

Higher-level mechanisms detect facial symmetryGillian Rhodes^{1,*}, Marianne Peters¹, Kieran Lee¹, M. Concetta Morrone^{2,3}
and David Burr^{2,4}¹*School of Psychology, University of Western Australia, 35 Stirling Highway, Crawley, Perth, WA 6009, Australia*²*Istituto di Neuroscienze del CNR, Via Moruzzi, Pisa, Italy*³*Facoltà di Psicologia, Università Vita-Salute San Raffaele, Via Olgettina 58, Milan, Italy*⁴*Dipartimento di Psicologia, Università di Firenze, Via S. Nicolò 89, Florence, Italy*

The role of symmetry detection in early visual processing and the sensitivity of biological visual systems to symmetry across a wide range of organisms suggest that symmetry can be detected by low-level visual mechanisms. However, computational and functional considerations suggest that higher-level mechanisms may also play a role in facial symmetry detection. We tested this hypothesis by examining whether symmetry detection is better for faces than comparable patterns, which share low-level properties with faces. Symmetry detection was better for upright faces than for inverted faces (experiment 1) and contrast-reversed faces (experiment 2), implicating high-level mechanisms in facial symmetry detection. In addition, facial symmetry detection was sensitive to spatial scale, unlike low-level symmetry detection mechanisms (experiment 3), and showed greater sensitivity to a 45° deviation from vertical than is found for other aspects of face perception (experiment 4). These results implicate specialized, higher-level mechanisms in the detection of facial symmetry. This specialization may reflect perceptual learning resulting from extensive experience of detecting symmetry in faces or evolutionary selection pressures associated with the important role of facial symmetry in mate choice and ‘mind-reading’.

Keywords: Please supply a minimum of three to a maximum of six keywords**Q2 1. INTRODUCTION**

Bilateral symmetry is highly salient to humans and other animals (Corballis & Beale 1976; Lehrer *et al.* 1994; Baylis & Driver 1995; Møller & Swaddle 1997; Wagemans 1997). It facilitates early visual processes, such as figure-ground segmentation (Rock 1983) and the perception of surface orientation (Saunders & Knill 2001), and it can be detected pre-attentively (Driver *et al.* 1992; Wolfe & Friedman-Hill 1992). The role of symmetry detection in early visual processing and the sensitivity of many biological visual systems to symmetry suggest that symmetry can be detected by low-level visual mechanisms. These mechanisms operate on simple image properties, independent of object identity. Consistent with this view, a low-level, biologically plausible model of symmetry detection performs well on natural images (Scognomilio *et al.* 2003; see also Wagemans 1997; Dakin & Herbert 1998).

All forms of symmetry perception do not, however, use the same mechanisms (Gurd *et al.* 2002). Neuropsychological dissociations indicate that different mechanisms underlie the implicit use of symmetry in figure-ground segmentation and explicit judgements of figural symmetry (Driver *et al.* 1992; Marshall & Halligan 1994). Different mechanisms also appear to be used for detecting symmetry in radial frequency-generated shapes, which resemble human head outlines, and in the dot patterns commonly used to study symmetry perception (Wilson & Wilkinson 2002). Furthermore, symmetry detection is not restricted to low-level visual processing,

contributing to high-level processes of object recognition (e.g. with symmetric image features signalling symmetric objects; Biederman 1987) and face perception (Rhodes *et al.* 1998; Simmons *et al.* 2004). These observations suggest that higher-level coding mechanisms, which respond to abstract properties of objects, may also play a role in symmetry detection (see also Wilson & Wilkinson 2002).

Here, we consider whether specialized, higher-level mechanisms contribute to the detection of symmetry in human faces. Both computational and functional considerations suggest that they might. People are highly sensitive to individual differences in facial symmetry (Rhodes *et al.* 1998; Simmons *et al.* 2004), which are at least as subtle as the structural differences that mediate recognition and other aspects of face perception, for which specialized, high-level computational and neural mechanisms are used (Campbell *et al.* 1990; Vecera & Johnson 1995; Farah 1996; Haxby *et al.* 2000; Kanwisher 2000; Ricciardelli *et al.* 2000). Therefore, computational considerations suggest that specialized, higher-level mechanisms may contribute to facial symmetry detection.

Functional considerations also suggest a role for specialized, higher-level mechanisms, because facial symmetry information is used in at least two biologically important domains—mate choice and ‘mind-reading’. In mate choice, humans are very sensitive to facial asymmetries (Møller & Swaddle 1997; Rhodes *et al.* 1998; Simmons *et al.* 2004). They find symmetric faces attractive (Rhodes *et al.* 1998, 1999; Mealey *et al.* 1999; Perrett *et al.* 1999; Rhodes & Zebrowitz 2002; Little & Jones 2003), and they interpret symmetry as a sign of

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important aspects of mate quality, such as health and intelligence (Rhodes *et al.* 2001b; Rhodes & Zebrowitz 2002; Zebrowitz & Rhodes 2004). To the extent that symmetry is a valid signal of mate quality, a preference for facial symmetry may be an adaptation for finding high-quality mates (Fink & Penton-Voak 2002; Little & Jones 2003; Møller & Swaddle 1997; Thornhill & Gangestad 1999), in which case specialized mechanisms may have evolved (Williams 1966). In mind-reading, facial symmetry can signal the intentional states and attentional focus of others. For example, a symmetric face and eyes indicate that we are the focus of another's attention and deviations from symmetry, resulting from deviated gaze or head turn, can indicate the direction of attention (Wilson *et al.* 2000). Functionally, the importance of facial symmetry detection in mate choice and mind-reading may have created selection pressure for the evolution of specialized, higher-level mechanisms for detecting facial symmetry.

In the present experiments, we investigate whether specialized, higher-level mechanisms contribute to facial symmetry detection. The use of such mechanisms in other aspects of face perception is characterized by superior performance on faces than other patterns, which share low-level properties but do not fully engage these mechanisms. In particular, performance is better on faces than either inverted (upside down) faces (Yin 1969; Moscovitch *et al.* 1997; Murray *et al.* 2000; Rossion & Gauthier 2002; Rhodes *et al.* 2004) or contrast-reversed faces (Galper 1970; Kemp *et al.* 1990; Lewis & Johnston 1997; George *et al.* 1999; Hole *et al.* 1999; Ricciardelli *et al.* 2000). Therefore, if specialized, higher-level mechanisms contribute to the perception of facial symmetry, then symmetry detection should be better for faces than inverted or contrast-reversed faces. Alternatively, if facial symmetry is detected by generic, low-level mechanisms (e.g. Dakin & Herbert 1998; Scognomilio *et al.* 2003), then there should be no advantage for normal, upright faces.

We compared symmetry detection for normal, upright faces and inverted faces in experiment 1, and contrast-reversed faces in experiment 2. Inverted and contrast-reversed faces both share low-level properties with normal faces, but are not fully processed as faces by the visual system (George *et al.* 1999; Rossion & Gauthier 2002; Rhodes *et al.* 2004). In experiment 3, we compared symmetry detection for normal and bandpass filtered faces containing either low (1.4 cycles per face), middle (10 cycles per face) or high (60 cycles per face) spatial frequencies. Low-level symmetry detection mechanisms show little effect of spatial scale (Dakin & Hess 1997; Dakin & Herbert 1998; Rainville & Kingdom 2002). Therefore, any sensitivity to spatial scale would implicate higher-level mechanisms. In experiment 4, we examined the sensitivity of symmetry detection in faces and non-faces to a deviation from the vertical. Given the well-known advantage for detecting vertical symmetry over other forms of bilateral symmetry (e.g. Palmer & Hemenway 1978; Wenderoth 1994), we expected that tilt would impair performance in both cases. Greater impairment for faces than non-faces would further implicate higher-level mechanisms.



Figure 1. Normal (left) and perfectly symmetric (right) versions of a face. Note that both versions have the perfectly symmetric hairstyle.

2. EXPERIMENT 1

We compared symmetry detection for briefly presented upright and inverted faces, using a 2AFC procedure in which a normal face and a perfectly symmetric version of that face were presented sequentially. Both faces were presented either upright or inverted. If specialized, higher-level mechanisms contribute to facial symmetry detection, then performance should be better for upright than inverted faces.

(a) Method

(i) Participants

Participants were 48 (24 male) University of Western Australia undergraduates.

(ii) Stimuli

Normal and perfectly symmetric versions of 26 faces (13 male) were taken from Rhodes *et al.* (1998; experiment 2). All had neutral expressions with head and eyes directed straight ahead. The perfectly symmetric versions were made by blending the forward and mirror images of a face. The normal versions were also blends, which were made by blending low and high symmetry morphs of the face. Because both the normal and perfectly symmetric versions were blends, cues associated with blending (e.g. amount of blur) could not be used to discriminate between the normal and symmetric versions. In addition, cues from the hair could not be used to discriminate between versions, because the normal and perfectly symmetric versions of each face had the same, perfectly symmetric hairstyle (achieved by pasting the symmetric hairstyle from the perfectly symmetric image on to its corresponding normal image). The faces were displayed in oval masks that hid most of the hair. The images measured approximately 10.5×14.5 cm on the computer screen. A normal and symmetric pair is shown in figure 1.

(iii) Procedure

In each trial, participants saw the following sequence: a mask (jumbled face) for 500 ms, a face for 200 ms, the mask for 500 ms, a second face for 200 ms and, finally, the mask for 500 ms. The two faces were the normal and perfectly symmetric versions of the same face. In each

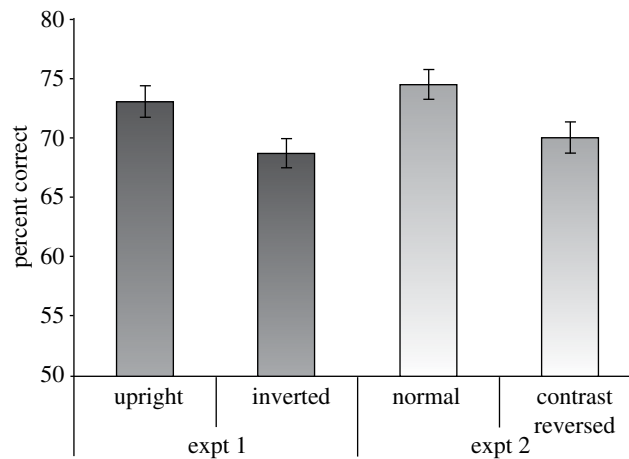


Figure 2. Mean percentage correct for symmetry detection in upright and inverted faces (experiment 1) and normal and contrast-reversed faces (experiment 2) with s.e.m. bars shown.

trial, participants had to indicate which of the two faces was symmetric. In half the trials, the symmetric version was shown first and on half the normal version was shown first. Half the trials were presented upright, and half inverted (counterbalanced with order of the normal and symmetric versions). Each pair of faces was shown once in each orientation and once in each order condition, giving a total of 104 ($26 \times 2 \times 2$) trials. Each participant viewed the trials in a different random order.

(b) Results and discussion

A three-way ANOVA was carried out on the percentage of correct scores, with gender of participant as a between-participants factor, and gender of face and orientation as repeated-measures factors. There was a significant main effect of orientation, $F_{(1,46)} = 12.02$, $p < 0.002$, with more accurate performance on upright ($M = 73.1\%$, s.e.m. = 1.3%) than inverted faces ($M = 68.7\%$, s.e.m. = 1.2%; figure 2). There were no other significant effects. The results implicate specialized, higher-level mechanisms in facial symmetry detection.

3. EXPERIMENT 2

This experiment was identical to experiment 1, except that inverted faces were replaced by contrast-reversed faces. Better performance for normal than contrast-reversed faces would implicate specialized, higher-level mechanisms in facial symmetry detection.

(a) Method

(i) Participants

Participants were 48 (24 male) new University of Western Australia undergraduates.

(ii) Stimuli

Contrast-reversed versions of the faces used in experiment 1 were made in ADOBE PHOTOSHOP.

(iii) Procedure

The procedure was identical to that of experiment 1, except that contrast-reversed faces replaced inverted faces.

(b) Results and discussion

A three-way ANOVA was carried out on the percentage of correct scores, with gender of participant as

a between-participants factor, and gender of face and face type (normal, contrast-reversed) as repeated-measures factors. There was a significant main effect of face type, $F_{(1,46)} = 10.00$, $p < 0.003$, with better performance on normal ($M = 74.5\%$, s.e.m. = 1.2%) than contrast-reversed faces ($M = 70.1\%$, s.e.m. = 1.2%; figure 2). This advantage for normal faces again implicates higher-level, specialized mechanisms in facial symmetry detection. There was a significant main effect of gender of face, $F_{(1,46)} = 6.39$, $p < 0.02$, with better performance on male ($M = 73.7\%$, s.e.m. = 1.1%) than female faces ($M = 70.9\%$, s.e.m. = 1.3%), but this did not interact with face type, $F < 1$. The advantage for male faces may reflect greater asymmetry in male than female faces (Simmons *et al.* 2004). There were no other significant effects.

4. EXPERIMENT 3

Here, we examined the sensitivity of facial symmetry detection to spatial scale. In addition to normal faces, we showed low, medium and high bandpass filtered faces, made using three separate bandpass filters of 1.4 octave width at half-height, with peak frequencies at 1.4, 10 and 60 cycles per face. Sensitivity to spatial scale would rule out purely low-level mechanisms, which are insensitive to spatial scale (Dakin & Hess 1997; Dakin & Herbert 1998; Rainville & Kingdom 2002).

(a) Method

(i) Participants

Participants were 48 (24 male) new University of Western Australia undergraduates.

(ii) Stimuli

Low, medium and high bandpass filtered versions were made for each of the faces used in experiment 1 (figure 3a). Each face image was padded to an image of 696×696 pixels with the mask luminance value and filtered with

$$G(w) = e^{\ln(w/p)^2 / \sigma^2},$$

where w is the norm of the (w_x, w_y) spatial frequency vector, p is the peak spatial frequency and σ is the band of the filter. The function $G(w)$ corresponds to a parabola on log-log coordinate with peak spatial frequency equal to p .

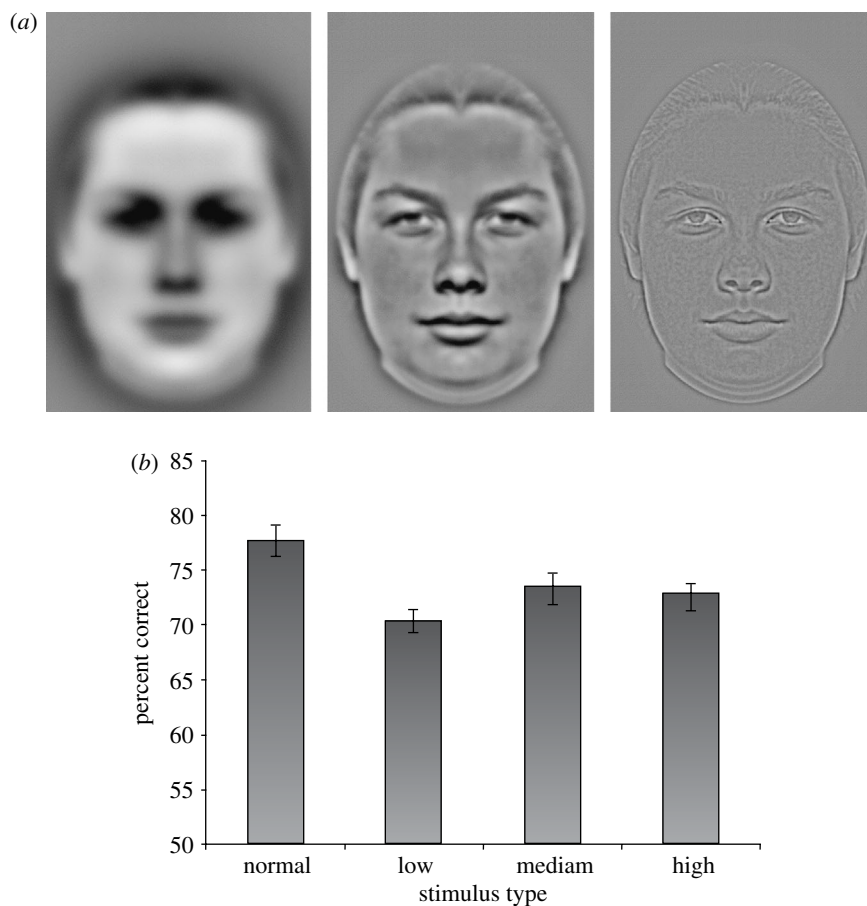


Figure 3. (a) Example of perfectly symmetric low-, medium- and high-pass filtered faces used in experiment 3. (b) Mean percentage correct for symmetry detection in normal, low-, medium- and high-pass filtered faces (experiment 3) with s.e.m. bars shown.

Three filters were used with p equal to 134, 20 and 3 cycles per picture corresponding on average to 60, 10 and 1.4 cycles per face. (The average face length was equal to 350 pixels). σ was equal to 1.2, generating a filter of 1.4 octave width at half-height. The filters had very little overlap in spatial frequencies. After filtering, the images were transformed back and cut to the original size. The relative contrast between the output images at various scales was unaffected by the filtering procedure.

(iii) Procedure

The procedure was the same as for experiment 1, except that there were four image types—normal-, low-, medium- and high-pass filtered faces.

(b) Results and discussion

A three-way ANOVA was carried out on the percentage of correct scores, with gender of participant as a between-participants factor, and gender of face and spatial frequency components (normal, low, medium and high) as repeated-measures factors. There was a significant main effect of spatial frequency composition, $F_{(3,46)}=10.75$, $p<0.0001$ (figure 3b). Performance was significantly better for normal faces ($M=77.7\%$, s.e.m. = 1.4%) than for any of the filtered faces ($M=69.9\%$, s.e.m. = 1.5%, low; $M=73.2\%$, s.e.m. = 1.5%, medium; $M=72.5\%$, s.e.m. = 1.2%, high), all t 's > 3.23 , p 's < 0.002 , indicating that all frequencies contributed to symmetry perception. However, performance was worst on the low-pass faces, which differed significantly from the medium-pass faces, $t(138)=2.34$, $p<0.03$. This sensitivity to spatial scale

contrasts with findings for low-level symmetry detection mechanisms, further implicating higher-level mechanisms. As in experiment 2, there was a significant effect of face gender, $F_{(1,46)}=23.94$, $p<0.0001$, with better performance on male ($M=75.5\%$, s.d. = 14.2%) than female faces ($M=71.1\%$, s.d. = 13.8%). There were no other significant effects.

5. EXPERIMENT 4

We examined the sensitivity of symmetry detection for faces and non-faces to a 45° deviation from vertical. The non-faces were created by inverting, contrast-reversing and low-pass filtering faces to produce images that do not look like faces. These 'non-faces' were well matched to faces on many low-level properties, but contained only low spatial frequency information. For both faces and non-faces, we expected tilt to reduce performance. The question of interest was whether tilt would differentially impair symmetry detection in faces and non-faces, thus implicating different mechanisms.

(a) Method

(i) Participants

Participants were 36 (18 male) new University of Western Australia undergraduates.

(ii) Stimuli

The normal faces were the same as in the previous experiments. The non-faces were created by inverting

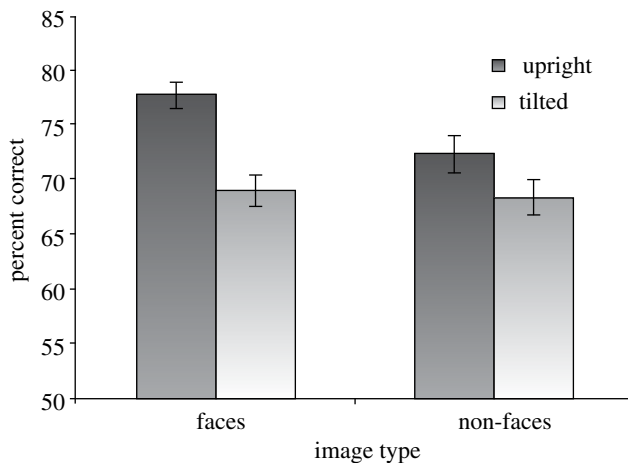


Figure 4. Mean percentage correct for symmetry detection in upright and 45° tilted faces and non-faces (experiment 4) with s.e.m. bars shown.

and contrast reversing the low bandpass filtered faces from experiment 3.

(iii) Procedure

The procedure was the same as for experiment 1, except that both types of image (face and non-face) were shown at 45 and 0°.

(b) Results and discussion

A four-way ANOVA was conducted on the percentage of correct scores, with gender of participant as a between-subjects factor, and gender of face, image type (face, non-face) and orientation (0°, 45°) as repeated-measures factors. There was a significant effect of orientation, as expected, $F_{(1,34)} = 33.67$, $p < 0.0001$, with better performance on upright ($M = 75.0$, s.e.m. = 1.0) than tilted images ($M = 68.6$, s.e.m. = 1.1). There was a marginal effect of image type, $F_{(1,34)} = 3.08$, $p < 0.09$, which interacted with orientation, $F_{(1,34)} = 5.25$, $p < 0.03$. Performance was significantly better for faces ($M = 77.7$, s.e.m. = 1.2) than non-faces ($M = 72.3$, s.e.m. = 1.7) at 0°, $t(34) = 3.63$, $p < 0.0009$, but not at 45° ($M = 68.8$, s.e.m. = 1.4, faces; $M = 68.3$, s.e.m. = 1.6, non-faces), $t < 1$. Most importantly, the effect of misorientation was larger for faces than non-faces (figure 4). A one-way repeated-measures ANOVA on difference scores (0–45°) confirmed that the upright advantage was significantly greater for faces ($M = 8.8$, s.e.m. = 1.7) than non-faces ($M = 4.0$, s.e.m. = 1.3), $F_{(1,35)} = 5.41$, $p < 0.03$, indicating that detection of symmetry in faces is more sensitive to tilt than detection of symmetry in other comparable patterns.

There was a significant main effect of gender of face, $F_{(1,34)} = 25.18$ ($M = 69.3$, s.e.m. = 1.0, female; $M = 74.3$, s.e.m. = 1.1, male), as found in experiments 2 and 3. However, in this case, it interacted with image type, $F_{(1,34)} = 15.94$, $p < 0.0003$, and the advantage for male images was restricted to non-faces. There were no other significant effects.

6. GENERAL DISCUSSION

Symmetry detection was better for faces than either inverted or contrast-reversed faces, which are well-matched to faces on low-level properties. These results implicate higher-level mechanisms in the detection of

facial symmetry and rule out purely low-level mechanisms (although these could contribute as well). The sensitivity of facial symmetry detection to spatial scale corroborates this conclusion, because low-level symmetry detection mechanisms are insensitive to changes in spatial scale (Dakin & Hess 1997; Dakin & Herbert 1998; Rainville & Kingdom 2002).

Facial symmetry detection was impaired by spatial frequency filtering. In contrast to face recognition (Nasanen 1999), middle spatial frequencies (8–16 cycles per face) were not the most useful. Therefore, different higher-level mechanisms may contribute to facial symmetry detection and face recognition. The advantage for facial symmetry detection was also narrowly tuned to vertical, disappearing with a 45° tilt. In contrast, other face-coding mechanisms continue to be engaged by misoriented faces up to 90° (Moscovitch *et al.* 1997; Murray *et al.* 2000; Sturzel & Spillman 2000; McKone *et al.* 2001), again suggesting distinct mechanisms for detecting facial symmetry and other aspects of face perception.

Our results cannot be explained either by generic symmetry detection mechanisms or by generic face processing mechanisms. They suggest that the higher-level mechanisms used to detect facial symmetry are jointly specialized for faces and symmetry detection. Such specialization could result from perceptual learning (Fahle & Poggio 2002), whereby generic symmetry detection mechanisms become tuned by extensive experience with faces. This experience might reflect the importance of facial symmetry in mate choice and mind-reading. This perceptual expertise account seems plausible given the rather small symmetry detection advantage we observed for faces (around four points).

Several lines of evidence are also consistent with a contribution from evolved mechanisms. First, young infants are sensitive to facial symmetry, suggesting a predisposition to attend to symmetry in faces (Rhodes *et al.* 2002). Second, facial symmetry is attractive across cultures (Rhodes *et al.* 2001a). Third, facial symmetry may provide valid cues to mate quality (Thornhill & Møller 1997; Rhodes & Zebrowitz 2002; but see Rhodes *et al.* 2001b).

Little & Jones (2003) have reported a preference for facial symmetry in upright but not inverted faces, which they interpret as an adaptation for mate choice. Alternatively, their results could reflect the greater difficulty of detecting symmetry in inverted faces, which are rarely seen. Symmetry preferences may also depend on relevant experience (see also Enquist & Arak 1994; Johnstone 1994; Jansson *et al.* 2002). Future research is needed to determine precisely how symmetry detection and preferences are related.

To conclude, our results show that despite the widespread sensitivity of biological visual systems to symmetry, the contribution of symmetry detection to low-level visual analysis and the effectiveness of low-level models of symmetry detection, symmetry detection is not always mediated by low-level mechanisms. Instead, higher-level mechanisms contribute to the detection of bilateral symmetry in human faces. Future research is needed to understand the computational and neural specializations underlying these mechanisms.

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