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Comparing sensitivity to facial asymmetry and facial identity

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Abstract. Bilateral symmetry is a facial feature that plays an important role in the aesthetic judgments of faces. The extent to which symmetry contributes to the identification of faces is less clear. We investigated the relationship between facial asymmetry and identity using synthetic face stimuli where the geometric identity of the face can be precisely controlled. Thresholds for all observers were 2 times lower for discriminating facial asymmetry than they were for discriminating facial identity. The advantage for discriminating asymmetrical forms was not observed using nonface shape stimuli, suggesting this advantage is face-specific. Moreover, asymmetry thresholds were not affected when faces were either inverted or constructed about a nonmean face. These results, taken together, suggest that facial asymmetry is a characteristic that we are exquisitely sensitive to, and that may not contribute to face identification. This conclusion is consistent with neuroimaging evidence that suggests that face symmetry and face identity are processed by different neural mechanisms.

Keywords: face perception, face symmetry, form vision, psychophysics.

1 Introduction

Face processing is a visual skill that has received a great deal of research attention over the past several decades. One reason for this is because of the unique perceptual skills that are involved in face processing: for example, face perception relies on processing mechanisms that are much more sensitive to image inversion (e.g., Freire, Lee, & Symons, 2000; Rossion & Gauthier, 2002; Yin, 1969) and configuration (e.g., Hole, 1994; Maurer, LeGrand, & Mondloch, 2002; Young, Hellawell, & Hay, 1987) than are other forms of object perception. Another reason for this research attention is because of the well-established role of specific cortical regions in face processing. Neurons in both the fusiform face area (FFA; Kanwisher, McDermott, & Chun, 1997; Sergent & Signoret, 1992) and more recently the occipital face area (OFA; Gauthier et al., 2000; Rossion et al., 2003; Steeves et al., 2005) have been demonstrated to play important roles in the mediation of face-specific behaviors. Given the volume of research into both the perception and neuroimaging of face-specific behaviors, researchers are now tasked with determining the relationship between neurons and behavior in face processing. One of the main goals of ongoing research is to try and determine which aspects specific of face processing are mediated by the identified neural structures.

One facial characteristic that has been investigated extensively is the bilateral symmetry of the face. Facial symmetry plays an important role in a variety of different face perception skills, including judgments of facial attractiveness (e.g., Grammer & Thornhill, 1994; Scheib, Gangestad, & Thornhill, 1999), and social attention (e.g., Langton, 2000). Recent evidence suggests that the mechanisms involved in processing face symmetry are functionally different from those mechanisms involved in other lower level forms of symmetry processing. For example, Rhodes, Peters, Lee, Morrone, and Burr (2005) demonstrated that symmetry detection is reduced in inverted and contrast-reversed faces, which are manipulations that are known to impair face identification. Moreover, the ability to detect symmetry is reduced for bandpass filtered faces, whereas the mechanisms involved in lower-level symmetry detection are not sensitive to spatial scale (Dakin & Hess, 1997; Rainville & Kingdom, 2002). Together, these results suggest that face symmetry is a feature that is processed by higher level mechanisms than those involved in basic symmetry perception. Little and Jones (2006) further demonstrated that while preference ratings for inverted symmetric faces were lower relative to ratings for upright symmetric faces, the ability to detect symmetry in both upright and inverted faces was not significantly different. They suggest that this demonstrates that the mechanisms involved in detecting facial symmetry may play a more important role in aesthetic face judgments than they do in face detection and recognition. If this is true, then symmetry may not be an important feature in tasks that probe the ability to detect changes in face identity.

In both of these studies, the stimuli that were used were realistic face images, where symmetry was achieved by either averaging the face with its mirror reversal (Rhodes, Peters, & Ewing, 2007; Rhodes et al., 2005) or by manually repositioning the facial features to symmetric coordinates (Little & Jones, 2006). These symmetrization techniques both result in realistic face stimuli that possess features that are geometrically symmetric, and performance for determining whether or not subjects can discriminate a symmetric face from its asymmetric counterpart can be measured. However, in neither of these studies was the *strength* of symmetry (or asymmetry) manipulated. Another method of evaluating sensitivity to facial asymmetry is to manipulate the degree of symmetry and evaluate thresholds for symmetry detection. Threshold, in this instance, would refer to the minimum amount of geometric variation that would need to be added to one side of the face for observers to reliably detect asymmetry. One advantage for using a quantifiable metric for symmetry manipulation is that asymmetry thresholds can then be directly compared to the same metric thresholds for discriminating the identity of the face. In other words, thresholds for detecting facial asymmetry and facial identity can be directly compared in a meaningful way.

In the current set of studies, we evaluated sensitivity to facial asymmetry using a set of synthetic faces where the geometric identity of the face can be precisely controlled. These faces retain the geometric properties of individual faces, but eliminate other cues that can be used to judge facial identity, such as shading and texture (Wilson, Loffler, & Wilkinson, 2002). Previous research has demonstrated that these highly reduced stimuli capture the identities of individual faces (Wilson et al., 2002), and elicit BOLD responses in the FFA that are similar to the BOLD responses elicited by photographs of faces (Loffler, Yourganov, Wilkinson, & Wilson, 2005). These results suggest that the synthetic faces recruit the same neural mechanisms used to process photorealistic faces. We assessed sensitivity to facial asymmetry by selectively adding individual geometric identity to only one half of the face, and measuring the minimum amount of asymmetry that was required for subjects to reliably determine whether or not the face was asymmetric. As this form of geometric manipulation can also be used to measure thresholds for identifying an individual face (Wilson et al., 2002), we could also directly compare sensitivity thresholds for discriminating asymmetry and identity in faces. We found that subjects were 2 times more sensitive to facial asymmetry, even though only half of the geometric information was added to the whole face. When the same comparison between sensitivity for shape asymmetry and identity was measured using a set of nonface geometric shapes (i.e., radial frequency (RF) patterns), the opposite pattern of responses was observed, suggesting that the advantage for detecting asymmetry over shape is specific to face stimuli. This exquisite sensitivity to facial asymmetry was not affected by the inversion of the faces, nor was it different for faces that were geometrically constructed from mean or nonmean faces (a manipulation that *does* influence identity thresholds). Taken together, we believe that these results suggest that facial asymmetry is processed by face-specific mechanisms that differ from the mechanisms that are involved in face identification.

2 Methods

2.1 Stimuli and apparatus

To evaluate both identity and asymmetry sensitivity, we used the synthetic faces described by Wilson et al (2002). These faces are generated by identifying 16 equiangular landmarks on the outer head contour, and nine landmarks on the hairline, on digital photographs of 40 individual faces. These landmarks are used to regenerate the hair and head face contours through the sum of seven radial frequencies (Wilkinson, Wilson, & Habak, 1998). The representation of the outer and inner head contour (R_{head}) in polar coordinates is thus:

$$R_{\text{head}} = R_{\text{mean}} \sum_{n=1}^{7} A_n \cos(2\pi n\theta) + B_n \sin(2\pi n\theta), \tag{1}$$

where A_n and B_n are amplitudes defining head shape ($n = 1$–7) and are defined relative to the mean head radius (R_{mean}). Generic internal face features are also placed according to 12 additional landmarks (with two xy coordinates for the placement of each eye) determined from the individual faces. Each individual face is therefore described as a 37 element vector describing the face coordinates. Faces are then reconstructed from these vectors. The resultant faces are bandpass filtered with a 2.0 octave difference of Gaussians filter with a peak frequency of 10 cycles per face, as this is the range of spatial frequencies that contains the most relevant information for face identification (Gold, Bennett, & Sekuler, 1999; Näsänen, 1999).

To generate synthetic faces where the individual identity of the face can be continuously varied, the 37 element vectors describing the 40 individual faces are averaged together to determine the mean face coordinates. This mean vector is then subtracted from each of the individual identity vectors, yielding a difference vector that describes the individual variation from the mean. To control the amount of geometric identity within the face, the amplitudes that define the identity of the individual face are added to the amplitudes of the mean face for strengths ranging from 0 to 15% mean head radius. The identity strength is therefore described as the percent variation of the individual face vector from the mean. For a more comprehensive description of the creation of these synthetic faces, see Wilson et al., 2002. An example of an identity continuum for one individual face with six identity strengths ranging from 0 to 15% is presented in Figure 1a.

Asymmetric faces were created by fusing one side of a face with varying amounts of facial identity to the complimentary side of the mean (i.e., 0% identity) face. To ensure that there were no artifacts due to contour misalignments between the two face halves, a weighted average of the gray levels ±30 pixels from the vertical midline in each half was calculated to create a smooth contour. The face was then bandpass filtered as described above. This fusion was completed for six identity strengths ranging from 0 to 10% for each individual, and also for the left and right sides of the individual face. An example of one asymmetric face trajectory is presented in Figure 1b, where the asymmetry is added to the left half of the face. The percentages provided below each exemplar correspond to the variation from the mean head radius in the asymmetric half of the face.

The RF patterns that were used as a nonface shape control stimulus were generated as described by Wilkinson et al. (1998). The shapes are generated by applying a sinusoidal modulation about a mean circle with a cross-sectional luminance profile of a fourth derivative Gaussian (Figure 4a, top). The frequency of the modulation determines the number of lobes in the shape, and the amplitude determines the “strength” of the shape and is expressed as the percent variation from the mean shape (i.e., circular) radius. In the current study, we generated RF patterns at two phases (90° and 270°) with a RF of 8, which is well above the frequency for optimal performance (Wilkinson et al., 1998). For each phase, we generated six shapes with shape strengths ranging from 0 to 1.5% mean shape radius. To create asymmetrical RF patterns, we used the same technique that was used to create asymmetrical

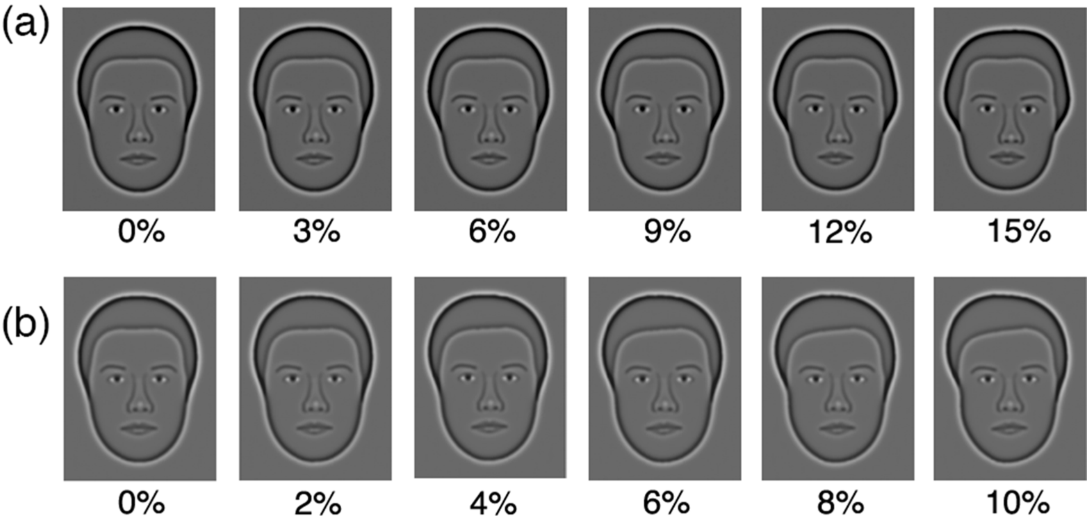

Figure 1. Examples of faces with increasing (a) identity and (b) asymmetry. (a) The trajectory for one individual for increasing identity strength. The percentages given below each image provide the amount of geometric variation from the mean head. (b) The trajectory for increasing asymmetry. In this example, the geometric variation has been added to the left half of the face, while the right side retains the mean head geometry. The percentage given below refers to the geometric variation on the asymmetric side of the face.

faces. RF patterns were bisected along the vertical midline, and were fused to the complimentary side of the mean circle. Again, the contour between each side was smoothed by taking the weighted average of the middle ± 30 pixels. An example of the asymmetric RF pattern is provided in the bottom of Figure 4a.

Two sets of experiments were conducted to determine whether the sensitivity to facial asymmetry was affected by stimulus manipulations that have been demonstrated to affect face identification. First, asymmetry thresholds were evaluated with faces that were inverted 180° (Figure 5a). All other aspects of the stimuli in this condition were identical to the upright faces used in the primary experiment. Second, asymmetry thresholds were evaluated for faces that were constructed about a nonmean face. In these stimuli, the amplitudes that define the identity of an individual face were added to a face with 12% identity variation from the mean. Increasing asymmetry was then added to the left or right side of the nonmean face in the same manner as it was in the faces constructed about the mean. An example of an asymmetric face constructed about a nonmean face is provided in Figure 6b.

Stimuli were presented on an Intel Mac Mini with a 1.66 GHz Core Duo processor and a 17 inch Seanix monitor with a resolution of 1024 × 1280 and a 75 Hz refresh rate. The average luminance of the display was 45 cd/m^2. Stimulus generation and presentation was accomplished using Psychtoolbox functions (Brainard, 1997) and custom software developed in the MATLAB™ programming environment. Subjects viewed the stimuli from a distance of 57 cm, which was maintained by the use of a chin rest.

2.2 Procedure

Thresholds were determined using a two interval-forced choice procedure, where one interval contained either a face from the identity trajectory for one individual (identity condition) or a face from the asymmetric trajectory (asymmetry condition), and the other interval contained the mean or symmetric face. Subjects responded, by keyboard, which interval contained the individual or asymmetric face. To ensure that discriminations were not based on local changes in contour features, the size of the faces across the two presentation intervals was randomly jittered from between 2.3° × 2.9° and 4.6° × 5.8°. Each face was presented for 120 ms, followed by a noise mask presented for 200 ms. The noise mask was matched to the size of the preceding face, and was bandpass filtered to contain the same peak spatial frequency as the faces.

Within each experimental run, faces were selected from four trajectories. In the identity condition, four individual identity trajectories were created, with identity strengths ranging from 0 to 15% mean head radius in 3% increments. In the asymmetry condition, two individual identities were used; however, for each identity, there were two asymmetry (i.e., left and right) conditions resulting in four asymmetry trajectories in each experimental run. The asymmetry strengths ranged from 0 to 10% in 2% increments. Thresholds did not differ between the left and right asymmetry conditions, and data across these conditions were collapsed into simply the "asymmetry" condition. Therefore, in each experimental run, there were 24 total face stimuli (four trajectories × six increments), which were each presented 20 times for a total of 480 trials.

Percent correct data for the 6 identity strength increments (x) were fit with a Quick (1974) function of the form:

$$f(x) = 1 - 0.5 \times 2^{-\left(\frac{x}{\alpha}\right)^{\beta}}, \qquad (2)$$

where α corresponds to threshold (75% correct) and β reflects the slope of the function. All of the data presented reflect the average threshold estimation for a minimum of three experimental runs for that condition, where each of the different runs contains faces taken from different identity trajectories. Although statistical significance was determined and presented using standard parametric statistics, significant effects were confirmed using non-parametric analyses (not presented).

2.3 Observers

A total of seven observers participated in some or all of the experiments. Five observers participated in the experiments evaluating face and RF asymmetry thresholds, whereas three observers participated in the conditions evaluating asymmetry thresholds with inverted and nonmean faces. The authors (NA and CG) participated in all of the conditions. All other observers were naïve to the purpose of the experiments. All observers had normal or corrected to normal vision. These experiments were approved by the MacEwan Research Ethics Board.

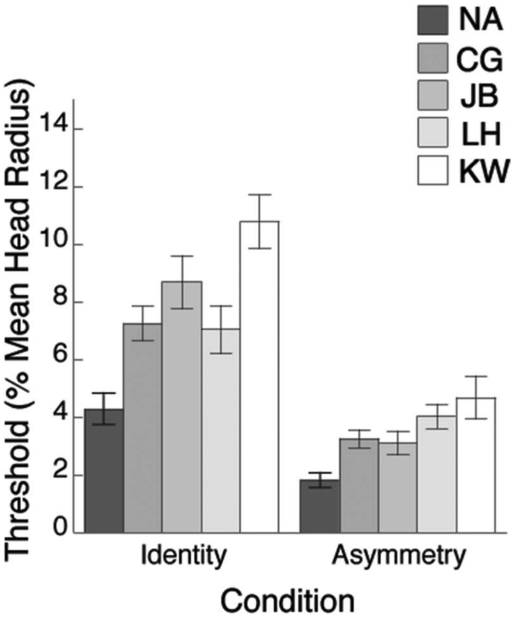

Figure 2. Individual thresholds for discriminating identity (left) and asymmetry (right) from a symmetric mean face. For all five observers, thresholds for discriminating asymmetry were 2 times lower than thresholds for discriminating identity. Error bars represent ±1 SEM.

3 Results

Identity and asymmetry discrimination thresholds were determined for five observers. For all five observers, thresholds for discriminating the identity of a face were higher than thresholds for discriminating asymmetric from symmetric faces.

Mean thresholds for all of the subjects are presented in Figure 2. Bars on the left-hand side of the graph denote threshold values for accurately discriminating individual identities from the mean face. On average, subjects required 7.58 ± 1.08% geometric change from the mean to reliably discriminate the individual face, which is similar to threshold values that have been observed with these synthetic faces previously (e.g., Wilson et al., 2002). Bars on the right-hand side of the graph display the average thresholds for discriminating an asymmetric from a symmetric face. For all five subjects, thresholds for discriminating the asymmetric face are considerably lower than they are for discriminating face identity; on average, subjects only required a 3.37 ± 0.48% geometric variation to discriminate the asymmetric faces. In fact, thresholds for every subject measured are 2 times lower for asymmetry discrimination than they are for identity discrimination. A paired *t*-test confirmed that the thresholds for asymmetry discrimination are reliably lower than the thresholds for identity discrimination ($t(4) = 4.9422$, $p < 0.01$). These results demonstrate that considerably less geometric variation is required to reliably detect facial asymmetry.

One potential feature that could be contributing to this benefit for detecting asymmetry could come from the nature of the information in the stimuli themselves. It is possible that facial asymmetry is more salient because there is a greater overall difference in the amount of information between the left and right sides of the face. With this logic, the better performance observed with asymmetric faces may be due to a difference in the amount of information available for a visual decision, as opposed to an advantage for asymmetric faces per se. To determine if there is in fact a difference in the amount of information between the two face types, we analyzed all of the face images to determine how many pixels differed between the left- and the right-half of the face. This method of analysis was straightforward: the face images were bisected and matched to one another in MATLAB™ (Figure 3a). If the pixels in the two corresponding images were the same gray level, then a zero was assigned to that spatial location, and if the pixels were a different gray level, then a one was assigned. This yielded a difference image that provides a quantitative measure of the difference between the two face sides: the greater the number of "difference" pixels, the greater the difference in overall information between the left and right sides of the face. We analyzed all of the images used in the current study, at all identity increments, and plotted the overall pixel difference for all of the images, in both the identity and

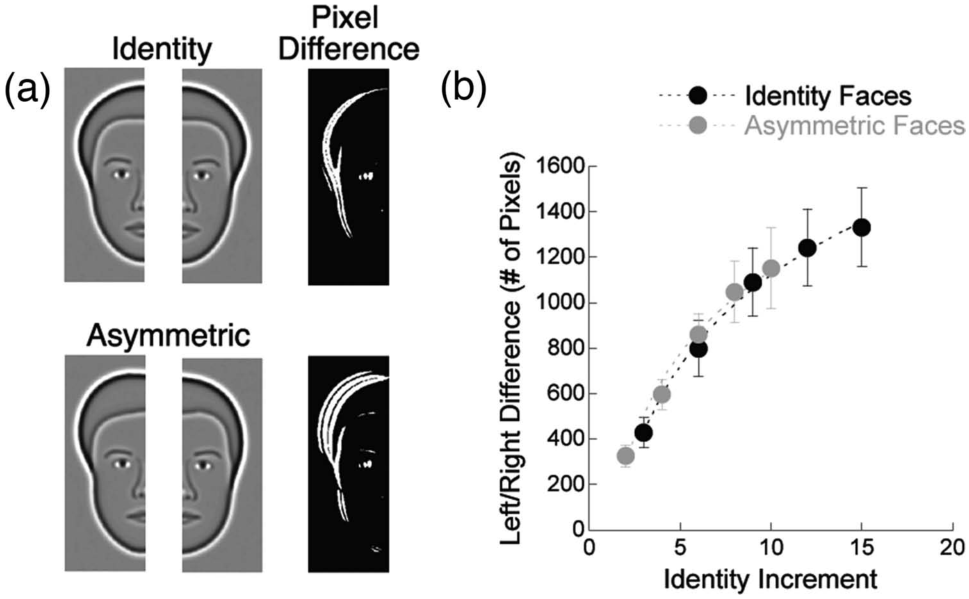

Figure 3. Information analysis and comparison between the two different face stimuli. (a) All face stimuli were divided along the vertical meridian (left (a)), and the left and right halves were compared to determine the number of pixels that differed in each face half (right (a)). This was performed for all faces from the identity sets (top (a)), and the asymmetry sets (bottom (a)). The total number of difference pixels was then summed over each face stimulus. (b) Average pixel differences between the left and right halves as a function of identity strength for faces with varying geometry identity (black circles) and asymmetry (gray circles). There is no significant difference in the overall amount of information between the left and right halves of the face for both face types.

asymmetric faces. The mean pixel difference for all identity increments for both face types is presented in Figure 3b. The important result here is that there is no significant difference in the number of difference pixels between the identity and asymmetry faces. Thus, the advantage for detecting asymmetry cannot be explained by a difference in the overall amount of information between the two face types: on average, the amount of geometric difference between the two face halves is the same for both the identity and asymmetry faces.

It is also possible that this advantage for discriminating asymmetry could reflect a more general object-processing advantage, as opposed to a face-specific benefit for asymmetry. To evaluate this possibility, we measured discrimination thresholds for RF patterns in five subjects. RF patterns are an ideal control stimulus in the current set of experiments, because they are the basis shapes for the construction of the synthetic faces. In the current experiments, subjects discriminated RF patterns from a circle using a 2IFC paradigm identical to that used in the face experiments (Figure 4a). Subjects also discriminated the asymmetric RF pattern from a circle in the asymmetric condition, again using a paradigm identical to that used to measure facial asymmetry discrimination (Figure 4a). Thresholds in the RF task reflect the minimum RF amplitude required for subjects to discriminate the shape from a mean circle. Threshold data for both RF conditions are provided in Figure 4b. For three subjects (NA, CG and AP), thresholds for discriminating the full RF pattern from the mean circle are lower than they are for discriminating the asymmetric pattern. For the other two subjects (LH and AM), there is no difference in thresholds between the conditions. Overall, thresholds approached, but did not reach, statistical significance ($t(4) = -2.5275$, $p = 0.065$). Regardless of the individual differences, none of the subjects were *better* at discriminating the asymmetric RF pattern relative to discriminating the full RF pattern. This suggests that the asymmetry advantage does not extend to judgments of more basic shape patterns, and instead reflects a face-specific advantage for asymmetric faces.

Given the finding that this advantage for asymmetry discrimination appears to be a face-specific effect, we also investigated whether or not it was disrupted by manipulations that have been demonstrated to disrupt face-specific processing. The first manipulation that we investigated was the inversion effect, where it has been clearly demonstrated that simply inverting a face disrupts face processing (Yin, 1969). We also measured face asymmetry thresholds in inverted faces and compared those results to the asymmetry thresholds for upright faces. Thresholds were measured for three subjects

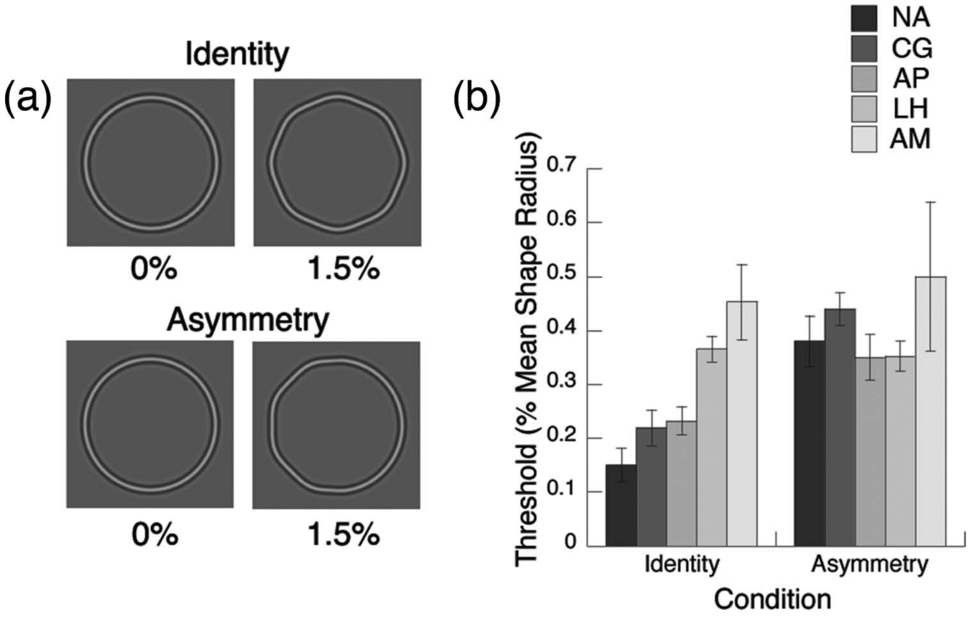

Figure 4. Individual thresholds for discriminating radial frequency (RF) patterns in both identity and asymmetry conditions. Subjects were required to either discriminate a full RF8 pattern from a mean circle (top (a): identity condition), or a pattern where the RF8 contour was only added to one half of the shape (bottom (a): asymmetry condition). (b) Identity (left) and asymmetry (right) thresholds for RF patterns for five individual subjects. Two subjects (LH and AM) had equivalent thresholds for each condition, whereas the other three subjects had lower thresholds for the identity condition than for the asymmetry condition. No subject demonstrated lower thresholds for RF asymmetry.

(NA, CG and KW), where the experimental paradigm was identical to that used in the asymmetry task except for the fact that the faces were rotated by 180° (Figure 5a). These results are presented in Figure 5b, with the original upright face asymmetry thresholds also presented as a comparison. The asymmetry thresholds for the inverted faces are not significantly different for the inverted faces

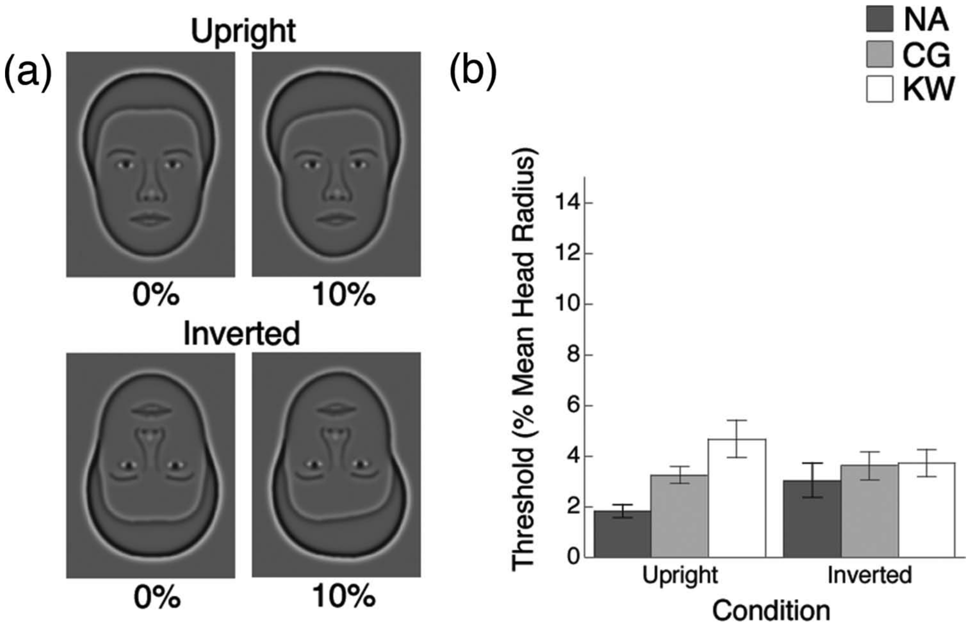

Figure 5. Asymmetry thresholds for upright and inverted faces. (a) Thresholds for detecting asymmetry were compared when the faces were presented upright (top (a)), or when rotated 180° (bottom (a)). (b) Individual asymmetry thresholds for three subjects for the upright (left) and inverted (right) faces. There was no significant difference in performance for the two conditions.

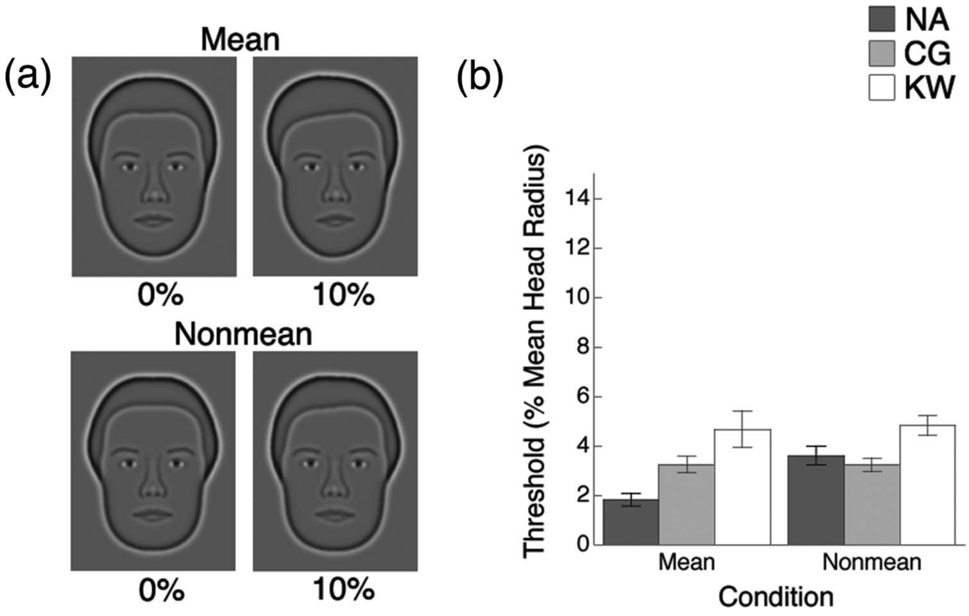

Figure 6. Asymmetry thresholds for faces constructed using either the mean or a nonmean face as a geometric base. (a) Asymmetric faces were created by adding geometric asymmetry to either the mean face (top (a)), or a nonmean face possessing 10% geometric identity (bottom (a)). The percentages given below refer to the amount asymmetry added to the face. In both examples, the asymmetry is added to the left half of the face. (b) Individual asymmetry thresholds for three subjects for the mean (left) and nonmean (right) base faces. Again, there was no significant difference in performance for the two conditions.

($t(2) = -0.32715, p > 0.2$), suggesting that inversion does not affect facial asymmetry perception with these stimuli.

Another feature of face processing that can affect identity thresholds is whether or not the identity of the face is geometrically close to the mean face. Specifically, some evidence suggests that sensitivity to face identity is greater when the geometric features of the face are closer to average than when they are geometrically distant from average (Wilson et al., 2002; but see Rhodes, Maloney, Turner, & Ewing, 2007). We also investigated whether or not face asymmetry discrimination depended on the geometric distance of the face from the mean. To this end, we generated asymmetries in faces that possessed 12% variation from the mean, which is well above identity detection thresholds for these faces. Geometrically asymmetric information was then added to either the left or right side of the nonmean face (Figure 6a). In these stimuli, a 0% geometric variation means that the face does not vary from the nonmean face that is used as a base, and the geometric variation refers to the amount of variation on the asymmetric side that is different from the nonmean base face. Thresholds for these nonmean asymmetric faces are presented in Figure 6b for three subjects (NA, CG and KW). Once again, asymmetry thresholds for the nonmean faces were not statistically different from faces that were asymmetric about the mean face ($t(2) = -1.1099, p > 0.2$). Facial asymmetry discrimination, therefore, does not depend on where the face is located in geometric face space.

4 Discussion

Our results demonstrate that human observers are more sensitive to changes in facial asymmetry than they are to changes in face identity when discriminating from a mean face. This is somewhat surprising, given the fact that there is actually *less* geometric variation in the asymmetric faces, since the variation is only added to one side of the face. This advantage for discriminating asymmetry over just a general deformation from the mean does not extend to more simple geometric forms, suggesting that the advantage for discriminating asymmetry is a face-specific effect. However, the advantage for discriminating asymmetry is not influenced by manipulations that typically affect face-specific processes, namely face inversion and nonmean face trajectories. Taken together, these results suggest that discriminating face asymmetry is a behavior that does not rely on the same mechanisms that support other face-specific behaviors (for example, face identification).

The advantage for judging asymmetry could arise because of differences in the stimuli themselves. Distorting the symmetry of the face could mean that there is more of a visual difference between the left and right sides of the face, which would make it visually easier to discriminate. We evaluated this possibility by analyzing the overall pixel difference between the left and right sides of the face in both the identity and asymmetry stimulus sets. We found that there was no overall difference in the amount of change between the left and right sides of the face for the two stimulus sets. This form of stimulus evaluation is a global analysis: the difference pixels simply reflect the overall number of pixels that differ, but not how those differences are spatially distributed. It is possible that while the overall difference between the left and right sides of the face is the same for both asymmetric and identity faces, the asymmetric faces possess greater differences between specific regions of the face (i.e., local differences). These could then be used as cues for discriminating the asymmetric face from the mean face. It is important to note here, however, that even if subjects are using local cues to discriminate asymmetric faces, these are cues that are not traditionally thought to be involved in face identification (a global process). If these potential local cues are then contributing to asymmetry discrimination, this still supports the idea that asymmetry relies on mechanisms that differ from those that are involved in traditional face identification.

The advantage for discriminating asymmetry also does not extend to nonface shape forms. We found that thresholds for discriminating an asymmetric RF pattern from circularity were higher than thresholds for discriminating a modulated shape from circularity. These results demonstrate that asymmetry perception is not in and of itself an easier task than shape discrimination, but instead appears to demonstrate a face-specific advantage. These results also suggest that superior performance in the asymmetry condition does not reflect the use of local midline cues for discrimination, as subjects would have exhibited similar advantages with asymmetric figures in the RF condition if midline cues were being used. Our finding that performance is better when the deformation extends across the entire stimulus is consistent with previous research demonstrating that discrimination thresholds for RF patterns improve as the number of deformation cycles increases (Loffler, Wilson, & Wilkinson, 2003). These results support the idea that the visual system pools contour information for shape discrimination, and that as more information can be pooled, individuals become more sensitive to shape information. In our study, thresholds for three subjects were 2 times better when the deformation extended around the entire shape, and for two subjects thresholds did not change between the two conditions. Under no circumstance did we see an improvement when the deformation was only added to half of the shape. Thus, the improvement with pooling that is observed with RF patterns does not appear to extend to processing contour information in face discrimination.

Our finding that face asymmetry discrimination was unaffected by inversion is consistent with the findings of Little and Jones (2006), who also found that symmetry detection was unaffected by face inversion. However, our results differ from Rhodes et al. (2005), who found subjects were less accurate when discriminating chimeras from their normal counterparts when the faces were inverted as opposed to upright. Two critical differences between our study and that of Rhodes et al. may account for these results. First, the stimuli used by Rhodes et al. were symmetric faces that were generated using naturalistic photographs, and where the hairlines of both the normal and symmetric faces possessed symmetric hairlines. As a result, the only cues for asymmetry with these faces were in either the feature placement, and/or the chinline of the faces. In the faces used in the present study, the asymmetry extended throughout the entire contour of the face, including the hairline. Judgment of asymmetry when a global asymmetry is applied to the principal components of curvature in a head form is better than when the asymmetry is applied to components that are not typically seen in head shapes (Wilson & Wilkinson, 2002). Perhaps the "fine-tuned" differences in asymmetry with the feature placement in the chimeras may be more susceptible to inversion, whereas the more global differences in asymmetry with our stimuli may overcome any effects of inversion. Moreover, performance in the Rhodes et al. study evaluated the ability for subjects to discriminate chimeric faces from their normal counterparts, without varying the *amount* of symmetry. As we were able to measure the minimum amount of asymmetry required to discriminate an asymmetric face (as opposed to classifying symmetric from asymmetric faces), it is possible that we are tapping into a different visual skill, one that is less susceptible to face inversion.

The current study has investigated sensitivity to bilateral face symmetry, where the axis of symmetry is located through the midline of the face. Bilateral symmetry is a feature that is often implicated in judgments of attractiveness or overall health (e.g., Grammer & Thornhill, 1994; Scheib et al, 1999).

However, another way that facial asymmetry can arise is through slight changes in head orientation; when viewing a face from the side, the left and right views of the face also become more asymmetric relative to one another. The type of information that is conveyed through asymmetries that occur due to head orientation is different from what we have described here; namely, asymmetric changes due to head rotations can provide important social cues for attention direction (e.g., Langton, Watt, & Bruce, 2000). Moreover, the type of asymmetry that arises through slight head rotation is different from bilateral asymmetry, in that slight head rotation can be modeled as an affine transform; the resulting asymmetry can be rectified by the visual system as an object invariance. The bilateral asymmetry that is introduced here, on the other hand, reflects a non-affine transformation. As such, asymmetry due to head rotation reflects a different form of asymmetry from the type that we have investigated here. Whether or not the advantage that we observed for discriminating asymmetry from identity would extend to asymmetries due to head orientation cannot be answered from the current study. However, given our exquisite sensitivity to social attention cues such as eye gaze (e.g., see Nummenmaa & Calder (2009) for a review), and the strong sensitivity that we observed in the current study for bilateral asymmetry, we would predict an advantage for discriminating asymmetries due to head orientation as well.

We propose that the difference between judgments of facial asymmetry and facial identity suggests that both visual skills rely on functionally different neural mechanisms. While the role of the FFA in face processing has been well established, other evidence suggests that a network of visual regions is involved in the variety of skills that are required for making different judgments of faces. For example, the distributed model of face processing proposes that different cortical regions are involved in processing invariant aspects of faces as opposed to variant aspects of faces (Haxby, Hoffman, & Gobbini, 2000; Winston et al., 2004) and/or the "building-blocks" of face processing (Nichols, Betts, & Wilson, 2010). fMRI evidence also suggests that the perception of face symmetry may rely upon activity in the right OFA (Chen, Kao, & Tyler, 2007). Taken together, these results suggest that discriminating facial asymmetry relies on functionally different mechanisms, and our results suggest that these mechanisms may be more sensitive to geometric change than those involved in perception of facial identity.

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