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Three-dimensional perception of facial asymmetry

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SUMMARY In orthodontic diagnosis, facial symmetry is important. The aim of the present study was to analyse the perception of various degrees of facial asymmetry exhibited by carefully designed virtual three-dimensional (3D) material.

Three groups of raters (30 orthodontists, 30 maxillofacial surgeons, and 30 laymen) rated, using a six-point scale, the degree of asymmetry of eight randomly presented 3D faces exhibiting incremental soft tissue alterations. The faces were created by gradually transforming the nose or chin in increments of 2 mm away from the computed symmetry plane. Differences between the groups in analysis of facial asymmetry, the rating of facial stimulus, and right and left facial asymmetry were determined using a *t*-test.

The results demonstrated that raters' profession did not influence the point at which they identified asymmetry. Even laymen were able to detect asymmetries when located near the midline of 3D faces. All raters identified asymmetries of the nose as more negative than those of the same degree of the chin. A left-sided deviation of the nose along the facial symmetry plane lead to a more negative rating of facial appearance, whereas a right-sided deviation of the chin was rated as less attractive.

Nasal architecture plays a crucial role in the perception of symmetry. These findings provide clinicians with a greater understanding of how faces are perceived, a process which is of particular interest in treating orthognathic patients, and those with congenital anomalies.

Introduction

In everyday life, the most important stimulus in interpersonal communication is the face. Faces are the focus of attention in human interaction and our initial impression of other people is formed from what we perceive when we look at them (Feragen *et al.*, 1999). Recent studies have shown that facial symmetry is of importance when identifying a suitable mate (Watson and Thornhill, 1994). Evolutionary biologists have proposed that a preference for symmetry must also be adaptive because symmetry is an indication of health and genetic quality (Thornhill and Moller, 1997). It therefore follows that symmetry has to be considered as one of the main factors of facial attractiveness (Rhodes, 2006).

The perception of facial appearance seems to be different between clinical experts and laymen (Prahl-Andersen *et al.*, 1979). A less critical rating by laymen compared with that of 'experts' has been postulated in the appraisal of facial attractiveness (Kerr and O'Donell, 1990). It was suggested that the observed differences were related to different levels of background knowledge and experience (Prahl-Andersen *et al.*, 1979). However, it has been shown that attractiveness is generally diminished the greater the extent of asymmetry and the closer the asymmetry is located to the midline (Springer *et al.*, 2007; Meyer-Marcotty *et al.*, 2010a).

To date, the subjective rating of facial asymmetry has been investigated on the basis of frontal photographs (Edler *et al.*, 2003). There was a high correlation among clinical experts between the subjective rating of facial asymmetry and the need for orthodontic treatment (Meyer-Marcotty and Stellzig-Eisenhauer, 2009). The more pronounced the asymmetry rating, the greater the need for treatment. Therefore, the conclusion was reached that clinical experts were more sensitive to the presence of asymmetry (Masuoka *et al.*, 2005). However, there is a lack of scientific evidence to define a range of facial asymmetry that is aesthetically acceptable. So far, there is no scientifically established threshold for facial asymmetry.

Previous studies have shown that faces are not bilaterally symmetrical and that there is a left/right asymmetry when an observer looks at a face (Gilbert and Bakan, 1973; Ricciardelli *et al.*, 2002). To investigate the consequences of facial right/left asymmetries, Zaidel *et al.* (1995) compared the judgements of the original faces with composites made of two left or two right hemifaces. They found that the right side of the face was judged as more attractive, suggesting that the attractiveness of the right hemiface is more vulnerable to asymmetries (Zaidel *et al.*, 1995). Furthermore, craniofacial research has shown differences between left and right hemifaces in skeletal structures and soft tissues, with the right side of the face being larger than the left side in both males and females (Vig and Hewitt, 1975; Peck *et al.*, 1991; Ferrario *et al.*, 1993). A possible link between asymmetric perceptual judgements of facial appearance and neuroanatomical control of facial perception has been suggested (Gilbert and Bakan, 1973; Ricciardelli *et al.*, 2002).

Studies of facial perception can be presumed to be limited when the visual stimulus involves static two-dimensional images. For a more realistic view in a rating task three-dimensional (3D) facial images, which are moving from one side to the other are available (Naini and Moss, 2004; Naini *et al.*, 2006). Moreover, using facial images without texture, the raters were not affected by facial features, such as skin complexity, freckles, or scars.

The aim of this 3D virtual material study was to analyse the perception of facial asymmetry, with the purpose of answering the following questions:

1. Are there differences between the ratings of clinical experts and those of laymen?
2. Are incremental virtual alterations of facial components reflected by analogous changes in subjective rating?
3. Are there differences between how alterations of the nose and the chin influence the perception of facial asymmetry?
4. Do left/right localized asymmetries influence facial perception?

Subjects and methods

Raters

Three groups of raters were recruited for the purpose of symmetry/asymmetry rating—30 orthodontists (15 females and 15 males, mean age 36.2, SD 8.7years), 30 maxillofacial surgeons (2 females and 28 males, mean age 35.8, SD 6.5 years), and 30 laymen (20 females and 10 males, mean age 33.7, SD 12.0 years).

The orthodontists and maxillofacial surgeons had completed a full postgraduate programme in their specialization with a minimum of 4 years professional experience. The laymen were recruited via an announcement in a newspaper, had no medical background, and were paid €10. A random recruitment of all raters was assured, any financial interests were excluded, and the Declaration of Helsinki and the ethical standards established by the Institutional Review Board of the University of Würzburg were maintained. The raters excluded from participating in the study were those who knew the individual presented as a stimulus face or who had a congenital facial anomaly.

Creation of the 3D facial stimulus

3D facial scan. The face of a Caucasian male proband (26.6 years) was used as the 'stimulus face'. He had a skeletal Class I occlusion, harmonious vertical, and transverse facial dimensions without a congenital anomaly or any other distinctive feature, such as facial piercings or tattoos. For 3D data acquisition of the proband's facial surface, a FaceScan^{3D} optical sensor (3D-Shape, Inc., Erlangen, Germany) was used. The sensor is based on a phase-measuring triangulation method (accuracy in the *z*-direction 0.2 mm, measurement time 300 ms). No special safety precautions were required to protect the subject being scanned because light intensity is low. A mirror construction designed for orthodontic purposes allowed the face to be captured from ear-to-ear in a single scan. The software Slim3D (3D-Shape, Inc.) was used for triangulation, merging, and post-processing of the 3D data. The final 3D output was a triangulated polygon mesh.

Computing the 3D facial midline. For creation of virtual 3D faces with different reproducible degrees of asymmetry, caused by gradual alterations of different parts of the face, it was first necessary to determine the facial midline. The method for computing the facial midline used in this study is illustrated in Figure 1a–c. Firstly, the triangulated polygon

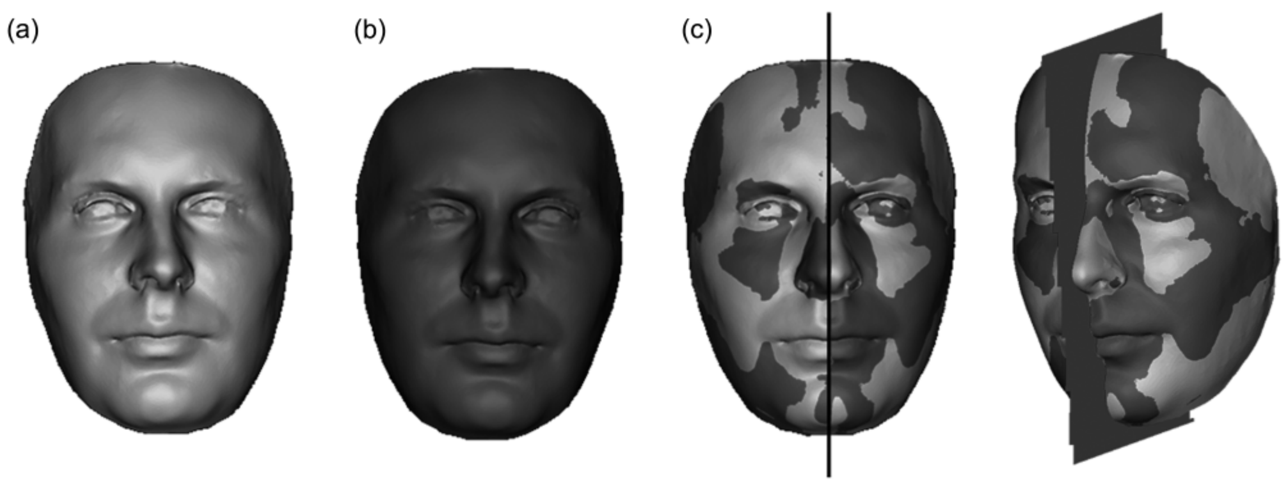

Figure 1 Three-dimensional (3D) surface scan of the male Caucasian (a). Mirrored data of the 3D surface scan (b). Registration of the original and mirrored data. Computation of the symmetry plane and the distances between both data by means of corresponding points (c).

meshes of the original face were mirrored. The original and the mirror image were then roughly registered followed by a fine registration to superimpose the original and mirror image more precisely. For each point of the original data set, the closest point in the superimposed mirror data set was determined. Thus, the distance of the two data sets was reduced to a minimum. A detailed description of the algorithm used for the registration procedure has been published (Laboureux and Häusler, 2001). After fine registration, the symmetry plane was determined from correlating points of the original and mirror image (Benz *et al.*, 2002). The advantages of the method used are its high degree of reproducibility and validity (Benz *et al.*, 2002; Nkenke *et al.*, 2006; Hartmann *et al.*, 2007). The absence of relevant systematic and random errors for the measurements shows that this technique is appropriate for clinical use (Nkenke *et al.*, 2003, 2006). The advantage of the procedure is that the use of single manually defined landmarks is avoided and instead the determination of the symmetry plane is based on 10 000–16 000 correlated points.

Incremental alteration of the 3D face. Upon registration of the facial midline, the soft tissue of the face was incrementally altered using the 3D software, Amira® (Visage Imaging, Inc., Berlin, Germany). By selective and gradual transformation of the nose, philtrum, lips, and lower jaw from the symmetry plane, virtual 3D faces with different degrees of asymmetry were created. 3D transformations of the different parts of the face were carried out by rotation at the *y*- and *z*-axes and translation in the *x*-direction (Figure 2a–c).

For similar incremental alterations of the soft tissues, the tip of the nose or the middle of the chin were at 2 mm intervals from the computed symmetry plane (Figure 3a and 3b). The 3D alteration was carried out in 2, 4, 6, and 8 mm steps. A total of eight faces were created.

Rating task

For presentation of the altered 3D facial stimuli, each rater was seated comfortably in front of a 17 inch monitor (resolution 1024 × 768). The presentation of the facial stimuli was controlled using Powerpoint® software (Microsoft Corporation, Microsoft Office Online, Version 2003).

The eight altered images of the faces were presented in random order on the monitor. All participants rated each face separately on a six-point scale for symmetry/asymmetry in intervals from 1 = very symmetric to 6 = very asymmetric. The presentation time for each face was set at 5 seconds. For rating, the mean rate and the standard error of the mean were used.

Statistical analysis

The Statistical Package for Social Sciences version 15.0 (SPSS®, Inc., Chicago, Illinois, USA) was used for statistical analyses. Distribution of the data using the Kolmogorov–Smirnov test showed a normal distribution. The *t*-test for paired groups was used to assess differences between the groups in the analysis of facial asymmetry, to analyse the ratings of each facial stimulus, and to detect differences between the ratings of right and left facial asymmetry. As the aim of this study was not to definitively prove a precise hypothesis, but to determine the visual perception of faces with different degrees of asymmetry, statistical analysis with the Bonferroni correction could be too conservative (Miller, 1981). To confirm the reported results, corresponding hypotheses have to be tested in further studies. The level of significance was set at $P < 0.05$.

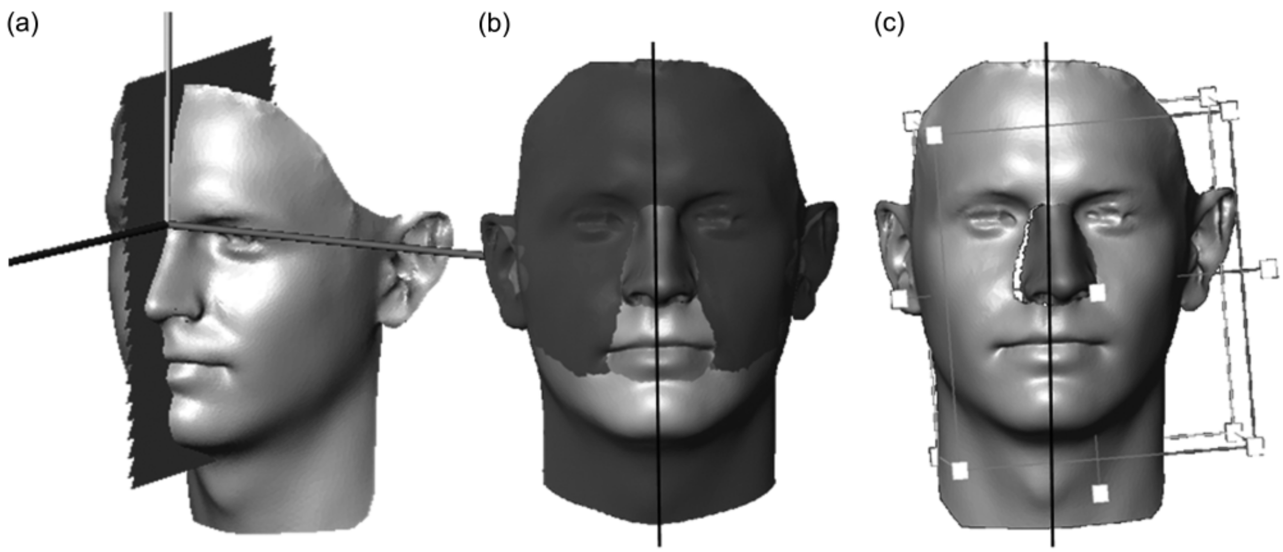

Figure 2 Orientation of the virtual three-dimensional face in a co-ordinate axis system defined by the *x*-axis (red line), *y*-axis (green line), and *z*-axis (blue line) (a). Creation of different degrees of asymmetry by gradual transformation of the nose, philtrum, lips, and the lower jaw from the symmetry plane (b). Exemplary selective and gradual transformation of the nose (c).

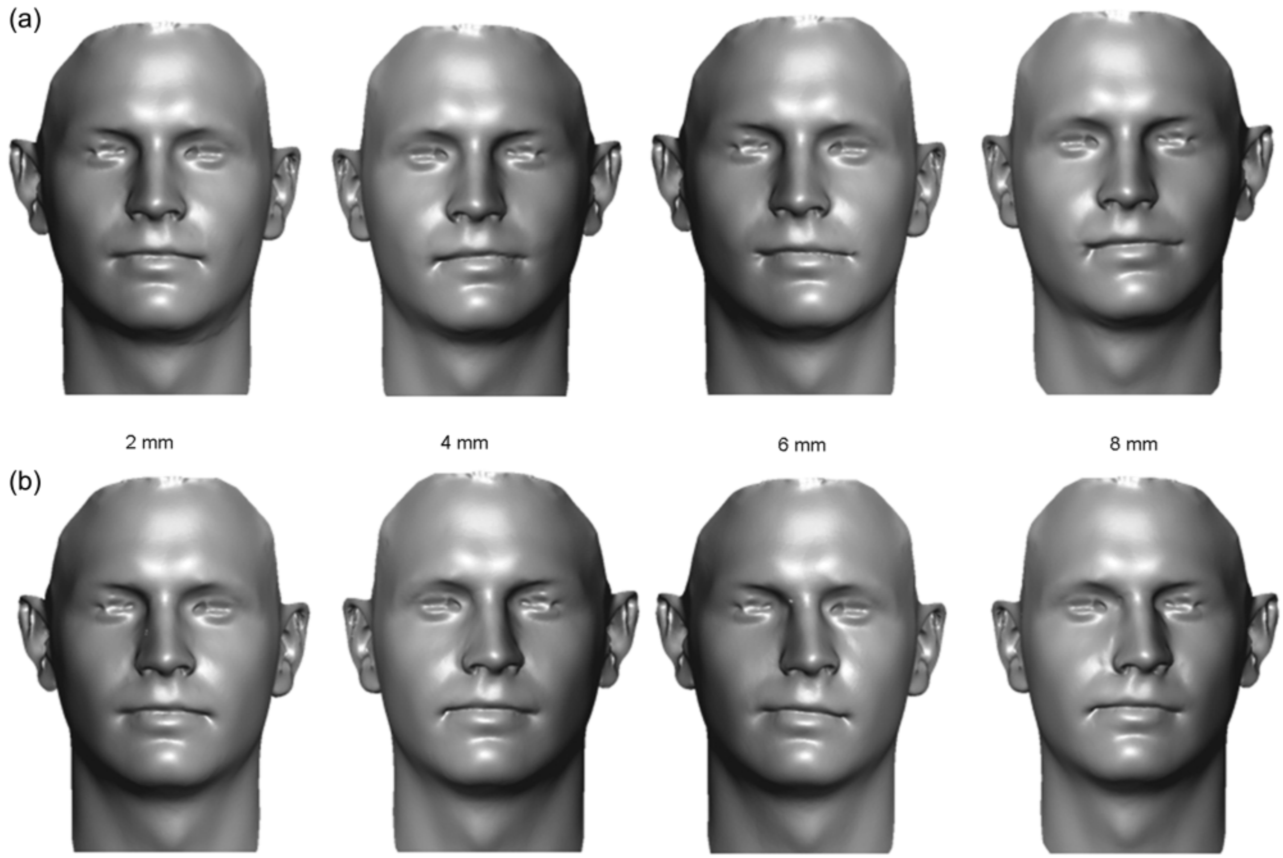

Figure 3 Reproducible alterations of the middle of the chin (a) and the tip of the nose (b) at intervals of 2 mm to the left side from the facial symmetry plane. The three-dimensional alteration of the soft tissues were from 2, 4, 6, and 8 mm.

Results

Rating task for symmetry of the nose

The results when rating incremental shifts of the tip of the nose are presented in Figure 4a. There was a significant difference in the perception of asymmetry between a 2 mm shift to the right and a 4 mm shift to the left. All groups rated a 4 mm displacement as being significantly more asymmetric than a 2 mm displacement ($P < 0.001$).

In contrast, a 6 mm deviation of the tip of the nose to the right was not significantly detected as more asymmetric either by the maxillofacial surgeons ($P = 0.096$) or by the laymen ($P = 0.083$). The orthodontists rated a 4 mm deviation to the left as more asymmetric than a 6 mm deviation to the right ($P = .003$). A deviation of the tip of the nose from 6 mm to the right to 8 mm to the left was identified as more asymmetric by all three groups ($P < 0.001$).

Rating task for symmetry of the chin

The results when rating an incremental shift of the middle of the chin are shown in Figure 4b. The maxillofacial surgeons and laymen evaluated a 4 mm shift to the left as less asymmetric than a 2 mm shift to the right (maxillofacial surgeons: $P = 0.001$; laymen: $P = 0.01$). The ratings of the orthodontists showed no significant difference between either image ($P = 0.484$). All three groups unanimously rated a 6 mm shift to the right as more asymmetric than a 4 mm shift to the left ($P < 0.001$).

An additional 2 mm increase (8 mm) in chin asymmetry to the left was not perceived by the maxillofacial surgeons (P =0.702) or laymen (P =0 .882). Only the orthodontists were aware of a significant increase in asymmetry ($P = 0.001$).

Asymmetry of the nose versus asymmetry of the chin

To determine if a difference exists between how asymmetries are perceived related to their location on the nose or the chin, all raters were combined into a single group. The results showed that deviations at the tip of the nose were always rated as significantly more asymmetric than the same deviations in the middle of the chin (Table 1).

Left-sided versus right-sided asymmetry of the nose and the chin

As the preliminary findings revealed inexplicable slopes of the curves in judging asymmetry of the nose and chin, an additional analysis was performed to test the influence of a left/right bias in perception. For that reason, the facial

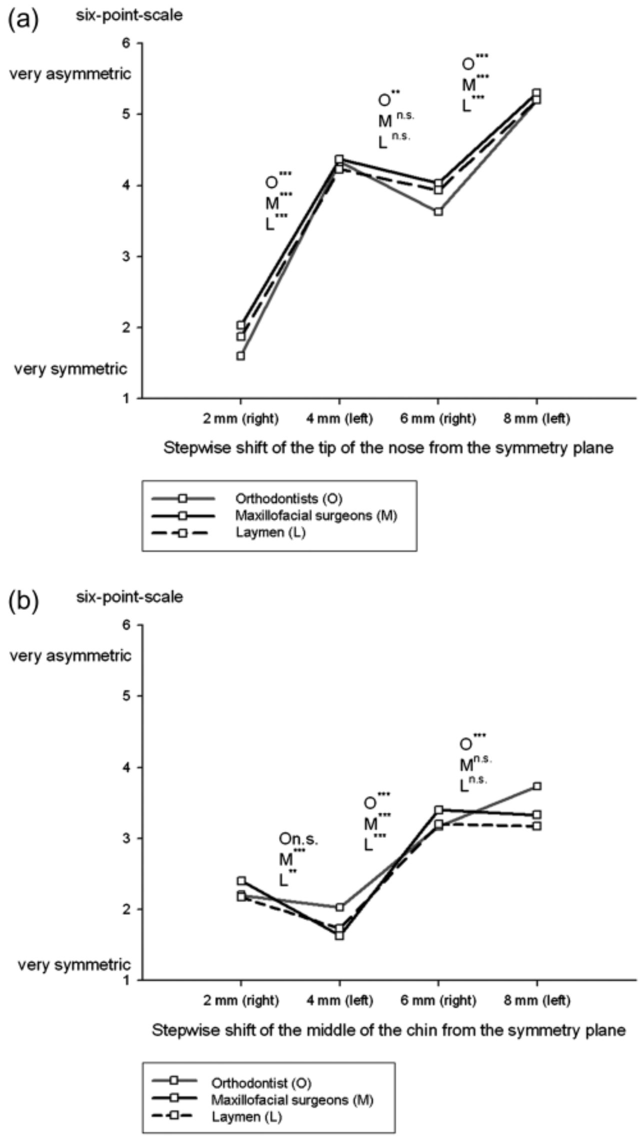

Figure 4 Rating of asymmetry for the s-hift of the tip of the nose (a) and the middle of the chin (b) on a six-point scale for orthodontists (O), maxillafacial surgeons (M), and laymen (L). Mean and standard error of the mean. n.s. = not significant; $**P < 0.01$; $***P < 0.001$.

Table 1 Results for rating asymmetry of a shift of the tip of the nose (mm) versus a shift of the middle of the chin (in millimetre) on a six-point scale for all raters ($N = 90$). Mean and standard error of the mean.

Incremental shift from the symmetry plane (mm)	Rating of the nose and chin		
	Tip of the nose	Middle of the chin	*P*
2	2.32 ± 0.63	2.17 ± 0.65	0.024*
4	4.05 ± 0.72	2.09 ± 0.59	***
6	4.00 ± 0.72	3.04 ± 0.75	***
8	5.02 ± 0.70	3.64 ± 0.83	***

$*P < 0.05$; $***P < 0.001$.

stimuli of a 4–8 mm shift of the tip of the nose and the middle of the chin were presented as originals and mirrored images to all raters in random order (Figure 5).

The results for the nasal tip shift showed that left-sided alterations were rated significantly more asymmetric than right-sided alterations (Table 2). This finding was independent of the degree of alteration.

In contrast, right-sided alterations of the centre of the chin were judged as significantly more asymmetric (Table 3). This result was apparent for all gradual deviations of the chin.

Discussion

In this study, the individual perception of 3D facial asymmetry rated by orthodontists, maxillofacial surgeons, and laymen was measured. A virtual 3D face with incremental alterations of asymmetry was used. For similar alterations, the soft tissue of the nose, philtrum, lips, and chin were shifted three dimensionally from the facial

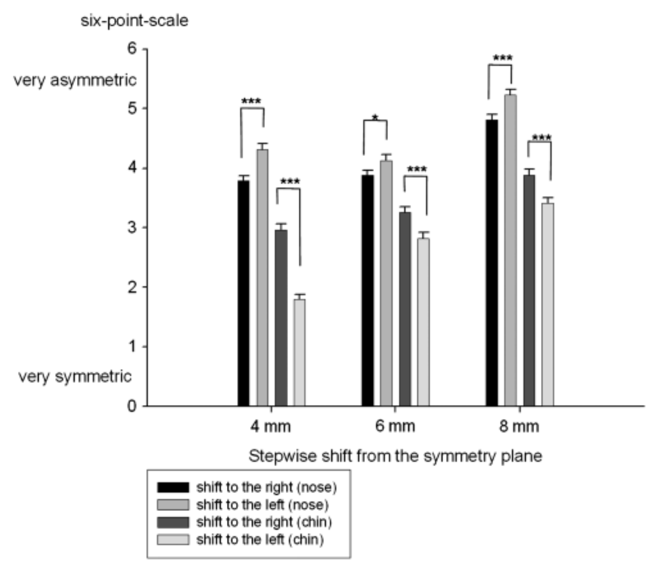

Figure 5 Rating of asymmetry of the shift of the tip of the nose and the shift of the middle of the chin according to left- or right-sided asymmetry for all raters ($N = 90$). Mean and standard error of the mean. $*P < 0.05$; $***P < 0.001$.

Table 2 Results for rating asymmetry of a shift of the tip of the nose (mm) on a six-point scale according to left- or right-sided asymmetry for all raters ($N = 90$). Mean and standard error of the mean.

Incremental shift from the symmetry plane (mm)	Rating of the nose		
	Left	Right	*P*
4	4.38 ± 1.02	3.79 ± 0.81	***
6	4.18 ± 0.97	3.88 ± 0.85	0.03*
8	5.23 ± 0.86	4.81 ± 0.90	***

$*P < 0.05$; $***P < 0.001$.

Table 3 Results for rating asymmetry of a shift of the middle of the chin (mm) on a six-point scale according to left- or right-sided asymmetry in all raters (N = 90). Mean and standard error of the mean.

Incremental shift from the symmetry plane	Rating of the chin		
	Left	Right	P
4	1.80 ± 0.77	2.96 ± 0.99	***
6	2.82 ± 0.97	3.26 ± 0.87	***
8	3.41 ± 0.92	3.88 ± 0.98	***

***$P < 0.001$.

midline. The tip of the nose or the centre of the chin was shifted from the facial symmetry plane in increments of 2, 4, 6, and 8 mm. The purpose was to analyse the impact of asymmetry of the nose and chin on facial aesthetics and the influence of a left/right bias for facial perception.

An increase of nasal asymmetry from 2 mm to the right versus 4 mm to the left was rated as more asymmetric by all three groups, independent of the profession of the raters. Identification of asymmetry even by laymen has been described (Kokich *et al.*, 2006). The findings of the present study showed that facial asymmetries were also identified by laymen who had no expertise in evaluating facial asymmetries. This is in contrast with previous reports that found that laymen were less critical in their appraisal of facial appearance compared with clinical experts (Kerr and O'Donell, 1990). This difference might be explained by the fact that the 3D images used in this study contributed to a more realistic situation in the experimental analysis of facial perception.

No significant differences were found between asymmetries of the nose from 4 mm to the left compared with 6 mm to the right by the maxillofacial surgeons and laymen. Moreover, the orthodontists rated the objective increase of nasal asymmetry at a reduced level. In contrast, an 8 mm deviation of the nose to the left was identified as more asymmetric than a shift of 6 mm to the right. Again an increase of asymmetry to the left side compared with a minor deviation to the right side was identified by all groups.

The results of the perception of asymmetry of the chin from 2 mm to the right versus 4 mm to the left were not detected by any group. Moreover, a 4 mm deviation was rated as less asymmetric. In contrast, an increase in deviation of the centre of the chin 6 mm to the right was identified by all groups. A similiar increase of asymmetry to the same extent to the left was only observed by the orthodontists. As in nasal alterations, a left/right bias of facial perception also seemed to exist for chin deviations. Contrary to the perception of nasal asymmetries, deviations of the chin to the right side were perceived to be more asymmetric.

Comparing perceptions of the nose with those of the chin, it was found that alterations of the nose were always judged as more asymmetric than identical aberrations of the chin by all raters. In general, deviations of the nose are supposed to be as more eye-catching than deviations of other facial features (Andretto Amodeo, 2007). Two factors might be responsible for the more conspicuous perception of nasal asymmetries: first the central position of the nose in the face and second the longitudinal shape of the nasal bridge along the facial vertical axis. This result is consistent with previous findings from eye-tracking studies. While a person's face is generally one of the most revealing parts of the human body, evidence suggests that most people focus their attention on the central region of the face (Mertens *et al.*, 1993; Meyer-Marcotty *et al.*, 2010b). In face-to-face interactions, the human gaze is located at the centre of the face near the symmetry plane (Mertens *et al.*, 1993). Therefore, asymmetry in this area, especially in the area of the nose, is evaluated more critically than other facial regions. This finding supports the hypothesis that for humans, nasal architecture plays a crucial role in the perception of asymmetries.

The results of the present study indicate a left/right bias in hemifacial perception. Deviations of the nose to the left side were always rated more asymmetric than those to the right. Evidence for different judgements of facial appearance in both hemifaces comes from research on hemispheric differences in cognitive processing of faces (Gilbert and Bakan, 1973; Ricciardelli *et al.*, 2002). An observer's bias to the left visual field suggesting a dominant contribution of the right cerebral hemisphere has been reported (Zaidel *et al.*, 1995). From this finding, it follows that the right side of a face is more salient in face-to-face interaction because of the observer's left visual field dominance (Gilbert and Bakan, 1973). Based on the present results, it could be suggested that a deviation of the nose to the left induces a deficiency of normally located structures in the facial midline. It can be assumed that this deviated structure along the facial symmetry plane with a lack of salient facial features in the right hemiface could consequently lead to a more asymmetric rating in the observer's facial perception.

Additionally, a difference in the size of both hemifaces could cause an observer's bias to the larger hemiface. This directional asymmetry, understood as an unequal development of one side of a face, is known as 'laterality' (Farkas and Cheung, 1981). Different factors causing the directional asymmetry of a face such as gender or muscular development have been discussed (Smith, 2000). In contrast, fluctuating asymmetry is characterized by random deviations of facial features, such as the incremental alteration of facial features. Human perceptions of facial symmetry are driven largely by fluctuating asymmetry and are unrelated to directional asymmetry (Simmons *et al.*, 2004). Therefore, differences in the global hemifacial size in the perception of facial symmetry could be also excluded in this study.

The more asymmetric ratings of a chin deviation to the right of the facial midline can be explained as follows: in facial perception, the decoding of facial expressions is organized functionally across the upper–lower facial axis

(Ross *et al.*, 2007). Both hemifaces express emotion, but the lower face prevails for happy–pleasant types of expressions (Ross *et al.*, 2007). If noticeable asymmetries in the lower face (decoding area for happy-pleasant emotions) are located on the right side, which is predominately responsible for facial perception, this might have a negative influence on visual perception. Therefore, a more asymmetric judgement was seen in right-sided deviations.

Conclusions

The identification of asymmetry in virtual 3D faces is independent of the profession of the raters. Laymen were able to detect asymmetries when located near the midline of 3D faces. Asymmetries of the nose were judged as more negative than asymmetries of the same degree of the chin. It can be assumed that the location and architecture of the nose play a crucial role in perception of symmetry. Moreover, a left/right bias of facial asymmetry perception was shown. A deviation of the nose to the left side along the facial symmetry plane leads to a more negative rating of facial perception, whereas a deviation of the chin to the right side was judged more negatively. For clinicians, these findings provide a deeper understanding of the process of facial perception, which is of particular interest in the treatment of orthognathic patients and/or those with congenital anomalies.

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