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The role of structural facial asymmetry in asymmetry of peak facial expressions

Karen L. Schmidt
University of Pittsburgh, PA, USA

Yanxi Liu
Carnegie Mellon University, Pittsburgh, PA, USA

Jeffrey F. Cohn
University of Pittsburgh, PA, USA

Asymmetric facial expression is generally attributed to asymmetry in movement, but structural asymmetry in the face may also affect asymmetry of expression. Asymmetry in posed expressions was measured using image-based approaches in digitised sequences of facial expression in 55 individuals, $N = 16$ men, $N = 39$ women. Structural asymmetry (at neutral expression) was higher in men than women and accounted for .54, .62, and .66 of the variance in asymmetry at peak expression for joy, anger, and disgust expressions, respectively. Movement asymmetry (measured by change in pixel values over time) was found, but was unrelated to peak asymmetry in joy or anger expressions over the whole face and in facial subregions relevant to the expression. Movement asymmetry was negatively related to peak asymmetry in disgust expressions. Sidedness of movement asymmetry (defined as the ratio of summed movement on the left to movement on the right) was consistent across emotions within individuals. Sidedness was found only for joy expressions, which had significantly more movement on the left. The significant role of structural asymmetry in asymmetry of emotion expression and the exploration of facial expression asymmetry have important implications for evolutionary interpretations of facial signalling and facial expressions in general.

Address correspondence to: Karen L. Schmidt, Department of Psychiatry, University of Pittsburgh, 121 University Place, Pittsburgh PA 15217, USA. E-mail: kschmidt@pitt.edu

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Asymmetric facial movement has generally been interpreted as the primary source of asymmetry in emotional facial expression (Sackeim, Weiman, & Forman, 1984). The side that moves more is described as corresponding to the more expressive side of the face at peak expression. This is attributed to the effects of functional brain asymmetry on facial muscles, especially during deliberate emotional expression (Sackeim, 1985; Sackeim, Gur, & Saucy, 1978). Human faces, however, are also structurally asymmetric, often with one side larger than the other. Structural asymmetry, approximated by distance from facial landmarks to centre points, ranges from 4% to 12% average difference, depending on the landmark measured (Ferrario, Sforza, Ciusa, Dellavia, & Tartaglia, 2001). It is logical to suggest therefore that structural asymmetry in the face could be a major source of expression asymmetry. Although earlier work found that asymmetry of facial measurements was not related to asymmetry of facial expression (Koff, Borod, & White, 1981; Sackeim et al., 1984), newer and more comprehensive objective measures of the face allow a more detailed analysis of this question.

In this study we used objective quantification of facial asymmetry to describe and evaluate structural, movement, and peak expression asymmetry across three emotion expressions (joy, anger, and disgust). We compared the role of movement asymmetry with the role of structural asymmetry in creating asymmetric emotion expressions, testing the hypothesis that structural asymmetry has a significant role in creating facial asymmetry at peak expression. Finally, we compared the sidedness of expression in three emotion conditions with previously identified values to determine if expressions were left-sided as previously found.

Although the asymmetry of facial expressions of emotion is well established in the literature (Borod, Koff, Yecker, Santschi & Schmidt, 1998), the relative contributions of structural facial asymmetry during emotional expression remain uncertain, since most studies of facial expression either have not measured structural asymmetry or were unable to assess asymmetry at resting neutral.[1] The chimeric approach that compares judgements of expressivity in right/right composite face images to left/left face images relies on judgements of relative expressiveness in peak expression images (Ekman, 1980). In this approach to measuring asymmetry of facial expression, the sides of the face are equally inexpressive at neutral by definition (the face as a whole is neutral). Judgement studies of the resting neutral face have found that perceivers did not differ in their attributions of situational disposition and emotion for different sides of the face (Van Gelder & Borod, 1990). This suggests that emotion in the expressive face chimeras resulted wholly from facial movements during expression.

[1] This is in contrast to studies where participants were asked to "pose neutral" (Borod, Kent, Koff, Martin, & Alpert, 1988).

However, Kowner (1995) found that the neutral left hemiface was viewed as more intense in more cases than the right neutral hemiface (Kowner, 1995). For example, Kowner (1998) found that composite faces constructed using the participants' smaller neutral hemifaces were perceived as revealing more positive and more intense emotion than those constructed of participants' larger neutral hemifaces (Kowner, 1998).

The effects of side-to-side differences in neutral expression are unresolved, as these studies do not compare hemifacial size or other measures of asymmetry in resting faces with the expressiveness of either side of the same face at peak facial expression. Particularly in the case of directional asymmetry, where one entire hemiface is larger than the other, one might reasonably conclude that expression on the larger side would appear more intense than that on the other side of the face. If hemifacial composites reveal differences in intensity of emotion in the neutral face, this suggests that there are significant side-to-side differences in facial structure.

A measurable and perceptible amount of asymmetry characterises the human face at rest, and this structural asymmetry is socially and biologically relevant. Evolutionarily, facial asymmetry (readily visible to interaction partners) has been proposed as a signal of developmental stability that can indicate mate quality (Grammer & Thornhill, 1994; Kowner 2001). In general, the less asymmetric a face is, the more attractive it appears (Grammer, Fink, Moller, & Thornhill, 2003; Grammer & Thornhill, 1994; but see Kowner, 2001, for an alternate view). Evolutionary hypotheses of facial asymmetry based on the concept of fluctuating asymmetry (asymmetries measured in features across the body) have found that the face is asymmetric (Fink, Manning, Neave, & Grammer, 2004; Gangestad & Thornhill, 1997; Grammer & Thornhill, 1994; Hume & Montgomerie, 2001; Namano, Behrend, Harcourt, & Wilson, 2000). This asymmetry is believed to reflect past developmental stresses and to be related to the likely quality of the individual as a potential mating partner (Fink et al., 2004). However, these articles do not address the question of whether or not the asymmetry is primarily directional or sided (for discussion of directional asymmetry see Swaddle & Cuthill, 1995). Rather, they report multiple variable departures from symmetry around a midline.

Two studies that assess the sidedness of the neutral face in holistic fashion, allowing for assessment of directional asymmetry, have found variation in hemifacial size or "facedness" by gender and occupation (Smith, 1998, 2000). Faces of male students and those of professors in academic departments requiring extensive spatial or mathematic ability were larger on the left side on average. Female students and professors in humanities departments were primarily right-faced. In the study of 90 undergraduates, women were found to have larger right faces, and men were found to have larger left faces (Smith, 2000).

The degree of reported structural asymmetry varies across studies in which it has been measured quantitatively rather than holistically. Anatomical measurements of the soft tissue of the face in North Americans have found an overall degree of asymmetry, about 3% in children (Farkas & Cheung, 1981), with greater upper face asymmetry in 18-year-old men than in 18-year-old women. Measurements in this study consisted of the relative position of anatomical landmarks or the length of chords running from laterally placed landmarks on the ear, cheekbones, and lower jaw to landmarks at the centre of the face (Farkas & Cheung, 1981). These measurements provide overall estimates of asymmetry in the different regions of the face, but may not be directly relevant to the focus of the current study on the question of facial expression asymmetry, where appearance changes in features occur more towards the midline of the face. Another study of facial soft tissue found asymmetry ranging from 4% to 12% in three-dimensional landmarks in adults of different ages and genders. There were no significant gender differences observed overall, although results were similar to those of Farkas and Cheung (1981) in that adolescents of both genders had the greatest asymmetry (Ferrario et al., 2001). This study, in contrast to earlier work, relied on a larger number of facial landmarks, with some positioned more to the front of the face, and therefore potentially more relevant to asymmetry change in facial expression.

Several earlier studies have reported the effects of measured structural facial asymmetry on expression asymmetry, as measured through judgements of expression in different sides of the face. Early reports of both structural asymmetry and asymmetric facial expression in the same participants showed no effect of structural asymmetry in a limited set of facial measurements on the judgements of expressivity in chimeric facial expressions (Sackeim, 1985) and on the overall mobility of the sides of the face (Koff et al., 1981). However, structural asymmetry has never been compared to quantitatively measured movement asymmetry in the same individuals, although the possibility that structural asymmetry may play a role in facial expression asymmetry has been suggested (Sackeim, 1985). In addition to finding asymmetry, researchers have found that the face is often asymmetric during facial expression, with one side—most often the left—appearing more expressive (Borod et al., 1998). However, the majority of studies of facial appearance during deliberate expression have found that both positive and negative emotional expressions, as well as non-emotional expressions, are likely to be left-sided (Asthana, 2001; Asthana & Mandal, 1997; Dimberg & Petterson, 2000; Kowner, 1995; Pennock, Johnson, Manders, & VanSwearingen, 1999; Skinner & Mullen, 1991). There is also support for a general left-sided bias for emotion expression in non-human primates (Fernandez-Carriba, Loeches, Morcillo, & Hopkins, 2002; Hauser & Akre, 2001). These data are interpreted as supporting the hypothesis that the right hemisphere dominates the processing of emotion, including emotional expression (Phillips & David, 1997). They are also interpreted as supporting facial movement as the origin of sidedness in facial expression.

The current study is based on the quantitative measure of asymmetry in image sequences that begin with neutral facial expression and end at peak facial expression. These quantitative image-based approaches to the measurement of facial asymmetry are based on computer vision (measurement of pixelwise change in images of the face) and preserve the capability of looking at the whole face while allowing the objective and accurate measure of asymmetry over the course of expression. In a study of pixelwise change in face images during expression, Scriba and coworkers (Scriba, Stoeckli, Pollack, Veraguth, & Fisch, 1999) reported an average of 7–9% movement asymmetry during deliberate expression in individuals of either gender, similar to the values reported in Richardson, Bowers, Bauer, Heilman, and Leonard (2000). O'Grady and Antonyshyn (1999) measured pathological asymmetry in the face using a combination of methods based on the information from three-dimensional scans. Their study primarily provides a comparison of methods for use in plastic surgery, detailing what could be considered normal amounts of facial asymmetry. Both of these studies, however, focus on the asymmetry of facial movement during the course of expression, rather than on the asymmetric appearance of the face at neutral or peak expression.

Asymmetry of peak expression likely represents both the effects of baseline structural facial asymmetry and asymmetry of movement during emotional expression. Although this point has been raised before (Ekman, 1980; Kowner, 1996; Van Gelder & Borod, 1990), newer methods of measurement of the face provide an opportunity to re-address this issue. As acknowledged by earlier researchers, there are several inadequacies in the comparison of facial morphology and expressive asymmetry (Sackeim, 1985). Although studies of facial features and facial size have not shown a correlation with expression asymmetry, they are quite limited in that they used only gross measures of structural asymmetry, such as facial width, hemifacial area, or the distance between facial landmarks. Soft tissue studies of asymmetry in the face tend to focus on landmarks that do not move, for obvious reasons (Farkas & Cheung, 1981). Although this simplifies measurement, these measurements may not be particularly relevant to the changes in the face during expression. Expression asymmetry, for the most part, relies on judgements of the whole face, including moving and non-moving features.

New methods of assessing asymmetry in facial expression allow us to compare baseline facial asymmetry at neutral expression and dynamic asymmetry with asymmetry at peak expression in images comparable to those used in previous studies. Asymmetry in this study was based on measures of pixel differences within frame images and between neutral and peak frames of facial expression image sequences (Liu, Weaver, Schmidt, Serban, & Cohn, 2001; Richardson et al., 2000; for additional complementary approaches, see Grammer et al., 2003). Extending the current emphasis on objective, quantitative measures of facial asymmetry to determine the effects of both baseline structural asymmetry and movement asymmetry on expression appearance allows re-interpretation of the results of previous experiments using classic, yet limited, measurement approaches.

Because the sides of the face are capable of independent voluntary movement, asymmetry is more likely to be apparent during deliberate, rather than spontaneous, expressions (Rinn, 1984; Ross & Mathiesen, 1998). The prediction of asymmetry in deliberate expressions is supported by the findings that laterality in observable facial actions, although inconsistent as to side, is increased in deliberate as compared to spontaneous expression (Hager & Ekman, 1997). We focused on deliberate rather than spontaneous expression in the current study because of the likelihood of greater variation in side-to-side asymmetry. This variation allowed for testing the differing roles of structural and movement asymmetry on peak facial expression asymmetry.

Overall movement asymmetry in this group of participants, as well as the sidedness of emotion expressions, was also measured and compared with previously obtained studies that utilised similar methods. Due to previous reports of gender differences in structural asymmetry (Farkas & Cheung, 1981), we expected that men and women in our sample would differ in asymmetry at neutral expression, and possibly also during movement and at peak expression.

The model of asymmetry in facial expression tested in this article proposes that the asymmetry in the face at peak is dependent on the asymmetry of the baseline neutral face as well as asymmetric movement occurring over the course of the expression. Using measured asymmetry, we then determined the relative contribution of movement (facial expression itself) and baseline asymmetry in the face (general trait asymmetry) in producing asymmetry at peak expression. Given the documented existence of structural facial asymmetry at rest, we predicted that this variable would account for a significant portion of the variance in asymmetry at peak expression. Finally, we explored the sidedness of emotion expression by comparing the total amount of movement on the right and left sides of the face.

METHOD, SAMPLE, AND PROCEDURES

Deliberate facial expressions

Original deliberate expression sequences used in this study were collected as part of a directed facial action task (Kanade, Cohn, & Tian, 2000).

Participants were seated in front of uniform grey background. The frontal camera was located at 180 degrees to the participant's face, participants were instructed to look directly at the camera, and both camera and participant were positioned in the direct frontal orientation before videotaping began. Participants were instructed by an experimenter to perform a series of 23 facial displays; these included single action units and emotion-specified expressions of joy, surprise, anger, disgust, fear, and sadness.

Image sequences were recorded using two synchronised S-VHS cameras and studio lighting. Videotape used in the current study originated from the camera positioned directly in front of the participant. Image sequences were digitised at 30 frames per second into 640 by 480 pixel arrays with 8-bit greyscale resolution.

Expression sequences were coded for facial actions by certified FACS coders (Ekman & Friesen, 1978), and on the basis of these codes, sequences were truncated to include neutral to peak expression only. Reliability of coding for peak expression was established in this sample at kappa $= 0.86$. Only image sequences from the frontal camera are used in this report. Data for three expressions (joy, anger, and disgust) were available from 55 participants ($n = 16$ men, $n = 39$ women) and these formed the data set for this study (see Figure 1 for examples of these expressions). The participants were young adults (ranging in age from 18 to 30) and a majority reported white or European ancestry ($n = 50$). The expressions (joy, anger, disgust) were chosen because they represented variation along two dimensions of affect: approach–withdrawal (joy and anger versus disgust; Davidson, Ekman, Saron, Senulis, & Friesen, 1990) and positive and negative valence (joy versus anger and disgust; Russell, 1980).

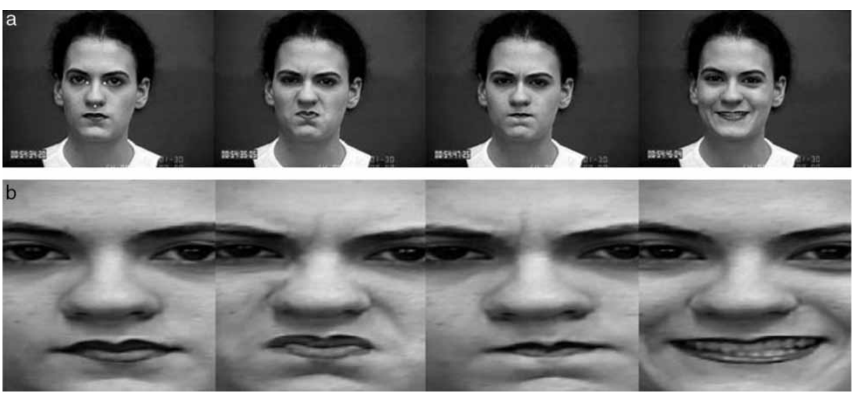

Figure 1. (a) Examples of neutral, disgust, anger, and joy images (640 × 480 pixels) from the Cohn Kanade database (Kanade et al., 2000). Feature tracking points are marked in the neutral image, as an example. (b) Examples of normalised neutral, disgust, anger, and joy images (128 × 128 pixels).

Measuring asymmetry in expression video sequences

To address the problem of potentially asymmetric lighting in the videotaped images, we used the measured luminance of the original image background (pre-normalisation); this was uniform for all participants, to control for any asymmetry in lighting. One neutral frame from each individual participant was used for this analysis. Luminance differences between left and right sides of the images were calculated from sample squares (80×80 pixels) of the original images' upper left and upper right corners. The background of the original images rather than the part of the image including the face was used. This is in contrast to the asymmetry of luminance of the face measured in Richardson et al. (2000), which includes not only asymmetry introduced by lighting, but also asymmetry introduced by the face itself. In this study, values for the background luminance difference for each individual were used to control for the effects of unequal lighting on facial asymmetry values (see method described below).

Only individuals whose frontal view showed all facial landmarks clearly (none obscured by other parts of the face) and with only minor deviation of head position (<5 degrees) from 180 degrees were included in the study. Reliance on eye gaze and physical head positioning at 180 degrees to the frontal camera may have introduced slight posing asymmetry into the sample. Head restraints were not used in the study in order to provide a more naturalistic pose. However, the greatest potential contribution of slight asymmetry in positioning was addressed by controlling for illumination differences side-to-side and through the normalisation process.

To remove the effects of spatial variation in face position and any slight head rotation, images were aligned and normalised prior to analysis. Three facial feature points were manually marked in the initial image of each sequence: the medial canthus of each eye and the uppermost point of the philtrum (base of the nasal septum). Because the normalisation process is designed to be used with a series of computer-tracked still images from a video (automated facial analysis), the physical stability of the landmarks on the face and the clarity of the points in the image were critical. These points were chosen because of their relative immobility during the course of facial expression and their distinctiveness as features within the image. Using an affine transformation, the images were then automatically mapped to a standard face model based on these feature points.[2] In this standard face model, the midline of the face was determined by the line running from the

[2] Expression sequences were tracked using an automated facial feature-tracking program (Cohn, Zlochower, Lien, & Kanade, 1999; Tian, Kanade, & Cohn, 2001) to follow the inner eye corners and the superior edge of the philtrum (top centre upper lip) automatically and provide points for standardisation of images (see Figure 1 for an example).

philtrum to the midpoint of the line between the two canthi (Liu, Schmidt, Cohn, & Mitra, 2003). A normalised face image (128×128 pixels) was produced, with row 48 of each normalised image defined as the inner eye corner (inner canthus) row and row 84 defined as the philtrum row. By automatically controlling for face position, orientation, and scale within the image in this initial processing step, asymmetry measures in each frame had exact geometric correspondence. This process allows the comparison of face images from different individuals, while preserving asymmetry inherent in the faces. Asymmetry was preserved, as values for individual pixels were not changed but affine transformed into the standard frame (128×128 pixels). Normalised face images were then processed and asymmetry scores were calculated for each row of the image.

Calculating structural (neutral) and peak asymmetry

The centre of image was identified (between pixel 64 and pixel 65 in each row) and pixels were measured in pairs, each pixel on the right paired with the corresponding pixel on the left side of the image (see Figure 2 for examples of paired pixels). Pixel difference scores (absolute values) were calculated for each pair of pixels, based on individual pixel intensity values (range: 0–255). These pixel pair difference values were summed by row, and data were smoothed based on these row values. For purposes of these analyses, row values were then summed over rows 20–128 of the face image

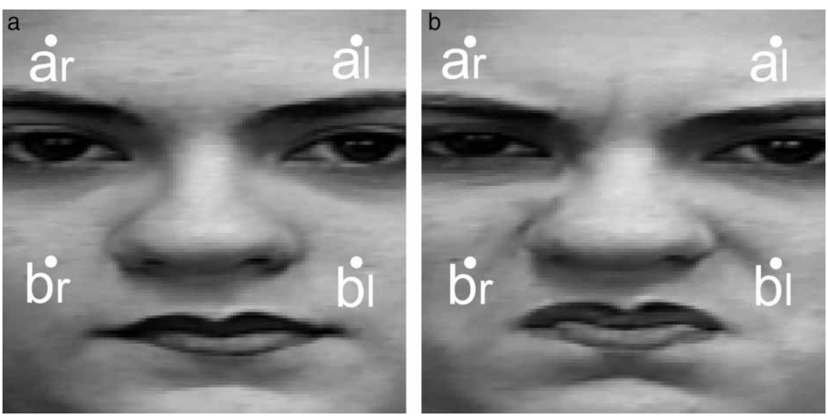

Figure 2. Measuring structural and peak asymmetry. In neutral frame, the absolute difference in intensity between a pixel (a_r) and the corresponding pixel on the opposite side (a_l) is measured. The sum of these differences for the whole image (N = 8192 pixel pairs) produces a measure of structural asymmetry (S). $S = |a_r - a_l| + |b_r - b_l| + \ldots + |x_r - x_l|$. In the peak frame, pixel difference is calculated in the same way, providing a measure of peak expression asymmetry (P).

for the whole face and rows 20–48 (upper face), rows 49–84 (midface), and rows 85–128 (lower face) separately for analyses of different facial subregions. Earlier studies have suggested that the innervation of the upper face (muscles located above the upper brow) is more bilateral than the innervation of the lower face (Rinn, 1984). Subregions were chosen to allow the separate analysis of upper versus mid or lower face, while tying data analysis to anatomically identifiable landmarks (inner canthi, philtrum). Data from the first 19 rows of each image were omitted because of the presence of hair in the normalised images of several of the participants. Values of pixel pair difference at neutral and at peak frames for rows 20–128 and for separate facial subregions were analysed with respect to independent variables such as gender and type of emotion expressed (joy, anger, or disgust). The most relevant facial subregions (those identified as involving major muscle activity in that region) for each emotion expression were also analysed (brow lowering in upper face for anger, nose wrinkling in midface for disgust, and lip movement in lower face for joy; Ekman & Friesen, 1978). These values constitute the neutral (structural) and peak asymmetry of the face.

Because structural and peak asymmetry were calculated from the sum of differences between the sides of the face, both were directly affected by luminance differences. Linear regression of whole face asymmetry scores on luminance difference scores (as described above) was performed on neutral (structural) and peak expression values, and residuals values were recorded. Regression analyses confirmed the effect of side-to-side luminance difference on asymmetry scores for joy, $F(1, 53) = 4.766$, $p = .03$, $F(1, 53) = 8.156$, $p = .006$ for structural and peak, respectively; anger $F(1, 53) = 5.647$, $p = .02$, $F(1, 53) = 5.564$, $p = .02$ for structural and peak, respectively; and disgust $F(1, 53) = 9.366$, $p = .003$, $F(1, 53) = 16.312$, $p = .0002$ for structural and peak, respectively. Therefore, for further analyses, only the residual values of structural and peak asymmetry scores were used, representing asymmetry not accounted for by luminance differences. Facial subregion scores for structural and peak asymmetry were residualised in the same manner.

Movement asymmetry was assessed using a measure of within-side pixel intensity change. In this case, the pixel change is the difference in intensity values of the same pixel, from frame to frame over the course of neutral-to-peak progression of the expression (see Figure 3). Absolute values of pixel change that were summed separately for each side of the face in each frame from neutral to peak represent the cumulative movement of the face during emotion expression, similar to calculation of entropy in Richardson et al. (2000). This procedure was performed separately on left and right sides of the face image, with pixels 1–64 in each row defined as the right side of the face (image left), and pixels 65–128 in each row defined as the left side of the face (image right). Because movement asymmetry was calculated separately

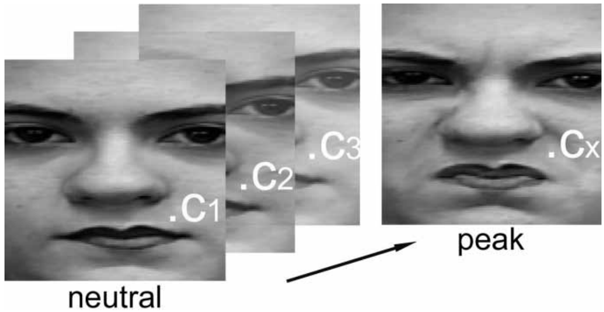

Figure 3. Measuring movement asymmetry. The change in pixel intensity (absolute value) is measured for each pixel (c) from frame to frame throughout the image sequence. For a single pixel, c, over n frames, movement $M_c = (|c_2 - c_1| + |c_3 - c_2| + |c_4 - c_3| + \ldots + |c_n - c_{n-1}|)$. Movement values are summed for all pixels on the left side, $L = (M_c + \ldots + M_x)$, and for all pixels on the right side of the image, giving a measure of movement (change) for each side of the image over time (L or R).

within left and right sides of the face image, there was no need to control for any asymmetry in luminance between the two sides. For comparison with previously published values, the proportional movement asymmetry was calculated by dividing the cumulative movement score of the less active side by the cumulative movement of the more active side. Values for movement asymmetry within upper, mid, and lower face subregions were also calculated. Sidedness of individual participants' facial movement was calculated as the ratio of left-sided movement to right-sided movement, in contrast to the variable proportional movement asymmetry, which was calculated as the ratio of the side with less movement to the side with more movement. As a result, sidedness values of less than or greater than 1.00 were obtained, where proportional movement asymmetry was always less than 1.00.

Data analysis

Individual consistency in structural asymmetry was investigated using coefficient alpha across the three emotion expressions to establish the suitability of the structural asymmetry measure for representing underlying anatomical asymmetry. The effects of emotion displayed (joy, anger, or disgust) and gender on structural, movement, and peak expression asymmetry were investigated using three separate repeated measures analyses of variance. In order to determine whether or not facial movement was asymmetric, and therefore a potential contributor to peak emotion asymmetry, the tendency of individual people to display more movement on one side of the face was tested by comparing the proportional asymmetry values to a standard of 1.00 (perfectly symmetric motion).

The central hypothesis that structural asymmetry has a significant role in creating asymmetry at peak expression was addressed using separate hierarchical regression analyses for each emotion condition. Predictors of peak asymmetry were structural asymmetry and movement asymmetry. To address the possible contribution of relatively immobile parts of the face to the effect of structural on peak asymmetry overall, separate regression analyses were conducted on individual facial subregions showing the most movement for each separate emotion: lower face for joy, upper face for anger, midface for disgust.

In follow-up analyses we examined the consistency of individual sidedness of expression (tendency of individual people to display more movement on one side of the face) using coefficient alpha. To determine whether gender of participant contributed to differences in sidedness of emotion expression, chi-square tests were used to investigate the proportion of left- versus right-sided expressions in men and women in each of three emotional expression categories (joy, anger, disgust). Overall sidedness of emotion expressions (joy, anger, disgust) was investigated by computing sidedness values as left movement divided by right movement (R/L) and comparing asymmetry values to a standard of 1.00.

RESULTS

Individual consistency of structural asymmetry across emotion conditions

In defining structural asymmetry as asymmetry at neutral expression, it was important to establish that these values were comparable across emotions (joy, anger, disgust) for each participant. Within participants, overall facial asymmetry at neutral expression was reliable with alpha = 0.90, $F(55, 108) = 10.05$, $p < .001$.

Structural, movement, and peak asymmetry

Results of repeated measures analyses of variance showed that differences in asymmetry between men and women were significant across emotion conditions, but that emotion and the interaction between emotion and gender did not significantly affect variation in asymmetry. Men had significantly higher values for both structural and peak overall asymmetry than did women, $F(1, 53) = 7.911$, $p = .007$, observed power = .79; $F(1, 53) = 8.967$, $p = .004$, observed power = .84, for structural and peak asymmetry, respectively. There was no gender difference in overall movement asymmetry, $F(1, 53) = .291$, $p = .592$, observed power = .083. Main effects of emotion on structural, movement, and peak asymmetry, and the interaction between independent variables (gender, emotion) were not significant (all $p > .10$).[3]

The average proportional overall movement asymmetry values were .92, .92, and .90 for joy, anger, and disgust respectively. Proportional movement asymmetry for all three expressions was well within the range found by Scriba et al. (1999) for a set of expressions including joy (smiling) and non-emotional expressions. It was also comparable to that found by Richardson et al. (2000) (see Table 1). Movement asymmetry was more apparent for each of the different emotion expressions in the relevant facial subregions as expected: .88, .91, and .88, for joy (rows 85–128), anger (rows 20–48), and disgust (rows 49–84), respectively.

TABLE 1
Mean values of asymmetry in emotion expressions

Emotion	*Group*	*Asymmetry*	*S*	*P*	*M*
Joy	Men	*M*	185.5	143.8	0.92
		SD	294.0	253.1	0.04
	Women	*M*	−76.1	−59.0	0.92
		SD	240.1	283.1	0.05
	Total	*M*	0	0	0.92
		SD	281.0	287.8	0.05
Anger	Men	*M*	121.3	80.7	0.92
		SD	196.9	142.5	0.06
	Women	*M*	−49.8	−33.1	0.93
		SD	284.6	260.7	0.05
	Total	*M*	0	0	0.93
		SD	271.9	237.0	0.06
Disgust	Men	*M*	111.9	139.4	0.90
		SD	211.9	225.7	0.11
	Women	*M*	−45.9	−57.2	0.91
		SD	279.0	260.9	0.07
	Total	*M*	0	0	0.91
		SD	269.2	264.9	0.08

Mean values of structural (S) and peak (P) asymmetry (residual of summed average pixel difference), and movement (M) asymmetry (side-to-side ratio of pixel change) in emotion expressions.

[3] When outliers for structural asymmetry were removed ($n = 1$ woman and $n = 2$ men with values in excess of the 95% confidence interval), analyses of gender differences in structural, peak, and movement asymmetry across three emotion conditions showed the same results as the full sample. Men in the restricted sample ($n = 52$) had higher values for structural and peak asymmetry, $F(1, 50) = 6.12$, $p = .017$, observed power = .680; $F(1, 50) = 5.70$, $p = .021$, observed power = .649, structural and peak asymmetry, respectively. There was no difference in overall movement asymmetry, $F(1, 50) = .497$, $p = .484$, observed power = .106.

TABLE 2
Regression analyses

Emotion	*Variables*	*B*	*SE B*	*β*
Joy	Structural	.762	.096	.741***
	Movement	149.2	557.0	.025
Anger	Structural	.694	.074	.796***
	Movement	24.9	358.3	.006
Disgust	Structural	.783	.081	.796***
	Movement	−272.6	267.1	−.084

Regression analyses for variables predicting peak asymmetry in three emotion expressions (joy, anger, disgust).
$R^2 = .53$ for Joy; $R^2 = .62$ for Anger; $R^2 = .67$ for Disgust.
*$p < .05$, ** $p < .01$, *** $p < .001$.

The tendency of individual people to display more movement on one side of the face was tested by comparing the proportional asymmetry values to a standard of 1.00 (perfectly symmetric motion). As expected for deliberate expressions, overall movement asymmetry values differed significantly from 1.00, $t(54) = -1.8$, $t(54) = -9.7$, $t(54) = -8.6$, for joy, anger, and disgust, respectively. See Table 1 for mean movement asymmetry values. Sidedness was not calculated for facial subregions as overall asymmetry is most comparable to previous judgement studies of facial sidedness.

Relative contributions of structural and movement asymmetry to expression asymmetry at peak

Hierarchical regression analysis of the relationships among structural asymmetry, movement asymmetry, and peak expression asymmetry showed that structural asymmetry explained a significant amount of the variance in peak expression asymmetry for all three emotion expressions. Adjusted R^2 values were .53, .62, and .67 for effects of structural asymmetry on peak asymmetry in joy, anger, and disgust, respectively. Overall movement asymmetry, in contrast, did not make a statistically significant contribution to variance in peak expression asymmetry, within the context of these regression analyses (see Figure 4 for examples of individual regression lines of peak anger asymmetry on structural and movement asymmetry, respectively).

Separate hierarchical regression analyses were conducted for lower, upper, and midface subregions for joy, anger, and disgust expressions, respectively. Structural asymmetry accounted for a significant amount of the variance in peak expression within the relevant facial subregions for each expression. Adjusted R^2 values were .29, .36, and .80 for effects of structural asymmetry

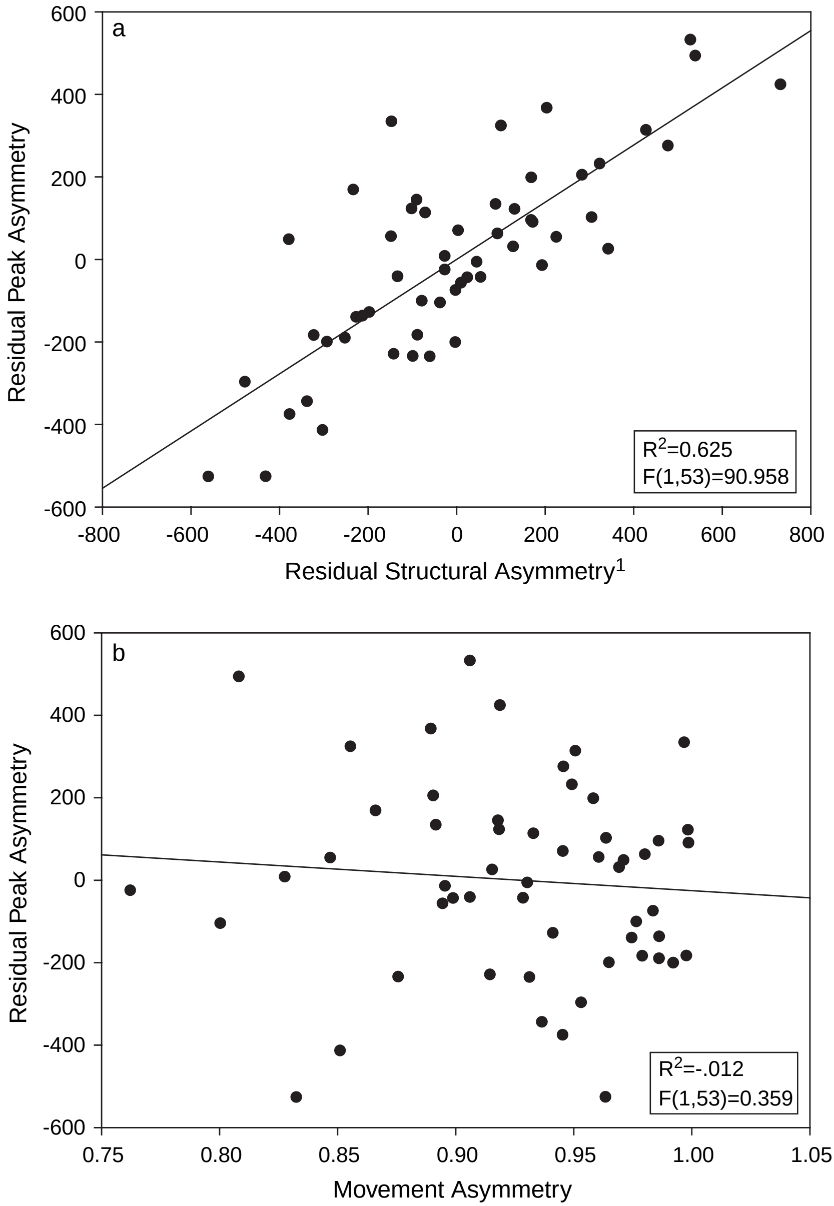

Figure 4. Sources of peak asymmetry in expression of anger. (a) Structural asymmetry and peak asymmetry ([1]structural and peak asymmetry values are residuals of summed average pixel difference following removal of effects of luminance asymmetry). (b) Movement asymmetry (side-to-side ratio of pixel change) and peak asymmetry (summed average pixel difference at peak expression).

on peak asymmetry for joy (lower face), anger (upper face), and disgust (midface). Subregion movement asymmetry did not contribute significantly to the variance of asymmetry in the subregion at peak expression for joy and anger expressions (all $p > .4$). There was a trend towards significance of midface movement asymmetry in peak asymmetry in the midface of disgust expressions ($p = .05$).

Sidedness of movement in expression

The sidedness of facial movement, based on the ratio of accumulated pixel change on the left to accumulated pixel change on the right, was determined for each individual's expression. For an analysis of consistency of sidedness within individuals, values greater than 1 were recoded as left-sided and values less than 1 were recoded as right-sided. Individual participants exhibited greater movement on either left or right, which was largely consistent across the three emotion expressions, alpha = 0.80; $N = 55$.

Between-participants analyses showed that the numbers of individuals with left-sided or right-sided expressions for each emotional expression varied. Of 17 men tested, 11 (65%) displayed left-sided joy and anger expressions, and 12 (71%) displayed left-sided disgust expressions. Of 41 women tested, a majority also displayed left-sided expressions: $n = 29$ (71%), $n = 24$ (59%), and $n = 23$ (56%) for joy, anger, and disgust, respectively. However, chi-square tests of the frequency of left- versus right-sided expressions in men and women were non-significant in each of three emotional expression categories, $\chi^2(1) = 0.20$, $\chi^2(1) = 0.19$, and $\chi^2(1) = 1.05$ for joy, anger, and disgust, respectively.

The sidedness of specific emotion expressions overall was also investigated. Posed emotion expressions had overall mean sidedness values of 1.04, 1.01, and 1.02 for joy, anger, and disgust, respectively. All emotion expressions were left-sided on average, although only sidedness for joy was significantly different from 1.00, $t(57) = 3.34$, $p = .001$, $t(57) = 1.62$, $p = .11$, $t(57) = 1.28$, $p = .21$ for joy, anger, and disgust, respectively.

DISCUSSION

The comparison of movement and structural asymmetry in these posed expressions indicates that the appearance of asymmetry at the peak of facial expression is significantly related to the amount of asymmetry in a neutral pose. Movement asymmetry results support this finding, in that side-to-side differences in movement during expression did not significantly contribute to increasing asymmetry at peak expression. Asymmetry of overall movement in disgust expressions even appeared to decrease asymmetry at peak.

Subregions were analysed as a way to explore variation in the structural/peak asymmetry relation in the context of greater amounts of facial movement during emotion expression. Similar results were found for facial subregions that were likely to have shown the most movement for each emotion. An exception was disgust, in which both structural and movement asymmetry were associated with peak expression asymmetry. This result is surprising, given earlier reports of the non-significance of structural facial asymmetry, but may provide an explanation for the varying experimental results that have found left-, right-, or non-sidedness in posed expressions in the past (Borod et al., 1998). The results for the amount of asymmetry within individuals are very similar to those obtained using similar quantitative methods, and are therefore likely to represent normally occurring amounts of asymmetry in the face, both at rest and during expression (Richardson et al., 2000; Scriba et al., 1999).

Asymmetry in judgement studies is fairly clear, with the left side predominating. Asymmetry in studies using more objective quantitative methods is less clear. Richardson et al. (2000) found that left was dominant on the lower face, but not upper, a result reinforcing a similar earlier finding of Asthana and Mandal (1997), who used judgement-based data. Scriba et al. (1999) found that the left side moved slightly more on average, though non-significantly, although neither side was dominant in the group as a whole. In a quantitative study using three-dimensional measures of sidedness of expression, movement was found to be greater on the left for both sad and happy expressions (Nicholls, Ellis, & Clement, 2004). An additional quantitative study, focusing on eyebrow movements only, found an average sidedness movement (displacement) asymmetry of 1.05 ($SD = 0.13$) in normals during deliberate brow raising (Bajaj-Luthra, Mueller, & Johnson, 1997). Pennock et al. (1999) found an average proportional movement (displacement) asymmetry of .83, with 13 of 16 individuals studied showing greater activity of the left brow. Results of both studies were comparable to sidedness and proportional movement asymmetry values reported here. The asymmetry of motion observed could potentially be accounted for by structural anatomical differences among individuals in either case. If movements are primarily left-sided, it could be that faces are primarily left-sided to begin with.

The advantage of the methods used in this study is that the degree of asymmetry during neutral expression can be assessed, as well as the degree of movement asymmetry. A limitation is that the description of a face as left-sided cannot be obtained using quantitative methods described here for the neutral (structural) face.

We did find that the face moved slightly more on the left (more pixel change) over the course of expression, although this left-sided advantage was relatively weak across individuals and expressions, with the ratio of left to right movement of 1.04, 1.01, and 1.02 for joy, disgust, and anger expressions. Only joy was significantly different from 1. These values for sidedness were similar to those of Scriba et al. (1999) who used similar, whole face methods to determine dynamic asymmetry (left–right asymmetry) during expression. However, smiles measured in their study were not significantly left- or right-sided (average left to right movement ratio = 1.01), while joy expressions in this study did have significantly more movement on the left side. To the extent that participants turned their faces slightly to one side or another despite the positioning at 180 degrees to the frontal camera, the normalisation procedures, and the controls in place for side-to-side illumination differences, it is possible that there may have been subtle effects on asymmetry measures. Posing differences from 180 degrees were apparently slight, and in none of the participants were facial features obscured by the turning of the head to the side (any slight posing differences were within 5 degrees of frontal). Additionally, the central portions of the face, which were the focus of this investigation, were adequately represented in all participant video frames and no systematic sidedness differences related to posing differences were identified.

At neutral and peak expression, men were more asymmetrical than were women, consistent with the work of Farkas and Cheung (1981) with adolescents. This is not surprising, since the college-age sample in this study is close in age to the 18-year-olds in the previous study, although the relatively small number of men in the current study limits interpretation of the gender differences described. Movement asymmetry, however, was not significantly different for men and women in the current sample, consistent with findings based on much larger samples (Borod et al., 1998).

The size and significance of the effect of structural asymmetry on asymmetry of the face at peak in these data confirms the importance of considering the role of baseline structural asymmetry in facial expression. Although movement asymmetry and sidedness of facial expressions were observed and appeared similar to asymmetry as described in comparable studies, asymmetric movement does not seem to have a consistent effect on the asymmetry of the face at peak expression. In some individuals, the appearance of facial asymmetry was reduced by the movements of facial expression, where in other cases apparent asymmetry was increased.

Overall, the total amount of facial movement was very similar between the sides of the face, even in the deliberate facial expressions described here. The relatively small differences between left- and right-sided movement in the face, even in posed expressions, suggest that the differences in neural control of the face are not as great as has been suggested. Although the face at peak expression was asymmetric, we conclude that this asymmetry cannot be related to the unequal movement of the different sides of the face. Left-sided change was, on average, only about 2% greater than right-sided change overall. However, this amount may still be perceptually significant, especially when one considers the perceptual bias towards looking first at the left face (Mertens, Siegmund, & Gruesser, 1993; Phillips & David, 1997; Schirillo, 2000). A tendency to look first at the side that has more movement could be an adaptation for nonverbal communication. This issue can be resolved with future study of the perception of these faces.

Additionally, the relation between perception of emotion and amount of movement in expression may require a more complex understanding of the role of movement asymmetry in emotion perception. A recent study showed that although movement in the happy and sad expressions was greater on the left, observers rated emotion in each hemiface differently. Sad expressions were perceived as sadder in the left hemiface and joyful expressions as more joyful in the right hemiface, despite the fact that expressions had both shown greater movement on the left (Nicholls et al., 2004).

By providing a baseline and objective data we have investigated the relative importance of facial movement asymmetry in creating asymmetry of the resulting expression. Theories of brain asymmetry for emotion depend in part on data from facial expression judgement studies implying that expressions appear stronger on one side because of differential movement of the face on that side. If movement is not the only major contributor to asymmetry of expression, then facial expression data can no longer be interpreted as strong support for theories of neurobiological emotional asymmetry.

Asymmetry in the face and its relationship to attractiveness has been studied extensively in recent years (Mealey, Bridgstock, & Townsend, 1999). Because of the congruence of asymmetry values reported here with those from other quantitative studies of facially normal individuals, an implication of this work is that a range of normal levels of expression asymmetry could be quantified and used as a screen for developmental or other clinical problems (Lahat, Heyman, Barkay, & Goldberg, 2000; Nakamura, Okamoto, & Maruyama, 2001).

Within the range of normal asymmetry, there are also implications for the role of asymmetry in facial signalling. The possibility that facial expressions provide a potential method for increasing symmetry has not been discussed. If, as suggested by these results, the face can actually become less asymmetrical in appearance during expression, then facial expression may act to increase symmetry and ultimately to increase attractiveness in some individuals. This perspective expands on and provides a dynamic view on current notions of asymmetry as a reliable trait marker of developmental disruption (Gangestad & Thornhill, 1997; Grammer & Thornhill, 1994; Rhodes, Proffitt, Grady, & Sumich, 1998). In most natural environments, attractiveness would be decided during social interaction, a context in which facial expression is typical. Variation in the ability of individuals to increase, consciously or unconsciously, the symmetry of expression in deliberate facial expression has important implications for evolutionary signalling hypotheses such as Brown and Moore's work concerning facial signals of altruistic intent (Brown & Moore, 2002; Schmidt & Cohn, 2001).

Nevertheless, the strength of structural asymmetry as a predictor of peak expression asymmetry reinforces the status of facial asymmetry as a reliable marker of mate quality, even during facial expression. More detailed study of faces, both at rest and in expression, would help to distinguish the contribution of structural asymmetry and the strategies adopted by raters in viewing either still or moving asymmetric faces.

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REFERENCES

Asthana, H. (2001). Hemiregional facial asymmetry in expression of emotion: A concept needs to be verified. *Perceptual and Motor Skills*, *93*, 690–692.

Asthana, H., & Mandal, M. (1997). Hemiregional variations in facial expressions of emotions. *British Journal of Psychology*, *88*, 519–525.

Bajaj-Luthra, A., Mueller, T., & Johnson, P. (1997). Quantitative analysis of facial motion components: Anatomic and nonanatomic motion in normal persons and in patients with complete facial paralysis. *Plastic and Reconstructive Surgery*, *99*, 1894–1902.

Borod, J. C., Kent, J., Koff, E., Martin, C., & Alpert, M. (1988). Facial asymmetry while posing positive and negative emotions: Support for the right hemisphere hypothesis. *Neuropsychologia*, *26*(5), 759–764.

Borod, J. C., Koff, E., Yecker, S., Santschi, C., & Schmidt, J. M. (1998). Facial asymmetry during emotional expression: Gender, valence and measurement technique. *Psychophysiology*, *36*, 1209–1215.

Brown, W. M., & Moore, C. (2002). Smile asymmetries and reputation as reliable indicators of likelihood to cooperate: An evolutionary analysis. In S. Shohov (Ed.), *Advances in psychology research* (Vol. 11 pp. 59–78). Huntington, NY: Nova Science Publishers.

Cohn, J. F., Zlochower, A., Lien, J., & Kanade, T. (1999). Automated face analysis by feature point tracking has high concurrent validity with manual FACS coding. *Psychophysiology*, *36*, 35–43.

Davidson, R., Ekman, P., Saron, C., Senulis, J., & Friesen, W. (1990). Approach–withdrawal and cerebral asymmetry: Emotional expression and brain physiology. *Journal of Personality and Social Psychology*, *58*, 330–341.

Dimberg, U., & Petterson, M. (2000). Facial reactions to happy and angry facial expressions: Evidence for right hemisphere dominance. *Psychophysiology*, *37*(5), 693–696.

Ekman, P. (1980). Asymmetry in facial expression. *Science*, *209*, 833–834.

Ekman, P., & Friesen, W. V. (1978). *Facial Action Coding System*. Palo Alto, CA: Consulting Psychologists Press.

Farkas, L. G., & Cheung, G. (1981). Facial asymmetry in healthy North American caucasians. *Angle Orthodontist*, *51*, 70–77.

Fernandez-Carriba, S., Loeches, A., Morcillo, A., & Hopkins, W. (2002). Asymmetry in facial expressions of emotion by chimpanzees. *Neuropsychologia*, *40*, 1523–1533.

Ferrario, V., Sforza, C., Ciusa, V., Dellavia, C., & Tartaglia, G. (2001). The effect of sex and age on facial asymmetry in healthy participants: A cross-sectional study from adolescence to mid-adulthood. *Journal of Oral and Maxillofacial Surgery*, *59*, 382–388.

Fink, B., Manning, J. T., Neave, N., & Grammer, K. (2004). Second to fourth digit ratio and facial asymmetry. *Evolution and Human Behavior*, *25*, 125–132.

Gangestad, S. W., & Thornhill, R. (1997). Human sexual selection and developmental stability. In J. A. Simpson & D. T. Kenrick (Eds.), *Evolutionary social psychology* (pp. 169–196). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Grammer, K., Fink, B., Moller, A. P., & Thornhill, R. (2003). Darwinian aesthetics: Sexual selection and the biology of beauty. *Biological Review*, *78*, 385–407.

Grammer, K., & Thornhill, R. (1994). Human (*Homo sapiens*) facial attractiveness and sexual selection: The role of symmetry and averageness. *Journal of Comparative Psychology*, *108*, 233–242.

Hager, J. C., & Ekman, P. (1997). The asymmetry of facial actions is inconsistent with models of hemispheric specialization. In P. Ekman & E. Rosenberg (Eds.), *What the face reveals* (pp. 40–62). New York: Oxford University Press.

Hauser, M. D., & Akre, K. (2001). Asymmetries in the timing of facial and vocal expressions by rhesus monkeys: Implications for hemispheric specialization. *Animal Behaviour*, *61*, 391–400.

Hume, D. K., & Montgomerie, R. (2001). Facial attractiveness signals different aspects of "quality" in women and men. *Evolution and Human Behavior*, *22*, 93–112.

Kanade, T., Cohn, J. F., & Tian, Y. (2000). Comprehensive database for facial expression analysis. *Proceedings of the Fourth IEEE International Conference on Automatic Face and Gesture Recognition (FG'00)* (pp. 46–53), Grenoble, France: Institute of Electrical & Electronics Engineers.

Koff, E., Borod, J. C., & White, B. (1981). Asymmetries for hemiface size and mobility. *Neuropsychologia*, *19*(6), 825–830.

Kowner, R. (1995). Laterality in facial expressions and its effect on attributions of emotion and personality. *Neuropsychologia*, *33*, 539–559.

Kowner, R. (1996). Facial asymmetry and attractiveness judgement in developmental perspective. *Journal of Experimental Psychology: Human Perception and Performance*, *22*(3), 525–529.

Kowner, R. (1998). Perceiving and attributing hemispheric width in faces of normal adults. *Perceptual and Motor Skills*, *87*, 567–572.

Kowner, R. (2001). Psychological perspective on developmental stability and fluctuating asymmetry: Sources, applications, and implications. *British Journal of Psychology*, *92*, 447–469.

Lahat, E., Heyman, E., Barkay, A., & Goldberg, M. (2000). Asymmetric crying faces and associated congenital anomalies: Prospective study and review of the literature. *Journal of Child Neurology*, *15*(12), 808–810.

Liu, Y., Schmidt, K. L., Cohn, J. F., & Mitra, S. (2003). Facial asymmetry quantification for expression invariant human identification. *Computer Vision and Image Understanding*, *91*, 138–159.

Liu, Y., Weaver, R., Schmidt, K., Serban, N., & Cohn, J. F. (2001). *Facial asymmetry: A new biometric* (Tech. Rep. No. CMU-RI-TR-01-23). Pittsburgh, PA: Carnegie Mellon University.

Mealey, L., Bridgstock, R., & Townsend, G. C. (1999). Symmetry and perceived facial attractiveness: A monozygotic co-twin comparison. *Journal of Personality and Social Psychology*, *76*, 151–158.

Mertens, I., Siegmund, H., & Gruesser, O. J. (1993). Gaze motor asymmetries in the perception of faces during a memory task. *Neuropsychologia*, *31*, 989–998.

Nakamura, T., Okamoto, K., & Maruyama, T. (2001). Facial asymmetry in patients with cervicobrachial pain and headache. *Journal of Oral Rehabilitation*, *28*, 1009–1014.

Namano, S., Behrend, D., Harcourt, J., & Wilson, P. (2000). Angular asymmetries of the human face. *International Journal of Prosthodontics*, *13*, 41–46.

Nicholls, M. E. R, Ellis, B. E., & Clement, J. G. (2004). Detecting hemifacial asymmetries in emotional expression with three-dimensional computerized image analysis. *Proceedings of the Royal Society of London, Series B*, *271*, 663–668.

O'Grady, K., & Antonyshyn, O. (1999). Facial asymmetry: Three-dimensional analysis using laser surface scanning. *Plastic and Reconstructive Surgery*, *104*, 928–937.

Pennock, J. D., Johnson, P. C., Manders, E. K., & Van Swearingen, J. M. (1999). Relationship between muscle activity of the frontalis and the associated brow displacement. *Plastic and Reconstructive Surgery*, *104*, 1789.

Phillips, M., & David, A. (1997). Viewing strategies for simple and chimeric faces: An investigation of perceptual bias in normals and schizophrenic patients using visual scan paths. *Brain and Cognition*, *35*, 225–238.

Rhodes, G., Proffitt, F., Grady, J. M., & Sumich, A. (1998). Facial symmetry and the perception of beauty. *Psychonomic Bulletin and Review*, *5*, 659–669.

Richardson, C., Bowers, D., Bauer, R., Heilman, K., & Leonard, C. (2000). Digitising the moving face during dynamic displays of emotion. *Neuropsychologia*, *38*, 1028–1039.

Rinn, W. E. (1984). The neuropsychology of facial expression: A review of the neurological and psychological mechanisms for producing facial expressions. *Psychological Bulletin*, *95*, 52–77.

Ross, R. T., & Mathiesen, R. (1998). Volitional and emotional supranuclear facial weakness. *New England Journal of Medicine*, *338*, 1515.

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology*, *39*, 1161–1178.

Sackeim, H. (1985). Facial morphologic asymmetry: A review. *Brain and Cognition*, *4*, 296–312.

Sackeim, H., Gur, R. C., & Saucy, M. C. (1978). Emotions are expressed more intensely on the left side of the face. *Science*, *202*, 434–436.

Sackeim, H. A., Weiman, A. L., & Forman, B. D. (1984). Asymmetry of the face at rest: Size, area and emotional expression. *Cortex*, *20*, 165–178.

Schirillo, J. (2000). Hemispheric asymmetries and gender influence Rembrandt's portrait orientations. *Neuropsychologia*, *38*, 1593–1606.

Schmidt, K. L., & Cohn, J. F. (2001). Human facial expressions as adaptations: Evolutionary questions in facial expression research. *Yearbook of Physical Anthropology*, *44*, 3–24.

Scriba, H., Stoeckli, S. J., Pollack, A., Veraguth, D., & Fisch, U. (1999). Objective evaluation of normal facial function. *Annals of Otology, Rhinology and Otolaryngology*, *108*, 641–644.

Skinner, M., & Mullen, B. (1991). Facial asymmetry in emotional expression: A meta-analysis of research. *British Journal of Social Psychology*, *30*, 113–124.

Smith, W. M. (1998). Hemispheric and facial asymmetry: Faces of academe. *Journal of Cognitive Neuroscience*, *10*, 663–667.

Smith, W. M. (2000). Hemispheric and facial asymmetry: Gender differences. *Laterality*, *5*, 251–258.

Swaddle, J. P., & Cuthill, I. C. (1995). Asymmetry and human facial attractiveness: Symmetry may not always be beautiful. *Proceedings of the Royal Society of London, B: Biological Sciences*, *1261* (1360), 111–116.

Tian, Y., Kanade, T., & Cohn, J. F. (2001). Recognizing action units for facial expression analysis. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *23*, 97–115.

Van Gelder, R. S., & Borod, J. C. (1990). Neurobiological and cultural aspects of facial asymmetry. *Journal of Communication Disorders*, *23*, 273–286.