Facial soft tissue norms in Caucasians using an innovative three-dimensional approach

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Background and aim: Contemporary orthodontic and surgical treatment goals are primarily focussed on achieving optimal aesthetic soft tissue outcomes in three dimensions. It is important, therefore, to establish valid three-dimensional normative models to assist in clinical decision-making. Ideally, such models should be customised to a patient's individual facial proportions. The aim of this study was to establish the most pleasing computer generated 3D facial form using a community-based sample population.

Methods: Three-dimensional facial surface data (3dMDface) were obtained from 375 young adult Caucasians (195 males and 180 females, all approximately 22 years old) without craniofacial anomalies, all of whom were participants in The Raine Study in Western Australia with participants from Generation 2. These data were used to generate seven faces that represented the variations in convexity distributed evenly around an average. The faces were subsequently rated by orthodontists, oral surgeons, plastic surgeons, dentists and laypeople for attractiveness.

Results and conclusion: Age, sex and occupation did not influence the preference among the various faces. The average face was rated as the most attractive. For males, a slightly concave profile and for females a slightly convex profile was preferred. The present study suggested that orthodontic/surgical treatment of Caucasians should be directed towards achieving an average facial form.

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Introduction

The desire of individuals to enhance facial aesthetics is a growing expectation of contemporary society. This social change has caused an increase in the demands placed on clinicians across numerous healthcare disciplines.[1-5] In many instances an improvement in facial aesthetics is the primary motive behind patients seeking orthodontic treatment, with patients increasingly evaluating the treatment outcome based on the achieved aesthetic result.[6-11]

The appreciation of facial beauty is inherent within all ethnic groups.[12] However, the contributing components of attractiveness are complex and are often difficult to describe, quantify and communicate. Various indices and 'norms' based on individual ethnicity have been established as tools to assist clinicians and patients in realising the overall success of any aesthetically-driven treatment.[2,3,13-16] In treatment involving combined surgery and orthodontics, clinicians often use averages or 'norms' based on aesthetic judgements to establish treatment goals;[17] however, many norms have been based on two-dimensional imaging techniques,[18] despite the face being a three-dimensional (3D) structure.

Contemporary methods to quantify shapes and shape changes in computer science and mathematics have enabled the development of 3D data sets of facial images that assist the clinician in diagnosis and treatment planning.[19] Various means of acquiring 3D data currently exist, including stereophotogrammetry, laser imaging, structured light technique, computed tomography (CT), magnetic resonance imaging (MRI) and ultrasonography.[20]

Stereophotogrammetry uses two or more cameras to produce 3D facial images using multiple point geometric triangulation to determine the surface coordinates. Thus, each face is measured as a series of 3D coordinates that represent the geometry of the face. Laser imaging generates 3D images by scanning a laser stripe and using triangulation or using time of flight to measure 3D facial surfaces. Early versions of this tool had the disadvantage of slow scanning speeds that resulted in significant artefacts secondary to subject movement including changes in facial expressions. However, these limitations have been overcome by newer, faster image capturing technologies.[21,22]

The structured light technique has been used to capture 3D facial information using a projected pattern of light in the form of squares, circles or stripes. Deviations in light patterns are captured by surrounding cameras and reflect variations in facial geometry in 3D. Other topography techniques have also been applied using a similar principle to display the interference pattern of the structured light after reflection.[23]

Computerised tomography (CT) generates multiple image slices at different depths (whilst the subject is lying down) which can be reconstructed to a 3D image, but there are significant soft tissue distortions related to patient positioning.[24] MRI suffers from a similar recording postural shortcoming as CT with the subject imaged whilst supine.[25,26] Cone beam computed tomography (CBCT) has facilitated image acquisition with minmal radiation dosage whilst the subject assumes an upright position, thereby reducing soft tissue distortion that accompanies routine CT.[27] However, CBCT does not produce photorealistic images due to the inability to capture the colour and texture of the skin.[28] 3D ultrasonography is widely used to evaluate foetal craniofacial anomalies and may be used to acquire high resolution images of the soft tissue of the face.[29]

Numerous databases have been developed in international clinical research centres to establish longitudinal 3D growth and treatment records. Moreover, significant interest has been shown to relate specific facial morphological traits with the underlying genotypes that are being applied to specifc diagnoses, therapeutic strategies and forensics.[30,31]

The aim of the present study was to determine the most pleasing computer generated 3D facial form using, firstly, a unique community-based sample population, and secondly, applying a mathematically-derived process to represent variations in facial convexity and concavity in Caucasians. Moreover, the study aimed to determine if there are occupation or gender biases in the determination of the optimal facial form.

Materials and methods

Ethics approval for this project was granted from the Human Ethics Committee of The University of Western Australia (UWA Human Research Ethics Committee Approval - RA/4/1/7418).

The present study used data from 3D facial photographs from 375 young adult (195 females and 180 females) participants of the Raine Study with participants from Generation 2, when the subjects were approximately 22 years of age.[32,33] Since its inception in 1989, the Raine Study has been gathering medically relevant information for research purposes from 2,900 predominantly Caucasian pregnant women who were recruited from the King Edward Memorial Hospital in Perth, Western Australia. The 2,868 children born to the mothers constituted the Raine cohort. Since birth, the child cohort participants have been reviewed in detail.

Three-dimensional facial images were collected using a 3dMD camera (3dMD Inc., GA, USA). To collect the necessary images, an array of cameras was mounted on a wall and the images captured while the subjects were instructed to sit upright and display a neutral facial expression. An identical head posture of all of the subjects was maintained during imaging to ensure repeatability and avoid stretching of the facial soft tissues due to postural changes. The subject's head and neck area was captured from ear to ear, producing a 180 degree facial image that was used to produce a 3D mesh. The 3DMD uses two pods to capture 180 degrees views of the face; the inbuilt software stitching the 3D images of the two pods to generate a single 3D polygonal mesh.

Generation of average face

An 'average' face was generated from the Raine study Generation 2 subjects demonstrating a 'normative' profile and a facial angle of between 159 and 167 degrees[2,3,34-39] (Figure 1). A dataset of 146 males and 134 female subjects were identified who exhibited this facial angle. The distribution of all facial angles from all participants is shown in Figure 2 (males) and Figure 3 (females).

To calculate the average of a set of vectors, the variables of the vectors must correspond, which means that the variables must be ordered such that the eyes correspond to the eyes, the nose to the nose, and the chin to the chin and so on. Moreover, all vectors (of 3D facial coordinates) must have exactly the same number of points. For the case of 3D faces, it is considered that each face be a vector described by $f=(x_1, y_1, z_1, x_2, y_2, z_2, \ldots, x_n, y_n, z_n)$ where x,y,z are the 3D coordinates of points and n is the number of points on the 3D face.

When faces are scanned with the 3dMD scanner (or any other scanner), the ordering and number of points are different in each case due to the differences in facial geometry and variation in angle and distance from the scanner. Therefore, the points for different faces must be ordered using software after the 3D scan is taken in a systematic and repeatable manner. This process is called 'dense correspondence'.

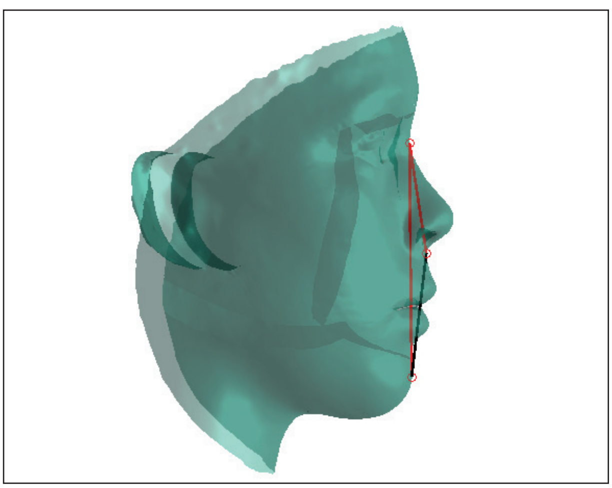

Figure 1. Facial angle measurement on profile view of each subject with soft tissue landmarks corresponding to Nasion (Na), Subnasale (Sn) and Pogonion (Pog).

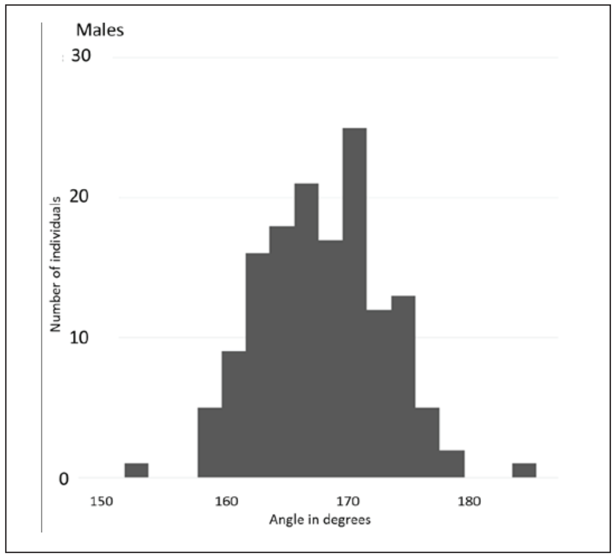

Figure 2. Distribution of facial angles (in degrees) in male subjects.

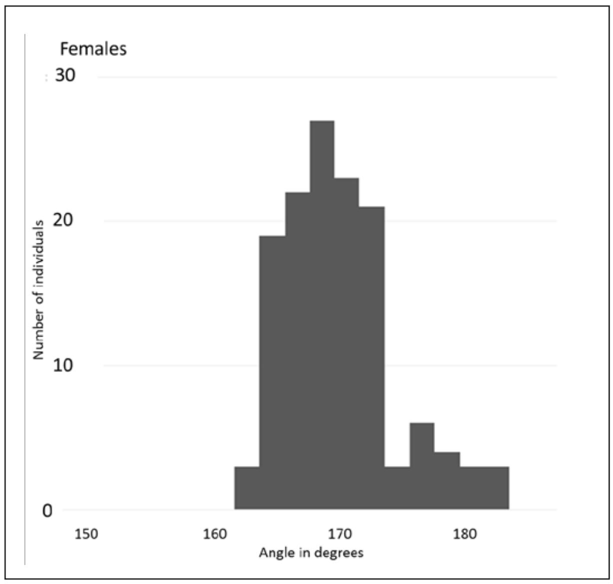

Figure 3. Distribution of facial angles (in degrees) in female subjects.

A proprietary algorithm for dense correspondence, which is based on the Basel Face Model (BFM), was applied.[40] The BFM is a linear model with 199 eigenvectors and an average face. The BFM was iteratively deformed to fit a new 3dMD scan as follows. First, the 3dMD scan was aligned to the BFM average face and then sets of nearest points were identified. The BFM was then deformed using the eigenvectors so that the distance between the nearest points between the two faces (the BFM and the new 3dMD scan) were minimised according to the following function:

$$min_{\alpha_t}\ \left(\|U\alpha_1 - f + \mu\|_2 + \lambda\|\alpha_t - \alpha_1\|_2\right)$$

where U are the eigenvectors of the BFM, α_t contains the deformation coefficients of the current iteration, f is the new 3dMD scan, μ is the average BFM face, λ is a control parameter and α_{t-1} contains the deformation coefficients of the previous iteration. At any iteration of t, only α_t is unknown and the remaing variables are known. Note that the second term controls the deformation of the face to be low at each iteration. This is because initial correspondences based on nearest neighbours are not correct and the correspondences must be established again after minor deformation of the BFM. The alignment and deformation steps are repeated iteratively until the BFM fits the new 3dMD face. The BFM is fitted to all 3dMD faces. Since the fitted (deformed) BFMs now resemble the shapes of the 3dMD facial scans of the patients, the raw 3dMD scans are replaced by the fitted (deformed) BFMs. It should be noted that the BFM is a (deformable) face model and the deformation process only changes the geometric locations of the points in the BFM and not their ordering or the numbering of points. Hence, the fitted BFMs are in dense correspondence, which means that they have exactly the same number of points and ordered in exactly the same manner. The average face can now be calculated as the arithmetic mean of the fitted BFMs.

Progressive modification of the average face

Using the above method, the average face of 147 males and the average face of 135 females was calculated. Class III faces were selected from the population (based on the angle shown in Figure 1) and also calculated the average Class III face. The average 'normative' face was then subtracted from the Class III face leaving a 3D facial geometry that defines a Class III face. This derived Class III face was then scaled by 50%, 100% and 150% and added to the average face to generate average Class III faces of varying severity. In a similar way, the Class II difference face was scaled and subtracted from the average face to generate average Class II faces of varying severity. The resultant faces in the case of males are shown in Figure 4a and 4b.

Assessment of generated faces

The computer-generated seven male and seven female faces were considered as 14 different individuals. Their faces were printed and laminated in individual sheets. Each face had five different views for raters to evaluate, including one straight view, two right and left lateral profile views and two right and left 90 degree views (Figure 5a and b). Each face was randomly assigned

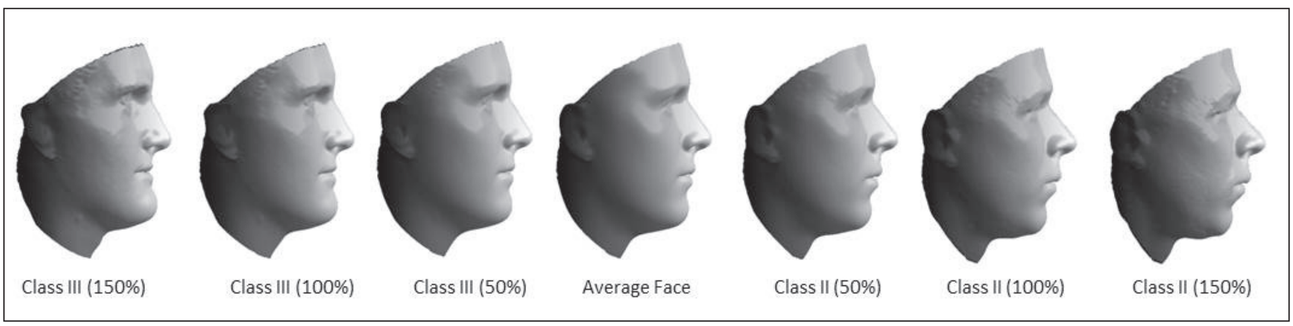

Figure 4a. Computer generated models of the average male face of different Classes and severities. The middle face represents the average (or 'norm'). The Class III derived face was scaled and added to/subtracted from the average face to generate average Class III/Class II faces of varying severity.

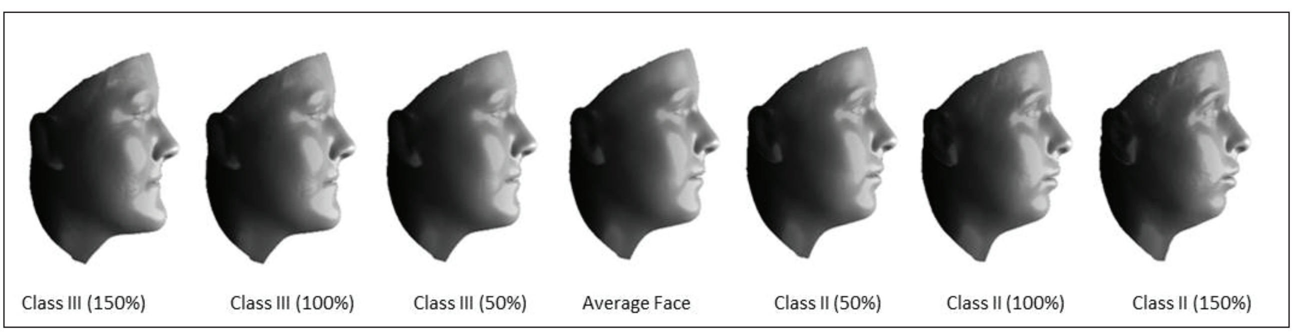

Figure 4b. Computer generated models of the average female face of different Classes and severities. The middle face represents the average (or 'norm'). The Class III derived face was scaled and added to/subtracted from the average face to generate average Class III/Class II faces of varying severity.

alphabetically from A to G. Raters included dentists, oral surgeons, plastic surgeons, orthodontists and laypeople.

A questionnaire was developed for each rater that included details of their age, gender and occupation. The seven images of males and females were presented to the raters in a random order to rank the images for 'attractiveness' from 1–7. The rankings were manually recorded at the end of each survey.

Statistical method

Summary statistics are provided for the age, gender and occupation of the raters. Separate analyses were carried out for images of males and females from most concave (A) to most convex (G). A linear mixed model was fitted to the males and females with ranking as the outcome variable. Fixed factors included rater age, rater gender, rater occupation and image, and a random effect factor was included for survey number (individual). Data were analysed using the R environment for statistical computing.

Results

Summary of respondents

This survey received 509 respondents. The youngest respondent was 18 and the oldest was 92 (Table I). There was a nearly even separation of males and females (50.9% and 49.1% respectively). The majority of respondents (73.1%) had an occupation of 'Other' (Table II).

Images of males

The image rankings for males did not depend on rater age, gender or occupation. The ranking scores for all pairs of images were significantly different from each other with the exception of image A and image D (Figure 6, Table IV).

Images of females

The rankings did not depend on rater age, gender or occupation. The ranking scores for all pairs of images were statistically significantly different from each other with the exception of images D and E and also images B and C (Figure 7, Table V).

Table I. Summary of rater age (years).

Demographic	N	N miss	Mean	Std Dev	Min	Median	Max
Age	509	0	44.69	15.01	18	44	92

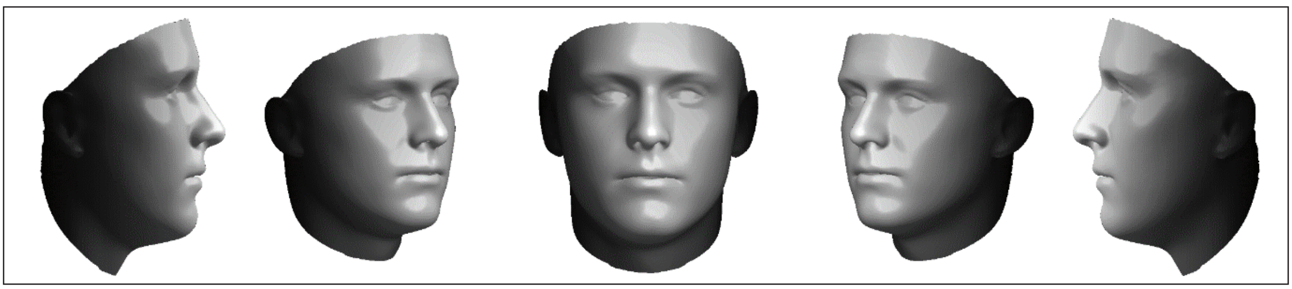

Figure 5a. Computer generated models of five different views of the average ('norm') male 3D face.

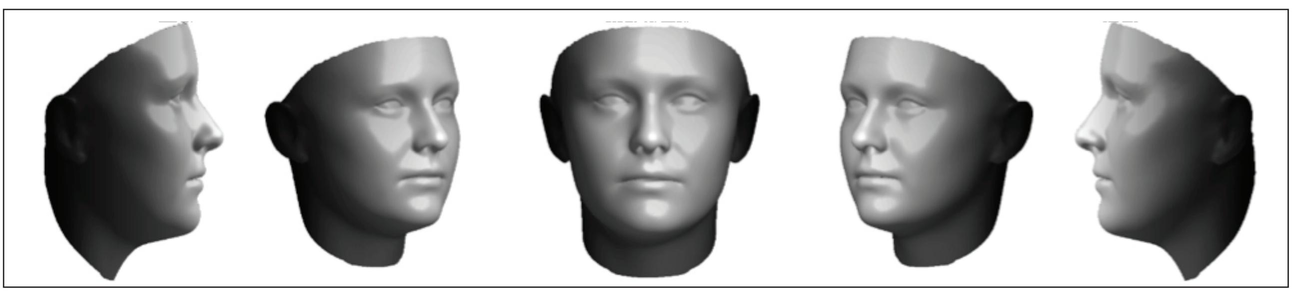

Figure 5b. Computer generated models of five different views of the average ('norm') female 3D face.

Discussion

The 'average' face or profile has been reported as the most attractive facial form in comparison to face types that deviate from the average.[41,42] The present study demonstrated that this finding is evident within a Caucasian population as the average profile was rated as the most attractive by all participant groups.

Facial convexity and perceived attractiveness appear to be associated. Regardless of the ethnic group, features including mid face deficiency, a protrusive chin or a retrusive chin have been judged as less attractive.[43,44] For example, a convex profile demonstrating extreme mandibular retrognathism has been reported to be least attractive in Arabic, Iranian, Turkish and European populations.[43,45-47] In contrast, studies in Asian populations have reported a concave profile to be the least attractive.[48,49] These differences suggest that the perception of facial attractiveness is likely to be culturally influenced.[50] A recent 3D study confirmed these earlier 2D preferences within an Asian population.[16]

Table II. Summary of the rater demographic variables.

Demographic	Value	Frequency	Percentage
Sex	Male	259	50.9
	Female	250	49.1
Occupation	Dentist	61	12.0
	Oral surgeon	13	2.5
	Orthodontist	50	9.8
	Other	372	73.1
	Plastic surgeon	13	2.6

Table III. Summary of the average ranking for each image by the categorical variables (Male Images).

	Number	A	B	C	D	E	F	G
Female	250	4.58	3.38	1.63	4.78	3.84	2.10	0.70
Male	259	4.55	3.45	1.54	4.77	3.83	2.13	0.82
Dentist	61	4.62	3.30	1.36	4.98	3.87	2.11	0.75
Oral surgeon	13	4.85	3.00	1.46	5.54	4.31	1.69	0.15
Orthodontist	50	4.96	3.10	1.22	5.30	3.88	2.04	0.54
Plastic surgeon	13	4.69	3.38	1.31	5.38	3.92	1.69	0.62
Other	372	4.49	3.50	1.69	4.62	3.8	2.16	0.81

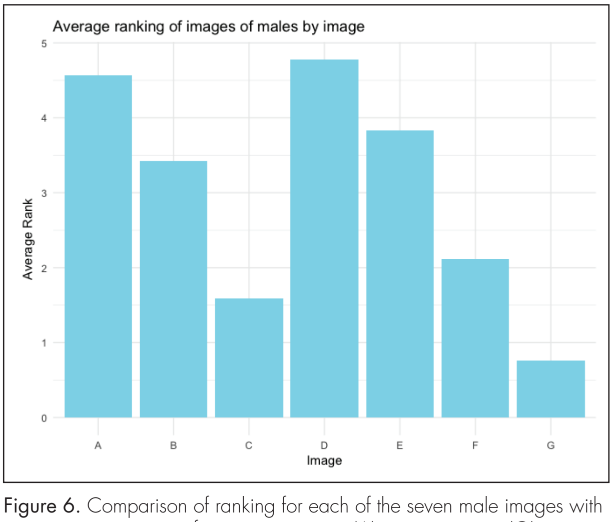

Figure 6. Comparison of ranking for each of the seven male images with variations in convexity, from most concave (A) to most convex (G).

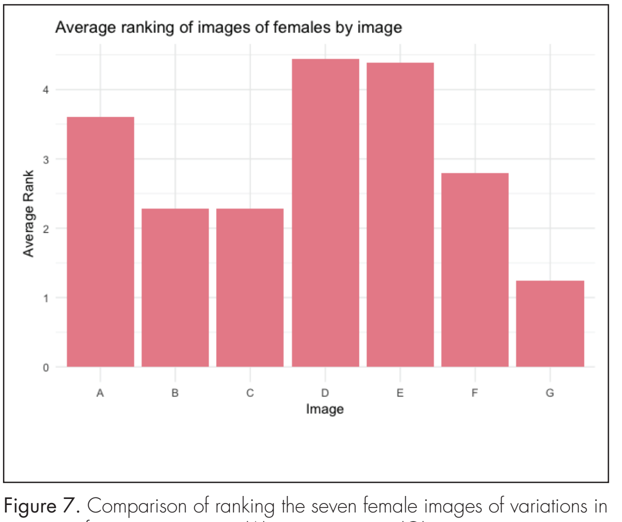

Figure 7. Comparison of ranking the seven female images of variations in convexity from most concave (A) to most convex (G).

Table IV. Summary of estimated mean differences (standard error), p-value for each pair of images for males.

	B	C	D	E	F	G
A	-1.15 (0.09), <.0001	-2.98 (0.09), <.0001	0.2 (0.09), 0.2417	-0.73 (0.09), <.0001	-2.45 (0.09), <.0001	-3.81 (0.09), <.0001
B		-1.83 (0.09), <.0001	1.35 (0.09), <.0001	0.42 (0.09), 0.0001	-1.3 (0.09), <.0001	-2.66 (0.09), <.0001
C			3.18 (0.09), <.0001	2.25 (0.09), <.0001	0.53 (0.09), <.0001	-0.85 (0.09), <.0001
D				-0.94 (0.09), <.0001	-2.66 (0.09), <.0001	-4.01 (0.09), <.0001
E					-1.72 (0.09), <.0001	-3.08 (0.09), <.0001
F						-1.36 (0.09), <.0001

Table V. Summary of estimated mean differences (standard error), p-value for each pair of images for females.

	B	C	D	E	F	G
A	-1.32 (0.11), <.0001	-1.32 (0.11), <.0001	0.83 (0.11), <.0001	0.79 (0.11), <.0001	-0.8 (0.11), <.0001	-2.35 (0.11), <.0001
B		0.01 (0.11), 1	2.16 (0.11), <.0001	2.21 (0.11), <.0001	0.52 (0.11), <.0001	-1.03 (0.11), <.0001
C			2.15 (0.11), <.0001	2.11 (0.11), <.0001	0.52 (0.11), <.0001	-1.04 (0.11), <.0001
D				-0.04 (0.11), 0.9997	-1.63 (0.11), <.0001	-3.19 (0.11), <.0001
E					-1.59 (0.11), <.0001	-3.15 (0.11), <.0001
F						-1.55 (0.11), <.0001

Table VI. Summary of the average ranking for each image by the categorical variables (Female Images).

	Number	A	B	C	D	E	F	G
Female	250	3.62	2.25	2.31	4.5	4.40	2.72	1.24
Male	259	3.58	2.30	2.26	4.38	4.39	2.88	1.25
Dentist	61	3.52	2.13	1.77	4.77	4.49	2.98	1.33
Oral surgeon	13	3.15	1.38	1.31	5.00	5.38	3.23	1.54
Orthodontist	50	3.50	1.18	1.46	5.40	5.02	3.10	1.34
Plastic surgeon	13	4.08	2.08	1.62	5.46	4.62	2.46	0.69
Other	372	3.63	2.49	2.54	4.20	4.25	2.73	1.23

In the present study, the individual perception of 3D profile variation rated by orthodontists, maxillofacial surgeons, plastic surgeons, dentists and laypeople was measured. A 3D average face was generated from a group of Class I profiles, young adult, males and females. This average face was incrementally modified by 50%, 100%, and 150% to generate varying severities of Class II and Class III facial forms. The average face was regarded as the most attractive face for both males and females by all groups, independent of the profession of the raters. Such a result is consistent with other studies considering facial profile attractiveness in Caucasian populations.[51]

The choice of the second most attractive profile differed beween genders. For males, a mildly concave profile was rated as the second most attractive facial form whilst, for females, a mildly convex profile was rated as the second most attaractive facial form. This finding is similar to that reported for a Japanese population.[50] Notably, this observation in previous studies has been attributed to limitations of some computer programs used in generating 'altered faces' leading to the exaggeration of some facial features.[52]

Numerous studies have involved different groups of raters to identify features of an attractive face. The majority of the studies have analysed two-dimensional images, making it difficult to make a direct comparison with the results of the present study.[43,53-56] Further, the majority of studies considering facial attractiveness tended not to involve raters from different professional backgrounds.[16,57-60] Additionally, a standard method to define and rate facial attractiveness has not been used across studies, although it has been recommended that a standardised approach towards facial type acquisition, raters panel and validated outcome measures be used.[61]

The influence of occupation and socioeconomic status on the perception of facial attractiveness remains unclear. However, this is potentially an important issue, particularly in the context of health professionals making decisions about treatments that affect facial appearance. For example, a disparity in the perception of facial attractiveness between professionals and laypeople might be a crucial factor to appreciate when addressing any dissatisfaction with treatment outcomes. Conflicting findings have been reported, with professionals more critical in the judgement of facial attractiveness,[62] while laypeople have also been reported to be more critical than professionals, [63] and reports of no difference between professionals and laypeople have been documented.[51] The present study supports that there is no difference in how professional and laypeople perceive facial attractiveness. Despite these disparate findings, it is always prudent to include laypeople in the assessment of facial treatment outcomes. The inclusion of a patient in treatment discussions enables the provision of care that is respectful of, and responsive to, individual patient preferences, needs and values and ensures that a focus on patient values is guiding clinical decision-making.[61]

The routine historical method by which clinicians evaluated faces and established visual treatment goals included a comprehensive clinical examination followed by a review of a series of 2D photographs. This soft tissue appraisal was then extended to a review of 2D radiographs. Numerous studies have reported an appraisal of facial aesthetics based on these methods. The contemporary clinician/researcher now includes 3D hard and soft tissue imaging techniques that have changed the way dentofacial deformity is evaluated. It is therefore necessary to engage clinicians with new 3D methods that have been validated consistent with this contemporary approach.

The major limitation of this study is the generalisability of the findings. The study sample was predominantly young adult Caucasians and the raters were of unknown ethnicity (not recorded). Therefore, the findings may not be applicable to different racial and ethnic groups. Because differences in the perceptions of attractiveness due to cultural differences were not accounted for, this study could not evaluate how race and ethnicity affected the overall attractiveness rating. Hence, similar studies need to be conducted amongst racially and ethnically diverse populations in order to improve the generalisability of findings.

Conclusion

Within the limitations of the present study, the following can be concluded:

- The average face was rated most attractive for both males and females.
- For males, a slightly concave profile was the second most preferred face, while for females, a slightly convex face was the second most preferred face.
- The rankings by raters for both males and females did not depend on their age, gender or occupation.
- For males no statistically significant relationship was found between the average face and the 50% concave face.
- For females no statistically significant relationship was found between the average face and the 50% convex face; 100% concave face; 150% concave face.

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