Original Research Article

The Relationship Between Facial Shape Asymmetry and Attractiveness in Mexican Students

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Objectives: It has been postulated that symmetric faces are considered more attractive than asymmetric ones because symmetry may signal high quality due to developmental stability. However, other studies showed that both symmetric and slightly asymmetric faces are considered attractive. Here we aim to explore this discrepancy, beginning with the analysis of the normal prevalence of facial symmetry in a population as a necessary first step prior to any attractiveness assessment.

Methods: We collected facial landmarks from two-dimensional digital images of a sample of Mexican individuals (280 females and 285 males aged 18–68 years) that were analyzed using geometric morphometric methods. Then, we chose a subsample of 100 photographs (50 females and 50 males aged 18–27 years) selected to represent a broad range of asymmetrical variation, in order to evaluate attractiveness using a sex-opposite test. Finally, we analyzed the linear correlation between attractiveness and asymmetry.

Results: We found that every evaluated subject presents some degree of facial asymmetry, and that both fluctuating asymmetry and directional asymmetry were significant ($P < 0.0001$) components of total facial asymmetry. Fluctuating asymmetry was slightly associated with age ($r = 0.0858$, $P = 0.0414$) and there were no differences between geographical regions ($P = 0.413$). Attractiveness was not correlated to levels of asymmetry in either sex (males: $P = 0.0973$; females $P = 0.7415$).

Conclusions: Asymmetry was a prevalent feature in the present sample, and preferences for symmetric faces were not operating in the studied population. Am. J. Hum. Biol. 00:000–000, 2014.

INTRODUCTION

The human face is bilaterally symmetrical, divided into right and left planes at the midline. Theoretically, both halves of this symmetric structure are mirror images of each other. However, there are some deviations from perfect symmetry that were grouped by Van Valen (1962) into three categories: directional asymmetry, fluctuating asymmetry and antisymmetry. Only directional asymmetry and fluctuating asymmetry have been reported for the face (Farkas and Cheung, 1981; Ferrario et al., 1995; Klingenberg et al., 2010; Song et al., 2007). Directional asymmetry refers to a tendency in a population to a greater development of a trait on one side than the other, whereas fluctuating asymmetries are small, random deviations from perfect symmetry that result from the inability of an organism to develop symmetrically (Palmer and Strobeck, 1992). It is worth saying that it is only when the right-minus-left value is statistically tested on a sample that one can assign directional or fluctuating asymmetry.

Human face asymmetries have been studied from different perspectives, including esthetics and facial reconstruction (Peck et al., 1991; Ponniah et al., 2006; Torres et al., 2011; Zhang et al., 2010), or medical comparative studies (DeLeon and Richtsmeier, 2009; Klingenberg et al., 2010; Shaner et al., 2000), even though most of those studies explore facial "beauty" as a signal of individual fitness (Jones et al., 2001; Little et al., 2007; Møller and Swaddle, 1997; Peters et al., 2008; Rhodes et al., 1998; Saxton et al., 2006; Scheib et al., 1999; Soler et al., 2003; Swaddle and Cuthill, 1995; Tovée and Cornelissen, 2001).

Even when genetic disturbances might influence the individual's buffering ability, and thus might contribute to it, fluctuating asymmetry is considered to be a measure of developmental instability (Palmer and Strobeck, 1986). Fluctuating asymmetry may be an indicator of stress, as it reflects the residual variation resulting from developmental noise (i.e., random ontogenic, nongenetic disturbance) and the individual's capacity to buffer against it. (Klingenberg and McIntyre, 1998; Møller and Swaddle, 1997; Palmer and Strobeck, 1986).

Some studies have found a significant correlation between fluctuating asymmetry and some environmental stressors in a variety of traits and organisms. These include temperature (Babbitt, 2008; Benderlioglu et al., 2007), population density (Serrano et al., 2008), poor environmental conditions (Teixeira et al., 2006) or minor morphological abnormalities (Polak and Taylor, 2007). In addition, some genetic factors like heterozygosity have also been postulated as sources of fluctuating asymmetry (FA) (Hutchison and Cheverud, 1995; Vangestel et al., 2011). In humans, facial fluctuating asymmetry has been correlated with reduced physiological health (Shackelford and Larsen, 1997), with individuals living in poor conditions (Özener, 2010), nutritional stress (DeLeon, 2007), Trisomy 21 (Starbuck et al., 2013), or semen quality (Peters et al., 2008). To sum up, both genetic and environmental factors can potentially increase the level of developmental stress in the system, and the inability of the

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Received 3 March 2014; Revision received 20 September 2014; Accepted 25 October 2014

DOI: 10.1002/ajhb.22657
Published online 00 Month 2014 in Wiley Online Library (wileyonlinelibrary.com).

organism to counteract such noise will result in fluctuating asymmetry. Therefore, high levels of FA would reflect reduced developmental stability of the individual (for a further review, see Møller and Swaddle, 1997).

Because of the ability of humans to extract information from faces, it was proposed that certain relevant psychological features for mate choice, such as detection of mate value, have been favored by selection (Fink and Penton-Voak, 2002; Luxen and Van de Vijver, 2006; Thornhill and Gangestad, 1999). Such ability to discriminate among potential mates has been proposed as an adaptation that has evolved to increase reproductive success throughout evolutionary history. This hypothesis states that attractiveness reflects information about the biological quality of an individual, and discrimination ability may provide direct (e.g., avoiding infertile mates) and indirect (for example, attractive offspring) benefits to the perceiver (for a review on this topic see, Fink and Penton-Voak, 2002; Little et al., 2011; Thornhill and Gangestad, 1999).

According to this idea, facial asymmetries are used to assess facial beauty as a trait that signals the individual's genetic background (for a review, see Weeden and Sabini, 2005). Individuals with high levels of fluctuating asymmetry will, therefore, exhibit reduced developmental stability and would be assessed less attractive. Following the same reasoning, preferences for symmetric faces would reflect an expectation of greater genetic success, since only high quality individuals can develop symmetrically under environmental stress. Analysis focused on measuring the relationship among attractiveness and facial asymmetry has been performed in two ways. Some analyses are based on unmanipulated, "real" faces (e.g., Jones et al., 2001; Penton-Voak et al., 2001; Scheib et al., 1999; Soler et al., 2012; Rikowski and Grammer, 1999). Other analyses use "chimeric" faces: images with distinct levels of asymmetry. These were constructed principally by the merging of the two halves of the face and its subsequent reflection, and were generated to assess the potential association between attractiveness and asymmetry (Grammer and Thornhill, 1994; Little et al., 2001, 2007; Rhodes et al., 1998, 1999; Saxton et al., 2011; Swaddle and Cuthill, 1995). These approaches offer incongruent results. Although most of them found that symmetry tends to be attractive, some studies reported that certain levels of asymmetry, particularly those within the natural range of facial asymmetry of the population, are preferred to symmetry (Kowner, 1996; Swaddle and Cuthill, 1995; Zaidel and Cohen, 2005; Zaidel and Deblieck, 2007). Unfortunately, previous approaches which consider levels of asymmetry within a specific population are scarce.

There are many methodologies available to measure facial asymmetry levels in two- and three- dimensional digital images, most of them using traditional morphometric measurements such as lengths, angles and ratios (e.g., Jones et al., 2001; Koehler et al., 2004; Penton-Voak et al., 2001). Other studies use geometric morphometrics methods applying Procrustes superimposition or Euclidean Distance Matrix Analysis (Ercan et al., 2008; Ferrario et al., 1995; Schaefer et al., 2006a). Typical difficulties concerning traditional lengths are related to the magnitude of fluctuating asymmetry, which in general terms increases with trait size (Bechshøft et al., 2008). Geometric morphometric shape analysis allows quantification of variation in *size* and *shape* as separate variables (Zelditch et al., 2004). Furthermore, geometric morphometrics incorporate specific methods (e.g., Procrustes ANOVA) that improve the framework for analyses of asymmetry in two- and three-dimensional data (see a detailed review in Klingenberg et al., 2002).

Considering that facial asymmetry is an important component of morphological variation, and that it is a potential factor influencing mate preference, the development of landmark-based methods for studying shape changes on bilateral structures provides a novel and powerful approach to analyze such relationships within a population-based comparative framework. The aim of this study is to explore facial asymmetric variation in a subset of frontal facial photographs from several Mexican samples, using geometric morphometrics and a Procrustes two-factor ANOVA model, in order to explore how asymmetry affects attractiveness assessments using a population based approach. This means that instead of assuming perfect symmetry as the standard value, we first measure normal population levels of asymmetry and perform the attractiveness tests considering the spectrum of asymmetries that are beyond the population basal value. We test here two main null hypotheses. The first one postulates that, as has been observed in other populations, both directional and fluctuating asymmetry are present at varying levels in the population under study. The second null hypothesis postulates that attractiveness is negatively associated with fluctuating asymmetry, as has been proposed elsewhere.

MATERIALS AND METHODS

Distribution of fluctuating asymmetry at the population level

The sample. The sample consisted of 565 digital images of Mexican individuals (280 females and 285 males; mean age 22.21, SD = 6.557 years; 18–68 age range) from different populations within the country (Table 1). All photographs were obtained from "La cara del mexicano" (The Mexican's face) project, that consists of a large database of facial photographs. The photograph protocol consisted of a portable studio using a Pentax K1000 camera mounted in a tripod, with a 135 mm AF Pentax lens. The studio also included two flashes and reflective umbrellas, and a white background with the individual ID and a scale in centimeters. The distance between subject and the camera was held constant (2 m), taking care that the subjects' heads were on the Frankfurt horizontal plane. Finally, the resulting 35 mm films were digitized using ScanMaker 35 scanner (for further details, see Serrano et al., 2000). Only digital images of faces in frontal view, neutral expressions, hair off the face, without plucked eyebrows, or any other aesthetic intervention were selected.

Data acquisition. Twenty-nine two-dimensional somatometric landmarks (9 midline and 20 bilateral) were collected (by AF) using TPSDIG 2.16 software (Rohlf, 2010), and were defined following Martin and Saller (1957). The aforesaid protocol was established to facilitate comparisons with previous surveys trying to avoid over redundancy in the data. The face was represented by midsaggital (gnathion PGN, labiale inferius LI, stomion STO, labiale superius LS, subnasale SN, pronasale PR, photographic nasion PN, photographic glabella PG, trichion TR), and bilateral landmarks (crista philtre CPH, cheilion CH, alare crest AL, endocanthion EN, exocanthion EX, palpebral inferius PI, palpebral superius PS, superciliare SC, photographic zygion PZY, and photographic gonion PGO). A detailed description and spatial location of landmarks are presented in Table 2 and Figure 1.

Four (26–29, left and right zygion and gonion) out of the 29 landmarks, are not derived from other landmarks. For instance, crista philtre, chelion, alare crests, endocanthion, exocanthion, inferior and superior palpebral, and superciliare represent extreme portions of anatomical structures, not dependent on other landmarks. In other words, they could be placed in the same location, no matter the position of the remaining landmarks. Other landmarks (gnathion, inferior and superior labiale, stomion, subnasale, pronasale, nasion, glabella, trichion) are defined by the facial sagittal plane, rather than by other landmarks, thus are not problematic for studying deviations from symmetry. Photographic zygion and gonion are "most external points", thus their location can be interpreted as a derivation of a maximum distance (e.g., the maximum width of the face). Thus, these four landmarks can be seen as more generally defined, not representing local variation. To guarantee that our results are not distorted by differences on the landmark-type definitions, we replicated all the analyses (excepting error measurement, see below) on a 25-landmark dataset, by removing landmarks 26–29.

TABLE 1. Population distribution in Mexican Republic

Geographical region	Population	n
Northern Mexican population (females = 65; mean age = 22.93; 18–61 age range)	Aguascalientes	3
	Baja California	2
	Baja California Sur	2
	Chihuahua	10
	Coahuila	4
	Durango	8
	Nayarit	2
	Nuevo León	2
	San Luis Potosí	8
	Sinaloa	10
	Sonora	59
	Tamaulipas	3
	Zacatecas	7
	Total	120
Central Mexican population (females = 184; mean age = 21.17; 18–50 age range).	Colima	137
	Distrito Federal	13
	Estado de México	25
	Guanajuato	11
	Hidalgo	18
	Jalisco	114
	Michoacán	40
	Morelos	1
	Puebla	5
	Querétaro	2
	Tlaxcala	4
	Total	370
Southern Mexican population (females = 31; mean age = 24.05; 18–68 age range)	Campeche	1
	Chiapas	5
	Guerrero	13
	Oaxaca	13
	Veracruz	17
	Yucatán	26
	Total	75
Total		565

Given that sample size varies dramatically between populations we grouped them within the corresponding geographical regions.

Measurement error analysis. Since measurement error has been pointed out as a confounding factor in the assessment of fluctuating asymmetry (Klingenberg et al., 2002; Palmer and Strobeck, 1986), ten faces were digitized twice (by AF) in order to estimate intra-observer error. After the Procrustes fit of this subsample, a shape Procrustes ANOVA was performed to decompose the total shape variation and to examine the proportion of mean squares of measurement error with respect to overall variation (Klingenberg et al., 2002).

Geometric morphometric analysis. We analyzed landmark configurations using the generalized least-squares Procrustes method that, in the case of the analysis of bilateral structures with object symmetry superimposes the original configurations and their mirror images, and partitions the total shape variation into components of symmetric and asymmetric variation (for a further review, see Mardia et al., 2000). The first step of this method generates a reflected copy of each configuration and relabels it in order to make the arrangement of landmarks compatible with the original forms. Then, a GLS Procrustes superimposition is performed with the original forms and their mirrored-relabeled counterparts, that translates them to a common origin, scales them to the same centroid size, and rotates them using a least squares

TABLE 2. Definitions of the landmark protocol used in this study (see also Fig. 1)

No.	Landmark	Definition
1	Gnathion	The lowest point in the midline on the lower border of the chin
2	Labiale inferius	The midpoint of the vermilion border of the lower lip
3	Stomion	The midpoint of the labial fissure when the lips are closed naturally
4	Labiale superius	The midpoint of the vermilion border of the upper lip
5, 8	Crista Philtre	The point on the crest of the philtrum, above the vermilion border
6, 7	Chelion	The outer corner of the mouth where the upper and lower lips meet
9	Subnasale	The junction between the lower border of the nasal septum
10	Photographic pronasale	The centroid on the surface of the nasal tip as seeing in frontal view, intersecting the facial sagittal plane
11, 12	Alare crest	The most lateral point on the nasal ala
13	Photographic nasion	The point in the sagittal plane at the level of the inner corner of the eyes
14	Photographic glabella	The point in the sagittal plane at the level of the eyebrows
15	Trichion	Midpoint of the hairline
16, 21	Endocanthion	The inner corner of the eye fissure where the eyelids meet
17, 22	Exocanthion	The outer corner of the eye fissure where the eyelids meet
18, 23	Palpebral superius	The highest point on the upper margin of the middle portion of the eyelid
19, 24	Palpebral inferius	The lowest point on the upper margin of the middle portion of the eyelid
20, 25	Superciliare	The most highest point on the margin of the superciliare crest
26, 29	Photographic zygion	The most external point on the margin of the face below the eyes
27, 28	Photographic gonion	The most outward projecting point on the face along the horizontal axis of the mouth

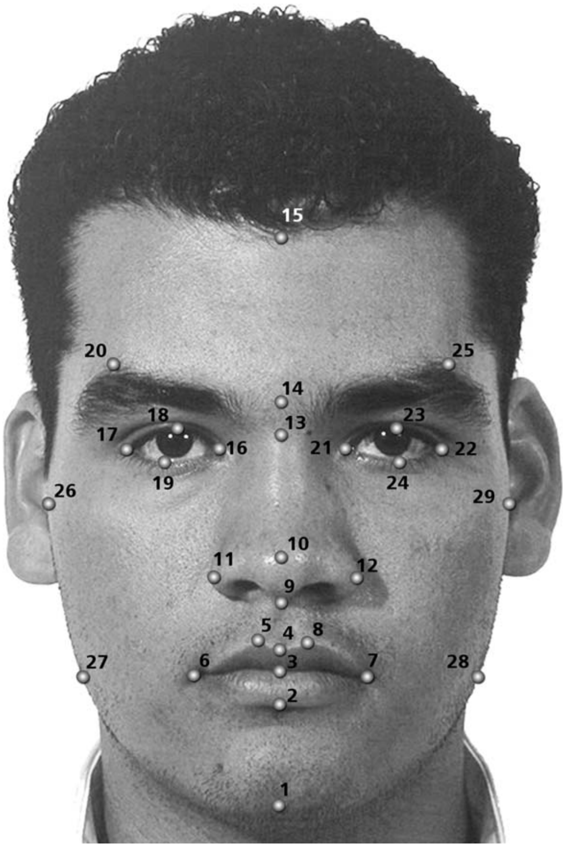

Fig. 1. Landmarks used in this study (see definitions in Table 2).

criterion (Bookstein, 1997; Dryden and Mardia, 1998). The consensus obtained from this fit is a perfectly symmetric shape with an exact axis or plane of symmetry determined by the unpaired landmarks together with the midpoints of the paired landmarks. The variation among individuals in such consensus is referred to as the symmetric component of the total shape variation, whereas the squared distances between the original configurations from this symmetric component refers to the asymmetric component. The decomposition of the latter component of shape variation into a term that is n times the squared distance of the average original configuration from the symmetric average corresponds to the notion of directional asymmetry seen in the literature; also, the notion of fluctuating asymmetry corresponds to the within-cases sum of squares about their average configuration.

In order to test our first null hypothesis, we computed a Procrustes ANOVA (see Klingenberg et al., 2002) to decompose the asymmetric component of shape variation of the whole sample into components due to “Individuals” (variation among individuals); “Side” (Directional asymmetry), and “Individual by Side interaction” (Fluctuating asymmetry). This ANOVA model assumes an isotropic variation around the landmark configuration, and establishes the statistical significance of the effects with a parametric Goodall’s F test and permutational P value. In order to be conservative, we assumed lack of isotropy and we computed a MANOVA test with a Pillai’s Trace and the associated parametric P value to assess the statistical significance. The individual scores of fluctuating asymmetry were obtained in order to perform an analysis of attractiveness (see below).

The relationship between individual scores of asymmetry and age was assessed through a Pearson’s product–moment correlation coefficient, and we used a one-way ANOVA to test if there were sexual or geographical differences in the set of individual asymmetry scores.

Relationship between asymmetry and attractiveness

Stimuli. We calculated the percentiles range (0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9) of the individual fluctuating asymmetry scores from the total sample by sex, so that each individual was assigned to their corresponding percentile. From this sample, only individuals between 18 and 27 years were selected for the stimuli test. No consensus has been achieved in the literature about the amount of photographs used to be rated. Thus, we decided to choose arbitrarily five photographs from each percentile randomly, so that the interviewee could rate them for attractiveness. The resulting photographs (50 men and 50 women) were black and white converted and aligned to the reference plane formed by the line connecting both left and right Exochanthion (Ras et al., 1995). An oval mask was added to cover the higher portion of the neck and hair in order to remove any additional effect that might influence the construction of attractiveness, as used in previous researches (e.g., Little et al., 2011; Swaddle and Cuthill, 1995; Rhodes et al., 1998, 1999). Finally, the stimuli were constructed by randomly selecting one of the five photographs available within each percentile range, and arranging them in five sets of ten images that spanned all the percentiles ranges (i.e., set 1 = 0, 0.1. . .0.9; set 2 = 0, 0.1. . .0.9; etc.).

Attractiveness assessment procedure. We recruited 123 raters (62 females, mean age = 19.40, SD = 1.77; 61 male, mean age = 20.89, SD = 2.83) heterosexual college students from the National Autonomous University of Mexico, covering the same age range of the *stimuli* used (18–27 years). All the raters were Mexican students from several regions, living in Mexico City at the moment of the data collection. The stimuli were presented to each rater in the same order, one at a time. Subjects rated each opposite-sex face on a Likert rating scale from 1 = not at all attractive to 4 = very attractive (Matell and Jacoby, 1972). To assess the effects of facial asymmetry on attractiveness judgments, we computed the Pearson’s product–moment correlation coefficient between the average value from the attractiveness test in each photograph and fluctuating asymmetry scores.

Whenever subjects perform in more than one condition (as they do in within-subject designs) there is a possibility of carryover effects. The question is whether or not having performed in one condition affects performance in the second condition. In our study, the question is if the rating of attractiveness on a photograph belonging to a given percentile affects the next rating. A common recommendation for crossover designs is to avoid the problems caused by differential carryover effects by employing lengthy washout periods where treatment and carryover are not aliased or confounded with each other. In our study, the rater was first subjected to a single stimulus from each percentile, beginning with percentile 0, 0.1, 0.2, etc. Then, a second round of stimuli exposure with a second round of

TABLE 3. Measurement error and fluctuating asymmetry as assessed by Procrustes ANOVA of repeated measures

Effect	SS	MS	DF	*F*	*P* (param.)
Individual	0.05482039	0.0002255983	243	9.27	<0.0001
Side	0.00166080	0.0000615109	27	2.53	<0.0001
Ind*Side	0.00591152	0.0000243272	243	1.70	<0.0001
Residual	0.00772079	0.0000142978	540		

Sums of squares (SS) and mean squares (MS) are in units of squared Procrustes distance.

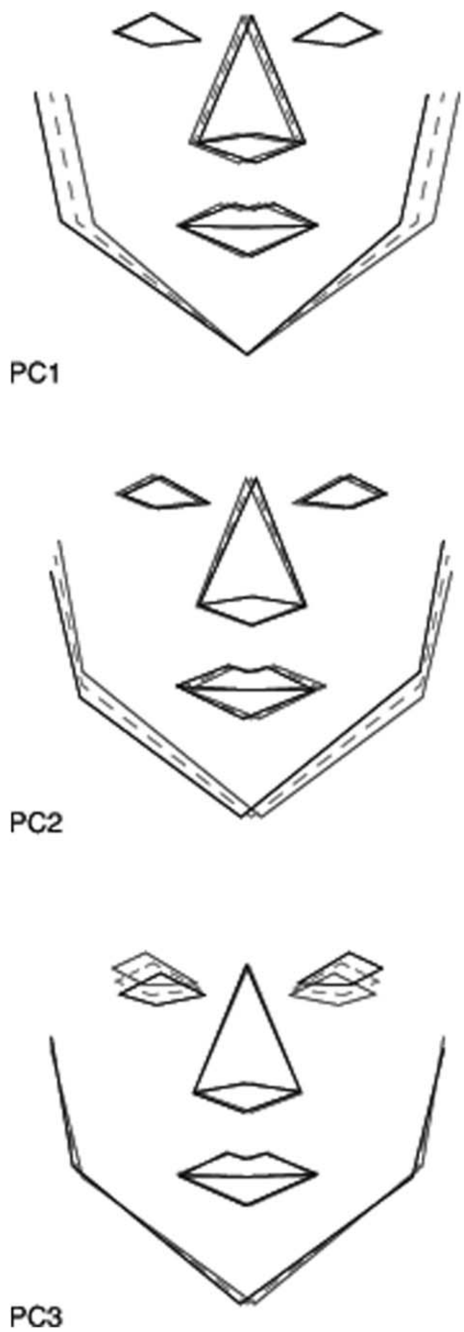

Fig. 2. Wireframes corresponding to shape changes observed on the first three PCs of the asymmetric component of variation.

TABLE 4. Shape Procrustes ANOVA with sex as individual effect

Effect	SS	MS	DF	*F*	*P* (param.)
Individual	0.27768211	0.0102845226	27	57.60	<0.0001
Side	0.07188098	0.0026622585	27	14.91	<0.0001
Ind × side	0.00482127	0.0001785656	27	2.41	<0.0001
Residual	2.25255892	0.0000740925	30402		

Sums of squares (SS) and mean squares (MS) are in units of squared procrustes distance.

photographs from each percentile, and so on until finishing five rounds. In this way, any carryover effect potentially affecting the average attractiveness assigned to each percentile is minimized by the washout period existent among each rating/percentile × and the following, which is asserted after the next nine ratings. Since the five photographs are taken randomly from each percentile subsample, we can consider this rating experiment as pseudo-randomized.

All morphometric analyses were conducted using Morpho J software (version 1.03d; Klingenberg, 2011), whereas statistical analyses were carried out using PAST software (version 2.17b; Hammer et al., 2001).

RESULTS

Population distribution of fluctuating asymmetry

Measurement error. The Procrustes ANOVA results indicate that individual and fluctuating asymmetry effects are twice the measurement error effect (Table 3), so, we consider the latter as negligible. All of the effects on this analysis were statistically significant.

Shape Procrustes ANOVA (Procrustes superimposition approach). According to the overall Procrustes ANOVA, both directional and fluctuating asymmetry show significant effects, thus suggesting nonrejection of the first null hypothesis. Also, our results on individual values of asymmetry indicate that all the individuals included in the analysis showed some degree of fluctuating asymmetry, in all the facial regions (e.g., the upper lip, nose, eyes, and the masticatory regions, Fig. 2). Thus, it is equally likely that individual values have a greater development on the right side than on the left side. Since the individual measurements focus on the magnitude of such deviation, they are expressed as absolute values (Klingenberg and Monteiro, 2005). The amount of fluctuating asymmetry was greater in females than in males (females = 2.947; males = 2.895; the scores have been multiplied by 1000 to make them more readable), and the one-way ANOVA showed that the differences between sexes were statistically significant [$F(1, 563) = 18.62$; $P < 0.0001$], and that directional and fluctuating asymmetry are significant effects as well ($P < 0.0001$, Table 4). All the above mentioned figures and significance levels are very similar on the 25-landmark dataset.

The MANOVA test confirmed the results detailed above (Pillai's trace = 0.34, $P < 0.0001$).

Finally, we found a slight relationship between asymmetry scores and age ($r = 0.0858$, $r^2 = 0.0074$, $P = 0.0414$; $r = 0.2098$, $r^2 = 0.0440$, $P < 0.0001$ when computed on the 25-landmark dataset), and no statistically significant differences in facial asymmetry among geographical regions ($F = 0.8852$; $P = 0.413$; $F = 1.336$; $P = 0.2638$ when computed on the 25-landmark dataset).

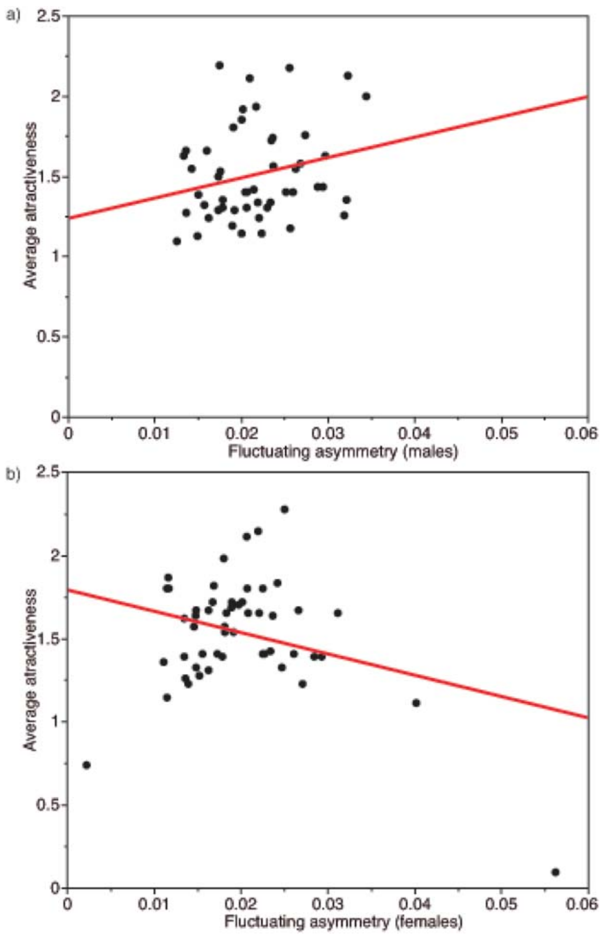

Fig. 3. Scatterplot of the association between fluctuating asymmetry individual values (FA scores) and mean attractiveness is presented, when (a) women rated photographs of men ($n = 50$; $r = 0.2371$; $P = 0.0973$; $r^2 = 0.0562$), and (b) men rated photographs of women ($n = 50$; $r = -0.0478$; $P = 0.7415$; $r^2 = 0.0023$).

Relationship between asymmetry and attractiveness

Photographs used in this analysis were selected considering the percentiles computed of individual asymmetry values on the 29 landmark dataset (female mean = 0.0195, SD = 0.005; male mean = 0.0215, SD = 0.005). Inter-rater agreement for ratings of attractiveness indicates a good reliability of the analysis (Cronbach's alpha > 0.95 for men assessing woman's photos; Cronbach's alpha > 0.94 for women assessing men's photos).

Figure 3 shows the scatterplot of the asymmetry levels and attractiveness when woman rated photographs of men and vice versa. The Pearson's product–moment correlation coefficient shows no statistical correlation between levels of fluctuating asymmetry and attractiveness rates when men's photographs were rated by women ($r = 0.2371$, $r^2 = 0.0562$, $P = 0.0973$), nor was a significant correlation found when women's photos were assessed by men ($r = -0.0478$, $r^2 = 0.0023$, $P = 0.7415$). When computed on the 25 landmark, results are concordant: there is no correlation between fluctuating asymmetry and attractiveness rates, when men's photographs were rated by women ($r = -0.0156$, $r^2 = 0.0002$, $P = 0.9141$), nor was there a significant correlation when women's photos were assessed by men ($r = 0.0569$, $r^2 = 0.0032$, $P = 0.6948$).

Overall, these results indicate rejection of the second null hypothesis of a relationship between attractiveness and symmetry. The hypothesis is also rejected using a conservative configuration of landmarks derived from localized anatomical structures that minimizes the potential noise of landmarks derived from overall facial dimensions.

DISCUSSION

Asymmetry as a complex phenotype

Our approach has two sequential phases. Firstly, we evaluated facial asymmetry by means of geometric morphometric methods to elucidate patterns of fluctuating and directional asymmetry on a Mexican population sample. This sample included individuals of a wide range of ages from the general population. Secondly, we developed an attractiveness test following previous studies, but instead of using photographic "chimeras", we used a sample covering the entire amount of the natural asymmetries observed in the population in order to examine their effect on attractiveness in Mexican college students. Because of that, this is an alternative to computer-generated faces, or analyses based mainly on "Caucasian" student populations. Our approach enables the discussion to center on attractiveness and asymmetries in the comparative framework of the population where the phenomena under study occur. This population (admixed Mexicans) has not been the focus of previous studies.

Measurement error is an important potential bias in any fluctuating asymmetry analysis. Both measurement error and fluctuating asymmetry are often of the same magnitude and are normally distributed (Palmer and Strobeck, 1986). We therefore developed a measurement of error analysis for this project. Measurement error was revealed as negligible in this sample.

We considered the potential impact of carryover effects, and argue that if there is some sequential effect in this analysis, this problem is not crucial. For example, sequential effects in face attractiveness judgment have been found (Kondo et al., 2012) in which the attractiveness rating positively correlated with the immediately preceding rating. However, the contribution of sequential effects was quite small compared to the contribution of attractiveness *per se*. In the present study, the stimulus order was from 0 (high symmetry) to 0.9 (low symmetry). Assuming that symmetry leads to attractiveness, although sequential effects may slightly bias the overall rating, the correlation between symmetry and attractiveness should have been observed if any. However, the obtained results clearly rule against this possibility.

Despite the large number of studies performed on the relationship between individual asymmetry and attractiveness, there is a remarkable lack of studies focused on analyzing the normal prevalence of this component of shape variation in specific human populations. Moreover, few studies consider samples above 100 individuals. One instance is the analysis of directional and fluctuating asymmetry patterns performed by Simmons et al. (2004), who examined facial asymmetries of different self-reported ethnicities of a wide range of ages. Other studies displaying large sample sizes are limited to adolescents (Rhodes et al., 2001) or undergraduate students (Hume and Montgomery, 2001), and do not summarize the normal prevalence of asymmetries within the sample. This is of crucial importance. Many previous approaches do not assume that symmetric faces are available to be selected, but some previous analyses (Ercan et al., 2008; Ferrario et al., 1995) and the results presented here clearly indicate that fluctuating and directional asymmetry both exist as a basal, normal trait of a population. As a result, the previous evidence supporting the influence of genetic and environmental processes on facial symmetries (e.g., Grammer and Thornhill, 1994; Little et al., 2001, 2007; Rhodes et al., 1998, 1999; Saxton et al., 2011; Swaddle and Cuthill, 1995), and their impact on attractiveness and other behaviors related to mating success should be seen with caution, and should be considered far from conclusive. Here we have estimated the magnitude and pattern of directional and fluctuating asymmetry in a large dataset of Mexican population, prior to the assessment of attractiveness.

Although the mechanisms or processes responsible for the expression of asymmetries are not addressed here, it has been suggested that because of facial plasticity, certain mechanical strains during craniofacial growth and development can influence facial asymmetries throughout bone remodeling (Hallgrímson, 1999). For example, the gradual and subtle changes of jaw shape in response to abnormal functions or posture (e.g., Yamaguchi and Sueishi, 2003), or the influence of a side preference for the sleeping position as a generator of some degree of plagiocephaly (e.g., Netherway et al., 2006) can be invoked as explanatory mechanisms. Furthermore, the relationship between asymmetry and age has been the focus of previous research, mainly focused on samples of young adults. Wilson and Manning (1996), for instance, found an overall decrease in the amount of asymmetry with age, in a sample of children from 2 to 18, although accompanied by an increase of asymmetry levels around 11 years for both sexes. The authors interpret these patterns as related to the rapid growth in adolescents. Sforza et al. (2010) also found a similar pattern of diminishing of the soft-tissue facial asymmetries with increasing age, when exploring a slightly wider range of age (4–30 years), within a sample of "attractive" individuals and a sample of controls. In contrast, several authors examining young adults have not found a relationship between these variables (Burke and Healy, 1993; Djordjevic et al., 2013; Farkas and Cheung, 1981). When examining a wide range of ages Penke et al. (2009) found a significantly higher mean of asymmetry and increased variance in adults of 83 years relative to young adults (20–30 years). Our study found no clear relationship between both variables, in concordance with that reported by Ferrario et al. (2001), on a sample of healthy northern Italians with a range of age similar to ours.

In the Mexican population studied here, facial fluctuating asymmetry is widely expressed, as has been reported in other populations (e.g., Ercan et al., 2008; Farkas and Cheung, 1981; Ferrario et al., 1995, 2001; Hume and Montgomery, 2001; Simmons et al., 2004). In other words, the "normal" variation in this population includes asymmetry. Moreover, asymmetry values do not present a geographical patterning, since it did not differ among regions. All the subjects evaluated in this study presented some degree of fluctuating asymmetry that could be explained because of the large amount of factors influencing the nonlinear development of the soft and bony facial structures. Our results also show that directional asymmetry contributes to the total asymmetric variation of the sample ($P < 0.0001$). It is important to consider that even in optimal environmental conditions, random developmental perturbations can likely produce asymmetries (Møller and Swaddle, 1997), and that in the absence of such developmental stress, the existence of directional asymmetry would be sufficient to produce an asymmetrical face (Rhodes et al., 1998). The above results confirm the first null hypothesis, similar to other studies that have argued that asymmetric faces would be, to some extent, the norm (e.g. Ercan et al., 2008; Ferrario et al., 1995; Haraguchi et al., 2002; Peck et al., 1991) rather than an exceptional condition in human faces. In addition, our results show that females had higher levels of facial asymmetry than males, in agreement with some previous reports (Ercan et al., 2008; Gray and Marlowe, 2002). However, other studies have found higher asymmetry in males rather than females (Özener, 2010; Simmons et al., 2004), or have reported no differences between sexes (Djordjevic et al., 2013; Ferrario et al., 2001).

There is no consensus in the literature about the degree and side of facial asymmetries (Ferrario et al., 1995, 2001), but it seems that gonial angle is a commonly reported landmark that influences facial asymmetries (Farkas and Cheung, 1981; Ferrario et al., 1994, 1995, 2001; Haraguchi et al., 2002; Lee et al., 2010; Severt and Proffit, 1997). The later maturation of the mandible, in relation to other craniofacial structures (Bastir et al., 2006) makes it more susceptible to developmental perturbations, such as unilateral mastication, a phenomenon that could explain the importance of some mandibular traits in the expression of asymmetries. Also, note that a landmark placed far from the symmetry plane is more likely to be asymmetric (Ferrario et al., 2001) than more medial structures. Our results lend support to these previous assertions, since photographic gonion and zygion were the two-most variable landmarks (Fig. 2).

It is worth emphasizing that despite the statistical considerations discussed here, our analysis is not aimed at detecting the developmental processes underlying the expression of directional or fluctuating asymmetries. Furthermore, considering that nothing prevents the combined presence of two forms of asymmetry for a given trait (McKenzie, 1997; Palmer and Strobeck, 1992), we interpret with caution the link among significant levels of fluctuating asymmetry as a straightforward proxy of developmental stability. In this context, note that in their study of fluctuating asymmetry of the mandible as a response to internal or external environmental stressors, Schaefer et al. (2006b) concluded that since not all the aspects of development can be quantified, the interpretation of homozygosity as a genetic factor producing stress and FA deserves caution.

Human facial attractiveness and fluctuating asymmetry

The results obtained here suggest that fluctuating asymmetry levels and attractiveness rates are uncorrelated, no matter the sex under study, thus indicating the rejection of the second null hypothesis. We can conclude that previous studies demonstrating preferences for symmetric faces were not supported in this population. Similar results have been found, however, in some previous studies. Swaddle and Cuthill (1995), for instance, reported that faces that were made more symmetrical were perceived as less attractive. Also Penton-Voak et al. (2001) found a nonsignificant correlation between attractiveness and measured asymmetry ($r = -0.226$, $P = 0.068$, $n = 66$). Using half and full natural faces, Zaidel and Hessamian (2010) demonstrated that facial asymmetry does not have a primary role in facial attractiveness. The review by Weeden and Sabini (2005) discusses several articles that assess this relationship using natural asymmetry of the faces, and the authors report a small effect in attractiveness of men, and essentially no effect in women. In contrast to these findings, some previous work did find an impact of asymmetry on attractiveness ratings (e.g., Grammer and Thornhill, 1994; Little et al., 2007; Penton-Voak et al., 2001; Perret et al., 1999; Peters et al., 2008; Rhodes et al., 1998; Rikowski and Grammer, 1999; Saxton et al. 2011; Schaefer et al., 2006a; Scheib et al., 1999; Soler et al., 2012; Watkins et al., 2012).

A more detailed inspection of the literature suggests some inconsistencies in two main points that may explain the contrasting results: (1) the strength and significance of the correlation between asymmetry and attractiveness and (2) differences in the set of traits under study or further methodological differences. Regarding the computation of correlations, in a recent meta-analysis Van Dongen (2011) evaluated the role of fluctuating asymmetry and developmental instability in attractiveness judgments by comparing the strength of associations reported in several papers. The author found evidence of publication bias due to a negative association between effect size and sample size. After correcting for it using the trim-and-fill method, the average effect size was lower by 30%, where studies with sample sizes above 100 had effective size estimates not statistically significant and close to zero. Van Dongen's (2011) results confirm a previous analysis by Palmer (1999), where selective reporting and publication bias were found on the studies between asymmetry and sexual selection (but see Thornhill et al., 1999). Much research is still needed, but these latter results are important for an unbiased examination of the implications of the facial asymmetry and attractiveness relationship, especially when interpretations are done on "real" human populations. On this topic, Palmer (1999) suggested that the studies based on sample sizes lower than 30 are most prone to bias. Here we achieved a sample size of 50 facial stimuli for both sexes to assess attractiveness. Thus, our estimates are based on reasonable effect sizes.

As stated elsewhere (Thornhill et al., 1999), another factor that could explain the dissimilar results in the relationship of asymmetry and attractiveness is the lack of consistency in the study design. One such difference is the different amount of selected landmarks. While some studies used more than 40 points (e.g., Schaefer et al., 2006a), others use less than 20 landmarks (e.g., Jones et al., 2001; Scheib et al., 1999) to assess facial asymmetry. This study summarized landmarks used in previous analyses, trying to avoid data redundancy as well as avoiding landmarks that are difficult to place in two-dimensional facial images. For example, gonion is difficult to place in frontal photographs because in some cases the cheek soft tissue could hide it. A more accurate and straightforward way to locate it would be in a lateral view. Therefore we modified some landmark definitions in order to place them accurately in all individuals (see Table 2; Fig. 1). Since there is no consensus about the way to determine midline face, midsagittal line estimation is another basic methodological difference that can lead to different results. Geometric morphometric approaches, however, benefit from the fact that Procrustes superimposition of object symmetry provide a estimate of the median axis (or plane) of symmetry, that is determined by the unpaired landmarks together with the midpoints of the paired landmarks (Klingenberg et al., 2002; Mardia et al., 2000).

Besides these methodological issues, a potentially important source of incongruence among studies is the population setting of the analyses. Regarding this, we support the idea that including natural asymmetric variation in attractiveness analysis (as in previous studies: e.g., Jones et al., 2001; Penton-Voak et al., 2001; Rikowski and Grammer, 1999; Scheib et al., 1999; Soler et al., 2012) is important since it ties the attractiveness assessment to a comparative framework that recognizes real, observed asymmetries in a given population. Under the assumption that symmetry represents the optimum phenotype (Debat and David, 2001), several previous studies constructed facial images with different degrees of symmetry (Grammer and Thornhill, 1994; Little et al., 2001, 2007; Rhodes et al., 1998, 1999; Saxton et al., 2011; Swaddle and Cuthill, 1995), that depict nonreal continuums of bilateral symmetric variation. A reliable analysis of facial asymmetry and attractiveness should take into account the population distribution of asymmetric variation, in order to avoid forced preconditions, such as perfect symmetry that do not exist in natural social and biological conditions.

CONCLUDING REMARKS

Our results indicate that attractiveness is not conditioned by natural levels of asymmetry in Mexico. Other work presents no general agreement in the interpretation of human asymmetry, but there is consensus regarding the prevalence of this trait in humans. Natural asymmetric variation properly measured in a study population can lead to more reliable estimates of the importance of factors contributing to mate choice. This raises questions about previous assertions regarding attractiveness and asymmetries, and whether they need to be reevaluated in order to properly calibrate the influence of normal levels of asymmetry during the assessment tests. Future research should benefit from using natural, observed levels of asymmetry in different social contexts or populations.

ACKNOWLEDGMENTS

We acknowledge to the volunteers who participated in this survey. We also want to thank to anonymous reviewers for their helpful comments and suggestions.

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