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The Effects of Objective 3D Measures of Facial Shape and Symmetry on Perceptions of Facial Attractiveness

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Abstract

Purpose—Meeting patient desires for enhanced facial esthetics requires that providers have standardized and objective methods to measure esthetics. We evaluated the effects of objective 3-dimensional (3D) facial shape and asymmetry measurements derived from 3D facial images on perceptions of facial attractiveness.

Patient and Methods—3D facial images of 313 adults in Iowa were digitized with 32 landmarks and objective 3D facial measures capturing symmetric and asymmetric components of shape variation, centroid size and fluctuating asymmetry were obtained from the 3D coordinate data using geo-morphometric analyses. Frontal and profile images of study participants were rated for facial attractiveness by ten volunteers (5 females and 5 males) on a 5-point Likert-scale and a visual analogue scale (VAS). Multivariate regression was used to identify the effects of the objective 3D facial measurements on the attractiveness ratings.

Results—Several of the objective 3D facial measures had significant effects on attractiveness ratings. Shorter facial heights with protrusive chins, mid-face retrusion, faces with protrusive noses and thin lips, flat mandibular planes with deep labio-mental folds, any cants of the lip commissures and floor of the nose, larger faces overall and increased fluctuating asymmetry were rated as significantly (p<0.001) less attractive.

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Conclusion—Perceptions of facial attractiveness can be explained by specific 3D measures of facial shapes and fluctuating asymmetry, which has important implications for clinical practice and research.

Introduction

Physical attractiveness continues to be an important factor in today's society, and facial appearance remains one of the most defining components of attractiveness. Individuals who are perceived as more attractive are commonly shown to achieve better social and labor market outcomes such as dating/marriage or greater earnings [1–6]. It is accepted that the face is a key factor in determining the perception of physical attractiveness [7]. Consequently, individuals often seek out dental/surgical treatments (i.e., orthodontic treatment, orthognathic surgeries, and cosmetic treatments) in an attempt to increase physical attractiveness by altering facial esthetics. Therefore, it is imperative that professionals providing these services have access to reliable objective measures of facial esthetics, in order to maximize the benefit to individuals seeking these treatments. Furthermore, it is important for individuals, providers, and researchers to better understand what aspects influence perceptions of facial attractiveness.

Given the increased demand for esthetic services, much research has been conducted to examine the aspects/components of the face that predict facial attractiveness. Previous studies have utilized a variety of 2-dimnesional (2D) imaging techniques [8–15]. With the recent advent of 3-dimensional (3D) imaging techniques however, it is now possible to quickly and accurately acquire full facial landscapes in a non-invasive manner. Three-dimensional imaging has become increasingly popular, with applications to the evaluation of facial growth patterns, facial asymmetries and assessment of orthodontic and orthognathic surgery outcomes [16–19]. The increasing reliance on 3D imaging for orthodontic treatment and orthognathic surgery creates greater need for understanding how objective esthetics measures derived from 3D data relate to individuals' perceptions of facial attractiveness.

In this study, we present comprehensive evidence on the relationships between multiple objective 3D measures of facial shape and symmetry derived from 3D images with perceptions of facial attractiveness. Specifically, we examine the effects of objective 3D facial shape and asymmetry measurements generated from 3D facial images from a large sample of individuals on attractiveness ratings provided by a group of raters who evaluated these images. The extant research is focused on how objective 2D measures of the face correlate with attractiveness ratings. Our key contribution is deriving objective 3D facial measures directly from 3D data by using advanced geo-morphometric methods, thus capturing more complex aspects of facial shape variation than what is captured by 2D measures. Furthermore, previous evidence remains largely based on small samples, and we employ one of the largest samples to date for examining this question.

Materials and Methods

Sample and Data Collection

The Institutional Review Board at the associated university approved the protocol for this study. Three-dimensional images were collected by the study investigators between 2009 and 2013 from 325 adult males (n=102) and females (n=223) of varying ages (mean=35.6 years, range=18 to 70 years). Individuals were required to be adults living in Iowa. These individuals were recruited for studies of oral clefts or facial variation. About 37% of these individuals were parents of children with oral clefts, but none of the participants had oral clefts. Nearly 90% of the sample self-reported their race as White. Three-dimensional images of each participant were captured using a 3dMD system and software (3dMD, Atlanta, GA, USA). The 3dMD system combines both stereophotogrammetry and structured light mechanisms to capture facial surface images very quickly (~1.5 milliseconds) and accurately (RMS of 0.2 mm) [20]. Thirty-two landmarks were located and marked on each participant's 3dMD image (Figure 1, Table I). Twelve of the 325 3D images were excluded from the analysis due to poor image quality; hence, a total of 313 images remained for analyses. Procedures for landmark placement reliability testing, described earlier [21], indicated good to excellent reliability with intra-class correlation values exceeding 0.8.

Objective 3D Measures of Facial Shape and Symmetry Derived from 3D Images

The 3D coordinates of the 32 landmarks were exported and submitted to geo-morphometric shape procedures implemented in the software Morpho J for data with object symmetry [21–24]. Object symmetry implies that both the left and the right side of the face are mirrored images from each other, divided by the midsagittal plane. A comprehensive shape analysis of structures with object symmetry should take into account variation in both sides (i.e., halves of a face) as well as how they relate to each other (i.e., variation in the midsagittal plane). Also, locations of bilateral landmarks (i.e., left and right endocanthion), even in the presence of asymmetries are correlated with each other which can lead to statistical problems due to collinearity. To overcome these issues, methods implemented in Morpho J for data with object symmetry partition the total shape into components of symmetric and asymmetric variation as follows. All original landmark configurations were reflected and relabeled. Subsequently, both the original and the relabeled mirrored configurations were registered using the Procrustes fit procedure and the variation observed is portioned into each of the two components. The symmetric component of shape variation constitutes the variation among individuals in the average between their original and reflected landmark configurations. Despite any left–right asymmetry present in the original landmark configuration in any given individual, the average configuration between the original and its reflection is always a symmetric shape [23]. In symmetric variation, bilateral paired facial landmarks can vary in any direction but midfacial unpaired landmarks can only vary along the midsagittal plane. In contrast, the asymmetric component of shape variation quantifies the differences between the original and reflected configurations within individuals. For the paired landmarks, asymmetry can be in any direction, but for the unpaired landmarks variation can only be in a direction perpendicular to the midsagittal plane [23]. Covariance matrices for both the symmetric and asymmetric components were generated and

subsequently submitted separately to principal component analyses (PCA) to determine the main components of symmetric and asymmetric facial shape variation [23, 24].

In PCA by construction, the first principal component (PC) accounts for the largest amount of variance followed by the second component, third, and fourth successively. In this study we utilized the first 4 PCs of each symmetric and asymmetric variations as our first and second categories of objective measures of facial shape. We also measured overall facial size via centroid size, calculated as the square root of the sum squared distances between the centroid and all other points in the landmark configurations. Finally, we evaluated fluctuating asymmetry (FA) which represents the overall magnitude to which an individual is asymmetric based on a zero mean value (laterality and directionality are not considered) using Mahalanobis distances (scaled relative to the variation of asymmetry in the sample) which complement the PCA of the asymmetric component of shape variation. While Asymmetric PCs provide detailed resolution on the particular aspects of asymmetry that explain the most variation in all the faces, individual FA scores capture overall levels of left–right differences in each individual. In summary, a total of 4 categories of objective facial shape measurements were obtained including: 4 PCs of symmetric and asymmetric variation, centroid size, and Mahalanobis FA scores.

Rating of Facial Attractiveness

Ten university students and staff (5 females and 5 males) were identified from a convenience sampling approach to rate facial attractiveness. Frontal and lateral (left and right) facial image views of each study subject were presented to the study raters. The frontal and lateral views presented to the raters sufficiently captured facial shape and symmetry features for the purpose of evaluating how one would view attractiveness in real life. We did not provide the images to the raters in a 3D viewing software that allows them to see the image in whatever position they wanted because it would unlikely add measurement precision and may instead introduce measurement error and noise. Humans typically view faces and assess facial attractiveness in frontal and profile dimensions in real life and not in flipped, rotated, reversed, or horizontal positions. Thus, allowing raters to manipulate images for rating attractiveness could bias attractiveness perceptions. For instance, seeing a vertically or obliquely flipped face is not meaningful for capturing how one may rate facial attractiveness in real life and may bias the rating downward. Furthermore, such manipulations could reduce rater sensitivity to meaningful and real differences in attractiveness between faces. Therefore, it is important to standardize how images are presented to the raters in order to reduce as much as possible random noise and systematic biases in how images are viewed and rated.

The raters were asked to rate overall facial attractiveness based on the frontal and lateral views on a 5-point Likert-scale (1=very unattractive, 2=unattractive, 3= average attractiveness, 4=attractive, 5=very attractive) and a 100-point visual analogue scale (VAS) (from 0 very unattractive to 100 very attractive); the VAS had no pre-markings other than the anchoring points. Thirty-three images were randomly duplicated to assess test-retest reliability.

Statistical Analysis

We employed linear regression analysis to examine the effects of the objective facial shape and symmetry measures on attractiveness ratings. Our regression model was based on the following specification:

$$R_{\mathrm{ij}}=\alpha_0+\mathbf{F}_i\boldsymbol{\beta}+\alpha_1 G_i+\alpha_2 M_j+u_j+e_{\mathrm{ij}}.$$

The dependent variable *R* was the rating of overall facial attractiveness of study subject *i* by rater *j*. We estimated a separate regression for the Likert-scale ratings and for the VAS ratings. The unit of the analysis was an image rating, with each image rated 10 times (once by each of 10 raters). Only one of the duplicated images (included for reliability testing) was retained for these regressions. The regressions were therefore based on a total of 313 images and 3130 ratings/observations (313 photos times 10 raters; 12 of the full set of 325 photos were excluded due to poor quality). We regressed the Likert-scale and VAS ratings on each category of objective facial measures, represented in vector **F** above, first one category at a time. Our main parameters of interest are the regression coefficients of these facial measures (vector **β**), which represent the effects of the facial shape and symmetry indicators derived from 3D images on subjective ratings of attractiveness. The categories of the facial measures in vector **F** were 1- the four symmetry PCs (Symm PC1-PC4); 2- the four asymmetry PCs (Asymm PC1-PC4); 3- centroid size; and 4-Mahalanobis FA score. Since all of the objective measures of facial shape are continuous, they were represented by binary (0/1) indicators for their quintiles with the 40–60th percentile as the reference category (i.e., 4 indicators for each measure) in order to capture non-linear effects of deviations from intermediate values. For example, four binary (0/1) indicators were used to represent the first symmetric PC, another four indicators represented the second symmetric PC, and so on. Finally, we estimated a regression that simultaneously included all these four categories of objective measures of facial shape in order to jointly assess their effects on attractiveness ratings.

The regression controlled for subject's gender (*G*) and rater's gender (*M*). In sensitivity models, we also controlled for subject's age and an indicator for White versus non-White race. We also accounted for other raters' influences (*u*). Our main approach was to model rater effects as random since raters' characteristics are unlikely to be correlated with the objective facial measures; in other words, there are no unobserved rater confounders since the raters were not selected in any way based on the images they were rating and the 3D facial measures derived from these images. Therefore, we estimated the model using generalized least squares linear regression including random effects for the raters.

In order to further account for potential dependence of the error terms within raters (e.g., some raters may tend to rate in the high, low, or medium range), we estimated the variance-covariance matrix using the Huber-type estimator with standard errors clustered at the rater level; this estimator is robust to both heteroscedasticity and non-independence of the errors within clusters [25]. We evaluated the robustness of our inference by estimating the standard errors alternatively using bootstrap with 1000 replications and generally found similar results.

We also estimated an alternative model to the random effects that included rater fixed effects (equivalent to including 0/1 binary indicators for the raters; raters' gender was omitted as it is accounted for by the fixed effects), also clustering the errors at the rater level. This model relaxes the assumption of no unobservable rater-level confounders. That model yielded similar regression coefficients but with less precision (higher standard errors) than the random effects model as expected [25]. Therefore, we focus on reporting the results from the random-effects model. All statistical analyses were done using Stata 14 [26].

Results

Descriptive Analysis

Table II provides descriptive statistics for the Likert-scale and VAS attractiveness ratings and the objective measures of facial shape. Mean attractiveness ratings were 2.7 on the Likert-scale and 39.8 on the VAS. The Likert-scale and VAS ratings were strongly correlated (r=0.87). By construction, the PCs of symmetry and asymmetry are made to have a mean of zero. Thirty-one percent of the study participants were males. The test-retest reliability for overall facial attractiveness ratings was 0.69 on the Likert-scale and 0.75 on the VAS indicating overall acceptable reliability amongst raters. There were no significant differences in reliability by raters' gender (p=0.68 for Likert-scale and p=0.61 for VAS).

Regression Results

Table III describes the main aspects of shape variation captured by each of the 4 categories of objective facial shape measurements along with phenotypic shape extremes that occur at the 1st and 5th quintiles for each of the components. Table III also reports the results of the regressions of the Likert-scale and VAS ratings on the objective 3D facial shape and symmetry indicators grouped into 4 categories – symmetric and asymmetric variation, centroid size and Mahalanobis FA – all included simultaneously in the regression. A separate regression was estimated for each rating scale (Likert-scale and VAS) including rater random effects as noted above. Each objective 3D facial measure was represented by binary indicators for its quintiles with the middle quintile (i.e., the 3rd quintile, 40–60th percentile) as the reference category. We also report the results for the regressions when each of the four facial measure categories was included in the regression on its own without the other categories in Supplementary Tables S1–S4 online. The results were overall comparable when including all these measures jointly so we focus on discussing the results from the full model (Table III). The standard errors and significance levels in Table III are based on the clustered standard error estimator discussed above; we observe similar results using the bootstrap standard error estimator (Supplementary Table S5 online). We also observe similar results when adding subject's age and indicator for White versus non-White race as covariates (Supplementary Table S6 online).

All categories of objective 3D facial variation were significantly related to the attractiveness ratings when included simultaneously in the regression, indicating that each is capturing unique variation in perception of attractiveness. Beginning with the first four principal components of symmetry, all of these had significant effects on one or both of the rating scales (Likert-scale or VAS). Individuals who were farther from the intermediate scores (40–

60th percentile) in either direction had lower attractiveness ratings, but reductions were more prominent for those in the first two quintiles. The first PC of symmetry (Symm PC1) accounted for 21.2% of the total variation in symmetric shape. It captured variation in total face height, chin projection, facial width and profile convexity or concavity as shown in Figure 2a. Individuals with shorter face heights and protrusive chins (0–40th percentile) were perceived as less attractive. The second PC (Symm PC2) accounted for 13.2% of the total variation in symmetric shape and captured variation ranging from mid-face protrusion and profile convexity to mid face retrusion and profile concavity (Figure 2b). Individuals with mid face protrusion and profile convexity (0–40th percentile) were perceived as more attractive, while those with mid face retrusion and profile concavity (60–100th percentile) were perceived as less attractive. Symm PC3 accounted for 10.3% of the total variation in symmetric facial shape and captured variation in lip height (i.e., lip thickness) and nose prominence as shown in Figure 2c. Based on Symm PC3, individuals with thinner lips in the vertical dimension and larger noses in the anterior-posterior dimension with a downturned tip of the nose (20–40th percentile) were perceived as less attractive. Symm PC4 accounted for 8.9% of variation in symmetric facial shape and reflected variation in lower facial height, mandibular plane inclination and depth of the labio-mental fold as (Figure 2d). Individuals with short lower faces and deep labio-mental folds (0–20th percentile) were perceived as less attractive.

The components of asymmetric facial variation also had significant effects on attractiveness ratings yet to a lesser extent than the symmetric components above. Some asymmetry components showed slightly inconsistent results for their effects on attractiveness ratings. The first PC of asymmetry (Asymm PC1) accounted for 17.3% of the variation in asymmetric facial shape and captured variation in the tip of the nose and chin, relative to the midsagittal plane as shown in Figure 3a. Asymm PC1 effects on attractiveness ratings were somewhat inconsistent. Results indicated that individuals with marked nose tip deviations to the right and chin deviations to the left (0–20th percentile) were perceived as more attractive, whereas individuals with less deviation in the same direction were less attractive (20–40th percentile). Asymm PC2 accounted for 14.9% of the variation in asymmetric facial shape and depicted orbital cants and asymmetry in the length of the mandibular border as shown in Figure 3b. This component only had a small effect on attractiveness ratings for individuals with larger inferior left to right orbital cants and right shorter mandibular border (0–20th percentile), who were perceived as slightly more attractive. Asymm PC3 accounted for 7.5% of the variation in asymmetric facial shape and reflected cants of the commissures of the lips and of the floor of the nose as seen in Figure 3c. Asymm PC3 had the largest effects on attractiveness ratings of the four asymmetry components. Individuals displaying cants of the lip commissures and nose floor (0–40th and 60–100th percentile) regardless of direction were perceived as significantly less attractive. Finally, Asymm PC4 accounted for 6.7% of the variation in asymmetric shape and represented deviations in the root and bridge of the nose relative to the midsagittal plane (Figure 3d). Asymm PC4 only had a significant effect for ratings on the Likert-scale. Individuals with more severely deviated nasal root and bridge to the left side (80–100th percentile) were perceived as less attractive.

Centroid size capturing facial size also had significant effects on attractiveness. Large faces (60–100th percentile) were perceived as less attractive whereas smaller faces (0–20th

percentile) were considered more attractive. Finally, fluctuating asymmetry, as determined by Mahalanobis distances, also had significant effects on perceived facial attractiveness. Individuals with greater facial asymmetry (60–100th percentile) were perceived as less attractive overall. However, the effect was only significant for those in the 60–80th percentile.

Male study participants were rated overall as more attractive than female participants. However, there were overall no major differences in ratings between male and female raters; male raters had lower VAS scores on average but the difference was only marginally significant.

In summary, 3D facial shape components related to facial height, midfacial projection, chin and nose prominence, lip thickness, mandibular plane inclination as well as specific and overall 3D aspects of facial asymmetry were significantly related to attractiveness ratings on the Likert-scale and VAS (p<0.001). Specifically, the following facial shape variations, all relative to individuals in the middle quintile of each measure (40–60th percentile), were associated with increased attractiveness ratings: Mid face protrusion (0–40th percentile), less prominent noses and thicker lips (80–100th percentile), steeper mandibular plane angle, shallow labio-mental folds (60–80th percentile) and smaller faces (0–20th percentile). Conversely, the following facial shapes were related to lower ratings of facial attractiveness: Shorter facial heights with protrusive chins (0–40th percentile); mid face retrusion (80–100th percentiles); faces with protrusive noses and thin lips (20–40%); flat mandibular planes with deep labio-mental folds (0–20%th percentile); any cants of the lip commissures and floor of the nose (0–40th and 60–100th percentiles); larger faces (60 −100th percentile); and increased FA (60–100th percentile).

Discussion

We examined the relationships between objective 3D measures of facial shape and symmetry directly derived from 3D images and subjective ratings of facial attractiveness in a large sample of images. We found several of these 3D measures to be significantly related to perceptions of attractiveness including those related to facial height, midfacial projection, chin and nose prominence, lip thickness, lower facial height, mandibular plane inclination and labio-mental fold depth as well as specific and overall aspects of facial asymmetry (FA). Furthermore, our analysis examined how deviations from the “average” values of these measures in either direction and in magnitude matter for attractiveness ratings. When considering the principal components (PCs) of symmetry, the first and the second PCs had the largest impact on perceived attractiveness. Symm PC1 and Symm PC2 depicting variation mainly on total facial height and midfacial protrusion/retrusion were associated with large changes in facial attractiveness ratings, with both extremes of total facial height or midfacial retrusion being perceived as less attractive. With regards to facial asymmetry, Asymm PC3 was associated with the greatest impact on perceived facial attractiveness indicating that cants of the lip commissures or of the floor of the nose in any direction have negative impacts on perceived facial attractiveness. Facial size, as measured by centroid size, also had effects of large magnitude on facial attractiveness that were observed at the extremes. Very small faces were perceived as more attractive, while very large faces were

perceived as less attractive. While some facial shape indicators such as overall facial size and FA have unidirectional effects on perceived attractiveness, measures captured by the symmetric and asymmetric components have bidirectional effects for deviations from intermediate values that are more prominent at the extremes. This observation of decreased facial attractiveness as facial shape components approach the extremes is consistent with the averageness theory of facial attractiveness, which postulates that within a given population of faces, those closer to the mathematical average face are perceived as more attractive than faces that deviate from the average [27].

Upper face retrusion with lower face protrusion was found to be associated with reduced attractiveness ratings, consistent with other studies [15, 28]. However, unlike those studies, we found upper face protrusion with lower face retrusion to be related to higher not lower attractiveness ratings. Observing a different study population and utilizing different measurements of lower facial retrusion may explain this discrepancy. The study described by Khosravanifard et al. (2013) was conducted with Iranian participants, and it was noted that on average Iranians' mandibles were 6 mm more retruded than their American counterparts. This may indicate that their population displayed more extreme lower facial retrusion that was associated with reduced attractiveness [15]. Naini et al. (2012) found that profiles with extreme mandibular retrusion (−24mm) were also rated as less attractive [28]. In contrast, our study may not have captured individuals with extreme low facial retrusion hence explaining the favorable attractiveness ratings related to low facial retrusion obtained in our study. Related to that, our study sample may have captured severe midfacial retrusion instead, given that one third of it consisted of parents of children with clefts but who themselves had no clefts. Previous studies on this population have shown a higher tendency for midfacial retrusion and longer facial heights compared to populations without cleft risk [21, 29]. This may skew the range of variation away from severe mandibular retrusion. However, in additional analyses that control for being a parent of a child with a cleft or not, we found similar results, suggesting that including this group did not seem to bias our findings.

The impact of facial asymmetry on perceived attractiveness has been generally inconsistent in the literature, with some studies finding it to be a significant predictor of facial attractiveness [8, 30] while others finding significant effects [31, 32]. Our study provides evidence that different 3D aspects of asymmetry including those captured by PCA as well as by overall FA have effects on perceptions of facial attractiveness. Our study showed that cants of the lip commissures and floor of the nose had the most impact in decreasing attractiveness ratings. On the other hand, higher scores of FA decreased attractiveness ratings overall with a significant effect for individuals in the 60–80th percentile. Thus, our study supports an impact of facial asymmetry on perceived attractiveness however not as significant as other aspects of facial variation.

Our study has important implications for clinical practice as well as research. For practice, the study identifies several objective 3D measures of facial shape that clinicians can consider in planning treatments aimed at improving facial esthetics such as orthodontic treatments and orthognathic surgeries and, in consultation with patients, add these into the set of objective indicators of treatment success, especially the ones with large effects. Our findings

indicate that perceptions of facial attractiveness are complex in being related to several aspects of 3D facial variation in unique ways. Follow-up studies to examine the interplays between these objective 3D indicators including how they influence each other's effects can be useful to further understand how individuals perceive attractiveness. For social scientists interested in examining how attractiveness modifies social and economic outcomes such as labor market participation, earnings, and marriage opportunities, our study provides strong evidence that taking 3D images of study participants when possible can provide objective 3D assessment of attractiveness in lieu of subjective ratings.

A limitation of our study is generalizability of results. Our study sample included mainly White individuals from the Midwest and all raters reported their race/ethnicity as non-Hispanic Whites. Therefore, findings may not be fully applicable across racial/ethnic groups and geographic areas due to cultural differences in perceptions of attractiveness. We are unable to evaluate in our study if and how race and ethnicity modify the relationships between objective facial measures and attractiveness ratings. Examining this question in racially/ethnically diverse populations is needed to evaluate generalizability of our results.

Conclusions

Objective 3D measures of facial shape variation derived from 3D images have significant effects on perceived attractiveness. Aspects of symmetric shape variation have the most impact and include facial height, midfacial projection, chin and nose prominence, lip thickness, lower facial height, mandibular plane inclination and labio-mental fold depth. Components of asymmetric variation such as cants of the lip commissures and the base of the nose have the most impact along with higher levels of fluctuating asymmetry and overall facial size.

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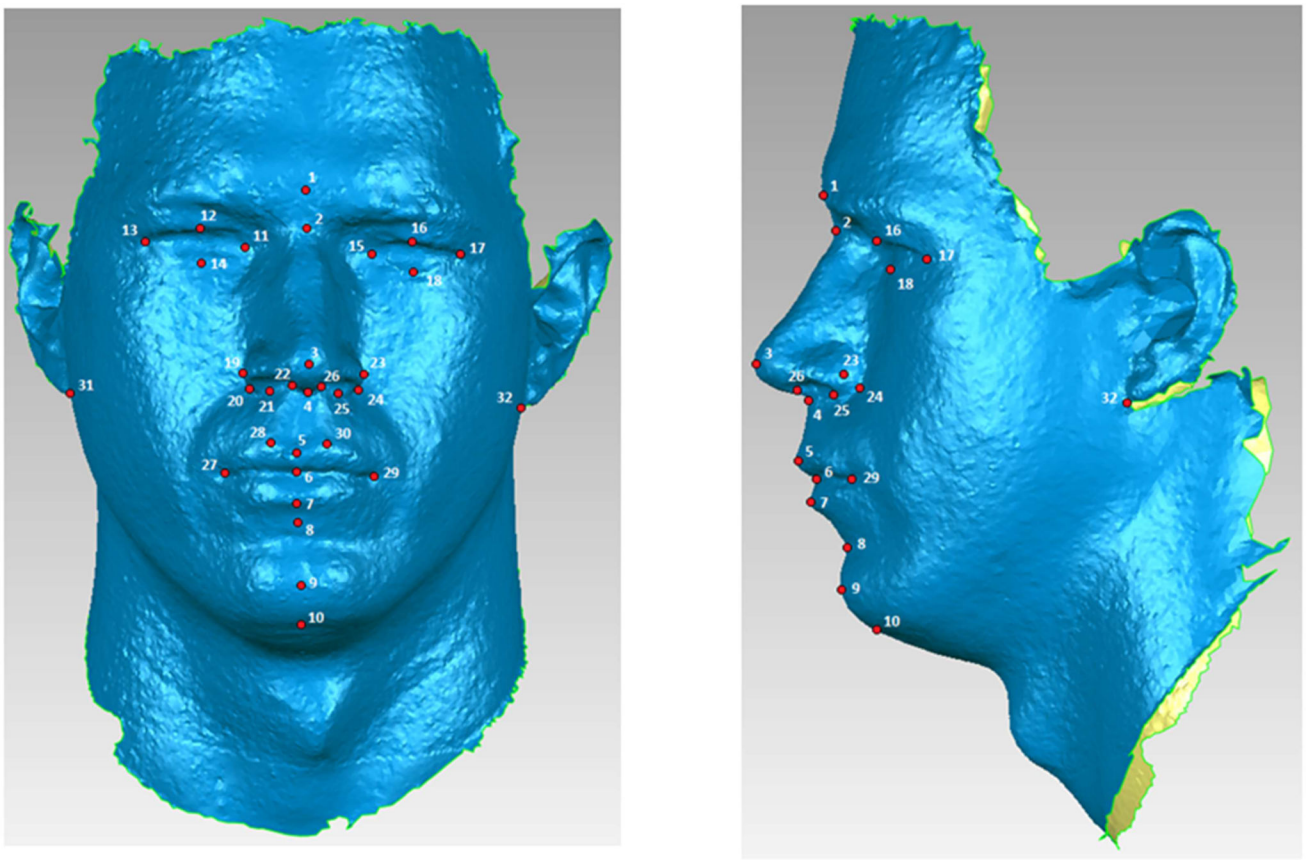
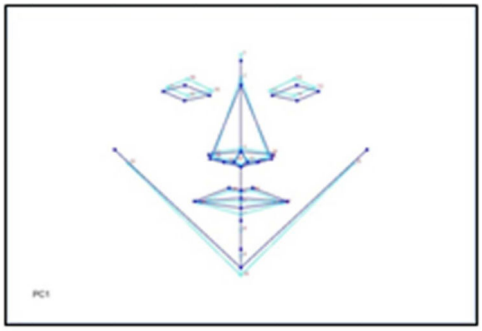
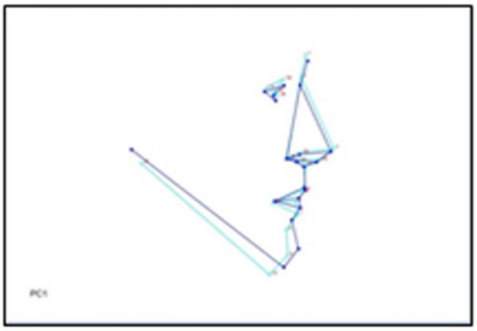


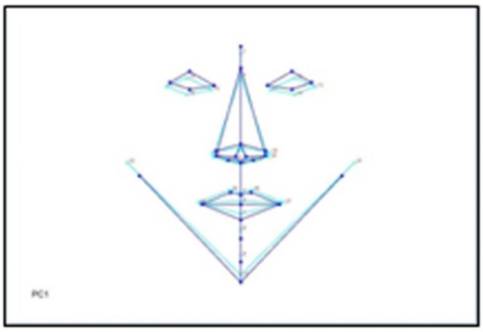
Figure 1.

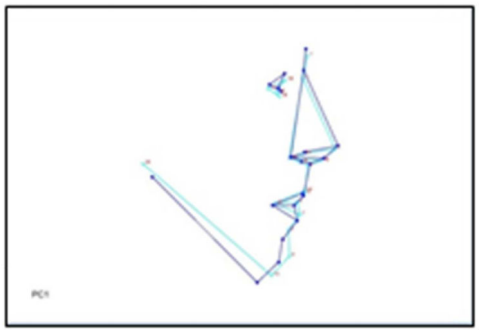
A graphical representation of the location of all 32 coordinate landmarks. For a complete list of landmarks names see Table I.



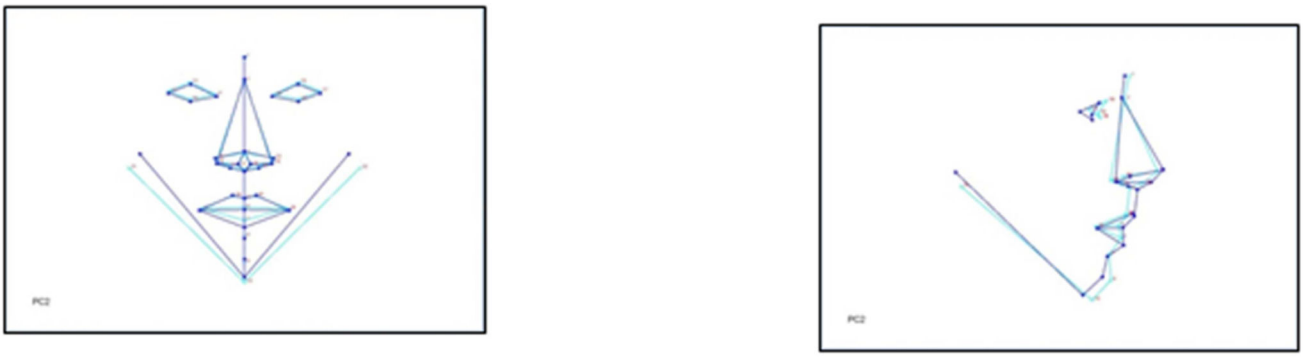


Symm PC1 0-20th percentile

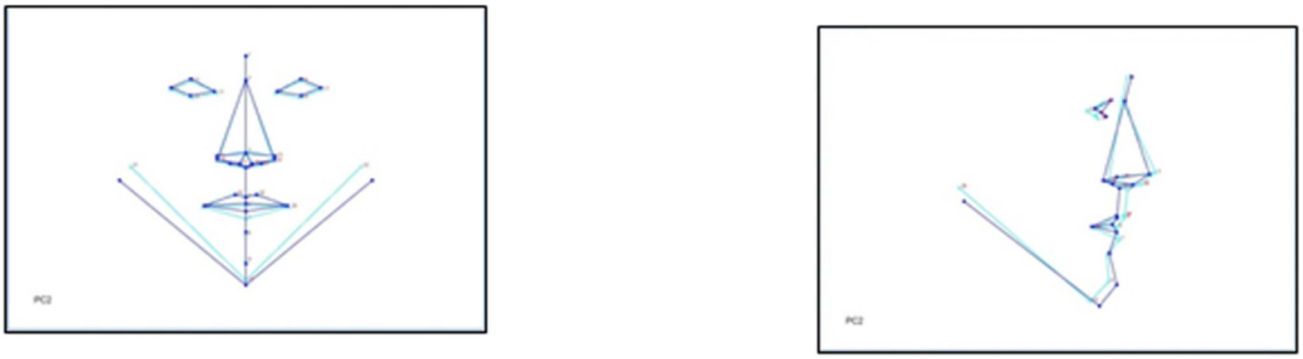




Symm PC1 80-100th percentile



Symm PC2 0-20th percentile



Symm PC2 80-100th percentile

Symm PC3 0-20th percentile

Symm PC3 80-100th percentile

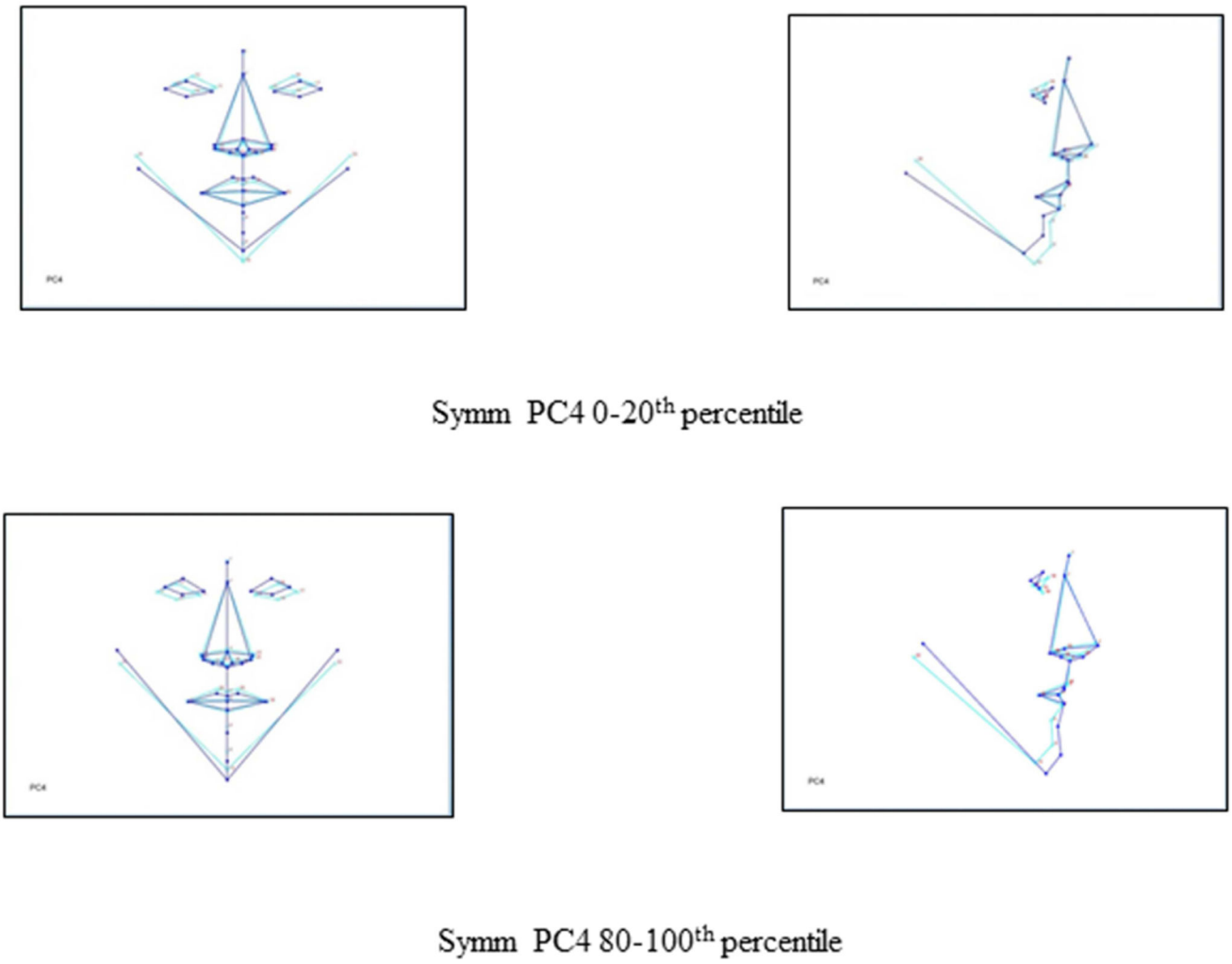
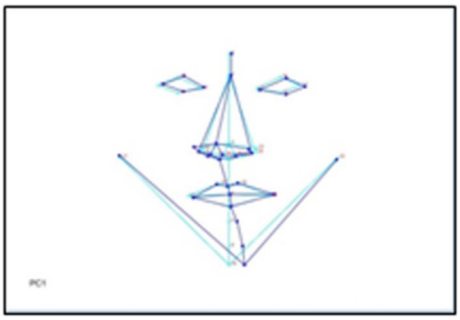
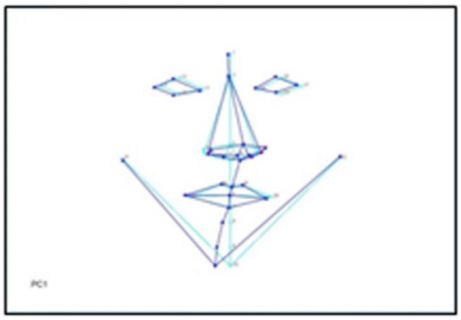


Figure 2.

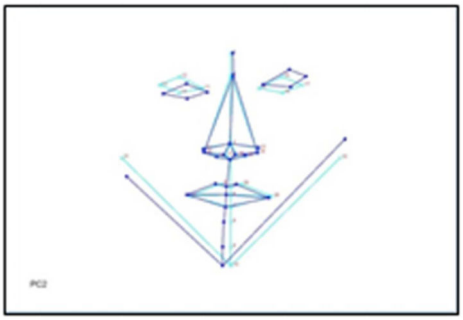
A) Frontal and lateral view of the facial shape symmetric variation depicted by Symm PC1. From this figure on, light blue represents the average facial shape configuration and dark blue represents a configuration with an arbitrary negative (top) or positive (bottom) PC score. Symm PC1 captured variation ranging from individuals with short faces and protrusive chins (negative PC scores, top) to those with long faces and retrusive chins (positive PC scores, bottom). **B)** Frontal and lateral view of the facial shape symmetric variation depicted by Symm PC2 which captured variation ranging from midfacial protrusion and profile convexity (negative PC scores, top) to midfacial retrusion and profile concavity (positive PC scores, bottom). **C)** Frontal and lateral view of the facial shape symmetric variation depicted by Symm PC3 which captured variation ranging from thin lips and protrusive noses (negative PC scores, top) to thick lips and retrusive noses (positive PC scores, bottom). **D)** Frontal and lateral view of the facial shape symmetric variation depicted by Symm PC4 which captured variation ranging from short lower facial heights and deep labio-mental folds (negative PC scores, top) to long lower facial heights and shallow labio-mental folds (positive PC scores, bottom).



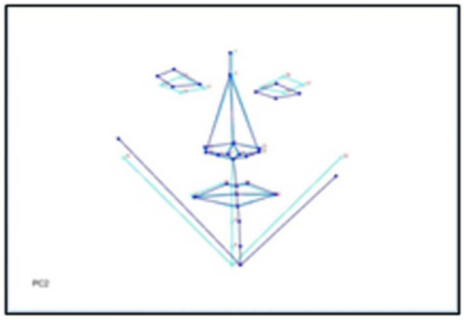
Asymm PC1 0-20th percentile



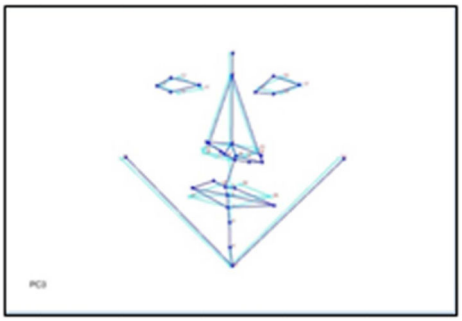
Asymm PC1 80-100th percentile



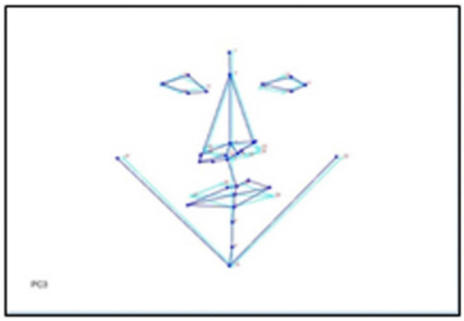
Asymm PC2 0-20th percentile



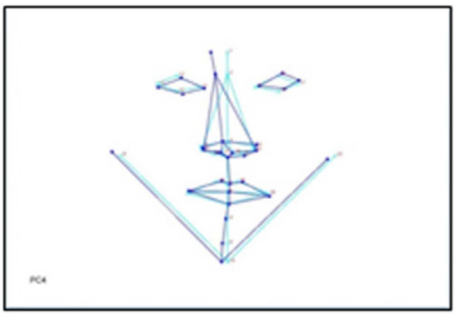
Asymm PC2 80-100th percentile



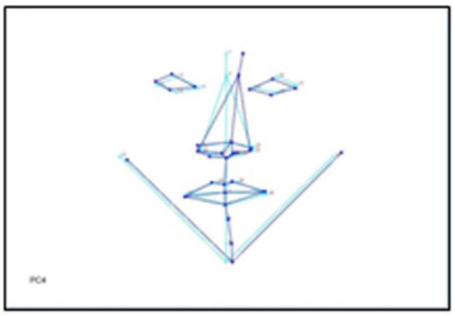
Asymm PC3 0-20th percentile



Asymm PC3 80-100th percentile



Asymm PC4 0-20th percentile



Asymm PC4 80-100th percentile

Figure 3.

A) Frontal view of the facial shape asymmetric variation depicted by Asymm PC1. From this figure on, light blue represents the average facial shape configuration and dark blue represents a configuration with an arbitrary negative (left) or positive (right) PC score. Asymm PC1 shows variation ranging from deviations of the nose tip to the right and chin to the left side (left image, negative PC scores) to the exact opposite configuration (nose tip to the left and chin to the right side, right image, positive PC scores). **B)** Asymm PC2 shows variation ranging from inferior left to right orbital cants and larger left mandibular border (left image, negative PC scores) to the exact opposite configuration (right image, positive PC scores). **C)** Asymm PC3 shows variation ranging from inferior right to left cants of lip commissures and floor of the nose (left image, negative PC scores), to the exact opposite morphology (right image, positive PC scores). **D)** Asymm PC4 shows deviations on the base and bridge of the nose to the right (left image, negative PC scores) or the left side (right image, positive PC scores).

Table 1

Anthropometric Landmarks used for Facial Shape Analysis

Number	Landmark	Number	Landmark
1	Glabella	17	Left Exocanthion
2	Nasion	18	Left Palpebrale Inferius
3	Pronasion	19	Right Alare
4	Subnasale	20	Right Alar Curvature Point
5	Labiale Superius	21	Right Subalare
6	Stomion	22	Right Columnella
7	Labiale Inferius	23	Left Alare
8	Sublabiale	24	Left Alar Curvature Point
9	Pogonion	25	Left Subalare
10	Gnathion	26	Left Columnella
11	Right Endocanthion	27	Right Chelion
12	Right Palpebrale Superior	28	Right Crista Philtri
13	Right Exocanthion	29	Left Chelion
14	Right Palpebrale Inferius	30	Left Crista Philtri
15	Left Endocanthion	31	Right Otobasion Inferius
16	Left Palpebrale Superius	32	Left Otobasion Inferious

Table 2

Descriptive Statistics of Study Variables

	Mean	Standard Deviation	Min	Max
Attractiveness Ratings				
Likert-Scale	2.68	0.75	1	5
VAS	39.84	17.46	0	93
Facial Symmetry Components				
PC1	0.00	0.03	−0.08	0.09
PC2	0.00	0.03	−0.08	0.07
PC3	0.00	0.02	−0.06	0.10
PC4	0.00	0.02	−0.06	0.06
Facial Asymmetry Components				
PC1	0.00	0.01	−0.03	0.03
PC2	0.00	0.01	−0.02	0.02
PC3	0.00	0.01	−0.02	0.02
PC4	0.00	0.01	−0.01	0.01
Centroid Size	269.50	13.18	238.70	302.72
Fluctuating Asymmetry				
Procrustes distance	0.02	0.00	0.01	0.03
Mahalanobis distance	6.25	0.91	4.00	8.98
Male participant	0.31	0.46	0	1
Male rater	0.50	0.50	0	1

Notes: The descriptive statistics are shown for the continuous objective measures. In the regression analyses, these measures are represented by dummy variables for their quintiles.

Table 3

Effects of All Facial Objective 3D Measures when Included Jointly in One Regression on Facial Attractiveness Ratings

Objective 3D Measures	Main aspect of facial shape variation captured	Likert-Scale		VAS	
		β	SE	β	SE
Facial Symmetry PC1	Total face height (TFH) & chin projection				
1st quintile	Short TFH, protrusive chin	−0.242 ***	(0.044)	−4.076 ***	(0.888)
2nd quintile	Long TFH, retrusive chin	−0.129 ***	(0.042)	−1.888 ***	(0.672)
4th quintile	↓	−0.014	(0.020)	0.356	(0.547)
5th quintile		−0.039	(0.032)	−0.571	(0.960)
Facial Symmetry PC2	Mid face projection				
1st quintile	Mid face protrusion	0.084 ***	(0.025)	1.327 **	(0.529)
2nd quintile	↓	0.065 **	(0.028)	0.683	(0.523)
4th quintile		−0.045 *	(0.028)	−3.333 ***	(0.707)
5th quintile	Mid face retrusion	−0.252 ***	(0.039)	−7.939 ***	(1.140)
Facial Symmetry PC3	Nose projection and lip thickness				
1st quintile	Protrusive nose & thin lips	−0.027	(0.028)	−0.870	(0.742)
2nd quintile	↓	−0.061 **	(0.027)	−1.692 ***	(0.554)
4th quintile		−0.021	(0.029)	−0.756	(0.507)
5th quintile	Retrusive nose & thick lips	0.046	(0.041)	1.266	(1.047)
Facial Symmetry PC4	Lower face height (LFH), mand. plane inclination & labio-mental fold depth				
1st quintile	Flat mand. plane, deep labio-mental fold	−0.063 ***	(0.023)	−1.688 ***	(0.559)
2nd quintile	↓	−0.019	(0.026)	0.506	(0.582)
4 quintile		0.070 **	(0.030)	1.408	(0.968)
5th quintile	Steep mand. plane, shallow labio-mental fold	0.030	(0.036)	1.108	(0.830)
Facial Asymmetry PC1	L-R deviation of nose tip and chin				

Objective 3D Measures	Main aspect of facial shape variation captured	Likert-Scale		VAS	
		β	SE	β	SE
1st quintile	Nose tip deviates right, chin left	0.061***	(0.022)	1.985***	(0.688)
2nd quintile	↓	−0.093***	(0.033)	−1.058*	(0.627)
4th quintile		−0.017	(0.039)	−0.127	(0.758)
5th quintile	Nose tip deviates left, chin right	0.027	(0.035)	0.457	(0.525)
Facial Asymmetry PC2	Orbital cants, chin deviation and lateral size discrepancy of mand. border				
1st quintile	Left to right inferior orbital cant, chin deviates right & smaller mand. right border	−0.042*	(0.025)	0.843*	(0.441)
2nd quintile		−0.021	(0.021)	−0.423	(0.504)
4th quintile	↓	−0.037	(0.029)	−1.236*	(0.632)
5th quintile	Right to left inferior orbital cant, chin deviates left & smaller mand. left border	−0.004	(0.032)	−0.462	(0.515)
Facial Asymmetry PC3	Commissure and floor of the nose cants				
1st quintile	Right to left inferior floor of the nose & commissure cant	−0.170***	(0.038)	−4.201***	(0.561)
2nd quintile	↓	−0.171***	(0.033)	−5.039***	(0.793)
4th quintile		−0.158***	(0.024)	−4.557***	(0.949)
5th quintile	Left to right inferior floor of the nose & commissure cant	−0.171***	(0.027)	−4.801***	(0.559)
Facial Asymmetry PC4	Root & bridge of the nose deviation				
1st quintile	Root & bridge deviates right	0.018	(0.057)	−1.022	(0.937)
2nd quintile	↓	0.014	(0.047)	−1.146	(1.001)
4th quintile		0.020	(0.045)	−1.082	(0.712)
5th quintile	Root & bridge deviates left	−0.065	(0.040)	−3.446***	(0.756)
Centroid Size	Overall facial size				
1st quintile	Smallest size	0.288***	(0.033)	6.533***	(0.989)
2nd quintile	↓	0.021	(0.021)	0.179	(0.432)
4th quintile		−0.235***	(0.037)	−5.929***	(1.065)

Objective 3D Measures	Main aspect of facial shape variation captured	Likert-Scale		VAS	
		β	SE	β	SE
5th quintile	Largest size	−0.342***	(0.033)	−9.312***	(1.071)
Mahalanobis FA	Overall Asymmetry				
1st quintile	Smallest Asymmetry	−0.034	(0.022)	−0.428	(0.718)
2nd quintile	↓	0.001	(0.040)	0.462	(0.866)
4th quintile		−0.154***	(0.023)	−3.843***	(0.618)
5th quintile	Largest Asymmetry	−0.029	(0.029)	−1.013	(0.701)

Notes: The Table reports the effects (β) and their standard errors (SE) of the objective 3D measures of facial shape and variation on the Likert scale and VAS ratings of attractiveness when these objective measures are included simultaneously in the regression for the attractiveness ratings. Each objective 3D measure is represented by 4 dummy variables for its 1st, 2nd, 4th, and 5th quintiles with the 3rd quintile (representing the average shape captured by each measure) as the reference category. The βs represent the effects of these quintiles on attractiveness relative to the 3rd quintile. For example, the first β under VAS of −4.076 indicates that individuals who ranked in the first quintile of the first symmetry principal component were rated as less attractive by about 4 units on average compared to those ranking in the third quintile of that principal component. The column labeled "Main aspect of facial shape variation captured" describes the facial shape captured by each objective 3D measure, and the solid downward arrow represents the overall change in facial shape when transitioning from the 1st quintile to the 5th quintile of that measure. The effects of the objective 3D measures were estimated using generalized least squares linear regression including random effects for the raters and controlling for raters' and study participants' gender (not shown for brevity). Separate regressions were estimated for the Likert scale and the VAS ratings of attractiveness. Standard errors are clustered at the rater level using a Huber-type estimator. PC=principal component.

*$p < 0.1$

**$p < 0.05$

***$p < 0.01$.

The regressions are estimated for 3130 ratings (10 raters each rating 313 study participants).