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# Measuring facial symmetry: a perception-based approach using 3D shape and color

**Abstract**

**Objective:** Facial symmetry is an important factor affecting esthetics. Thus, its restoration is an essential task in maxillofacial surgery. The aim of this study is to develop an objective measure of facial asymmetry by a novel approach where both the shape and the color are taken into account and to validate its correlation with perception.

**Methods:** Optical three-dimensional (3D) face scans of 30 healthy adults are performed. Face-specific asymmetry indices are calculated by quantifying color differences as well as spatial distances between 3D data of a face and its mirrored copy. Subjective ratings of symmetry and attractiveness of the faces by 100 subjects are used to validate these indices.

**Results:** The symmetry ratings show significant correlations with color and geometric asymmetry indices. The attractiveness ratings correlate only weakly with both indices. However, the product of the indices exhibits significant correlations with both attractiveness and symmetry ratings.

**Conclusion:** The presented combined asymmetry index comprising shape and coloring turned out to reflect subjective perception of both facial symmetry and attractiveness. It thus promises to be a valid objective measure for facial esthetics, which could contribute, e.g., to the evaluation of surgical methods as well as to the design of craniofacial prostheses.

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## Introduction

The human face plays a key role in visual perception und social interaction. Against this background, it is not surprising that in oral and maxillofacial surgery, one has always been seeking for an objective measure to assess the outcome of surgical procedures with respect to esthetics [1, 2]. Whether such a general objective measure can be found may be questionable, as the perception of "beauty" will always rely on the historical and cultural imprint as well as on individual factors [11]. Nevertheless, facial symmetry, i.e., mirror symmetry, is regarded as one of its basic constituents [3, 14, 16, 17, 24], and a significant correlation has been found between ratings of symmetry and attractiveness [18, 20]. Although a completely symmetrical facial surface does not occur in nature and is not achievable by surgery, it is also obvious that perceivable deviations from symmetry are no desirable result of surgery. This has, e.g., been shown with respect to the perception of facial asymmetry in rhinoplasty patients [8] and is widely accepted in the context of surgical procedures concerning the correction of a cleft lip and palate [12, 22, 23, 25]. Thus, maintaining or restoring a symmetric appearance is also a primary goal when, e.g., designing craniofacial prostheses [21].

The symmetry characteristics of a face involve its shape and its color. Various kinds of facial symmetry analyses based on two-dimensional (2D) data, like photographs [1, 11, 19] or radiographs [15], or based on three-dimensional (3D) data [4, 9, 10], gained from soft tissue surface measurements, have been presented in literature so far. Either a set of only a few anatomically defined landmarks or a spatially dense point cloud is used as the typical data basis. Often, a face-specific measure of asymmetry is subsequently calculated. In all these approaches, color information is either completely omitted or just used to identify anatomical landmarks.

In this contribution, we present a new approach for calculating a face-specific asymmetry index from optical 3D scans that include color information. For this purpose, distances in color space as well as spatial distances between the facial surface and its mirrored copy are analyzed automatically. First, a color and a geometric asymmetry index are calculated separately. Both indices are then combined to obtain a single overall face-specific score including shape as well as coloring for the first time to our knowledge.

Asymmetry indices aim at providing objective measures. In applications, like maxillofacial surgery or design of craniofacial prostheses, an important question is how such objective measures are related to subjective perceptions. The approach of the color asymmetry index is inherently linked closely to esthetics because color itself is a concept involving human perception. To investigate the relationship between objective measurements and subjective assessments, color and geometry-based asymmetry indices are compared with ratings with respect to the attributes “symmetry” and “attractiveness”. Although one can intuitively assume that severely asymmetric faces will be rated less attractive, it is a more challenging task to find such a relationship for faces being within an ordinary range of asymmetries.

In summary, in this study, the aim is to develop techniques useful in the investigation of facial asymmetry in terms of shape and coloring that make esthetics measurable.

# Materials and methods

## Participants

For this study, two independent groups of participants are recruited. 3D face scans of the members of the first group are performed and the members of the second group are asked to rate the face stimuli they are presented with. The first group consists of 30 healthy young adults aged between 22 and 43 years (average 27.4 years; 15 women and 15 men). Participants with self-reported prior surgery or any obvious negative impacts on facial symmetry or proportions are excluded from the study. The group of raters includes 50 women and 50 men aged between 22 and 76 years (average 42.5 years).

## The topometric measuring system

The facial surface of a subject is acquired using a measuring system developed by our group [7], which is based on a fringe projection technique. It consists of a color video camera in the middle (main camera), two monochrome video cameras, and a video projector for fringe projection (Figure 1).

Together, these three cameras form two stereoscopic imaging pairs sharing the main camera as a common basis. For the current configuration, the spatial resolution is estimated to be 0.2 mm in the viewing direction of the main camera and 0.5 mm in directions perpendicular to that. The result of the acquisition is a 3D point cloud. A surface is then reconstructed by adding a triangle mesh. A standard red green blue (sRGB) color value from the main camera image is assigned to each 3D point of the cloud.

## Acquisition of colored 3D facial surface data

Colored point clouds of the faces of the 30 participants in the first group are acquired. The facial region used for analyzing asymmetry is extracted from the surface data by removing the ears, the neck, and

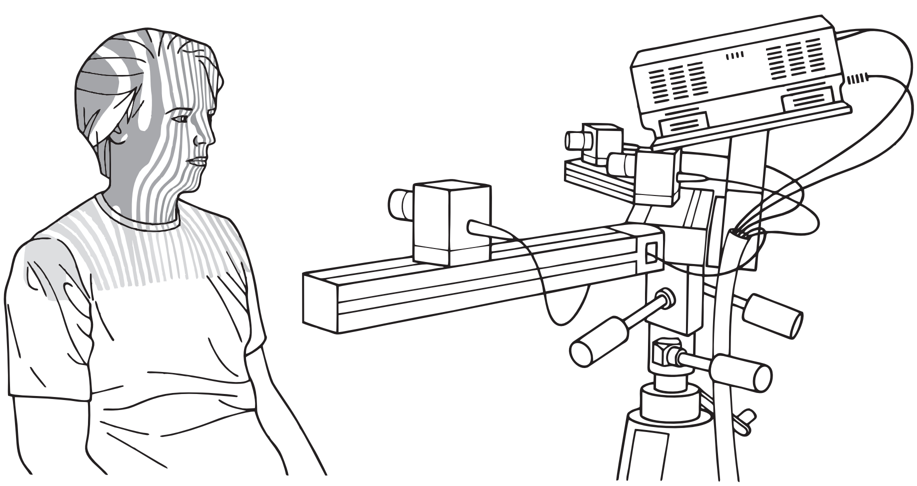

**Figure 1** Topometric system based on a fringe projection technique used for 3D data acquisition of the facial surface.

all points above the hairline. We decided to exclude the ears because their complex surface could not be acquired with sufficient detail. Since they are located in the peripheral area, they are expected to be less important for perception [24]. The face stimuli presented to the raters are generated from these trimmed point clouds so that hairstyle, ears, clothing, and neck are not visible.

The trimmed point clouds contain around 8000–13,000 3D points depending on the actual face size. This is approximately one tenth of the maximum number achievable at full resolution and considered to render a sufficiently detailed reconstruction of facial structures.

To determine a reliable color asymmetry index, the following procedure has been implemented:

– Preceding each measurement, a white balance is performed with the projector switched to white light projection to avoid color casts.
– The distance between the face and the measuring system has to be kept constant to ensure a fixed reproduction scale and a constant brightness of the projector illumination.
– The subject is not allowed to wear any makeup, glasses, beard, or piercings for an unbiased and comparable color appearance.
– Oily or sweaty marks on the skin are removed prior to the measurement to avoid disturbing reflections.
– Finally, a precise alignment of the subject's face within the measurement setup has to be ensured to obtain a symmetrical illumination.

## Preprocessing of facial color data

Despite the aforementioned preventive measures, the skin of the subjects may still have a glossy appearance in certain points when exposed to the directional illumination of the projector. These effects may appear, e.g., as single bright spots on the tip of the nose, on the forehead, or within the open eyes. Additional chromatic and luminance noise can be caused by the color camera. In Figure 2, the result of a 3D colored surface measurement of a subject's face containing local color errors is displayed.

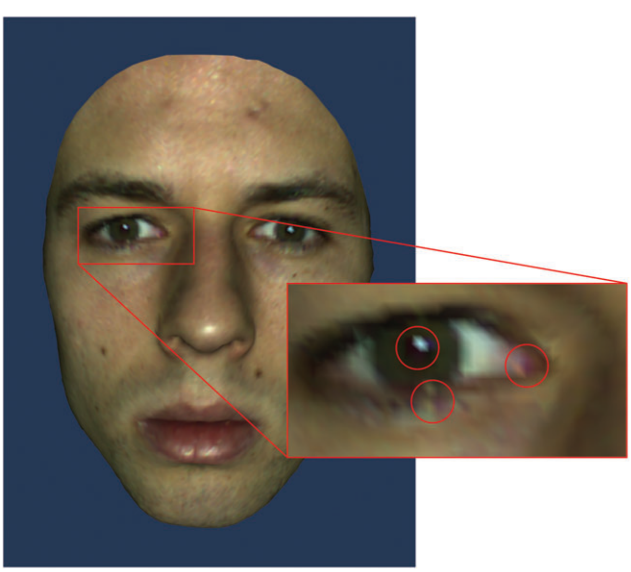

**Figure 2** Colored point cloud with marked color errors.

These errors, which may affect the color asymmetry index, have to be identified and the corresponding points have to be deleted from the cloud.

Figure 3 displays all colors of the face as coordinates in the CIELAB color space.

Most color values are located within a compact region representing typical skin colors. In contrast, outliers are found within a region of lower point density, a fact that can be exploited to identify them. First, for each point, the $k$ nearest neighbors in terms of Euclidean distance ($\Delta E$) are searched. If the average of the distances $\Delta E_{NN_i}$, $i$=1,…, $k$ of a point to its $k$ nearest neighbors exceeds a threshold $\Delta E_{\text{thres}}$, this point will be defined as an outlier:

$$\frac{1}{k}\sum_{i=1}^{k}\Delta E_{NN_i} > \Delta E_{\text{thres}}. \tag{1}$$

The parameters $k$=3 and $\Delta E_{\text{thres}}$=6.0 have turned out to be suitable for finding the disturbing color artifacts. Those are marked in red in Figure 3.

Then, the 3D points corresponding to the outlying colors are identified within the face (Figure 4) and are removed from the point cloud.

Finally, resulting gaps are closed by a new triangulation, i.e., new triangles are generated to connect the points, interpolating the colors in the gaps.

To reduce the remaining color noise, a Gaussian blur filter with a filter radius of 2 pixels is applied. It provides a suitable blurring for the given image resolution, so that relevant color asymmetric features, like nevi, are preserved. Figure 5 depicts the blurred face.

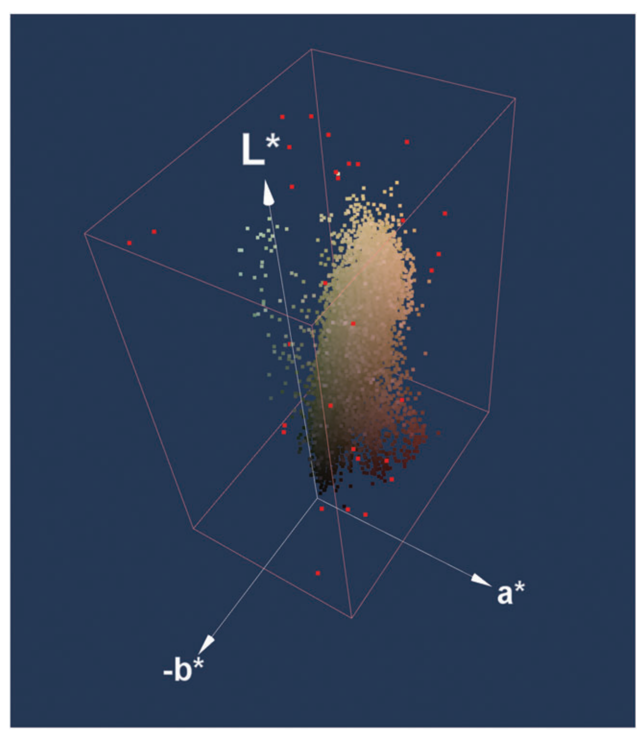


**Figure 3** Facial colors displayed as points in CIELAB color space. Outliers are marked in red.

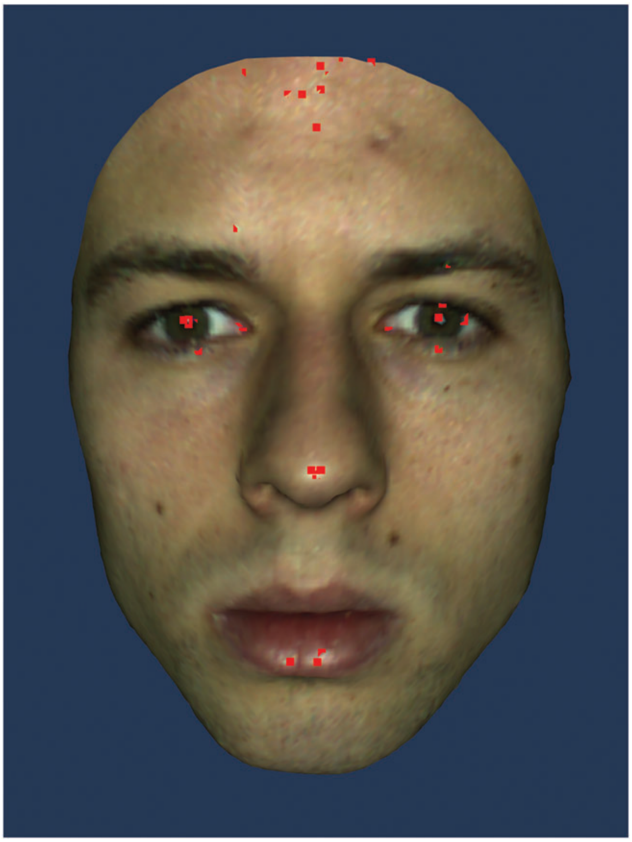

**Figure 4** Face with identified color artifacts.

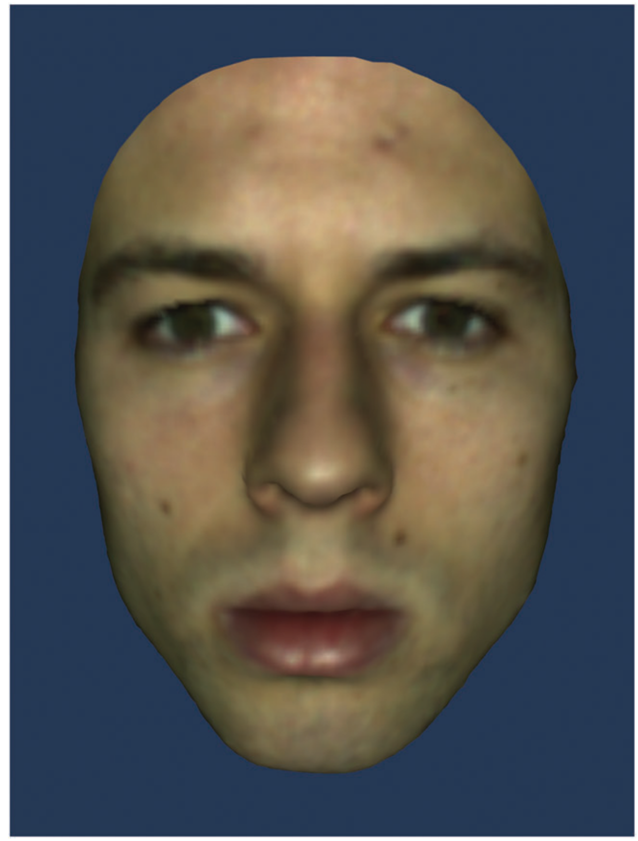

**Figure 5** Face filtered by a Gaussian blur.

## Determination of the asymmetry indices

The method used to determine a symmetry plane is a crucial factor when creating an objective asymmetry index. Here, the facial symmetry plane is determined on the basis of the shape of the face using the technique described in detail in [5], which is a modified version of the approach proposed by Benz et al. [4]. The facial point cloud is repeatedly mirrored and registered to the original cloud using the iterative closest point algorithm [6]. Between each repetition, asymmetrical parts are removed according to a threshold. Finally, from the pair of original and processed clouds, an average symmetry plane is calculated by a least squares fitting. Using this plane, a mirrored copy of the point cloud is then calculated. From these two surfaces, a geometric and a color asymmetry index are determined.

The geometric asymmetry index $AI_{geom}$ is defined as the mean spatial distance $\bar{d}$ between the facial surface and its mirrored copy, scaled by the size of the face. The face size is estimated by the diagonal $D$ of its bounding box in frontal view. The resulting (typically very small) dimensionless values are multiplied by a factor of 1000, which of course does not influence the statistics:

$$AI_{geom} := \frac{\bar{d}}{D} \cdot 1000. \tag{2}$$

Analogously, a color asymmetry index $AI_{color}$ is defined from the color distance calculated as $\Delta E$ values between the points of the original cloud and the corresponding points of the reflected cloud. For this purpose, the sRGB color values from the main camera of the measuring system are transformed into CIELAB color values using the 10° standard observer and the D65 standard illuminant as a reference white [13, 26]. The $\Delta E$ values are a measure of the local color asymmetry (see Figure 7).

An overall face-specific score of color asymmetry, the color asymmetry index $AI_{color}$, is obtained by averaging over all $\Delta E$ values within the face.

$$AI_{color} := \overline{\Delta E}. \tag{3}$$

## Survey of subjects for subjective ratings of symmetry and attractiveness

One hundred test persons are asked to assess the recorded faces with respect to the two attributes symmetry and attractiveness. For each acquired face, a rotation sequence consisting of 20 images is presented to the test person. This sequence contains rendered 3D views of the face rotating by 120° in total and lasts overall 4 s. A part of it is depicted in Figure 6.

After the animation is finished, the test person is asked to rate the symmetry on a visual analogue scale. The order of the faces presented is randomized. At least 1 week later, the presentation of the face stimuli is shown again and the same person is asked to rate the attractiveness.

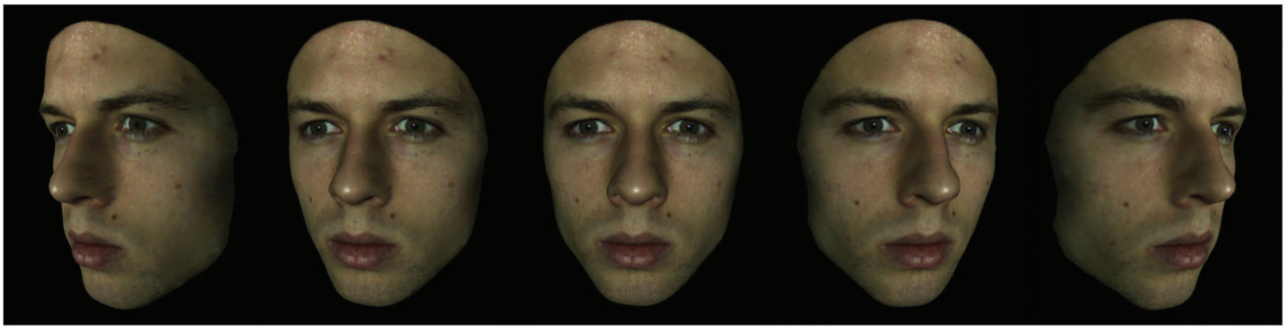

**Figure 6** Part of a rendered sequence of images representing an animated rotation of 120°.

For the evaluation of the rating, the position chosen on the scale is converted into an integer number in the range between 0 (meaning "very unsymmetrical" or "very unattractive") and 100 (meaning "very symmetrical" or "very attractive").

### Statistical analysis

To investigate the relationship between objective measures and subjective ratings, correlation coefficients *r* (Pearson) are calculated. For this purpose, the 100 subjective ratings per attribute and per face are averaged. For all scatterplots displayed in the Results section, each showing a combination of objective and subjective values, linear regression lines (least squares fitting) will be added, if the correlations are significant with respect to a 5% level. Statistical evaluation of the data is carried out with the software package "R" [27].

## Results

### Asymmetry analyses

The study presented here is carried out in two steps. First, the 30 faces are scanned, and for each of them, the color asymmetry index as well as the geometric asymmetry index is calculated. An example of local asymmetry distributions in terms of color distances or spatial distances [5] between a face and its reflection is depicted in Figures 7 and 8, respectively. In Figure 7, asymmetric features, like nevi, appear on both sides of the face in the local asymmetry map. The asymmetric reflections on the tip of the nose and on the lower lip (see Figure 5) have not disappeared by the preparing procedures, but have been reduced.

In a second step, the acquired colored point clouds of the faces are presented to a group of 100 subjects. They are asked to assess the faces with respect to symmetry and attractiveness.

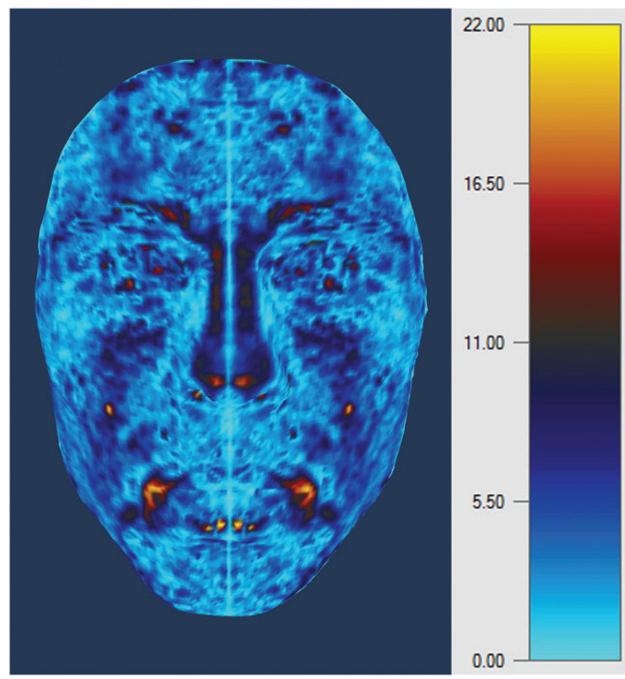


**Figure 7** Distribution of local color asymmetry in units of $\Delta E$.

### Correlations between the objective asymmetry indices and subjective ratings

Figure 9 displays the mean subjective symmetry ratings $Sym_{mean}$ versus the measured color asymmetry index $AI_{color}$.

The same is done for the second rated attribute, the attractiveness. The equivalent plot is shown in Figure 10.

Although the symmetry ratings correlate significantly to the measured color asymmetry, the attractiveness ratings do not. Both correlation coefficients are negative because the scales of subjective and objective values are opposite to each other.

The $AI_{geom}$ shows correlations with both subjective assessments quite similar to those of the $AI_{color}$. This is depicted in Figures 11 and 12, respectively.

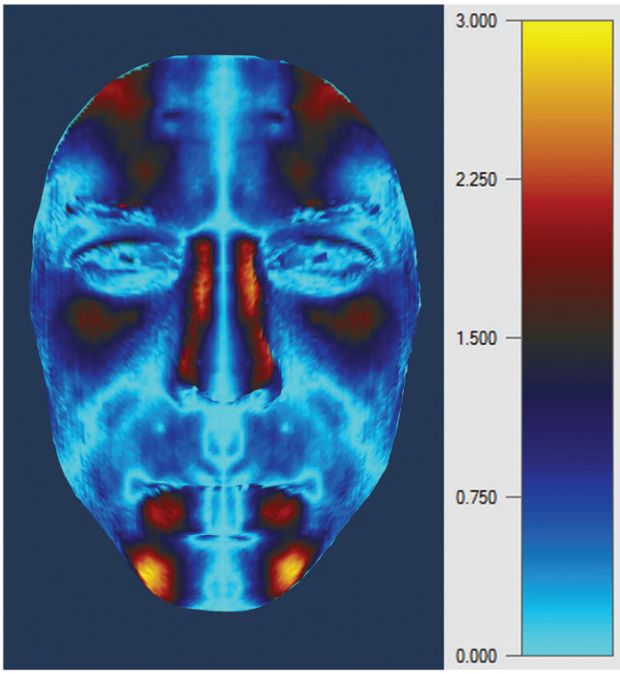


**Figure 8** Distribution of local geometric asymmetry in mm.

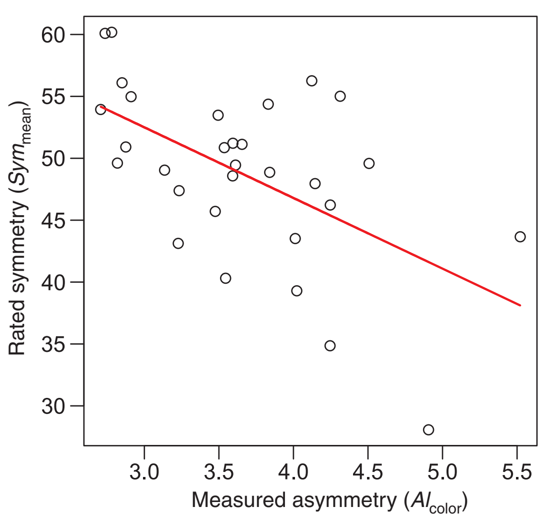


**Figure 9** Scatterplot of symmetry ratings averaged per face $Sym_{mean}$ against $AI_{color}$ ($r$=-0.552, p=0.002).
The red line denotes the linear regression line.

Compared with each other, the objective measures $AI_{color}$ and $AI_{geom}$ show a significant correlation of $r$=0.433, with p=0.017. The observed correlations between both objective asymmetry indices and the perceived symmetry raise the question whether a combination of both can enhance the correlation. We suggest to combine them using their direct product. This is motivated in the Discussion section. Figure 13 shows the product of the two

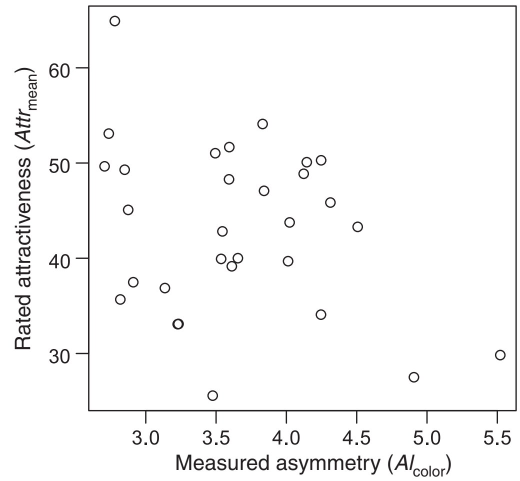


**Figure 10** Scatterplot of attractiveness assessments averaged per face $Attr_{mean}$ against $AI_{color}$ ($r$=-0.302, p=0.105).

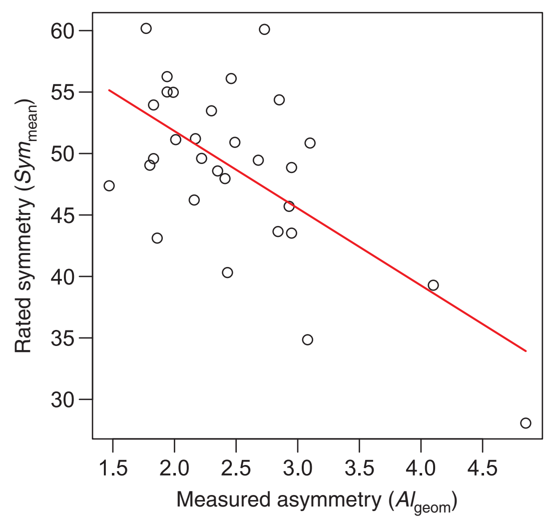


**Figure 11** Scatterplot of symmetry assessments averaged per face $Sym_{mean}$ against $AI_{geom}$ ($r$=-0.633, p<0.001).
The red line denotes the linear regression line.

asymmetry indices $AI_{color} \cdot AI_{geom}$ versus the mean subjective symmetry assessments $Sym_{mean}$.

This correlation is significant (p<0.001) and the highest among all values investigated here. It is especially notable, that even the correlation of the product with the subjective attractiveness ratings is significant, as illustrated in Figure 14.

## Discussion

A novel method of calculating a facial asymmetry index from colored 3D scans has been demonstrated. It is based

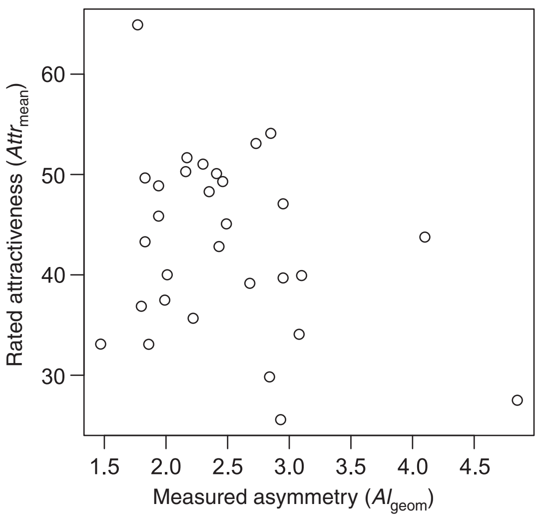


**Figure 12** Scatterplot of attractiveness assessments averaged per face $Attr_{mean}$ against $AI_{geom}$ ($r$=-0.303, p=0.104).

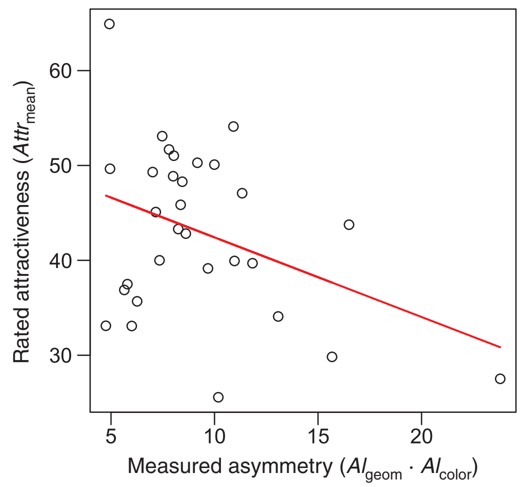


**Figure 14** Scatterplot of attractiveness assessments averaged per face $Attr_{mean}$ against $AI_{color}{\cdot}AI_{geom}$ ($r$=-0.378, p=0.039). The red line denotes the linear regression line.

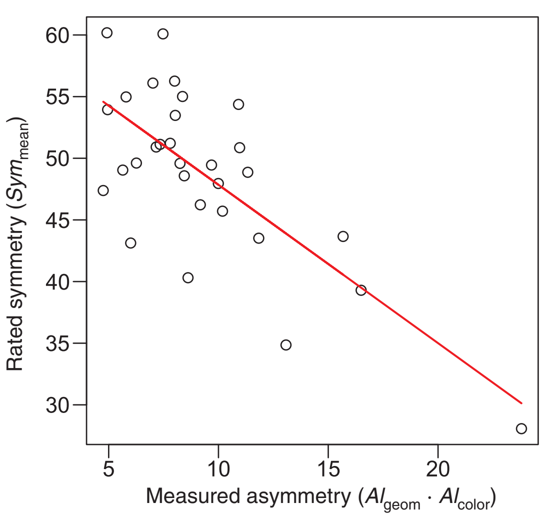


**Figure 13** Scatterplot of symmetry assessments averaged per face $Sym_{mean}$ against $AI_{color}{\cdot}AI_{geom}$ ($r$=-0.730, p<0.001). The red line denotes the linear regression line.

on a geometric and a color asymmetry value. Since only color differences ($\Delta E$ values) are calculated for the determination of the latter, the accuracy of absolute color values is of little importance. Thus, a simple white balance performed before each facial surface measurement is sufficient to ensure that the acquired facial colors are located within a well-reproducible region of typical skin colors. This provides more reliable $\Delta E$ values and thereby enhances the relevance of the color asymmetry index for human perception. A more sophisticated procedure of color calibration is not considered to be necessary.

Both kinds of facial asymmetry distributions, the color distance one, denoted in units of $\Delta E$, and the spatial distance one, denoted in millimeters, are different. The asymmetrical regions with respect to shape (Figure 8) include large areas, in this example, of the forehead, the nose, the cheeks, and the chin. In contrast, the asymmetrical regions with respect to color values (Figure 7) are rather fragmented and do not necessarily match the shape asymmetries. They include nevi, the eyes, the eyebrows, transitions between normal skin and the lips, like the corners of the mouth, and specular spots, which could not be removed completely by the preprocessing. In the case discussed here, the nose is a region where shape and color asymmetry overlap. This behavior can be explained by a shading effect. With the nose being slanted a little to one side and under straight directional lighting during the measurement, one side of the nose appears darker than the other. Therefore, shape and color appearance interfere. Typically, however, geometric and color asymmetries complement one another.

A crucial question with respect to the validity of an asymmetry index is whether it is related to human perception. Figure 15 gives an overview of all correlations of measured asymmetry indices and subjective ratings evaluated in this contribution.

Both $AI_{color}$ and $AI_{geom}$ show significant correlations with the symmetry ratings. Their correlations with the attractiveness ratings are smaller and not significant with respect to a 5%–threshold. The two asymmetry indices are, on the one hand, not completely independent as they correlate significantly with each other. On the other hand, the color asymmetry index contains a considerable amount of supplemental information, which is important for visual perception.

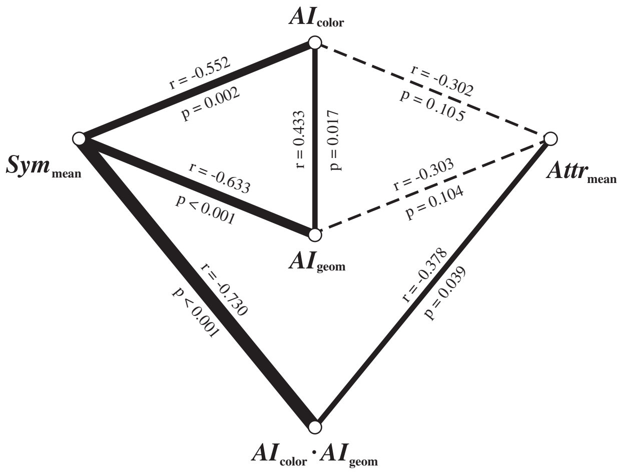


**Figure 15** Pearson correlation coefficients *r* between objective measurements and subjective ratings encoded as line widths. Dotted lines denote nonsignificant correlations.

Hence, the question arises whether a suitable combination of both asymmetry indices can result in a higher correlation with the subjective ratings. The indices represent averages of different quantities (a dimensionless length and distance in the CIELAB color space). Thus, adding them would not be reasonable. As they correlate positively with each other and take values within a similar range, we chose to multiply them. The resulting product shows a high correlation with the symmetry ratings and even a significant one with the attractiveness ratings. Therefore, it has been demonstrated that it accounts for a significant part of facial esthetics.

To obtain the face-specific asymmetry indices, the distributions of local color or spatial asymmetries are averaged per face. This is the simplest way of calculating one single value from a distribution of many values. It implies that all facial regions are weighted equally regardless of their individual importance for visual perception but yet is successful. However, it can reasonably be expected that the current correlation values will be easily surpassed by finding a sophisticated weighting in future research.

The geometric asymmetry index has already been used to evaluate the amount of soft tissue symmetry changes after orthognatic surgery [28]. Both shape and color asymmetry indices also appear to be promising tools to support, e.g., the manufacturing of craniofacial prostheses.

As the technique of calculating the geometric asymmetry index is not limited to faces, diverse new fields of application are conceivable. Plaster casts of the maxilla or the mandible may be analyzed to investigate the results of surgeries or orthodontic treatments. Even asymmetry analyses of the cranium based on tomography images seem possible.

A further optimization of measured asymmetry indices with respect to their correlation with perception may enhance their practical significance and therefore is an important task for future work. Which measurable features of a face are perceived and associated with esthetics and which of these are more or less relevant should be investigated. For instance, is an asymmetry index derived solely from grayscale values as meaningful as the color asymmetry index? In addition, how single features can be weighted and combined to obtain an optimal asymmetry index or attractiveness measure will be subject to further investigations.

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