THE PERCEPTION OF FACIAL ASYMMETRY

By

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ABSTRACT

The objective of this study was to assess the perception of facial asymmetry, in particular of the lower third of the face (chin point), as assessed by different types of observers. It was considered important to investigate the opinion of more than one observing group as the profession of the observer may be an influencing factor with respect to how the deviations are perceived. Average three-dimensional images of male and female faces were produced and subsequent deviations were applied to simulate chin point asymmetry. Five observer groups (lay people, dental students, dental care professionals, general dental practitioners and orthodontists) assessed the images, rating each image as either; normal, acceptable or would benefit from correction. Analysis of the results indicated that factors that influenced the perception of facial asymmetry included the degree of asymmetry and the profession of the observer, while the direction of the asymmetry and the gender of the individual with the asymmetry did not affect the perception of asymmetry, except when the asymmetry ranged from 4 – 6 mm. The gender of the observer was found to have no influence on how images were rated. There was a highly significant difference ($P < 0.001$) between the range that the lay people ($0 - 5.60 \pm 2.68$ mm) and orthodontists ($0 - 3.60 \pm 1.54$mm) considered to be normal, and similarly a statistically significant difference ($P = 0.001$) at the level at which the lay people (11.79 ± 4.04 mm) and orthodontists (9.73 ± 2.98 mm) considered surgery to be appropriate.

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CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF GRAPHS

LIST OF TABLES

1. Introduction

Orthodontics is a dental speciality that includes both, the correction and prevention of dental irregularities as well as the assessment and correction of facial form. Assessment of the face is carried out in all three planes of space, frontal, profile and coronal. One aspect of facial form that can influence treatment decision is the presence of asymmetry.

Asymmetry, as defined by the Oxford dictionary (2010), "is a lack of equality of equivalence between parts or aspects of something; lack of symmetry." Mild asymmetry of the human body occurs in all individuals. In relation to the face, symmetry and balance can be considered as correspondence in size shape and arrangement of the facial features on both sides of the mid sagittal plane (Peck *et al*, 1991)

Facial asymmetry can manifest as part of a number of craniofacial syndromes, or can develop as a result of trauma, pathology, or abnormal growth. When it is apparent, it can have major implications for the patient, in terms of psychology, function and aesthetics. Correction of such an asymmetry requires the input of the surgical team and as such is not a procedure that should be undertaken without serious consideration.

For patients considering the possibility of surgical correction to address their asymmetry it would be beneficial to know how the general population views asymmetry in the assessment of facial form.

It is the intent of this research to attempt to determine the degree of asymmetry that is considered to be:

(1) normal,

(2) apparent, but within acceptable aesthetic range, and

(3) apparent and considered appropriate for treatment.

1.1 Background and significance of facial asymmetry

Artists such as Leonardo da Vinci and Albrecht Dürer believed that the human body and face expressed symmetry and used this philosophy in their art work. However, in 1887 the Greek artist, Hasse, noted that asymmetry of the craniofacial complex was a common occurrence and sculptors at that time reproduced this in their art. The debate on symmetry was not confined to the world of art. A German orthodontist, Simon (1924), stated "bilateral symmetry is a most manifest morphological characteristic of the body and especially the head." However, further investigations into symmetry dispel this notion, therefore agreeing that a certain unquantified level of asymmetry can and should be accepted as normal.

Anthropological investigations into the craniofacial structure confirm that asymmetry extends to the human craniofacial complex (Woo, 1931). However, skeletal asymmetry may be completely or partially masked by the soft tissues (Haraguchi *et al*, 2002). Despite the potential camouflage provided by the soft tissues investigators found that asymmetry is also a common occurrence in the facial soft tissues. Farkas and Cheung (1981) examined over 300 subjects in three age groups (6, 12 and 18 year olds) for facial asymmetry using direct anthropometry. Their measurements included point to point distance and angular measurements and they found average differences between the right and left sides were mild in both the absolute measurements (3mm) and relative values (3%). Haraguchi *et al* (2002) suggested that humans are sensitive to deviations of approximately 4mm when assessing soft tissue facial asymmetry. This was based on the assessment of 2D facial photographs of a Japanese sample by orthodontic judges.

If it is agreed that a certain level of asymmetry is normal, it would be beneficial to know the level at which asymmetry can be described as abnormal and at what stage it affects aesthetics such that treatment is considered appropriate.

1.2 Asymmetry in the general population

Severt and Proffit (1997) conducted a retrospective study of a referred population in the university clinic of North Carolina, where, 1460 patients with dentofacial deformity were assessed with respect to facial asymmetry. It was found that 34% of the sample had a clinically detectable asymmetry that had been identified and recorded in their patient notes prior to treatment. Asymmetries affecting the upper face occurred in only 5% of their sample, 36% had asymmetry of the mid-face and 74% had asymmetry of the mandible. Furthermore it was concluded that individuals with a class II skeletal base were least likely to have facial asymmetry.

Peck and Peck (1991) studied the prevalence of skeletal asymmetry in subjects deemed to have aesthetically pleasing faces. Using cephalometric analysis they determined that all of the 52 subjects exhibited asymmetry in at least one measurement and the facial skeleton appears to become more symmetrical towards the cranium.

Haraguchi *et al* (2002) found that in a sample of 220 Japanese adults attending their orthodontic department with a class III skeletal relationship 80% had a skeletal asymmetry and 56% of the group had an asymmetry that could be detected at a soft tissue level. This is a much higher percentage than that reported by Severt and Proffit (1997) who claimed that 40% of skeletal III base patients displayed a degree of asymmetry. However, the methods used to assess the asymmetry were not standardised.

1.3 Causes of facial asymmetry

Many explanations have been suggested to account for facial asymmetries, including, genetics and non genetic influences on development. The effect of the muscle on skeletal development has been extensively investigated by many authors using animal models. It has been concluded that the muscles have the potential to cause a modifying effect on the bone, but are not solely responsible for the overall shape of the bone (Scott, 1954).

A twin study carried out by Mulik in 1965 concluded that heredity was not the main aetiological factor in the development of craniofacial asymmetry. For this investigation six same sex triplets were sub-divided into six same-sex identical twins and 12 fraternal twins. Records, including lateral and posterior cephalograms and dental study models were taken at two time periods 3 years apart. Analysis of the records allowed comparisons to be made between twin groups and over time for the individual.

1.3.1 Trauma

Individuals who experience trauma before the completion of growth will potentially suffer subsequent deformity. This deformity may be caused by interruption of normal growth at the trauma site as a result of scar tissue in conjunction with normal growth on the unaffected side. A history of trauma was found in 14% of the University of North Carolina patients with asymmetry (Severt and Proffit, 1997)

1.3.2 Muscular disturbances

Muscular activity has the potential to affect jaw growth by two possible mechanisms. Firstly the formation of bone at the point of muscle attachment is dependent on the muscle and secondly, muscle is part of the soft-tissue matrix that is claimed to be responsible for the displacement of the skeletal unit and subsequent bone deposition (Gorlin *et al*, 1990).

Research into partial and total nerve paralysis has shown that where nerve function to a muscle group is affected causing the function of the muscle to be impaired normal development of the underlying skeleton can be affected. Washburn (1946) conducted animal studies and found that severing the motor nerve could produce muscle atrophy and subsequent deviation of cranial growth towards the affected side. Further animal studies have shown similar results, but have found that total muscle paralysis is not necessary to cause asymmetry to develop (Gardner *et al*, 1980; Byrd, 1984)

1.3.3 Idiopathic asymmetry

Hemimandibular hypertrophy (previously known as condylar hyperplasia) can also occur in metabolically normal individuals. Growth tends to be asymmetrical and the patient presents with facial asymmetry. This condition tends to affect females between the ages of 15 – 25 years, but has been known to affects individuals in both sexes as early as 10 years up until 40 years of age. Usually it is self-limiting with varying degrees of deformity experienced. Obwegeser and Makek (1986) further classified this condition in an effort to highlight that the condyle was not the only region were abnormal growth occurred. They described three classes, namely, hemimandibular hyperplasia, hemimandibular elongation and hybrid forms of the two. The classification represent the area of the mandible that is most affected and the vertical/horizontal component of the deformity. Excessive growth may stop spontaneously or require intervention.

Asymmetry in the mandible can lead to compensatory deformation of the maxilla. Unilateral excessive vertical growth of the mandible produces compensatory change in the maxilla which is seen clinically as a maxillary occlusal cant. The degree to which this compensatory growth occurs depends on the rate of growth of the mandible.

1.3.4 Inheritance

It has been suggested that, with the exception of mandibular prognathism, approximately 50% of the variation of facial skeletal characteristics might be influenced by inheritance, whereas the remaining 50% might be related to environmental factors (Proffit, 2000). This indicates that severe dentofacial deformities are unlikely to be explained by inheritance alone.

1.3.5 Facial asymmetry in children

Facial asymmetry in childhood can be as a result of a congenital malformation but is more commonly secondary to fracture of the condyle as a result of trauma. Following condylar fracture 75% of children continue to grow normally and the prognosis is better the earlier the fracture occurs (Proffit, 2000). Rarely, the cause of the asymmetry could be as a result of a destructive process that affects the tempromandibular joint and this should not be overlooked.

1.3.6 Facial asymmetry in the new born

Pre-natal restriction in growth is rare, but when it occurs the effects can be severe and affect both facial form and function. Such cases may be observed when a limb presses against the face *in utero*, causing a depression, usually in the mid face region. However, in such cases post-natal development tends to be normal and deformity tends to stabilise or improve. Similar restriction can occur with the mandible and this is classically seen in individuals with Pierre Robin syndrome. This results from the head being flexed tightly against the chest, preventing the mandible from growing forward. Fortunately such individuals tend to improve with growth and may even achieve normal mandibular length.

1.3.7 Facial syndromes

Several craniofacial syndromes present with some degree of facial asymmetry. Usually these individuals have characteristic facies and treatment tends to be complex and involve a multi-disciplinary approach. Such syndromes include; Crouzon syndrome, Aperts's Syndrome, Orofacial syndrome, Hemifacial microsomia and cleft lip and palate (Proffit, 2000).

1.4 Facial Aesthetics

It has been documented that the desire to improve aesthetics is the primary motivating factor for 80% of adults seeking orthodontic treatment, either for themselves or for their children (Baldwin 1980). Conversely children appear to be unaffected by their aesthetics unless they experience harassment (Shaw *et al* 1980).

Before getting to know a person, their outward appearance is what people might base their opinions on and this can affect an individual's self-esteem and quality of life (Rumsey *et al* 2004). On this basis, facial appearance is a key factor with regards to how people rate and interact with others. Macgregor et al (1970) suggested that facial deformity could be considered a social disability affecting both the individual and those around them and that those with a mild-moderate disfigurement potentially had lower psychological scores than those with a more severe deformity.

Several studies have concluded that facial symmetry is associated with attractiveness (Grammer and Thornhill, 1994; Hume and Montgomerie, 2001; Mealey *et al*, 1999). It has been postulated that facial symmetry is associated with the perception of good health and may be a factor for partner selection. Jones *et al* (2001) found that there was an opposite-sex bias in sensitivity to facial asymmetry. This was also found by Little *et al* (2001), but, conversely Rhodes *et al* (2001) did not find this correlation when they conducted a similar study.

Darwin (1871) stated that beauty was specific to cultural and racial groups and that a universal standard did not exist. Since this suggestion many investigators have disputed this notion. Little *et al* (2007) investigated preferences for facial symmetry between UK population and a hunter-gatherer population. It was found that both cultures preferred a more symmetrical face and the hunter-gathers more strongly preferred the symmetrical face. The authors concluded that the predilection for symmetrical faces was due to the assumption that symmetry was related to better genetics and part of the mating selection. It was also noted in this paper that women were more sensitive to asymmetry during pregnancy and lactation.

Francis Galton's work on composite photographic images (Galton, 1878) revealed that averageness was ideal and such composite images tended to achieve higher attractiveness ratings. Further investigations in this field (Perrett *et al* 1994) suggested the theory that average faces were attractive could not be upheld, instead attractive faces were based on average faces with exaggerated features, which features to be exaggerated was not reported.

As beauty is highly subjective, a more precise method of assessing the face is to use the objective measure of proportions. Clinical assessment can be carried out objectively using proportionality as described by artists and architects. As it is the outward soft tissue appearance of a person that our aesthetic opinions are based upon, it seems logical that the clinical assessment, treatment goals and outcomes should be influenced by the patient's outward appearance. (Sarver 1998 and Proffit *et al* 2003).

1.5 Evaluation of facial form

1.5.1 Clinical assessment of facial proportions

Assessment is carried out in natural head position (NHP). This is the position that we habitually carry ourselves (Moorrees and Kean, 1956; Solow and Tallgren, 1976; Solow *et al*,

1983) and is deemed to be the most appropriate position to allow assessment of a patient's facial form (Cooke and Wei, 1988; Viazis, 1991). NHP appears to be reproducible and has been documented to be within the clinically acceptable variance of 4°. This degree of error is preferable to the 26° that has been found in relation to reproducibility of the Frankfort plane (plane that connects the highest point of the ear canal to the lowest point of the orbital rim) (Luyk *et al*, 1986; Viazis, 1991).

1.5.2 Monitoring growth

Longitudinal measurements of facial proportions are necessary to monitor stability or progression of asymmetries in both the growing patient and those who have reached skeletal maturity. Methods of recoding longitudinal measurements include regular radiographs, photographs, study models or anthropometric measurements.

1.5.3 Patient perception of their facial appearance

It has been suggested that Orthodontists and Maxillofacial Surgeons may be more sensitive to perceive facial imbalances than the general population (Johnston *et al*, 1999). A pilot study investigating the threshold of visual perception of facial asymmetry in a facial paralysis model by Chu *et al* (2011) found that a minimum of 3mm of facial asymmetry was needed for the lay person to notice the asymmetry in digitally manipulated images. However, this level of asymmetry was specific to the oral commissure, brow or both. It would be interesting to compare Chu's results with the findings from this proposed project and investigate if there is any difference between where asymmetry is noted and the point at which is it deemed notable and in need of correction.

1.5.4 Anthropometry

Anthropometry is the scientific measurement of human beings. With advances in digital technology anthropometry is no longer restricted to direct measurements with instruments such as calipers, but is more increasingly being carried out using three dimensional scanner technology.

Farkas and Cheug (1981) used direct anthropometry to measure asymmetry in healthy Caucasian children, with a sample size of over 300 they found that mild asymmetry (defined as a difference between the left and right sides of less than 3 mm in absolute measurements or 3% between comparative size) was common, the right side of the face was more likely to be the larger side and asymmetry was most likely to affect the upper third of the face. Measurements were recorded from the lateral aspect of the face using a standard spreading calliper after the facial landmarks had been identified and marked with ink on each subject. Studies being carried out now are more likely to use indirect measurements. Wong *et al* (2008) investigated the validity and reliability of facial anthropometric linear distances measured both directly and indirectly using 3D digital photogrammetry. They found that the 3dMD photogrammtey system (3 dimensional imaging system) that they used was valid and reliable. Aynechi *et al* (2011) assessed the accuracy and precision of 3D systems either with or without prior landmark identification against direct anthropometry and found that the 3dMD system offered an accurate and precise method that was comparable to direct anthropometry either with or without prior landmark identification.

1.5.5 Radiography

1.5.5.1 Panoramic radiography

A panoramic radiograph (also known as orthopantomogram or dental panoramic radiograph) is a 2-dimensional radiographic view that captures the area from condyle to condyle, including the mandible, the dentition and parts of the maxilla and its associated structures, in addition, images relating to the spine and other anatomy may be seen on the film but are not necessarily beneficial to the reason for image capture. The panoramic radiographic may be used as a general overview image, from which other special investigations may be indicated, and it is one of the routine radiographic projections used for the assessment of orthodontic patients. However, it is subject to magnification error and distortion. Although this projection allows overall assessment Ramstad *et al* (1978) suggested that panoramic radiography should not be used for quantitative measurements. In particular horizontal measurements have been shown to be unreliable due to the variation in magnification.

In contrast Kambylafkas *et al* (2006) used panoramic radiographs for quantifying vertical and angular measurements in their assessment of vertical mandibular asymmetry using dried skulls and living patients. They concluded that the panoramic radiograph tended to underestimate the asymmetry and was not reliable for all necessary measurements, therefore this radiographic view cannot be recommended as the view of choice for the assessment of facial asymmetry.

1.5.5.2 PA cephalogram

Cephalometrics is the analysis of standardised radiographs to assess the underlying cranial skeletal structure, dentition and to some extent the soft tissues. There are three standardised radiographic projections that can be employed, namely: the lateral cephalogram, the posterior-anterior (PA) caphalogram and the axial cephalogram. In Orthodontics, the lateral cephalogram is the most commonly used of the three views, the PA and axial cephalographs are less frequently used, but are useful views for assessing asymmetry. Profitt (1991) claims that the primary indication for the PA cephalogram is the assessment of asymmetry. Various methods of analysis have been suggested to allow interpretation of PA cephalograms when asymmetry is being measured (Chebib and Chamma, 1981; Grummons and Kappeyene van de Coppello 1987; Edler *et al*, 2003).

1.5.5.3 Submentovertex radiographs

One of the inherent problems associated with the PA cephaologram is the identification of an appropriate mid-sagittal reference plane. In attempt to overcome this problem the submentovertex (SMV) radiograph was suggested as the radiograph of choice for the assessment of facial asymmetry. The SMV cephalogram has the advantage that the mid sagittal reference plane can be based on cranial structures (Ritucci and Burstone, 1981) that are remote from the facial bones and some of these structures have been found to have a high degree of symmetry (Pearson and Woo, 1935). Several methods for analysing the SMV radiograph are currently in use (Fosberg *et al*, 1984; Lew and Tay, 1993) but reliability can be affected by the patient positioning during x-ray exposure (Lew and Tay, 1993).

1.5.6 Photography

Photographs can be used to both assess and monitor asymmetry. In 1933 Wolff carried out a psychological experiment using composite photographs of individuals. The objective of Wolff's experiment was to gain a better understanding of the human mind, not to assess asymmetry, however, the method he used to produce the composite face highlighted any inherent facial asymmetry. He found that images constructed of the original image and a reverse left or right side, when viewed by strangers, were not identified as belonging to the original image, whereas, the individuals from which the images were taken were able to recognise themselves from the image made of the left sides. This method of forming a composite image is a simple, but crude method of observing mild asymmetries of an individual.

1.5.6.1 Two-Dimensional photographic measurements of asymmetry

This is a simple, inexpensive method of capturing and monitoring soft tissue facial asymmetry. Edler (2002) described a technique using 2D facial photographs to quantify mandibular asymmetry. In this study four descriptors; area, perimeter length, compactness and the moment ratio of the mandible, were used to categorise patients. For each patient the region of interest was identified on a standardised 2-dimensional facial photograph and then divided into right and left segments for comparison. The identified region was bounded by the border of the mandible, up to the point of the ear insertions to the mandibular border, with the upper limit being the horizontal line that connected the right and left ear insertion points. The area and perimeter of the right and left regions were compared for each face. In addition the compactnesss, defined as the square of the perimeter divided by the area, was calculated for each side, giving an indication of shape that could then be compared numerically. Finally the moment ratio of the entire mandibular region was calculated to allowassessment of the extent of any identified asymmetry. Edler found that area, perimeter and compactness were adequate markers for asymmetry and treatment planning.

1.5.6.2 Stereophotogrammetry

Photogrammetry is a method of calculating geometric values between facial landmarks from photographic images, an extension of this is stereophotogrammetry. The 3dMD camera (3dMD LLc, Atlanta, Ga) provides a method of acquiring such images allowing 3-dimensional co-ordinates to be established for points on an object by making measurements on two or more photographic images which have been taken from different angles.

In recent times popularity has grown in the use of 3D methods of image registration. 3-dimensional image capture allows the face to viewed from multiple perspectives and this is especially important for patients with facial asymmetry as the abnormality is not always obvious from a single photographic image.

For asymmetry to be defined quantitatively and qualitatively in 3d images, a reliable reference plane is necessary. Various methods have been proposed to allow identification of a reliable reference plane, including, the identification of 3 mid-sagittal landmarks or alternatively the plane can be based on a pair of bilateral landmarks with a third landmark centred between the two. Ras *et al* (1995) found that the most appropriate reference plane for assessing facial asymmetry is formed by the vertical that bisects the line connecting the bilateral landmarks exocanthion (Table 1).

1.5.7 Three-dimensional image analysis

Three-dimensional image analysis is becoming a more popular and viable option for assessing the soft and hard tissues. Methods include lasers, structured light (included stereo-photogrammetry as described above), video-imaging allowing dynamic image analysis, radiation methods such as three dimensional cephaolometry, computed tomography scans

(CT) and cone beam computed tomography (CBCT) and other methods including magnetic resonance imaging (MRI) and ultrasound.

There are many potential advantages and disadvantages associated with the above methods. However, perhaps the greatest disadvantage is the associated cost, including purchasing the equipment and necessary software, therefore limiting the number of clinicians able to offer such techniques. Another important aspect to consider is the radiation exposure, which is substantially higher for CT and CBCT in comparison to conventional radiography and should therefore not be used routinely, but instead used only for exceptional cases.

1.6 Aims and objectives

The aim of this study is to assess to what extent facial asymmetry is perceived and which values are perceived to be outside the normal range. This knowledge would be useful for both patients with asymmetry and clinicians who are responsible for assessing and formulating treatment plans for such patients. Such information may provide patients with an unbiased measure of how asymmetry is perceived by others and allow comparison of their own asymmetry to the levels found to be viewed as within the normal range and in need of correction, whereas, clinicians may be able to use the information to define levels suitable for acceptable or surgical correction. The specific objectives of this study are to:

1. Determine the range of chin point deviations that can regarded as normal
2. Determine the range of chin point deviations that are perceived to be outside the normal range, but aesthetically acceptable
3. Determine the degree of chin point deviation that is perceived to be outside the normal range and thought to warrant surgical correction

4. Determine whether there are any differences in perception of asymmetry between different types of observers (lay people, dental students, dental care professionals, general dental professionals, orthodontists).

1.7 Null hypothesis

Two null hypotheses are considered in this study:

1. There is no difference between the level of asymmetry perceived to be abnormal by lay people and by various levels of dentally-qualified individuals.
2. There is no difference between the level at which asymmetry is first noted by the observers and the level of asymmetry that is considered to be worth correction.

2. MATERIALS AND METHODS

2.1 Ethical approval

Ethical approval was obtained from the Birmingham University Research and Ethics Committee (ERN_11_0117). The NHS RES board was also approached to verify whether ethical approval was needed and this was deemed unnecessary.

2.2 Preparation of the average faces

2.2.1 Trial 2-dimensional technique

Prior to attempting production of a 3-dimensional multi-racial average face, a trial was conducted using standardised 2-dimensional facial images. Forty facial images of individuals from a variety of ethnic backgrounds were input and manipulated with the image processing software ImageJ (1997 – 2012) to produce average male and female faces (Figures 1 - 3). The resultant faces were assessed subjectively and independently (GL and GM). It was decided that there was potential to produce an acceptable 3-dimensional average face based on a relatively small number of individual multi-racial faces as the average faces did not appear to be driven by any particular ethic group.

Figure 1 Flow diagram describing the process involved in the production of the 2-dimensional average face in ImageJ.

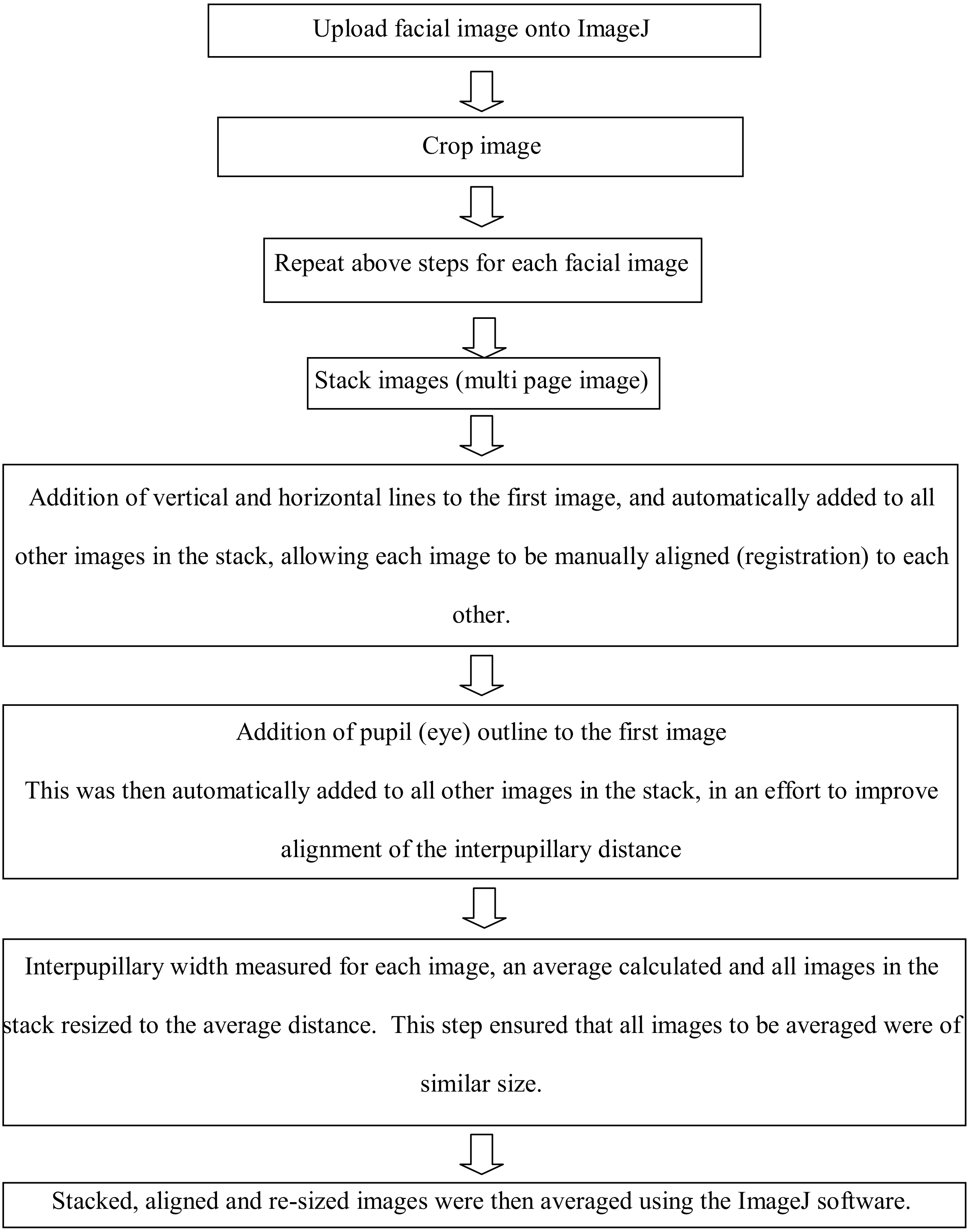


Figure 2 Average female face based on 2-dimensional standardised facial photographs

Figure 3 Average male face based on 2-dimensional standardised facial photographs

2.2.2 Acquisition of images for the average face

The individual images included in the average male and female face production where recruited from Birmingham University Dental School.

Inclusion criteria

Aged between 18 and 35 years (the upper and lower age limits were placed to help to eliminate the effect of age related soft tissue changes that may have affected the final average face)

Any ethnic origin

Male or female

Exclusion criteria

Facial hair (as the camera system is unable to capture hair-covered surfaces)

Unwilling to consent to have their 3D facial image taken and included in the average face production

The number of individuals recruited to produce the average faces was limited by time, the inclusion and exclusion criteria, the availability of the individuals to have their images taken during working hours and the static nature of the camera. The final number of images that was able to be taken during the available photographic sessions was 56, including 24 male subjects and 32 female subjects.

Subjects were recruited via an email sent to all staff and students of the Birmingham University Dental School, an open invitation made to all students at individual lectures and clinics and verbal invitation made to clinical staff on the days of image capture.

Those who were eligible for inclusion in the production of the average faces had their facial image recorded in the Clinical Illustration Unit located within the Birmingham University Dental School using the static 3dMd camera (3dMD LLc, Atlanta, Ga).

2.2.3 Imaging system

All individual images were taken using the static 3dMD face system (3dMD LLc, Atlanta, Ga). This system is capable of capturing photorealistic images via a combination of structured light and stereophotogrammetry. The 3dMD system uses a combination of six digital cameras, three mounted on the right and three on the left of the position of the individual. Of these one is colour and two are infra-red cameras. This combination is used for capturing a random light pattern projected onto the subject (simultaneously captured by all six cameras from precise angulations). Image capture takes 1.5 milliseconds, when the highest resolution is selected. The resultant image has the potential to scan from ear to ear and under the chin, however, this is dependent on individual variability, especially in the area under the chin. The accuracy of the capture, according to the manufacture, is reported to be less than 0.5 mm, while the clinical accuracy has been reported at 1.5% of the observed variance (Aldridge *et al*; 2005). Previous studies have shown that images recorded in this manner have a high degree of repeatability and precision (Kau *et al* 2007; Kau *et al* 2006).

2.2.4 Image capture

Before image capture each individual was given an information leaflet (Appendix I) outlining the project and how their image would be used, they were then asked to sign a consent form (Appendix II) to confirm their acceptance for inclusion in the production of the average face. Each subject was asked to remove any spectacles and jewellery and to tie all loose hair back from the face.

The subject was positioned on an adjustable chair in front of the wall mounted 3dMD camera system and asked to look directly into a mirror, to ensure that natural head position was achieved. They were then moved, as necessary, to ensure that their face was framed within the limits of the viewer as seen from the computer screen. The subject was instructed to sit still with their teeth and lips in contact, with a relaxed facial expression.

The image captured was transferred directly to the viewing system (3dMD viewer) where it was converted automatically to a 3d image (Figure 4). All images were stored as object (OBJ) Files and files were named according to number allocated to the subject on signing the consent form. The subject was given a copy of this consent form with their study number, advising how they could remove themselves from the study if desired.

Figure 4 Example of a facial image taken using the 3dMD camera

2.2.5 Processing of images

The individual images were transferred to Radpiform Basis 2006 software for processing and production of the average faces. The files were converted to mdl.files for use with the Rapidform software.

Each image was then processed, landmarked and normalised (described below) in preparation for production of the average faces. It was not possible to combine the individual images whilst in colour, therefore, prior to combining the images the faces were converted to greyscale.

Processing consists of the removal of any part of the image that was beyond the boundary to be used in the final image. Everything beyond the hairline, the anterior border of the ears to the face and under the chin was cropped, ensuring that all images had a similar outline assisting with better averaging at the periphery. In addition to cropping unwanted information from the image, any holes (small gaps in the facial shell, usually as the result of a stray hair or missing data) had to be filled. Failure to complete this stage appropriately may have affected the final face (Figure 5).

Landmarking: For each image 21 landmarks (Djordjevic *et al*, 2011) were identified (Figure 6), including 7 midline landmarks and 7 paired bilateral landmarks (Table 1). The landmarks were identified by one operator. One of the benefits of using a 3-dimensional face was that the image could be rotated in all three planes of space in order to improve the landmarking accuracy.

Normalisation of the individual processed and landmarked faces is a key stage prior to the averaging process. Included within this stage are three sub sections; removal of translation, removal of rotation and removal of size difference. Failure to complete this stage would otherwise result in a distorted final image, as no two faces would be in the same plane of space nor would they be scaled to the same size. Identification of the mid-sagittal plane was based on the superimposition of the original and mirror image facial shells. The two images were superimposed using the best-fit technique, allowing a symmetrical image to be produced, from which the mid-sagittal plane could be identified. This process was completed automatically using a programme developed by the team at the Orthodontic Unit at the School of Dentistry at Cardiff University. This programme is for use with Rapidform software (INUS Technology, Inc, Seoul, Korea) and the Cardiff Orthodontic team kindly allowed me to use it in conjunction with their equipment. Coronal and transverse plane identification relied on a novel method of encapsulating the symmetrical superimposition face with all its associated data-points within a computer generated cylinder. This process allowed the face to be orientated within a defined parameter, therefore allowing the x-axis to be identified. From the x-axis the transverse plane could then be identified as the plane passing through mid-endocanthion. The coronal plane is then generated to pass perpendicular to both the transverse and sagittal planes through the identified origin (mid-endocanthion). Following this identification process the original image is then translated so that mid-endocanthion represents co-ordinate points (0, 0, 0) and the transverse, sagittal and coronal represent the xy-, yx- and xz- axis respectively. Again this procedure was automatically carried out using a set of in-house VBA (Visual Basic Applications) subroutines for Rapidform that had been developed by the Orthodontic Unit at Cardiff Dental School.

Figure 5 Processed image

Figure 6 Landmarked image, showing the seven mid-line and seven bilateral landmarks

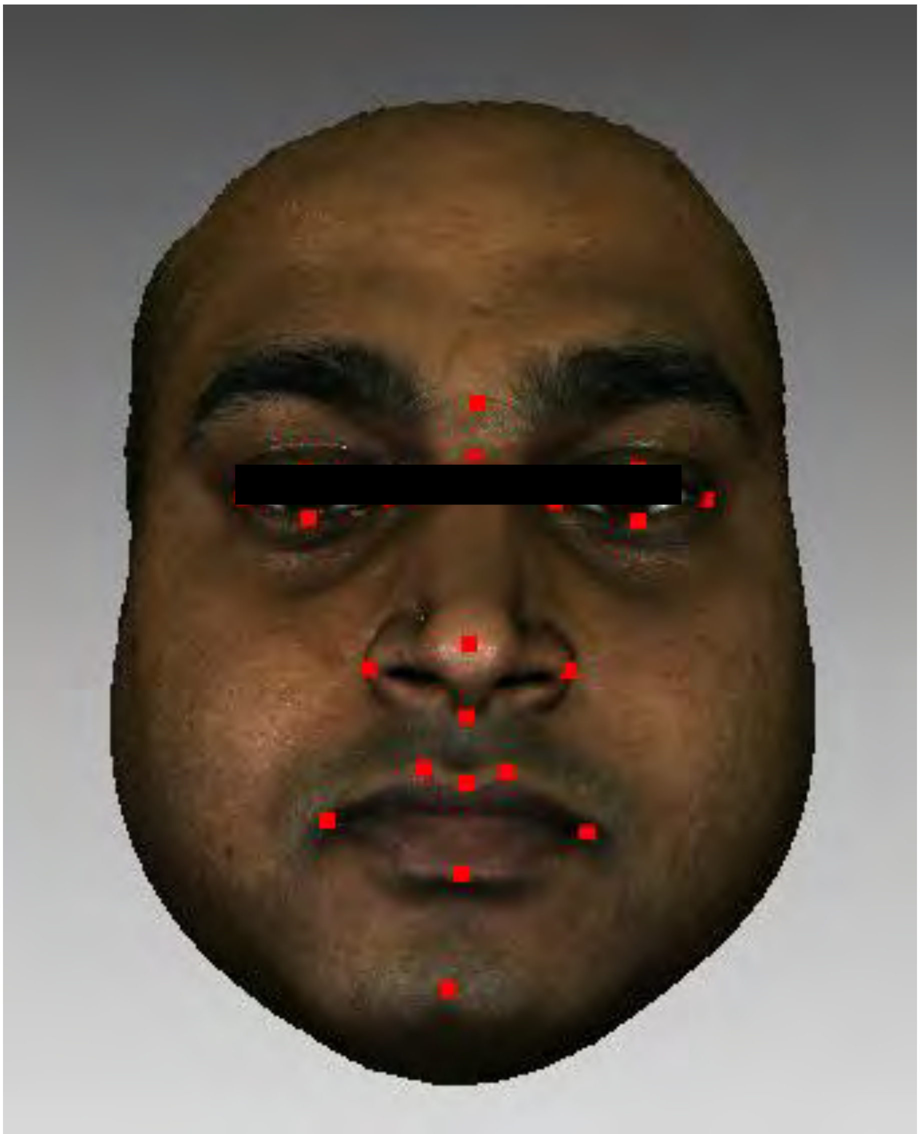


Table 1 Facial landmarks (Farkas, 1994)

Soft tissue landmarks	Description
Glabella (g)	Most prominent midline point between the eyebrows. Is identical to the bony glabella on the frontal bone
Nasion (n)	The point in the midline of both the nasal root and the nasofrontal suture
Pronasale (prn)	Most protruded point of the apex of the nose
Subnasale (sn)	Midpoint of the columella base, at the apex of the angle where the lower border of the nasal septum and the surface of the upper lip meet
Labiale superius (ls)	Midpoint of the upper vermillion line
Labiale inferius (li)	Midpoint of the lower vermillion line
Pogonion (pg)	The most anterior point of the chin on the mandible in the midline
Palpebrale superius (ps)	Highest point in the midportion of the free margin of each upper eyelid
Palpebrale inferius (pi)	Lowest point in the midportion of the free margin of each lower eyelid
Endocanthion (en)	The point at the inner commissure of the eye fissure
Exocanthion (ex)	The point at the outer commissure of the eye fissure
Alare (al)	Most lateral point on each alar contour
Cheilion (ch)	The point located at each labial commissure
Crista philtri (cph)	The point on each elevated margin of the philtrum just above the vermillion line

2.2. 6 Average face production

The average faces were constructed using the VBA subroutines produced by the Orthodontic Unit at the Cardiff Dental School for use with Rapidform. The method chosen for the averaging process was based on the template method. After the images had been processed, landmarked and normalised they were combined along the z-axis to produce an average face. Using the first produced average male and female faces template averaging was then carried out to produce superior average male and female faces. In this process the original average face is used as the template shell for which a subsequent average face is produced, this new face can then be used at the template for the next template and so on. This procedure can be continued until a face of adequate accuracy is produced (Figures 7 and 8). This process allows better quality images to be produced (Kau and Richmond, 2010). Once the final average faces were complete any small voids or areas of irregular contour were filled and smoothed to produce a more realistic facial shell.

Figure 7 Final average female facial shell – frontal and profile perspective

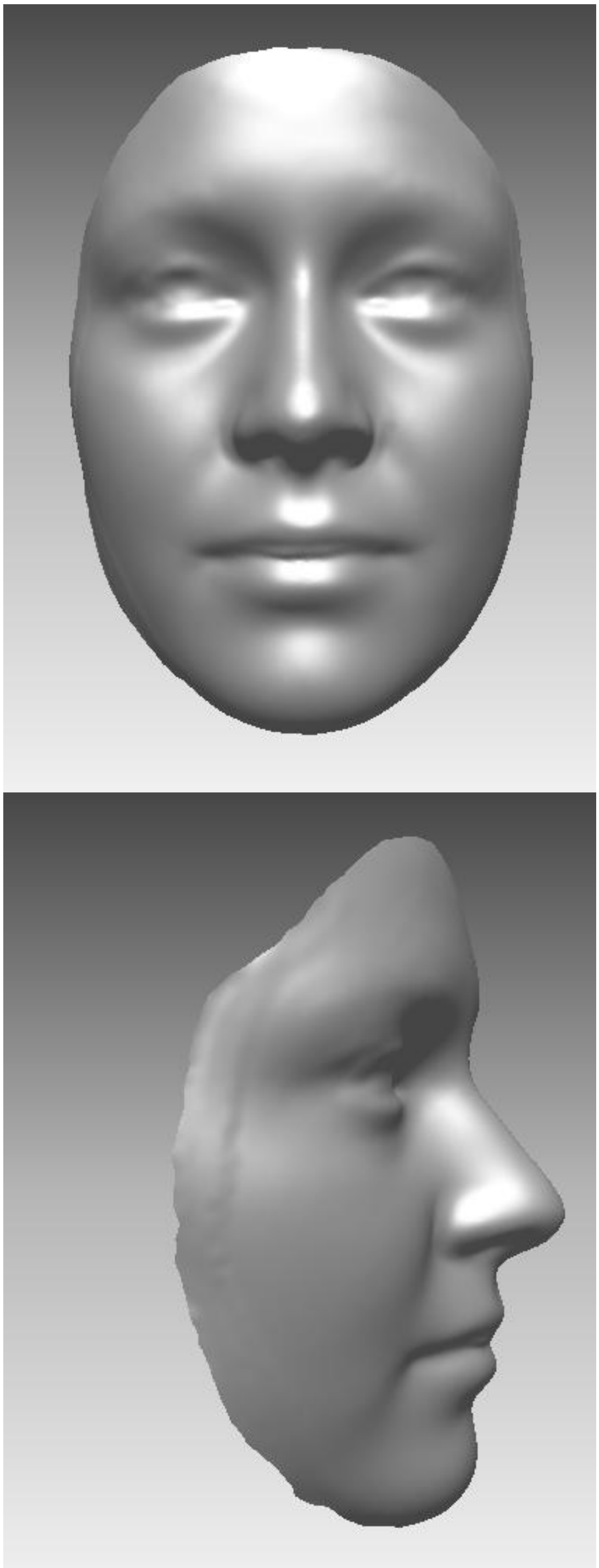
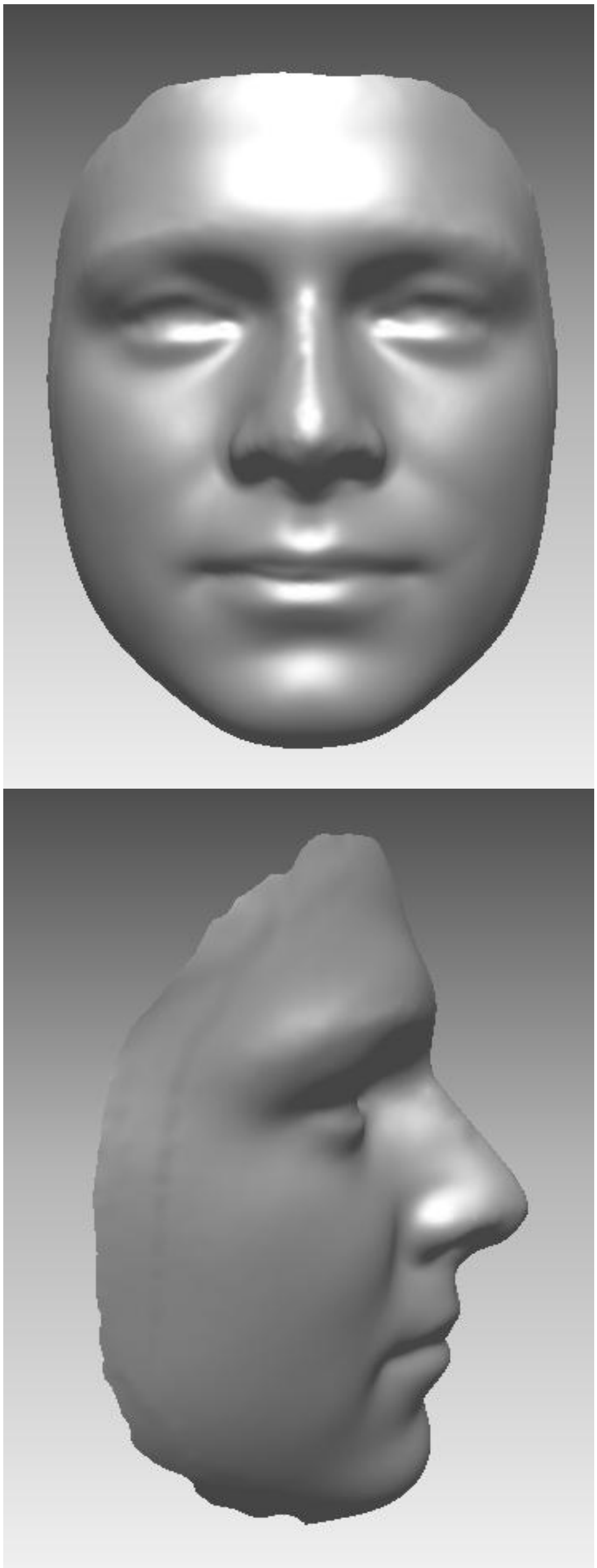


Figure 8 Final average male facial shell – frontal and profile perspectives



2.3 Assessment of symmetry

Using the previously processed, landmarked and normalised images it was possible to assess the level of symmetry present in each image by running a programme produced by the Cardiff team for use with the Rapidform Basis 2006 software. This programme produced a mirror image of the face which was then superimposed onto the original image using a best fit technique, to allow identification of a mid-sagittal plane. This mid-sagittal plane was used to assess absolute deviation of the landmarks. In addition the percentage of symmetry was calculated based on the amount of the original image that mapped to the mirror image at a tolerance of 0.5 mm (manufacturers error less than 0.5mm).

2.4 Production of the manipulated faces

Using the average male and female 3-dimensional faces manipulations were produced to simulate chin point deviation. The manipulated images were produced by a computer programming collaborator (Ms Faye Maxim, Birmingham City University) using the Maya software package as this required a level of knowledge for manipulation and expertise which was not available in our institution. As the average faces were produced in a grey scale with no skin colour or texture, prior to manipulation a skin map was overlaid onto the average face using a 2-dimensional facial colour wrap. Colour and texture were applied to produce a more realistic face for assessment. Based on the results of the pilot study the deviations to be rated ranged from 0 – 20 mm, in 2 mm increments, to both the right and left. The final number of images to be rated was 42, for the female and male faces there was a symmetric face and 20 manipulated faces (Figures 8 and 9).

Figure 9 Selection of the manipulated female faces showing a range of chin point asymmetry

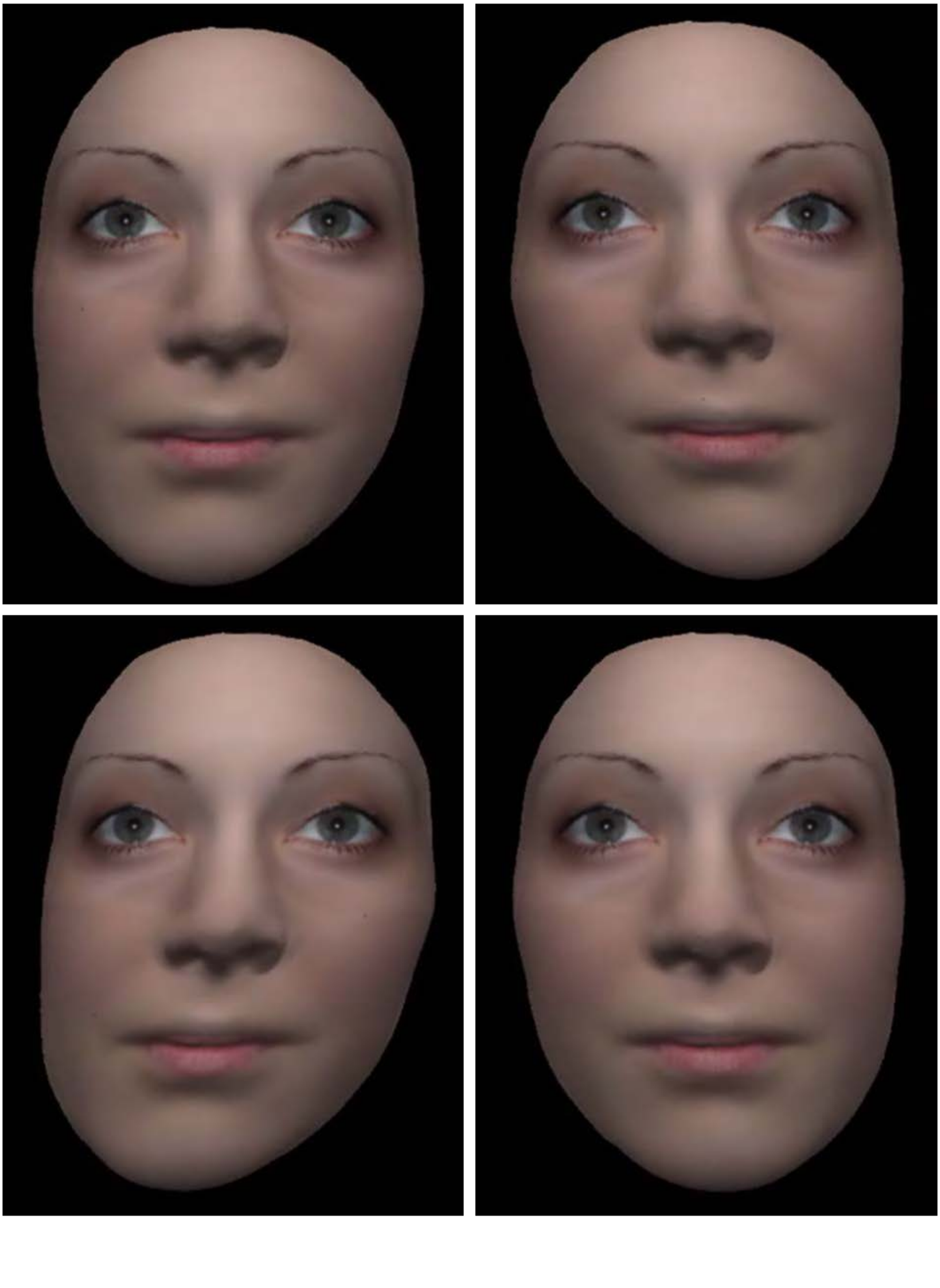
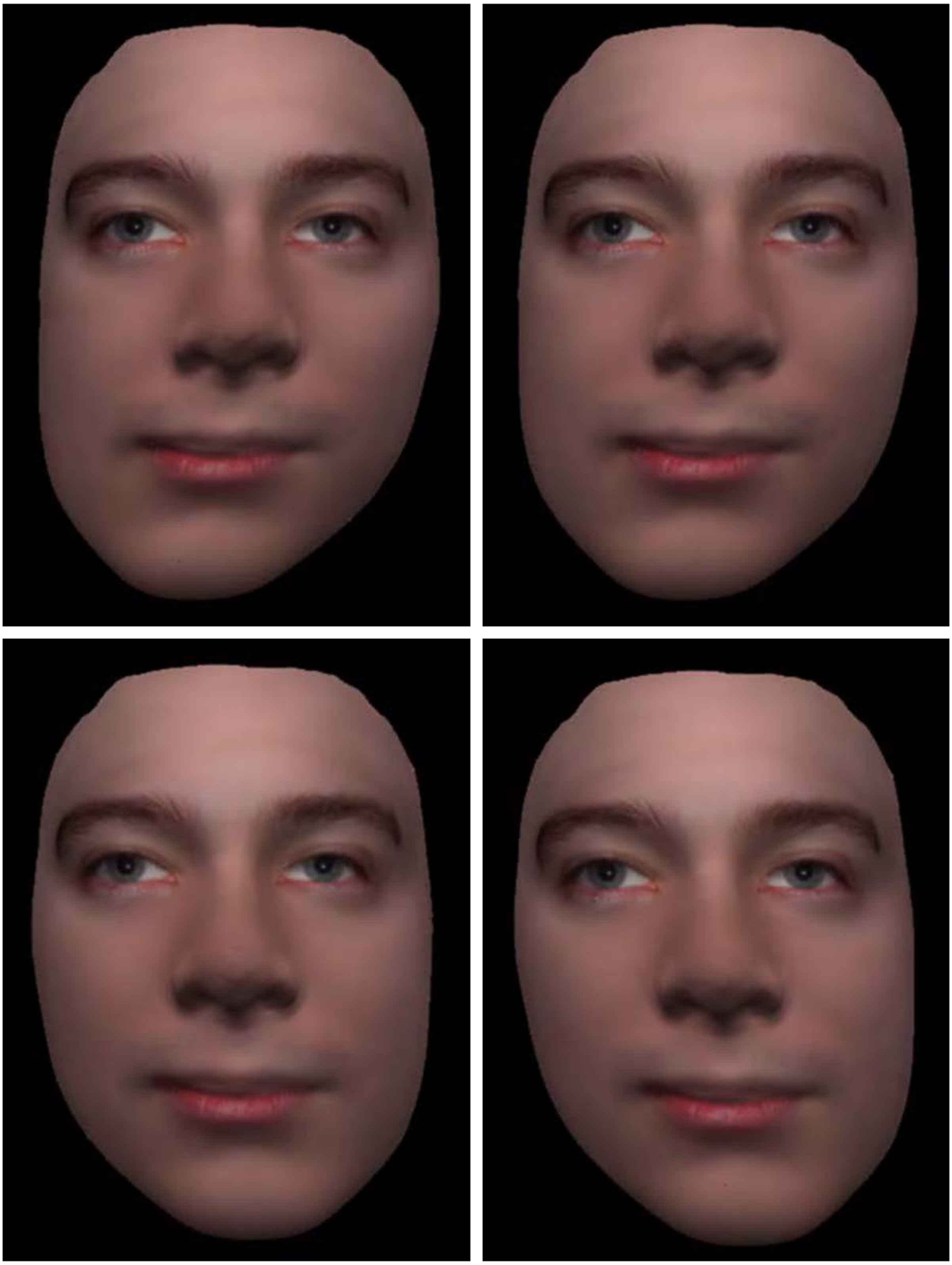


Figure 10 Selection of the manipulated male faces showing varying levels of asymmetry



2.5 Preparing the images for presentation

The facial images were presented to the observers in a pre-determined order (Appendix 3), on a timed power point presentation. Each modified image was shown for 14 seconds. The images where presented as a rotating image starting from the frontal view before rotating 90^{o} to the right and left profile views. Between each manipulated image a black screen was shown for 2 seconds. The order of the images was randomised by pulling numbers from a hat. Both male and female images were shown within the one presentation. The observers were asked to rate the images during the time that each image was on the screen. For each image the observers were asked to classify the face as one of three options (appendix 4):

- balanced, acceptable face (no abnormality noted)
- some abnormality, socially acceptable, not requiring correction
- the case would benefit from correction of the asymmetry

2.6 Rating of the manipulated average faces

2.6.1 Rating groups

Subjects from five sub-groups were asked to rate the manipulated images. The five groups were: non dentally qualified individuals (lay people), dental students, dental care professionals, general dental practitioners and orthodontists.

Each participant was asked to complete a consent form and indicate their gender and the group to which they best belonged. The dental students, consisted of fourth and fifth year dental students, therefore ensuring that they had some degree of clinical experience. Dental care professionals included a range of unqualified nurses in training at the Birmingham Dental School, qualified nurses and dental technicians. The general dental practitioner group consisted of qualified dentists with no additional registered qualifications in any dental speciality. The orthodontist group consisted of orthodontic registrars, specialist orthodontists and consultant orthodontists. The lay group consisted of any individual who had received no formal dental training, included in this group were porters, administration staff, parents of patients and electricians.

2.6.2 Sample size calculation – observer groups

The sample size calculation was based on an 80% sensitivity, with the aim of discriminating between groups at 0.8 and 0.5 levels (i.e. one proportion of 80% and one of 50%). The lay person category was chosen as the base group and all other groups were compared to this.
The resultant sample size, when input into SPSS, was 39 observers per group, this was rounded to 40, giving an overall sample size of 200 rating individuals.

There have been two (Meyer-Marcotty *et al*, 2011; Naini *et al* in 2012) recent studies that have investigated perception of facial asymmetry. Of these two studies the maximum overall sample size was smaller than this current study at 185 observers (Naini *et al* 2012), however their individual group sample size for two of their groups was greater at 75.

2.7 Statistical analysis

The data obtained from the rating observers was categorical, therefore, analysis was based on comparison of proportions. In an effort to define ranges representing normal asymmetry and a quantifiable level for which correction was deemed appropriate time-to-event analysis was carried out. From these results a General Linear Model analysis was performed, with post-hoc Tukey testing was carried out, as well as analysis of the homogeneous subsets in the data.

3. RESULTS

3.1 Demographics of the individuals included in the production of the average faces

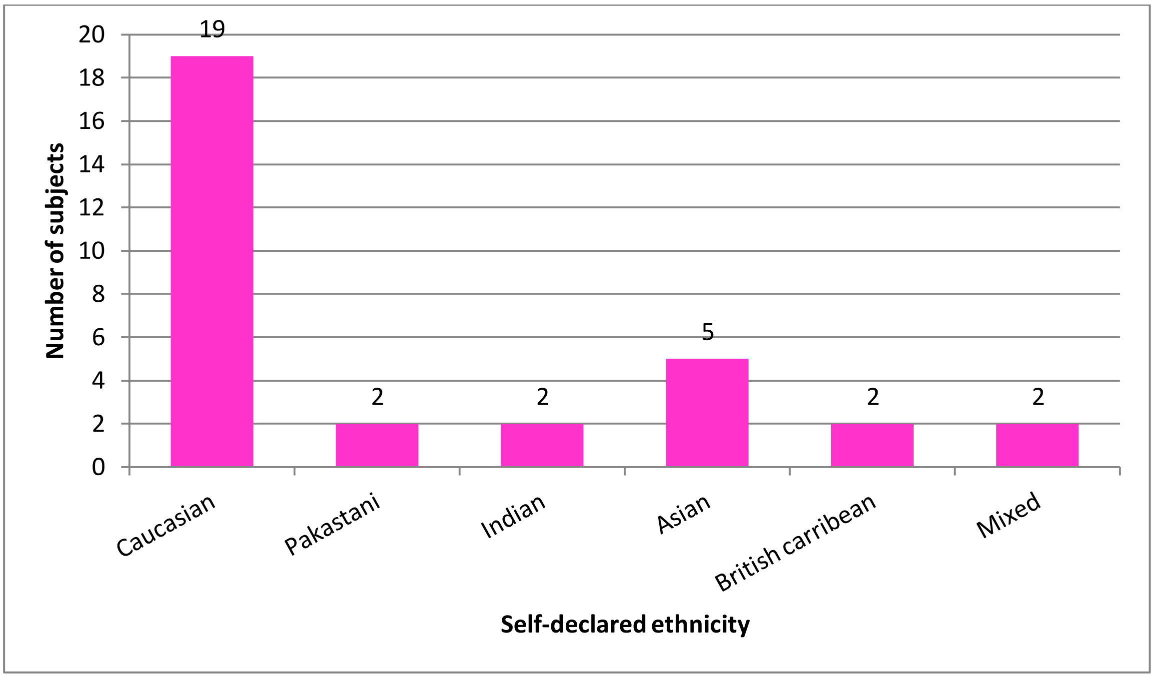
Total sample size:	56 subjects
Average age	26.6 years (standard deviation 4.6 years)
Average age of females	26.6 years (standard deviation 4.6 years)
Average age of males	27.5 years (standard deviation 4.7 years)

At the time of consent, the subjects for inclusion in the average faces were asked to indicate their ethnic origin. The individual was allowed to state this without constrains of categorisation (Table 2, Graph 1 and 2).

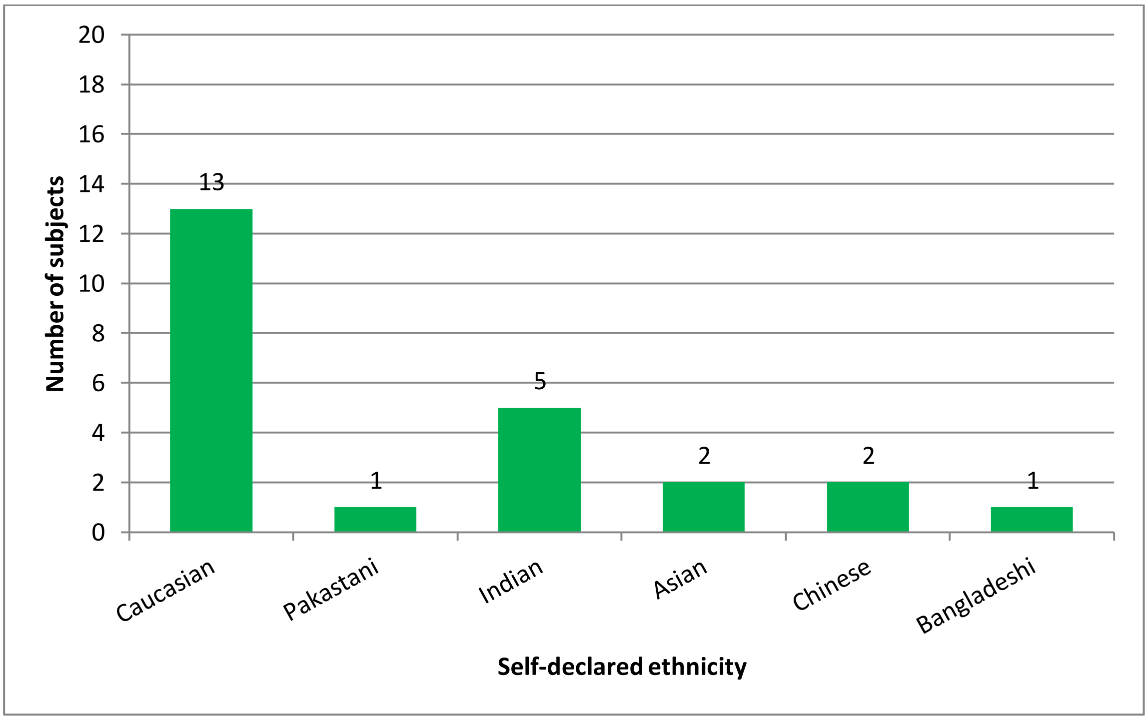
Table 2 Ethnic origin, as indicated by the individuals included in the average faces

Ethnicity	Males	Females
Caucasian	13	19
Indian	5	2
Bangladeshi	1	0
Pakistani	1	2
Mixed	0	2
Caribbean-British	0	2
Chinese	2	0
Asian	2	5
TOTAL	**24**	**32**

Graph 1 Ethnicity of the females included in the average face
59.4% of the sample of the females used to produce the average face were Caucasian, with the remaining 40.6% of other origin, including 28.1% of Asian origin (including Indian and Pakastani).



Graph 2 Ethnicity of the males included in the average face
54.2% of the male sample included in the average face production were Caucasian, with the remaining sample being of Asian origin.



3.2 Symmetry assessment of individuals included in the average face production

3.2.1 Results for female faces included in the average face

3D facial images were taken for 34 individuals, however two had to be excluded from the symmetry assessment as their hair was not sufficiently tied back from their face to allow accurate assessment of symmetry. The final sample size for symmetry assessment in the female group was therefore 32.

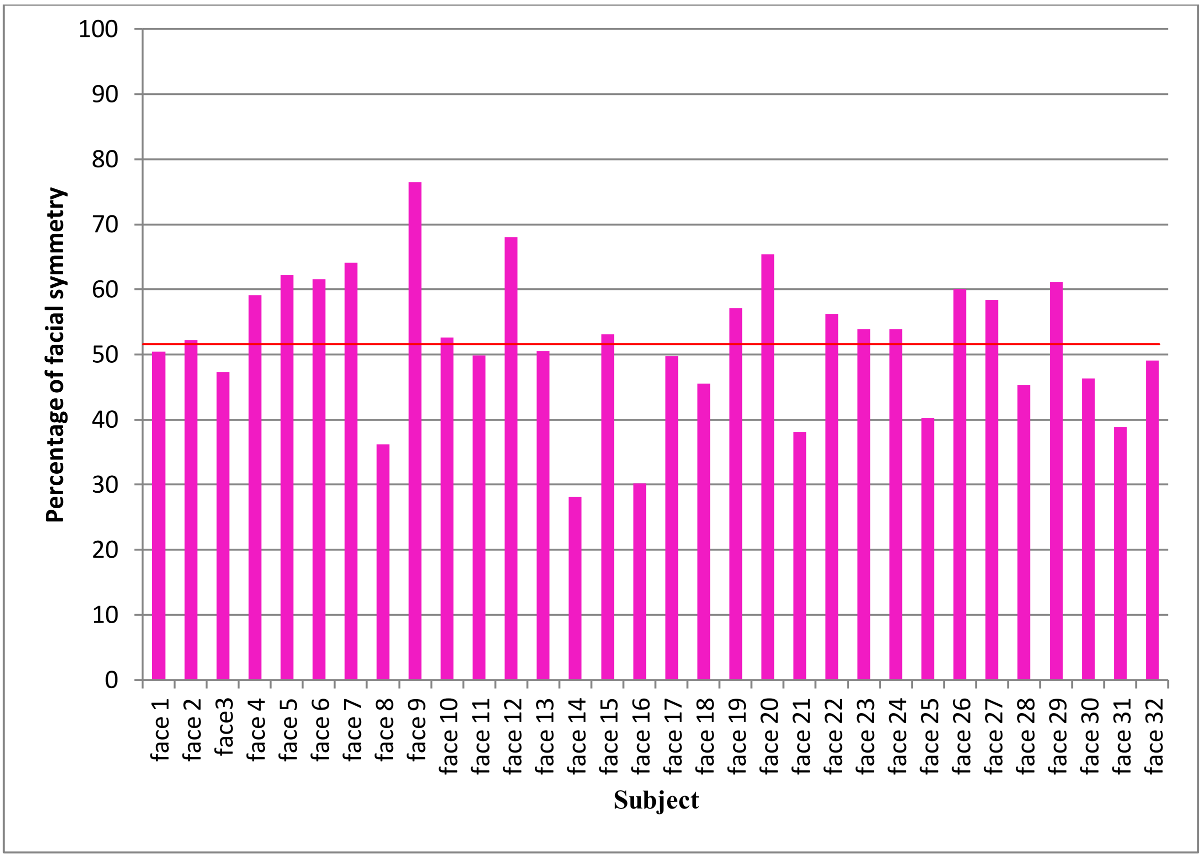
The overall symmetry of each individual face was calculated as a percentage of the original surface scan that matched the mirror image to an accuracy of at least 0.5mm (Graph 3 and figure 11).

The overall average level of symmetry found for the entire face, based on this tolerance level of 0.5mm, was 51.92%. The symmetry values were then assessed for four sub-sections of the face allowing investigation of any patterns of symmetry. It was found that, on average, the degree of symmetry reduced as the distance from the cranium increased (Graph 4 and figure 12). The average level of symmetry found for the forehead region of the female subjects included in the average face was 65.61%, this reduced to 61.33% for the region bounded by the horizontal planes at mid eye level (exocanthion) and beneath the nose (sub nasale), the region of the face extending from subnasale to the mid lip level (cheilion) was again less symmetric at 41.83%, and the chin region showed less than half the level of symmetry found in the forehead region at 30.34%.

Linear deviations were then assessed based on the distance of the 7 midline landmarks (glabella, nasion, pronasale, subnasale, labiale superius, labiale inferius, pogonion)(Graph 5 and 6) and the midpoint between the 7 bilateral landmarks (palpebrale superius, palpebrale inferius, exocanthion, endocanthion, alare, crista philtre, cheilion) (Graph 7) from the identified mid-sagittal plane. It was found that there was a relatively large range of deviation for each landmark in this sample, however, this can partially be explained by one subject with marked deviations (Graphs a and b). For the midline landmarks there was a range of deviations from 0.06 – 7.16 mm and for the bilateral landmarks the values ranged from 0.02 – 5.91mm. Despite this outlier, the average deviation for each midline (0.5 – 1.89 mm) and midpoint of bilateral (0.99 – 1.38mm) landmarks was still below 3mm.

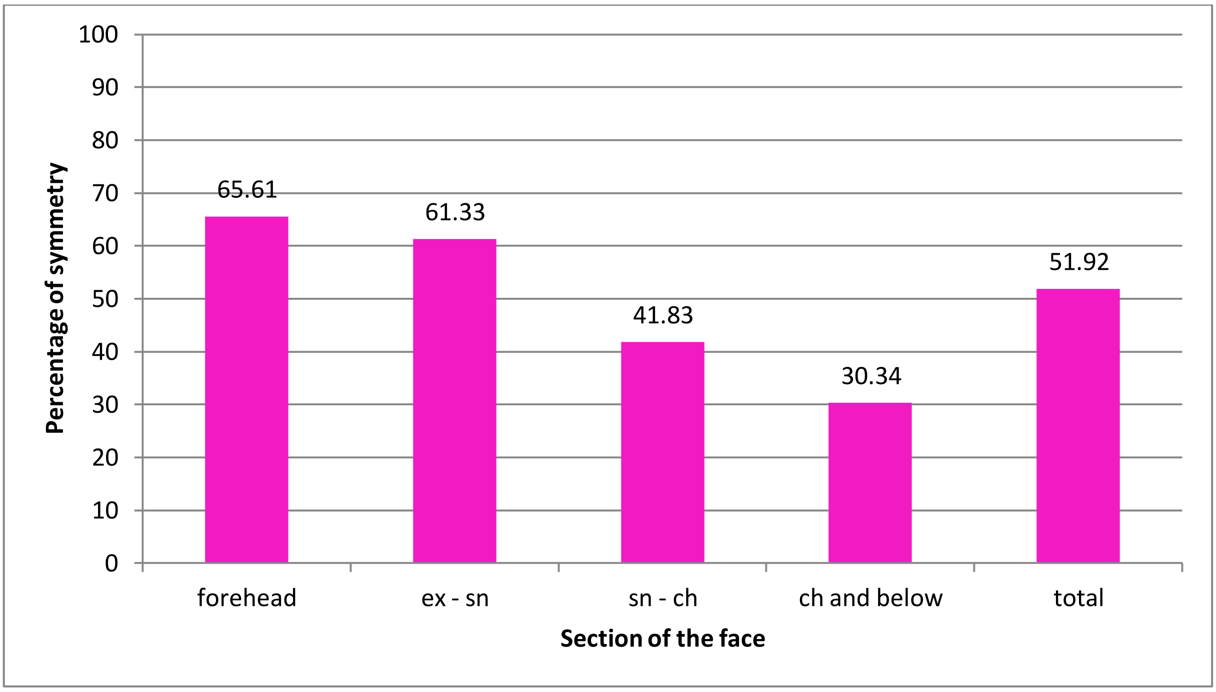
Graph 3 Percentage of symmetry at the 0.5 mm level for each of the female faces included in the average female face.

The percentage of symmetry ranged from 28.13 – 76.53 % with an average overall level of symmetry for the female faces of 51.92%, this is indicated on the graph by the horizontal red line.



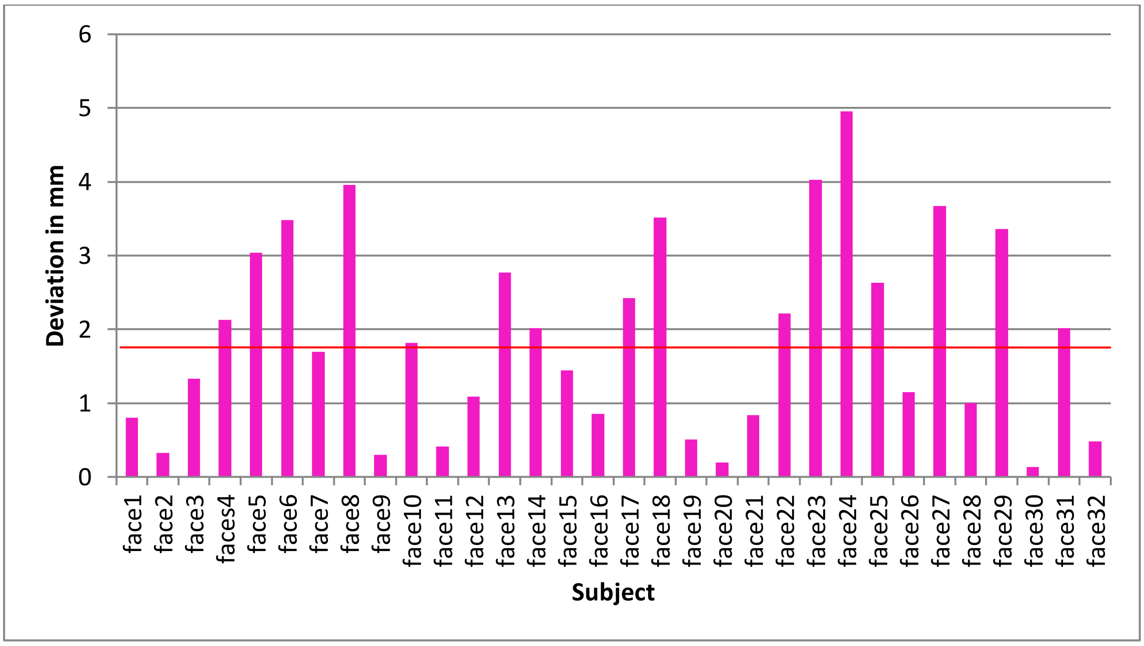
Graph 4 Overall trend in symmetry for the female faces included in the production of the average female face

For each sub-section of the face the average percentage symmetry value for the female faces included in the average face is presented, in addition to the average overall symmetry value. The sub-sections include: the forehead extending to the level of exocanthion ("forehead"), the area bounded by the horizontals at exocanthion and subnasale ("ex-sn"), the area bounded by the horizontals at subnasale and cheilion ("sn-ch"), and the chin area including everything below the horizontal level of cheilion ("ch and below"). The bar chart demonstrates that symmetry reduces as the distance from the forehead increases.



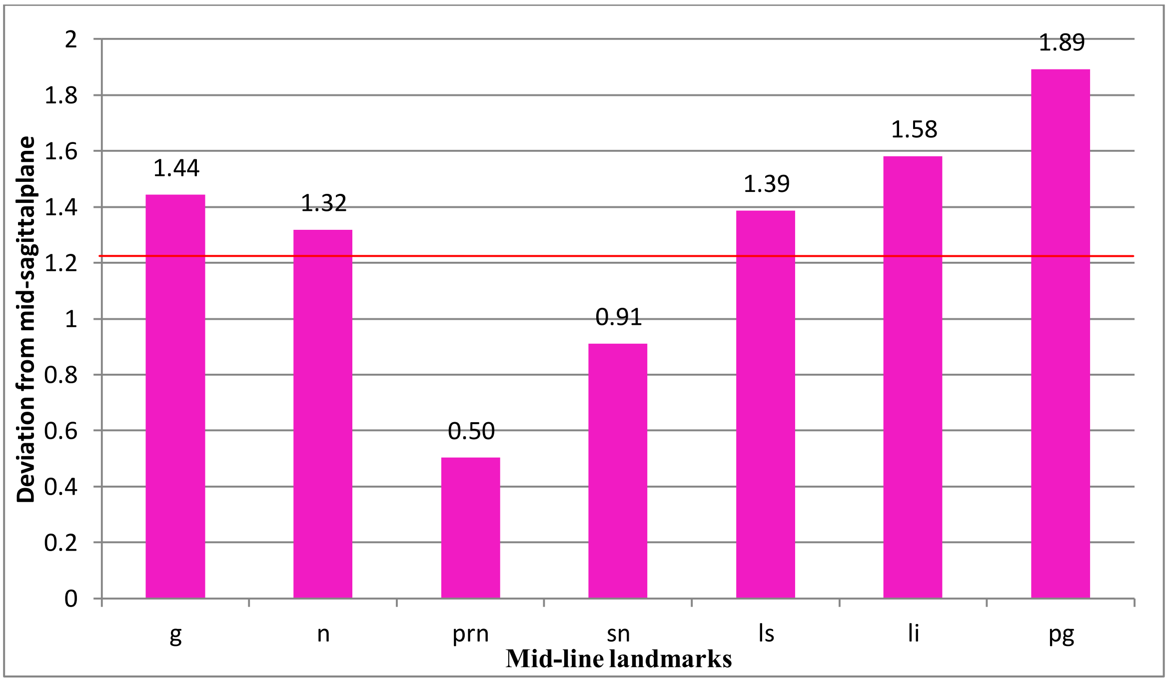
Graph 5 Deviation of pogonion (mm) from the identified mid-sagittal plane for each of the female faces included in the average face.

The deviation of pogonion from the mid-sagittal plane ranged from 0.14 – 4.95 mm with an average overall deviation of 1.89 mm (indicated by red horizontal line)



Graph 6 Average deviation of the mid-line landmarks from the mid-sagittal plane for the female faces included in the average face

The range of average mid-line landmark deviation from the mid-sagittal plane was 0.5 – 1.89 mm with an overall average of 1.29 mm (indicated by red horizontal line)



Graph 7 Average deviation of the mid-point of the bilateral landmarks from the identified mid-sagittal plane for the female faces included in the average female face

The average range of deviation from the mid-sagittal plane for the bilateral landmarks was 0.99 mm -1.38 mm with an overall average deviation of 1.23 mm (indicated by horizontal red line)

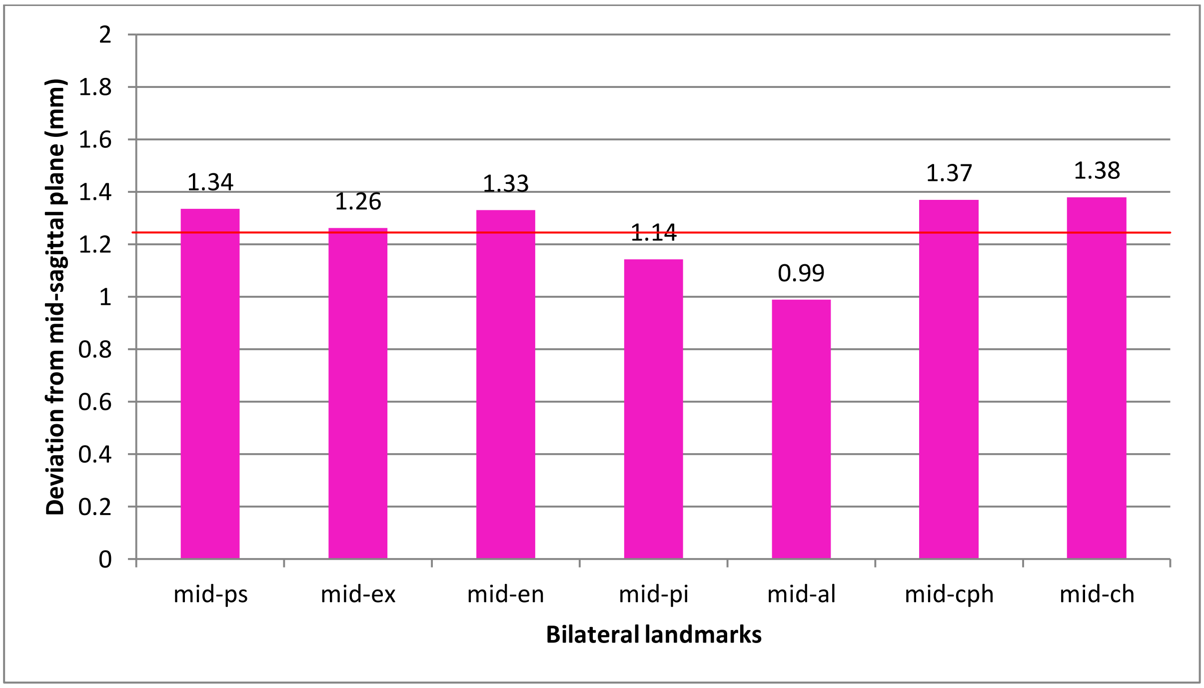


Figure 11 A colour map showing the absolute value of the three-dimensional facial symmetry for an individual facial image.

The colours indicate the degree of deviation between the original and mirror facial shells (blue: 0.0 – 1.5 mm, green: 1.5 – 2.7 mm, yellow: 2.7 – 3.0 mm, red: 3.0 – 4.0 mm). For this subject the percentage of symmetry for the entire face at the 0.05 mm tolerance level is 42.04%

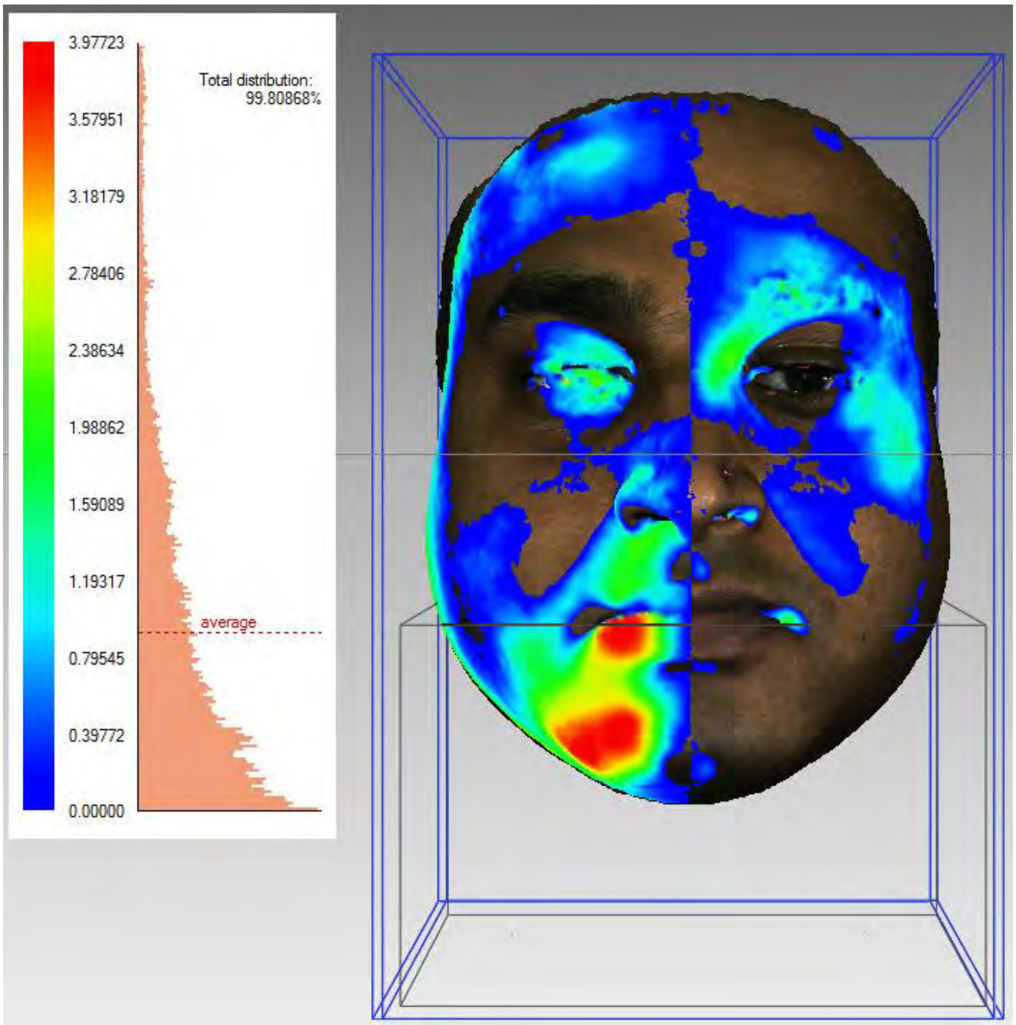
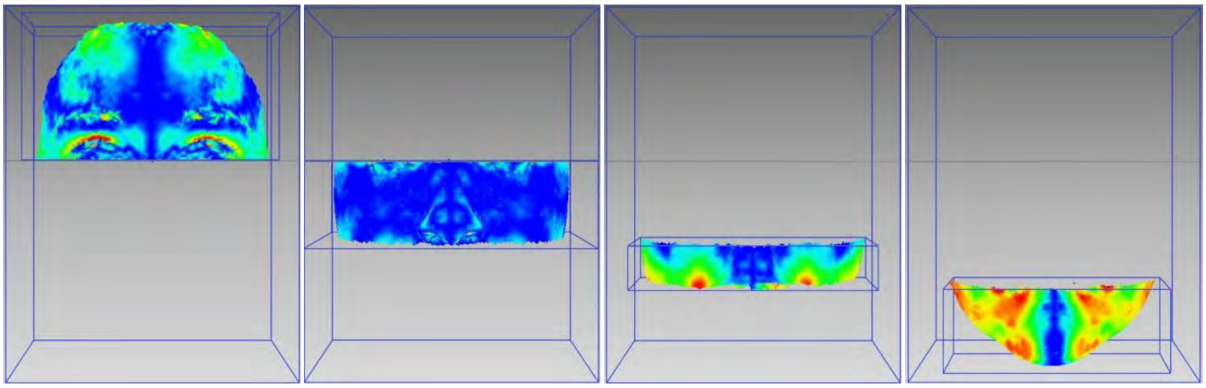


Figure 12 Colour maps showing the face divided into its four portions.

It is clearly evident that the lower third is the most asymmetric shown by the relatively high levels of red in the image. The colours indicate the degree of deviation between the original and mirror facial shells (blue: 0.0 – 1.5 mm, green: 1.5 – 2.7 mm, yellow: 2.7 – 3.0 mm, red: 3.0 – 4.0 mm)



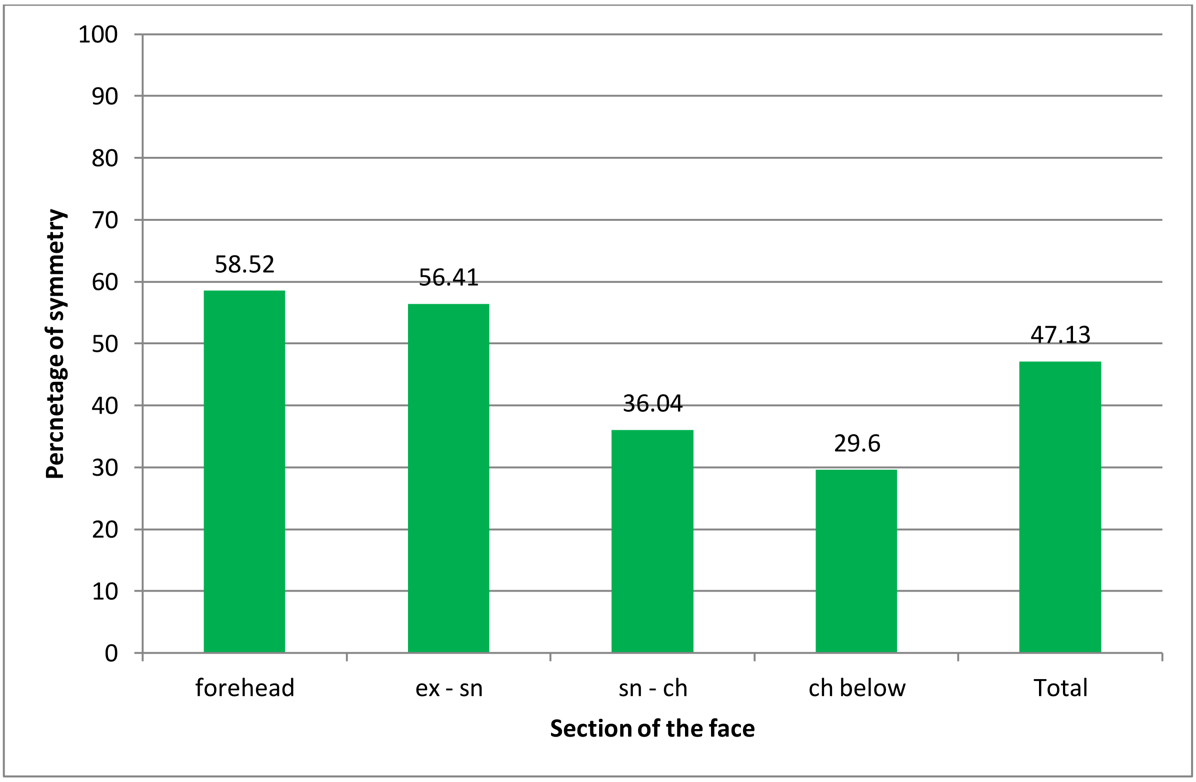
3.2.2 Results for the male faces included in the average face

The male sample consisted of 24 subjects. The pattern of asymmetry observed followed that seen in the female sample, with asymmetry becoming more apparent as the distance from the cranium increased (Graph 8). In the forehead region a level of symmetry was noted of 58.52%, this reduced to 56.41% for the subsection below the forehead extending to the base of the nose, reducing again for the section extending from the base of the nose to the mid lip level (36.04%) and the chin region demonstrated the least symmetry at 29.60%, almost half that recorded in the forehead region. The overall facial symmetry noted in the sample was 47.13% (graph 9) with the maximum average distance between the two shells being 3.18mm, with an average of 0.8mm.

Linear distances of the midline landmarks and the midpoint of the bilateral landmarks from the identified mid-sagittal plane were also investigated (Graphs 10 – 12). Overall it was found that there was less variation between these points than identified in the female sample. The range of deviation found for the midline landmarks extended from 0.06 – 3.53 mm and for the bilateral landmarks ranged from 0.00 – 2.90 mm.

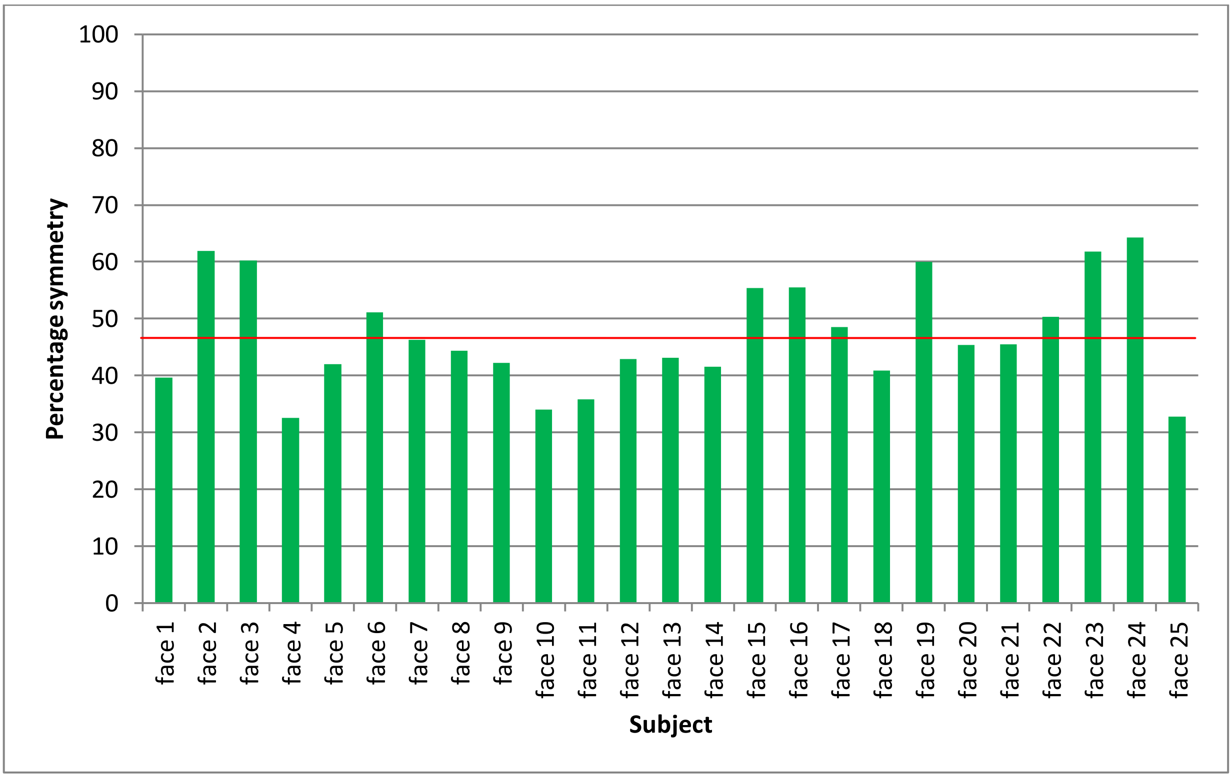
Graph 8 Overall trend in symmetry for the male faces included in the production of the average male face

For each sub-section of the face the average percentage symmetry value for the female faces included in the average face is presented, in addition to the average overall symmetry value. The sub-sections include: the forehead extending to the level of exocathion ("forehead"), the area bounded by the horizontals at exocathion and subnasale ("ex-sn"), the area bounded by the horizontals at subnasale and chelion ("sn-ch"), and the chin area including everything below the horizontal level of chelion ("ch and below"). The pattern of decreasing symmetry from the cranium to the chin is demonstrated on the bar chart.



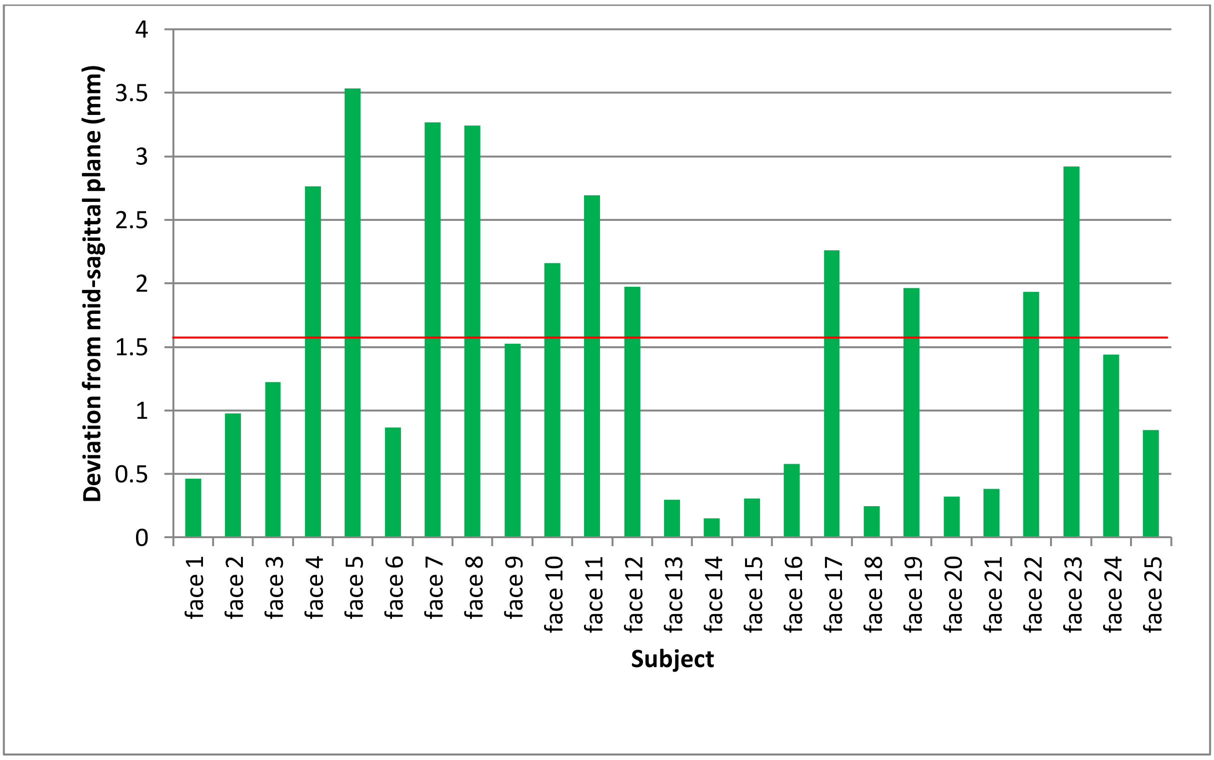
Graph 9 Percentage of symmetry at the 0.5 mm level for each of the male faces included in the average male face.

The percentage of symmetry ranged from 32.60 – 64.29 % with an average overall level of symmetry for the male faces of 47.13%, this is indicated on the graph by the horizontal red line.



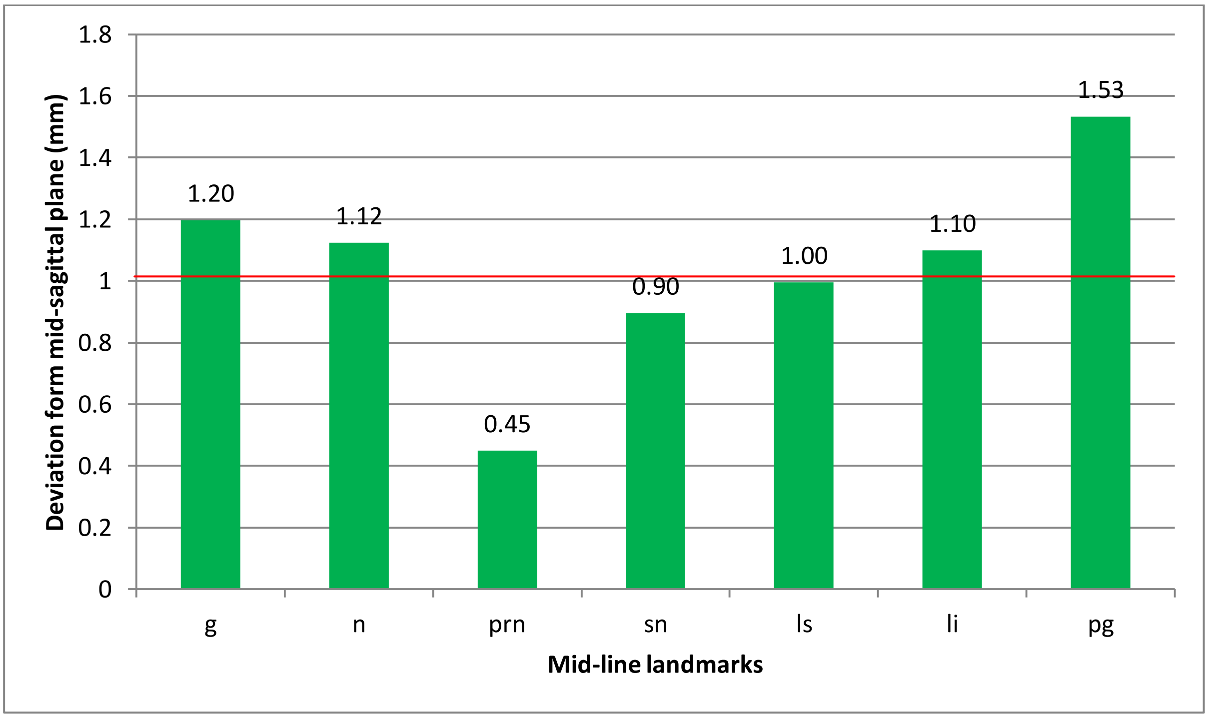
Graph 10 Deviation of pogonion from the identified mid sagittal plane for the male faces included in the average face.

The deviation of pogonion from the mid-sagittal plane ranged from 0.15 – 3.53 mm with an average deviation of 1.53 mm (indicated by the red horizontal line)



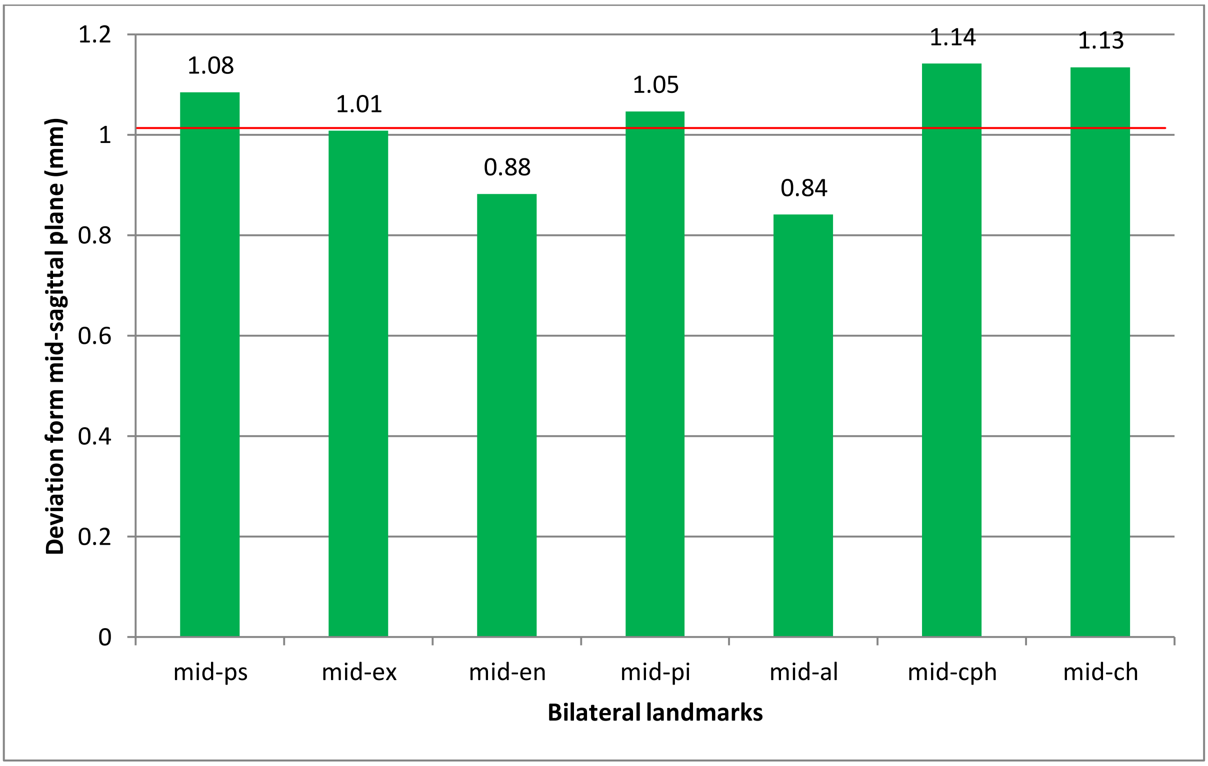
Graph 11 Average deviation of the mid-line landmarks from the identified mid sagittal plane (mm)

The average range of deviation from the mid-sagittal plane for the bilateral landmarks was 0.45 mm -1.53 mm with an overall average deviation of 1.04 mm (indicated by horizontal red line)



Graph 12 Average deviation of the mid-point of the bilateral landmarks from the identified mid sagittal plane

The average deviation from the mid-sagittal plane of the bilateral landmarks ranged from 0.84 – 1.14 mm with an overall average deviation of 1.02 mm (indicated by horizontal red line)



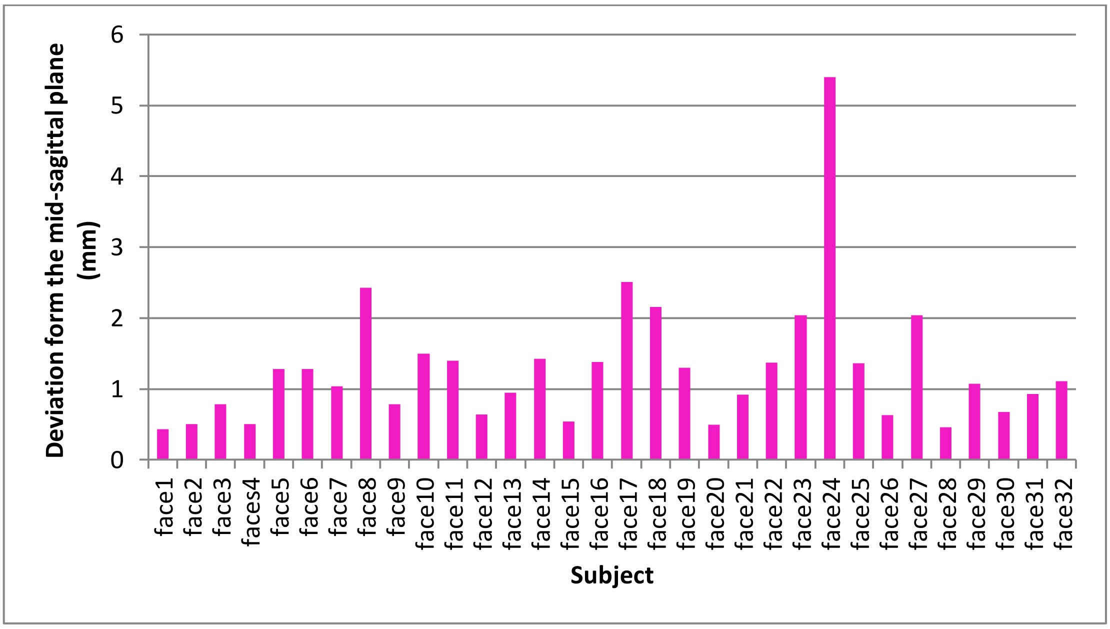
3.2.3 Differences between the male and female results

Both the male and female sample displayed an increase in asymmetry from cranium to chin point. The overall average facial symmetry was 47.13% for males and 51.92% for females. The female sample displayed slightly reduced absolute (0.68 mm) and maximum (2.93 mm) average deviation between the two shells when compared to males (0.8 mm and 3.18 mm respectively).

For the individual midline landmarks and midpoint of bilateral landmarks, it was found that the average deviation, for both male and females, was consistently less than 3mm from the mid-sagittal plane. However, the range of deviation for each landmark was much greater for females (0.02 – 7.16 mm) than males (0.00 – 3.53 mm), this could be partially explained by the presence of one individual female with marked deviation (Graphs 13 and 14).

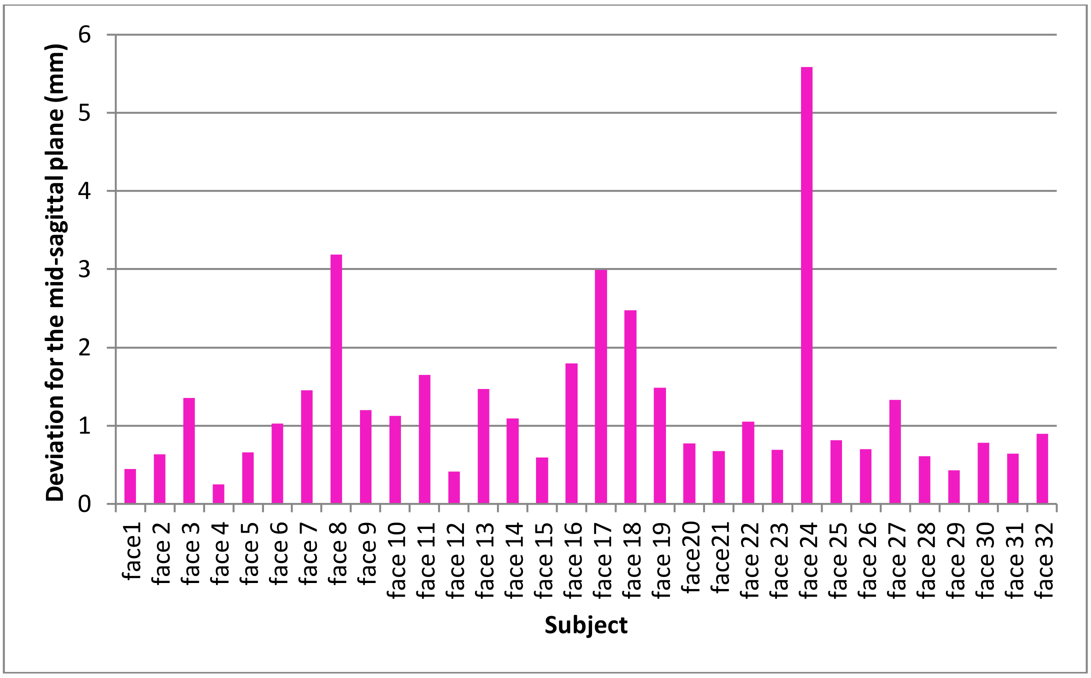
Graph 13 Average deviation of the mid line landmarks for each subject included in the female average face

It is evident that subject 24 has marked asymmetry of the facial landmarks.



Graph 14 Average deviation of the bilateral landmarks for each subject included in the average female face.

From the graph it is apparent that subject 24 has substantial asymmetry of these landmarks



3.3 Assessment of the perception of facial asymmetry

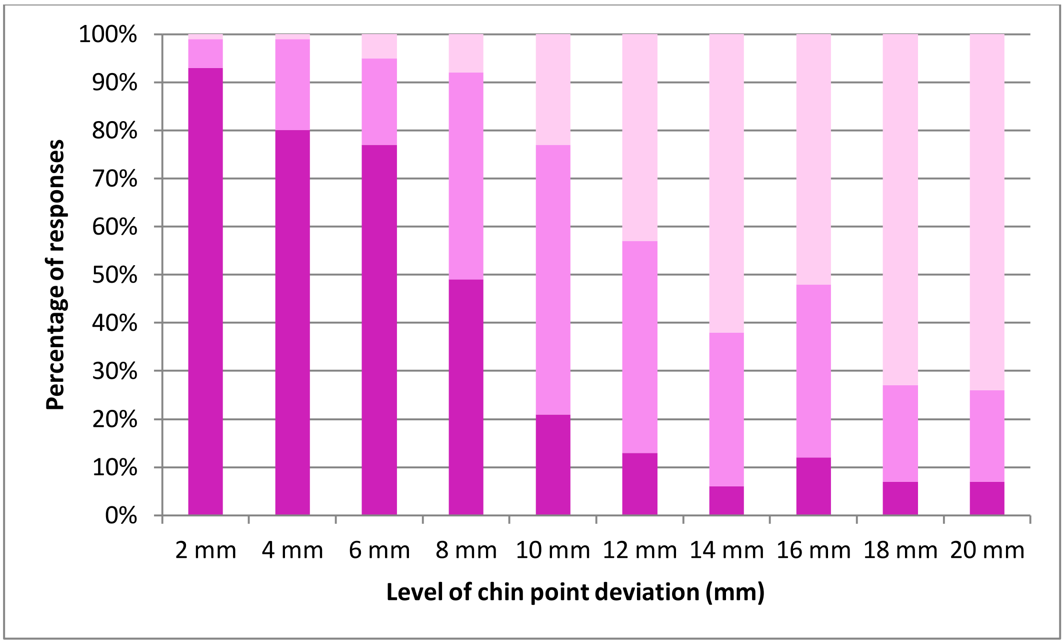
The male and female average faces with the simulated chin point asymmetry were assessed by the five observer groups under standardised conditions. The overall observer sample size was 209. The demographics of the rating groups are outlined in Table 3.

Table 3 Demographics of the subjects in the rating groups

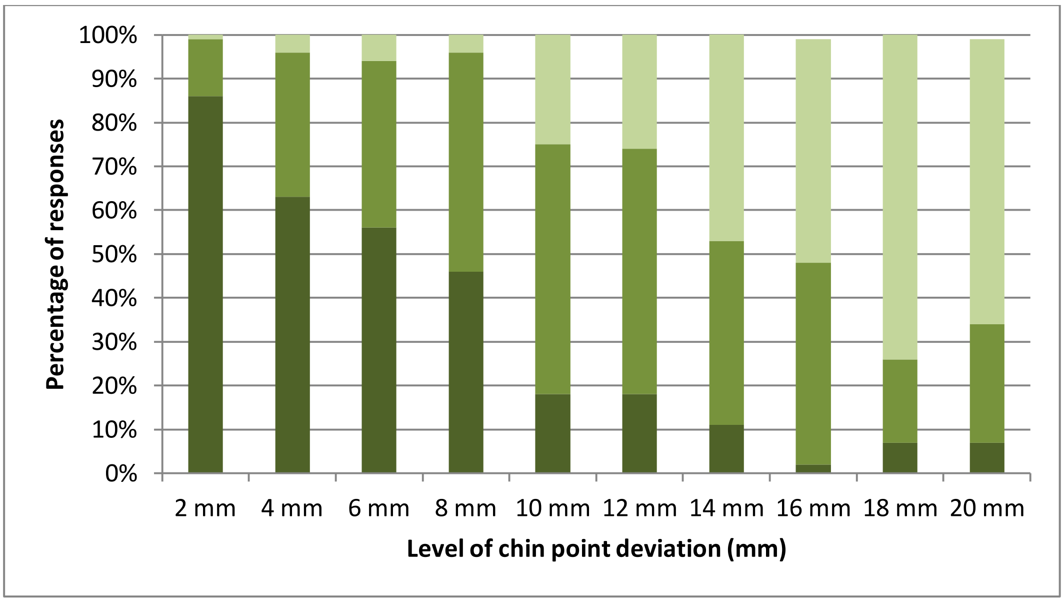
	Females	Males	Total
Lay people	26	16	42
Dental students	29	18	47
Dental care professionals	36	4	40
General dental practitioners	23	17	40
Orthodontists	18	22	40
Overall	**132**	**77**	**209**

On the following pages stacked graphs (Graphs 15 – 28) are used to show the responses of the observer groups for the assessment of the manipulated male and female average faces. Magenta is used to represent responses related to the assessment of female faces and green is used for the assessment of the male faces. Each column represents the degree of simulated deviation and the associated responses for that level of asymmetry. Dark magenta/green corresponds to the proportion of option ***a*** (normal face), medium magenta/green corresponds to option ***b*** (socially acceptable) and light magenta/green represents option ***c*** (correction needed). There is a general trend observed throughout all of the stacked graphs, with the proportion of option ***a*** starting high for the small deviations and reducing, in some cases to zero, for the larger levels of asymmetry. The opposite is true for the proportion of option ***c*** which starts small and increases for the larger deviations. The proportion of option ***b*** recorded for each asymmetry level is largest for the mid-range deviations, however, the responses for mid-range deviations appear to be less predictable. The corresponding numerical data can be found in the appendix (Appendix 5)

Graph 15 Stacked bar graph showing the responses from the lay people group for the manipulated female faces.
Dark magenta corresponds to option ***a***, medium magenta corresponds to option ***b*** and light magenta corresponds to option ***c***. Option ***a*** is high for mild asymmetries and reduces as the level of asymmetry increases. The opposite is true for option ***c***. Option ***b*** was most likely to be recorded for the mid-range asymmetries.

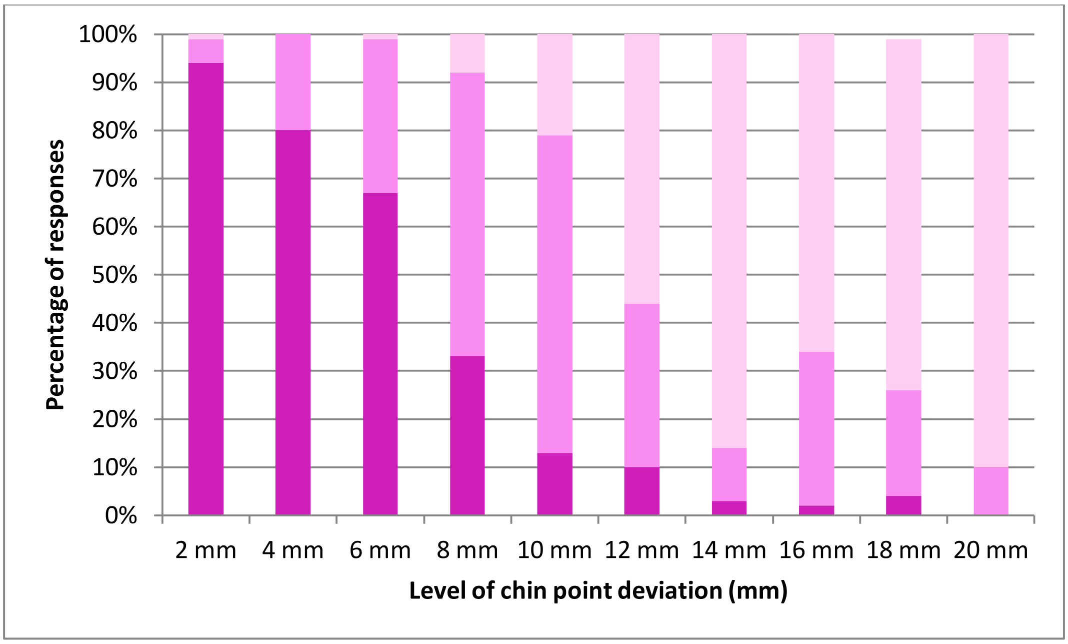


Graph 16 Stacked graph showing the responses from the lay people for the manipulated male faces.
Dark green corresponds to option ***a***, medium green corresponds to option ***b*** and light green corresponds to option ***c***. Option ***a*** is high for mild asymmetries and reduces as the level of asymmetry increases. The opposite is true for option ***c***. Option ***b*** was most likely to be recorded for the mid-range asymmetries.



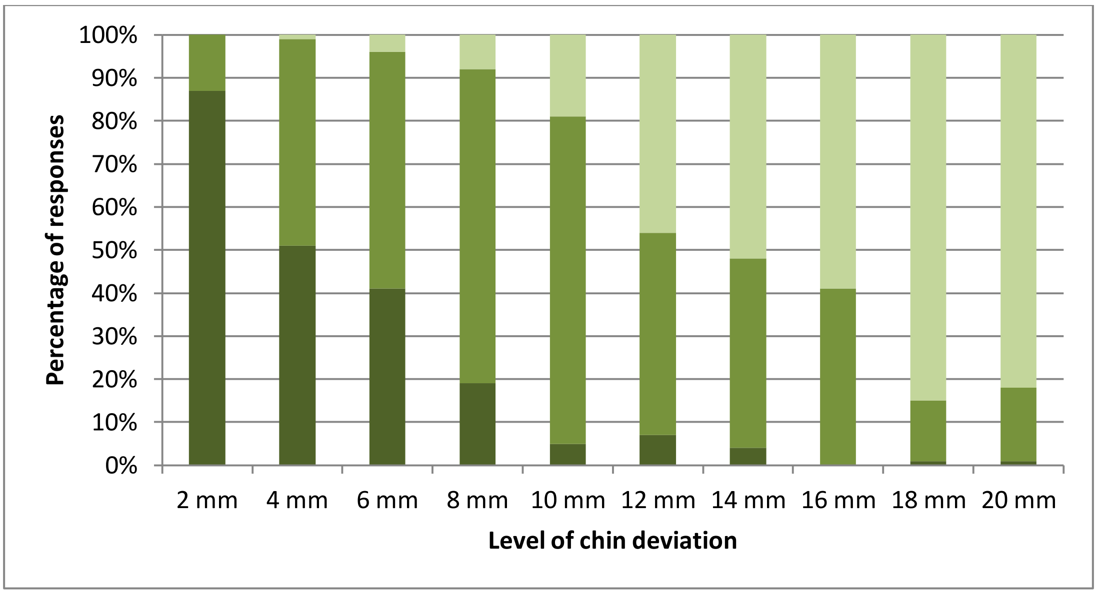
Graph 17 Stacked graph showing the responses from the dental student group for the manipulated female faces

Dark magenta corresponds to option ***a***, medium magenta corresponds to option ***b*** and light magenta corresponds to option ***c***. Option ***a*** is high for mild asymmetries and reduces as the level of asymmetry increases. The opposite is true for option ***c***. Option ***b*** was most likely to be recorded for the mid-range asymmetries.



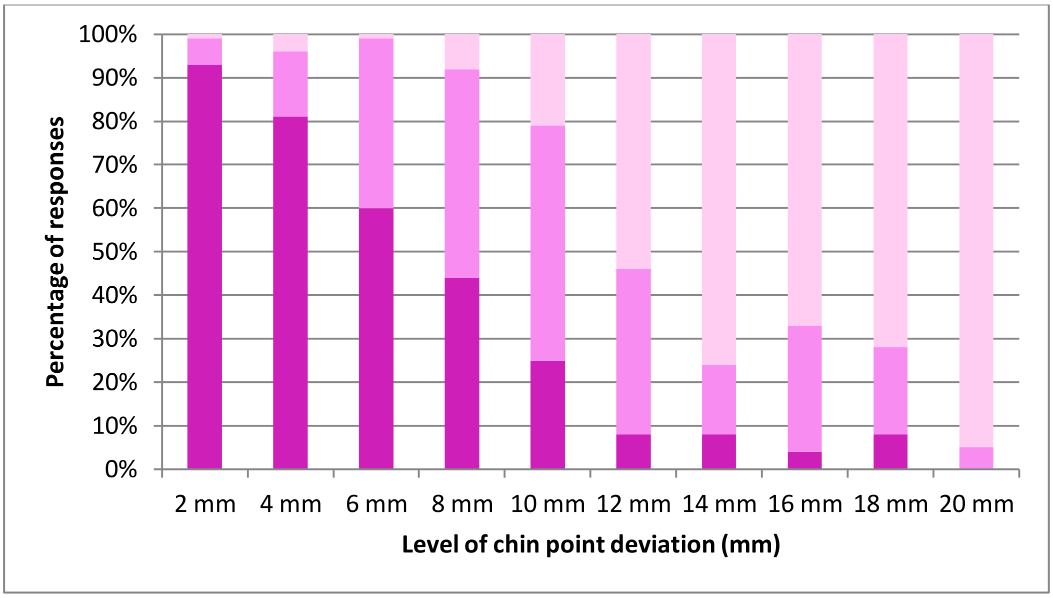
Graph 18 Stacked graph showing the responses from the dental student group for the manipulated male faces

Dark green corresponds to option ***a***, medium green corresponds to option ***b*** and light green corresponds to option ***c***. Option ***a*** is high for mild asymmetries and reduces as the level of asymmetry increases. The opposite is true for option ***c***. Option ***b*** was most likely to be recorded for the mid-range asymmetries.



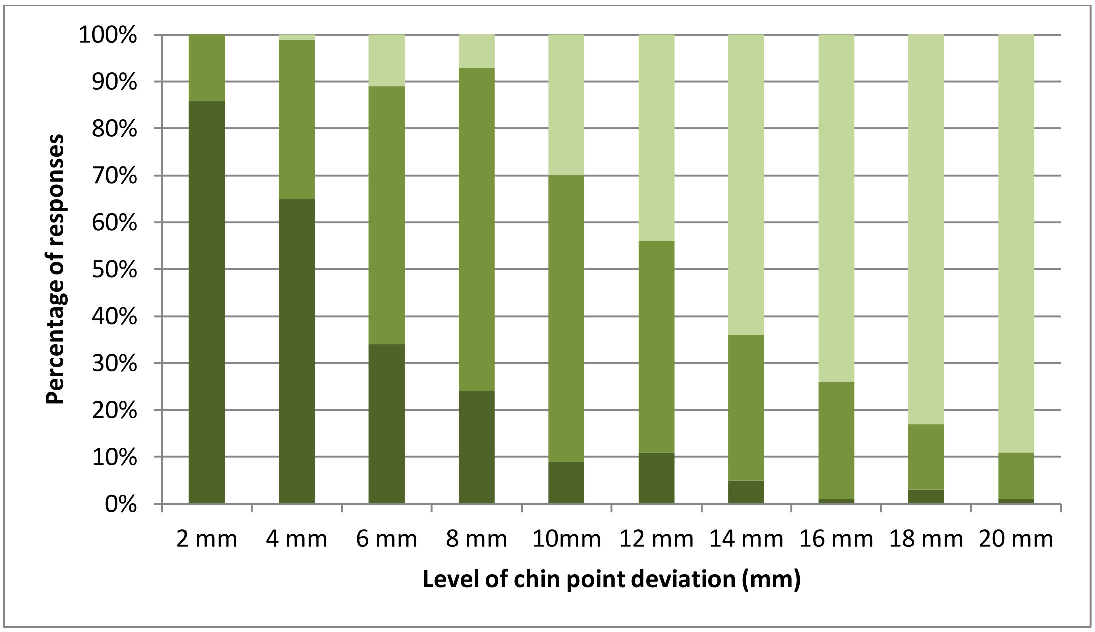
Graph 19 Stacked graph showing the responses from the dental care professional group for the manipulated female faces

Dark magenta corresponds to option ***a***, medium magenta corresponds to option ***b*** and light magenta corresponds to option ***c***. Option ***a*** is high for mild asymmetries and reduces as the level of asymmetry increases. The opposite is true for option ***c***. Option ***b*** was most likely to be recorded for the mid-range asymmetries.



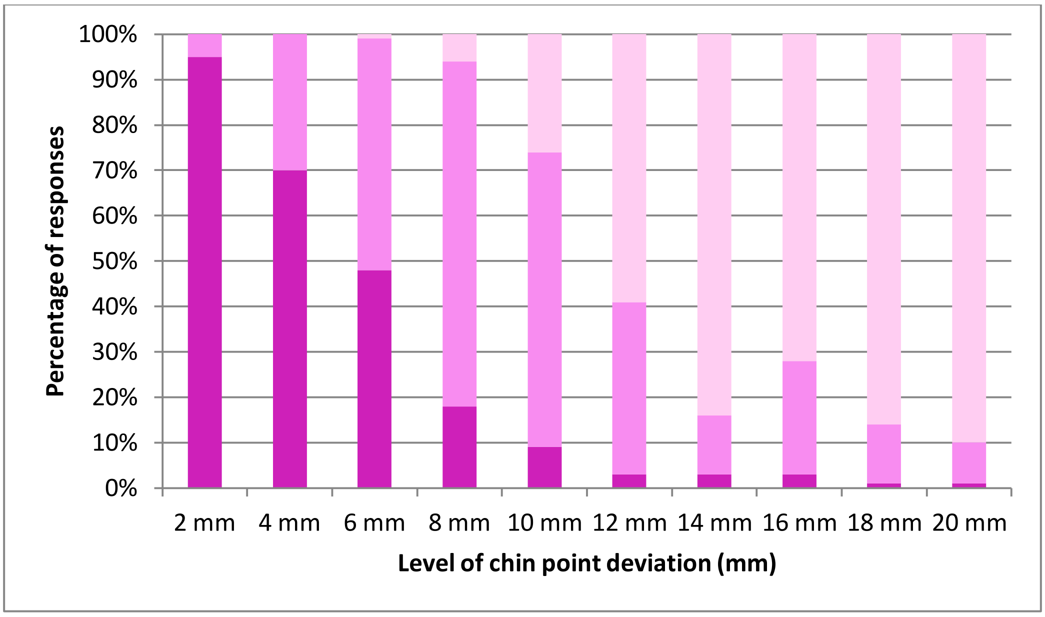
Graph 20 Stacked graph showing the responses from the dental care professional group for the manipulated male faces

Dark green corresponds to option ***a***, medium green corresponds to option ***b*** and light green corresponds to option ***c***. Option ***a*** is high for mild asymmetries and reduces as the level of asymmetry increases. The opposite is true for option ***c***. Option ***b*** was most likely to be recorded for the mid-range asymmetries.



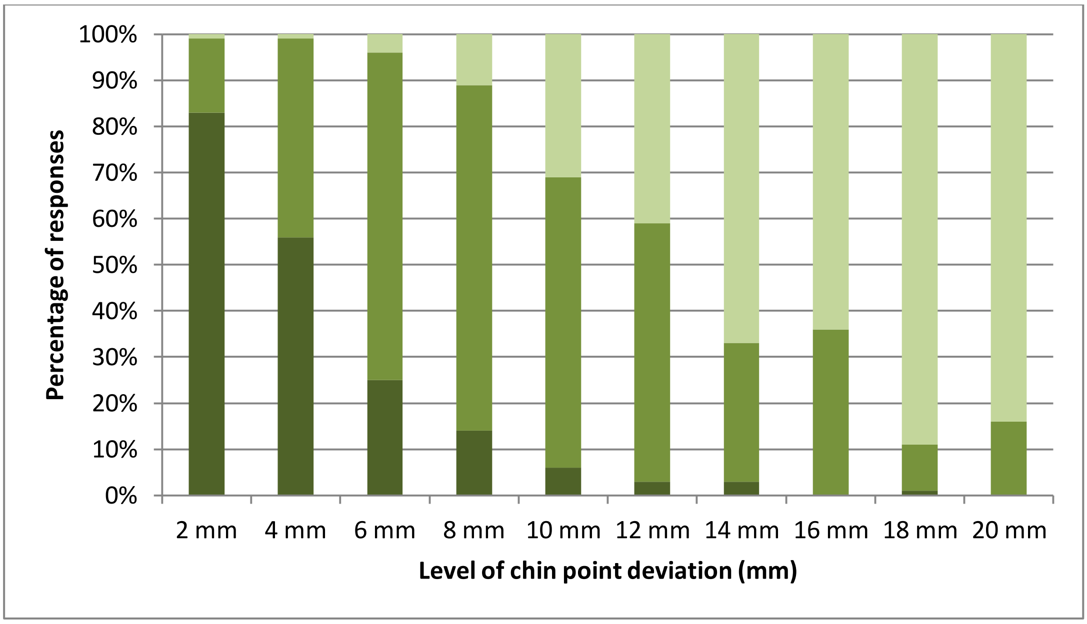
Graph 21 Stacked graph showing the responses from the general dental practitioner group for the manipulated female faces

Dark magenta corresponds to option ***a***, medium magenta corresponds to option ***b*** and light magenta corresponds to option ***c***. Option ***a*** is high for mild asymmetries and reduces as the level of asymmetry increases. The opposite is true for option ***c***. Option ***b*** was most likely to be recorded for the mid-range asymmetries.



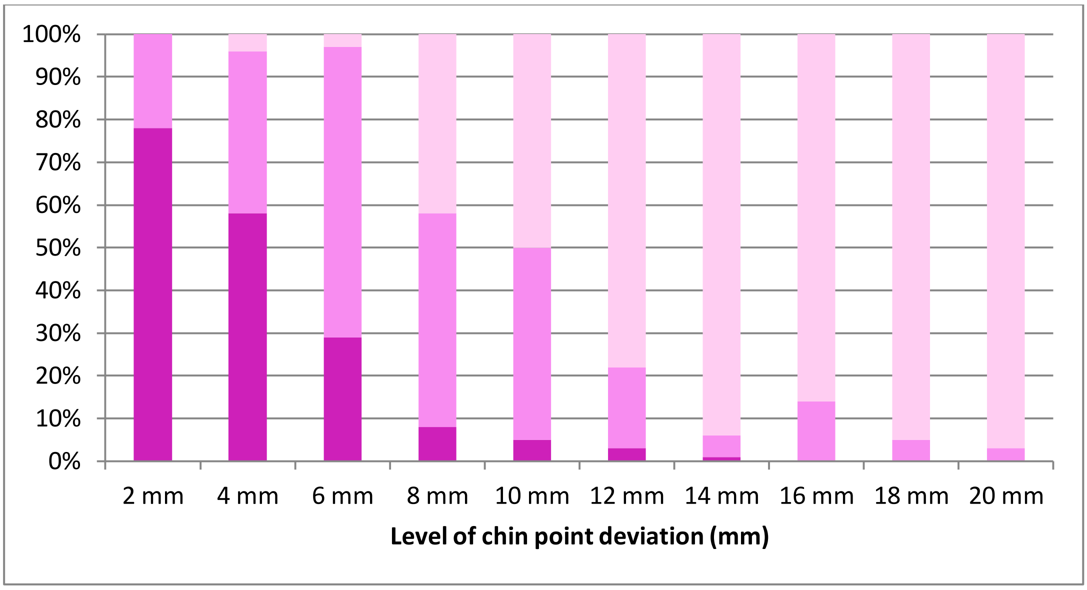
Graph 22 Stacked graph showing the responses from the general dental practitioner group for the manipulated male faces

Dark green corresponds to option ***a***, medium green corresponds to option ***b*** and light green corresponds to option ***c***. Option ***a*** is high for mild asymmetries and reduces as the level of asymmetry increases. The opposite is true for option ***c***. Option ***b*** was most likely to be recorded for the mid-range asymmetries.



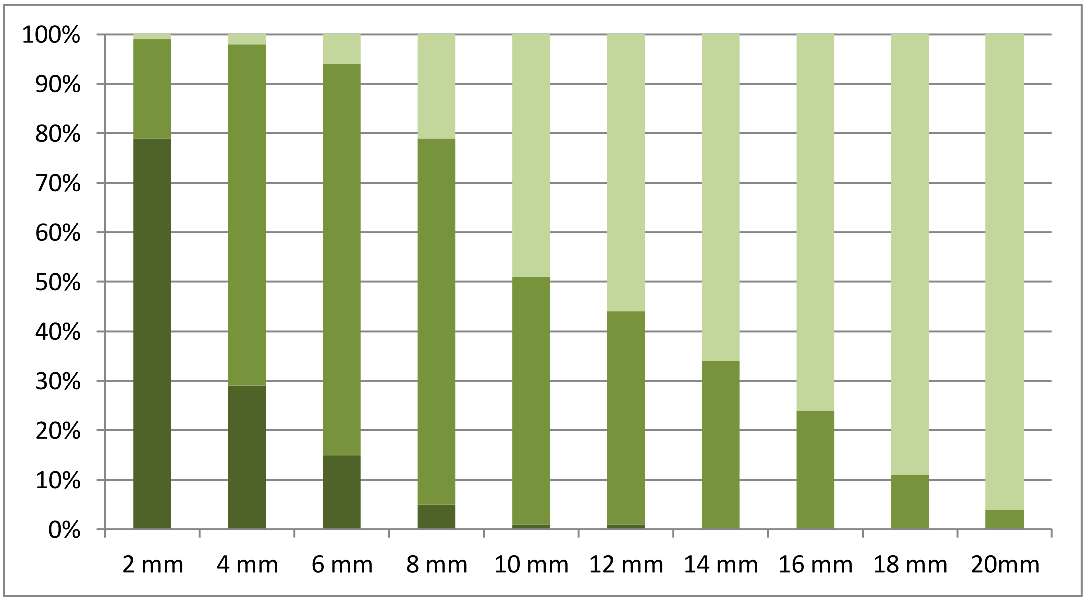
Graph 23 Stacked graph showing the responses from the orthodontist group for the manipulated female faces

Dark magenta corresponds to option ***a***, medium magenta corresponds to option ***b*** and light magenta corresponds to option ***c***. Option ***a*** is high for mild asymmetries and reduces as the level of asymmetry increases. The opposite is true for option ***c***. Option ***b*** was most likely to be recorded for the mid-range asymmetries.

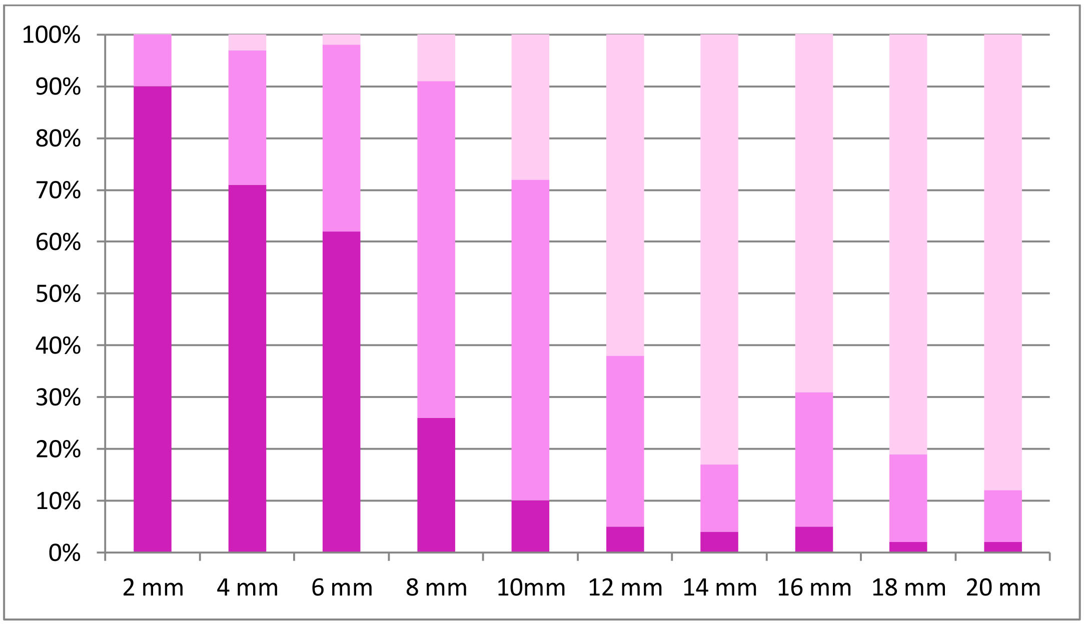


Graph 24 Orthodontists responses for the manipulated male faces

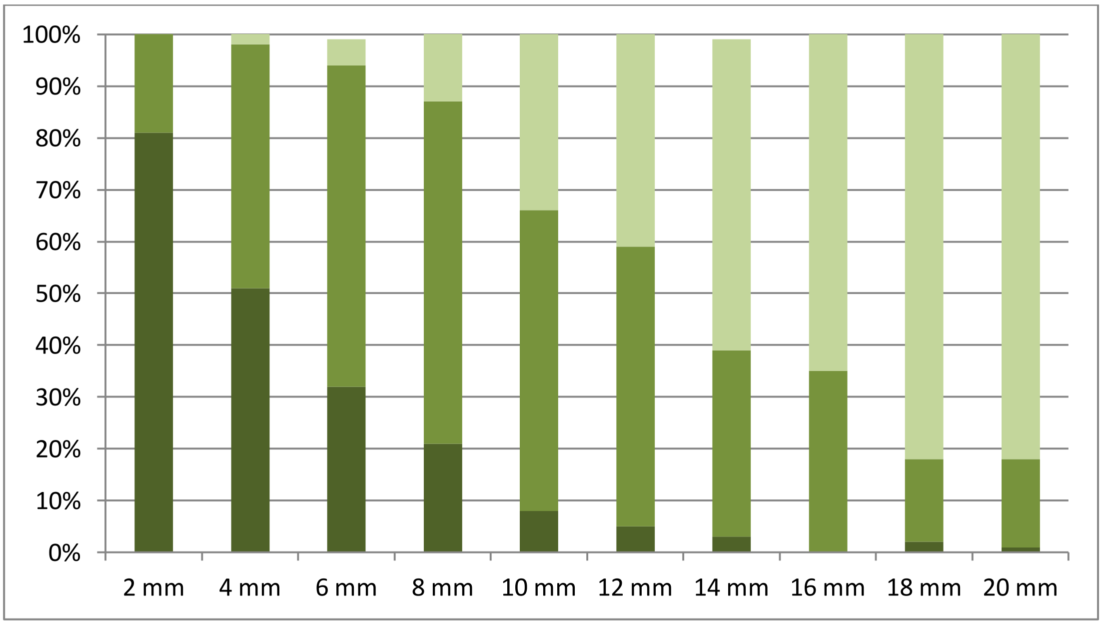
Dark green corresponds to option ***a***, medium green corresponds to option ***b*** and light green corresponds to option ***c***. Option ***a*** is high for mild asymmetries and reduces as the level of asymmetry increases. The opposite is true for option ***c***. Option ***b*** was most likely to be recorded for the mid-range asymmetries.



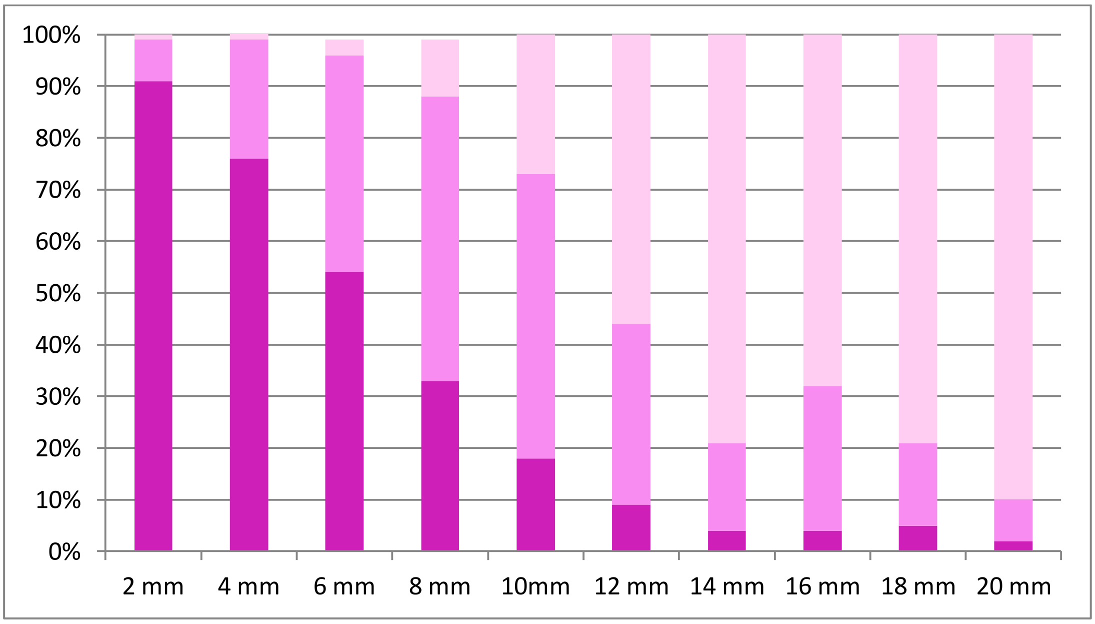
Graph 25 Stacked graph showing the male responses for the female faces
Dark magenta corresponds to option ***a***, medium magenta corresponds to option ***b*** and light magenta corresponds to option ***c***. Option ***a*** is high for mild asymmetries and reduces as the level of asymmetry increases. The opposite is true for option ***c***. Option ***b*** was most likely to be recorded for the mid-range asymmetries.



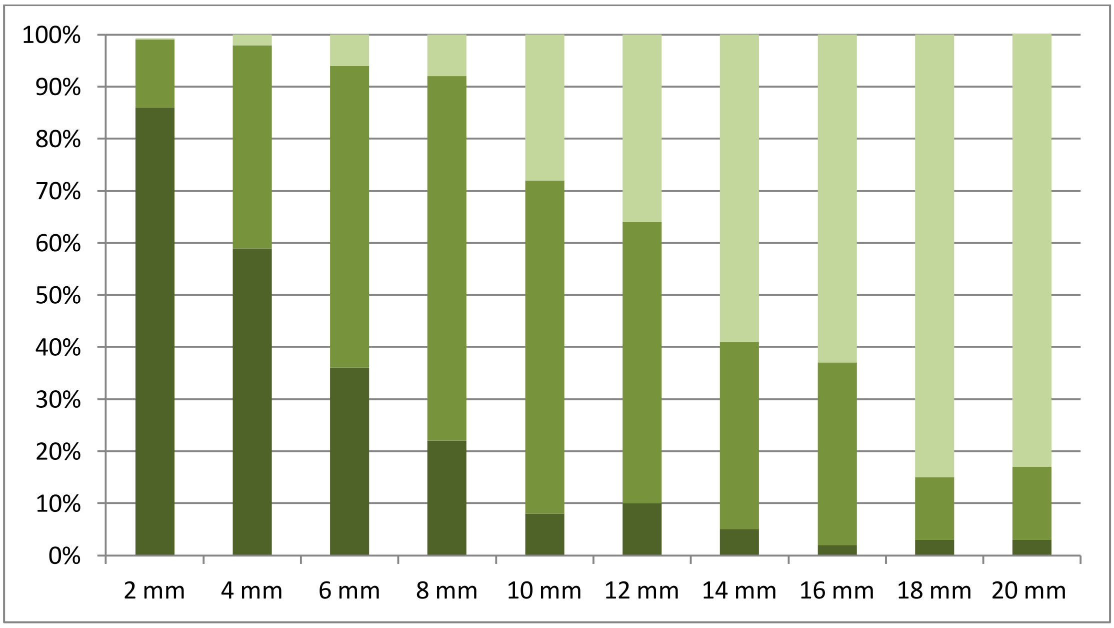
Graph 26 Stacked graph showing the male responses for the male faces
Dark green corresponds to option ***a***, medium green corresponds to option ***b*** and light green corresponds to option ***c***. Option ***a*** is high for mild asymmetries and reduces as the level of asymmetry increases. The opposite is true for option ***c***. Option ***b*** was most likely to be recorded for the mid-range asymmetries.



Graph 27 Stacked graph showing female responses for the female manipulated faces
Dark magenta corresponds to option ***a***, medium magenta corresponds to option ***b*** and light magenta corresponds to option ***c***. Option ***a*** is high for mild asymmetries and reduces as the level of asymmetry increases. The opposite is true for option ***c***. Option ***b*** was most likely to be recorded for the mid-range asymmetries.



Graph 28 Stacked graph showing female responses for the male manipulated faces
Dark green corresponds to option ***a***, medium green corresponds to option ***b*** and light green corresponds to option ***c***. Option ***a*** is high for mild asymmetries and reduces as the level of asymmetry increases. The opposite is true for option ***c***. Option ***b*** was most likely to be recorded for the mid-range asymmetries.



3.4 Statistical analysis

3.4.1 Intra-operator reliability of the landmark identification

The ideal method for assessing the reliability of landmarking would be to reassess landmark identification of the same face on many different occasions. Each landmarking episode should occur at least one week apart in order to minimise the effect of memory on the positioning of the landmark points. Unfortunately, as the software was located off site, it was not possible to carry out such regime. As an alternative, two landmarking sessions (greater than 4 weeks apart) were completed for 15 randomly selected individual faces that were included in the average faces (figure 13).

The error *Sx* of the method was calculated using the Dahlberg equation (Dahlberg, 1940),

$$Sx = \sqrt{\frac{\sum D^2}{2n}}, \qquad \text{[Eq. 1]}$$

where *D* is the difference between the duplicated measurements and *n* is the number of double measurements.

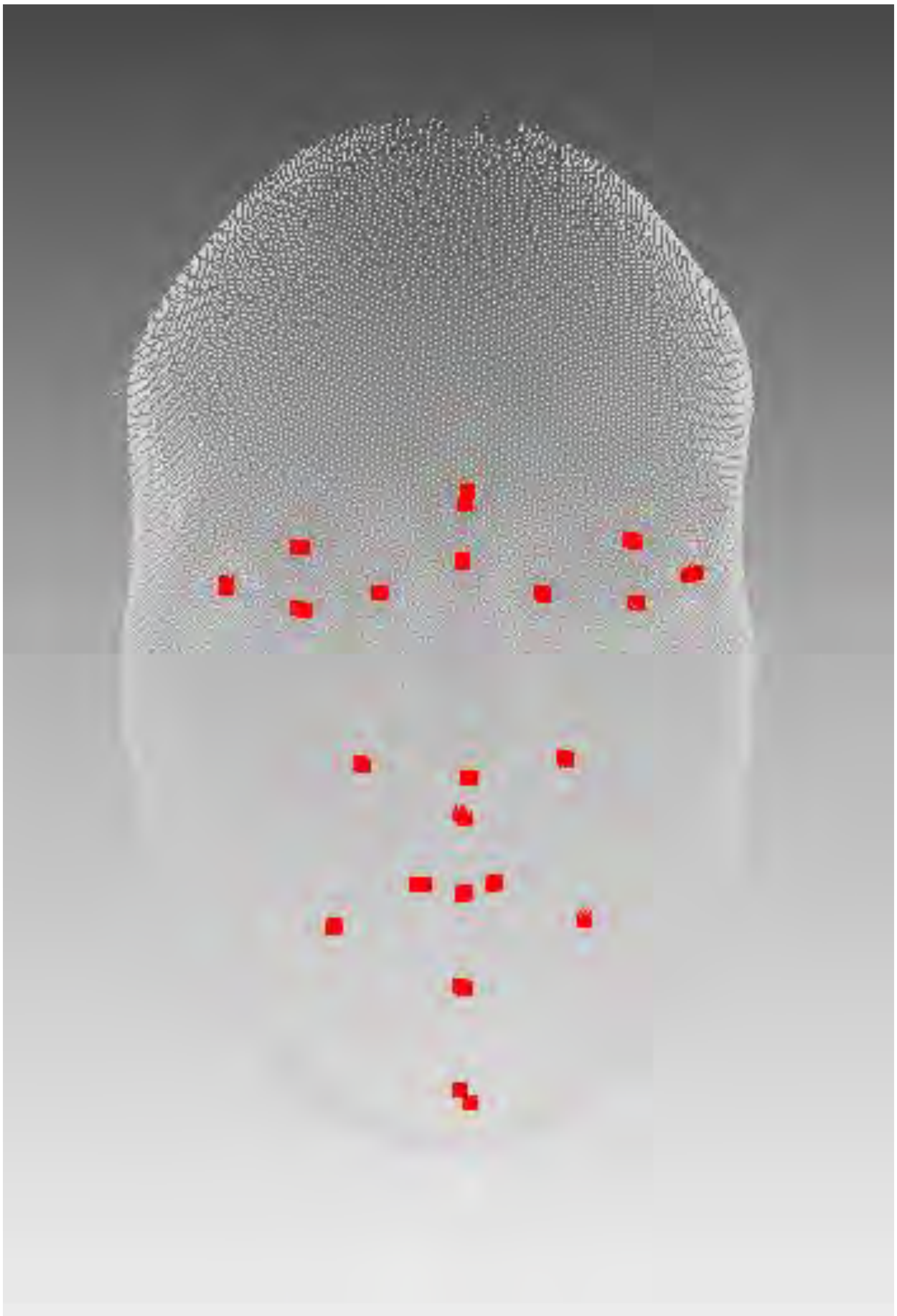
Dahlberg's equation values for random errors ranged from 0.03 mm to 0.97 mm. It should be noted that this method does not allow for discrimination between the operators ability to reliably identify the same point repeatedly and the ease of identification of facial landmarks.

Dahlberg's values for random errors ranged from 0.11 mm to 0.38 mm for the X co-ordinates, from 0.11 mm to 0.97m for the Y co-ordinates and from 0.03 mm to 0.66 mm in the Z co-ordinates (Table 4). All average measurements were accurate to less than 1 mm.

Table 4 Intra-reliability assessment for each landmark in the x, y, z co-ordinates

	Difference according to Dahlberg's formula (mm)		
	X	Y	Z
Gnathion	0.20	0.35	0.03
Nasion	0.22	0.59	0.22
Endocanthion (L)	0.16	0.15	0.16
Endocanthion (R)	0.17	024	0.15
Exocanthion (L)	0.25	0.18	0.22
Exocanthion (R)	0.30	0.19	0.33
Palpebrale superius (L)	0.26	0.19	0.15
Palpebrale superius (R)	0.22	0.19	0.25
Palpebrale inferius (L)	0.18	0.14	0.10
Palpebrale inferius (R)	0.27	0.16	0.07
Pronasale	0.17	0.58	0.16
Subnasale	0.12	0.34	0.66
Alare (L)	0.13	0.32	0.43
Alare (R)	0.15	0.37	0.55
Labiale superius	0.11	0.15	0.06
Labiale inferius	0.18	0.14	0.11
Crista philtre (L)	0.23	0.19	0.10
Crista philtre (R)	0.25	0.16	0.12
Cheilion (L)	0.38	0.11	0.21
Cheilion (R)	0.29	0.12	0.17
Pogonion	0.31	0.97	0.20

Figure 13 Template face with superimpositions of repeat landmarking sessions



3.4.2 Assessment of the impact of observer group on perception of facial asymmetry

For each of the manipulated images, the observers scored the face according to one of three available options:

a. balanced, acceptable face

b. some abnormality, socially acceptable, not requiring correction

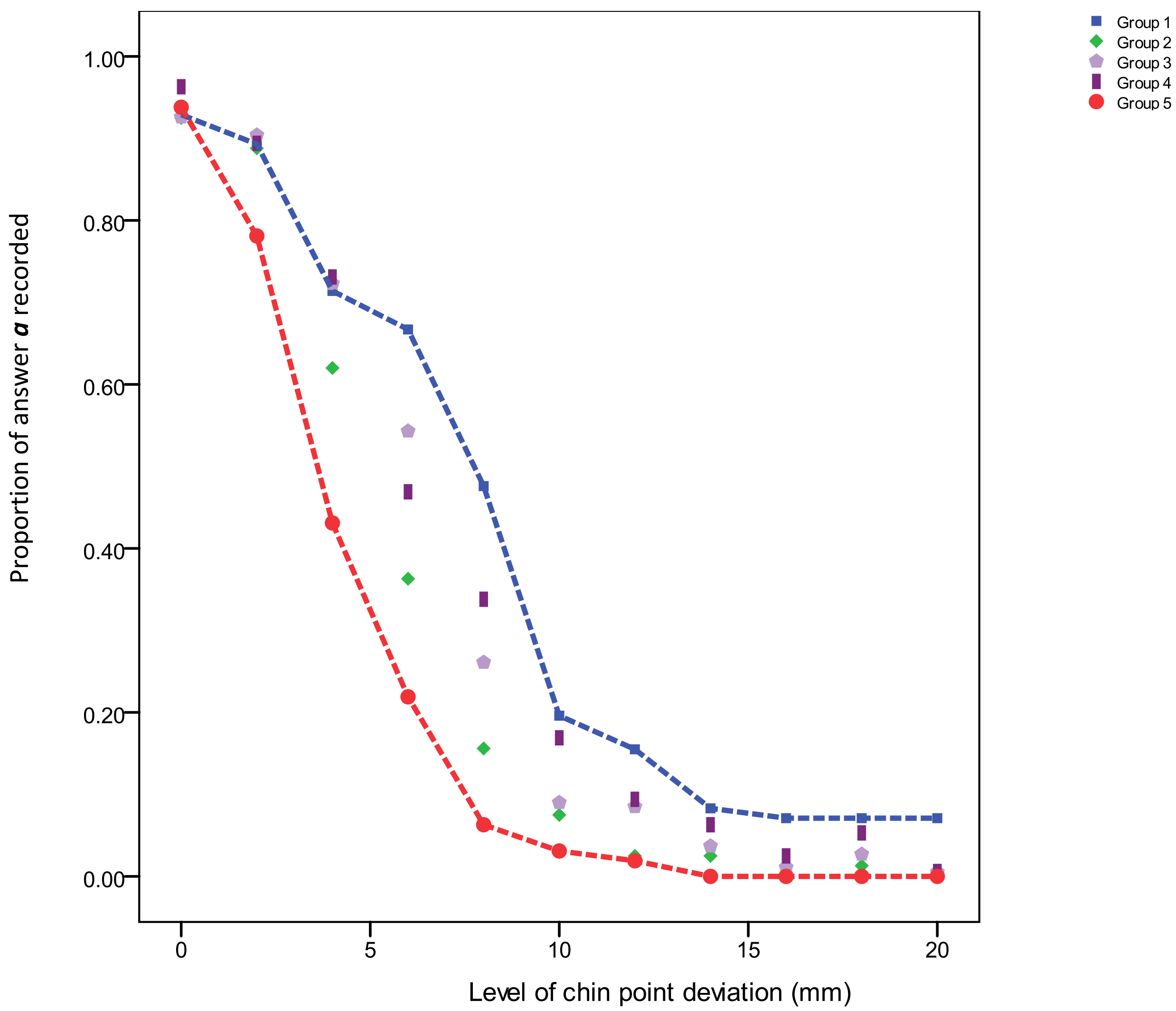
c. the case would benefit from correction of the asymmetry

The first null hypothesis proposed, states there is no difference between the level of asymmetry perceived to be abnormal by lay people and by various levels of dentally-qualified individuals. From the three available options that could be recorded for each face, option ***a*** corresponds to faces perceived as normal and both option ***b*** and ***c*** correspond to a degree of abnormality perceived by the observer. Therefore to answer the question regarding the perception of normality it is sufficient to analyse the proportion of option ***a***, recorded from the observers. It was felt that at this stage, assessment of option ***b*** and ***c*** was unnecessary as their combined proportion indicated abnormality and therefore if option ***a*** was not selected the observer must have selected option ***b*** or ***c***. The graph below (Graph 29) shows the proportion of option ***a*** ("normal") answered by each group in relation to the degree of asymmetry. For low values of deviation the proportion of ***a*** is high and for larger discrepancies, the proportion of ***a*** is at its lowest level. For the mid range asymmetry levels there is greater variation in the response of the observers to the images.

On comparison of the individual observer groups (Graph 29) the proportion of answer ***a*** recorded for each level of asymmetry follows a similar trend, however, it is apparent that the lay group (group 1) require a larger level of asymmetry before they become aware of its presence, whereas, the orthodontist group notice the asymmetry at a smaller level. Graphically this can be shown by the two curves represented by the lay and orthodontist groups. Although the other observer groups also appear to notice the asymmetry at varying levels of chin point deviation, their perception of asymmetry seems to fall between the lay and orthodontist groups. It can therefore be concluded that the observer group is an important factor with regard to perception of asymmetry, however, only the lay and orthodontist groups will be considered in the subsequent analysis in this thesis, as these define the upper and lower limit groups.

Graph 29 Proportion of option ***a*** selected for each asymmetry level for each group.

For each level of asymmetry the proportion of option ***a*** is indicated for each group. Group 1 (blue square) corresponds to the lay person group, group 2 (green diamond) dental students, group 3 (grey pentagon) dental care professionals, group 4 (purple rectangle) general dental practitioners and group 5 (red circle) orthodontists. Group 1 and group 5 can be seen to represent the upper and lower tolerances for the perception of chin point asymmetry, with the lay people needing greater levels of asymmetry to be present before they are aware of it than the orthodontist group.



3.4.3 The impact of the direction of the asymmetry on perception

It has been suggested that there is a difference in the sensitivity of our perception to asymmetry dependent on the side to which the deviation occurs (Ricciardelli *et al*; 2002). The following analysis assesses the proportion of answer ***a*** recorded by the orthodontist and lay person groups for each deviation increment to both the right and left side.

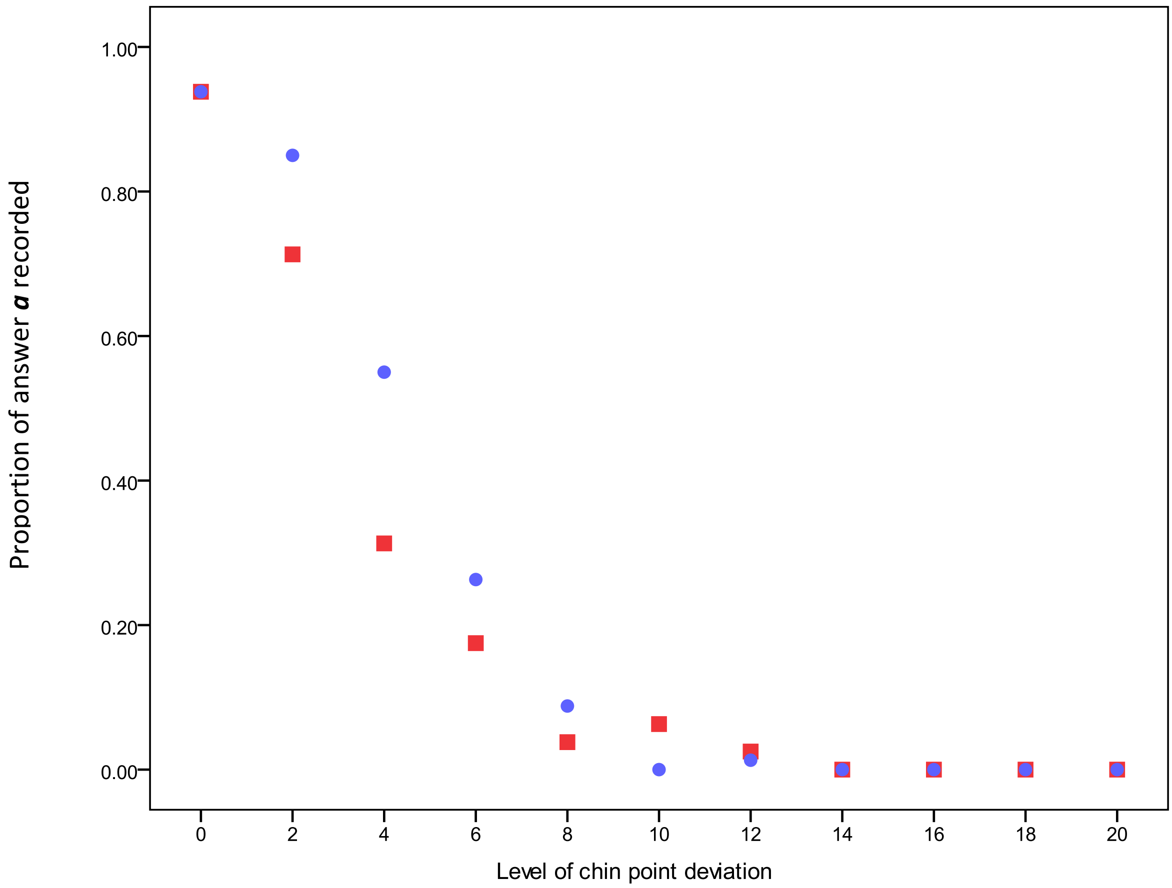
Graph 30 shows how the combined proportion of answer ***a*** from the lay and orthodontist group for each asymmetry level comparing between right and left. The graph shows that the observers perceived deviation of chin point similarly whether to the right or left, especially at the upper and lower end of the spectrum. However, for the mid-range values there was a greater difference.

Confidence intervals for the difference in proportions were calculated to assess any differences between the data comparing the perception of asymmetry to the right and left, this was then displayed graphically (Graph 31). When the confidence intervals cross the x-axis (zero) it means that the true difference in proportions cannot be considered statistically, i.e., we would accept the hypothesis that the proportions were the same at the 5% level of significance. In general there were no significant differences between the perception of asymmetry in terms of the direction of the chin point deviation. However, at 4 mm chin point deviation, the upper confidence limit merely approaches zero, indicating that for that magnitude, the direction has its influence on perception, albeit a small impact. When interpreting multiple tests, at different asymmetry levels, we would expect 1 in 20 confidence intervals, on average, to include zero by chance.

Overall, in the combined sample of lay people and orthodontists, there were only two significant results out of 11 and so direction of the asymmetry is not thought to be a significant variable of perception of facial asymmetry and therefore will not be further investigated as an independent variable in the following analyses.

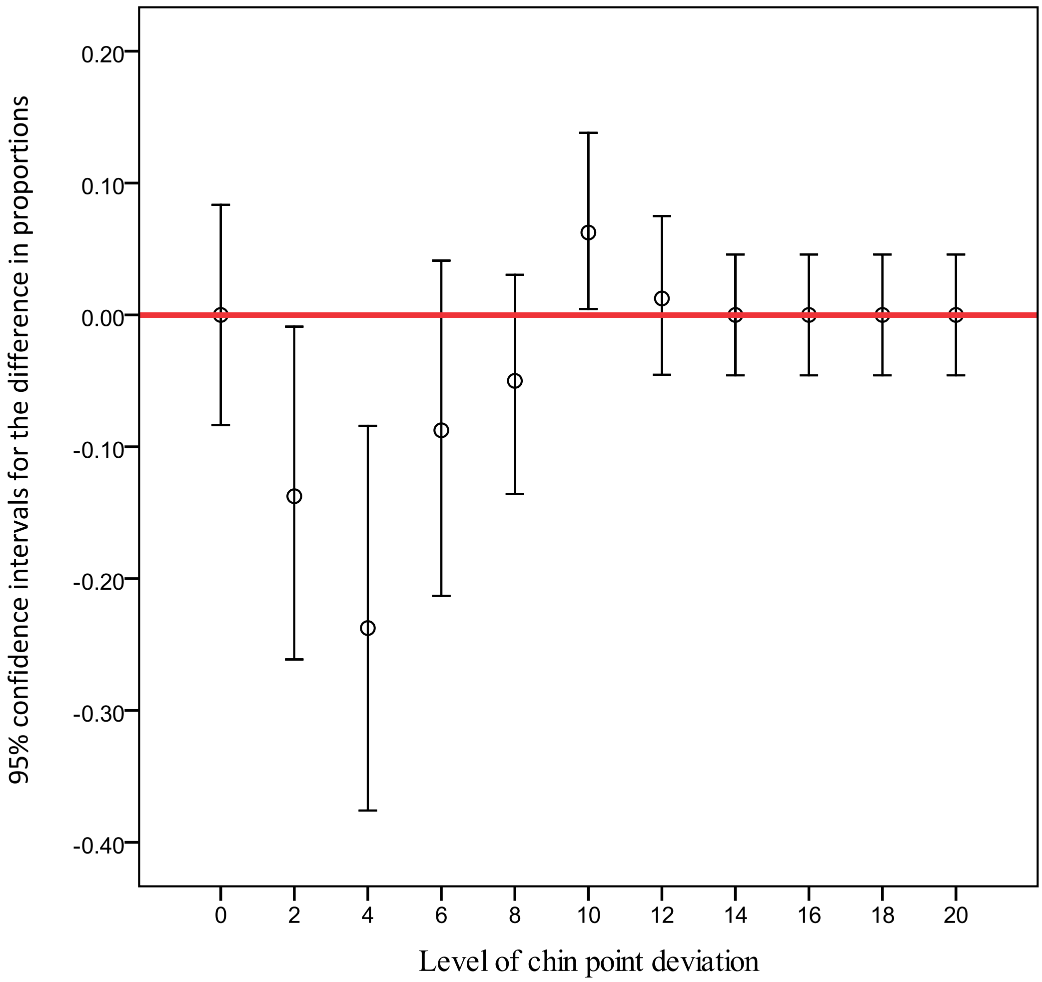
Graph 30 Proportion of option ***a*** recorded for each asymmetry level to right and left

The combined proportion of option ***a*** for both the orthodontist and lay people groups for each deviation increment to both the right and left are shown. The red markers indicate asymmetry to the right and the blue markers indicate asymmetry to the left. There is close correspondence between the responses at each increment, with the exception of 4 mm level



Graph 31 Difference of proportion of ***a*** responses recorded for each asymmetry level for right and left

The 95% confidence limits, corresponding to the difference in proportion for option ***a*** between right and left asymmetry perception are shown graphically. Each vertical line indicates the upper and lower limits of the confidence interval and the circle represents the mean for that level of asymmetry. For each level of asymmetry a statistically significant difference cannot be found, with the exception of 4 mm. At 4 mm the vertical line does not cross or lie close to the x-axis, indicating that a difference, although small, exists at this level.

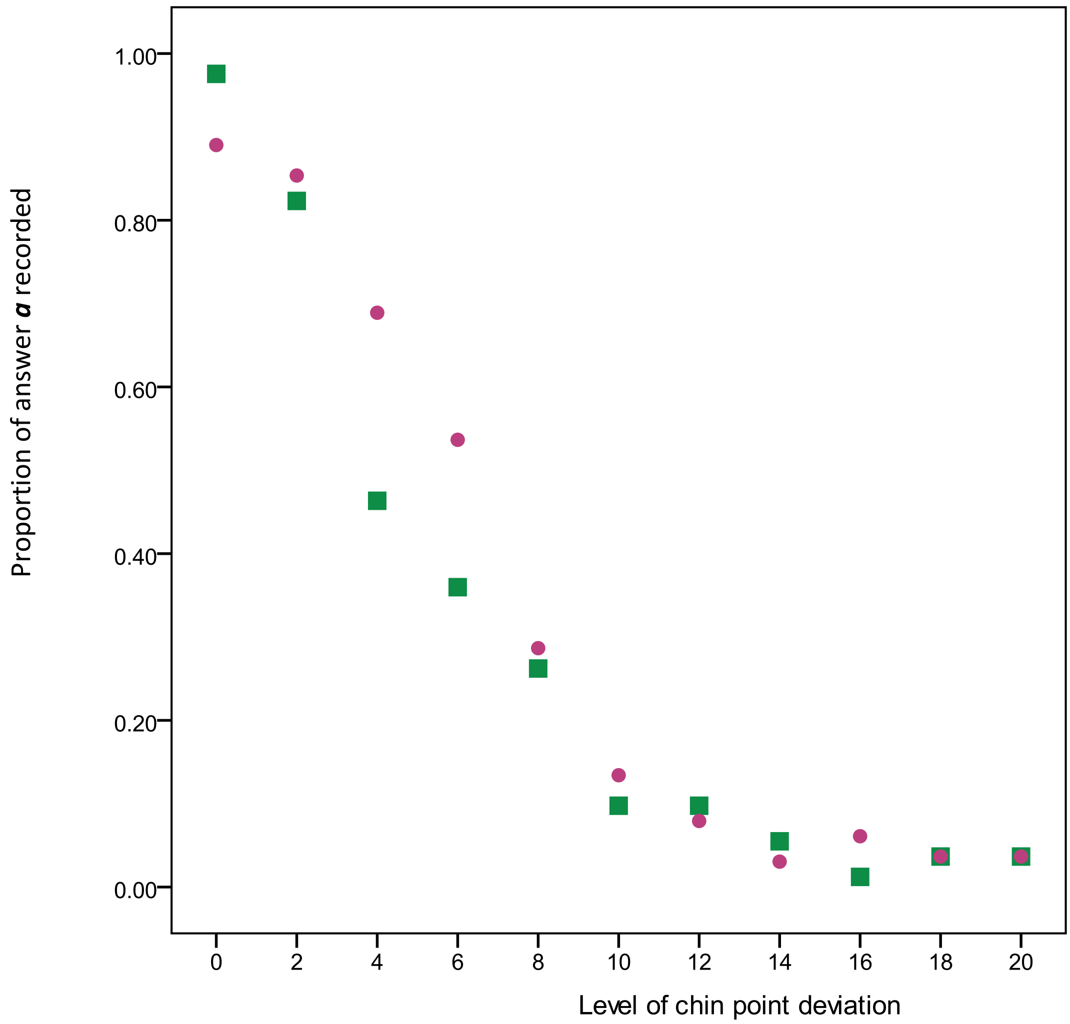


3.4.4 The impact of image gender on the perception of facial asymmetry

It has been suggested that observers may potentially rate the male and female faces differently (Little *et al* 2007 and 2008). The combined results for option ***a,*** from the orthodontist and lay groups, were used to test for any significant difference between the perception of the observers to the asymmetry observed in the male and female manipulated faces. Graph 32 shows that the responses of option ***a*** for each level of deviation were very similar for both the male and female faces. As previously observed, for the mid-range deviations there is a larger variation of responses. This variation was assessed by comparing the difference in proportions. The confidence limits between responses for the male and female images where plotted (Graph 31). At each level of asymmetry, with the exception of 0, 4, 6 and 16 mm, the upper and lower confidence limits cross zero (x-axis) indicating that there is no statistically significant difference with respect to the gender of the person with the asymmetry on the perception of asymmetry. At 0 and 16 mm deviations the limits are close to zero indicating a weaker effect but at 4 and 6 mm larger significant effects are observed, however, the upper confidence limits do approach zero indicating that the effect size might be small.

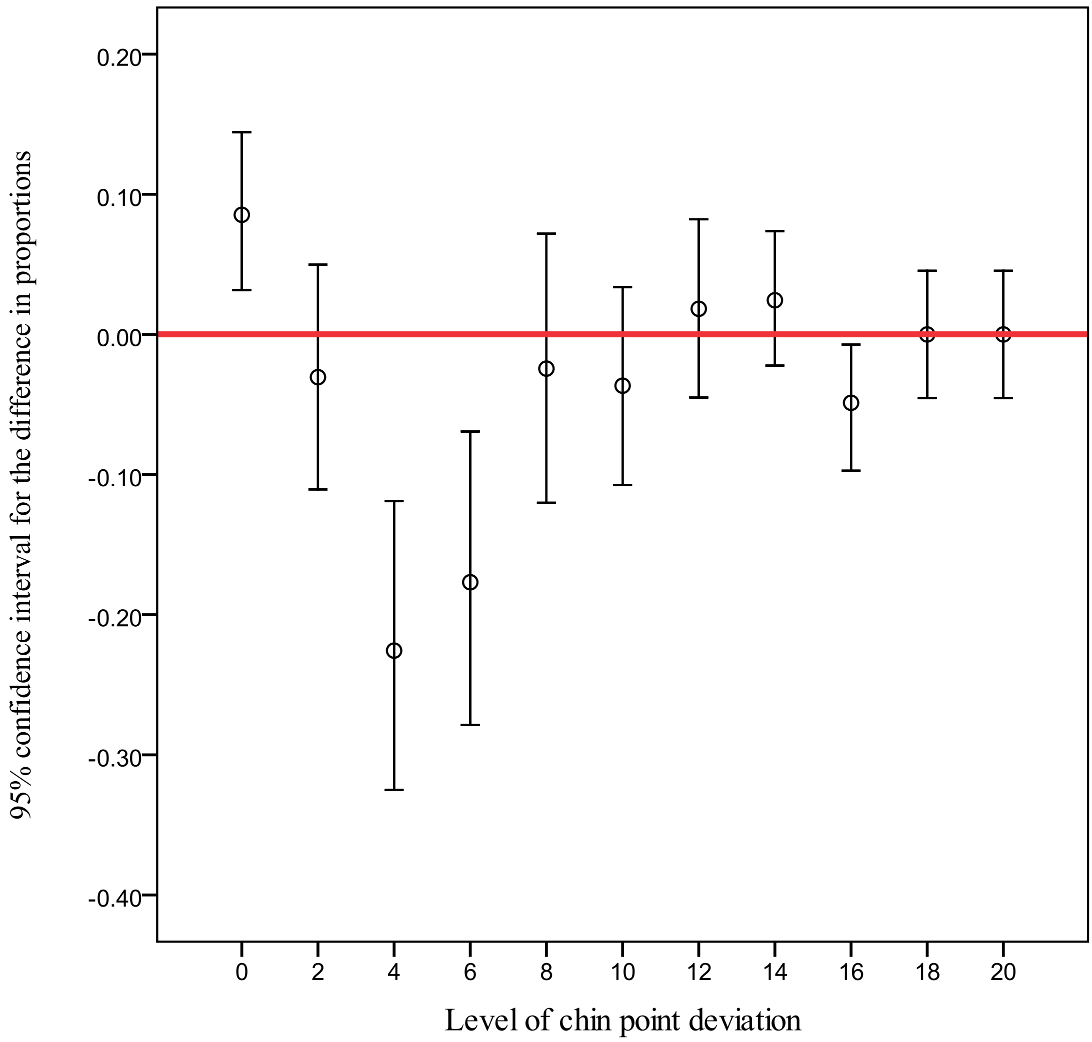
Graph 32 Differences in the rating of the male and female faces

In the graph below pink markers indicate the proportion of option a recorded for each level of asymmetry for the female faces, whereas, the green markers indicate the options for the male faces. There is close association between the responses for the genders, but increased variation at the 4 and 6 mm level.



Graph 33 Difference of proportion comparing the impact of male and female faces on perception

The 95% confidence limits, corresponding to the difference in proportion for option ***a*** between male and female manipulated faces are shown graphically. Each vertical line indicates the upper and lower limits of the confidence interval and the circle represents the mean for that level of asymmetry. For most of the levels of asymmetry a statistically significant difference cannot be found, with the exception of 0, 4, 6 and 16 mm. At these levels the vertical line does not cross the x-axis, indicating that a difference, small for 0 and 16 mm and larger for 4 and 6 mm, may exist for these degrees of asymmetry.

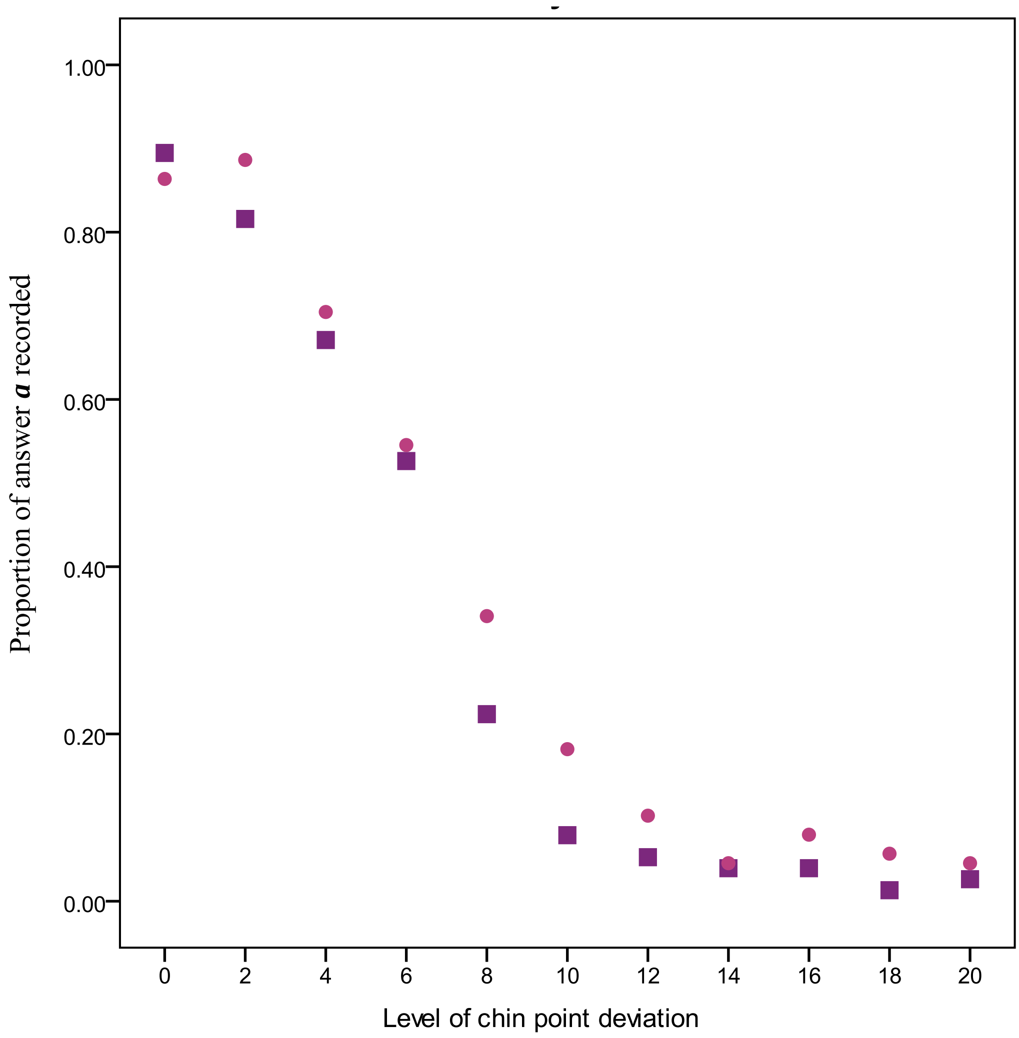


3.4.5 The impact of observer gender on perception of facial asymmetry

The gender of the observers has been proposed as a variable that can affect the perception of facial asymmetry (Little *et al* 2007; 2008). For both the male and female manipulated faces the proportion of option ***a*** recorded by all the females from the orthodontic and lay person groups were compared with the proportion of option ***a*** recorded by the male from these two groups. Graphs 34 – 37 show that no significant difference, at any level of asymmetry, was found with respect to the gender of the observers. It can therefore be concluded, that in this sample, the gender of the observers does not affect the perception of facial asymmetry for neither the male or female manipulated faces.

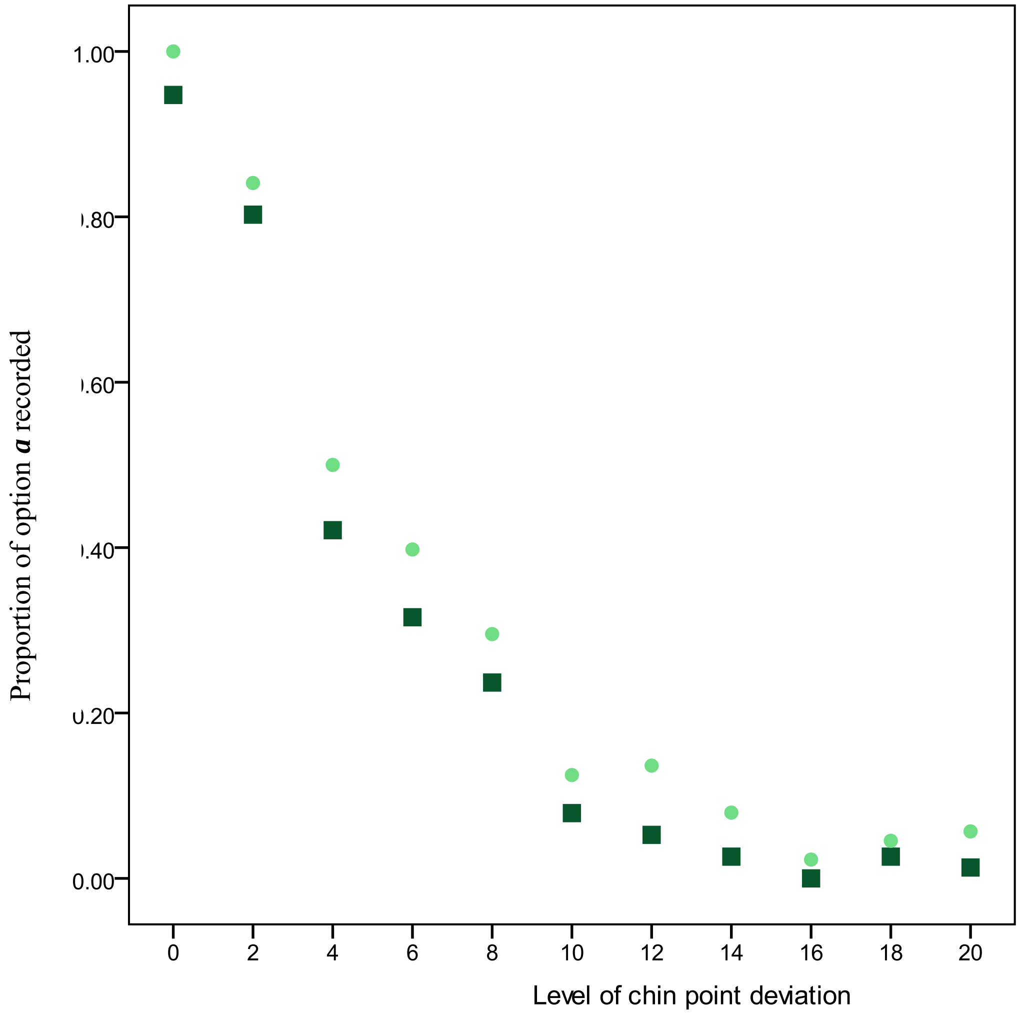
Graph 34 Comparison of gender of the observer in relation to the proportion of ***a*** recorded for simulated chin point discrepancies on the female face

In the graph below the square markers represent the proportion of option ***a*** recorded for each level of simulated asymmetry on the female face by the male observers. The circular markers represent the proportion of option ***a*** for the same faces by the female observers. There is close association between the perception of asymmetry on the female face by both the male and female observers.



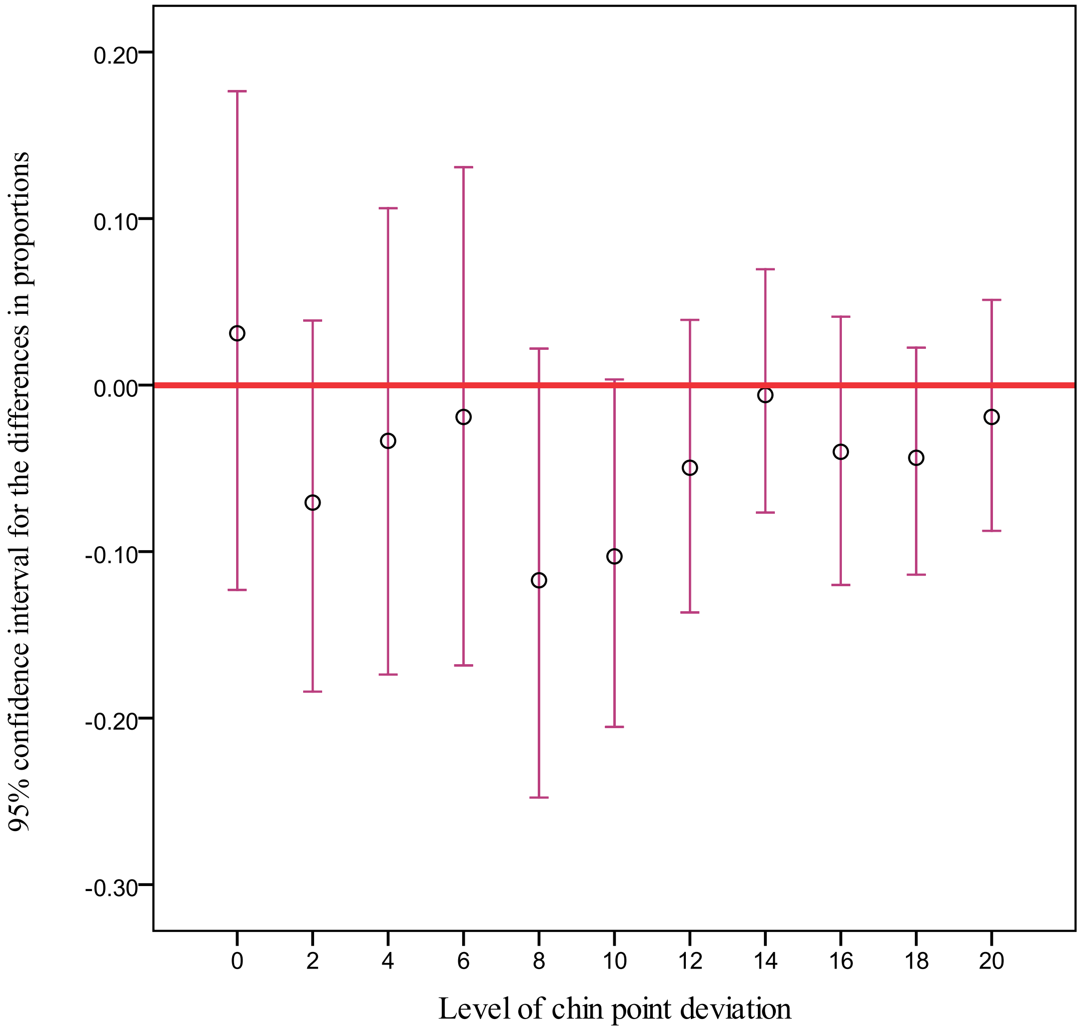
Graph 35 Comparison of gender of the observer in relation to the proportion of ***a*** recorded for simulated chin point discrepancies on the male face

In the graph below the square markers represent the proportion of option ***a*** recorded for each level of simulated asymmetry on the male face by the male observers. The circular markers represent the proportion of option ***a*** for the same faces by the female observers. There is close association between the perception of asymmetry on the male face by both the male and female observers.



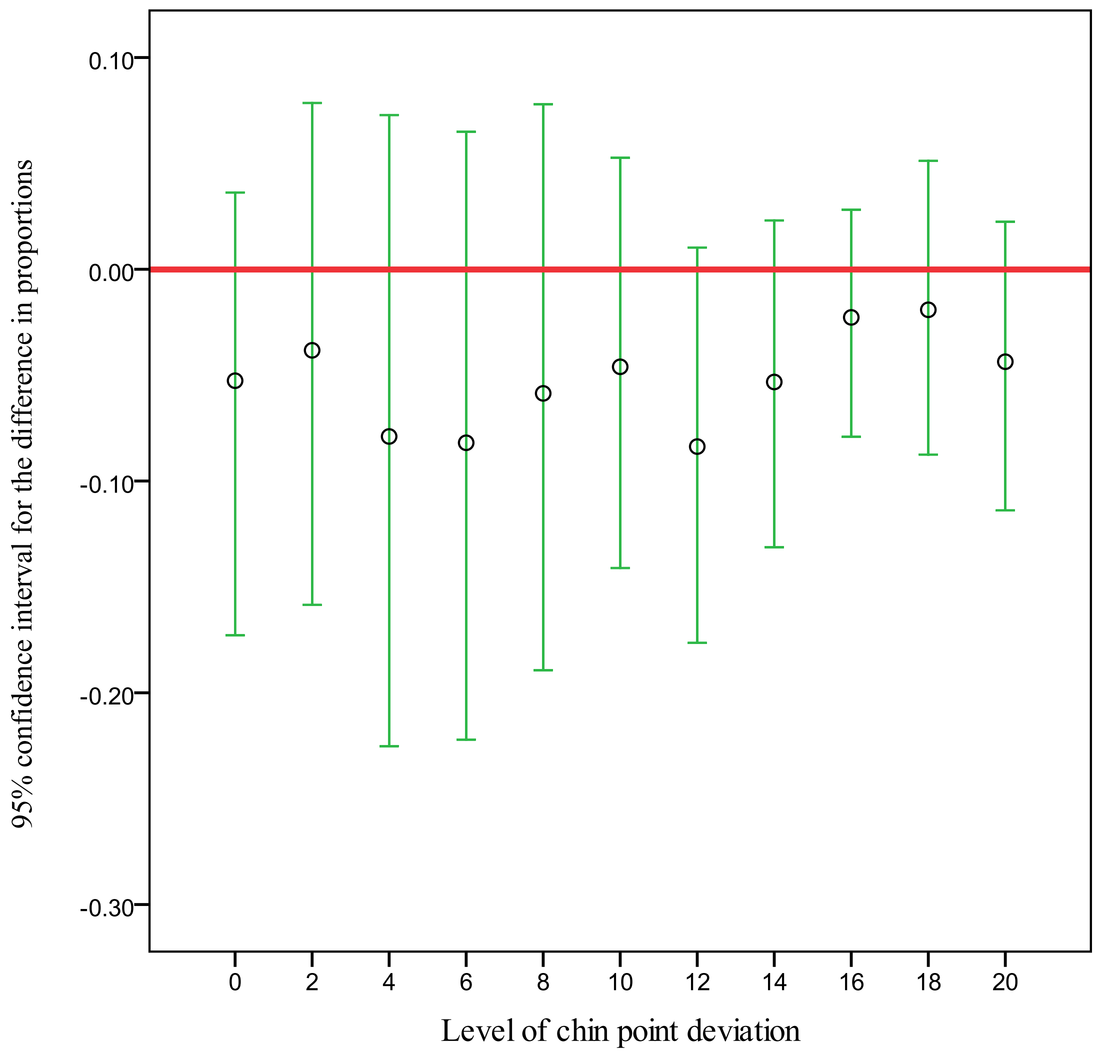
Graph 36 Difference of proportion for comparison of observer gender on female faces

The difference of proportion graph below shows the upper and lower confidence limits for the perception of asymmetry on the female faces by both male and female observers. As indicated by the crossing of the x-axis by vertical line for each level of deviation it can be confirmed that the gender of the observer does not influence the perception of asymmetry with respect to the female manipulated faces in this sample.



Graph 37 Difference of proportion for comparison of observer gender on male faces

The difference of proportion graph below shows the upper and lower confidence limits for the perception of asymmetry on the male faces by both male and female observers. As indicated by the crossing of the x-axis by vertical line for each level of deviation it can be confirmed that the gender of the observer does not influence the perception of asymmetry with respect to the male manipulated faces in this sample.



3.4.6 Assessment of normal and acceptable range

Having assessed the collected data and analysed the results it has become apparent that the significant variables that affect the perception of chin point asymmetry are:

- The degree of deviation
- The observer group

In general the following variables were not found to influence the perception of facial asymmetry, however, for the mid range asymmetry levels (4 – 6 mm) there was an indication that the have the potential to affect perception:

- The direction of the asymmetry
- The gender of the individual with the asymmetry

The gender of the observer was not found to influence the perception of asymmetry

In order to define the range of asymmetries that each of the groups considered to be normal and the level at which correction of the asymmetry was deemed appropriate, the results obtained from the observers were subjected to time-to-event analysis. For this analysis the level of asymmetry at which the first change from option ***a*** to option ***b*** was recorded for each observer, therefore, allowing the range of normal asymmetry range to be quantified. Similarly, the level of the asymmetry at which the first change from option ***b*** to option ***c*** occurred was recorded for each observer, allowing the level at which correction was deemed appropriate to be quantified. The time-to-event results were analysed according to group and then inter-group comparisons were carried out to assess any differences between the groups.

3.4.6.1 Normal range of asymmetry

Using the time-to-event results the mean value was calculated for each group along with the standard deviation (Table 5), this value was used to represent the upper limit of the normal range for each observer group. As discussed from the outset the lay person group was regarded as the base group, as it is this group that is likely to represent the general population and hence the group that might be of relevance in every-day life for patients with facial asymmetry. It was found that the range of normality, as defined by the lay person group, was 0 - 5.60 ± 2.68 mm, whereas the range for the orthodontic group was 0 – 3.6 ± 1.54 mm. For the other three groups assessed (dental students, dental professionals and general dental practitioners) the ranges considered normal were greater than that of the orthodontist group but more narrow than the lay person group, indicating that the these three groups noticed the asymmetry earlier than the lay group, but later than the orthodontists. Using the general linear model it was found that the observer group was a statistically significant ($P < 0.001$) factor with respect to the perception of chin point asymmetry for the range of deviations that were considered to normal.

Post-hoc Tukey tests (Table 6) were performed to determine any differences between the values that each observer group considered to be the threshold of normal asymmetry. It was found that the orthodontic group differed significantly ($P < 0.05$) from all other groups, with the exception of the general dental practitioner group, with respect to the normal range values (Table 6). There was also a significant difference between the lay person group and general dental practitioner group for the range of normality ($P < 0.05$).

Based on the comparison of the observed means in the normal range for each of the five observer groups, SPSS was used to compute the homogeneous subsets in the data (i.e. subsets of the data containing the original groups that display significant difference ($P < 0.05$)

with the others). When comparing the subsets produced for the observer groups, with respect to the range of normality, it was found that three homogenous subsets existed. Group one was made up of the orthodontists and the general dental practitioners, the second group consisted of the general dental practitioners, dental students and dental care professionals and the final group was formed by the dental care professionals, dental students and lay people. Further analysis of the subsets shows that some of the observer groups are present in more than one subset, indicating that the variation between the observer group represents a relatively gradual and small difference in perception, with only the orthodontist and lay groups not being present in multiple subsets. It can be concluded that the perception of the orthodontic and lay groups, in relation to the range of normality of chin point asymmetry, is statistically significant ($P < 0.05$) with a clinical difference of 2 mm between the threshold limits.

Table 5 Range of asymmetry regarded as normal for observer each group

Observer group	Mean chin point deviation (mm)	Standard deviation (mm)	Identified normal range (mm)
Lay people	5.60	2.68	0 – 5.60 ± 2.68
Dental Students	5.13	2.06	0 – 5.13 ± 2.06
Dental care professionals	5.06	2.36	0 – 5.06 ± 2.36
General dental practitioners	4.40	1.60	0 – 4.40 ± 1.60
Orthodontists	3.60	1.54	0 – 3.60 ± 1.54

Table 6 Results of Multiple comparison (Tukey) tests between observer groups for the "normal" range of asymmetries. In bold are shown the statistically significant P values

Group a	Group b	Mean difference between a and b	Std. error	Significance	95% confidence interval	
					Lower bound	Upper bound
Lay people	Dental students	0.468	0.316	0.575	-0.397	1.332
	Dental care professionals	0.533	0.328	0.484	-0.367	1.432
	General dental practitioners	1.195	0.328	**0.003**	0.296	2.095
	Orthodontists	1.995	0.328	**0.00000003**	1.096	2.895
Dental students	Lay people	0.468	0.316	0.575	-1.332	0.347
	Dental care professionals	-0.065	0.320	1.000	-0.811	0.941
	General dental practitioners	0.728	0.320	0.155	-0.148	1.604
	Orthodontists	1.528	0.320	**0.00002**	0.652	2.404
Dental care professionals	Lay people	-0.533	0.328	0.484	-1.432	0.367
	Dental students	-0.652	0.320	1.000	-0.941	0.811
	General dental practitioners	0.663	0.332	0.271	-0.248	1.573
	Orthodontists	1.463	0.332	**0.0001**	0.552	2.373
General dental practitioners	Lay people	-1.195	0.328	**0.003**	-2.095	-0.296
	Dental students	-0.728	0.320	0.155	-1.604	0.148
	Dental care professionals	-0.663	0.332	0.271	-1.573	0.248
	Orthodontists	0.800	0.332	0.115	-0.110	1.710
Orthodontists	Lay people	-1.995	0.328	**0.00000003**	-2.895	-1.096
	Dental students	-1.527	0.320	**0.00002**	-2.404	-0.652
	Dental care professionals	-1.463	0.332	**0.0001**	-2.373	-0.552
	General dental practitioners	-0.800	0.332	0.115	-1.710	0.110

3.4.6.2 Level of asymmetry deemed appropriate for correction

The time-to-event results were assessed in a similar manner for the first change from option ***b*** to option ***c*** as rated by the observers. The mean values for each of the groups are shown in table 7, indicating the level at which correction is deemed appropriate. The combination of the values found from the time-to-event changes ***a-b*** and ***b-c*** suggest a range of asymmetries that each of the groups consider to represent abnormal yet socially acceptable. As for the normal range, the orthodontist group also had the lowest threshold for correction of asymmetry (9.73 ± 2.98 mm) and the lay people group was one of the groups that allowed a larger level of asymmetry to exist in the acceptable range (11.79 ± 4.04 mm. The general linear model showed that the observer group was statistically significant ($P < 0.05$) with respect to the perception of the level of chin point asymmetry that was deemed necessary for correction (Table 8).

Any differences between the groups with respect to the level deemed appropriate for correction were assessed using the Tukey test and it was found that significant differences ($P < 0.05$) existed between the orthodontist group and the other groups with the exception of the dental care professionals.

Two homogeneous subsets were produced based on the values of the time-to-event analysis for the level appropriate for correction. The first subset comprised of the orthodontist and dental care professional groups and the second subset consisted of the dental care professionals, general dental practitioners, dental students and the lay people groups, with dental care professionals existing in both subsets. The difference between the orthodontist group and general dental practitioner, dental student and lay person groups was found to be both statistically significant ($P < 0.05$) and clinically equated to average difference of 1.98 mm.

Table 7 Mean level of chin point asymmetry at the level at which surgical correction was deemed appropriate by each of the groups

Observer group	Mean chin point deviation (mm)	Standard deviation (mm)
Lay people	11.79	4.04
Dental Students	11.98	3.62
Dental care professionals	10.60	2.85
General dental practitioners	11.35	2.80
Orthodontists	9.73	2.98

Table 8 Results of Multiple comparison (Tukey) tests between the observer groups for the level deemed appropriate for surgical correction. In bold are shown the statistically significant P values.

Group a	**Group b**	**Mean difference between a and b**	**Std. error**	**Significance.**	**95% confidence interval**	
					Lower bound	Upper bound
Lay people	Dental students	-0.193	0.498	0.995	-1.557	1.171
	Dental care professionals	1.186	0.518	0.150	0.233	2.605
	General dental practitioners	0.436	0.518	0.918	-0.983	1.855
	Orthodontists	2.061	0.518	**0.001**	0.642	3.480
Dental students	Lay people	0.193	0.498	0.995	-1.171	1.557
	Dental care professionals	1.379	0.504	0.051	-0.003	2.760
	General dental practitioners	0.629	0.504	0.724	-0.753	2.010
	Orthodontists	2.254	0.504	**0.0001**	0.872	3.635
Dental care professionals	Lay people	-1.186	0.518	0.150	-2.600	0.233
	Dental students	-1.138	0.504	0.051	-2.760	0.003
	General dental practitioners	-0.750	0.524	0.608	-2.186	0.686
	Orthodontists	0.875	0.524	0.454	-0.561	2.311
General dental practitioners	Lay people	-0.436	0.518	0.918	-1.855	0.983
	Dental students	-0.629	0.504	0.724	-2.010	0.753
	Dental care professionals	0.750	0.524	0.608	-0.686	2.186
	Orthodontists	1.625	0.524	**0.018**	0.189	3.061
Orthodontists	Lay people	-2.061	0.518	**0.001**	-3.480	-0.642
	Dental students	-2.254	0.504	**0.0001**	-3.635	-0.872
	Dental care professionals	-0.875	0.524	0.454	-2.311	0.561
	General dental practitioners	-1.625	0.524	**0.018**	-3.061	-0.189

4.0 DISCUSSION

The purpose of this study was to investigate the perception of facial asymmetry, in particular asymmetry of the chin in the horizontal direction. Previous investigations into facial and dental asymmetry have revealed that the perception of asymmetry is dependent on a variety of variables including those associated with the observer such as profession (Johnson *et al*; 1999) and those associated with the individual with the asymmetry such as location of asymmetry (Meyer-Marcotty, 2011). It was therefore decided that it would be insufficient to analyse the perception of asymmetry of only one group of observers and in an effort to limit the variables related to the individual with the asymmetry an average face was used with simulated asymmetries and the location of the asymmetry restricted to the chin.

Information regarding the perception of facial asymmetry is important to clinicians involved with the assessment and treatment of patients with asymmetry, patients with asymmetry and governing bodies responsible for resource allocation with respect to the management of affected individuals. It has previously been reported that a significant proportion of the population are affected by asymmetry (Severt and Proffit, 1997), in a referred population 1460 patients with dentofacial deformity, 34% had a clinically detectable asymmetry, with 74% of those asymmetries affecting the mandible. The cost of combined orthodontic and orthognathic treatment in the UK is difficult to calculate as each patient will receive a variable number of treatment appointments, the cost of materials is clinician dependant, the type of surgery carried out is dependent on individual need and surgeon preference and the number of nights stay in hospital following surgery may vary. Cunningham *et al* (2002) investigated cost-utility analysis of patients undergoing orthognathic treatment, the method her team employed was based on a cohort of 21 patients and estimations of treatment costs based on a single UK trust. It was found that the average cost for treatment involving single jaw surgery was almost £2,700 and for bimaxillary surgery approximately £3,600. In addition to significant NHS cost implications associated with a surgical treatment approach, it should be appreciated that patients will be in treatment for usually a minimum of 18 months and will be required to take time off work/studies to attend all appointments, therefore resulting in further financial implications to the patient and disruption to their work and studies. The risks to patients include both the risks associated with orthodontic treatment including decalcification ,root resorption and relapse and the risks associated with surgery and being placed under a general anaesthetic. Usually the most important risk to be discussed with the patient considering orthognathic treatment is the risk of damage to part of the mental nerve and its associated paraesthsia to the affected area. With the combination of the financial implication, the clinical and patient time commitments and the associated risks of embarking on corrective surgery it is imperative that all involved in the process are adequately informed of the pros, cons, risks and benefits as well as the option for accepting the asymmetry and the implications of this action. Ideally the perception of facial asymmetry should be discussed as part of this process, allowing subjective evaluation of the asymmetry.

4.1 Individual faces included in the average face production

An average male and female face were used as the master faces to which all simulated asymmetries where made. The reasons for using average faces in preference to real life patients with the required amount of asymmetry or a proband face with simulated deviations were to avoid the associated bias of using multiple faces with no method of standardising the other features and to ensure that the original face had no other abnormalities that could influence the perception of the chin point deviation. On the other hand the use of an average face introduces an artificial element to the study and it can be reasoned that the perception of the average face is dissimilar to the perception of a real life human with asymmetry.

There is no gold standard method of assessing realistic asymmetry at varying levels of deviation without compromise, such as digital manipulation. Recently Meyer-Marcotty *et al* (2011) investigated the perception of asymmetry using a digitally altered male proband face potentially the use of a single face is more acceptable than the use of an average face, however, the images they showed to their observers were grey in colour, based on the captured laser scanned image, and the asymmetry was digitally simulated, therefore, it can be argued that their faces were less realistic the natural-looking average faces in this present study for perception of asymmetry. Another study (Naini *et al*, 2012) used stylised 2Dcartoon images to represent an individual with asymmetry. It can be argued that this method is the least realistic method of assessing the perception of asymmetry as the stylised cartoons provide no realistic representation of facial form, proportions, texture or colour compared with these digitally altered average faces used here.

In an effort to increase the number of individuals included in the creation of the average male and female faces it was decided that there would be no ethnic origin limit to the selection criteria. The use a heterogeneous race in the production of the average face is a potentially controversial issue with all other studies looked at used homogeneous ethnicities.

Several studies have used average faces to demonstrate inter-racial or ethnic differences between 3-dimensional facial images (Seager et al 2009; Bozic *et al* 2009) and various cephalometric investigations have confirmed that there are abundant dental and skeletal differences between individuals of different racial type (Fonseca and Klein 1978; Hamdan and Rock 2001). However, based on preliminary results using 2-dimensional images, it was found that the composite faces did not appear driven by a specific ethnic group

(Figures 2 and 3). In addition, the average faces were intended to be used only as a base face from which manipulated images could be produced and not to derive a statistical model of a particular kind. For example, if the average faces were to be used as a template to assess syndromic or disease states then the use of an homogenous sample would have been more relevant (Cox-Brinkman *et al*; 2007).

4.2 Sample size calculation

At the outset of this study the number of observers needed to evaluate the images with asymmetry was calculated, unfortunately at this time there were no similar studies available from which to base a sample size calculation. It was decided the sample size calculation for this study would be based on finding a difference of proportion between observer groups with a power of 80%. The final sample size for each group was calculated at 40, giving an overall sample of 200 observers needed to complete the investigation.

In recent times studies have been carried out investigating the perception of facial asymmetry. Meyer-Marcotty (2011) assessed perception of facial asymmetry using simulated 3-dmensional models with asymmetry of the chin or nose. In their study they compared the opinions of three rating groups, including orthodontists, maxillofacial surgeons and lay people. The sample size for each group was 30, however, no sample size calculation was discussed.

Another study that assessed the perception of facial asymmetry was carried out by Naini *et al* in 2012. In their study caricature faces were assessed by three observer groups (orthognathnic patients, clinicians and lay people) and the sample size power calculation was based on a pilot study that they initially carried out, indicating that 35 observers would be desirable for the clinician group and 75 observers were needed in each of the remaining groups, giving an overall sample size of 185, therefore allowing a power of 80% with respect to a pre-determined difference in the Likert scale responses..

Of note in both the aforementioned studies the observers were asked to rate their opinion of the faces based on a Likert scale, which differs from this current study.

In conclusion, the power of this current study compares favourably with Naini *et al* (2012) as both had a power of 80%, however, there was no sample size calculation discussed in the Meyer-Marcotty (2011) study and therefore this cannot be assessed.

4.3 Level of asymmetry found in the faces used for average face production

The literature is inconclusive with regards to the affect of age on the level of facial asymmetry. Ferrario *et al* (2001) carried out a cross-sectional study to assess the effect of age and sex on facial asymmetry. Their sample consisted of 77 male and female adolescents, 162 male and female 18 -30 year olds and 79 male and female 31 – 56 year olds. They found that age and gender did not affect the level of asymmetry noted between the groups. Conversely Clinton *et al* (2012) investigated the relationship between age and facial asymmetry in a sample of 97 subjects. They concluded that facial asymmetry increased with age, with a reported 4% increase in asymmetry for each decade of life.

In this present study the average age of the males included in the average face production was 27.5 years (standard deviation 4.7 years) and the average age for the female sample was 26.6 years (standard deviation 4.6 years). The individuals used in the production of the average face where recruited from the Birmingham Dental Hospital staff and where therefore over 18 years of age and the age limit was capped at 35 years. This ensured that all individuals were of an age that surgical correction would be considered appropriate and therefore were likely to better represent the age group of the patients most likely to undergo such treatment.

The results obtained from the analysis of symmetry of the faces included in the average male and female face production can be compared to a similar study carried out by Djordjevic *et al* 2011). The sample used by Djordjevic *et al* consisted of 20 female and 19 male 16 – 17 year old Finnish subjects and the images were captured using a laser scanner. The average overall level of symmetry found in their sample was 62.6% for females and 58.1% for males. These values are considerably different from the levels of symmetry found in this current study, where the females had an average overall facial symmetry of 51.92% and the males 47.13%. The differences may be explained by a combination of factors including an older sample population, mixed ethnic origin of the subjects and different methods of image capture (laser scanner versus stereophotogrammetry).

Levels of facial asymmetry may be different in varying racial groups. Severt and Proffit (1997) reported that 40% of their referred class III sample assessed at the university of North Carolina had a clinically detectable facial asymmetry, whereas Haraguchi *et al* (2002) reported that in their sample of 220 adult class III patients 56% had a clinically detectable facial asymmetry. Unfortunately, neither of these two studies quoted a measurable level of asymmetry, only stating that the asymmetry was apparent clinically, therefore, the data appears to be subjective and not comparable to our current study.

For both the male and female facial images a similar pattern of symmetry was found, represented by a decrease in the level of symmetry as the distance from the forehead increased. This pattern of symmetry reduction has been reported earlier by Severt and Proffit (1997) using retrospective results obtained from clinical examination of a referred population of 1460 patients with dentofacial deformities, and by Peck and Peck (1991) using cephalometry, in a group of 52 subjects with apparently aesthetically pleasing faces.

The average deviation of the mid-line and mid-point of the bilateral landmarks from the mid-sagittal plane for both male (1.04 mm and 1.02 mm respectively) and females (1.29 mm and 1.23 mm respectively) was consistently less than 3 mm. This correlates well with the results quoted by Farkas and Cheug (1981) who found an average difference of 3 mm in asymmetric measurement in their sample of healthy North American Caucasians.

4.4 Perception of facial asymmetry

In this study a general trend was observed across all observer groups, showing that, as expected, observers were less sensitive to asymmetry of the chin when discrepancies were small and more likely to notice the asymmetry when the discrepancies were larger. In the mid-range of discrepancies, the response approached a sigmoid curve and there was greater inter-group variability, suggesting that other variables might come into play in this range, such as direction of the asymmetry and gender of the individual with the asymmetry.

From analysis of the data it can be concluded that observer group played a significant role in the perception of facial asymmetry as did the magnitude of the discrepancy. Overall the direction of the asymmetry, the gender of the face with the asymmetry and the gender of the observer did not influence the perception of asymmetry. However, for the range of 4 – 6 mm deviation at the chin point, direction and gender of the patient where significant.

In a recent study (Meyer-Marcotty *et al*, 2011) assessing perception of facial asymmetry using 3-dimensional simulated images, it was concluded that the profession of the rater did not influence their opinion of the simulated asymmetry, deviation of the nose were more readily noticed than chin point discrepancies and the direction of the asymmetry had an impact on how the asymmetry was rated. Of note in that study the observers were asked to rate the images on a Likert scale of 1 to 6 with 1 = very symmetric and 6 = very asymmetric. By virtue of asking this question, bias is automatically introduced into the study as the observer is immediately alerted to the variable being assessed. The images used in that study were 3-dimensional manipulated images, similar to the images used in this thesis. However, the face was presented to their observers as a grey 3-dimensional shell and therefore lacked skin colour and texture which may have affected the results.

Meyer-Marcotty *et al* (2010) carried out an earlier investigation on perception of facial asymmetry. They assessed the opinion of observers with regard to appearance, symmetry and expression for the images of repaired adult unilateral cleft lip and palate patients compared with adults without congenital anomaly of matched age and sex. They found that the greater the level of asymmetry in the mid-face the more negative the opinion of the observer towards the image. In their study they made use of real life three-dimensional images, therefore removing the disadvantage of having to use simulated images, however, also had the disadvantage of comparing uncontrolled images, where the observer may have be influenced by features other than those to be assessed. The authors claimed that they tried to account for this by ensuring the images were black and white and cropped the images so that the peripheral features such as ears and hair did not influence observer opinion.

More recently Naini *et al* (2012) reported on a study that they undertook to assess the influence of chin point asymmetry on perceived attractiveness of the individual. The rating groups included orthognathic patients, clinicians and lay people. Their study used simulated basic 2-dimensional images based on stylised cartoons, which unfortunately represented poorly the purpose of the study. Favourable points of that study included the use of both male and female caricatures, simulated deviations to the right and left, multiple rating groups, the inclusion of orthognathic patients as a observer group, and the observers were asked to rate the images based on attractiveness and therefore were not led to look for asymmetry. Their conclusions, agreed with our present study with respect to the following: the perception of the asymmetry increased as the deviation increased, at deviations less than 5 mm the asymmetry was not considered important, the desire for surgery was more likely above 10 mm, orthodontists were more critical of asymmetry than lay people and gender of the observer does not affect the perception of the asymmetry.

In addition they also concluded that ethnicity and the handedness of the observer, vertical face height of the image, the observers perception of their own appearance and the importance the observer places on attractiveness had no significant affect on the perception of asymmetry.

An interesting study by Huisinga-Fischer *et al* (2004) assessed the perception of facial symmetry. Their study investigated three observer groups (lay people, professionals and sculptors) assessment of 2-dimensional facial photographs of control children with no apparent asymmetry, children with hemifacial microsomnia (HFM) and manipulated image of the children with HFM at various stages of symmetry. Unfortunately the method used for rating the images was complex and may have influenced their results and the authors admitted in their discussion that calibration of the observers may have been beneficial. Huisinga-Fisher *et al* (2004) found that the different observer groups assessed the images differently, however, contrary to the findings we found in this study, there was no inter-group difference in the level at which treatment was deemed necessary.

In another study, Chu *et al* (2011) investigated the perception of facial asymmetry in a facial paralysis model. In their study the asymmetry was confined to the oral commissure and/or brow simulating the affect observed in individuals with facial paralysis. They found that a minimum of 3 mm asymmetry was needed before it was consistently detected. Variables that affected perception included that degree of asymmetry and the time allowed for assessment of the image. Similar to this current study digitally altered images were used to simulate the asymmetry.

The range of asymmetry that was considered clinically acceptable in this study, in the opinion of the lay person group, extends to 11.79 ± 4.04 mm. This is based on assessment of a static, digitally altered, average face with no peripheral features such as hair or ears assessed in a controlled environment. It should be remembered that this threshold level may vary significantly when applied to the clinical or real-world setting as facial movement, other facial features and patient personality may affect perception.

5.0 CONCLUSION

This study was carried out to attempt to define parameters which could be used to describe normal and acceptable levels of asymmetry and the level at which correction should be considered appropriate. The null hypothesises stated that there was no difference in the perception of asymmetry by the different rating groups and there was no difference between the level considered outside the normal range of asymmetry and that deemed appropriate for correction. Both of these statements were rejected.

Variables that were found not to influence the perception of asymmetry were the gender of the individual with the asymmetry, the gender of the observer rating the asymmetric face and the direction of the asymmetry. Variables that were found affect the perception of asymmetry were the degree of asymmetry and the profession of the observer.

The lay person group was considered to be the group that best represented the general population. For this group it was found that normal asymmetry ranged from 0-5.6 ± 2.68 mm and the threshold level which the lay person group considered acceptable for surgery was 11.79 ± 4.04 mm. These values could be used by clinicians to inform patients who are considering correction of their chin asymmetry and in evaluation of treatment outcomes. Knowledge pertaining to how others will view asymmetry is important for any patient as it allows them to objectively evaluate their deformity. In addition such information may be used by governing bodies to set out standards and allocate funding appropriately, ensuring that those in greatest need are preferentially treated.

It was found that the profession of the observer group had an impact on the perception of the asymmetry, with the orthodontist group being the most sensitive to asymmetry. It is important that clinicians do not over-prescribe treatment, especially where the treatment is long duration and involves surgery with potential complications. Clinicians should not lower their examination standards, but rather should be careful not to project their opinion on the patient, especially if correction would be for aesthetic reasons only.

5.1 Further work

Two potentially important observer groups that were not included in this study were those affected by asymmetry and those with facial deformity. The opinion of these groups is important in relation to treatment needs, resource allocation and informed consent. For those with asymmetry it would be important to note the level of their own asymmetry and whether they are concerned with their asymmetry. With regards to the facial deformity group it would be relevant to know whether they are more accepting of asymmetry in view of their own particular facial concerns.

It is important for clinicians and service providers to be aware of the perceptions of facial asymmetry not only among peers, but also in the general population, so that they can educate patients with concerns of minor or more substantial deviations. Information regarding what is considered normal and levels considered appropriate for correction can be used as useful tools to help a patient to come to terms with their appearance or help the patient to decide to accept or decline surgical correction. However, the impact the asymmetry has on the individual patient should not be overlooked. It would be beneficial to carry out a patient impact survey on patients identified as having clinically detectable facial asymmetry. The level of the asymmetry could then be compared to the levels found in this study to be normal, socially acceptable or deemed appropriate for surgical correction. This information could help to further the clinicians understanding of facial asymmetry and aid service provision.

This study was carried out on simulated 3 dimensional static images, it would be interesting to assess perception of asymmetry on dynamic images and compare the findings. This could be carried out using simulated models or live actors.

As the current study was carried out on simulated faces in a controlled manner a further line of investigation could involve assessing on real life individuals with asymmetry.

A method of assessing the impact of facial asymmetry could be to select an actor with the identified levels of asymmetry (11.79 ± 4.04 mm) for correction and a control and monitor how observers assess the individuals in a real life situation. A method for doing this could be to record the selected individual speaking on a chosen topic for a short period and then to have this watched by the observers. After watching the video the observers could be asked to retrospectively describe the salient features of the individual. The downfall of any such investigation is that it is impossible to control other facial features which may impact on the observer's assessment and any control subject would automatically be different.

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APPENDIX I

Information leaflet given to the subjects prior to image capture

INFORMATION SHEET

3D photograph survey

Orthodontics Unit, School of Dentistry

University of Birmingham

Grainne McAvinchey

Thank you for taking the time to assist in my research project related to perceived needs for surgical correction of facial asymmetry.

In order to carry out my project I need to construct an "average face". This is a composite face made up of multiple facial 3D photographs which are averaged into one. Not one original image will be identifiable in the final composite. By using an average image, it is hoped that any individual facial features will be absent and therefore reduce the bias of observers in my project. This image will be manipulated to simulate certain facial asymmetries and the results will be graded by a range of professional and non-professional observers.

Although your individual face will NOT be identifiable in the final face, your image will be used in its construction. The final average image will be used in my research and possibly in scientific publications including a Master's Thesis and possible journal articles, posters or presentations. These average faces will not be limited to viewing by clinical professionals, and as a result may be seen by members of the public.

Volunteers must fulfil the following criteria:

1. Willing to have their 3D photograph taken at the Clinical Illustration Unit and agree to have their photograph used to form part of a composite face that will be used in the research project

2. Aged between 18 and 35 years

3. No facial hair, glasses and/or piercings are removed and long hair is tied Back

4. Sign a consent form

Thank you

APPENDIX II

Consent form completed by subjects prior to image capture

Consent form for 3D photograph survey

Orthodontics Unit, School of Dentistry
University of Birmingham
Grainne McAvinchey

Gender (please circle): male female

Ethnic group: ______________________

Date of birth: __ __ / __ __ / __ __ __ __

Study number: ________

I (name)________________________ consent to having my 3d photograph taken for construction of an ideal average face to investigate facial asymmetry.

I understand that the image will be used to help construct an “average” (composite) face, which will then be used in a research project to assess facial asymmetry by various observers.

I am aware that the results of the research (but not the individual images) may be used for publication in a journal/textbook/poster/presentation/open access website which are likely to be seen by members of the general public as well as clinical professionals.

I understand that I can withdraw my consent at any time prior to the completion of the construction of the average face. In that case my photograph and all information provided will be destroyed appropriately.

To withdraw from this research please contact Grainne McAvinchey [redacted] quoting the reference number allocated on this consent form.

Signature: ____

DATE: ______

APPENDIX III

Order of the manipulated images presented to the observers for assessment

Image sequence number	Chin Point Deviation
1	4mm to Left (Female)
2	18 mm to right (female)
3	10 mm Left (male)
4	4 mm to right (female)
5	10 mm to right (male)
6	12 mm to right (female)
7	12 mm to left (female)
8	6 mm to left (male)
9	14 mm to right (male)
10	20 mm to left (female)
11	20 mm to right (female)
12	20 mm to left (male)
13	8 mm to left (male)
14	6 mm to right (male)
15	0 mm (male)
16	16 mm to left (female)
17	8 mm to right (male)
18	12 mm to right (male)
19	8 mm to right (female)
20	4 mm to left (male)
21	8 mm to left (female)
22	18 mm to left (male)
23	2 mm to left (female)
24	6 mm to left (female)
25	16 mm to left (male)
26	20 mm to right (male)
27	12 mm to left (male)
28	14 mm to left (male)
29	16 mm to tight (female)
30	10 mm to right (female)
31	6 mm to right (female)
32	14 mm to left (female)
33	2 mm to right (female)
34	0 mm (female)
35	14 mm to right (female)
36	18 mm to right (male)
37	18 mm to left (female)
38	4 mm to right (male)
39	2 mm to right (male)
40	2 mm to left (male)
41	16 mm to right (male)
42	10 mm to left (female)

APPENDIX IV

Assessment form completed by the observers

3D photograph survey

Orthodontics Unit, School of Dentistry

University of Birmingham

Grainne McAvinchey

Assessment of the average face

1. **Name** ___________

2. Gender (Please circle) **male** **female**

3. Which group best describes you (please circle one):

    Administrative/Non_Dental_Professional
    Dental_Care_Professional
    Dental_Practitioner
    Dental_Student
    Orthodontist (including specialist trainee)

Number (do not fill out, internal use)_____

I understand that I can withdraw my consent from this study at any time (please tick) ☐

To withdraw from this research please contact Grainne McAvinchey
quoting your name.

Information:

On the following page you will be asked to rate, **in your opinion**, the most appropriate option from the following:

a. This face is balanced, acceptable face
b. This face has some abnormality, socially acceptable, does not require correction
c. This face has an abnormality that would benefit from correction

Image number	(a) Balanced acceptable face	(b) Some abnormality, but socially acceptable, and does not require correction	(c) Would benefit from correction
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			
31			
32			
33			
34			
35			
36			
37			
38			
39			
40			
41			
42			

APPENDIX V

Data from all five observer groups following assessment of the manipulated images

Ratings of the lay people group for the female face

	Direction of deviation taken into account				Direction of deviation not accounted for		
	a	b	c		a	b	c
Average face	86%	14%	0%				
2mm right	88%	10%	2%		93%	6%	1%
2 mm left	98%	2%	0%				
4 mm right	69%	29%	2%		80%	19%	4%
4 mm left	90%	10%	0%				
6 mm right	81%	17%	2%		77%	18%	5%
6 mm left	74%	19%	7%				
8 mm right	52%	43%	5%		49%	43%	8%
8 mm left	45%	43%	12%				
10 mm right	33%	57%	10%		21%	56%	23%
10 mm left	10%	55%	36%				
12 mm right	19%	62%	19%		13%	44%	43%
12 mm left	7%	26%	67%				
14 mm right	7%	48%	45%		6%	32%	62%
14 mm left	5%	17%	79%				
16 mm right	10%	33%	57%		12%	36%	54%
16 mm left	14%	36%	50%				
18 mm right	12%	26%	62%		7%	20%	73%
18 mm left	2%	14%	83%				
20 mm right	7%	19%	74%		7%	19%	74%
20 mm left	7%	19%	74%				

Ratings by the lay people for the male face

	Direction of deviation accounted for				Direction of deviation unaccounted for		
	a	b	c		a	b	c
Average face	100%	0%	0%				
2mm right	93%	7%	0%		86%	13%	1%
2mm left	79%	19%	2%				
4 mm right	71%	26%	2%		63%	33%	4%
4 mm left	55%	40%	5%				
6 mm right	62%	36%	2%		56%	38%	6%
6 mm left	50%	40%	10%				
8 mm right	33%	62%	5%		46%	50%	4%
8 mm left	60%	38%	2%				
10 mm right	19%	62%	19%		18%	57%	25%
10 mm left	17%	52%	31%				
12 mm right	21%	52%	26%		18%	56%	26%
12 mm left	14%	60%	26%				
14 mm right	5%	31%	64%		11%	42%	48%
14 mm left	17%	52%	31%				
16 mm right	5%	48%	48%		2%	46%	51%
16 mm left	0%	45%	55%				
18 mm right	5%	19%	76%		7%	19%	74%
18 mm left	10%	19%	71%				
20 mm right	5%	14%	81%		7%	27%	65%
20 mm left	10%	40%	50%				

Dental student’s ratings for the female face

	Direction of deviation accounted for			**Direction of deviation unaccounted for**		
	a	B	c	a	b	c
Average face	91%	6%	2%			
2mm right	91%	8%	0%	94%	5%	1%
2mm left	96%	2%	2%			
4 mm right	66%	34%	0%	80%	20%	0%
4 mm left	94%	6%	0%			
6 mm right	68%	32%	0%	67%	32%	1%
6 mm left	66%	32%	2%			
8 mm right	40%	60%	0%	33%	59%	9%
8 mm left	26%	57%	17%			
10 mm right	21%	64%	15%	13%	66%	21%
10 mm left	4%	68%	28%			
12 mm right	13%	49%	38%	10%	34%	56%
12 mm left	6%	19%	74%			
14 mm right	2%	15%	83%	3%	11%	86%
14 mm left	4%	6%	89%			
16 mm right	0%	19%	81%	2%	32%	66%
16 mm left	4%	45%	51%			
18 mm right	6%	38%	55%	4%	22%	73%
18 mm left	2%	6%	91%			
20 mm right	0%	6%	94%	0%	10%	90%
20 mm left	0%	13%	87%			

Dental student’s ratings for male faces

	Direction of deviation accounted for				**Direction of deviation unaccounted for**		
	a	B	c		A	b	c
Average face	94%	6%	0%				
2mm right	98%	2%	0%		87%	13%	0%
2mm left	77%	23%	0%				
4 mm right	64%	36%	0%		51%	48%	1%
4 mm left	66%	32%	2%				
6 mm right	47%	53%	0%		41%	55%	3%
6 mm left	36%	57%	6%				
8 mm right	15%	79%	6%		19%	73%	7%
8 mm left	23%	68%	9%				
10 mm right	2%	85%	13%		5%	76%	19%
10 mm left	9%	66%	26%				
12 mm right	6%	68%	26%		7%	47%	46%
12 mm left	9%	68%	23%				
14 mm right	0%	28%	72%		4%	44%	52%
14 mm left	9%	60%	32%				
16 mm right	0%	32%	68%		0%	41%	59%
16 mm left	0%	51%	49%				
18 mm right	0%	11%	89%		1%	14%	85%
18 mm left	2%	17%	81%				
20 mm right	2%	7%	91%		1%	17%	82%
20 mm left	0%	28%	72%				

Dental care professional’s ratings for the female faces

	Direction of deviation accounted for				**Direction of deviation unaccounted for**		
	A	B	c		A	B	C
Average face	95%	5%	0%				
2mm right	90%	8%	3%		93%	6%	1%
2mm left	95%	5%	0%				
4 mm right	65%	28%	8%		81%	15%	4%
4 mm left	98%	3%	0%				
6 mm right	75%	23%	3%		60%	39%	1%
6 mm left	45%	55%	0%				
8 mm right	53%	43%	5%		44%	48%	9%
8 mm left	35%	53%	5%				
10 mm right	45%	50%	5%		25%	54%	21%
10 mm left	5%	58%	38%				
12 mm right	15%	55%	30%		8%	38%	55%
12 mm left	0%	20%	80%				
14 mm right	8%	25%	68%		8%	16%	76%
14 mm left	8%	8%	85%				
16 mm right	3%	35%	63%		4%	29%	68%
16 mm left	5%	23%	73%				
18 mm right	15%	33%	53%		8%	20%	73%
18 mm left	0%	8%	93%				
20 mm right	0%	3%	98%		0%	5%	95%
20 mm left	0%	8%	93%				

Dental care professional's ratings for the male faces

	Direction of deviation accounted for				**Direction of deviation unaccounted for**		
	A	B	c		A	B	C
Average face	98%	3%	0%				
2mm right	98%	3%	0%		86%	14%	0%
2mm left	75%	25%	0%				
4 mm right	75%	25%	0%		65%	34%	1%
4 mm left	55%	43%	3%				
6 mm right	43%	50%	8%		34%	55%	11%
6 mm left	25%	60%	15%				
8 mm right	25%	68%	8%		24%	69%	8%
8 mm left	23%	70%	8%				
10 mm right	10%	70%	20%		9%	61%	30%
10 mm left	8%	53%	50%				
12 mm right	15%	43%	43%		11%	45%	44%
12 mm left	8%	48%	45%				
14 mm right	0%	28%	73%		5%	31%	64%
14 mm left	10%	35%	55%				
16 mm right	0%	38%	63%		1%	25%	74%
16 mm left	3%	13%	85%				
18 mm right	0%	20%	80%		3%	14%	84%
18 mm left	5%	8%	88%				
20 mm right	0%	13%	93%		1%	10%	91%
20 mm left	3%	8%	90%				

General dental practitioner’s ratings for female faces

	Direction of deviation accounted for				**Direction of deviation unaccounted for**		
	A	B	C		A	B	C
Average face	93%	8%	0%				
2mm right	95%	5%	0%		95%	5%	0%
2mm left	95%	5%	0%				
4 mm right	53%	48%	0%		70%	30%	0%
4 mm left	88%	13%	0%				
6 mm right	50%	48%	3%		48%	51%	1%
6 mm left	45%	55%	0%				
8 mm right	18%	75%	8%		18%	76%	6%
8 mm left	18%	78%	5%				
10 mm right	10%	78%	5%		9%	65%	26%
10 mm left	8%	53%	40%				
12 mm right	5%	53%	43%		3%	38%	60%
12 mm left	0%	23%	78%				
14 mm right	3%	15%	83%		3%	13%	85%
14 mm left	3%	10%	88%				
16 mm right	5%	20%	75%		3%	25%	73%
16 mm left	0%	30%	70%				
18 mm right	3%	20%	78%		1%	13%	86%
18 mm left	0%	5%	95%				
20 mm right	0%	10%	90%		1%	9%	90%
20 mm left	3%	8%	90%				

General practitioners ratings for male faces

	Direction of deviation accounted for				Direction of deviation unaccounted for		
	A	B	C		A	B	C
Average face	93%	5%	3%				
2mm right	90%	10%	0%		83%	16%	1%
2mm left	75%	23%	3%				
4 mm right	60%	40%	0%		56%	43%	5%
4 mm left	53%	45%	10%				
6 mm right	28%	73%	0%		25%	71%	4%
6 mm left	23%	70%	8%				
8 mm right	3%	80%	18%		14%	75%	11%
8 mm left	25%	70%	5%				
10 mm right	8%	70%	23%		6%	63%	31%
10 mm left	5%	55%	40%				
12 mm right	3%	53%	45%		3%	56%	41%
12 mm left	3%	60%	38%				
14 mm right	5%	25%	70%		3%	30%	68%
14 mm left	0%	35%	65%				
16 mm right	0%	35%	65%		0%	36%	64%
16 mm left	0%	38%	63%				
18 mm right	0%	8%	93%		1%	10%	89%
18 mm left	3%	13%	85%				
20 mm right	0%	5%	95%		0%	16%	84%
20 mm left	0%	28%	73%				

Orthodontists rating for female faces

	Direction of deviation accounted for			Direction of deviation unaccounted for		
	A	B	C	A	B	C
Average face	93%	8%	0%			
2mm right	60%	40%	0%	78%	23%	0%
2mm left	95%	5%	0%			
4 mm right	29%	63%	10%	58%	38%	5%
4 mm left	88%	13%	0%			
6 mm right	25%	70%	5%	29%	68%	4%
6 mm left	33%	65%	3%			
8 mm right	8%	75%	18%	8%	50%	43%
8 mm left	8%	25%	68%			
10 mm right	10%	55%	35%	5%	45%	50%
10 mm left	0%	35%	65%			
12 mm right	3%	33%	65%	3%	19%	79%
12 mm left	3%	5%	93%			
14 mm right	0%	10%	90%	1%	5%	94%
14 mm left	3%	0%	98%			
16 mm right	0%	10%	90%	0%	14%	86%
16 mm left	0%	18%	83%			
18 mm right	0%	10%	90%	0%	5%	95%
18 mm left	0%	0%	100%			
20 mm right	0%	3%	98%	0%	3%	98%
20 mm left	0%	3%	98%			

Orthodontist’s ratings for the male face

	Direction of deviation accounted for				**Direction of deviation unaccounted for**		
	A	B	C		A	B	C
Average face	95%	5%	0%				
2mm right	83%	18%	0%		79%	20%	1%
2mm left	75%	23%	3%				
4 mm right	35%	65%	0%		29%	69%	6%
4 mm left	23%	73%	5%				
6 mm right	10%	83%	8%		15%	79%	6%
6 mm left	20%	73%	8%				
8 mm right	0%	70%	30%		5%	74%	21%
8 mm left	10%	78%	13%				
10 mm right	3%	58%	40%		1%	50%	49%
10 mm left	0%	43%	58%				
12 mm right	3%	28%	70%		1%	43%	56%
12 mm left	0%	58%	43%				
14 mm right	0%	18%	73%		0%	34%	66%
14 mm left	0%	50%	50%				
16 mm right	0%	18%	73%		0%	24%	76%
16 mm left	0%	30%	70%				
18 mm right	0%	8%	93%		0%	11%	89%
18 mm left	0%	15%	85%				
20 mm right	0%	0%	100%		0%	4%	96%
20 mm left	0%	8%	93%				

Male ratings for the female faces

	Direction of deviation accounted for				**Direction of deviation unaccounted for**		
	A	B	C		A	B	C
Average face	92%	8%	0%				
2mm right	83%	16%	1%		90%	10%	1%
2mm left	96%	4%	0%				
4 mm right	47%	47%	6%		71%	26%	3%
4 mm left	95%	5%	0%				
6 mm right	57%	42%	1%		62%	36%	1%
6 mm left	68%	31%	1%				
8 mm right	22%	68%	10%		26%	65%	9%
8 mm left	30%	62%	8%				
10 mm right	13%	70%	17%		10%	62%	28%
10 mm left	6%	55%	39%				
12 mm right	8%	49%	43%		5%	33%	62%
12 mm left	1%	17%	82%				
14 mm right	4%	19%	78%		4%	13%	83%
14 mm left	4%	8%	88%				
16 mm right	4%	16%	81%		5%	26%	70%
16 mm left	5%	36%	60%				
18 mm right	4%	23%	73%		2%	17%	81%
18 mm left	0%	10%	90%				
20 mm right	1%	10%	90%		2%	10%	88%
20 mm left	3%	12%	86%				

Male rating for the male faces

	Direction of deviation accounted for				Direction of deviation unaccounted for		
	A	B	C		A	B	C
Average face	94%	5%	1%				
2mm right	87%	13%	0%		81%	19%	1%
2mm left	74%	25%	1%				
4 mm right	52%	47%	1%		51%	47%	3%
4 mm left	49%	47%	4%				
6 mm right	35%	61%	4%		32%	62%	5%
6 mm left	30%	64%	6%				
8 mm right	10%	69%	21%		21%	66%	14%
8 mm left	31%	63%	6%				
10 mm right	6%	61%	32%		8%	54%	34%
10 mm left	9%	55%	36%				
12 mm right	3%	49%	48%		5%	54%	41%
12 mm left	8%	58%	34%				
14 mm right	1%	19%	79%		3%	36%	60%
14 mm left	5%	53%	42%				
16 mm right	0%	30%	70%		0%	35%	65%
16 mm left	0%	40%	60%				
18 mm right	3%	12%	86%		2%	16%	82%
18 mm left	1%	21%	78%				
20 mm right	1%	8%	91%		1%	17%	82%
20 mm left	0%	26%	74%				

Female ratings for female faces

	Direction of deviation accounted for				Direction of deviation unaccounted for		
	A	B	C		A	B	C
Average face	89%	10%	1%				
2mm right	86%	13%	1%		91%	8%	1%
2mm left	96%	3%	1%				
4 mm right	62%	36%	2%		76%	23%	2%
4 mm left	89%	11%	0%				
6 mm right	62%	35%	3%		54%	42%	3%
6 mm left	46%	52%	3%				
8 mm right	42%	53%	5%		33%	55%	11%
8 mm left	24%	58%	18%				
10 mm right	30%	57%	13%		18%	55%	27%
10 mm left	5%	54%	40%				
12 mm right	13%	50%	37%		9%	35%	56%
12 mm left	5%	20%	76%				
14 mm right	4%	25%	71%		4%	17%	79%
14 mm left	5%	8%	87%				
16 mm right	3%	28%	69%		4%	28%	68%
16 mm left	5%	28%	67%				
18 mm right	9%	27%	64%		5%	16%	79%
18 mm left	1%	5%	95%				
20 mm right	2%	8%	91%		2%	8%	90%
20 mm left	2%	9%	89%				

Female ratings for male faces

	Direction of deviation accounted for				Direction of deviation unaccounted for		
	A	B	C		A	B	C
Average face	97%	3%	0%				
2mm right	94%	6%	0%		86%	13%	0.3%
2mm left	79%	20%	1%				
4 mm right	67%	33%	0%		59%	39%	2%
4 mm left	52%	45%	3%				
6 mm right	41%	72%	2%		36%	58%	6%
6 mm left	32%	58%	10%				
8 mm right	18%	73%	8%		22%	70%	8%
8 mm left	27%	66%	8%				
10 mm right	9%	75%	16%		8%	64%	28%
10 mm left	7%	54%	40%				
12 mm right	14%	49%	37%		10%	54%	36%
12 mm left	6%	59%	35%				
14 mm right	2%	29%	69%		5%	36%	59%
14 mm left	8%	43%	48%				
16 mm right	2%	36%	62%		2%	35%	63%
16 mm left	2%	33%	64%				
18 mm right	1%	13%	84%		3%	12%	85%
18 mm left	5%	11%	84%				
20 mm right	2%	10%	89%		3%	14%	84%
20 mm left	4%	17%	79%				