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Factors Affecting the Perception of 3D Facial Symmetry from 2D Projections

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Received: 28 September 2017; Accepted: 19 October 2017; Published: 21 October 2017

Abstract: Facial symmetry is believed to have an evolutionary significance and so its detection should be robust in natural settings. Previous studies of facial symmetry detection have used front views of faces where the decision could be made on 2D image properties rather than 3D facial properties. These studies also employed comparative judgements, which could be influenced by attractiveness rather than symmetry. Two experiments explored the ability to detect typical levels of 3D facial asymmetry (contrasted with wholly symmetrical faces) from 2D projections of faces. Experiment 1 showed that asymmetry detection was impaired by inversion but even more impaired by 90 degrees rotation demonstrating the importance of the vertical reflection. Asymmetry detection was also reduced by yaw rotation of the head but still above-chance at 30 degrees rotation. Experiment 2 explored the effect of asymmetrical lighting and yaw rotation up to 45 degrees. Detection of asymmetry was affected by asymmetrical lighting and yaw rotation in a non-additive manner. The results are discussed in terms of the special role that faces and vertical symmetry play in visual perception.

Keywords: facial symmetry; 3D structure; face inversion

1. Introduction

Human faces, like many biological forms, show high levels of mirror symmetry. However, the human body is asymmetrical with many internal organs showing directional asymmetry developed in the first few weeks of life [1,2]. Even facial symmetry is not perfect and faces tend to display varying levels of fluctuating asymmetry [3]. It has been proposed that lower levels of fluctuating asymmetry are reflective of an individual's greater health and genetic quality [4,5]. It is argued that lower fluctuating asymmetry is a consequence of greater development stability [6]. Greater symmetry, therefore, suggests greater phenotypic quality and hence an evolutionary adaptive response would be to seek out reproductive partners that are symmetrical [7] in the hope that offspring will similarly be able to cope with stresses. Higher levels of facial symmetry should, therefore, be more attractive in mates as they communicate greater genetic fitness. Further, we should be particularly good at detecting asymmetries as they are evolutionarily significant in the same way as food sources or threats.

There has been considerable scientific interest in finding a link between facial symmetry and facial attractiveness (see [8] for a review). Many studies have demonstrated that more symmetrical faces are more attractive (e.g., [9,10]). There has also been debate concerning whether a general preference for symmetry derives from an evolutionary preference for symmetrical mates or whether the evolutionary preference is just a feature of a general preference for symmetry (contrast [11] and [12]). Support for this general-preference account comes from the findings that within normal populations there is, in fact, no link between health and facial asymmetry [13].

The current research aims to explore the process of facial asymmetry detection. Few studies have looked at this process in spite of it being a necessary cognitive stage if symmetry is to play a role in attractiveness. Understanding the factors that affect this process will potentially help to provide an understanding of the role that symmetry plays in mate selection and hence evolution. The research presented here differs from much of the existing literature in two main ways. The first difference is that signal detection theory is used to investigate the discrimination performance and response bias in an asymmetry detection task. The second difference is that the stimuli are computer generated faces, which allows for greater control over the degree of symmetry and lighting conditions but also allows for rotation of the 3D heads such that different angles of yaw are available. Together, these differences offer a novel insight into the perception of facial asymmetry. The current research aims to answer the questions of whether the ability to detect facial asymmetry is greater than general symmetry detection. It does this by looking at inversion effects in asymmetry detection. The current research also asks to what extent 3D symmetry can be extracted from asymmetrical 2D projections.

1.1. Symmetry Detection Versus Symmetry Preference

Many of the studies that have explored the role of symmetry in facial attraction have used this two alternative forced choice (2afc) design. Typically, pairs of almost identical faces are presented in which one face has more asymmetry than the other. The participant chooses which face is either more symmetrical [14], more attractive [15,16] or both [17,18]. In the attractiveness task, an attractiveness preference for more symmetrical faces is therefore interpreted from increased selection of the most symmetrical of the pair: the more common the selection of the symmetrical faces the stronger the preference for symmetry over asymmetry. In the symmetry detection task, greater selection of the symmetrical face suggests a stronger ability to detect asymmetries.

The use of the 2afc design is useful when looking for preferences between pairs of very similar stimuli but it has a number of limitations. One limitation is that it is not clear whether increased preference for symmetrical faces is a consequence of a stronger preference for symmetrical faces or an increase in the ability to detect symmetry. Research that has explored the effect of inversion on facial symmetry illustrates the difficulties of making conclusions based on 2afc tasks. Little and Jones [12] showed no symmetry preference for inverted faces suggesting that when the task is difficult there is a reduced preference. This has two possible conclusions. First, the lower preference for symmetry may represent a decreased ability to evaluate facial images when upside down. This would mean that performance would be at near chance level in any task that presented pairs of two faces that only differed in terms of symmetry and so no symmetry preference would be possible. Second, the asymmetry is detected in inverted faces but it is not considered important in the evaluation of the attractiveness of inverted faces. The 2afc design is unable to distinguish these two possibilities.

The second limitation with the 2afc design is that the researcher is not necessarily confident of what decision is in fact being made by participants. The demand characteristics of a typical experiment are such that the participant is being asked which out of a pair of faces is more attractive and the only difference is that one face is more symmetrical than the other [19]. Forcing a choice in this task could direct the participant to think that he or she should select the more symmetrical face. The same pattern of results might be observed if the question was not which is more attractive but rather which face is more trustworthy or more dominant. What is being assessed in the 2afc design is whether the participant is able to determine whether one of the faces is more asymmetric than the other. Little and Jones [17] compared two different 2afc tasks on the same set of stimuli. In their first experiment, pairs of faces were presented and participants chose the more attractive member of the pair, but later, in a second task, the participants also selected the face that was most symmetrical. A preference for the symmetrical faces was shown in both tasks. Analyses of the items suggest that there is poor correlation between performance on the two tasks suggesting that symmetry detection and attractiveness preference involve different processes. Little and Jones [17] also showed that there was an effect of inversion for attractiveness decisions but not for symmetry detection providing further evidence of separate processes. Effects of inversion are discussed in detail below.

Oinonen and Mazmanian [18] also used two different questions with the same 2afc task. Like Little and Jones [17], they looked at the detection of symmetry and the attractiveness preference, grouping participants based on the stage of their menstrual cycle. Performance on the two different 2afc tasks were highly correlated in that participants that showed higher levels of symmetry detection also showed a stronger attractiveness preference (r = 0.42). This suggests that there is considerable overlap in the characteristics of the two tasks although they also found that there was a menstrual stage effect for the symmetry detection task but not the attractiveness judgement.

An alternative to the 2afc task is to use symmetry detection task. In such a task, single faces are presented and the participant judges whether each face is symmetrical or not. This task has the advantage of providing a direct measure of symmetry processing that is independent from judgement of attractiveness. Lewis [20] demonstrated how discrimination ability in this task was related to the size of the preference shown in the 2afc task. This demonstrated a link between the size of symmetry preference and the ability to detect symmetry. A similar symmetry detection task is employed in the current experiments to explore visual processing ability.

1.2. Inversion Effects on Symmetry

The effects of face inversion have been widely studied. Yin [21] showed a face inversion effect that was stronger than for other objects and many experiments have followed that attempt to explain this finding (see [22] and [23] for reviews). It is sometimes argued that inverted faces are not processed like faces but rather like objects. They forego the special analysis that is given to upright faces as indicated by rapid and accurate recognition [24], holistic processing effects [25], and specific patterns of neural activity [26]. The face inversion effect is one way in which faces show themselves to be a special category of visual stimuli.

A preference for visual symmetry, however, is not special to faces. It is observed for animals, objects [27], works of art [28], random dot patterns [29] and complex objects [30]. Indeed, it has been suggested that parts of the extrastriate visual cortex are specifically tuned to visual symmetry [31]. If the preference for facial symmetry were just a general preference for symmetry then similar preferences would be found for upright as inverted faces because inversion does not affect the faces bilateral symmetry.

A test of symmetry preference for upright and inverted faces was carried out by Little and Jones [12]. They found a symmetry preference for upright faces but no symmetry preference for inverted faces. As discussed above, this result has two possible conclusions. First, the lower preference for symmetry may represent a decreased ability to evaluate facial images when upside down. This would mean that performance would be at near chance level in any task that presented pairs of two faces that only differed in terms of symmetry and so no symmetry preference would be possible. Second, the asymmetry is detected in inverted faces but it is not considered important in the evaluation of the attractiveness of inverted faces (which are processed as objects rather than faces). The 2afc design is unable to distinguish these two possibilities of inversion affecting detection ability or symmetry preference.

The follow up study by Little and Jones [17] looked at inversion effects for both a symmetry preference task and a symmetry detection task. An inversion effect was found only for the symmetry preference task. This was used as support for the idea that symmetry preference for faces exists beyond simple visual symmetry preference. There are systems that people use to judge the attractiveness of faces based on their symmetry but these are subconscious and are not available to simple symmetry detection tasks. A conclusion they draw, therefore, is that there are different mechanisms involved in preference for symmetrical faces than are involved in detection of asymmetry with only the former being affected by inversion.

One further study explored the effect of inversion in symmetry detection. Rhodes and colleagues [14] used a consecutively presented 2afc design to show that symmetry could be detected in both upright and inverted faces at above-chance levels. The symmetry was detected significantly less accurately for inverted faces than for upright faces. This inversion effect was roughly the same size as the effect of contrast reversal or band-bass filtering the faces. Given that this experiment used a 2afc design, it could be argued that the inversion effect was a result of participants using a heuristic of selecting the image that is more attractive to say it is more symmetrical. Such an argument would mean that the findings of Rhodes and colleagues can be reconciled with those of Little and Jones [17] and there is no effect of inversion on symmetry detection only an effect on symmetry preference.

As well as inversion, the current research explores orthogonal rotations of faces. Inversion of a face maintains the vertical axis of symmetry whereas orthogonal rotation does not. This is relevant as it has been indicated that vertical symmetry has a particular salience [32,33]. Symmetry with a vertical axis is more easily detected than symmetry with a horizontal axis (see [34] for a review). Symmetry detection has not previously been explored in faces that do not have a vertical axis of symmetry. Orthogonal rotation has been explored in other aspects of face processing and it has been found that performance falls between that of upright faces and inverted faces [35,36].

In order to clearly establish whether picture-plane rotation (inverted or orthogonally presentation) affects the detection of symmetry, it is necessary to use a task where comparative attractiveness cannot be used as a proxy for symmetry. The current research, therefore, used a single image asymmetry detection task in order to establish the ease of asymmetry detection for upright, inverted and orthogonally presented faces.

1.3. Three-Dimenional Symmetry in 2D Projections

Unlike much of the research conducted on facial symmetry, the current research does not directly concern facial attractiveness but rather the ability to detect whether a face has an asymmetry. If symmetry is to play a meaningful role in mate selection or evolution then it is necessary that humans have the biological systems required to detect it easily in natural settings. Given that many studies have shown that participants have a preference for symmetrical faces over asymmetrical ones, one might consider this question answered. These studies, however, have almost all employed faces angled directly towards the viewer and so participants may be assessing 2D pictorial symmetry rather than 3D structural symmetry (see [20] for an exception). Natural viewing of faces is unlikely to be from a full frontal angle. Similarly, many of the studies use symmetrical lighting to illuminate the face (see [37] for an exception), which again would be an unusual situation in which to view a face. If evaluation of facial symmetry is adaptively important in reproduction then it would be expected that the 3D symmetry of a face could be assessed in more natural viewing conditions—that is at various angles of rotation and asymmetric lighting conditions.

Psychological research into facial symmetry has almost exclusively used 2D symmetry (although see [20,38] for counter examples). Projections of 3D symmetry have been more widely investigated for abstract objects. For example, see Wagemans [34] for a review of how visual skew (visually equivalent to 3D rotation) of a 2D symmetrical pattern affects detection of symmetry. This review demonstrates that symmetry detection is a remarkable robust and versatile process. Koning and Wagemans [39] also explored the relative ability to detect symmetry compared to repetition in rotated planes. Sawada [40] demonstrated that humans could establish 3D symmetry from asymmetrical 2D projections of irregular polyhedra. Chen and Sio [41] explored the effect of 3D distortion and rotation on the detection of symmetry in random-dot stereograms. These studies show that symmetry detection can be based on analysis of the 3D structure rather than being dependent on the 2D projections. In fact, assumed symmetry can be used to bring structure to vision as illustrated by: Saunders and Knill [42] who demonstrated that the degree of tilt and skew in 3D could be assessed in random objects if symmetry of the object was assumed, and by Sawada, Li & Pizlo [43] who showed that automatic object processing systems could make use of 3D symmetry information to help to identify objects in a scene. Further research into 3D symmetry has demonstrated that the direction of symmetry affects its detection. Farell [44] showed that the thresholds to detect symmetry are lower when the symmetry is across a vertical plane than when it is across a horizontal plane. Although this effect was discovered using abstract stereo displays, it does have clear implications for the current research particularly when comparing inverted faces (which have a vertical plane of symmetry) with orthogonal faces (which have a horizontal plane of symmetry).

The current experiments take this previous research further by evaluating the ability to detect 3D symmetry of a complex biological form that is projected onto a 2D image. A variety of levels of yaw rotation, which quickly destroys the 2D symmetry, were tested to determine whether it was still possible to extract 3D symmetry. Asymmetric lighting conditions were also used to introduce 2D asymmetries and it is evaluated whether 3D symmetry can still be identified.

2. Experiment 1

The current study assessed the conditions that affect whether asymmetry can be detected in the 3D structure of faces. Detection of asymmetry is a necessary requirement if symmetry is to play a role in attractiveness but attractiveness is not directly measured here. Of primary interest was whether inversion or orthogonal rotation affects the ability to detect symmetry in faces. In order to assess whether it is 2D pictorial symmetry or 3D face symmetry that is being used in symmetry decisions, the faces varied in their degree of yaw rotation. Front views were contrasted with views with either small or large degrees of yaw rotation.

The task employed was an asymmetry detection task. Single facial images were presented and the participants' task was to identify whether the face (the 3D structure rather than the 2D projection) was asymmetrical or not. The images were computer generated projections generated from either a symmetrical or asymmetrical 3D head. From this task it was possible to use signal detection theory to find a discrimination ability and a response bias for each condition.

2.1. Method

2.1.1. Participants

Forty-four female participants received course credit for taking part in the experiment. All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Cardiff University, School of Psychology.

2.1.2. Stimuli

FaceGen 3.0 software (Singular Inversions Inc.: Toronto, ON, Canada) was used to generate all of the stimuli. This software generates color 3D renders of faces based on a sampled set of real faces. Four base faces were generated randomly such that they were European looking, female looking and had a fixed level of asymmetry (these properties were defined by the database used by FaceGen which was based on a large corpus of natural faces). The measure of asymmetry of the faces was 1.0 times the standard amount of asymmetry in the database of faces used to make the system. This is a meaningful metric of asymmetry as it is not dependent on the arbitrary selection of a subset of facial parameters (Previous studies measuring symmetry have used asymmetry metrics based on a limited number of facial feature locations: Scheib, Gangestad & Thornhill [45] used 14, Farrera, Villaneuva, Quinto-Sánchez and González-José [46] used 28 and Kaipainen, Sieber, Nada, Mall, Katsaros & Fudalej [47] used 59 feature locations. Different numbers of locations means that the metrics are not comparable between experiments. Further, Schmid, Marx & Samal [48] demonstrated that the asymmetry metric was affected by the choice of features and, also, that some features were more important than others when it came to attractiveness assessments. The asymmetry metric used in the current study is one that is related to the variability in real-world faces and so is comparable with other experiments that use naturally occurring facial asymmetry). All faces were given a standard short, dark hair style. From these base faces, four further faces were generated such that their asymmetry was set to zero making a set of perfectly symmetrical faces.

The stimuli were generated by capturing images of the eight faces at various angles of rotation of yaw. These were split up into front views (0 degrees yaw rotation), small rotations (between 5 and 15 degrees rotation) and large rotations (between 20 and 45 degrees rotations). The images were lit by one source of lighting images from just above the viewer's point of view providing a symmetrical lighting pattern. Further sets of images were generated by rotating the images through 180 degrees in the picture plane (inversion) or by 90 degrees in the picture plane (orthogonal). The number of stimuli was also doubled by presenting them all mirror reversed as well in their original format. Examples of the stimuli are shown in Figure 1.

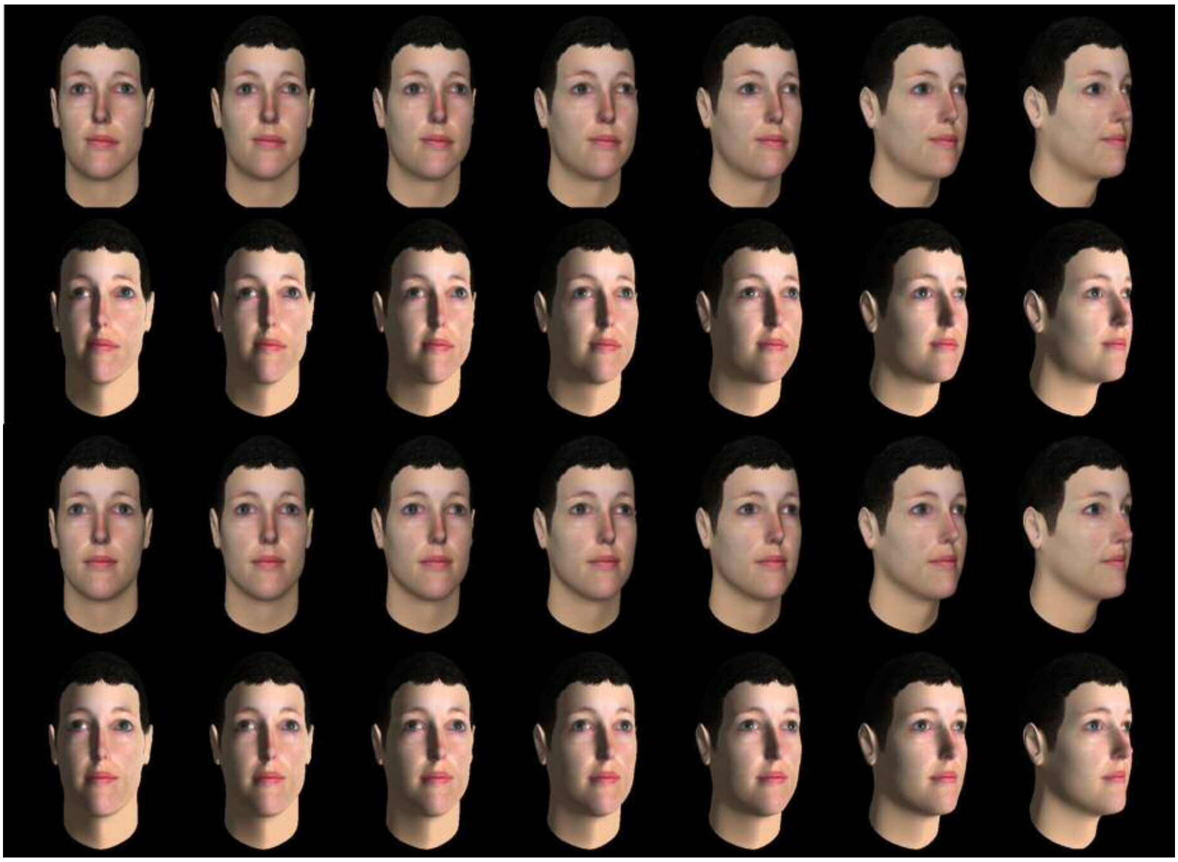

Figure 1. Examples of the stimuli showing asymmetrical faces (top two rows) and symmetrical faces (bottom two rows) used in both experiments. The first and third rows show symmetrical lighting (used in Experiment 1 and 2) whereas the second and fourth row show asymmetrical lighting (used in Experiment 2 only). Seven angles of yaw rotation shown are, from right to left, 0°, 5°, 10°, 15°, 20°, 30°, 45°. In Experiment 1, rotations of 5° to 15° were categorised as small whereas 20° to 45° were categorised as large.

2.1.3. Procedure

Participants sat at a computer and responded to a series of faces as to whether they were symmetrical or not. The task started with six practice trials before the stimuli were presented in a random order. Each of the stimuli was presented individually until a response was made via a keyboard. It was stressed to the participants that they were judging the symmetry of the face rather than the symmetry of the image or hair.

2.1.4. Design

The dependent variable was whether the images were correctly classified as being symmetrical or not. From these responses, signal detection theory was used to calculate a discriminability of the asymmetries and the response bias in determining whether there was 3D symmetry. The independent variables were the angle of yaw of the face and the orientation of the face (upright, orthogonal or inverted).

2.2. Results

The collected data were converted into symmetry discrimination and response bias scores for each category of stimuli for each participant. Means are shown in Figure 2. Applying one-sample *t* tests, all conditions had discrimination levels significantly greater than zero except for large yaw rotations when the faces were either inverted, $t(43) = 1.746$; $p = 0.088$, or orthogonal, $t(43) = 1.397$; $p = 0.170$.

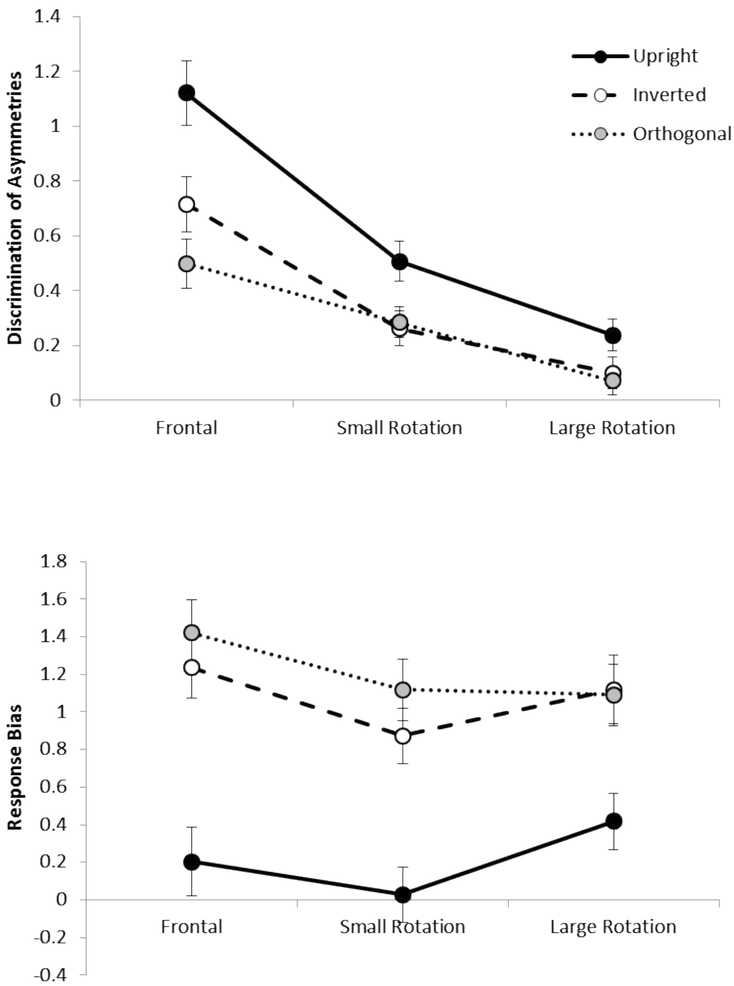

Figure 2. Analysis of performance on the discrimination of asymmetries based on signal detection analysis in Experiment 1. The top panel shows the accuracy of performance whereas the bottom panel shows the response bias with a higher value meaning that the participant is less likely to report an asymmetry. Data points are split according to angle of yaw, whether the image was upright, inverted or orthogonal. Error bars show standard errors.

A three-by-three ANOVA was carried out to explore the significance of manipulations of orientation and yaw on symmetry discrimination. There was a significant effect of orientation,

$F(2,86) = 15.445$; $p < 0.001$; $\omega^2 = 0.245$, and a significant effect of yaw, $F(2,86) = 89.751$; $p < 0.001$; $\omega^2 = 0.666$. In addition to these main effects, there was also a significant interaction, $F(4,172) = 4.123$; $p = 0.003$; $\omega^2 = 0.066$. In order to analyse the interaction, comparisons were made at each level of yaw rotation. For front views, performance was significantly better for the upright faces than the inverted faces, $t(43) = 3.117$; $p = 0.002$, which were significantly better than the orthogonal faces, $t(43) = 1.695$; $p = 0.049$. For the small yaw rotations, performance was significantly better for the upright faces than the inverted faces, $t(43) = 2.955$; $p = 0.003$, which were not significantly better than the orthogonal faces, $t(43) = 0.277$; $p = 0.609$. For the large yaw rotations, performance was better for the upright faces than the inverted faces and this approached significance, $t(43) = 1.641$; $p = 0.054$, and performance on the inverted faces was not significantly better than on the orthogonal faces, $t(43) = 0.451$; $p = 0.327$. All simple comparisons across yaw rotation were significant at every level of orientation, all $t(43)$ values > 2.134; all p values < 0.02.

A three-by-three ANOVA was also carried out to explore the significance of manipulations of orientation and yaw on the response bias. A higher value indicates that the participant were more inclined to respond with a symmetrical response. This analysis found a significant effect of orientation, $F(2,86) = 54.844$; $p < 0.001$; $\omega^2 = 0.548$, a significant effect of yaw, $F(2,86) = 3.874$; $p < 0.025$; $\omega^2 = 0.061$, and a significant interaction, $F(4,172) = 4.390$; $p = 0.002$; $\omega^2 = 0.071$. Analysis of the interaction revealed that there were significant differences between upright faces and the other two orientations but orthogonal and inverted faces produce similar response biases.

2.3. Discussion

The results clearly demonstrate that yaw rotation of a face affects the ability to detect asymmetry. Performance is best when the face is presented as a front view. In such cases, the task of asymmetry detection can be performed as a 2D-image-processing task. Rotation of the face away from the viewer reduces the utility of 2D symmetry and so the task requires 3D analysis of the object. There is a loss of accuracy as the faces are rotated but, importantly, asymmetry detection can still be performed at above-chance levels at 30 degrees yaw rotation. This is a demonstration that asymmetry detection in faces is not purely a result of 2D image processing.

Picture-plane rotation of a face was also found to affect the accuracy of asymmetry detection. This is important because Little and Jones [17] presented evidence that inversion did not affect the process of asymmetry detection. Further, Rhodes and colleagues' [14] evidence of an inversion effect could have been a result of symmetry preference being used instead of symmetry detection. The current research shows a clear inversion effect in symmetry detection. This inversion effect is an indication of the special processing of faces, which now includes preferential evaluation of facial symmetry. What is more, there is a larger detrimental effect of orthogonal presentation than inversion on performance. Orthogonal presentation disrupts the bilateral symmetry that is present in both upright and inverted faces. The difference between the inverted faces and the orthogonal faces, therefore, represents the loss of this bilateral symmetry. This is consistent with the findings of Farell [44] who found that symmetry with a vertical axis is easier to detect than symmetry with a horizontal axis. The current data show that this difference only occurs for the front-view versions of the faces. These are the images that can be processed using 2D information. As such, the bilateral symmetry advantage appears to be a feature of the 2D analysis of the image only.

3. Experiment 2

Experiment 1 demonstrated the possibility of 3D facial asymmetry detection at large angles of yaw rotation. What is not clear is how performance changes across smaller divisions of yaw rotation and at what point are people no longer able to detect typical levels of facial asymmetry. The second experiment repeated the research in the first experiment but explored more specifically the performance at various levels of yaw rotation.

Yaw rotation is not the only factor that affects the link between 3D and 2D symmetry. Asymmetrical lighting can lead to faces that are structurally symmetrical giving a 2D projection that is visually asymmetrical even when viewed from the front. Previous research has shown that asymmetrical lighting affects the detection of symmetry [20]. Here it was investigated whether this is as a loss of 2D symmetry or whether 3D symmetry is also affected by lighting. By looking at inversion effects, it was investigated whether any lighting effects were specific to faces or a general feature of symmetry detection.

This experiment, therefore, was an asymmetry detection experiment looking at yaw rotation, inversion and lighting condition. The procedure was similar to that of Experiment 1.

3.1. Method

3.1.1. Participants

Sixty female participants received course credit for taking part in the experiment. All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Cardiff University, School of Psychology.

3.1.2. Stimuli

FaceGen 3.0 software was used to generate all of the stimuli using the same base faces as in Experiment 1 including the symmetrical faces and the asymmetrical faces. The stimuli were generated by capturing images of the eight faces at seven different angles of rotation of yaw (0°, 5°, 10°, 15°, 20°, 30°, 45°). Two different lighting conditions were used at each angle for all of the faces: one lit the images from just above the viewer's point of view providing a symmetrical lighting pattern and the other lit the faces from the side. Further sets of images were generated by inverting the images and mirror reversing them. Examples of the stimuli are shown in Figure 1.

3.1.3. Procedure

The procedure was the same as for Experiment 1. Each of the 448 stimuli was presented individually until a response was made via a keyboard indicating whether the face was symmetrical or not.

3.1.4. Design

The dependent variables were the signal detection analysis based on whether the images were correctly classified as being symmetrical or not. The independent variables were the angle of yaw of the face, the lighting condition (front or side) and the orientation of the face (upright or inverted).

3.2. Results

The means for the discrimination and response bias over the 60 participants are shown in Figure 3. Looking at one-sample t test, discrimination of asymmetry was above-chance for all levels of yaw rotation up to 45 degrees, $t(59)$s > 2.15; ps < 0.018, for centrally lit upright faces. For side-lit upright faces, performance was above-chance up to 30 degrees, $t(59)$s > 6.293; ps < 0.001, but not at 45 degrees, $t(59) = .635$; $p = 0.264$. Similarly, for inverted faces, performance was above-chance up to 30 degrees, $t(59)$s > 1.941; ps < 0.029, but not at 45 degrees, $t(59)$s < 0.462; ps > 0.501.

An ANOVA was carried out assessing the discrimination scores. The independent variables were orientation, lighting, and yaw. Discrimination was significantly better for upright faces than for inverted faces, $F(1,59) = 89.507$, $p < 0.001$, $\omega^2 = 0.592$. Discrimination was not significantly better for front-lit faces than for side-lit faces, $F(1,59) = 0.054$, $p = 0.817$, $\omega^2 < 0.001$. The effect of yaw was significant, $F(6,354) = 57.956$, $p < 0.001$, $\omega^2 = 0.486$, and the relationship followed a roughly linear decrease in performance as yaw increased. The effect of lighting significantly interacted with yaw, $F(6,354) = 5.704$, $p < 0.001$, $\omega^2 = 0.073$, such that for small angles of yaw forward lighting led to better performance but for larger angles of yaw the side lit faces were discriminated better. Orientation did not significantly interact with lighting, $F(6,354) = 0.584$, $p = 0.448$, $\omega^2 < 0.001$.

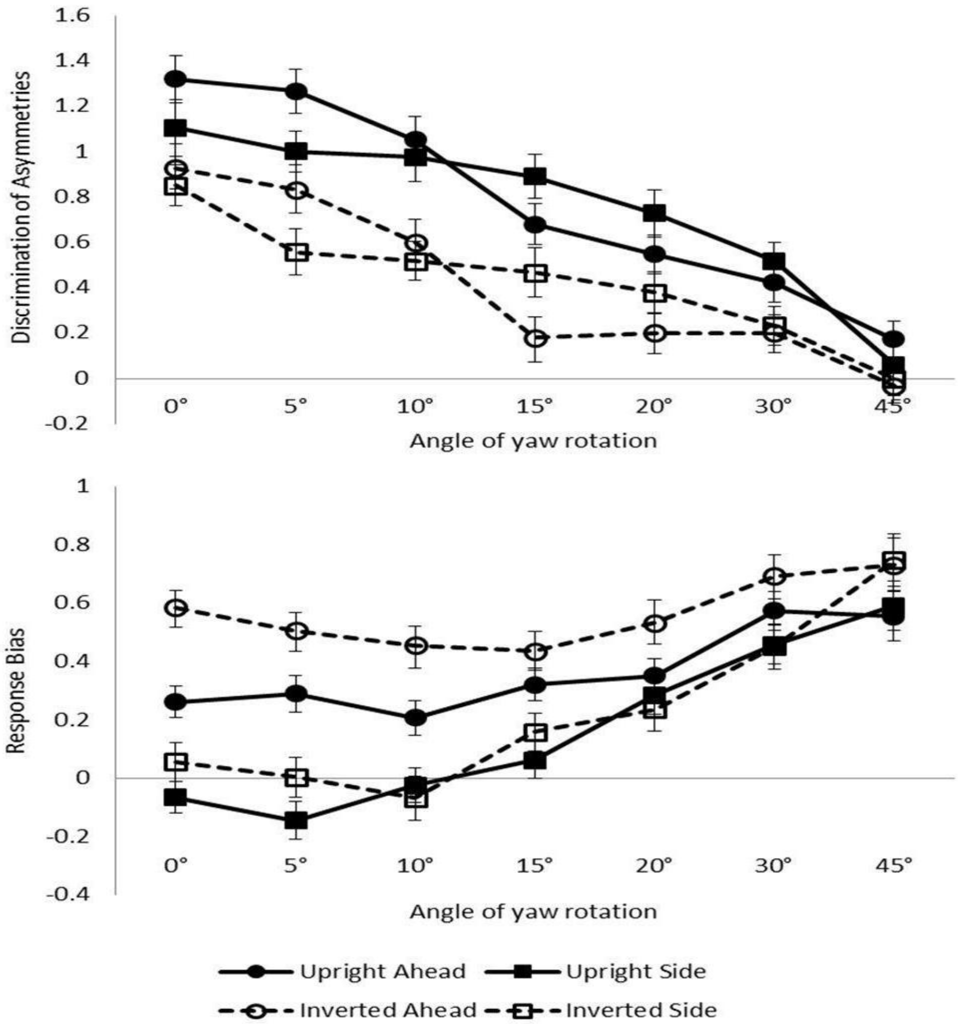

Figure 3. Analysis of performance on the discrimination of asymmetries based on signal detection analysis in Experiment 2. The top panel shows the accuracy of performance whereas the bottom panel shows the response bias with a higher value meaning that the participant is less likely to report an asymmetry. Data points are split according to angle of yaw, whether the image was upright or inverted and whether the lighting was from ahead of the side of the head. Error bars show standard errors.

A second ANOVA was performed on the response biases. A higher response bias means that the participant was less likely to say that a face has an asymmetry. The angle of yaw had a significant effect on the response bias, $F(1,59) = 39.972$, $p < 0.001$, $\omega^2 = 0.382$. Unlike for discrimination, the effect of yaw was nonlinear with a flat pattern up to 15° and then an increase following this. The effects of orientation, $F(1,59) = 19.133$, $p < 0.001$, $\omega^2 = 0.217$, and lighting, $F(1,59) = 146.601$, $p < 0.001$, $\omega^2 = 0.698$, were both significant but these were moderated by an interaction between them, $F(1,59) = 11.534$, $p < 0.001$, $\omega^2 = 0.113$. This interaction can be characterised as there being a stronger effect of inversion when the lighting is from the front rather than from the side. The angle of yaw significantly interacted with lighting, $F(6,354) = 14.389$, $p < 0.001$, $\omega^2 = 0.183$.

3.3. Discussion

The results show that people are able to assess facial symmetry even when the face is not presented frontally and with asymmetrical lighting. Performance on the symmetry detection task was above-chance even at 45 degrees angle of yaw rotation. This is not to say that yaw rotation did not have an effect. Changing the angle of yaw by as little as 10 degrees had a detectable and significant effect on discrimination of asymmetry. Just as Wagemans [34] explained for object asymmetry detection, face asymmetry detection is robust but still susceptible to changes in rotation. Changing from frontal lighting to side lighting did not remove the ability to detect symmetry but it did reduce it. In fact, the reduction caused by the 10 degree yaw rotation was similar in size to the reduction as a result of change in lighting and these effects were not additive. Together, this suggests that this detriment in performance (from discrimination levels of about $d' = 1.3$ to about $d' = 1.1$) represent the loss of the ability to employ pictorial 2D symmetry clues in the symmetry decision either through head rotation or lighting effects.

The effect of inversion on discrimination performance was significant across almost all levels of yaw rotation. The exception was at 45 degrees yaw at which point upright performance was almost at the chance level and so it would not be expected that there would be any further detriment for inversion at this point. This result is consistent with the findings of Little and Jones [12] which showed a reduction in attractiveness preference for symmetry in inverted faces. The explanation for Little and Jones's [12] result, therefore, is not that there is necessarily less of a preference for symmetry when faces are inverted, but asymmetry is harder to detect when the faces are inverted. The fact that performance for asymmetry detection for inverted faces is not at chance helps to understand the findings of Little and Jones [17] who found that inversion did not affect symmetry detection but did affect symmetry preference. The current finding demonstrates that symmetry detection is affected by inversion even if the Little and Jones (2006) task was not sensitive enough to find it.

The analysis of response bias provides an insight into the decision strategies being employed by participants. When the face was upright, frontally presented and with symmetrical lighting, there was a small bias towards a symmetrical response. This bias was reduced if the lighting was asymmetrical suggesting that sometimes the asymmetrical lighting conditions may have been interpreted as facial asymmetries: that is, 2D asymmetries were being interpreted as 3D asymmetries. Inversion increased the symmetry bias suggesting that where an asymmetry could not be located the face was considered symmetrical. This heuristic is further supported by the fact that increased yaw rotation increased the symmetry bias particularly after 15 degrees rotation. In this case, participants were correctly interpreting 2D asymmetries as resulting from 3D rotation but also discounting some 3D asymmetries as being a result of rotation.

As can be seen in Figure 3, there is a clear cross-over in performance between front-lit and side-lit faces as yaw rotation increases. This is present for both upright and inverted faces and so is not a feature of specialised face processing. This pattern can be explained by the fact that the lighting is relative to the viewer rather than the face and so as a face is yaw rotated, it is rotated towards the light source in the side lit condition. After 15 degrees, the rotated face is more evenly illuminated in the side lit condition than the front-lit condition. As such, this cross-over is merely a feature of the stimuli construction rather than a psychological effect.

Finally, there was effect of lighting on both upright and inverted faces as indicated by the lack of a significant interaction. This indicates that the lighting effects on facial asymmetry detection are not special to faces but are a general feature of processing of 3D objects.

4. Conclusions

The current research provides a range of insights into the perception of facial symmetry. The first important finding is that the ability to detect facial symmetry is not restricted to front views of faces. Almost all previous research into facial symmetry has employed images of faces that are orientated directly towards the viewer. These stimuli confound 2D image symmetry with 3D facial symmetry.

By using 2D projections of 3D rendered computer generated faces, the current research was able to disentangle the effects of 2D symmetry and 3D symmetry. As a consequence, this study is the first to demonstrate that typical levels of facial symmetry can be accurately determined at up to 30 degrees and possibly even at 45 degrees of yaw rotation. In these yaw-rotated faces, there is no 2D symmetry, but people have the processing ability to evaluate the symmetry of the 3D form producing the 2D projection. The research also indicates that central lighting is not essential for assessing the symmetry of faces. These findings demonstrate that the evaluation of facial symmetry is not wholly dependent on pictorial 2D symmetry although pictorial symmetry does aid the identification of 3D symmetry. If facial symmetry is to have any real world relevance and hence evolutionary importance it is necessary that 3D symmetry can be assessed quickly and accurately in naturalistic viewing conditions. This study demonstrates that this is the case.

It is possible to make some speculation as to how people are able to make the symmetry judgements of the 3D forms based on the 2D projections. The asymmetries introduced into the stimuli would be both lateral asymmetries and vertical asymmetries. A lateral asymmetry could be something like the nose being not quite central between the eyes or the mouth being slightly left or right of the centre of the face. A vertical asymmetry could be something like one eye being higher than the other or the mouth being slightly angled from the horizontal. Yaw rotation of a face would quickly introduce new lateral asymmetries in the 2D image such that the nose would not be centred between the eyes even if it was in the 3D face. This means that lateral asymmetries would not be useful for detecting asymmetries once the face is yaw rotated and the loss of these would explain the poorer performance for yaw-rotated faces. Vertical asymmetries, however, would still be present for small degrees of yaw rotation. For example, if a mouth is not horizontal when it is in front view, yaw rotating the face will make the angle of this deviation greater. The fact that there is a gradual drop off in symmetry detection performance as yaw angle is increased suggests that people use a combination of lateral asymmetries and vertical asymmetries when evaluating the faces.

The findings with regard to picture-plane rotation reveal important factors about the processing of asymmetry detection. First, it appears that there is more accurate asymmetry detection for upright faces than inverted faces. This demonstrates a face-superiority effect indicating that preference for facial symmetry is not simply a preference for symmetry. Facial symmetry is specifically well analysed and this advantage over non-faces (in this case inverted faces) is consistent across naturalistic viewing. This finding of an inversion effect for symmetry detection is different to the findings of Little & Jones [17]. That earlier study used a 2afc design to assess symmetry detection and it is possible that the choice of task affected the results they obtained. Orthogonal presentation appears to disrupt symmetry detection in ways additional to the loss of this face-superiority effect. Performance is poorer for orthogonal faces than inverted faces only for front views and not yaw-rotated faces. Inverted faces have the advantage of the axis of symmetry being vertical and it appears that changing to a horizontal axis reduces symmetry detection but only that detection that is based on the front view of the face. It can be concluded therefore that the symmetry axis affects the processing of the 2D symmetry of the front-view faces rather than the 3D analysis of the rotated faces.

The picture-plane rotation effects on asymmetry detection are at odds with similar effects in other face processing tasks. Typically it is found that orthogonal rotation produces performance somewhere between that of performance with upright and inverted faces. Given that asymmetry detection performance on orthogonally rotated faces is poorer than on inverted faces, this means that the differences cannot simply be explained in terms of perceptual fluency or ease of processing. The vertical axis does have an important role to play in the assessment of the symmetry of faces.

Of course, one limitation of the research is that the images used were all female looking and European looking. As such, it is possible that the findings do not generalise beyond this type of face. However, as these images were computer generated rather than being real, there is no reason to think that the findings would not be the same had a difference range of base values been used to create the images. Whether this is true is, of course, an empirical question.

In summary, the current research used a signal detection procedure to assess facial symmetry detection with computer generated faces varying the angle of yaw rotation between 0 and 45 degrees and with symmetrical or asymmetrical lighting conditions. Participants showed robust symmetry decisions under natural viewing conditions confirming that previous symmetry detection effects were not a result of 2D picture analysis. Further, inversion and, to a greater extent, orthogonal rotation had a detrimental effect on the ability to detect symmetry in faces.

Conflicts of Interest: The authors declare no conflict of interest.

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