 100 or 200 dots, and comparison displays were adjusted using the QUEST procedure to obtain the point of subjective equality (PSE). Symmetrical displays were consistently judged to be less numerous than asymmetrical displays. Across a two-octave change in base number, vertically mirror symmetrical displays required approximately 10% more elements to appear as numerous as asymmetric displays (see Figure 1B). There was a main effect of the base number of reference dots, $F(2,8) = 7.63$, $p = 0.014$, consistent with the bias remaining at a constant proportion of the base number, and the number of additional dots was significantly different from zero for each display, corrected for multiple comparisons ($p = 0.003$, 0.015 and 0.033, respectively).

Next we demonstrated that the magnitude of this effect is tied to the salience of the symmetry. Symmetry defined about the vertical axis is known to be most salient to an observer [1], relative to oblique or horizontal axes, and we expected the symmetry number bias to reflect this pattern. Vertical and oblique (45°) axes were tested, for base displays of 50 and 100 dots (Figure 1C). The oblique symmetry condition produced a number bias, but, crucially, this was reduced by 35% relative to the vertical symmetry configuration. By showing

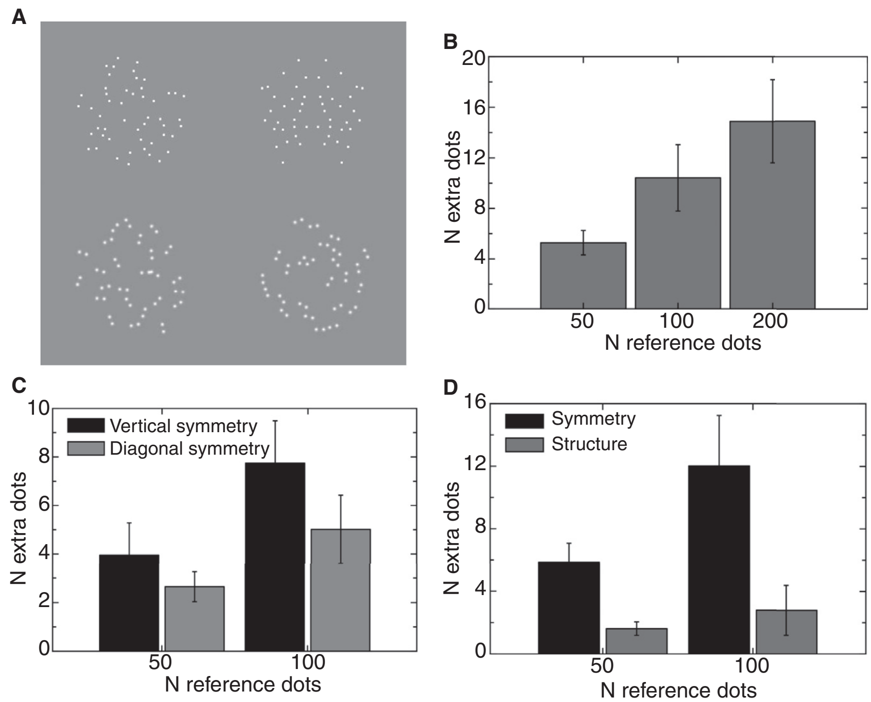

Figure 1. Display examples and results from Experiments 1–3.
(A) An example of the displays used in Experiments 1 and 3. On the top left is an asymmetrical, and on the top right a symmetrical display. On the lower left is a randomly oriented Glass pattern display; on the right is a structured Glass pattern display, showing concentric structure. Observers judged our mirror symmetrical and Glass patterns (top and bottom right) as equally high in perceived structure, and both (top and bottom left) unstructured reference patterns were rated equally low (see Supplemental Information). Reference and comparison displays were presented sequentially for a very brief period (300 ms each), in random order, and participants judged which appeared more numerous. (B) The number of extra dots (averaged across trials and participants) required to make a symmetrical display look as numerous as an asymmetrical display, for base displays of 50, 100 or 200 dots. We used both symmetrical and asymmetrical references; the results are collapsed here. (C) Results from Experiment 2 (comparing vertical and diagonal axes of symmetry). (D) Results from Experiment 3 (comparing symmetry to structure, using either concentric or randomly oriented Glass pattern displays, which provide a form of structure without symmetry.

that the numerosity bias induced by symmetrical stimuli is reduced for a display with an oblique axis of symmetry, we have demonstrated that our effect is related to the salience of symmetry at the observer.

Finally, we showed that our findings were not due to the perceived structure in our symmetrical dot displays. For this, we used Glass pattern displays [7], which were either structured (concentric) or unstructured (randomly oriented; Figure 1A, lower half). To check whether the Glass patterns were perceived to contain a similar level of structure to the symmetrical patterns, we asked participants to rate the perceived level of structure in each of the patterns tested, using a visual analogue scale. Glass and vertically symmetrical patterns were both rated as highly structured while asymmetrical and random Glass patterns were both perceived as low in structure (full details are provided in the Supplemental Information). However, by comparison with symmetrical stimuli, structured Glass patterns induced a very small number bias of approximately 2% (non-significant after correction), or an 80% reduction relative to the mirror symmetrical display (Figure 1D). The absence of a strong effect of structure on perceived number in the Glass pattern stimuli (despite an equally strong percept of structure) suggests that the influence of symmetry on perceived number cannot be solely attributed to the perceived structure in the symmetrical patterns. Instead we can conclude that the effect of symmetry on number is due to an interaction with form-insensitive visual mechanisms.

This work provides the first demonstration that symmetry can affect the accuracy with which we process items in a scene, by reducing the number of items consciously perceived in a display. Our findings have important implications for understanding the computation of visual number. Physically linking items, either by overlapping or by connecting lines, reduces their perceived number [8]. Our results show that there need not be any physical link between items to bias number, though our findings are also compatible with a bias in perceived density [8].

Symmetrical patterns contain redundancy. It has long been theorized that displays containing redundant information can lead to economies in visual processing of those displays, from contour shapes [5] to printed English [6]. In the context of symmetry, there is evidence that visual attention is biased away from redundant information in symmetrical patterns. Visual scan paths show that observers cluster their fixations to one side of symmetrical but not asymmetrical shapes [9]. Consistent with reduced attention to the redundant information, symmetrical patterns are perceived to be smaller than their asymmetric counterparts [10]. We have discovered that mirror symmetry reduces the number of perceived components in a scene: a finding consistent with a theory predicting inattention to redundant items when estimating number or density. Further, we show that the importance of symmetry extends beyond the processing of shape and objects. With regard to the time course of these biases, it is a testable assumption that redundancies are assigned *after* the symmetry of the pattern has been detected, implying multiple stages of processing. Separable processes also provide an explanation for the reduced effect with oblique axes of symmetry. If, however, detection of symmetry is not a necessary stage, then less salient but equally redundant patterns (such as translational symmetry [1]) should produce an equivalent effect. Our methods provide a new way to investigate the time course and functional nature of these symmetry processes.

SUPPLEMENTAL INFORMATION

Supplemental Information includes experimental procedures, further details of results, an additional control experiment on perceived structure, analyses of pairwise distances between dots in the displays and two figures, and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2015.02.017. Additional information is also available at http://dx.doi.org/10.6084/m9.figshare.130018.

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