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No role for colour in symmetry perception

Bilateral colour symmetry, such as that evident in a Siberian tiger's face (Fig. 1a), is relevant to many animals^{1,2}, including humans^{3,4}. We examined the role of colour in symmetry perception by asking observers to detect colour symmetry in regular grids of coloured squares (a colour-symmetrical image has regions of the same colour located equidistantly from a vertical axis). Our results suggest, unexpectedly, that the mechanisms of symmetry perception are inherently colour-blind: although observers can verify colour symmetry, they do so only by shifting attention from one colour to the next and assessing the symmetry of regions of that colour.

Observers were shown displays that either exhibited complete colour symmetry about the vertical midline (Fig. 1b), or contained one pair of squares that were mismatched in colour. Subjects pressed a button to indicate whether the pattern was colour-symmetrical, and response times and errors were assessed. The displays were constructed with either two colours (crimson and scarlet) or four colours (green, yellow, blue and red). Colours were chosen such that every pair of colours in the four-colour displays was more easily discriminated than the pair used in the two-colour displays.

The most obvious hypothesis about colour symmetry perception, called colour matching, involves the colours of corresponding points or regions on different sides of an axis being compared at the same time. Colour symmetry is registered when

every matching process is successful. This account predicts that responses to two-colour displays should be slower and more prone to errors than responses to four-colour displays, because the greater similarity of mismatched mates in the two-colour condition should slow the matching. The number of colours should in itself have no effect. But if colour symmetry is verified by attending to individual colours one at a time (the attention-switching hypothesis), the opposite should be true: response times should increase markedly with the number of colours, because each additional colour requires an additional symmetry-checking process.

The 21 subjects each began with 60 practice trials, followed by six blocks of 40 trials. A fixation cross in the screen centre preceded the display and remained until a key was depressed. Subjects were told to respond quickly and accurately. A beep sounded whenever an error was made. Displays subtended 9° of visual angle and were composed of 32 evenly spaced squares (16 elements per side), in either two or four colours, in either two or four colours. Colours were randomly assigned to squares, with the constraint that each colour was assigned to equal numbers of elements in the symmetrical displays; the colour of one square was altered to make asymmetrical displays.

Responses to four-colour displays were slower and less accurate, and responses to symmetrical displays were slower than responses to asymmetrical ones (Fig. 1c). The results support the attention-switching hypothesis and reject the more obvious colour-matching account. The mean response time to two-colour displays was 1,187 ms and that to four-colour displays was 1,961 ms; this difference was significant ($F(1,20) = 113.6$; mean squared error (MSe) = 109,585; $P < 0.0001$). The mean response time to asymmetrical displays was 1,395 ms and to symmetrical displays 1,755 ms; this difference was significant ($F(1,20) = 40.7$; MSe = 63,664; $P < 0.0001$). The overall ranking of mean response times by conditions seen in Fig. 1c was shown by 17 out of 21 observers. The mean error rate to two-colour displays was 5%, to four-colour displays 9%, to symmetrical displays 3%, and to asymmetrical displays 11%. The lower error rate for symmetrical displays suggests that the judgement 'symmetrical' is made after an exhaustive search for mismatches has failed, because mismatches are more often missed than falsely registered.

The attention-switching hypothesis makes a further, distinctive prediction for displays in which two squares differ in colour from their mates on the opposite side of the display. We used four-colour symmetrical displays, as in the previous experiment. In this experiment, however,

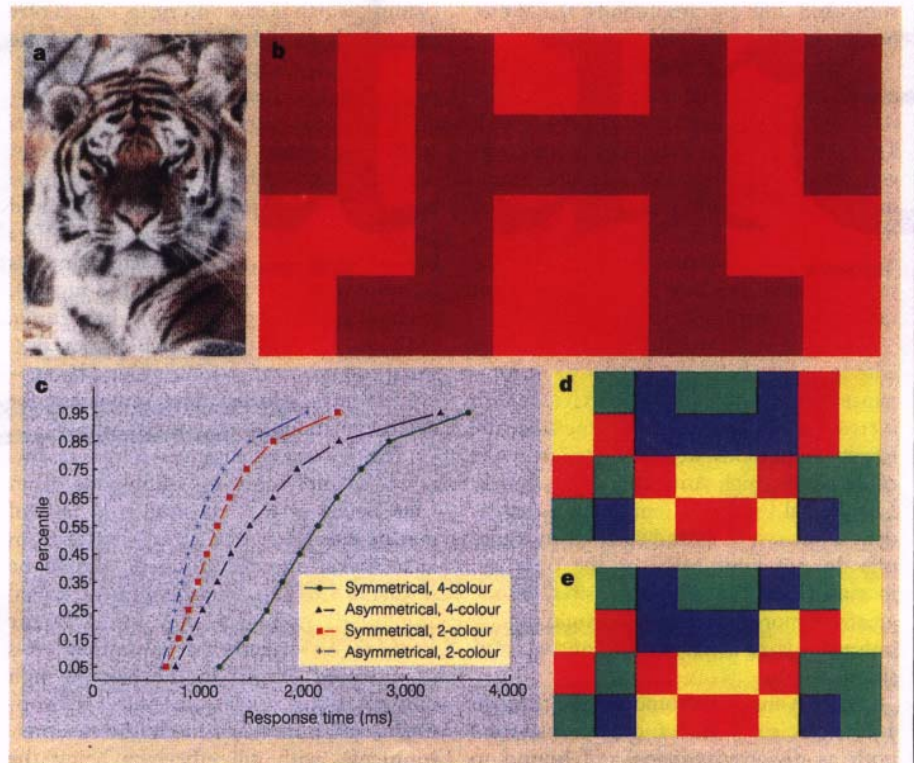


Figure 1 Colour symmetry, **a**, Siberian tiger (photographed by M. Fontaine); **b**, symmetrical two-colour display; **c**, 'Vincentized'⁸ data distributions to two-colour and four-colour symmetrical and asymmetrical displays; **d**, asymmetrical 'ABBA' two-mismatch display; **e**, asymmetrical 'ABCD' two-mismatch display.

two types of asymmetrical displays were compared, both of which included two mismatching pairs. In 'ABBA-asymmetrical' displays (Fig. 1d), both mismatched squares involved two colours, for example red and green. In contrast, in the 'ABCD-asymmetrical' displays shown in Fig. 1e, the two mismatches affected all four colours. If observers check colours sequentially, then in the ABCD display the first colour checked will always reveal an asymmetry. Thus, response times should, on average, be faster in this condition. When only two colours are involved, observers might need to check two or even three colours before encountering an asymmetry. Thus, attention switching predicts faster responses to ABCD-asymmetrical displays, whereas colour matching makes no such prediction.

Responses to ABBA-asymmetrical displays (1,449 ms) were significantly slower than to ABCD-asymmetrical displays (1,304 ms) ($F(1,15) = 23.9$; MSe = 7,071; $P < 0.0001$), supporting the attention-switching hypothesis. The ranking of mean response times (in ascending duration: ABCD-asymmetrical, ABBA-asymmetrical, and symmetrical) was shown by 13 out of 15 subjects. The error rate for ABCD-asymmetrical displays (7%) was also lower than for the ABBA-asymmetrical displays (12%) ($F(1,15) = 12.8$; MSe = 0.0016; $P < 0.003$).

The results described here suggest that, despite the apparent conspicuousness of

colour symmetry, and contrary to previous suggestions^{5,6}, symmetry detection in the human visual system is insensitive to colour in itself. When people seek to judge colour symmetry, they can do so accurately, but only by relying on a strategy of attention switching based on colour. Presumably this is done by selectively attending to one colour at a time. Evidently, then, attentional gating must arise earlier in the visual pathway than symmetry detection. This conclusion closely parallels the conclusions of Lu and Sperling about motion perception⁷. These authors reported that voluntary attention to a feature permits information to be gated before its analysis by motion-perception mechanisms. Both phenomena reinforce the emerging consensus that visual selective attention gates the flow of information early in the visual system. Dawn Morales, Harold Pashler *Department of Psychology, 0109, University of California, San Diego, 9500 Gilman Drive, San Diego, California 92093, USA e-mail: hpashler@ucsd.edu*

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