PAEDIATRIC FACIAL ANTHROPOMETRY APPLIED TO SPECTACLE FRAME DESIGN

ALICIA JANE THOMPSON

Doctor of Philosophy

ASTON UNIVERSITY

June 2021

Aston University

Paediatric Facial Anthropometry Applied to Spectacle Frame Design

Alicia Jane Thompson

Doctor of Philosophy

2021

This thesis describes measurements of paediatric facial parameters that specifically relate to the design of spectacle frames. In the current market, the majority of paediatric spectacle frames are scaled down versions of frames designed for adults which assumes that facial characteristics do not change with growth. This often results in an ineffective delivery of any refractive correction prescribed at a critical time in a child's development.

Three-dimensional stereophotogrammetry was employed to capture images in a rapid, non-invasive manner. Fifteen paediatric facial measurements associated with spectacle frame parameters were measured using custom software in a sample of 1334 children observing differences in gender, ethnicity and Down's syndrome.

Principal findings:

- The typically-developed White British children showed a definite emergence of the nasal bearing surface at a young age from which all parameters surrounding the nose narrowed with age.
- A distinct nasal bearing surface emergence was not observed in either Chinese children or children with Down's syndrome therefore requiring larger spectacle parameters in terms of frontal and splay angles, distance between rim and apical radius.
- Chinese children and children with Down's syndrome have a lower crest height and a shorter front to bend compared to typically-developed White British children and differences were detected in head width and pupillary distance between these two groups.
- Children with Down's syndrome are not wholly smaller or larger than typically-developed White British children but need their requirements to be incorporated into frame design to accommodate differences in facial development.

Percentiles were calculated each of the largest study groups. This data combined with the model of facial growth and inter-relationships between facial measurements presented in this thesis will inform spectacle frame manufacturers on appropriate parameters and design features required to produce a more encompassing range of paediatric frames, resulting in a more stable and comfortable fit.

Key words:

paediatric spectacle dispensing, facial anthropometry, stereophotogrammetry, Down's syndrome, spectacle frame manufacture

For Darren, Charlotte and Abigail

Acknowledgements

I wish to thank my supervisor Dr Robert Cubbidge for all of his support and guidance.

I am also grateful to my employer Sir Anthony Garrett (Association of British Dispensing Opticians) for supporting me along with my colleagues Mrs Miranda Richardson and Mr Mark Chandler, the support team at 3dMD™ for technological guidance and Dr Mark Dunne for his statistical advice.

Thank you to all the schools, clinics, charitable organisations and support groups who helped me recruit participants.

Finally, I am indebted to all the children and their families for taking part in this study.

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS	
FA	Frontal angle
SA	Splay angle
HW	Head width
TW	Temple width
DBR10	Distance between rims at 10mm below crest
DBR15	Distance between rims at 15mm below crest
AR	Apical radius
CH	Crest height
DBPC	Distance between pad centres
FTB	Front to bend
PD	Pupillary distance
TD	Typically-developed
DS	Down's syndrome
WB	White British

All facial images throughout this thesis have been included will full patient or parental/carer consent that they will be published in the public domain.

Chapter 1 Introduction to facial anthropometry and paediatric spectacle dispensing.

The main features of a spectacle frame are position, stability, comfort, safety and cosmetic appeal. It is vital to position the refractive correction, or intervention, in the correct place in front of the eye in order to maximise the vision and field of view for the wearer. This position also needs to be stable and comfortable to the wearer; the focal power of the lenses received at the eye will change if the frame constantly moves and multifocal lens wear can become intolerable if the correct zone of the lens cannot be easily achieved with slight head movement. Aside from being an annoyance to the wearer and intolerant of advancement in lens design, it can also present a safety issue for patients in their daily life, such as judging steps, stairs and driving manoeuvres. Spectacle frames become uncomfortable if they constantly move, or are moved by the wearer, causing pressure sores on the bridge of the nose and around the ear point.

In children, the visual pathway is deemed somewhat 'plastic' up until the age of 7-8 years (Stidwill, 1990), this means there is a window of opportunity to influence visual development and therefore it is vital that any refractive correction or intervention is delivered effectively during this critical period (Harvey et al., 2007). A common occurrence is for the child to be looking over the top of their spectacle frame, therefore receiving no visual correction or intervention during a period of such rapid development in education, social skills and visual development. The fit of the frame will affect all these factors and yet it appears that recent facial anthropometrical data to inform parameters specifically for spectacle frame design for the entire population is somewhat scarce.

Finally, the frame needs to be cosmetically appealing to the wearer to ensure compliance, and in the case of children, also desirable to the parents/carers and invariably gaining peer approval.

1.1 Current design of spectacle frames

A set of different sizes for each individual frame design is not conducive to the increasingly competitive market and the rapid turnaround of fashionable designs; therefore, the majority of spectacle frames are now produced in a single-sized option. Frames can be adjusted and manipulated however there are limitations to the extent of adjustments or alterations and they vary immensely by frame design and material. In metal frames (figure 1.1a), there is some degree of alteration possible with nose pad arms allowing the overall bridge width to be slightly adjusted in terms of distance between the pad centres, and the angles of the pads to be somewhat manipulated in order to match both the frontal and splay angles of the nose and to ensure a stable frame position that will optimise the visual performance of the spectacle lenses. Metal sides can be physically shortened but only if the design of the side allows. For plastics frames (figure 1.1b), the regular or fixed-pad bridge design allows no possible height adjustments to be made to the vertical plane of the front, nor any angular adjustments to the frontal or splay aspects. Since continuous contact with the bridge is essential for an effective and comfortable fit, this must therefore be initially precise. Plastic sides generally cannot be physically shortened unless the joint is pinned (Obstfeld, 1997) as exposing the metal reinforcement core can cause discomfort and injury to the wearer.

Figure 1.1a. A typical metal frame with pads on arms.

Figure 1.1b. A typical plastics frame with a fixed pad bridge.

Considering the spectacle frame range available on the National Health Service (NHS) from 1948 to 1986, frames were widely available in a choice of different eye size aperture dimensions, bridge widths, bridge designs, side lengths and side designs in order to cater for the general population (Sasieni, 1962). This range may have been criticised for lack of fashionable design (Gooding, 2020) yet was able to accommodate differences in facial anthropometry, including those specific designs for children. These ranges featured multiple lens and bridge size availability, but the design features and proportions differed considerably to those designed for adults. For example, Saseini (1962) noted the changes in frame design required for the child’s relatively shallow bridge and suggested frame design recommendations such as a shallow lens depth, lower pad tops and wide angles of the pads.

Presently, the parameters for most children’s frames are set by scaling down the adult design templates (Wang et al., 2005, Sasieni, 1975). The range of fitting sizes in both adult and children’s frames has been dramatically curtailed in order to increase manufacturing efficiencies in a rapidly changing market, driven by fashion, cost, and convenience. Frame and facial measurement terminology will be explained further in section 1.42, but by measuring and comparing two plastics frames below, it can be seen that frame ‘A’, marketed as a child’s character frame, and frame ‘B’ aimed at the adult female market are reasonably similar in design.

Figure 1.1c. Child frame 'A' compared to adult frame 'B'.

	Frame A	Frame B	Scaling factor
Eyesize (mm) width x depth	45 x 33	51 x 37	1.13 x 1.12
Crest height (mm)	6	6	1
Splay angles (degrees)	25	30	1.2
Frontal angles (degrees)	20	25	1.25
Length to bend (mm)	90	95	1.05
DBR 10/15 (mm)	15 /19	16 /23	1.06/1.21
Apical radius (mm)	6	6	1
Head width (mm)	110	120	1.09

Table 1.1d. Comparison of frame measurements showing scaling factor which is the ratio of the representation of the two parameters.

In table 1.1d, the scaling factor lies between 1:1 and 1:1.25. This comparison shows either the same measurements in terms of crest height and apical radius or 'A' is proportionately smaller than 'B'. The crest height determines the vertical position of the bearing surface of the nose and the apical radius determines the radius of the circle which represents the profile of the bearing surface in the frontal plane. Thus, in this example, the child's frame 'A' (figure 1.1c) suggests that a child has the same nasal profile and position of the bridge of the nose in comparison to an adult.

<u>Figure 1.1e.</u> Comparison of nasal profile and facial features of a father and son.

Comparing the two images above (figure 1.1e) the bearing surface of the young boy is very low compared to the top of the lower lid. The child's father in the right image shows a bearing surface that is markedly above the top of the lower lid. In terms of frame fit, this difference in crest height results in the common sight of children peering over the top rim of the frame as the narrow bridge of the frame naturally slides, due to no underlying support, to find anchorage where the nose widens and protrudes at the nasal tip. In addition, a young child will spend most of their time looking upwards in our adult-centred world, and this average 20-degree elevation (Obstfeld, 1997) exaggerates the problem of looking above the top rim of the spectacles.

The rationale for producing paediatric spectacle frames in scaled-down adult parameters is potentially due to three reasons: manufacturing cost, perceived market demand and lack of facial anthropometrical data. There is undoubtedly a manufacturing cost saving by producing a scalable product in one size, rather than several options of moulds being cast for one model. Also, it may be reasonable to assume that older children and parental influence over younger children demand the same fashionable designs as are available to the adult market, evidenced in practitioner responses to a questionnaire on paediatric dispensing (section 3.54). It could also be argued that a lack of anthropometrical data relating to spectacle frames, especially in young children, has compounded the current situation as manufacturers have such limited data to work with in this field. At the outset of this study a small number of companies manufacturing paediatric frames which do not resemble that of an adult design were contacted to investigate production of prototypes. These companies were not aware of any available anthropometric data and as such personal communications revealed their production is based on either a combination of design adjustments made due to feedback from the sector and adjusting proposed models/prototypes based on physical appraisal with a sample of local children (Giovanninni, 2014, Priest, 2013).

In order to achieve improvement in fitting parameters, it is necessary to appreciate why a young child's face has differing parameters from a small adult's face and hence why these scaled-down frames are rarely acceptable in terms of an effective fit. Thus, the formation of the facial features from birth needs to be considered, especially cranial dimensions which impact on the head width, temple width, pupillary distance as well as the parameters surrounding the nasal bridge area where a typical spectacle frame would rest.

1.2 Facial anatomy

The skull is formed of eight bones that form the neurocranium; the frontal, temporal (x2), parietal (x 2) sphenoid, occipital and ethmoid (figure 1.2a). The other 14 bones are deemed to be facial bones (figure 1.2b) and consist of the pairs of nasal, lacrimal, palatine, zygomatic, inferior nasal concha, maxilla and the singular bones; vomer and mandible.

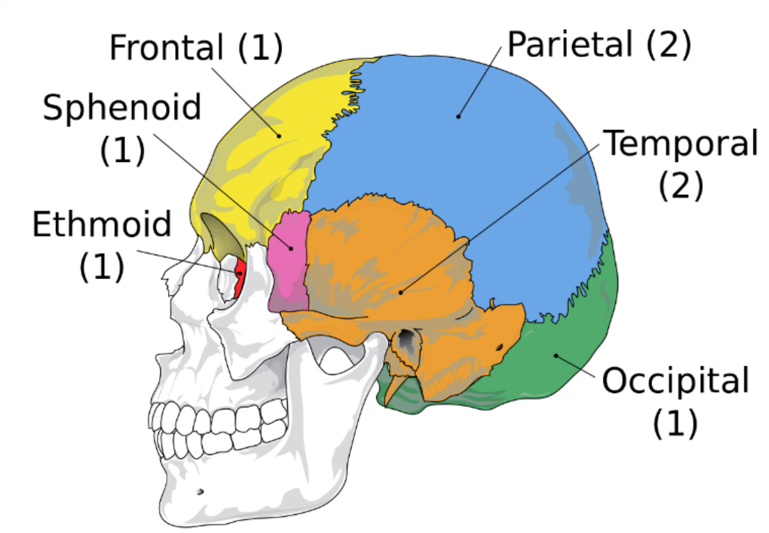


Figure 1.2a. Diagram to show the position of the eight cranial bones (Wikimedia Commons 2012).

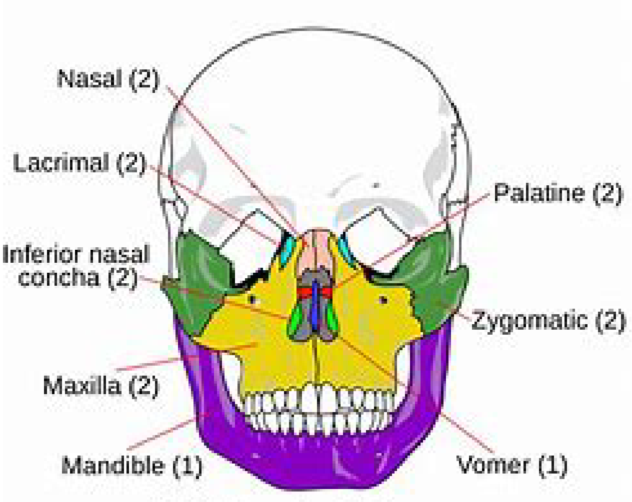


Figure 1.2b. Diagram to show the position of the fourteen facial bones (Wikimedia Commons 2015).

The face itself can be divided into three general areas, the upper face is the top third down to the pupillary line, the mid face is regarded from the pupillary line down to the mouth opening (rima oris) and the lower face largely comprises of the mandible. These divisions can be attributed to the five prominences that form the face; the singular frontonasal process surrounds the forebrain and forms the forehead and nose of the upper face, the paired maxillary processes forms the midface comprising of the maxilla, the lateral part of the face and the zygomatic bones, and the paired mandibular process which forms the mandible.

1.21 Cranial development

The first areas of bone ossification become apparent in the embryo at 8-12 weeks post conception, including the nasal and lacrimal bones in the membranes covering the developing nasal structure.

The upper and midface boundaries contain three of the sensory organs, the eye, the nasal cavity and the external ear which naturally drive facial development and the pattern that follows; a similar pattern to the teeth, tongue and jaw muscles which influence the lower face and lower boundary midface development.

The early development of the cranium in relation to the rest of the body and limbs results in a disproportionate size of the head in relation to the body. This is evident in the embryonic stage of development (figure 1.21a), in which the head is reported to be 50% of the total body length at 5-12 weeks post conception, reducing to 25% at birth and between 6-12% in adulthood (Du Raan, 2017, Proffit et al., 2014, Sperber et al., 2010) with the face remaining proportionally small in comparison to the head (Proffit et al., 2014). The upper face shows the most rapid initial development due to the associated cranial development and therefore reaches maturity first, ceasing significant growth when the child reaches 12 years old (Sperber et al., 2010).

The growth of the eyes also contributes to the height of the skull, and due to the huge growth of the frontal and temporal lobe of the brain, a shift occurs from their initial lateral position to a more medial position. The eyes and orbital growth are also attributed to the widening of the face as they compete for space with the developing brain. This results in the eyes appearing relatively large as a feature of the face in young children, having achieved half their overall orbital growth by the age of 2 years and completed growth at approximately 7 years of age (Sperber et al., 2010).

This head and face proportional change are also highlighted in the field of allometry (the study of relationships between body size and shape) where it is reported the facial width of a baby is also twice that of an adult when compared to their respective heights, and similarly, decreases in proportion with age (Sperber et al., 2010, Kolar and Salter, 1997).

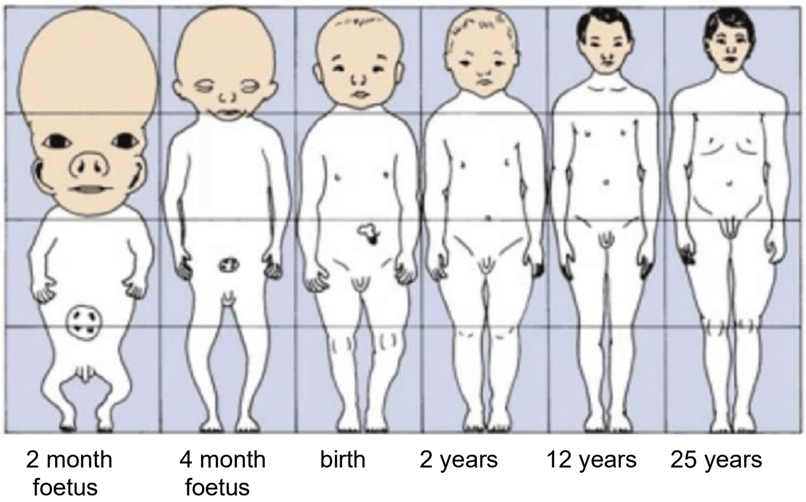


Figure 1.21a. Diagrammatic representation of facial growth in relation to total body size.

Image redrawn from (Robbins, 1928).

1.22 Facial development

This rapid growth of the foetal head impacts on the facial development which also does not develop and form at an equal rate (Sperber et al., 2010, Farkas and Munro, 1987).The early development of the frontal lobes of the brain results in the top third of the face growing more rapidly in relation to the other two thirds, and the competition for space with the eyes results in the orbits also appearing large in proportion to the face (figure 1.22a), the central facial region (area between the eyes) remains relatively constant whilst the lateral region expands rapidly broadening the head and reducing the inter-ocular distance, whilst the eyes migrate from a lateral to more medial position, the largest movement occurring at around 5-9 weeks pc (Sperber et al., 2010). In contrast, the lower two thirds are much slower to develop and continue to grow into early adulthood reaching maturity when the eruption of the third molars occur around age 18-25 years (Sperber et al. 2010).

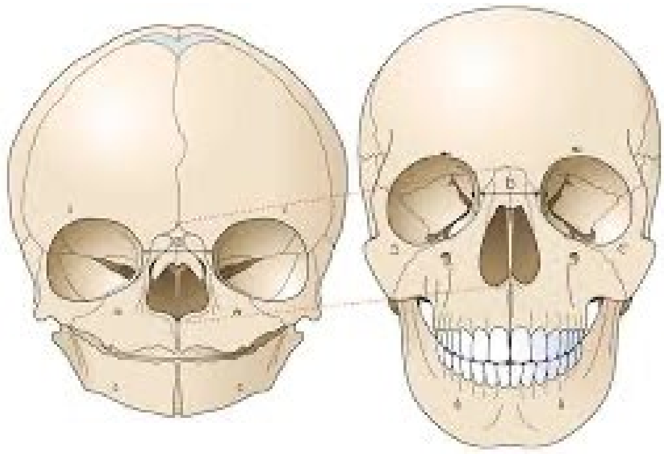


Figure 1.22a. Craniofacial development at birth compared to an adult skull (myhealthclass.net, 2013).

The complex midface grows in a general anterior and inferior direction (nasal bridge and medial orbital rim), opposed by the lateral orbital rim in a lateral and posterior direction. Premkumar (2011) describes the relatively flat profile and lack of depth to the face at birth with the nasal floor lying initially in line with the lower orbital rim (figure 1.22). After the age of 4 years, facial growth is still not proportional yet changes in areas of activity with the cranial area now developing the least, the mandible developing the most and the midface following intermediate patterns, giving the face more proportion and prominence following the rapid early cranial development.

The mechanics of facial growth is a complex series of actions which does not just depend on growth as an enlarging factor; structures such as the orbits physically move their location as well as remodelling and enlarging. This is explained by the mechanics of 'drift' and 'displacement' first described by Enlow (1966) where primary displacement is due to the whole bone growth and remodelling takes place to adjust shape, dimension and proportion (Du Raan, 2017, Premkumar, 2011) whereas 'drift' is a growth movement process of simultaneous depositing and resorption of opposing bone surfaces.

1.23 Nasal development

The glabella (see figure 1.23a) receives bone deposits resulting in both the elevation and emergence of the nasal bridge. Frontal, nasal bones and the nasal portion of maxilla also receive deposits of bone that carry this region forwards and upwards in growth (Enlow, 1966), resulting in the tip of the nasal bone progressing further forward compared to the nasal spine. The nasal bone consists of a pair of symmetrical bones which form the bridge of the nose and connect on the inferior border with the nasal cartilage to form the superior margin of the nasal aperture. Growth of the nasal bone is reported to be complete around the age of 10 years old, after which the resultant nasal growth is due to the cartilage and soft tissues (Proffit et al., 2014).

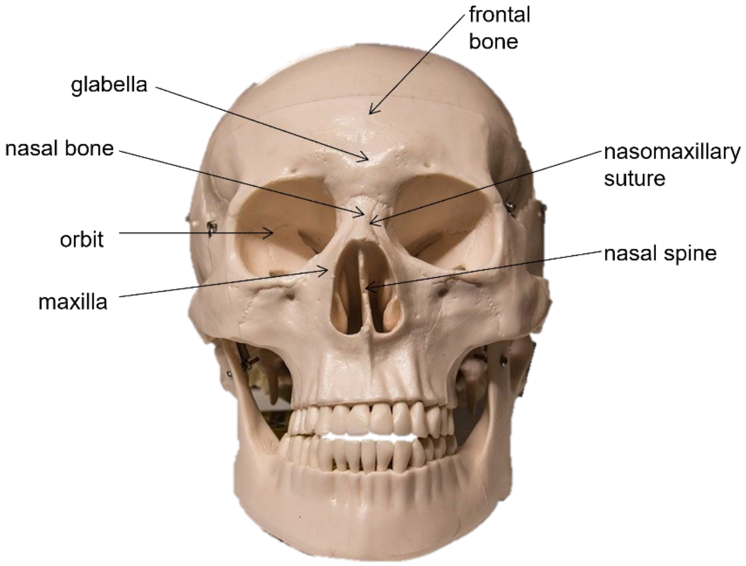


Figure 1.23a. Internal nasal anatomy (adapted from Pixabay, 2015).

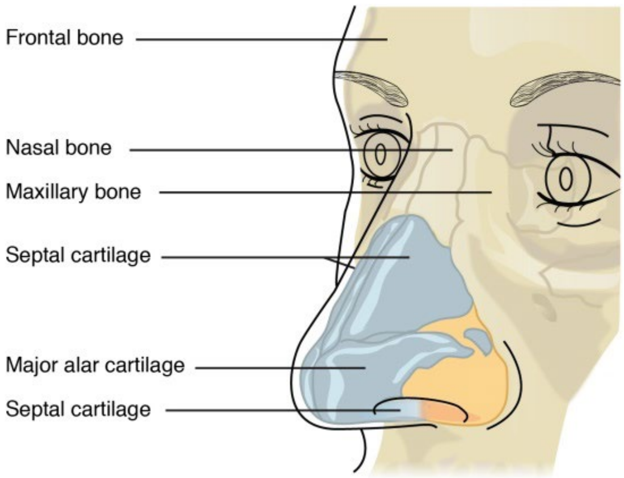


Figure 1.23b. External nasal anatomy (Wikimedia Commons contributors, 2017)

The soft tissue covering the complex cartilaginous structure gives rise to the main shape of the nose which is highly individual, influenced by gender (Premkumar, 2011), ethnicity and is often found to be asymmetrical (Spooner 1957).

The trigger to the facial anterior-inferior shift is reported by Premkumar (2011) as arising as a result of the growth of the nasal septal cartilage. The septal cartilage of the nose forms 8-12 weeks post conception and extends its length seven-fold during development in the womb (Sperber et al., 2010). This spurt of growth moves the facial growth in an anterior inferior direction, the most significant shift seen before the age of 4 years. This growth force has the trigger effect of causing the anterior posterior growth of the nasomaxillary suture which then forms the bridge of the nose.

1.3 Craniofacial growth studies and reference landmarks

Craniofacial anthropometric studies have been carried out for more than a century to determine information on growth and form for many clinical, diagnostic and forensic fields. Hrdlicka (1920) described basic facial length and width measurements, along with the length of the nose and the width across the nostrils. Methods of measuring include the sliding and spreading callipers and a measuring tape for circumferences. This direct method of anthropometry is still favoured in certain studies on either skulls (Rossi et al., 2009) or in living subjects, having the ability to palpate the soft tissue and therefore identify the relevant underlying bony structure for landmark location (Zankl et al., 2002). The reported disadvantage to direct anthropometry is depression of the soft tissue when using callipers leading to inaccurate results (Sforza et al., 2011).

In many growth studies, traced cephalograms (cephalometric radiographic images) are traditional yet still popular (Mellion et al., 2013, Arshad, 2013, Enlow, 1966) as these images (figure 1.3a) can easily be traced onto acetate sheets and overlaid; matching exact defined landmarks from successive images and hence reporting on growth.

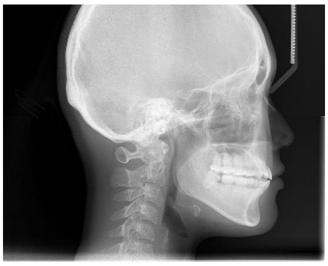


Figure 1.3a. Lateral cephalometric radiograph (Wikimedia Commons contributors, 2014)

A disadvantage to this method is the lack of three-dimensional information and the exposure to radiation; however, in the field of orthodontics, many growth studies utilise existing or pre-treatment patient records (Arshad, 2013, Mellion et al., 2013). Three-dimensional image studies are becoming more popular as accuracy in landmark placing is being reported and the lack of radiation exposure a noted benefit. These can be facial landmarks made onto the skin and measured by an electromagnetic digitiser (Sforza et al., 2011), stereophotogrammetry (Ferrario et al., 1999, Ferrario et al., 1997) or direct stereophotogrammetry with no pre-marking of the face (Ritschl et al., 2018, Bugaighis et al., 2013) resulting in a non-invasive experience, which is ideal for young children.

Anatomical growth studies of the nasal area utilise landmarks such as the nasion, pronasale (tip), subnasale and position of the alae in order to calculate nasal bridge length or dorsum length, height, width, tip protrusion and columella (figure 1.3b).

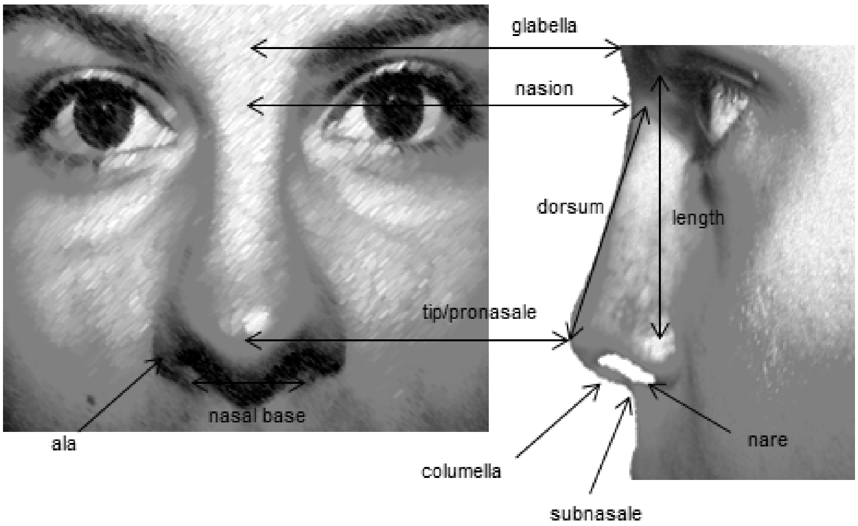


Figure 1.3b. Common landmarks and anthropometrical nasal measurements (image authors own)

glabella (landmark)	most prominent point in the median sagittal plane between the supraorbital ridges and just above the nasion
nasion (landmark)	midpoint of the nasofrontal suture
pronasale (landmark)	most protruded point of the nasal tip
subnasale (landmark)	point under the nose between the lower border of the nasal septum (the partition that divides the nostrils) and the cutaneous portion of the upper lip, in the midline
columella (structure)	flesh that links the nasal tip to the subnasale between the nares
nare (structure)	the nostril
ala (landmark)	lower most lateral surface of external nose surrounding the nares
nasal height (measurement)	nasion to subnasale
nasal bridge length (measurement) along nasal ridge	nasion to pronasale
nasal base (measurement)	bi-alare lateral width

Table 1.3c. Table to define landmarks, structures and measurements depicted in figure 1.3b.

Premkumar (2011) suggested that nasal soft tissue growth is independent to the growth of the underlying hard tissue, although this contradicts the work of Robison et al. (1986) who reported significant correlations between skeletal and soft tissue forms. In support of the independent growth theory is the work of Anderson et al. (2008) who reported the angle of the dorsum does not follow the profile of the nasal bone, and also a variation in soft tissue thickness along the ridge of 9mm between individuals. This is further evidenced by the variation in nasal profiles reported by Arshad (2013) who considered the complexities of nasal profiles and measured nasal bone angles and the convexity of the dorsum.

A study on new-born babies by Ritschl et al. (2018) using three-dimensional images captured each month for 6 months describes the growth of the nasal and orbital areas in early life. The nasal length and height showed an almost linear growth with over 27% and over 30% respectively after 150 days; similarly inter-canthal distances were showing a similar pattern with 12.8% growth at the same time point.

Drawing on the complexities of the rapid upper and intermediate midface growth, it is reasonable to conclude that the facial features of a growing child will therefore not be proportionate to that of a small adult as the face and underlying structure is not only still developing until early adulthood, but developing at different rates in the upper and midface regions which relate directly to spectacle frame wear, such as, the head and temple width dimensions, the ear points and the nasal bridge prominence and position.

1.31 Gender differences

In studies on older children, growth spurts affecting facial features are more commonly reported at differing ages up to skeletal maturity, these all have the common theme of a marked gender difference in timings of growth periods.

The sexual dimorphism is apparent on facial parameters due to the varying times of onset of the growth spurt, reported to be an average of 9.8 years (SD 1.19) in girls reaching its peak at 11.5 years (SD 1.16), whereas with boys the onset is apparent after the peak of the girls, at 12.0 years (SD 1.08), peaking at an average of 14.4 (SD 1.14) years (Mellion et al., 2013). This agrees with the findings of Sforza et al. (2011) Mori et al. (2005) and Ferrario et al. (1999) where nasal growth in girls is larger and earlier compared to boys who have generally larger parameters overall and marked growth reported for a longer period of time, although Zankl et al. (2002) and Premkumar (2011) reported the male peak growth age to be later, around 18.0 years of age. In a systematic review of the literature, van der Heijden et al. (2008) concluded that nasal maturity can be found in 98% of white adolescent girls at 15.8 years and 16.9 years for boys when exploring nasal growth patterns to indicate when nasal surgery could be safely performed.

In a study of 859 subjects incorporating ages 4-73 years, Sforza et al. (2011) recorded digitised positions of facial landmarks physically marked on the skin and found that nasal height was the parameter showing fastest growth and doubling in length from birth to adolescence, thus concurring with earlier growth studies that nasal parameters change at differing rates in children and adolescents. Despite maturity being reached in the mid-teenage years, the nasal structure continues to change throughout life, concurring with the findings of Zankl et al. (2002).

It is clear from the literature that there are age-related peaks and gender differences in nasal growth; however, the data are somewhat limited to parameters that are not associated directly with spectacle wear and very few studies consider growth from birth. However, it would be reasonable to assume that the measured growth reported will impact on the angles and linear dimensions at the bearing surface of the crest. Where linear facial width was measured by Bugaighis et al. (2013) who reported a difference between genders in the form of a larger binocular facial width and endocanthion nasal width in male subjects between 8 and 12 years of age, these findings concur with Agbolade et al. (2020) who studied 292 three-dimensional facial images of a wide-ranging age sample of subjects.

These findings can be correlated to spectacle frame design with associated linear measurements such as temple width, head width, horizontal centre distance and distance between pad centres (see section 1.42) indicating the need for considerable design differences between genders and an overall appreciation of when facial maturity may mean that adult frame parameters may indeed prove to be a suitable fit.

It may be useful to appreciate the anthropometric term of '*nasal bridge length*' (figure 1.3b) which is often interchanged with '*dorsum length*' or '*nasal ridge length'* in some literature. This is a linear measurement of the length of the nose from the nasion to the pronasale, or tip of the nose (figure 1.3b), not to be confused with the more common definition of the '*bridge*' where a spectacle frame may rest across the top of the nose in the transverse plane. The relevant definition of this landmark to this field is the '*crest'* or the '*bearing surface*' and this is potentially one of the most important considerations in frame design for young children as it positions the frame vertically and potentially carries the majority of the weight of spectacle frames.

1.4 Measuring frames and faces

To fully appreciate how a frame will fit on a patient's face, it is deemed a necessary competency for registered Dispensing Opticians (General Optical Council, 2011) to demonstrate the ability to measure any frame or mount as defined by British Standards (British Standards Institute, 2019, British Standards Institute, 1991) and take a full complement of facial measurements from any patient.

1.41 Instrumentation

There are several designs of spectacle frame rulers in production which are capable of measuring linear and angular parameters on a frame or mount of any type.

Facial measurements are not defined by a standard but are defined by the manufacturer of a facial gauge, Paul Fairbanks FSMC (Sasieni, 1975). This rule is still used in practice today for many measurements including bespoke handmade frame production and is deemed essential practice equipment in professional examinations for Dispensing Opticians.

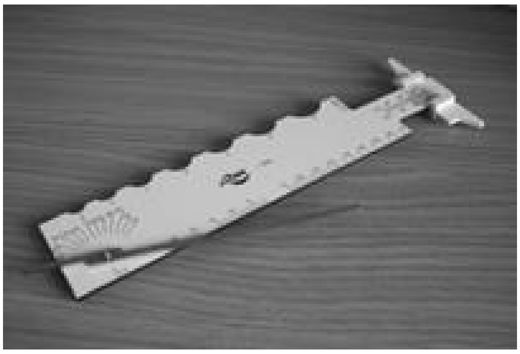


Figure 1.41a. Fairbanks facial gauge.

Figure 1.41b. Head and temple width caliper.

In order to fully understand the requirements of a frame for a child, it is necessary to illustrate the *frame measurement* alongside the corresponding *facial measurement*, as well as the rationale behind the importance of each measurement.

1.42 The relationship between spectacle frame parameters and facial measurements

Current practice in dispensing of frames is…. frame manufacturers do not necessarily consider the relationship between produced frame parameters and an equivalent facial measurement (Giovanninni, 2014, Priest, 2013). Frame manufacturers often specify the width and depth of an eye size (referred to as A and B measurement), the minimum distance between lenses and the total side length. These measurements provide a guide on whether a frame is likely to fit a patient's anatomical characteristics in terms of overall width but are not measurements of the patient's actual facial anatomy. As a consequence, this leads to confusion as the general public perceive the numbers printed on the frame relate to 'their size' and actively seek out frames to purchase with the same numbers.

There is a direct correlation between the frame and facial measurements used in dispensing practice. Thus, the precise facial information gained in this thesis will have a direct influence on frame manufacture.

All quoted, italicised text in this section are definitions and terminology from the following British Standards:

BS EN ISO 13666:2019 *Ophthalmic Optics. Spectacle lenses. Vocabulary*

BS 3521 Part 1:1991 *Terms relating to ophthalmic lenses and spectacle frames. Glossary of terms relating to ophthalmic lenses.*

BS 3521 Part 2:1991 *Terms relating to ophthalmic lenses and spectacle frames. Glossary of terms relating to ophthalmic lenses.*

It should be noted that most facial measurements are not defined in British Standards and therefore have been interpreted from their frame equivalent for definition.

1.42a Interpupillary distance and boxed centre

Interpupillary distance (IPD) is defined as the *‘distance between the centres of the pupils when the eyes are in the primary position’*. The *‘boxed centre’* is the *‘intersection of the horizontal centreline and the vertical centreline of the rectangular box which circumscribes the lens shape’*.

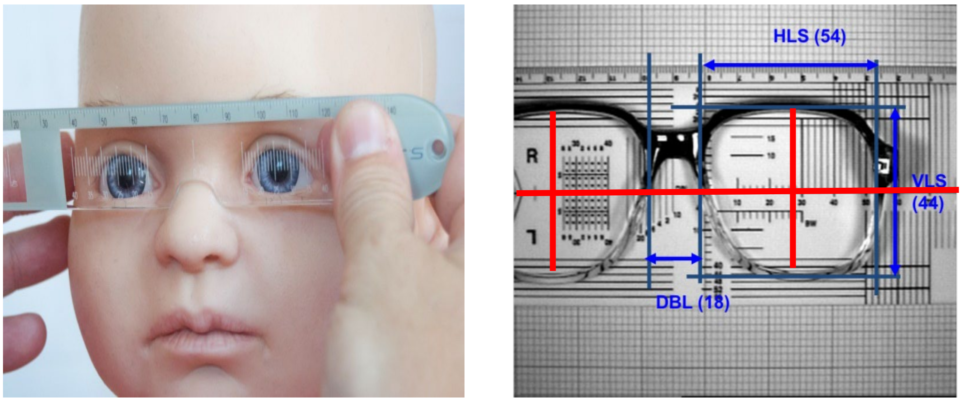


Figure 1.42a. Pupillary distance and horizontal centre distance of the frame.

The boxed centre distance is equal to adding the horizontal lens size (HLS) and the distance between lenses (DBL – the *‘distance between the nearest points of the apices of the two lenses’*).

The objective of frame fitting is to maximise the performance of the lenses for the patient by placing the optical centres of the lenses directly in front of the pupil centres, which ideally sit at the geometric (boxed) centres of the frame. If the optical centres need to be decentred, i.e. the lens is bodily moved in order to match the pupil centres; this can cause excessive lens thickness at the nasal edge for positive power lenses, or at the temporal edge for negative powered lenses. This unnecessary thickness may have a detrimental impact on fitting as thickness at the nasal edge could then make contact with the patient’s nose and/or cheek or can restrict the nose pads from being able to be splayed to match facial anatomy. Thickness at the temporal edge can restrict side closure, increase the risk of impact damage to the face as well as being cosmetically unacceptable.

On measuring the IPD, the observer should be aware of any strabismus, ensure the eye is looking in the primary direction, i.e. the ‘*direction of the line of sight, usually taken to be the horizontal, to an object at an infinite distance measured with habitual head and body posture when looking straight ahead in unaided vision’*, and take monocular pupillary distance if possible as these are more accurate due to most patients not being symmetrical if bisected nasally in the frontal plane.

1.42b Crest height

Crest height relating to a frame front is defined as *'vertical distance from the centre line of the frame to the midpoint of the lower edge of the bridge*'. This translates to the face as a vertical measurement from the top of the lower lid to the bearing surface or crest of the nose, i.e. the point at which a spectacle frame will rest on the bridge of the nose.

Figure 1.42b. Crest height of the face and corresponding crest height of the frame.

This should not be confused with 'bridge height' which is measured to the bridge width line (taken to be 5mm below the HCL).

To expand further on the bearing surface of the nose, as described earlier in this chapter the nasion or the root of the nose is defined as the nasofrontal midpoint, i.e. the junction of the nasal and frontal bones (figures 1.3b, 1.3c). It can be appreciated that this can take various forms and can be continuous with the forehead or offset and parallel to the forehead.

The elevation that is referred to as the crest or bearing surface is formed by the nasal bones and is therefore where a spectacle frame will rest. In profile, the crest may take on various shapes and be described as straight, convex, concave or form a wave-like configuration (Obstfeld, 1997).

a) b) c) d)

Figure 1.42c. Diagrammatic representation of differing nasal profiles (image adapted from Obstfeld).

The crest height is vitally important as this will determine the vertical position of the frame. On taking this measurement, the observer must match the eye level of the subject in order to obtain accuracy.

Young children with an underdeveloped crest such as in figure b) above will find most frames will slide down the nose to find some form of anchorage and this results in the child looking over the top rim of the frame. To combat this, frames designed for young children should ideally have the crest positioned on, or below the HCL, creating an enlarged area above the bridge position to ensure that visual correction is achieved.

1.42d Apical radius

From the crest, or bearing surface of the bridge, it is now necessary to build up a picture of the sagittal profile of the nose. This begins with the arc of a circle that fits the bearing surface and corresponds to the underside of the bridge which, in the case of a regular bridge fit will contact evenly to spread the weight of the spectacles efficiently across the bearing surface.

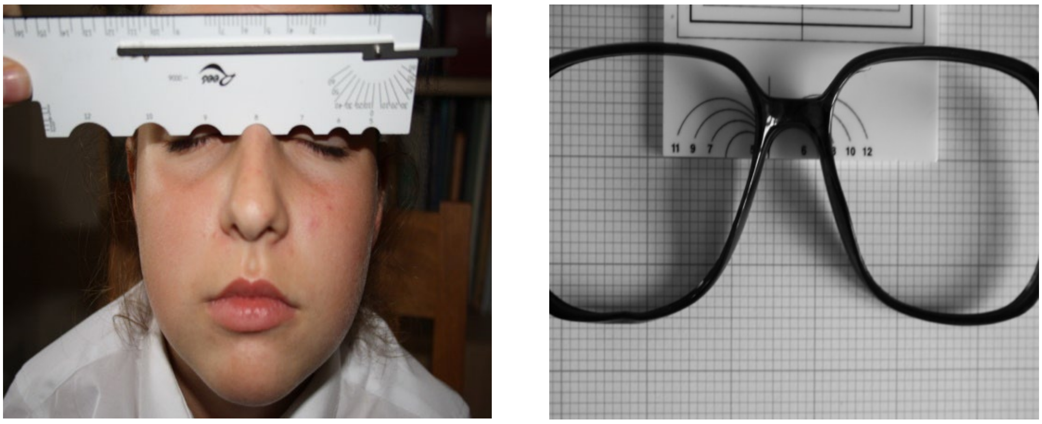


Figure 1.42d. Apical radius of the face and corresponding bridge apical radius measurement.

This measurement is defined as the *'radius of the arc forming the lower edge of the bridge viewed perpendicularly to the back plane of the front'.* On taking this facial measurement the contact needs to be regarded carefully, with emphasis on the corners of the arc to ensure they are not indenting the skin when the appropriate pantoscopic angle is applied.

1.42e Distance between rims at 10mm and 15mm below the crest

Moving down the nose in the sagittal plane, two width measurements are taken which will define the distance between rims of a regular bridge spectacle frame, designed to contact the entire sagittal nasal profile as opposed to the use of nose pads. The definition of this measurement is the *'horizontal distance between the nasal surfaces of the rims, measured at a stated level below the midpoint of the lower edge of the bridge'.*

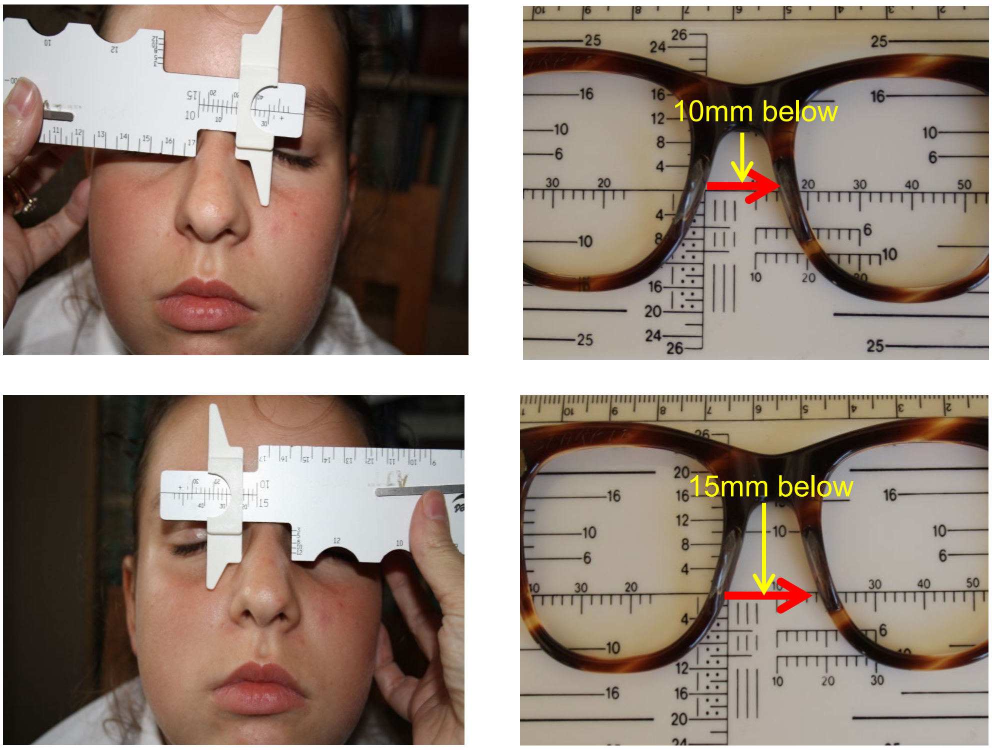


Figure 1.42e. Distance between rims at 10mm (upper images) and 15mm (lower images) below the crest.

The cursor of the facial rule must be placed correctly for each measurement to ensure accuracy, as shown in the images in figure 1.42e. The two vertices of the rule and cursor form a box which is either 10 or 15mm deep, there needs to be contact on the bearing surface at the top of the box and the two vertices must be just in contact and not indenting the skin on either side of the nose. It is also recommended to remove the facial rule away from the face in order to adjust the cursor rather than adjusting on the face which may cause injury.

The rule needs to be placed at an appropriate pantoscopic angle for the subject in order to mimic the vertical tilt of the frame front to ensure accuracy. In the case of young children, this should be zero, i.e. the frame front (and ruler) is vertical to the plane of the face as any inclination of the frame front would undoubtedly contact the cheeks. This angle will incrementally increase to approximately ten degrees for an adult to ensure the line of the frame front follows the profile of the developed face and allows ease of access to lower portions of the lens for the near vision correction.

1.42f Head and temple width

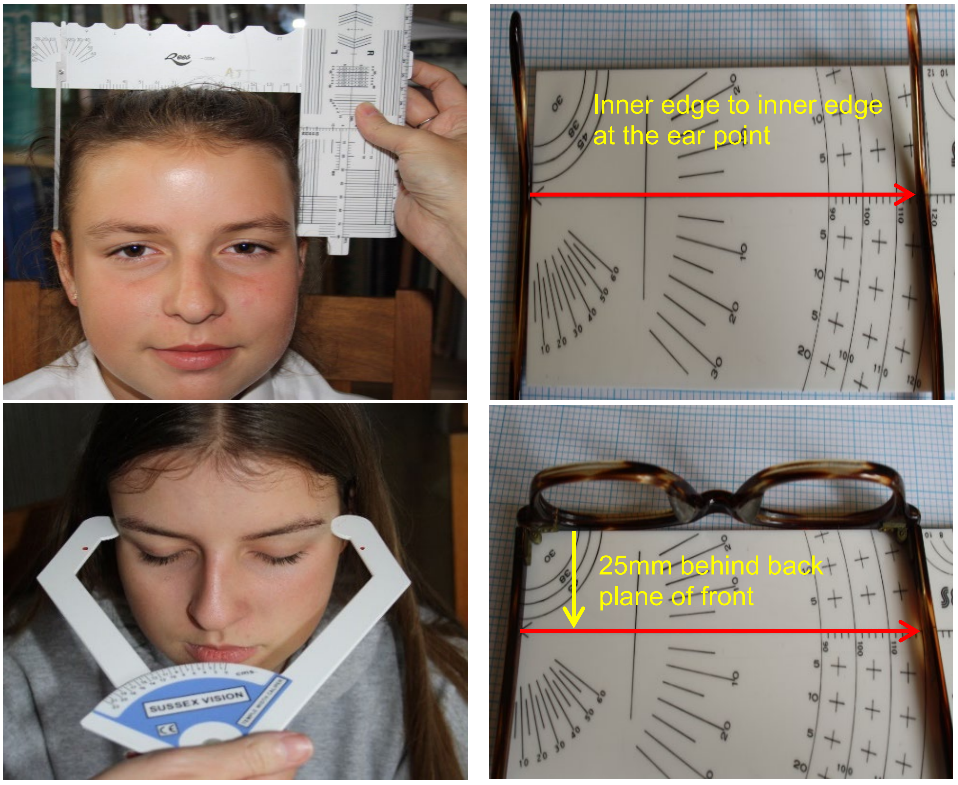


Figure 1.42f. Head and temple width.

The nose is the more obvious surface to bear weight of the spectacles, however, even with the most accurate fit of the bridge to take the full weight would be uncomfortable to any patient, let alone a child with developing features. The ideal scenario is that weight and subsequent mechanical force of the spectacles is distributed from the nose to the ears and the head can take a small amount of lateral pressure at the ear points to ensure a comfortable and stable fit.

The frame head width is defined as *'the distance between the sides at the ear points'* and the frame temple width is the *'distance between the sides 25mm behind the back plane of the front'.* The ear points are where the ear is joined to the head at the highest point, that is, where the bend of a frame side would need to start.

The simplest way to take these measurements is with the callipers as shown in the lower figure 1.42f, and these also feature a pair of red dots 25mm behind the end tips of the calliper to aid with placement for the temple width. A combination of a facial and frame ruler is also capable of taking a head width measurement, as shown in the upper image of figure 1.42f, although it is more difficult to ensure the box remains square during measurement. No pressure on the temple or ear point is required during measurement on the face, reducing the frame measurement by 10mm from the facial measurements gives an acceptable pressure on the head to balance the weight and force of the frame (Obstfeld, 1997).

1.42g Frontal angle

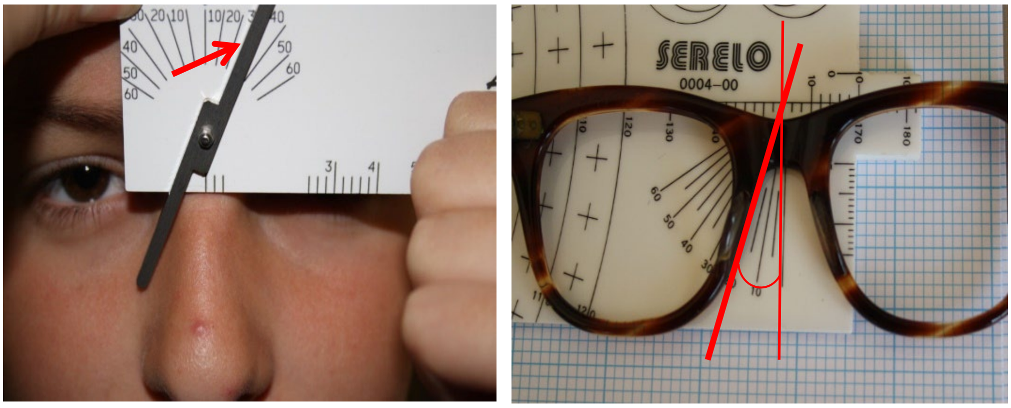


Figure 1.42g. Frontal angle.

This refers to the nose pad on a frame and is defined as the *'angle between the vertical and the line of intersection of the pad plane with the back plane of the front'.*

This gives the angular measurement in the vertical plane and the cursor of the facial rule needs to be placed in the plane of where the pad would sit, angling the rule at an appropriate pantoscopic angle. If the frontal angle of the frame is too wide, then all the weight of the frame will be on the bearing surface; likewise, if it is too narrow, the frame will sit higher on the face and the weight will be concentrated onto the side of the nose causing discomfort to the wearer.

1.42h Splay angle

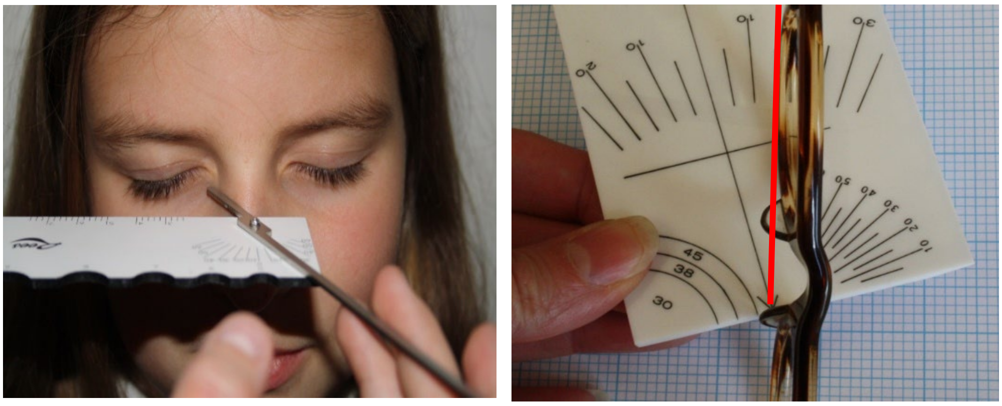


Figure 1.42h. Splay angle.

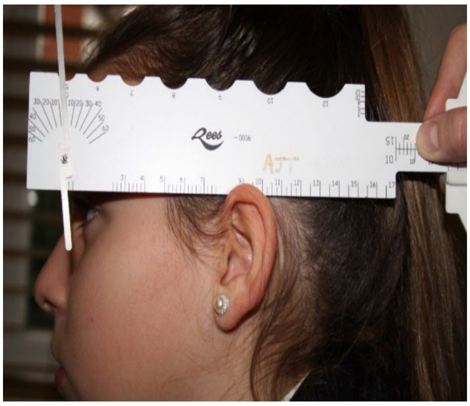
Splay angle is the *'angle between the pad plane and a normal to the back plane of the front'.* Taken in the transverse plane, again the cursor needs to be placed at the centre of where the nose pad would sit. The optimal fit of the nose pad consists of the weight spread evenly across the full surface of the pad, that is, the contact is constant with the side of the nose. Any variation from will result in pressure marks forming very quickly as the weight is concentrated on one edge of the pad if it is not correctly angled in both planes.

1.42i Front to bend

The 'ear point' on the head is where the bend of the side needs to start on the top of the ear/head attachment point, as this is a gentle bend rather than an exact point, it is defined as *'the midpoint of the arc of contact between the bend of the side and the circle which fits it'.*

The front to bend (figure 1.42i(left)) is defined as 'the *'distance between the lug point and the ear point'*, with the 'lug point' being the *'point on the back surface of the lug where it begins its backward sweep…'*

Each frame side will have a 'dowel point', that is, the *'centre of the bottom of the dowel hole'*, where the side is attached to the front, usually by a small screw. The 'length to bend' of a frame (figure 1.42i(right)) is defined by the *'distance between the dowel point and the ear point'.* As the face does not have a dowel point equivalent and all frames vary in the position of their dowel points in relation to the frame front, in practice it is common for the length to bend measurement to be taken with the selected frame on the face.



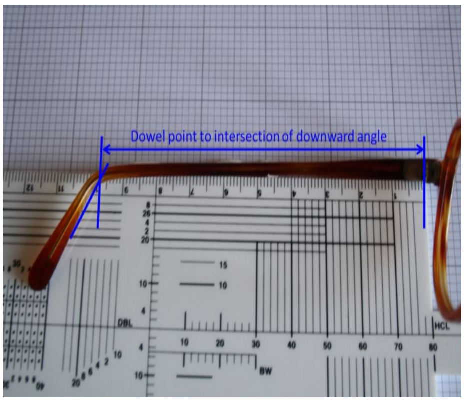


Figure 1.42i. Front to bend and length to bend.

If a handmade frame was to be ordered and therefore no sample frame available, and for the purposes of this study to inform a more reproducible parameter, the 'front to bend' measurement is taken as shown in figure 1.42i(left), the pointer of the facial ruler is used to represent the front and the length is measured to the ear point.

1.42j Distance between pad centres

This is a frame measurement, specifically of a frame with pads on arms as shown in figure 1.42j. The facial equivalent is not common in current practice as it is usually appraised and adjusted directly for the patient with the frame present. The necessary adjustments can be quite limited depending on the design of the frame and therefore it was deemed a useful linear measurement for this study to capture and add to the body of data.

Figure 1.42j. Distance between pad centres

1.43 Limitations of instrumentation

The Fairbanks facial rule is widely accepted as the only facial ruler that a practising Dispensing Optician will require from professional examinations throughout their career in practice. It does have some limitations when patients are very young or find it more challenging to remain still for the duration of taking a full set of facial measurements.

To place a solid white rule in front of a child's eyes, or near the face can be quite distressing for the child if no explanation is given or they do not fully understand the reason for it. In addition, the thin metal pointer which rotates to indicate angles or mimic frame fronts could be quite dangerous to a small child, especially with the required close proximity to the eyes that facial measurements require.

As indicated earlier in figure 1.1e, the bearing surface of a young child is often located below the horizontal line located at the top of the lower lid and this would therefore indicate a negative crest height, rather than the positive crest height as illustrated in figure 1.42b. The facial rule does not have any capability of measuring a negative crest as the lower lid, and eyes would be covered by the body of the rule once contact is made with the bearing surface.

The two distance between rim measurements (figure 1.42e) at 10 mm and 15mm below the bearing surface can also be challenging as it is often impossible to obtain an accurate measurement at 15mm below when the nasal projection as a whole may not extend to that depth.

1.44 Longitudinal observation of nasal growth

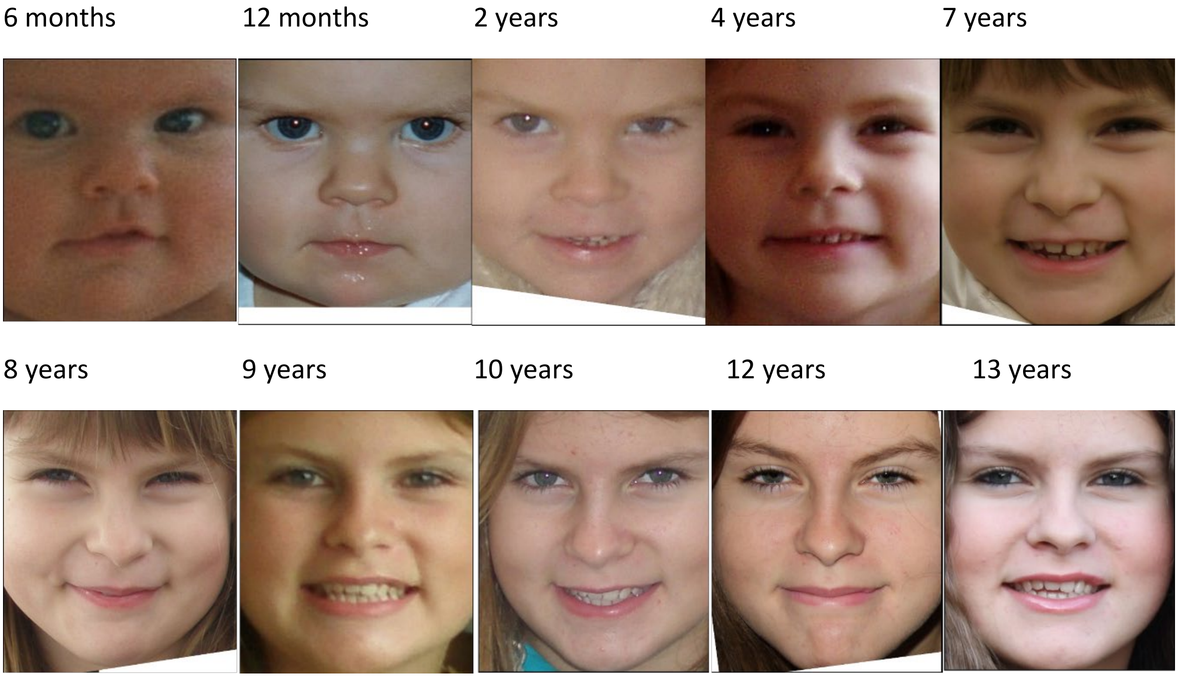


Figure 1.44a. Longitudinal nasal growth showing anterior changes in nasal appearance (image authors own).

As has been seen previously, the crest area of the nose is predominantly flat in babies, resulting in low and wide angles and therefore a lack of a useful bearing surface for spectacle frames. This does not seem to change significantly during the early years.

At the age of 4, the young girl in figure 1.44a is showing signs of the typical downward and forward thrust of nasal growth resulting in a more positive crest, i.e. the bearing surface in relation to the top of the lower lid. This continues to rise and at ages 7 years onwards, the frontal and splay angles are decreasing as the nose narrows in the frontal plane, along with a marked smaller apical radius at the top of the bearing surface. In addition, the crest is becoming much more positive as the bearing surface becomes more prominent and defined. From 10-13 years, there is a noticeable difference in the narrowing angles and deeper projection of the eyes in the transverse plane at the onset of the peak growth period for females.

1.45. Studies involving children and frame design

Kaye & Obstfeld (1989) measured 154 Caucasian children from ages 5-14 years using a series of rules and gauges in a study to provide parameters for children's eyewear. The child's head was secured in a head and chin rest and 15 measurements were taken.

The results show the growth in terms of facial features correlate with the craniofacial growth studies reported in section 1.3 and the observational figure 1.44a, the emergence of the crest, 0.3mm at age 5, to 3.5mm at 14 years. The projection of the bridge starts at a negative value for the 5 year old, rising to +3.8mm at 14 years; this indicates the profile of the crest positioned behind the sweep of the lashes. A significant change is noticed in the values from the 9.5 age group which also agrees with the study by (Mellion et al., 2013) and it would therefore indicate that maybe the 22 children in this group could possibly be female and embarking on their period of peak growth. It was noted that differences between male and female mean measurements were detected, although the difference was deemed too small to report separately based on gender. Interestingly, the study reports no change in apical radius across this growth period and a less than expected narrowing of the splay and frontal angles. In contrast, the distance between rims measurements at 10mm and 15mm below the crest show an expected distinct narrowing as the nose matures and this would therefore suggest the frontal angle narrows in conjunction. Even though a gender difference was detected it was not deemed to be significant and so suggesting the lack of angle change may possibly be due to combining male and female results. To conclude, Kaye & Obstfeld (1989) reported that the parameters required for a child's spectacle frame are disproportionate to those of an adult.

To highlight the above fact, if we consider the growth of two facial parameters, the crest height and bridge projection (figure 1.45a) the initial negative crest at birth shows little change until around 4 years where steady growth then continues until around age 7 where rapid growth in the crest is shown. Conversely, the projection measurement is somewhat steadier in progression until later, around 11 years. In terms of frame fitting, the crest height affects the vertical positioning of the frame, and it is not until over age 13 years when adult values of crest heights are encountered, this explains the low fitting spectacles from a bridge positioned too high on the frame allowing younger children to peer over the top rim. The projection is concerned with the distance the lenses are held in the frame away from the lashes, i.e. the crest and tip of the lash in the transverse plane. Prior to the crest emerging, fitting an adult-designed frame with a positive bridge projection will result in the lashes making contact with the back surface of the lenses due to the lack of any nasal protrusion to hold the lenses away from the face, ideally a negative bridge projection design is required that has the bridge built up behind the frame front in order to clear the sweep of the lashes and hold the lenses at the prescribed vertex distance. As the crest emerges in older children, fitting an adult frame with a more positive projection will result in the lenses positioned in a more suitable position behind the plane of the bearing surface to take into account the protrusion of the bearing surface and the relative lash sweep.

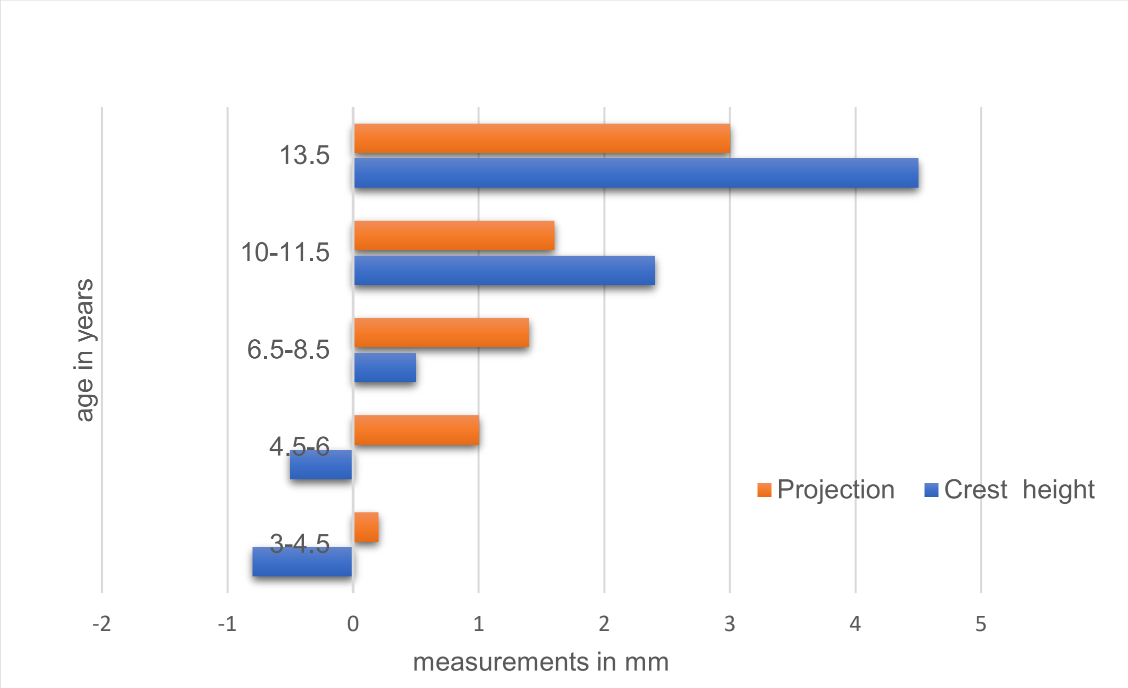


Figure 1.45a. Bar chart representing growth in terms of crest height and bridge projection (Kaye & Obstfeld 1989).

An indication for manufacturers of a realistic side length would be very useful in practice, as was reported in this study (Kaye & Obstfeld 1989) that a minimum of 85mm front to bend (FTB) should be available. This agrees with an earlier study in Moscow where 400 children were measured aged 6-16 years and the resultant parameters for FTB are 85-100mm which will encompass 92% of children within that range where 2-4% require shorter than 85% and 4-6% require a longer FTB (Zhuk, 1973).

Sides that are manufactured too long seems to be a typical encounter for Dispensing Opticians as manufacturers today produce lengthened sides to encompass as many children as possible (see section 4.2). Some designs allow for sides to be permanently shortened; however, the fashionable, thicker acetate sides leave only the option of increasing the length of drop which both looks unsightly but also becomes uncomfortable as pressure is transferred to the delicate mastoid area behind the ear.

A positive correlation has also been reported between pupillary distance measurements (PD) and temporal width (Quant and Woo, 1992, Zhuk, 1973) which appears obvious due to lateral growth, but also the PD and bridge height and width which may indicate parameters for children's frames should concentrate more on the PD measurement rather than the age of the child. The PD and head/temple width correlation was also reported in a large study of Chinese children by Wang et al (2005). Over ten thousand children between the ages of 5-17 years were measured with the objective of stipulating parameters for spectacle frames by using six measurements. In accordance with previous studies, the most rapid growth was reported at aged 10-11 and 5-7 years with significant gender differences. These measurements, with the exception of PD and head width, do not directly relate to standard facial or frame measurements (British Standards Institute, 1991); however, it can be appreciated that by using the orbital rim to ear-point and corneal apex to orbital rim, a front to bend measurement can be deduced. The inter-orbit distance could equate to a frontal width of a frame, and the calculation for the nasal base angle could be interpreted as the frontal angle.

1.46. Facial differences due to ethnicity

In 1878, the anthropological nasal index was first described by Paul Topinard as a representation of race by calculating the ration of nasal width to length (Topinard, 1878). This gave rise to a numerical classification and the terms of leptorrine, mesorrhine and platyrrhine and their corresponding proposed ethnicities.

Index value	Descriptive	Ethnicity
Low index below 70 (narrow appearance)	Leptorrhine	Caucasian
Mid index 70-85	Mesorrhine	Asian
High index over 85 (broad appearance)	Platyrrhine	African

Table 1.46a. Nasal index descriptors (Topinard, 1878).

Whilst many studies concur that there are significant differences between the measurements of different ethnic groups, there is, however, also a considerable degree of overlap with similar values across all groups. Couple this fact with a lack of scientific definition of ‘race’ and Doddi and Eccles suggested, following a systematic review of the literature in 2010, that published data are therefore not useful in terms of planning nasal surgery.

Ethnicity is usually determined by the subject themselves, with an often limited choice which also does not take into account ancestry and migration. For successful spectacle fitting, it is important to at least have an appreciation of facial characteristics due to ethnicity and to have an understanding of parameters and combinations of parameters required in order to fully serve the needs of the population thus allowing all children access to suitable eyewear.

In children of African Caribbean ethnicity, Kaye and Obsfeld (1989) reported significant differences in the facial characteristics, namely a lower crest height and smaller projection coupled with larger splay and frontal angles and a longer FTB requirement. Currently the only option for these children is to select a frame with pads on arms that can be widened to accommodate the large angles. This is not an ideal solution as this will also result in the frame sitting even lower on the face in addition to the relatively low crest height. Care must be taken to ensure the eye rim of the frame does not contact the side of the nose or the cheek as a result of this adjustment.

In a study of the Chinese adult population, Quant and Woo (1992) reported similar values to Caucasians for inter-pupillary distance (IPD) and exophthalmos; however, a larger inner inter-canthus distance and outer orbital distance would suggest a wider bridge and temple width in comparison. In a later study of Chinese children aged 7-11 (Quant & Woo 1993), it was found that IPD was also larger for this group in comparison to Caucasian children and the head and temple widths on average were found to be 20mm larger concluding that Caucasian-designed spectacle frames would be unsuitable for Chinese children.

1.47. Children with Down's syndrome

Down's syndrome is a chromosomal abnormality first described in 1866 by Dr Langdon Down. Children with Down's syndrome are prone to several health issues in addition to learning difficulties (Woodhouse et al., 1993b) and a high prevalence of refractive error reported to be 77%, along with 80% of school age children with Down's syndrome having a reduced accommodative function (Woodhouse et al., 1993b)

The appearance of a child with Down's syndrome includes a general flat facial profile due to the absence of the nasal bone or hypoplasia (Sforza et al. 2011) giving rise to a much more negative crest (Woodhouse et al., 1993a) and reduced lateral, vertical and anteroposterior dimensions (Ferrario et al. 2004).

Whilst developmentally typical children show marked facial changes between 3-13.7 years, children with Down's syndrome typically show little relative difference in facial growth from 7 to 14 years (Woodhouse et al., 1993a). The IPD and head width is generally smaller in older children with DS, but the head width is larger in younger children. The temple width is larger than expected although the front to bend is considerably shorter. The frontal angle is smaller in comparison although the splay angle is larger and the crest more negative.

Age years	3-4.5	4.5-6	6.5-8.5		10-11.5		13	
Crest height mm	-0.8	-0.5	+0.5	-3.0	+2.4	-1.3	+4.5	-1.4
Projection mm	+0.2	+1.0	+1.4	-1.0	+1.6	-2.4	+3.0	-2.8
Frontal Angle (degrees)	34	34	32	26.3	31	26.4	30	26.3
Splay Angle (degrees)	35	34	32	33.8	29	35.0	29	33.8

Black figures relate to facial parameters of typically-developed children

Red figures relate to facial parameters of children with DS

Table 1.47a. Age and typical facial measurements for typically-developed children (Kaye and Obstfeld, 1989) and children with Down's syndrome (Woodhouse et al., 1993a).

Therefore, children with Down's syndrome can never be successfully fitted with conventional frames as their facial characteristics are not consistently larger or smaller in all dimensions.

The study by Woodhouse et.al (1993) consisted of a small sample of twenty children and only in the age range 6.5-13 years. Some measurements such as head and temple width were noted as being difficult to achieve as the child did not enjoy this aspect of being physically measured with a calliper. Although research has been carried out in this area, the literature is sparse limited by small sample size which may not be representative of the true population characteristics. Research to date has not focussed on the whole of the growth period, i.e. birth to mid-teens and has not considered the full range of ethnicities. The existing literature has used manual measurement methods at a resolution of approximately 1mm for linear measurements and 5 degrees for angular measurements. Technological advances in anthropometric measurement deployed in this research now make it possible to update our knowledge in this area with higher precision; 0.01mm for linear measurements and 0.01 degrees for angular measurements.

1.48. Research Scope and Aims

As this literature review has demonstrated, there are differences in facial parameters between children and adults that have not been considered in the manufactured dimensions of a spectacle frame. This is particularly reflected in facial growth of children with Down's syndrome. Thus, the primary aim of this thesis is to broaden the knowledge base in this area and to suggest data for frame parameters based on facial image analysis performed by three-dimensional stereophotogrammetry which can be used in the manufacture of spectacle frames. These facial measurements will also inform on growth and identify any differences between children who are of different ethnicities and children who have Down's syndrome compared to typically-developed children. In addition, a suggestion of spectacle frame design features which would support the information gained on facial anthropometry and assist in ensuring frames encompass more children by allowing adjustment and modification.

Chapter 2 Methods and Logistics.

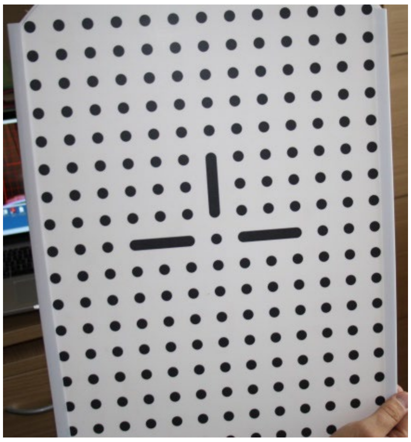
2.1 Facial measurement and growth studies

Traditional craniofacial imaging studies such as celaphograms use the cranial base as a fixed anatomical position in order to allow subsequent tracings to be superimposed and hence the pattern of growth recorded and measured (Mellion et al., 2013, Enlow, 1966). The visible facial form and associated growth in respect of spectacle wear requires accurate landmarking of soft tissue, which is naturally more pliable, hence it is more difficult to locate specific points (see Chapter 4). These studies, therefore, traditionally mark several standard landmarks on the face, as described in figure 1.3b and then either scan digitally (Sforza et al., 2011, Ferrario et al., 1997) or use direct measurement involving sliding or spreading callipers (Kouchi and Mochimaru, 2004, Zankl et al., 2002). As the soft tissue is pliable, depression of the tissue is inevitable using physical instrumentation and palpation is sometimes required to locate the harder underlying structures, however, with training and experience, a high degree of accuracy can be established using this traditional direct anthropometry methodology (Kolar and Salter, 1997).The demand on the subject to remain still during this lengthy process of landmarking and repeated measurements could explain why a general lack of facial growth data exists in the literature for babies and young children. In addition, traditional cephalometry studies used radiography which in itself is an exposure to potentially harmful ionising radiation which ideally should be avoided (Long et al., 2014). Digital imaging offers the opportunity to gain highly accurate measurements of facial anatomy non-invasively.

Considering the age and attention span of the proposed subjects, the study employed the 3DMDFace™ (3dMD, Atlanta, USA), a three-dimensional stereo photogrammetry system as this is a rapidly deployed, non-invasive technique that can easily be transported to different locations. Camera capture speeds of less than 1.5 milliseconds (3dMD, Atlanta, USA) is advantageous for the measurement of babies and young children. There is no need for pre-location of landmarks, nor is there the need for the child to be restrained or subject to precise head positioning. The system gives a 190-degree, ear to ear, three-dimensional image, which can then subsequently be analysed and measured.

Figure 2.1a. The 3dMDFace™ measurement system adapted for portability by attaching to a regular camera tripod and altering the design of the horizontal camera brace bar.

2.2 Calibration



The calibration board (figure 2.4a) must be held and imaged in two separate positions in order to calibrate the system successfully. Position one (figure 2.4b) is with the board tilted 45 degrees forwards with the central 'T' shape inverted. The board should fill the entire screen with the central dot matching the centre of the red cross on screen.

Figure 2.2a. The calibration board.

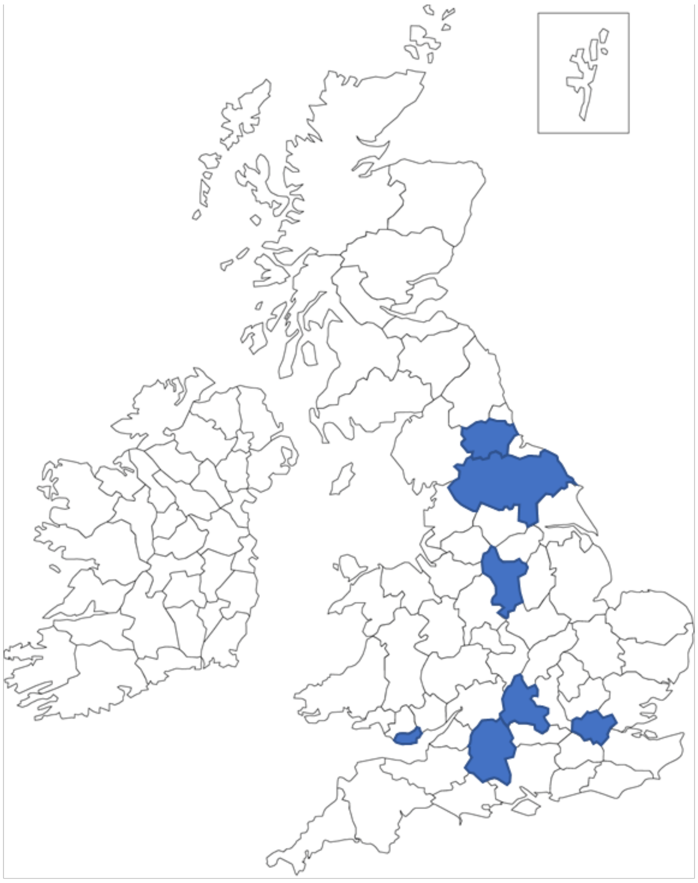
Figure 2.2b. Position for calibration showing the image screens on the laptop.

A sole investigator will find a mouse useful to fire the system whilst holding the calibration board. Position two can be imaged after 12 seconds when the flash has recharged and is the same as position one except the board is tilted 45 degrees backwards.

The system then builds the information and an audible beep sounds that it is ready to acquire images if the calibration has been successful. Calibration must be performed at the start of every session, although any knocks to the cameras or brace bar will affect accuracy and performance and calibration must be repeated. A small barrier, such as the storm cases placed in front of the camera pods will aid to protect the system and avoid the need for multiple calibration activity.

2.3 Data acquisition sessions

Once ethics approval for the study was granted from Aston University Ethics Committee, locations were approached from contacts within schools, charitable organisations and children's centres. This resulted in images being acquired from several locations in the UK as shown (figure 2.5a) and also Wenzhou in China. The majority of the locations agreed to return visits in order to not only recruit additional subjects, but to re-capture the image of existing subjects at 6 monthly intervals over an 18-month period.



	Typically Developing		Down's Syndrome	
Location	Male	Female	Male	Female
City & County of Cardiff	7 (1.67-12.22 years)	6 (3.32-10.47 years)	13 (0.81-16.39 years)	15 (1.68-16.59 years)
County Durham	44 (2.01-12.88 years)	41 (0.43-11.04 years)	6 (10.72-11.90 years)	5 (9.75-10.82 years)
Derbyshire	189 (0.23-15.42 years)	173 (1.54-16.52 years)	n/a	n/a
Greater London	5 (3.82-12.19 years)	5 (0.82-12.34 years)	48 (0.40-13.30 years)	32 (0.82-13.38 years)
North Yorkshire	3 (6.75-10.61 years)	3 (3.69-10.22 years)	4 (5.31-11.36 years)	9 (4.22-16.56 years)
Oxfordshire	n/a	n/a	7 (1.07-4.06 years)	3 (1.75-3.40 years)
Wiltshire	198 (4.37-11.49 years)	229 (4.39-11.73 years)	n/a	n/a
Totals	446	457	78	64
	903		142	

Table 2.3a. General image acquisition UK locations and subject recruitment demographics (age range).

	Typically Developing	
Location	Male	Female
Wenzhou, China	160 (1.81-15.22 years)	144 (2.54-16.30 years)
Totals	304	

Table 2.3b. General image acquisition in Wenzhou, China and subject recruitment demographics (age range).

Group	Children scanned once	Children scanned twice	Children scanned three times	Children scanned four times	(Total number of images)
White British typically-developed	218	142	99	3	811
Chinese typically-developed	307	1	0	0	309
Other ethnicities typically-developed	41	16	3	0	82
Down's syndrome White British	73	10	4	0	105
Down's syndrome other ethnicities	16	10	2	0	42
Totals	655	179	108	3	(1349 images acquired)
	945 total number of children				

Table 2.3c. Table to show numbers of children per group participating in the study and the numbers of acquired images per child.

Table 2.3c shows how many children in each group were scanned either only once or on multiple occasions. The opportunity to visit to Wenzhou in China was a planned single visit, the child captured twice in this group was a child of Chinese ethnicity from the United Kingdom. Three children presented for a fourth image capture, and this was due to them moving up to a different school and the timeframe being at least 6 months.

Initial discussions were held with senior staff at the acquisition locations to discuss the study with a potential view to contacting parents/carers by letter and if required, an information presentation to parents was also offered. After agreement to participate, any advertising for subject recruitment was placed by the school, charity or centre as applicable and the approved information and consent forms (Appendix 2-3) were distributed for consideration. As this study aimed to recruit a large age span of children, from birth to sixteen, three separate information sheets were designed (National Health Service Health Research Authority, 2007). For children aged birth to 5 years, this was in the form of a cartoon, for 6-10 years it was written information using simple terms and an image, and for 11-16 years it was considered appropriate to add more detail to the text, keeping the language easy to understand (Appendices 4-6).

An information sheet for parents was produced alongside the consent form which captured the child's age, gender and ethnicity using the recommended ethnic group descriptors for England (Office for National Statistics, 2015) and whether the child has Down's syndrome which is relevant information for this study. For the study in China, additional ethics approval was sought from both Aston University and Wenzhou Medical University and all participant information material was translated into Chinese. Each child was allocated a unique number so that no personal details or location appear anywhere in the data on the acquisition system. The database of participants was kept on a separate system and appropriate security arrangements enabled.

A prior plan was agreed with the school or centre to fit with their timetable and ensure a constant flow of children ensuring as minimal disruption to their day as possible. Data was collected over a three year period (2015-2018) consisting of return visits at 6 monthly intervals whenever possible.

2.4 Image acquisition

On arrival, the child's consent form was checked, a verbal explanation of the purpose of the research and a final verbal check that the child was happy to proceed. A viewing target was placed just above the central flash unit on a wall or similar, to direct the child where to look. The height-adjustable chair on wheels enabled the child to be positioned for both camera pods quickly and easily. For babies and younger children, the parent or carer positioned them on their lap. The objective was to see the child in both screens with a clear view of each ear; this meant that children may need to be instructed to tuck their hair behind their ears and the use of headbands proved to be invaluable. Hair is a known feature that will interfere with the image acquisition and the use of wig caps is often used in 360-degree imagery (Heike et al., 2010). Similarly, any wet (reflective) substance will cause artefacts on the image so it was often necessary to ask the child or parent/carer to wipe or dry parts of their face.

Once positioned, a verbal warning of the imminent flash was given and the image was taken. As the image is rendered by the system in 7 seconds (3dMD, 2015), the child could be shown their image in three-dimensions whilst the integrity was simultaneously checked and saved if deemed acceptable. Unacceptable images such as those where the child moved, resulting in motion artifacts, were deleted and re-taken with consent, and hence very few images were subsequently discarded during the acquisition process.

2.5 Three-Dimensional Image Rendering

The hardware consists of two modular units containing a total of 6 medical-grade cameras which are controlled by a laptop to synchronise a single image capture with the aid of three industrial-grade flash units. The two camera pods are positioned at a known distance apart on a fixed brace bar, positioned in an optimal arrangement to capture the ear-to-ear image. The subject is positioned in front of the central bar at the mid-point, hence forming a triangular arrangement.

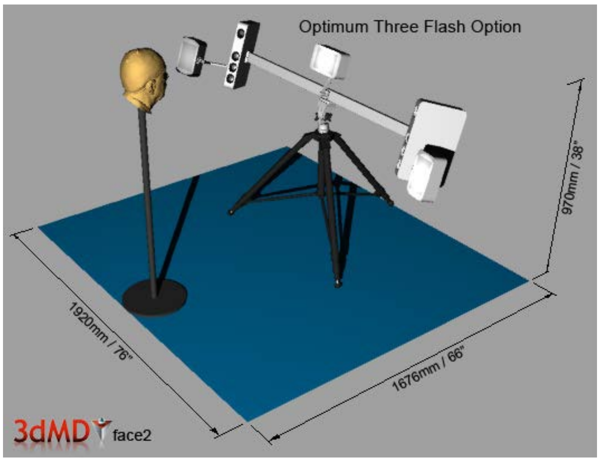


Figure 2.5a. Set up position of subject in relation to cameras (image courtesy of 3dMD).

The industrial grade machine vision cameras produce 6 images synchronised during the capture speed of 1.5ms, 4 black and white under structured light conditions and 2 colour images which produce skin tone and texture.

The calibration plate (figure 2.2a) consists of a defined pattern of dots with the central line shape which is imaged in two different positions (figure 2.2b) simultaneously by the system. It can then determine the position and orientation of the image as well as the pixel size, focal length and lens distortion parameters for each of the six cameras. This information then produces a comprehensive digital model of the geometry, made more accurate by two images taken in different planes which allow the algorithm to avoid confounding parameters.

The system deploys a technique using a hybrid active/passive stereophotogrammetry system in order to obtain 3D data. Stereophotogrammetry involves multiple versions of the same image taken from different angles. Passive stereophotogrammetry involves capture of the natural surface patterns of the face in terms of texture, colour and 3D shape. Active stereophotogrammetry involves projected unstructured light patterns on the subject's face combined with the natural pattern of the surface in order to give the stereo algorithms as much information as possible to build an accurate 3D image.

The white light speckle projectors are triggered first with the two pairs of monochrome cameras which project a unique pattern on the subject's face, half a millisecond later, the colour cameras and the flash units are fired simultaneously. This means the system can then identify the same corresponding points on the face from the several images in which it appears in order to produce a texture map.

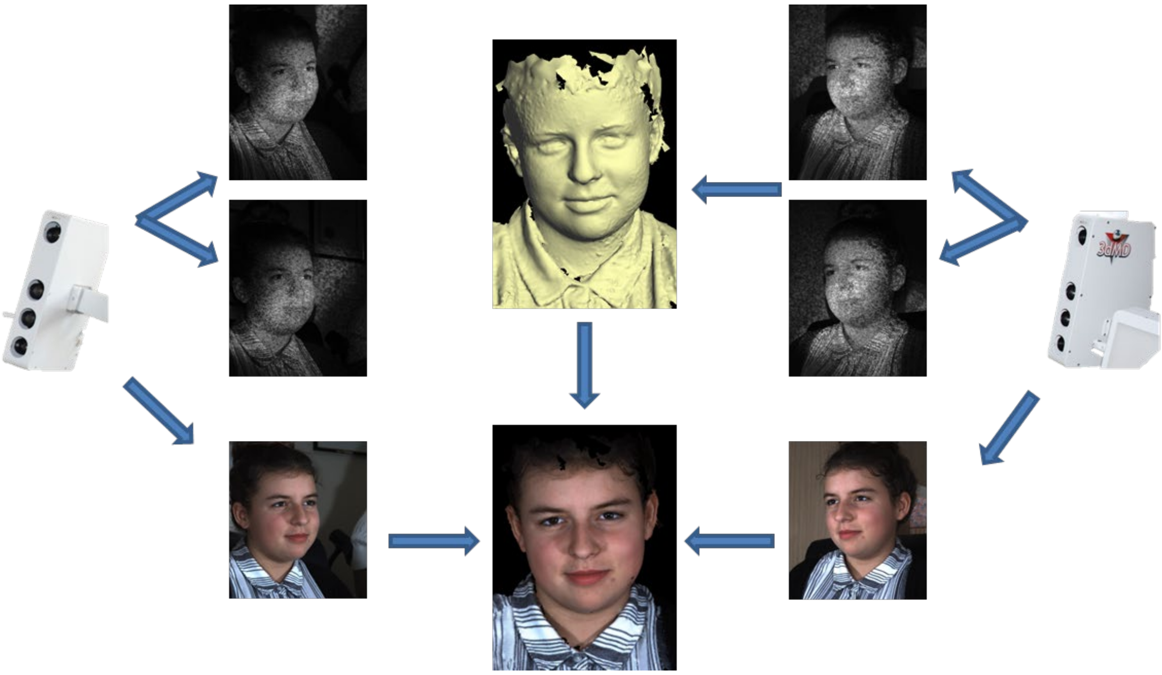


Figure 2.5b. Images received by the system to allow build of 3D coloured, textured image.

The system produces a mesh construction from the 3D points calculated using triangulation algorithms to produce a single 3D point cloud, this has the benefit of eliminating errors due to stitching or merging separate images (Aldridge et al., 2005). Each 3D point then forms a mesh construction where each point is linked by vertices, approximately 62 vertices per cm^2, and neighbouring points are connected by edges forming a continuous surface of a single x, y, z coordinate from all stereo pairs of images. The texture map is then projected onto the polygonal mesh to give a more realistic appearance of the 3D image. Each image consists of high-resolution surface geometry (x, y and z axes) including colour and texture and geometry accuracy is reported to be less than 0.2mm root mean square (3dMD, 2013)

2.6 Image Analysis

The images can then be viewed and analysed post-capture using the 3dMD Vultus™ software (3dmd, Atlanta, USA). Features of the software such as zooming and rotation, removing the skin texture and the use of the mesh view proved to be very useful in accurate placement of facial landmarks.

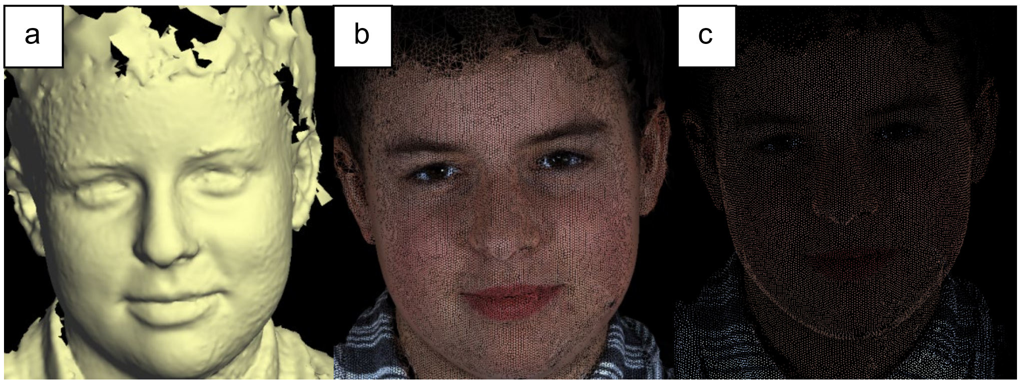


Figure 2.6a. Image with a) texture removed, b) wire frame view, c) joint frame view.

Landmarks placed on the facial images by the user have reference coordinates that can be saved and re-applied. Each point is a coloured dot that lies accurately along the facial contour at that point.

2.61 Reference plane

In order to place all of the subjects in the same head position prior to measuring, this study utilised the '3dMD reference plane' program and each aligned image then selected to the bespoke measuring software for facial parameters relating to spectacle wear.

Once the image has been selected, on the 3dMD analysis tab, the pointer icon is selected entitled 'landmarking calculations'. Load the landmarking template named '3dMD reference plane' and this then lists the positions of five standard facial anthropometric landmarks (figure 2.81a) which are placed on the right and left sides of the face:

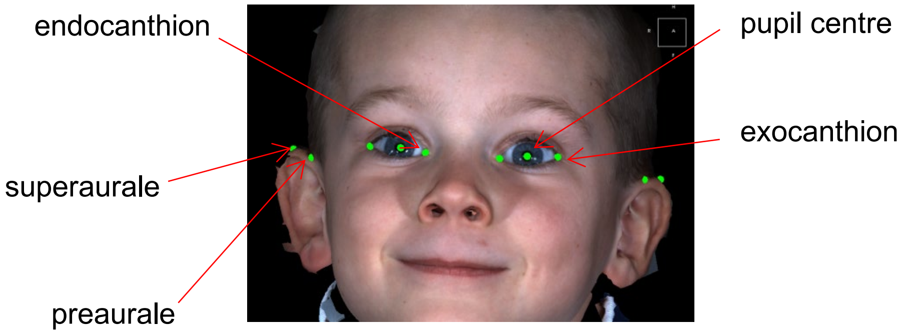


Figure 2. 61a.Ten facial landmarks positioned to determine the reference frame.

Once these landmarks have been placed, the natural head position is registered, along with the centre of the pupil distance. This image was then saved as *'_aligned'* to ensure any further analysis recalled the correct, aligned image.

Figure 2.61b. Comparison of the natural head position during image capture (left) with the facial image when in a standardised reference plane (right).

The Cartesian 3D photograph-based reference plane employed by the system was first described by Swennen et al. (2005) and is determined from marking firstly the canthal line in the horizontal plane by selection of both exocanthia. This is followed by then marking the superaurale which is the highest point on the free margin of the ear. This gives a canthion superaurale line in the side view of the subject. Finally, the pupil central point (PCP) gives the midline of the nose along the pupillary line.

The reference plane is then determined as follows:

Horizontal plane is then automatically calculated 7 degrees below the canthion-superaurale line, along the horizontal direction and through the PCP. The vertical plane determined as a perpendicular to the horizontal plane and the median plane is then placed perpendicular to the vertical and horizontal planes.

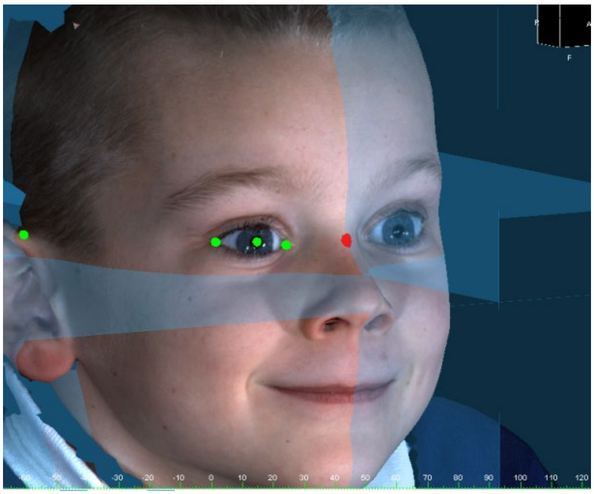


Figure 2.61c. Reference frame definition.

2.62 Image measurement

Once the image was aligned, the custom written landmarking program ‘ABDOv13’ was selected for the semi-automated measurement of other facial landmarks specific to ophthalmic dispensing. The ‘v13’ refers to the multiple iterations of this program to achieve the outcome of a reliable and accurate system of taking facial measurements with as much automation as possible. No previous 3dmdFace™ programs could be adapted as this was an area of the face that the software engineers had little experience in and therefore positions of landmarks needed careful exploration and testing. For example, the temple width measurement in practice is taken at a point approximately 25mm behind the back plane of a spectacle front, so there is a certain amount of approximation as to where this point should be measured. With the development of this program, a virtual frame front could be created from the bearing surface and a caliper measurement is fully automated at 25mm behind this virtual front, therefore improving both accuracy and reproducibility. The template contains the nine facial landmarks which are necessary to be placed manually to form the reference points for the automated landmark placement and subsequent facial measurements (see section 1.42 for definitions).

Landmark code	Landmark description
BS	Bearing surface
BS_R and BS_L	Bearing surface of a pad centre
P_R and P_L	Pupil centre
TTL_R and TTL _L	Top of the lower lid
OBS_R and OBS_L	Otobasion Superious (Ear point)

Table 2.62a. Table to show manually placed landmark codes and descriptions.

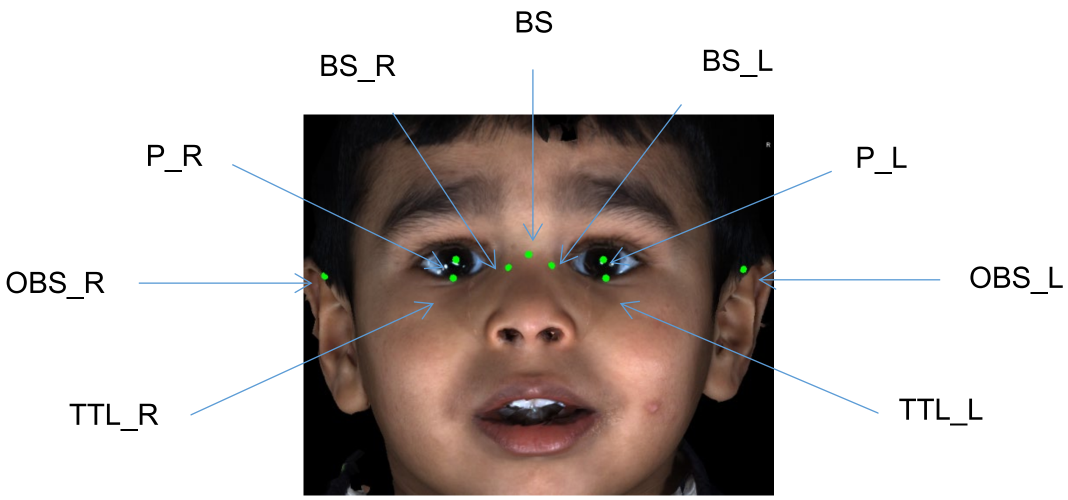


Figure 2.62b. Manually placed landmarks.

The three-dimensional facial image was rotated into different planes in order to determine where each landmark needed to be placed. Once the landmarks were placed, a second analysis template was loaded (ABDO v13) which automatically placed eight further landmarks based on the manual placements above, in order to determine and measure the facial measurements required for this research.

Landmark code	Landmark description
BS_H	Bearing surface in axial plane
BS_LOW	Bearing surface low vertical point
RIM10_R and RIM10_L	Rim distance at a point 10mm below the bearing surface
RIM15_R and RIM15_L	Rim distance at a point 15mm below the bearing surface
TP_R and TP_L	Temple point situated 25mm behind the projected plane of the spectacle front

Table 2.62c. Table to show automatically placed landmark codes and descriptions.

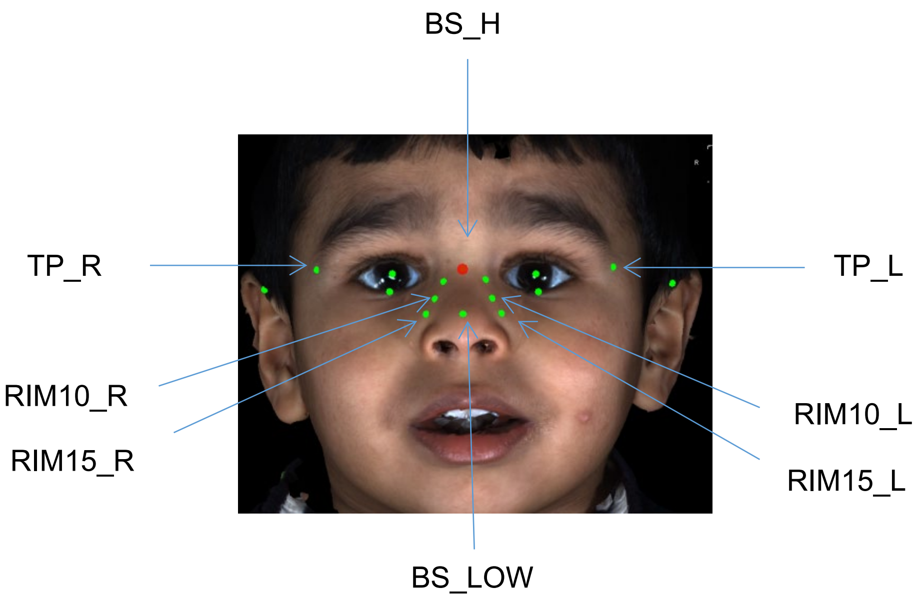


Figure 2.62d. Automatically placed landmarks.

Once the landmark placements had been made, the ‘analysis’ tab revealed the facial measurements. All measurements were then exported to a separate spreadsheet for data analysis coupled with the decimal age of the subject, approximated to 0.01 years and calculated on the image capture date.

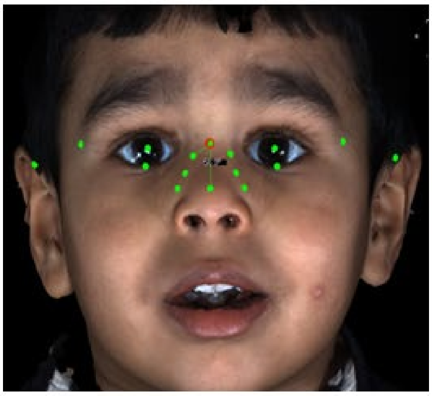


Figure 2.62e. Frontal angle.

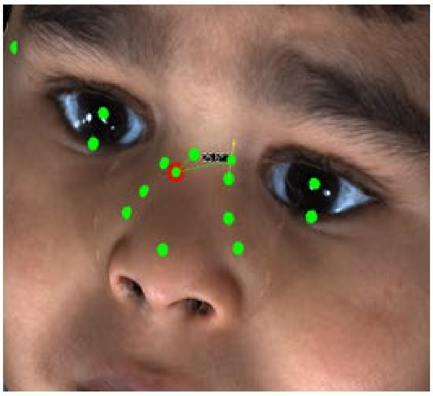


Figure 2.62f. Splay angle.

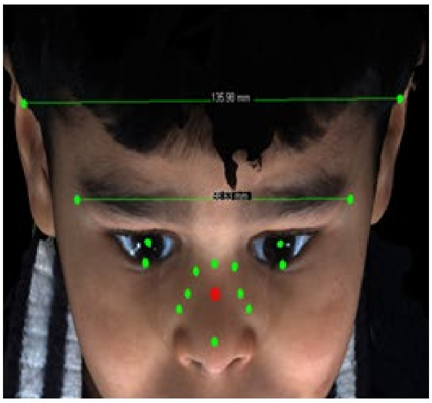


Figure 2.62g. Head and temple width.

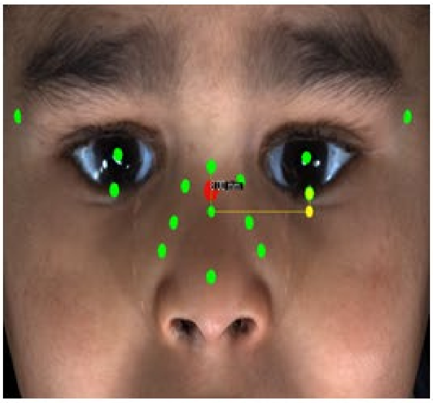


Figure 2.62h. Crest height.

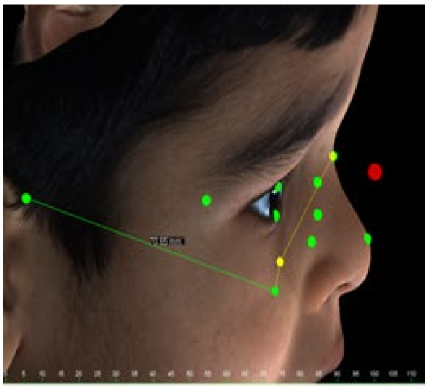


Figure 2.62i. Front to bend.

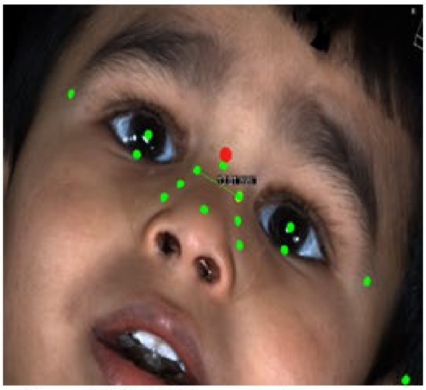


Figure 2.62j. Distance between pad centres.

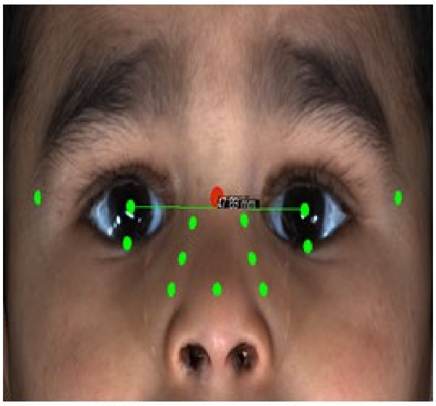


Figure 2.62k. Distance between pupil centres.

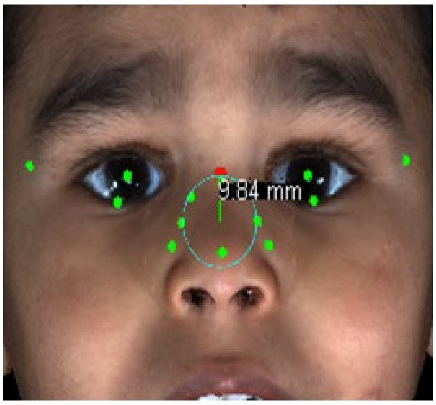


Figure 2.62l. Apical radius.

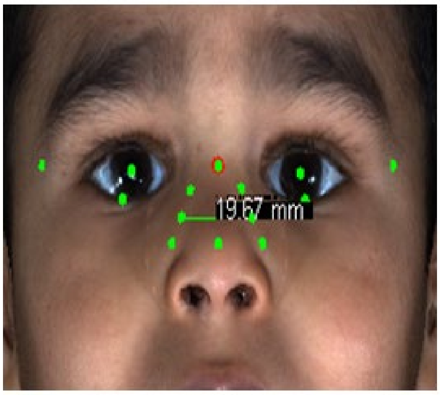


Figure 2.62m. Distance between rims at 10 mm below crest.

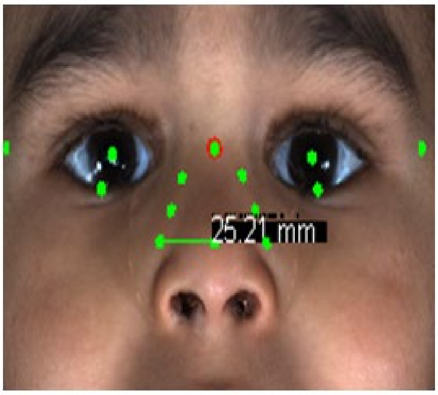


Figure 2.62n. Distance between rims at 15mm below crest.

Figure 2.62e-n. Facial measurements from landmarks.

2.7 Sample size

Examining the literature to determine sample size, studies with direct relevance to facial measurements for spectacles or related eye and head measurements in children, the work of Kaye and Obstfeld (1989) recruited 154 subjects aged between 5-14 years, 232 7-11 year olds (Quant and Woo, 1993), 400 6-15 year olds (Zhuk, 1973) and the largest number of subjects was 10,171 5-17 year olds (Wang et al., 2005).

In the field of spectacle related facial parameters in adults, there was a range of subject numbers from 56 adult males (Kouchi and Mochimaru, 2004), 100 adults (Rosyidi et al., 2016) 290 adults (Liu et al., 2013) and 500 adults (Tang et al., 1998b).

In a systematic review in 2013 of stereophotogrammetry which included the 3dMDFace™ system, reported sample sizes were to be between 10 and 181 individual subjects (Ladeira et al., 2013).

With relatively few studies in this field, the sample size deemed appropriate considered studies in a wider field involving children and growth in the fields of orthodontics and related craniofacial studies, particularly those involving nasal growth. Sample sizes reported showed similar variance to the spectacle-related studies from 80 (Bugaighis et al., 2013), 100 (Mellion et al., 2013), to 402 (Ferrario et al., 1997).

It was indicated from the earlier literature search that significant facial parameter variance may be encountered for reasons of gender, ethnicity and Down's syndrome; therefore it is reasonable to assume that a large sample size will be divided and further sub-divided into several categories. As the ultimate aim of this research is to inform frame manufacturers of sizing information for spectacle frames, recruitment was aimed at a reasonable number per age bracket.

2.71 Sample size for this research

This project was aiming for an ideal of 50 males and 50 females per age category as recommended by Kolar and Salter (1997) who indicated that 25-30 males and females for each age group would be a minimum sample size, but 50 would give a more reliable result (Kolar and Salter, 1997).

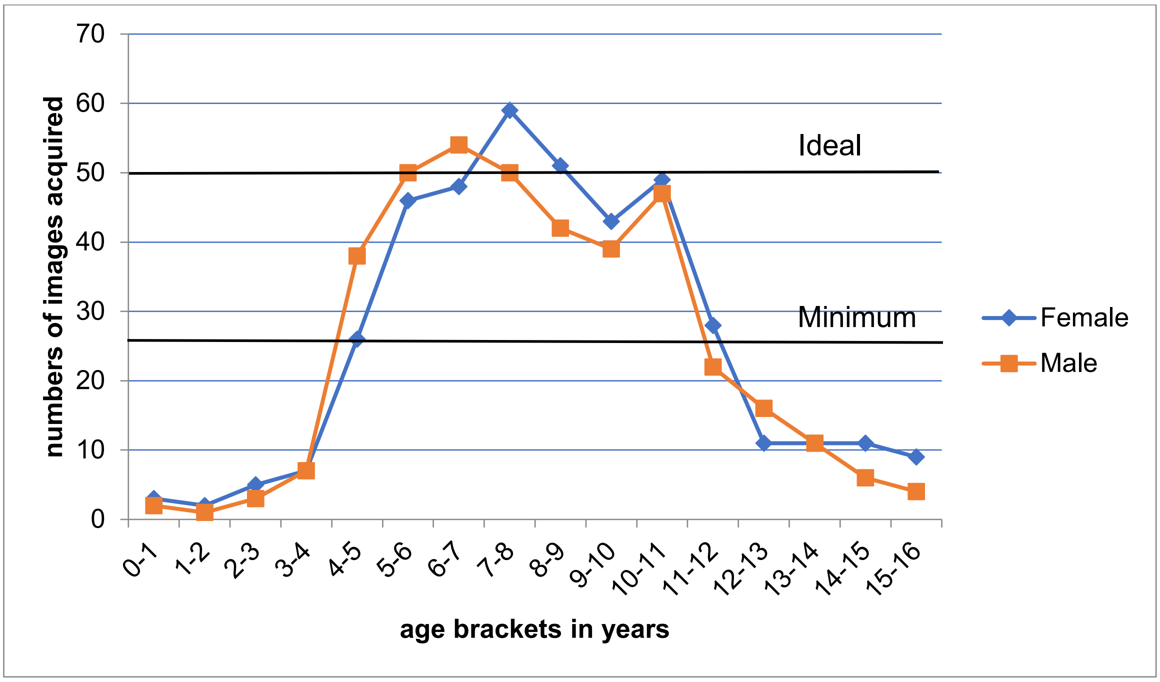


Figure 2.71a. Images acquired of White British subjects per age bracket showing minimum and ideal numbers of subjects (Kolar and Salter, 1997).

In this study, the White British male and female subject numbers reached those targets in the main for children aged 4-12 years. Children under 4 years are known to produce rapid (Weinberg et al., 2016) and disproportional (Sperber et al., 2010) facial growth.

Anatomically, these children are more challenging to fit spectacle frames due to the lack of a formed nasal crest and relatively flat facial profile as illustrated in section 1.1e. The numbers of children under 4 years presenting for dispensing may be relatively low as it is above that age that they are more typically seen in high street practice, as a result of the vision screening programme (National Health Service, 2019). However, it is equally as important that Dispensing Opticians have access to product that will fit all children. In terms of children in the upper age band, it may be apparent that this age group have developed the facial parameters that may reflect a small adult and that an age-specific frame design may not be necessary, as appears to be evident in spectacle frames typically encountered in practice.

Chapter 3 Paediatric dispensing questionnaire.

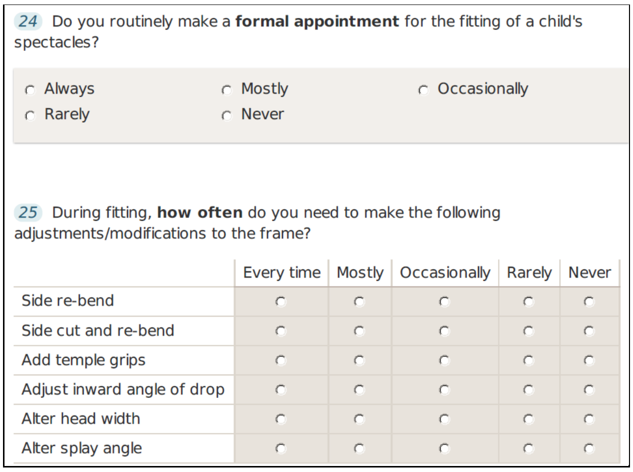
3.1 Attitudes within the optical profession to paediatric dispensing

In order to gauge professional opinion and provide an evidence base of issues and attitudes associated with paediatric dispensing, there was an identifiable need for qualitative data in the form of an online questionnaire designed for Optometrists and Dispensing Opticians registered with the General Optical Council (GOC). The questionnaire aimed to discover typical behaviours and attitudes of registrants on dispensing children in various practice settings.

3.2 Questionnaire design considerations

Questionnaires are beneficial in terms of fast administration, they can be filled out when the respondent has time to do so, and they can progress at their own pace without any interviewer bias (Brace, 2013, Gilham, 2000). However, it is also acknowledged that this method can produce a low response rate and asking a series of simple, closed questions may not elicit the quality of data required (Gilham, 2000). The web-based platform has the advantage that the respondent has to answer the questions in the designed order (Brace, 2013).

The information required was grouped into sections of questions clearly titled and following a logical sequence to reflect the patient pathway experienced in clinical practice. The individual question design focussed on clear, simple, short questions or statements (Hague, 1993) coupled with a mixture of Likert- type scales, statements with radio-button responses and open text where necessary (Gilham, 2000) in order to retain participant interest.



24 Do you routinely make a **formal appointment** for the fitting of a child's spectacles?

○ Always ○ Mostly ○ Occasionally
○ Rarely ○ Never

25 During fitting, **how often** do you need to make the following adjustments/modifications to the frame?

	Every time	Mostly	Occasionally	Rarely	Never
Side re-bend	○	○	○	○	○
Side cut and re-bend	○	○	○	○	○
Add temple grips	○	○	○	○	○
Adjust inward angle of drop	○	○	○	○	○
Alter head width	○	○	○	○	○
Alter splay angle	○	○	○	○	○

Figure 3.2a. Example of radio-button responses in the administered questionnaire.

Regarding ethical considerations, it was identified that both responsibility for this regulated function and practical ability might be deemed sensitive to some practitioners and cause negative reflections on their own practice. In order to minimise this potential sensitivity, the questionnaire respondent could remain anonymous and no questions were deemed compulsory. It was felt that anonymity would lead to more honest and open responses and non-compulsory questions would lead to practitioners not being forced to answer something they may not know (Brace, 2013) or feel uncomfortable in admitting, and hence less abandonment of participation.

The questionnaire was tested on a pilot group of 25 Optometrists and Dispensing Opticians randomly selected from a communication to registrant dispensing practical examiners and optometrist colleagues who were asked to comment on any aspect of the questionnaire and record the length of time it took to complete. The results of the pilot enabled refinement of questions to reduce any ambiguity, different answer options added and a reasonable idea of a completion time to be advertised. In addition, the design was sent to Aston University Market Research department for their advice and feedback.

3.3 Sample size

With 14,000 Optometrists (College of Optometrists, 2015) and 5,700 Dispensing Opticians in the UK (Association of British Dispensing Opticians, 2015) the desired sample size calculation, based on a population of 14,700 is 583 (Creative Research Systems, 2012) giving a 95% confidence level and a confidence indicator of 4. The confidence indicator is the accepted margin of error calculated from the mean and standard deviation of the sample distribution which means that one can be 95% confident that within +/- 4 is a true representation of the population in question.

Formula used by Creative Research Systems:
(https://www.surveysoftware.net/ssformu.htm)

$SS = \frac{Z^2 * (p) * (1-p)}{c^2}$ Where:

Z=z value (1.96 for 95% confidence level)

p = percentage picking a choice, expressed as a decimal (0.5 used for sample size needed)

c = confidence interval, expressed as a decimal (0.04)

Correction for finite population:

$$New\ SS = \frac{SS}{1 + \frac{SS - 1}{pop}}$$

3.4 Delivery

The questionnaire contained 34 questions covering sections on general overview, activity and confidence, your practice, spectacle dispensing, spectacle fitting, and a final section about the respondent. The questionnaire was launched on April 15th 2015 and was live for a period of four months until August 15th 2015, during which time promotion included professional magazines, websites, newsletters, direct emails and social media platforms Twitter™ and Facebook™. The full questionnaire can be found in Appendix 1.

3.5 Principal findings

A total of 699 registrants responded (89.7% dispensing opticians, 9.9% optometrists and 0.4% '*other*') which represents 3.5% of the combined optical register, and 11% of the dispensing optician's register which was expected since paediatric dispensing is more likely to be carried out by this particular sector. The majority of respondents were female (65.4%) which reflects the demography of the dispensing and optometry professions (Mayhew, 2020, General Optical Council, 2018). Ages ranged from 21-61 years old with length of registration varying from under 5 years to over 25 years. This is useful as more experienced registrants may possibly be influenced by products that historically were available, especially frames available on the National Health Service (NHS) where a large range of sizes was available in many styles. Newly qualified dispensing optician registrants will have experienced the recent emphasis on paediatric dispensing with a specific competency being introduced in 2011 (General Optical Council, 2011). A good spread of registrants covering nearly all counties of the UK and a few from overseas gives a wide perspective of any changes in behaviour across different practice settings and areas. At the close of the questionnaire 45% worked in independent practice (1-3 practices) and 48.1% worked in a multiple practice, the others in hospital practice, franchised practices, university teaching practices, as a locum, in a charity organisation or academia.

3.51 General Overview

This section asked for information on the amount of dispensing the practitioner typically carries out and if there is additional responsibility for this regulated function. 95.5% of respondents were actively dispensing and over half of all respondents also had responsibility for overseeing paediatric dispensing which could be supervising trainees or optically unregistered members of staff.

Following this, a direct opinion was sought on the overall fit of children's frames and the sizes available from manufacturers. The positioning of the latter two questions was felt to be crucial to gauge initial opinion before other questions may have influenced the answer or interest was lost. Rating the fit of a spectacle frame is a very subjective question, however 30% rated children's frames as '*poor*' or '*dreadful*' and a further 45.6% rated '*average*'.

Similar results were returned for the choice of children's frame sizes with 40.2% rating '*poor*' or '*dreadful*' (Figure 3.51).

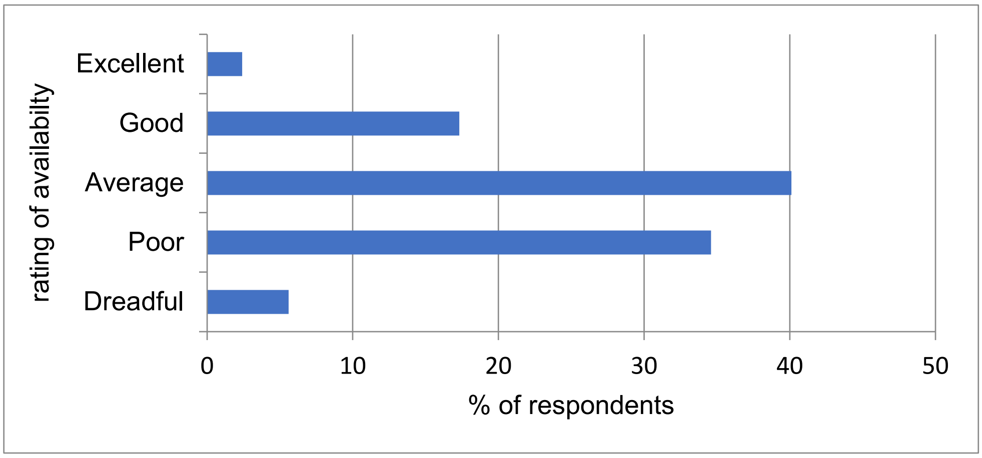


Figure 3.51a. Choice of children's frame sizes available in the market.

3.52 Activity and confidence

These questions were aimed to elude how much dispensing to children of specific age groups was occurring regularly in practice and in addition, how confident the practitioner felt dispensing children of different ages (Figure 3.52a). The high apprehension reported by practitioners with respect to dispensing the youngest age group could be explained due to the lack of experience in seeing very young children for dispensing due to the gap in screening from birth checks to pre-school vision screening (Hall and Elliman, 2003) unless there is an apparent issue and they present via the Hospital Eye Services (HES). However, it may also be explained by the lack of appropriate product in terms of frame availability for this age range as there is certainly more supplier choice for the older child which was explored later in the questionnaire. More frequently children are seen in high street practice over the age of one year old, but again the apprehension is present for the 1-3 age group, almost disappearing by age 4-6 and above. This could also be explained by perceived difficulties in communicating with young children (Figure 3.52b) and achieving an appropriate, compliant wearing regime.

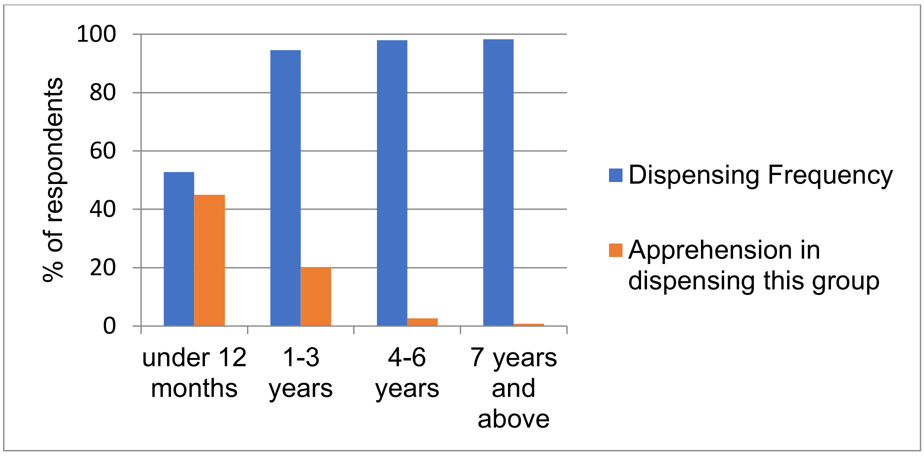


Figure 3.52a. Compilation of frequency of dispensing age groups (‘*often*’ and ‘*occasionally*’) compared to apprehension (‘*nervous*’ and ‘*slightly nervous*’).

In order to potentially address any practitioner confidence issues relating to paediatric dispensing, a series of options on further training and qualification were presented to be rated in terms of importance (Figure 3.52b). It is evident from these options that exposure to paediatric patients either in training or a further hands-on practical course would be required to gain the confidence in dispensing young children and communication skills with both the child and parent/carer. Interestingly over 95% responded that a wider range of frame sizes would be ‘*important*’ or ‘*essential*’ in raising their confidence. This supports the earlier hypothesis that practitioners may not have access to the products they need in order to dispense children of all ages and parameters.

Finally, a popular option would be for the respondent to learn additional skills which enable them to adapt frames or even convert them into options more suitable for the presenting patient. This could indicate these skills are missing in education or the frames available to the practitioner are not capable of being manipulated to fit the patient.

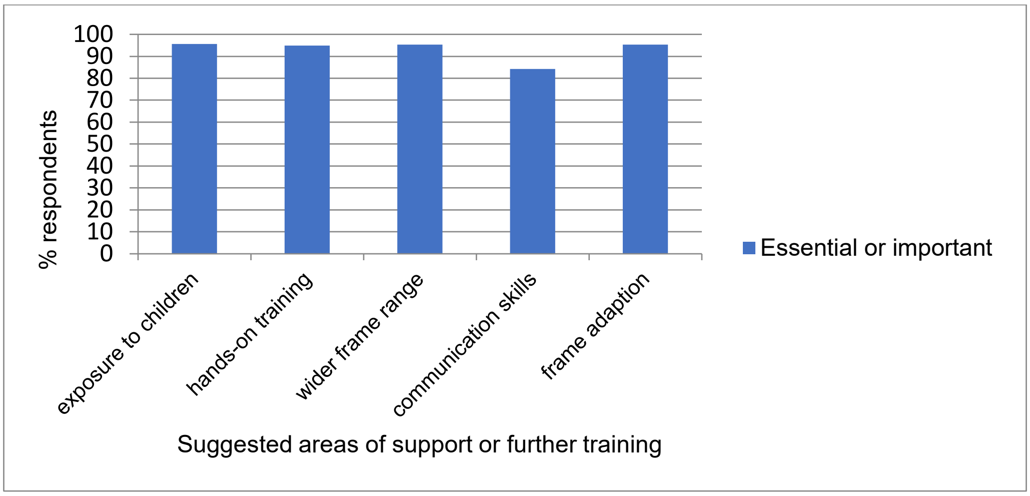


Figure 3.52b. Response to various support options suggested rated as '*essential*' or '*important*' by respondents.

3.53 Your practice

This section of the questionnaire explored typical behaviours when dispensing a child and covers both frame selection and how the practitioner offers the child the most suitable frame choices.

The majority of high street practices (93.8%) have a dedicated area for children's frames although only 62.6% reported activities available for the child to keep them occupied during the dispensing process. This may be due to a lack of physical space in the practice, a general lack of time to dedicate to children, or the lack of understanding of child attention spans and how to appropriately perform duality of communication with the parent/carer and child. Having a dedicated area may appeal to parents/carers and children to see the frames on offer and the associated popular character-branding. There is no doubt that the choice in terms of cosmetic appeal is rated very highly by our respondents (79.7% '*excellent*' or '*good*') showing that manufacturers are producing frames children want to wear. However, it could be argued that a child should only be presented with a choice of frames that actually fit. Good practice would suggest that once measurements and appraisal of requirements have been considered, a selection of suitable choices are made and not expose the child to the full range where potential negativity may be encountered if that particular range is not suitable for their facial features. This appears to be a real issue for the respondents when asked about their range of eye sizes across a range of ages in their practice and the result was 43.3% rating their range as '*average*', '*poor*' or '*dreadful*' coupled with lack of adjustability (50.8%). Two-thirds of respondents (66.5%) have no or limited input into purchasing the range which are often decided by central purchasing teams or practice management who may not be optically qualified and understand the needs of paediatric patients beyond cosmetic appeal.

3.54 Spectacle dispensing

In this section of the questionnaire, the objective was to establish what spectacle frames are offered for a child in the particular practice the respondent was working in and at the same time elicit more detail on the availability of frame sizes and be able to provide feedback to the manufacturers of spectacle frames. Where frame purchasing is practice-based, the respondent was requested to identify the suppliers used for spectacle frames catering for differing age ranges and to indicate the rationale for selecting that particular supplier. The age ranges selected were under 12 months old, 1-3 years, 4-6 years and over 7 years up to the age of 16 years.

The figures below show the preferred suppliers for each age bracket and the reasons for choosing suppliers. This was an open text designed question with no suppliers offered. Named suppliers received 5 votes or more and respondents could name any number of manufacturers that they use for particular age groups.

3.54.1 Children aged under 12 months

Figure 3.54.1a. Word Cloud showing suppliers or ranges named for children under 12 months old. The larger the font size, the more frequent the supplier was used.

The following pie charts show reasons given for using each frame supplier named for children under 12 months old. The criterion for each of the suppliers shown was having more than ten comments received and more than one comment per category. As this was a free text box, categories vary per supplier, however, segments have been highlighted which relate directly to fit, bridge fit, anatomical design and adjustability.

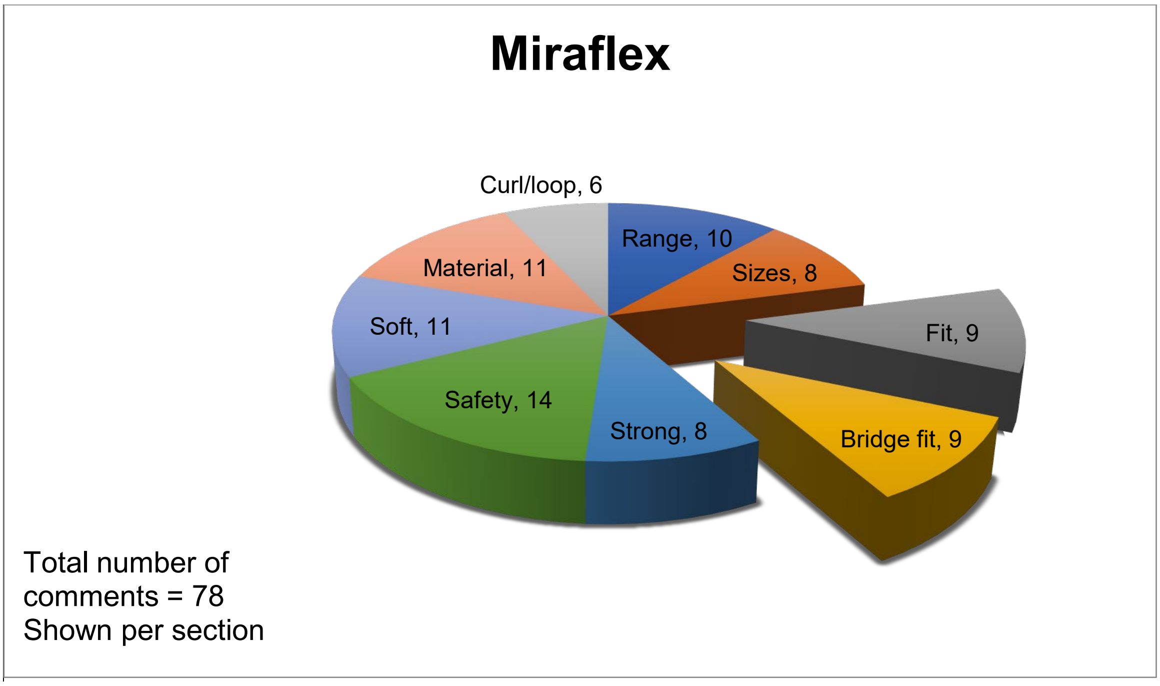


Figure 3.54.1b. Reasons given for using Miraflex as a supplier for children under 12 months old.

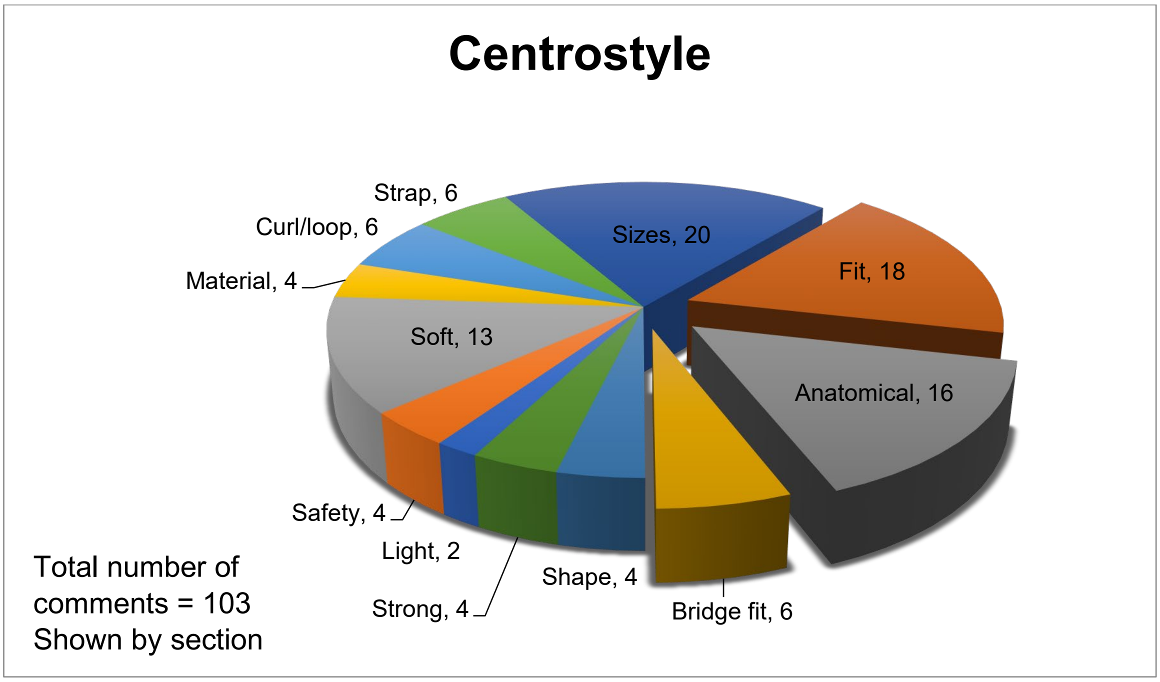


Figure 3.54.1c. Reasons given for using Centrostyle as a supplier for children under 12 months old.

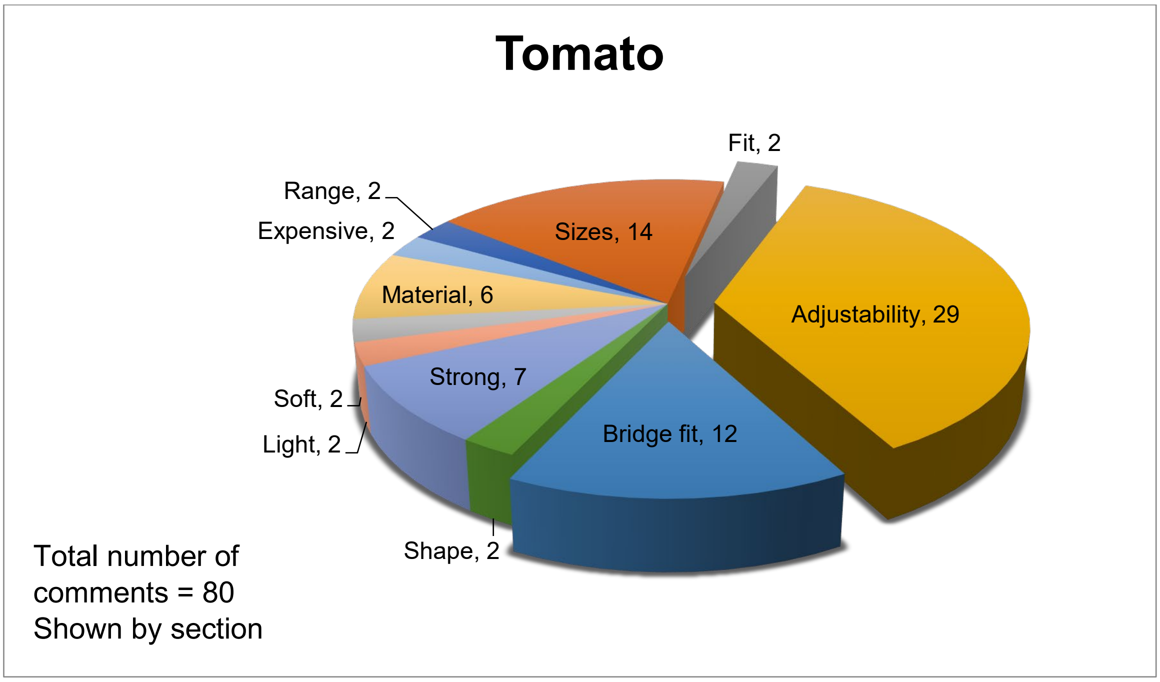


Figure 3.54.1d. Reasons given for using Tomato as a supplier for children under 12 months old.

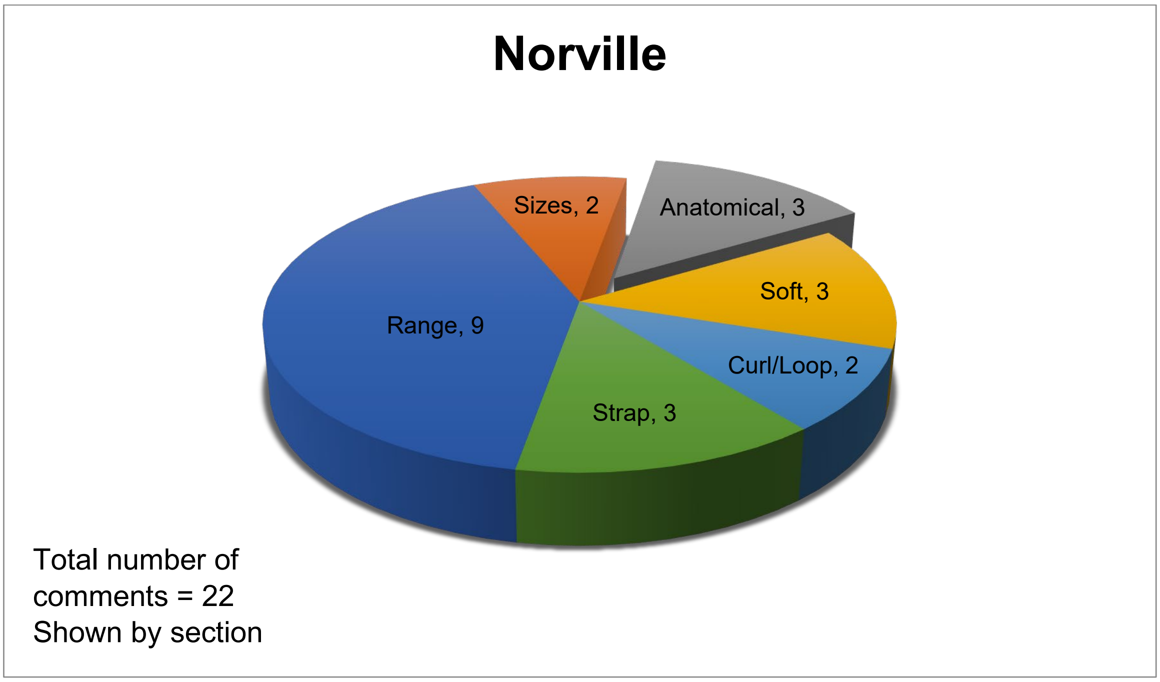


Figure 3.54.1e. Reasons given for using Norville as a supplier for children under 12 months old.

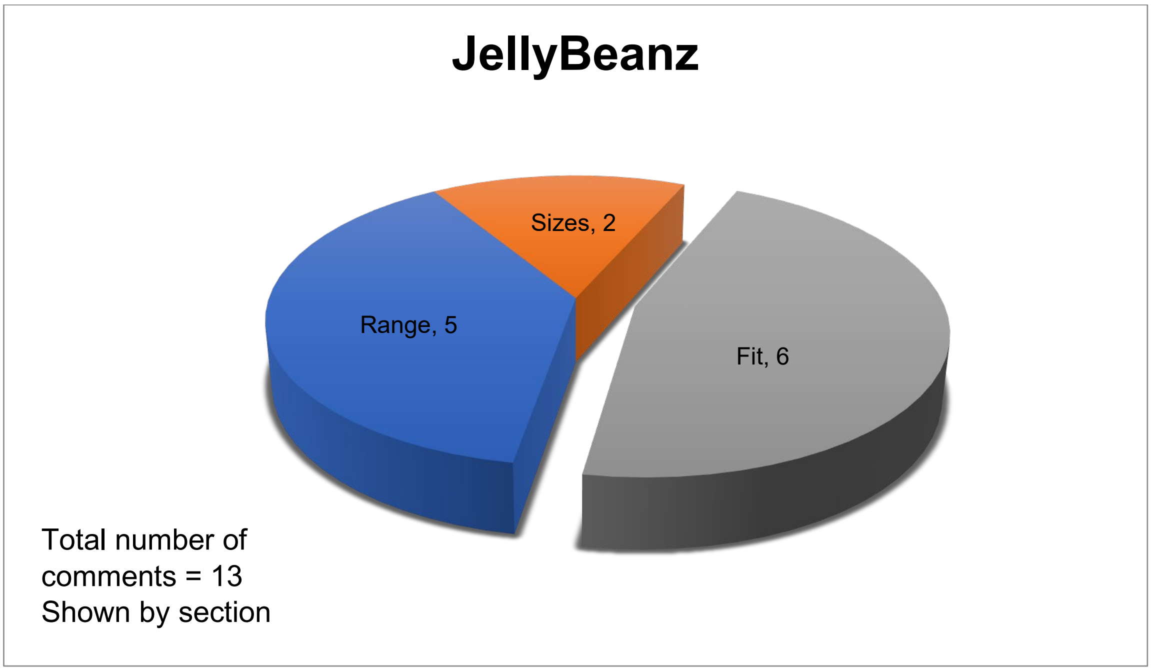


Figure 3.54.1f. Reasons given for using JellyBeanz as a supplier for children under 12 months old.

The most commonly named frame suppliers Miraflex™ (Dibble Optical), Centrostyle™ and Tomato™ Glasses market their ranges primarily on the fit of the frames and these appear to have different design parameters rather than scaling down a frame designed for an adult. This was reflected in the free text comments from optical practitioners where the range and sizes, anatomical considerations, especially in terms of bridge design and lens shape, giving rise to a soft, safe and comfortable frame that is capable of being adjusted. Tomato™ Glasses scored highly on adjustability (Figure 3.54.1d) as it has the unique design feature to physically shorten soft plastic sides and to change the vertical position of the soft pad bridge.

Overall, there were relatively fewer frame manufacturers mentioned for the child under 12 months compared to older children which suggest limited availability for this age range. Interestingly, 4.5% of practitioners commented that they do not dispense children under a year old, do not stock any frames or would source frames if necessary. The perceived value is also interesting as two out of three of the most popular companies in this category received comments indicating they are expensive and the rest are '*cheap'* according to respondents. The NHS General Ophthalmic Services (GOS) voucher is claimed towards the cost of the child's complete spectacles and many practices promote that this covers the entire cost, it is therefore reasonable to assume that the frames designed for 'fit' may be out of reach for some parents who may not be in a position to pay or reluctant to pay as they see frames as items that will require replacement at frequent intervals.

3.54.2 Children aged 1-3 years

Figure 3.54.2a. Word Cloud showing suppliers or ranges named for children aged 1-3 years. The larger the font size, the more frequent the supplier was used.

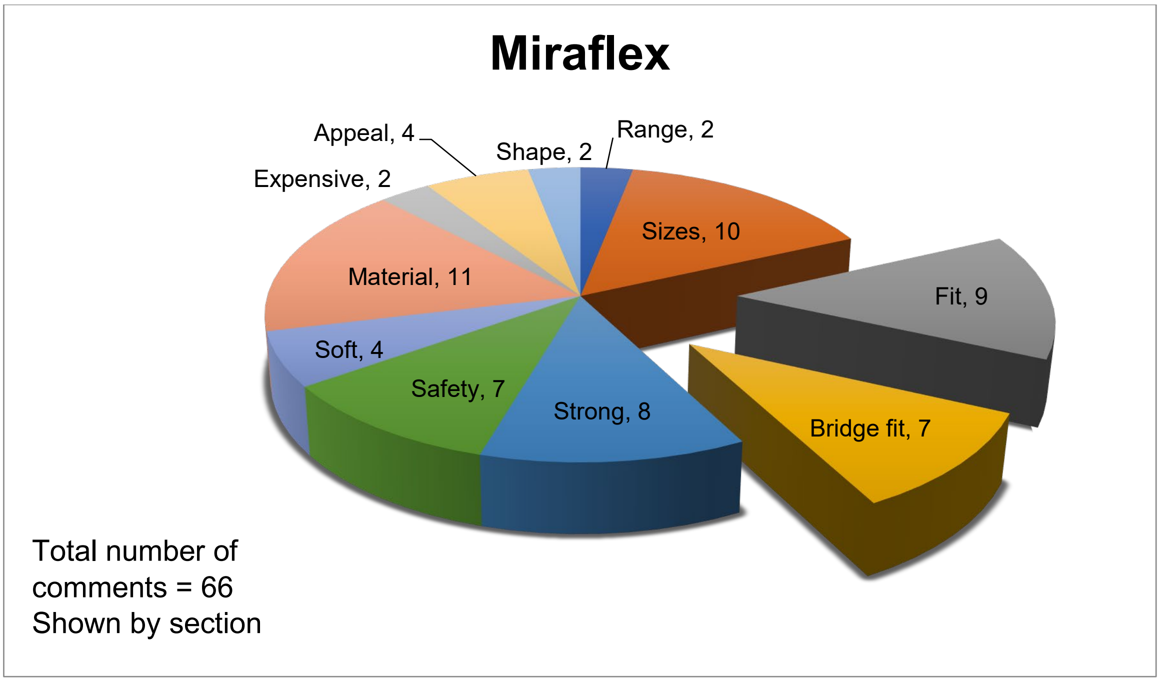


Figure 3.54.2b. Reasons given for using Miraflex as a supplier for children aged between 1-3 years.

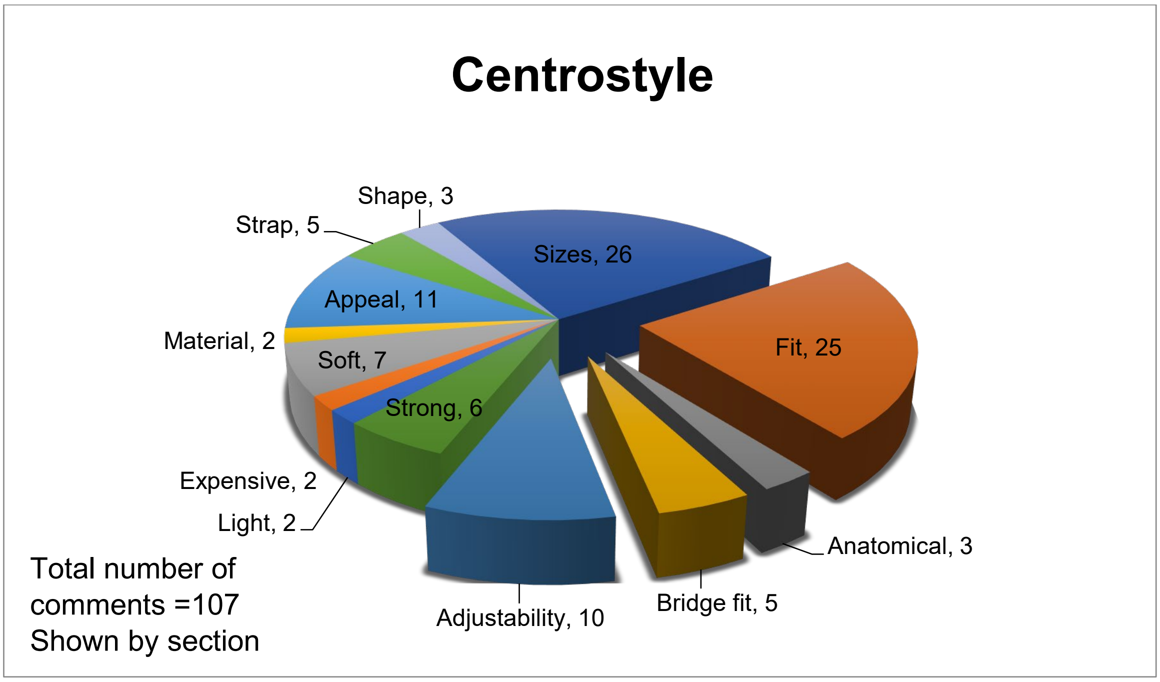


Figure 3.54.2c. Reasons given for using Centrostyle as a supplier for children aged between 1-3 years.

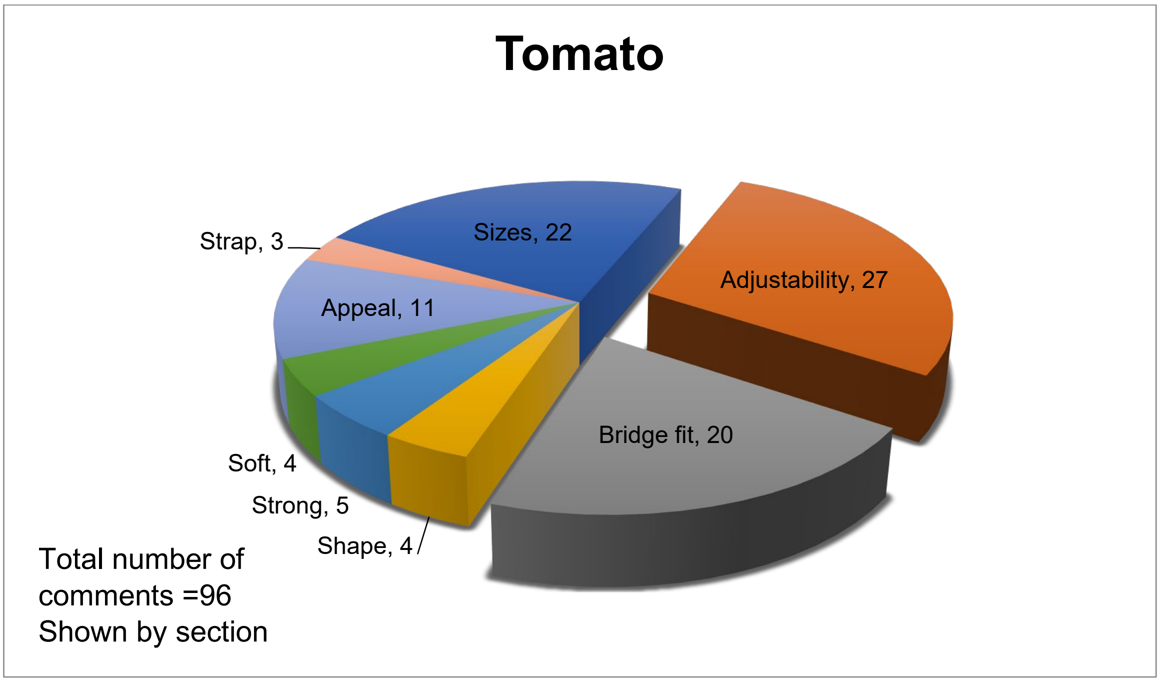


Figure 3.54.2d. Reasons given for using Tomato as a supplier for children aged between 1-3 years.

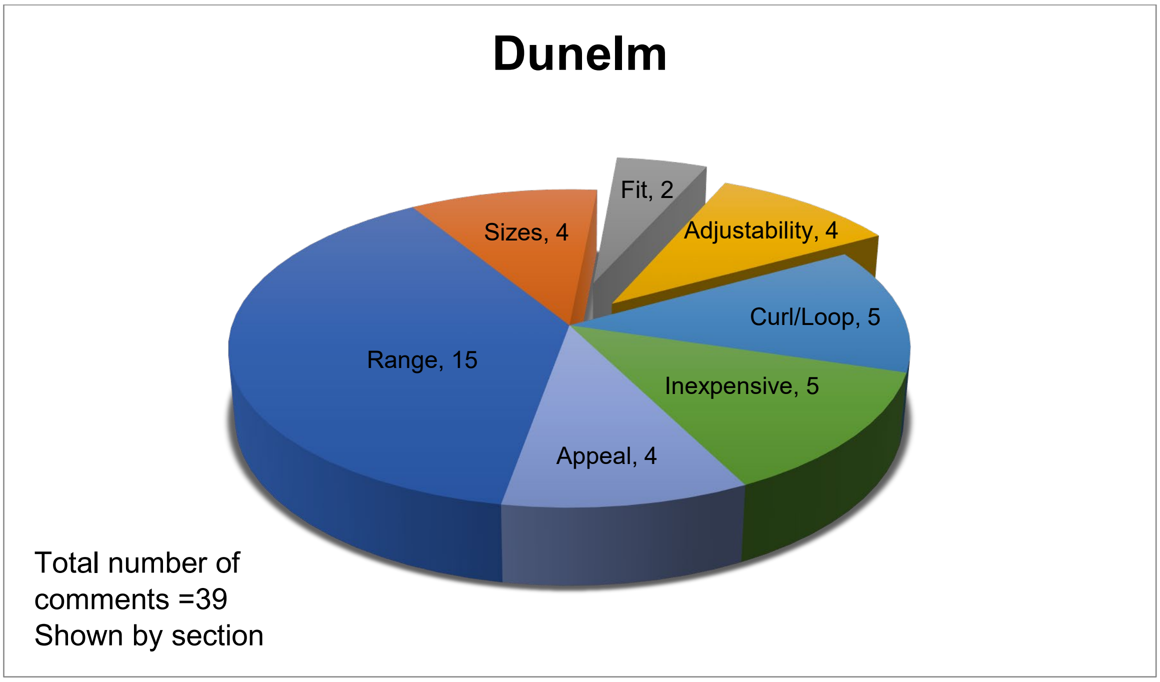


Figure 3.54.2e. Reasons given for using Dunelm as a supplier for children aged between 1-3 years.

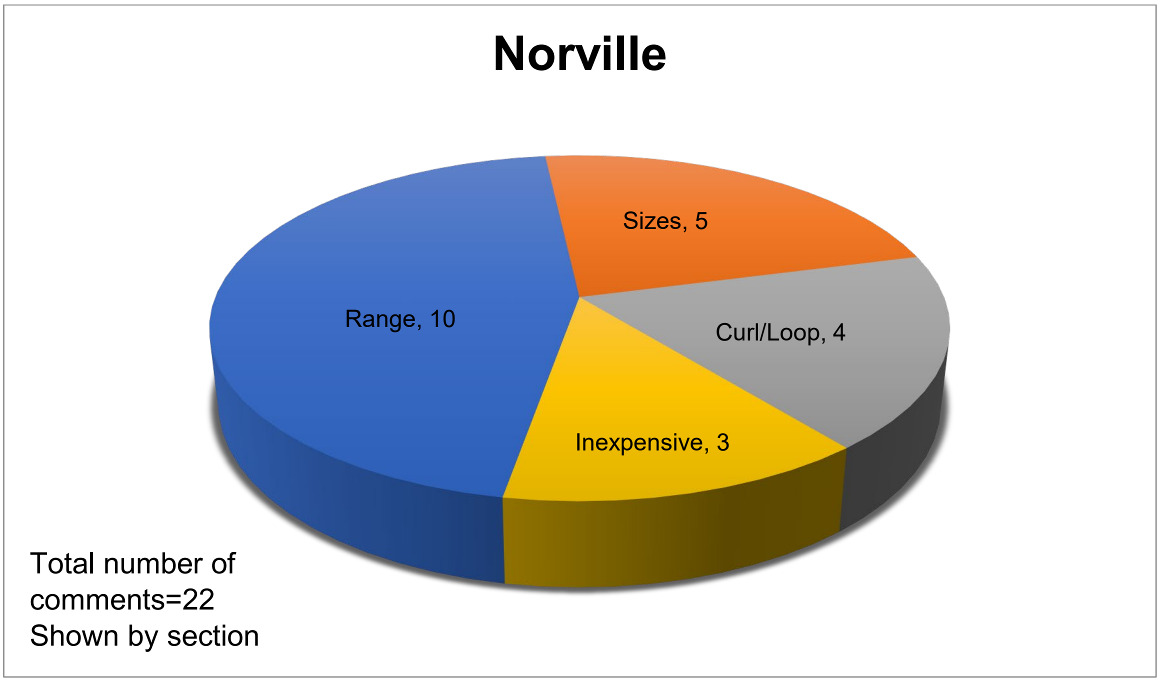


Figure 3.54.2f. Reasons given for using Norville as a supplier for children aged between 1-3 years.

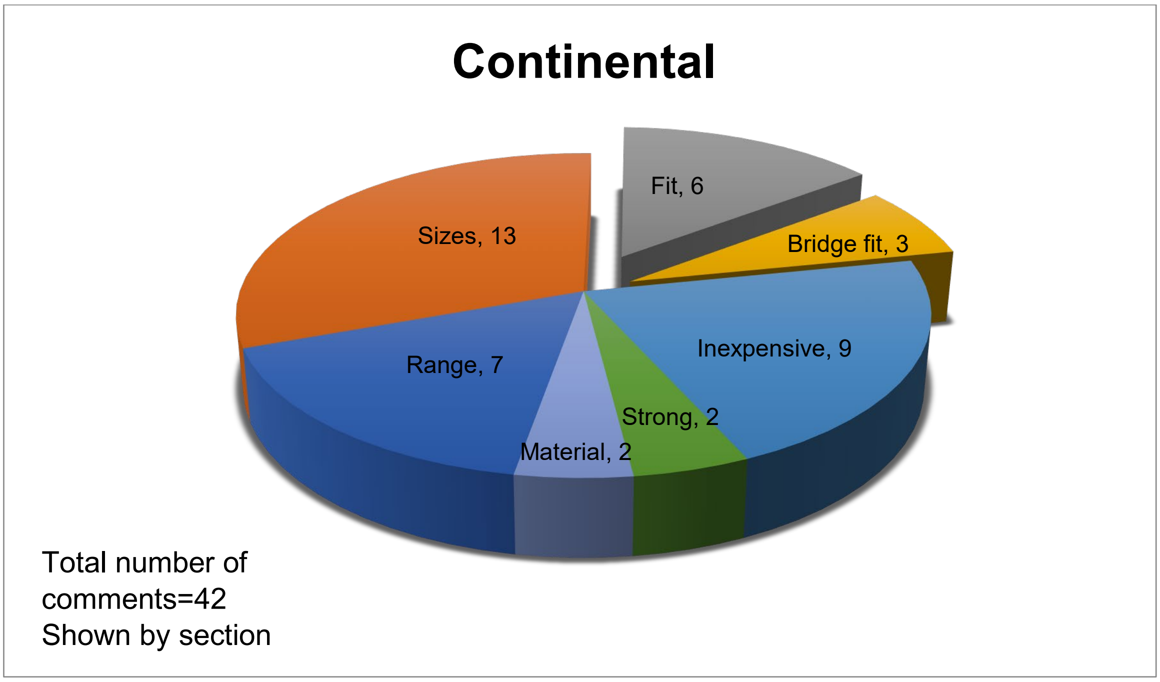


Figure 3.54.2g. Reasons given for using Continental as a supplier for children aged between 1-3 years.

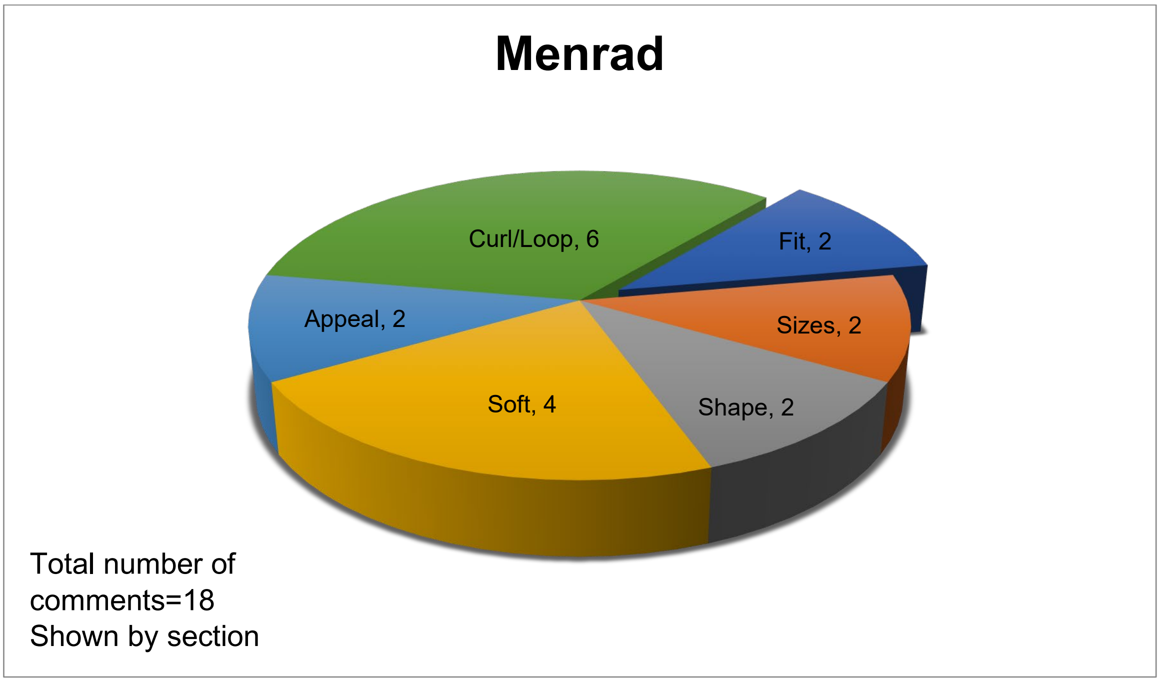


Figure 3.54.2h. Reasons given for using Menrad as a supplier for children aged between 1-3 years.

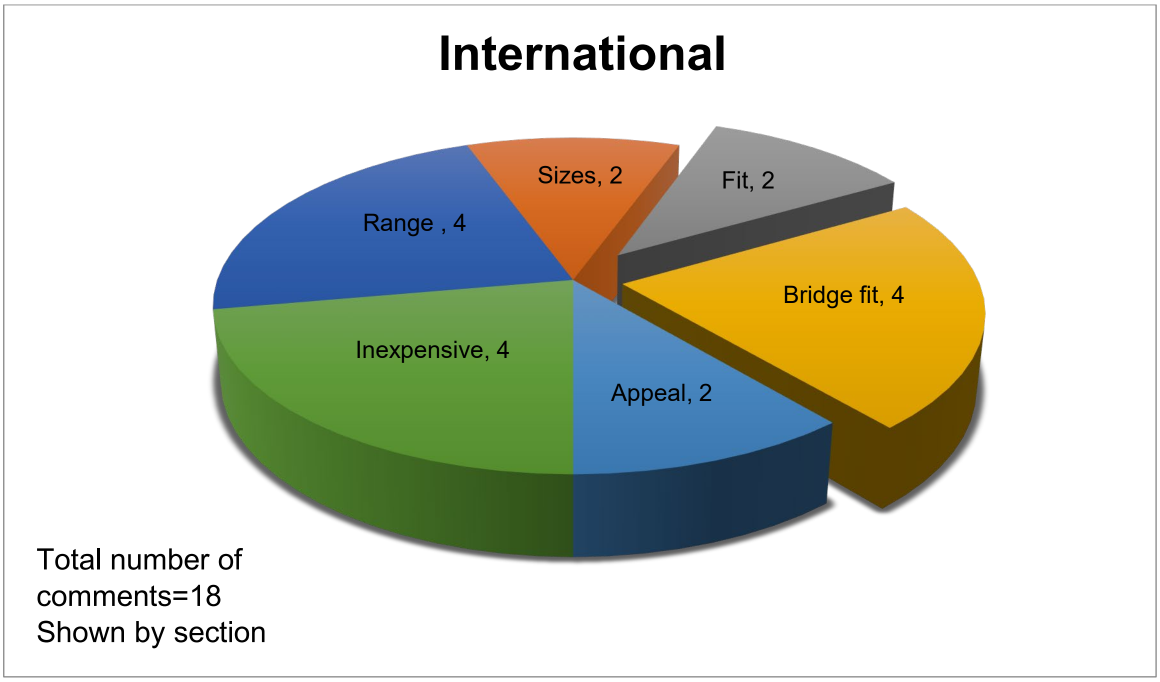


Figure 3.54.2i. Reasons given for using International as a supplier for children aged between 1-3 years.

For this age group we see approximately 50% more companies mentioned, but Miraflex™, Centrostyle™ and Tomato™ retain the majority share for this market. It is interesting to note very few respondents mention the range for these three, but this is a significant feature for Dunelm and Norville. What they do note are the appealing designs, fit, adjustability, bridge fit and range of sizes. Strength and comfort are also noted more for the top three, but this appears to be at a price since cost has been mentioned. Where price is a factor there appears to be little noted alongside in terms of quality, fit and adjustability of the frames dispensed with little in the range of sizes expressed (except for the supplier Continental). This may indicate a shift in practitioner behaviour towards these patients where more companies are offering a range that may not fit perfectly, may not be of premium quality or have a range of sizes, but is appealing to the child and parents/carers and therefore the practitioner performs the best dispense and fit they can with the product that is selected.

3.54.3 Children aged 4-6 years

Figure 3.54.3a. Word Cloud showing suppliers or ranges named for children aged 4-6 years. The larger the font size, the more frequent the supplier was used.

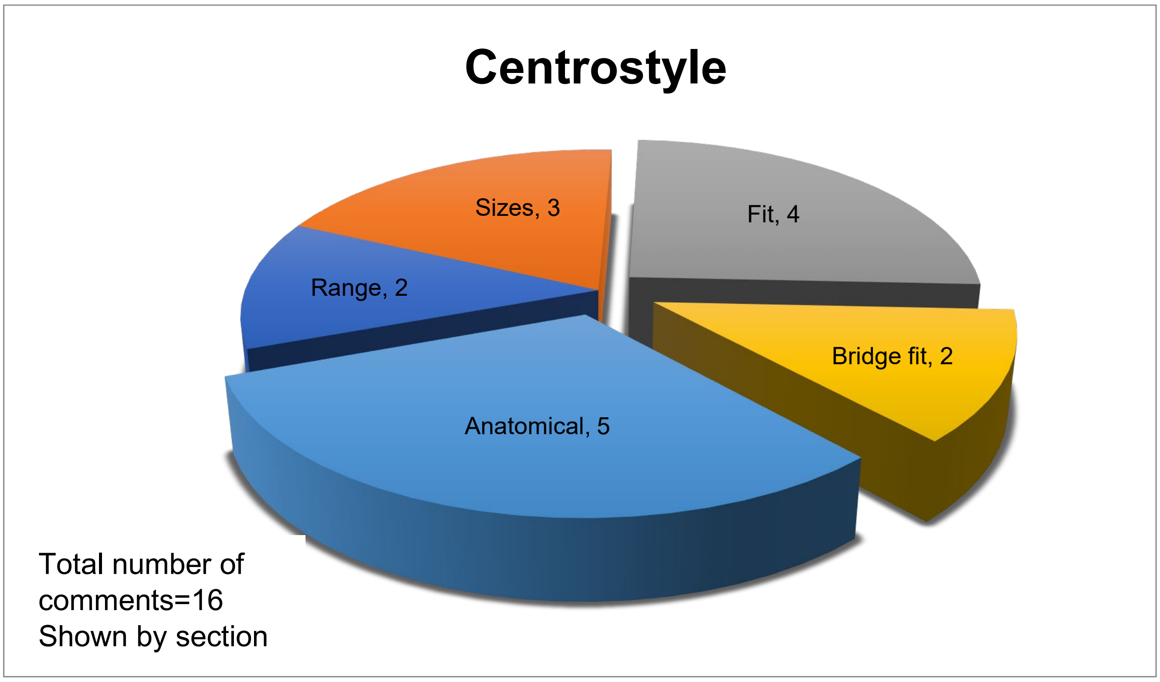


Figure 3.54.3b. Reasons given for using Centrostyle as a supplier for children aged between 4-6 years.

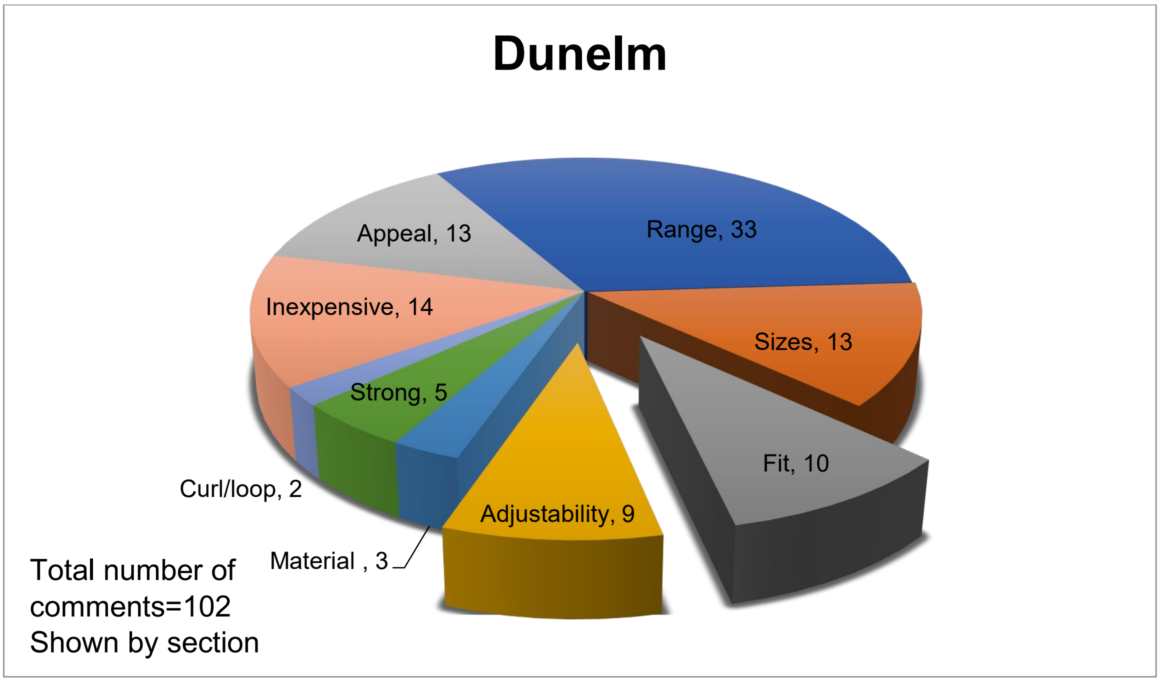


Figure 3.54.3c. Reasons given for using Dunelm as a supplier for children aged between 4-6 years.

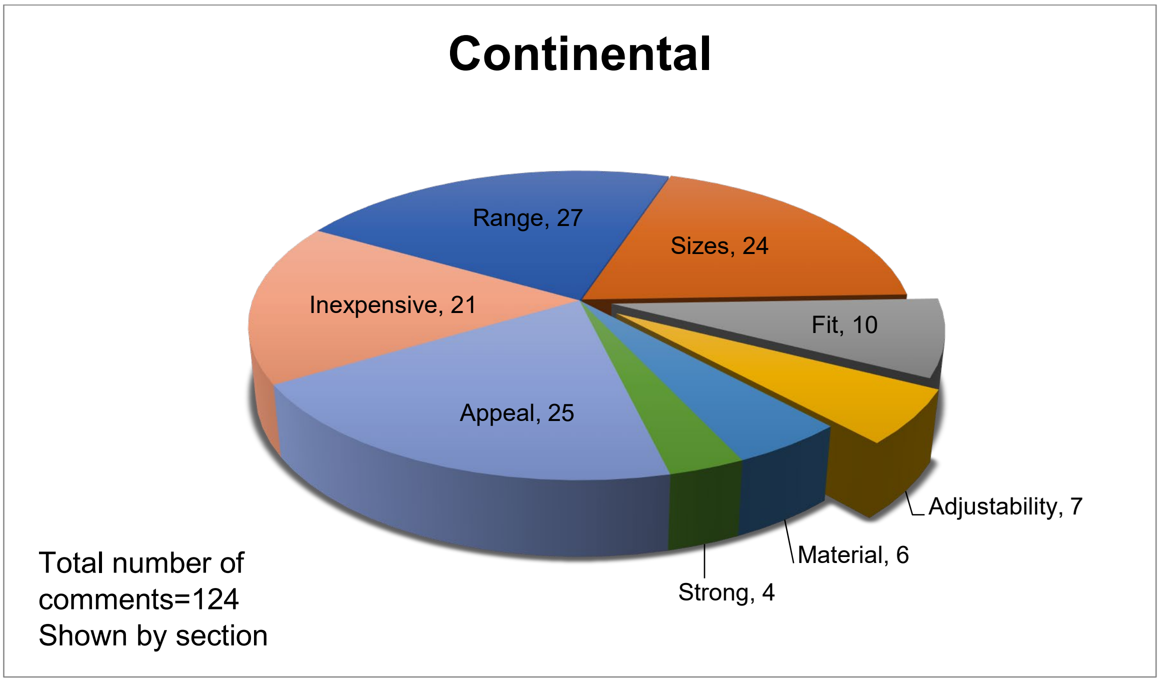


Figure 3.54.3d. Reasons given for using Continental as a supplier for children aged between 4-6 years.

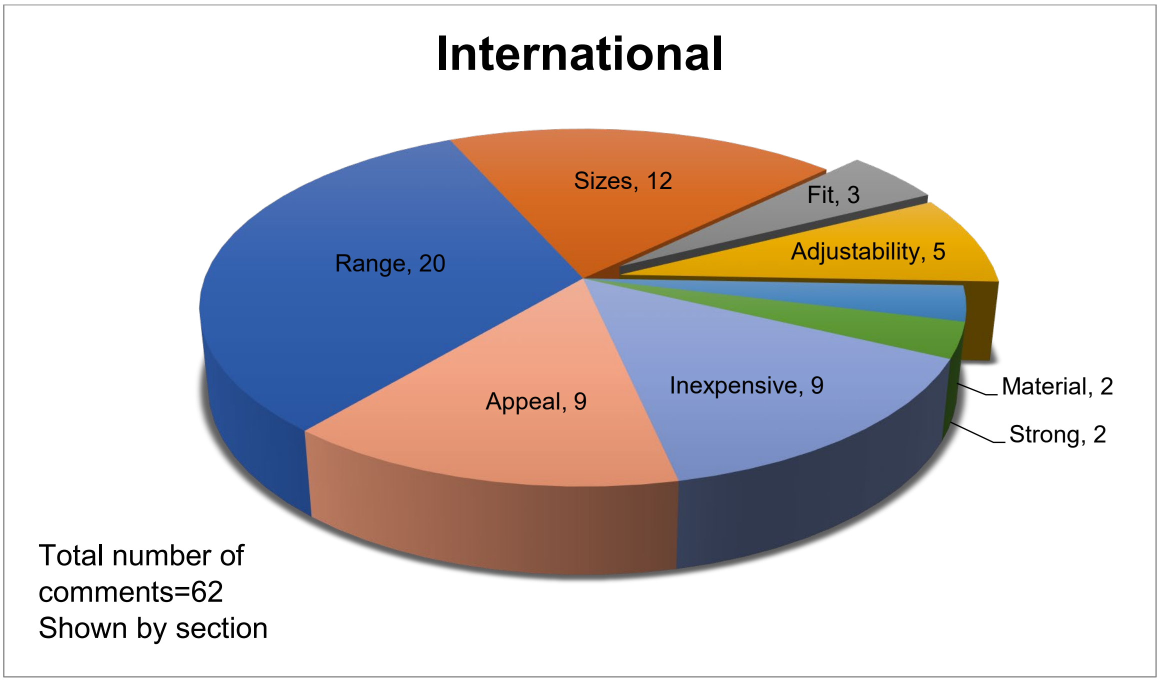


Figure 3.54.3e. Reasons given for using International as a supplier for children aged between 4-6 years.

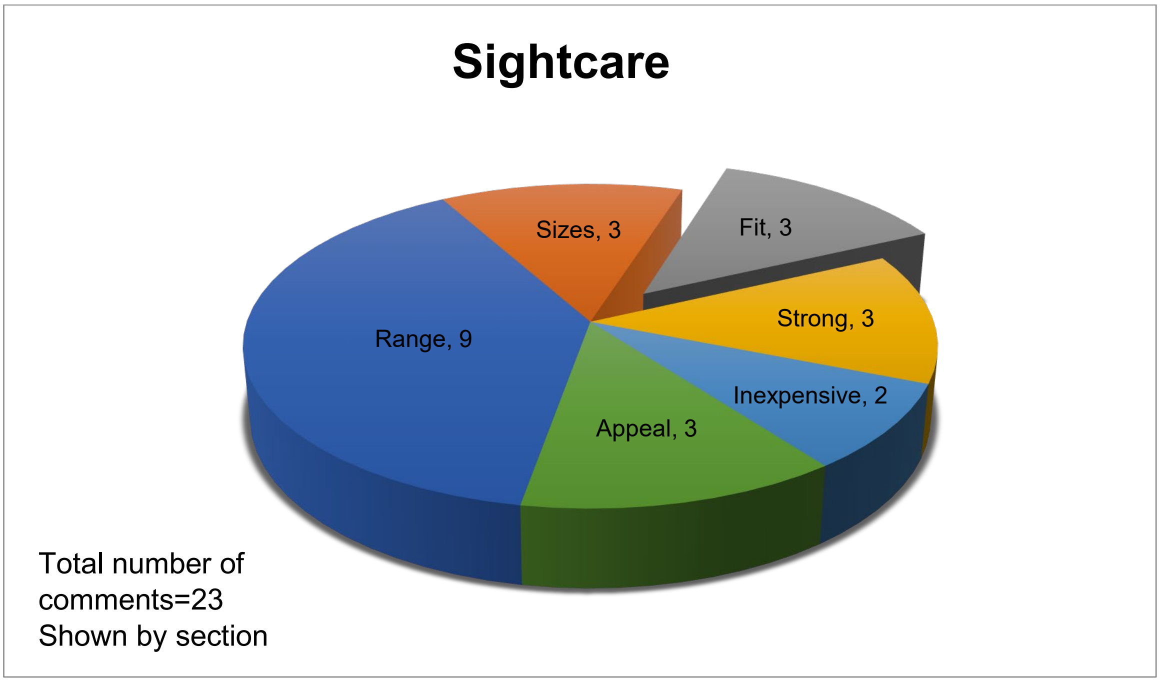


Figure 3.54.3f. Reasons given for using Sightcare as a supplier for children aged between 4-6 years.

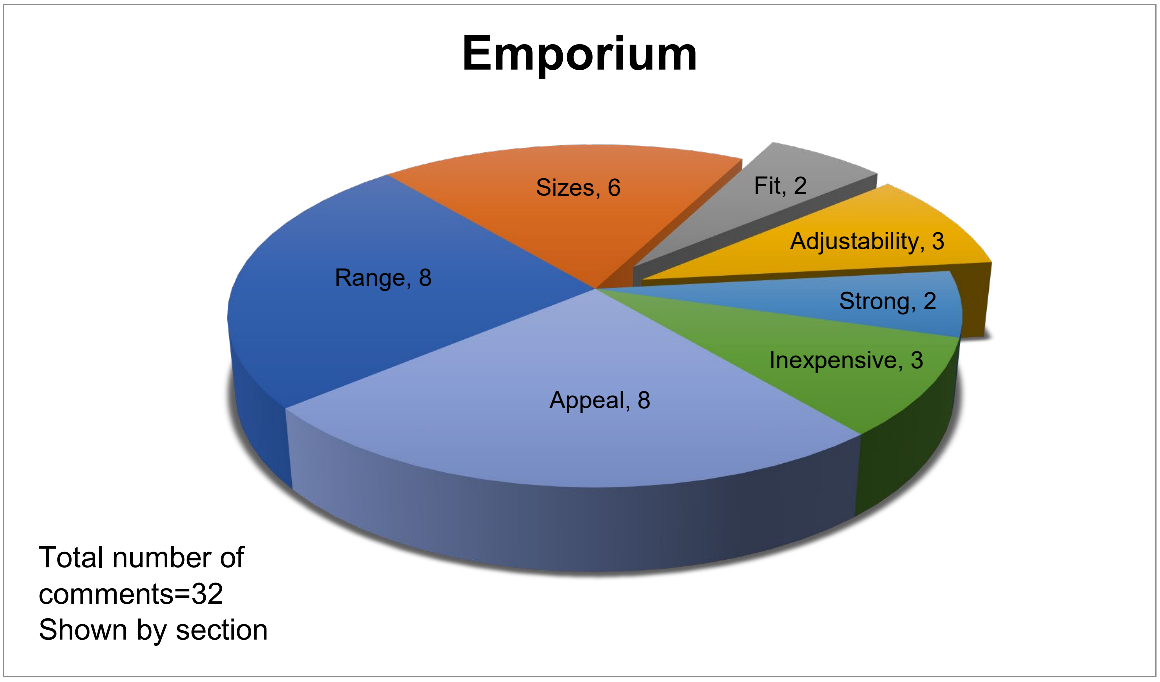


Figure 3.54.3g. Reasons given for using Emporium as a supplier for children aged between 4-6 years.

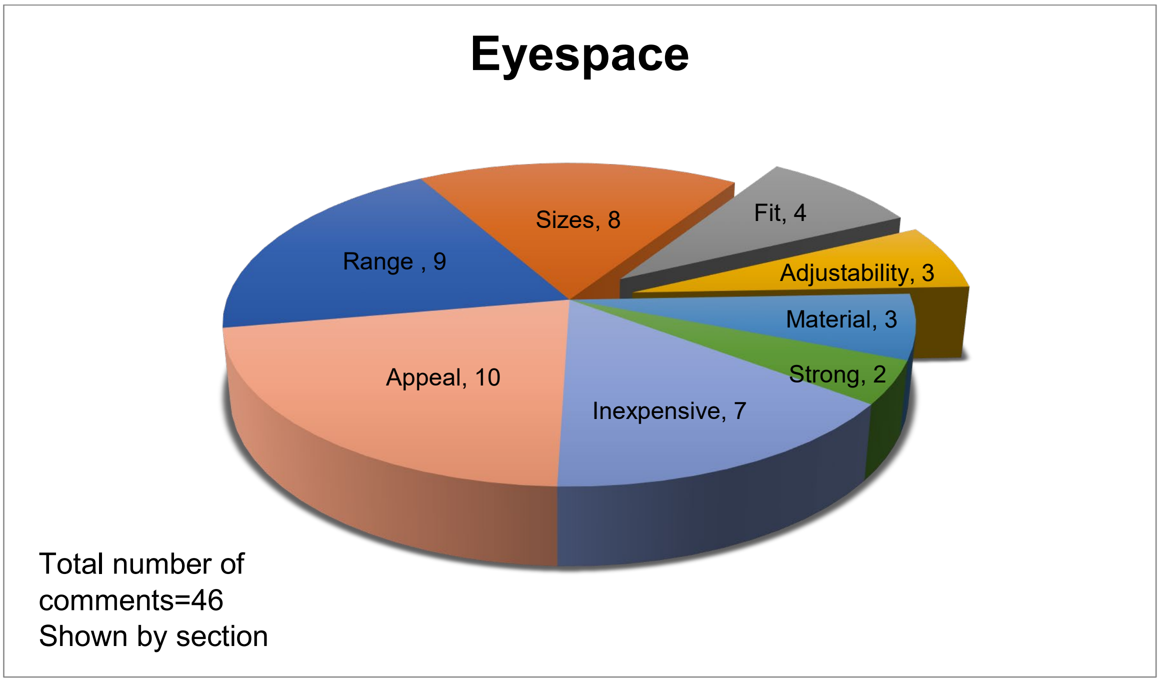


Figure 3.54.3h. Reasons given for using Eyespace as a supplier for children aged between 4-6 years.

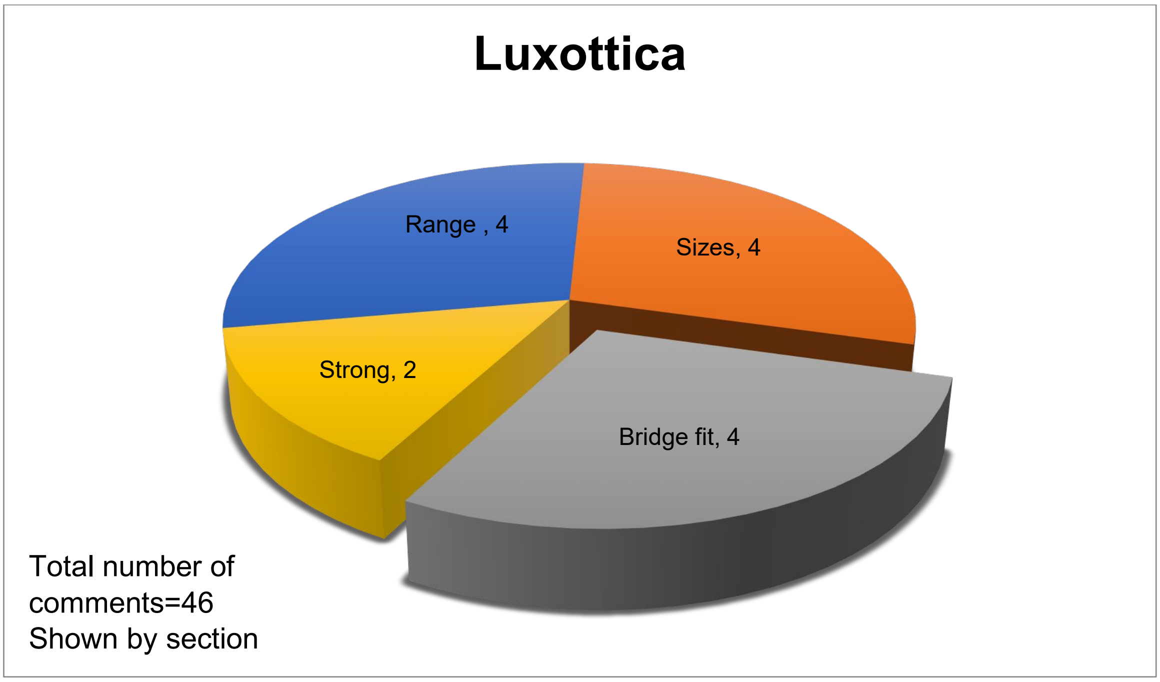


Figure 3.54.3i. Reasons given for using Luxottica as a supplier for children aged between 4-6 years.

Despite their ranges extending into this age bracket, Miraflex™ and Tomato™ are no longer mentioned as a supplier and the range is considerably larger with 57 '*others*' in addition to those named. Size is a frequent reason cited despite most models only come in one size from the common suppliers reported so this maybe because the larger ranges on offer influence this.

For this age range, we now see a multiple practice's internal range meet the criteria of 5 votes which is surprising as there is a fairly even split between respondents working for independent and multiple practice. This could be explained that for the younger patient, a certain degree of buying power is still an option, even for those working for multiples where the buying is generally centralised.

Respondents seem to be happy with the '*fit*' being mentioned several times for Dunelm and Continental which may indicate that children of this age are easier to fit, i.e. their anatomical features are similar to a small adult. Many respondents mention the '*mini-me*' and '*scaled-down adult*' descriptive of ranges and yet affordability and appeal seems to be an overriding feature rather than adjustability of the sides and appropriate bridge fits.

There is also now a distinct lack of mention of appropriate lens shapes, again this may indicate that the child's bridge is developed enough to support the shallower lens shapes that are heavily influenced by fashion. Alternatively, it may be that the initial fit seems satisfactory however the resultant fit once the frame has slid down the nose to find anchorage means that the child potentially looks over the top rim of the frame.

Comments relating to safety and comfort are distinctly lacking too, along with an option for curls and loop sides. These frames are available for this age range and it would be unusual for a 4 year old to be dispensed without safety in mind or the security of keeping a frame on with a curl side. This age group may be starting to take more of an interest in their own frame choice, and along with the parents/carers view, the cosmetic appeal and the desire for the '*mini-me*' look of the frame overrides other factors.

3.54.4 Children aged over 7 years

Figure 3.54.4a. Word Cloud showing suppliers or ranges named for children aged 4-6 years. The larger the font size, the more frequent the supplier was used.

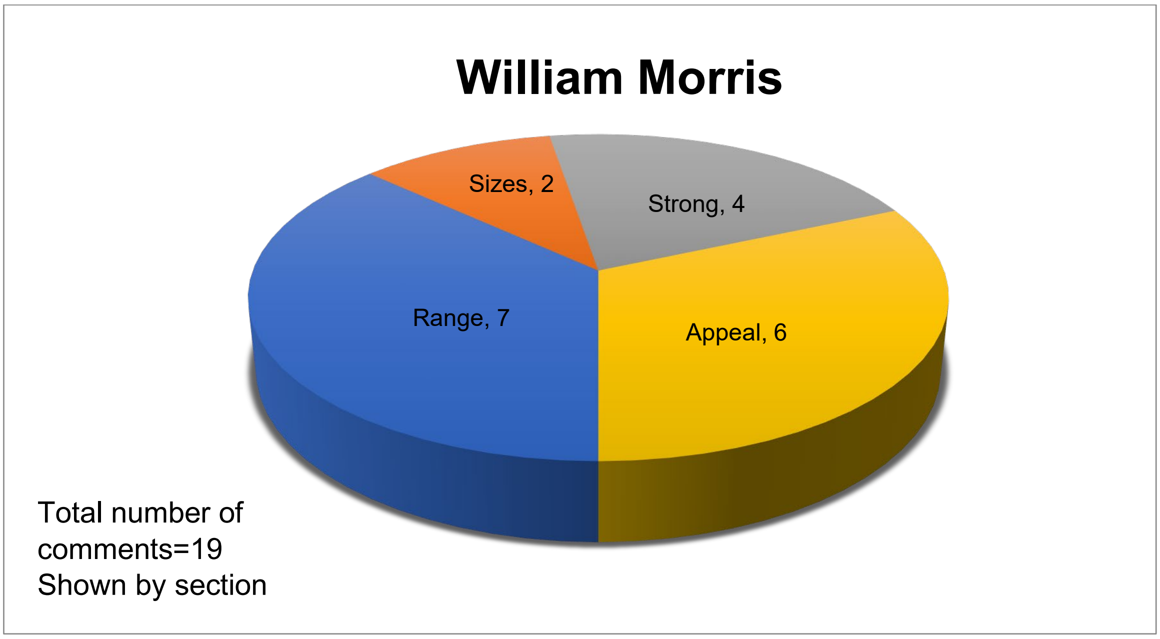


Figure 3.54.4b. Reasons given for using William Morris as a supplier for children aged over 7 years.

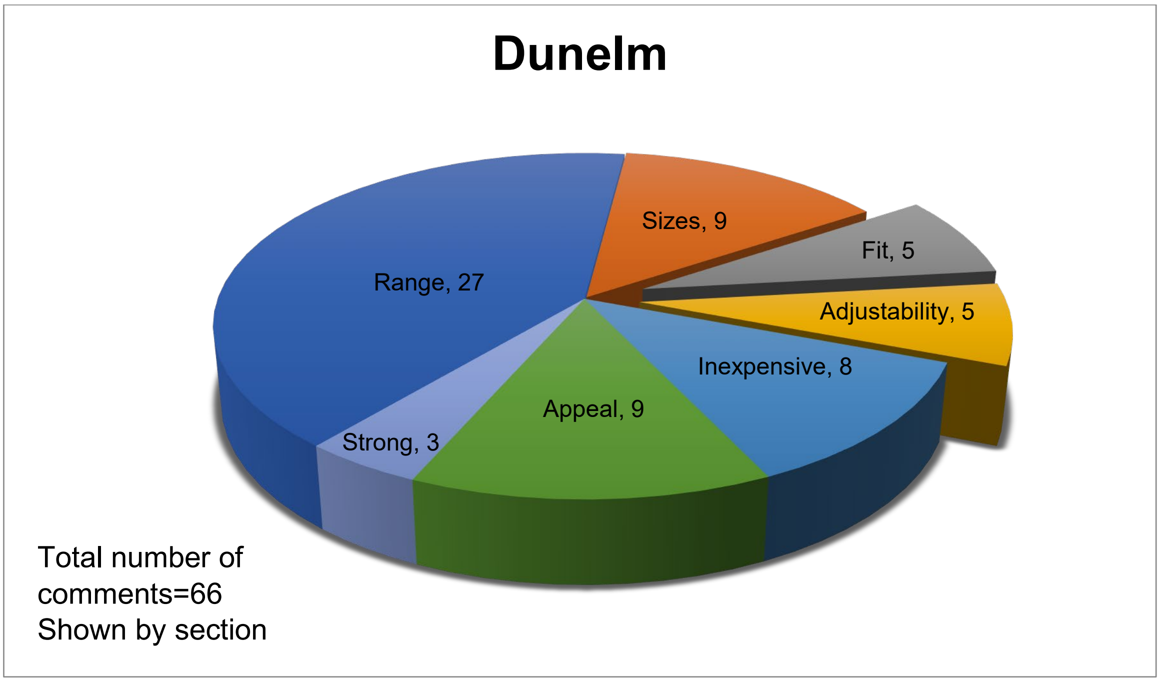


Figure 3.54.4c. Reasons given for using Dunelm as a supplier for children aged over 7 years.

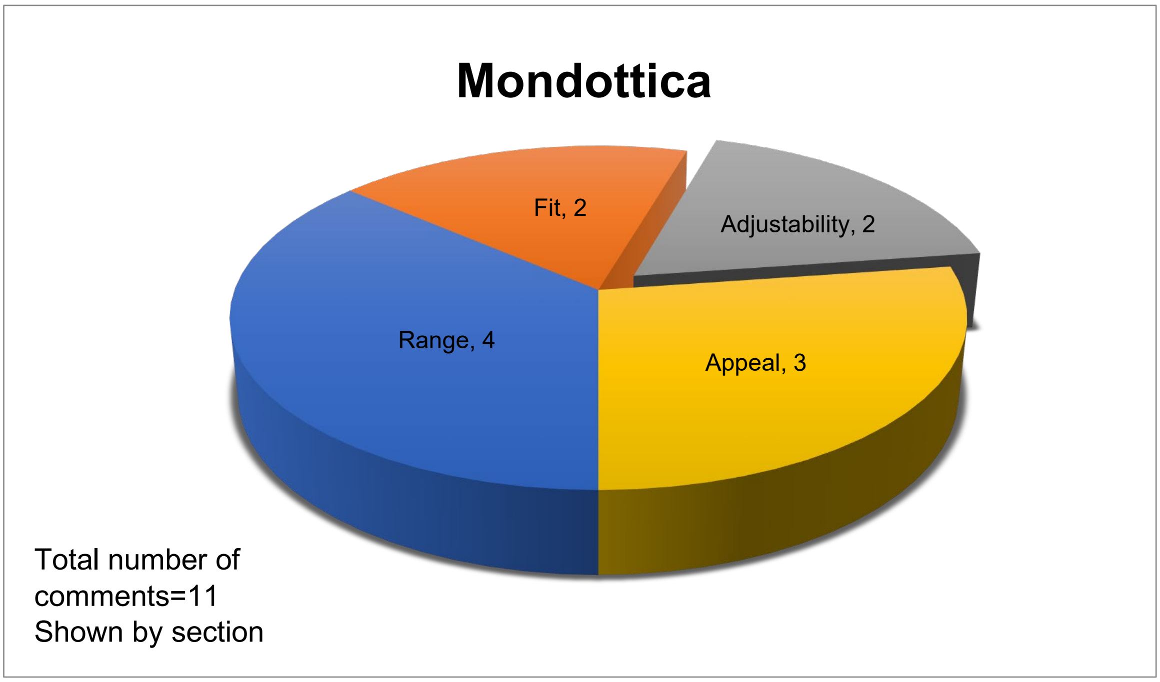


Figure 3.54.4d. Reasons given for using Mondottica as a supplier for children aged over 7 years.

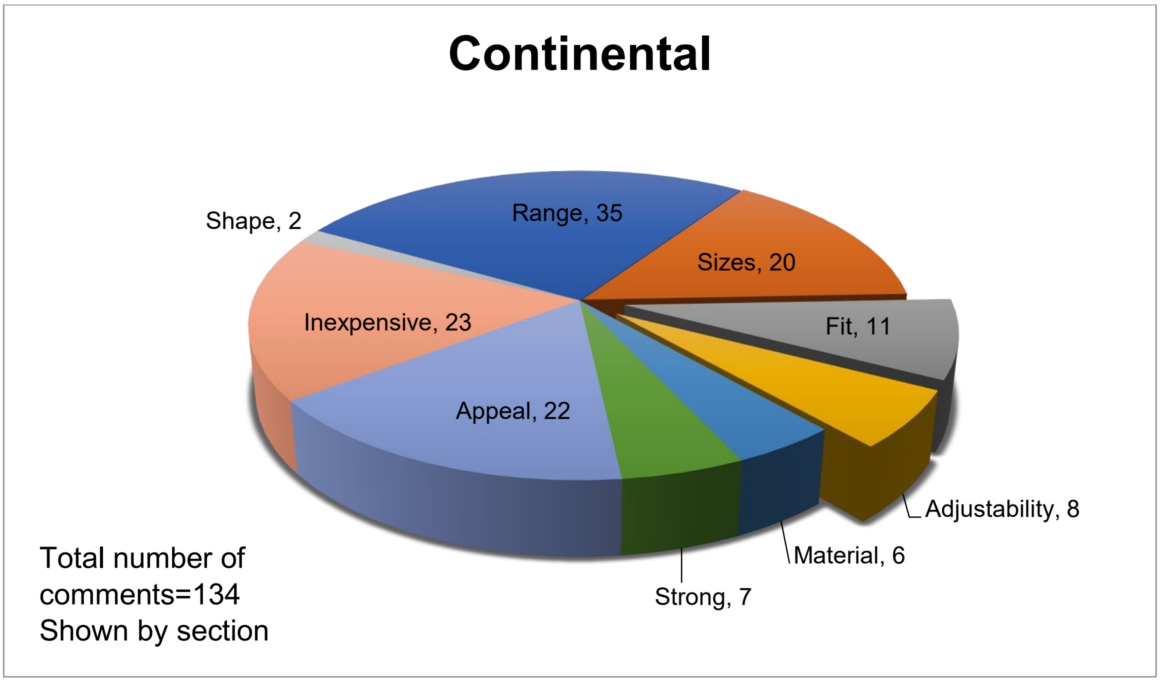


Figure 3.54.4e. Reasons given for using Continental as a supplier for children aged over 7 years.

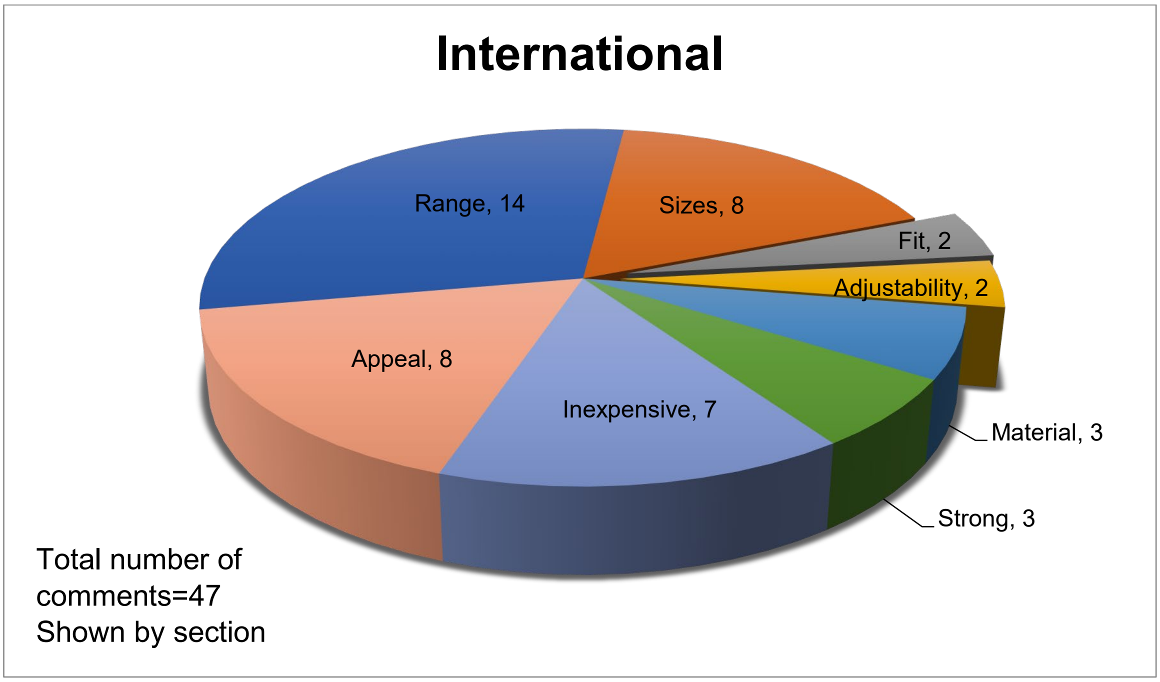


Figure 3.54.4f. Reasons given for using International as a supplier for children aged over 7 years.

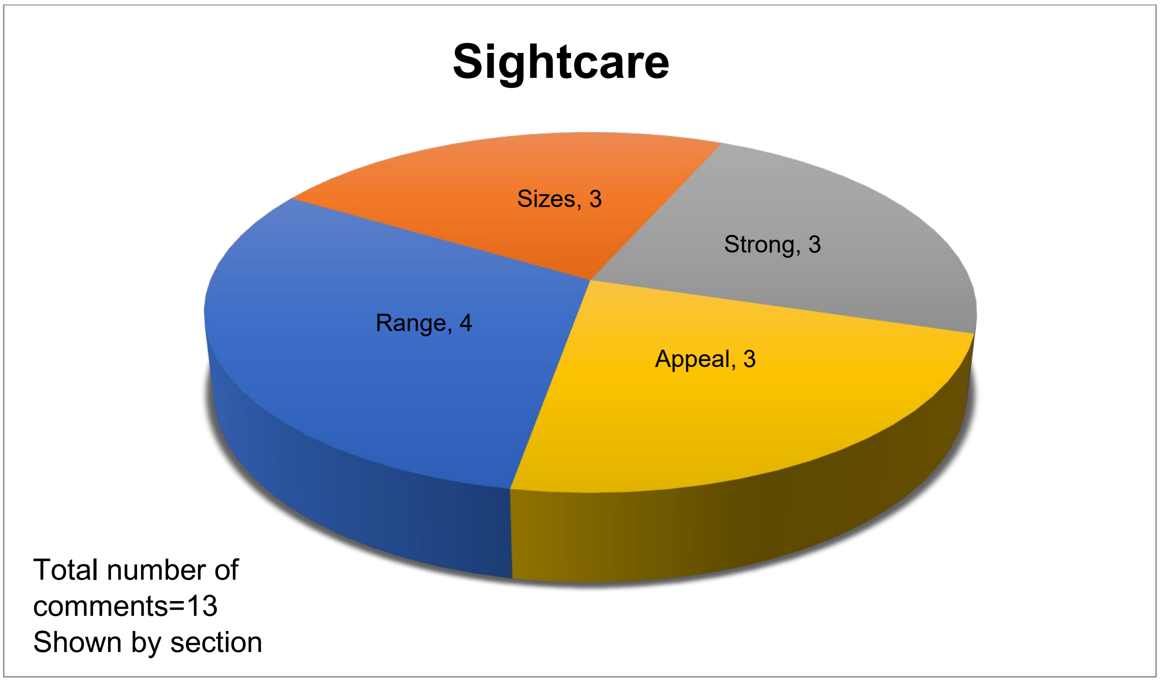


Figure 3.54.4g. Reasons given for using Sightcare as a supplier for children aged over 7 years.

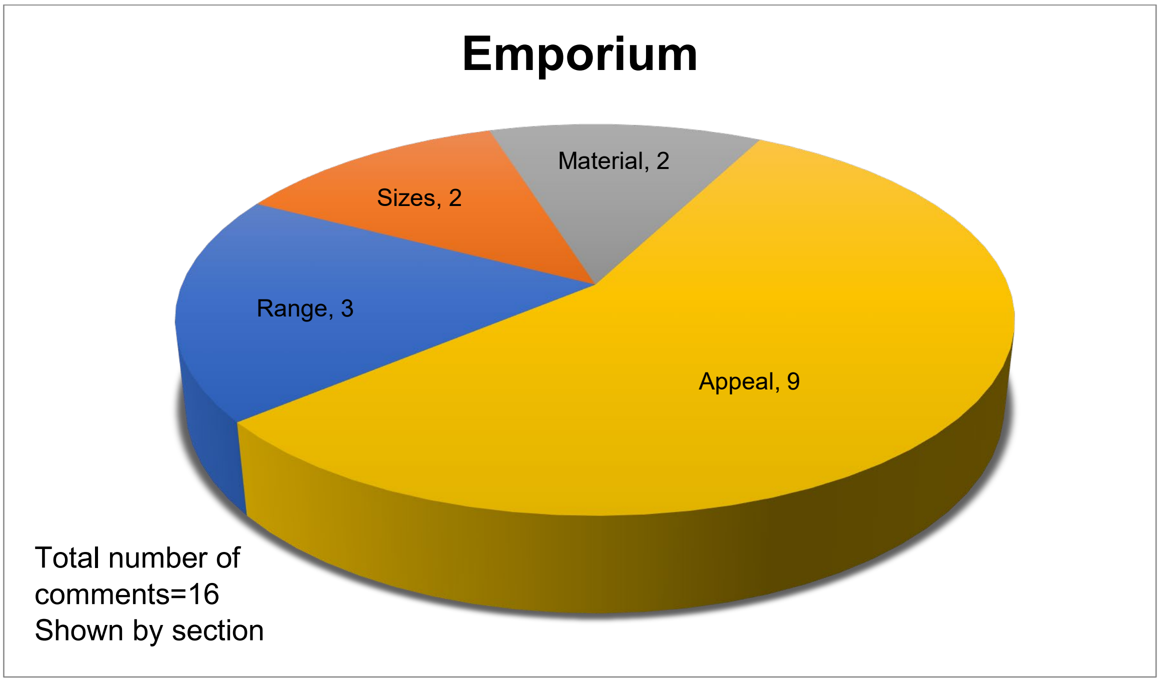


Figure 3.54.4h. Reasons given for using Emporium as a supplier for children aged over 7 years.

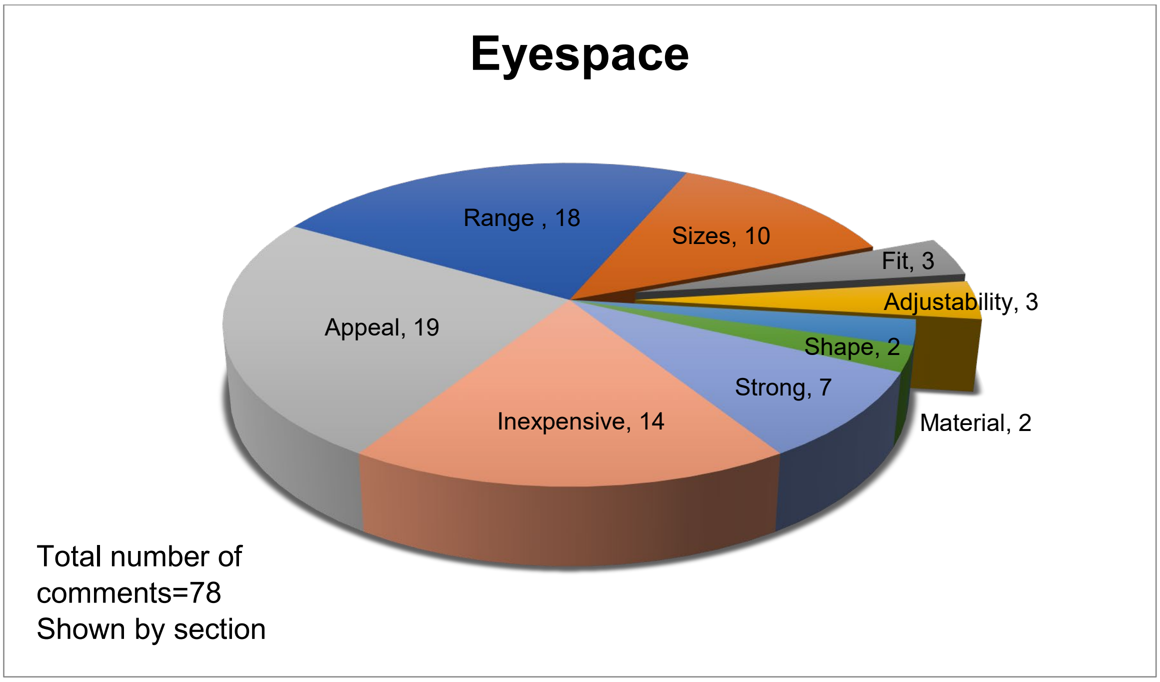


Figure 3.54.4i. Reasons given for using Eyespace as a supplier for children aged over 7 years.

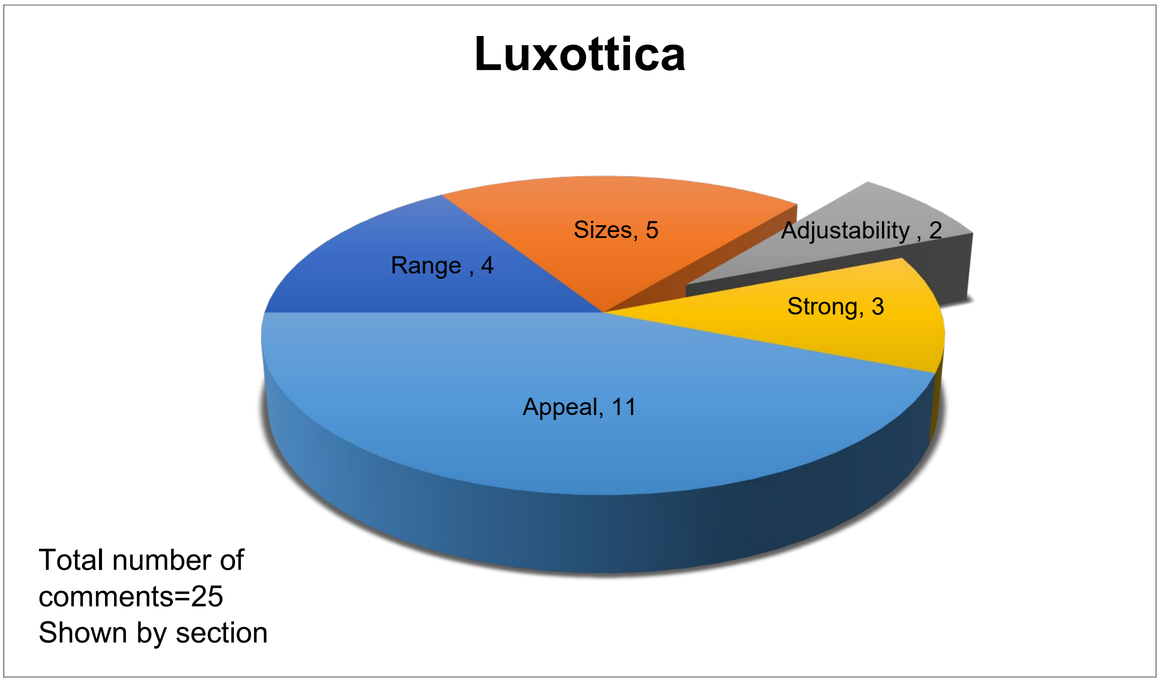


Figure 3.54.4j. Reasons given for using Luxottica as a supplier for children aged over 7 years.

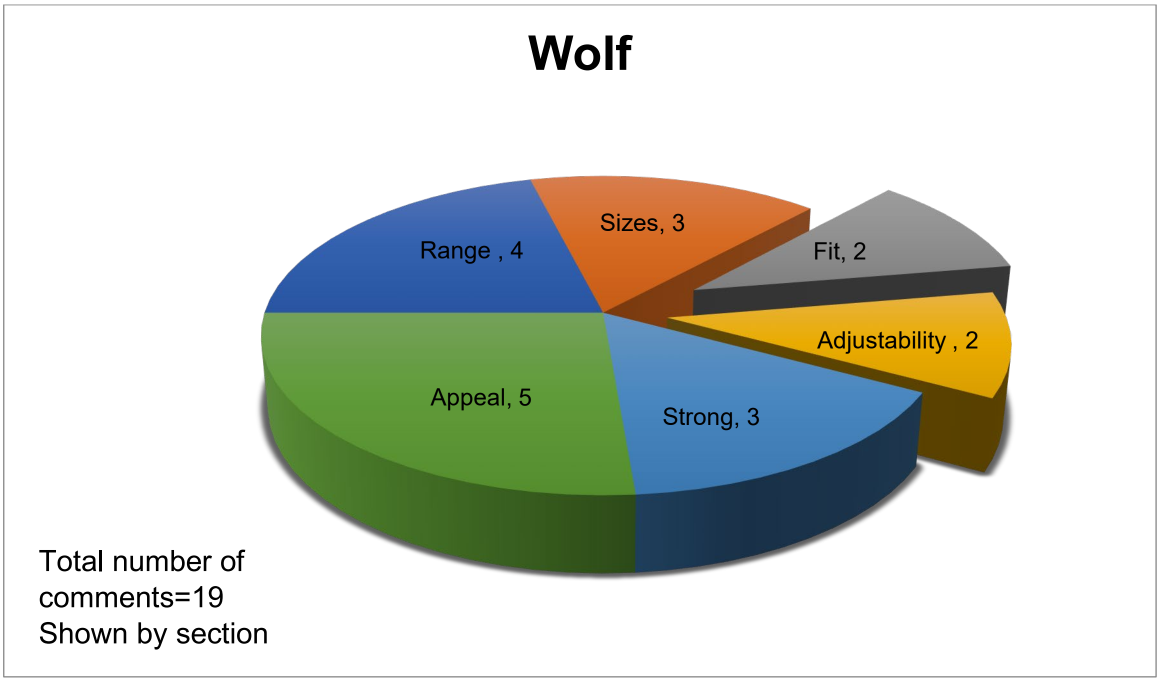


Figure 3.54.4k. Reasons given for using Wolf as a supplier for children aged over 7 years.

For this age range, the choice increases yet again and companies appearing that do not necessarily market at very young children but do aim at younger teenagers with less character but more named brands. These ranges are characteristically small adult designs and follow trends in the seasons. This is further evidenced with many comments on appeal, designs and colours.

Again, range and sizes were a common comment although this may not necessarily infer there are a range of sizes per model, more likely the range is larger and hence more size options across a range. Additional comments mentioned lack of size options which then leads to whether this ultimately means disappointing the patient or fitting the only size in the desired frame to the best of the registrant's ability. The other most common comment was lack of side length choice, similar to the frame sizes, this is commonplace to be available in only one size and the design rarely allows for this to be shortened physically. Lack of adjustability comments concur with this, along with very few mentions of anything related to anatomical design such a low, wide bridge, rounder, deeper lens shape, sides adjustable or in different length options.

Summary of reasons for selecting frame suppliers

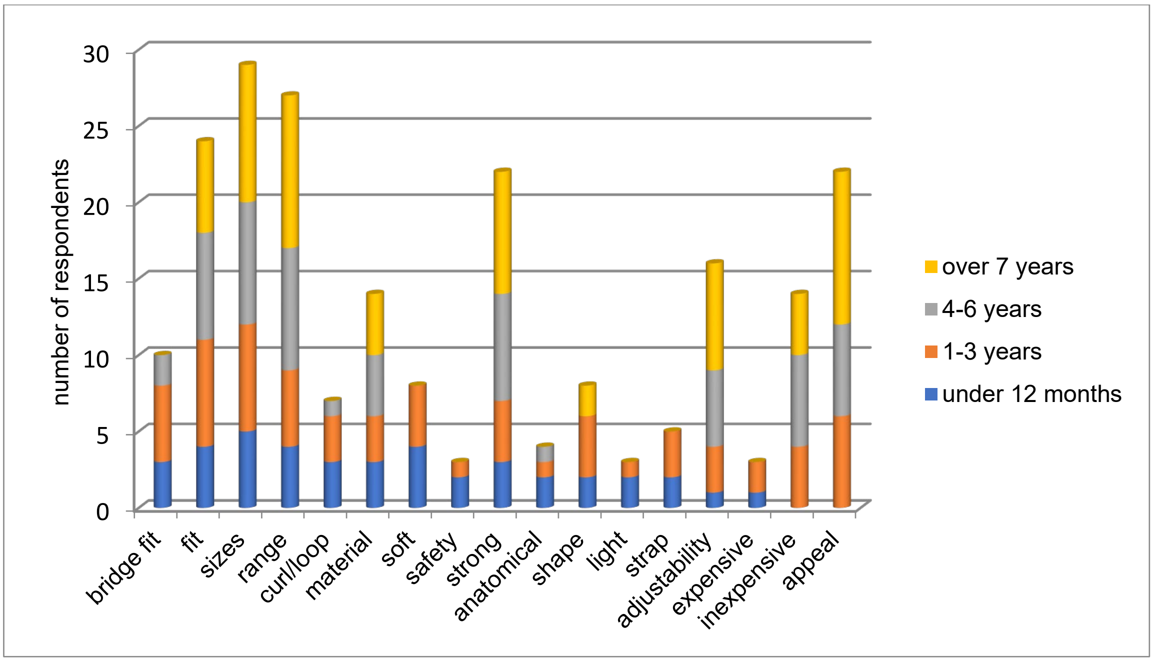
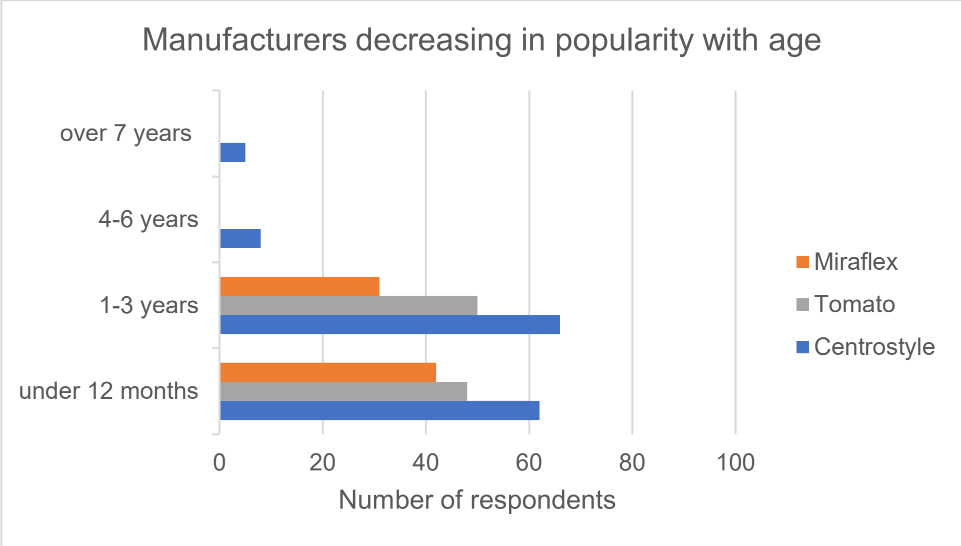


Figure 3.54.4I. Summary of reasons given for selecting particular suppliers shown by age groups.

It can be seen from the summary graph (Figure 3.5.4I) above:

- More reasons overall are given for selecting frame suppliers for younger children.
- Anatomical design and bridge fit are more prominent comments for the younger age groups.
- Safety and comfort (soft, lightweight) only appear to be considered for those children under 3 years old.
- Price (inexpensive) and appeal become more apparent for older children's frames.



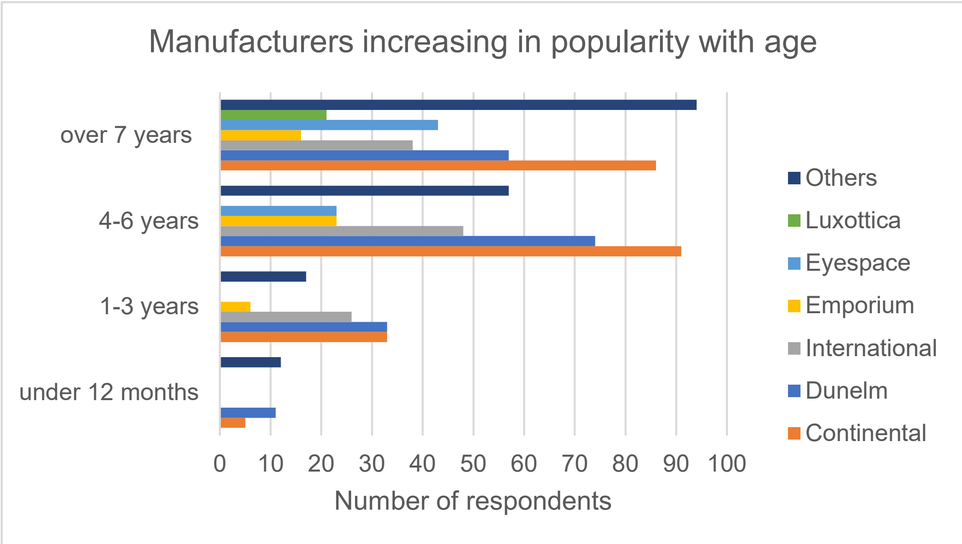


Figure 3.54.4m. Graphs to show frame suppliers decreasing in popularity (upper) compared to increasing in popularity (lower) with age who received more than 20 votes.

From the summary graph above (figure 3.54.4m) we can see the decline in popularity of Centrostyle™, Tomato™ and Miraflex™ from initially holding the majority of the market share for under 12 months to zero for the group aged 4-6 years (except Centrostyle™). These styles and ranges are available above this age group therefore it is reasonable to assume that it is the design of these spectacle frames and therefore lack of appeal to either children or their parents/carers. Despite being manufactured and marketed with the child's anatomical features at the forefront of designs, parents/carers often will not take advice on the fit from professionals and influence children themselves into being more concerned with fashion and character-branding. Regardless of the fact if a curl or loop-end side will help the spectacles stay on due to the under-developed bridge, there is a natural reluctance for their child not to 'stand out' from the crowd and in addition a concern on how their child will be regarded by their peers.

We also note the larger range of choice as the child becomes older than 3 years, depicted by the huge range of '*others*'. Again, these are not necessarily frame ranges designed for a child with developing facial features, the branding of characters and appeal become more important and scaled-down versions of parent/carers frames remain popular.

In addition, popular brands for '*appeal*' seem to decline for children over 7 years of age. As this category includes children up until the age of 16 years, there will naturally be increased choice as potentially the practice's adult range may now fit some of these older, more developed children.

3.54.5 Future frame requirements

The majority of respondents agreed that frame manufacturers need to improve their ranges 85.5% '*yes*', (3.2% '*no*' and 11.3% '*unsure*') Indeed over three-quarters of respondents rate their own frame range '*average*', '*poor*' or '*dreadful*' in terms of eye sizes (figure 3.51a) and when questioned in an open text format what they would like to see (figure 3.54.5) most alluded to the range of eye sizes, the shape of the eye-rim, the bridge positioning, the side length availability and overall adjustability of the frame design and material. Conversely, the cosmetic appeal was rated highly as 'good' or 'excellent' in almost 80% of responses, showing that the manufacturers are producing frames that children want to wear irrespective of fit.

In general sizing, respondents requested more choice (23.2%) with specific requests of wider head widths (5.9%) and a lower positioning of the lugs (1.1%).

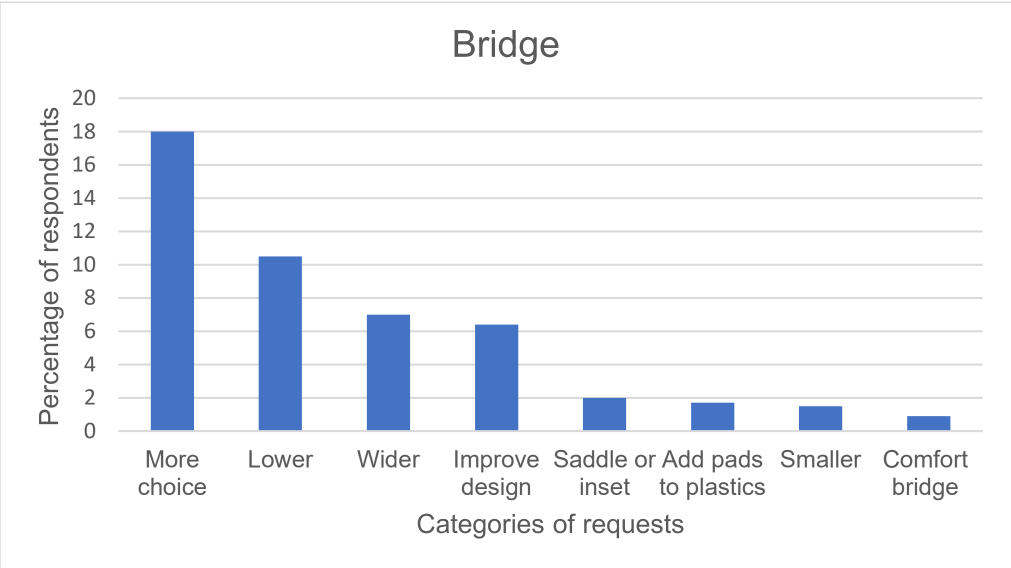


Figure 3.54.5a. Graph to show responses relating to the bridge of a spectacle frame.

Comments received are comparable to the previous sections in the requirement for a general wider choice of sizes amongst children's frames. It was interesting the see the level of detail respondents noted, especially bridges where the general fit needs more options, plastics are not designed well but generally they need to be wider (distance between lenses and bridge width) and lower in position. Eight respondents requested smaller bridges which is contradicting the majority, yet it may be explained that as children are generally smaller than adults, they may perceive parameters are required to be smaller to fit the small, flat nose rather than the lack of bearing surface which requires a much wider, lower bridge to make adequate contact and support the spectacles.

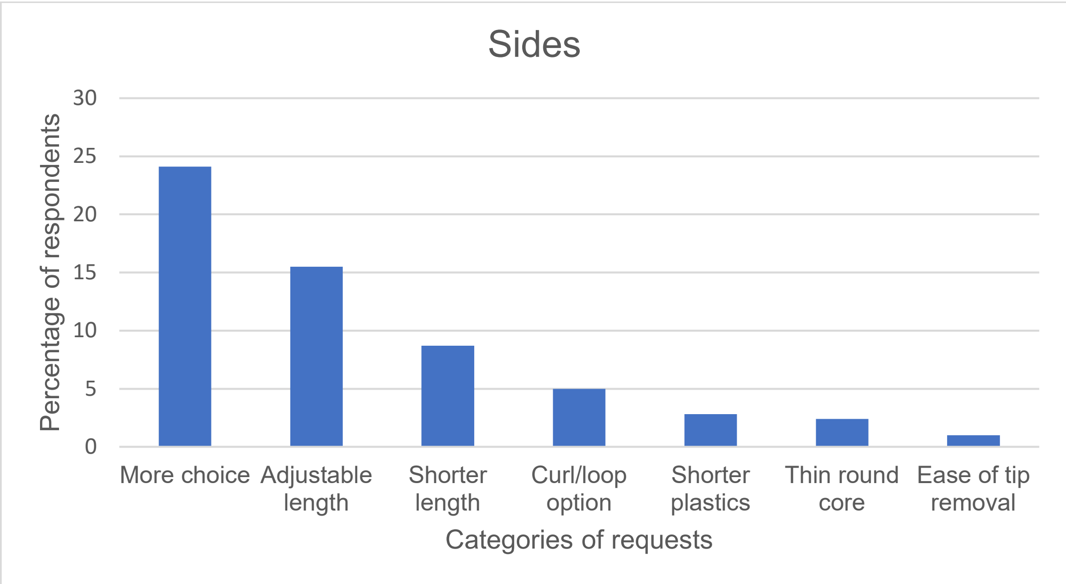


Figure 3.54.5b. Graph to show responses relating to the sides of a spectacle frame.

Most wanted to see more side length options but generally wanted them to be shorter which may indicate that registrants struggle to shorten the sides physically and this may then have the resultant effect of a very long drop sitting behind the child's ear causing discomfort and being cosmetically unacceptable. Only two respondents asked for a larger length to bend measurement which can be required occasionally. There appears to be no options on side lengths and unless the side wire is round, relatively thin and made of a metal that can be cut, the adjustability can be an issue in achieving a physically shortened side and hence satisfactory fit.

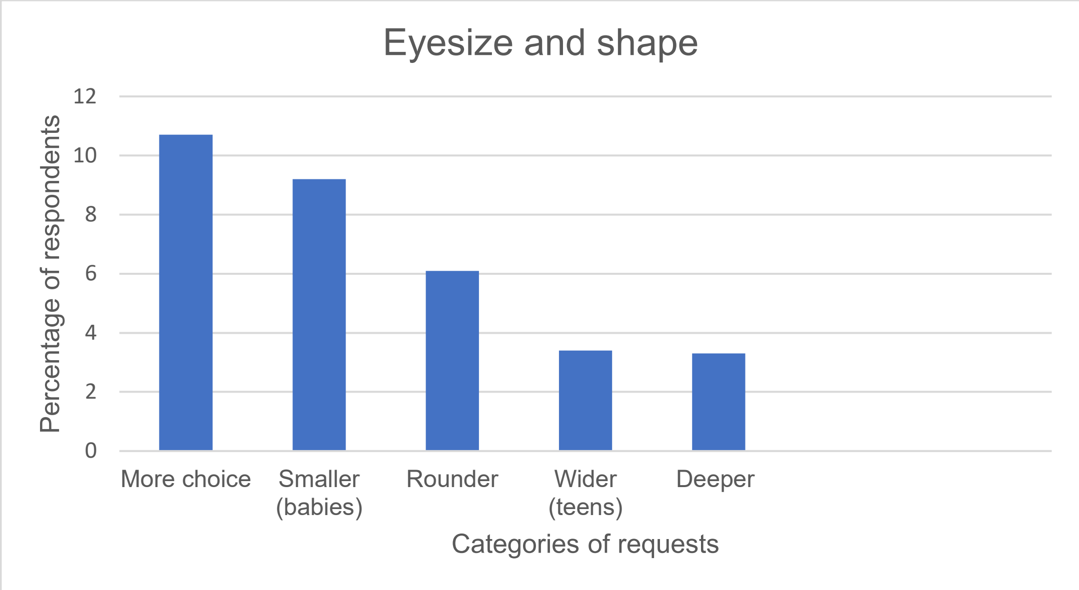


Figure 3.54.5c. Graph to show responses relating to the eyesize and shape of a spectacle frame.

Whilst many called for a wider range of eyesizes, it appears that the extreme ends of the age range of paediatric patients have even less choice, i.e. smaller for the babies and wider for the teens. In terms of fit, the call for anatomically-based design was a common request, as was ‘age-appropriate’ that could be interpreted as the same thing although children of similar ages or ethnicities may fall into widely different size categories so age bracketing frames might not be as successful as hoped. Similarly, pupillary distance has been discussed as a parameter for frame size categories but in this response, 31 respondents asked for frames designed for children with a narrow pupillary distance but wide head and short sides. This translates to a frame with a small eyesize but a wide lug and a short length to bend. Eye shapes have also been requested to be rounder and deeper to avoid the child looking over the top as is commonplace with a shallow rectangular design. The current prevalence of rectangular designs highlights the influence of fashion in adult frames with respect to the design of paediatric spectacle frames.

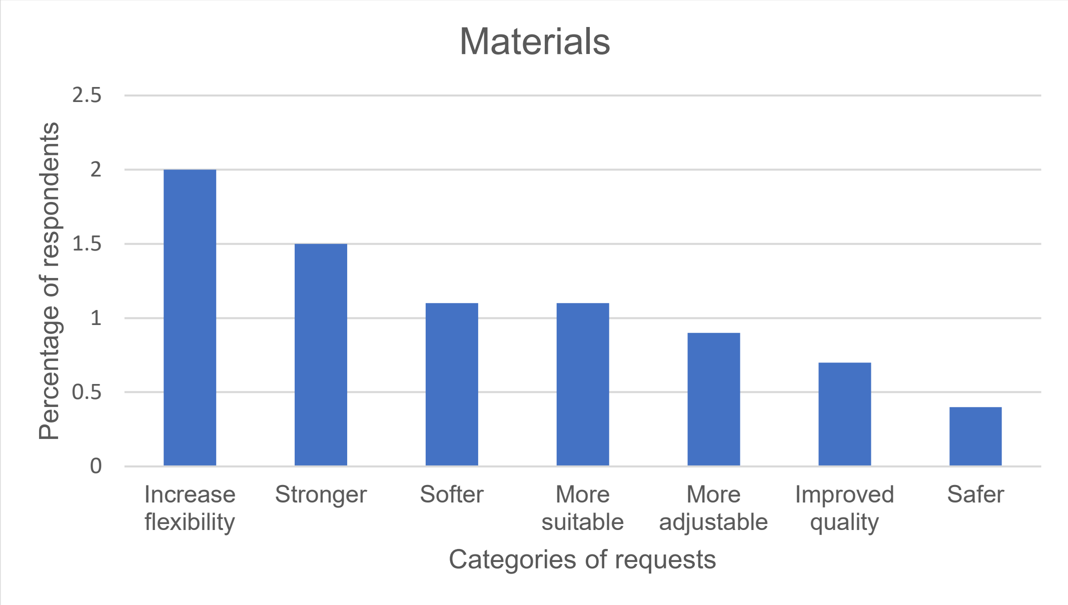


Figure 3.54.5d. Graph to show responses relating to the materials used in frame manufacture.

Ease of adjustment was found to be another request from the questionnaire respondents 9.4% – to have an adjustable material with sides that can be shortened, angles that can be changed, different side options such as curl, loop or band, different pad types or even the option of adding pads on arms to a plastics frame.

This was an open text, undirected question about what the registrant would like to see produced by spectacle frame manufacturers and many actually noted what they no longer wanted and called for manufacturers to actually '*stop making*' small adult designs (7.7%) with rectangular eye shapes (2.4%) and thick, flat side wires (1.3%) that cannot be shortened or adjusted.

Additional comments praised the designs of many spectacle frames but questioned why there was no choice on any size parameters and a total lack of adjustability. This indicates there may be a trade-off here between what the child (or parent) wants in terms of cosmetic appearance, designer brand, shape and colour and which compromises the fit.

For a range of small eyesizes suitable for babies or very young children, very few practices appear to stock these with only 12.8% stocking 33-36mm and only 5.8% stocking anything smaller. General practice may suggest these would be ordered in for a patient, rather than stocked which reflects the limited number of these age groups presenting in general high street practice.

3.6 Frame selection

To investigate the behaviours of the respondent during the frame selection process, questions were posed in the form of three scenarios when dispensing a 5-year-old child, namely; letting the child browse alone, accompanied browsing with advice on fit, or selecting a suitable range presented in the dispensing area. There was also a free text 'other' option to capture any variations from these processes.

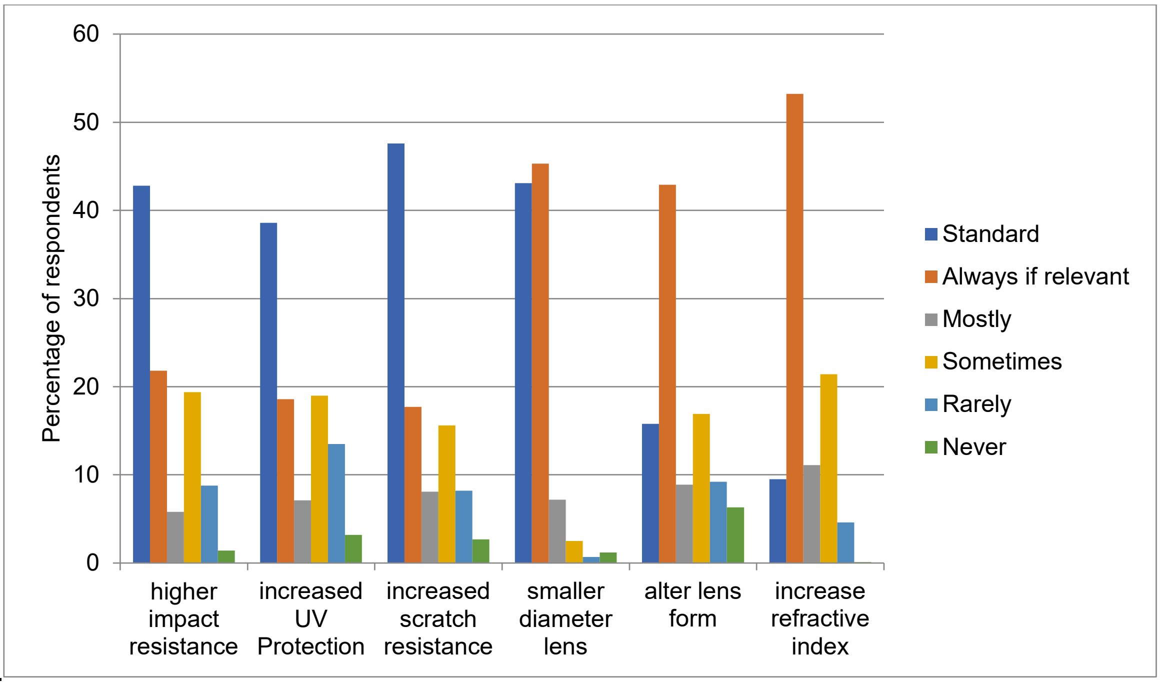
Overall, 67% of respondents will advise on fit during the browsing process and present a suitable selection to the patient, 28% said they would offer a selection of suitable frames in the dispensing area, hence not encouraging the child to browse the entire frame selection The 1% of respondents that chose '*other*' were mainly a combination of giving clear advice and educating parents/carers on what constitutes a good fit, accompanied browsing and then a selection presented for the child to make the final decision. Several respondents stated that they took facial measurements whilst others estimated the parameters required by looking at the child's face. Interestingly, there does appear to be further evidence here of the real balancing act into what the parents/carers want their child to look like, what the child themselves wants and a frame that fits the child, the latter being suggested as possibly less important than the look of the frame to parents/carers. Some respondents delegate this task to unregistered staff checking the final selection for fit as they cite the practice is just too busy for them to oversee this regulated function in its entirety. To that end it would be interesting to explore if the registrant then feels obliged to accept the choice presented by the non-registrant due to time pressure and not wishing to disappoint the child.

3.7 Dispensing lens options

The questionnaire then goes on to look at lens dispensing options and again, what is offered to the parents/carers as an option. It was acknowledged that some practices supply lens materials and coatings as standard to children. Thus, there needed to be an option to state this as supplying a product as standard is quite different from recommendation and informed choice. This is also reflected in the question on National Health Service (NHS) General Ophthalmic Services (GOS) vouchers and whether the cost of the spectacles is covered wholly, or in part, but more importantly, does the practitioner make any assumptions on whether payment contributions will be made and therefore offer full advice according to the child's individual needs.

In discussing lens options (figure 3.7a), many practices offer a superior product to children as standard which does negate the need to discuss products that may be beneficial. These include lenses which offer a higher impact and scratch resistance and enhanced ultra-violet protection. To improve the cosmesis of the lens, the form of the lens may be altered; that is the refractive index increased, or the minimum diameter of the surfaced lens calculated. The latter, relatively inexpensive option seems to be a common occurrence where almost 90% of respondents will do this as standard or offer if relevant to the patient. Altering the lens form or increasing the refractive index was still offered or supplied automatically by almost half of respondents, and yet *'sometimes'*, *'rarely'* or *'never'* is the action of at least 25% of respondents. This is often associated with the perception that children will change their lenses more frequently so the associated extra cost is not agreeable to parents/carers.

Where a GOS voucher covers the complete cost of standard spectacles for children, an option available in 84.7% of our respondent's practices, it appears to be uncommon to routinely mention the options to parents/carers and let them have an informed choice. It is interesting to see the reasoning of respondents to whether parents/carers either want to or are able to pay an additional cost to their child's spectacles, 5.8% only offer extra benefits if they assume the parents can afford it and 3.2% admit they assume the parents do not want to pay. In the case where the registrant always offers additional lens benefits, 48% state parents don't want to pay but 42.9% state parents will pay the extra cost so it is therefore understandable that assumptions are made however best practice would indicate if the benefit were relevant to that child, then the parent/carer having an informed choice is the best option.



.

Figure 3.7a. Graph to show the frequency of discussing non-standard lens options.

The above is further evidenced by asking whether the child's hobbies and activities are ever explored during the dispensing process. Many children are extremely active and activities such as sports, swimming, outdoor pursuits may all have a need for either prescription eyewear and/or extra protection in terms of safety or ultraviolet protection, yet only 53.1% of respondents *'always'* or *'mostly'* have this discussion.

British Standards 2738 Part 3 (British Standards Institute, 2004) dictates that for any prescription offered over a +/- 5.00D, there needs to be a vertex distance stated on the prescription. This is important to record because any variation on the vertex distance, measured from the apex of the cornea to the back surface of the lens, would mean the eye receives a significantly different prescription due to effectivity and therefore must be compensated by ordering a different prescription of lens to that which was prescribed. A form of spreading calliper is the usual method with the older patient instructed to close their eye. This method was favoured by 7.9% of respondents, possibly because for a young child this may be more dangerous as the calliper sits on the closed eyelid therefore remaining still and calm for a few seconds may be impossible. Viewing the distance from the side of the patient gives a reasonable ruler measurement, 88% of respondents use this method, but it is sometimes difficult to judge the back surface of the lens if the frame rim is fairly thick. Others opted for digital measurement but again, any device has limitations due to the estimation of where the lens sits as above. Respondents were asked if this measurement was always checked as per the Standard, 8.6% reported '*no*' and 26.6% rated '*sometimes*' which is quite concerning. One issue that may impact on this is the lack of testing distances being recorded, especially by the Hospital Eye Service (HES) where ophthalmologists may not rely on a standard method of arriving at the prescription in a young child; hence there is no distance to record.

3.8 Spectacle collection

This section looks at the typical routine of what happens when the child collects their spectacles and what adjustments, or modifications are made with what degree of frequency.

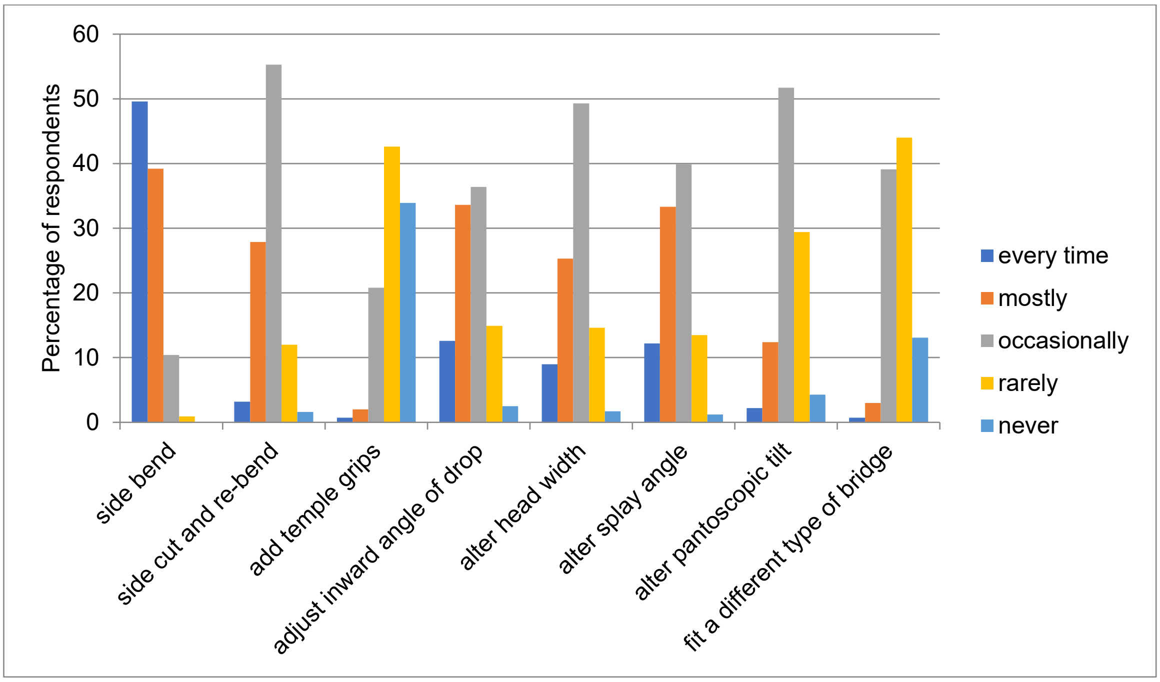


Figure 3.8a. Graph to show the frequency of adjustments and modifications made to spectacle frames.

The most frequent adjustment is the side re-bend, usually consisting of heating the tip or side in a frame heater and straightening and re-bending to make it shorter, however this will then increase the length of drop and it is a common sight to see children having the tip of the side visible at the bottom of their ear and almost a 90 degree bend which may keep the spectacles on the face initially but will ultimately cause discomfort behind the ears.

Physically shortening the side was less frequently reported by the respondents than expected since this instigated the largest response (131 votes) when asked what spectacle frame manufacturers should change. This could suggest that either the respondents are re-bending the side only which is a quicker process, or that the sides presented are not capable of being physically shortened due to design reasons such as the thick, flat core wire, or a tapered side that will not allow a tip to be seated nearer to the joint.

Adding frame temple grips is reported to be a rarely used option, it is a solution that should really only be executed as a last resort option as they often mask a poorly fitting side.

The inward angle of drop of the spectacle frame side should be tucked in gently behind the ear so as to distribute some of the weight along the anatomical line and not sit on the mastoid process which can cause discomfort to the wearer. The results for this particular adjustment were not as expected in terms of frequency that the inward angle of drop is adjusted. It is reasonable to assume that if the bend of the side is adjusted, for example to shorten the side, that the inward angle will also need consideration by the practitioner.

Respondents also requested that frame manufacturers provide paediatric frames with a wider head width. Widening the head width involves the use of pliers at the lugs and many frames have joints that are difficult to access even with the range of pliers available. To not widen a head width as required will form the common indentations seen on the sides of children's heads and this undue pressure will cause the frame to also slide forward. Similarly, splay angle on a pads on arms frame is altered on a regular basis and usual practice would require this to be widened and flattened for children to match their low, flat bridges. The danger with this is that there are limitations to the widening before the rim itself of the frame is resting on the nose or cheek of the child's face. Changing pads or fitting a strap bridge may help with this and yet that was reported to be a rare occurrence. The question could have possibly been worded better as it may have been interpreted to mean adding pads on arms to a fixed pad bridge frame or a more drastic change in bridge.

3.9 Spectacle aftercare

Once the spectacle frame has been fitted over half of the questionnaire respondents will informally invite the child back when passing to check the alignment and fit of the spectacles. This is vitally important in not only the comfort of the child and therefore compliance in wearing, but also the alignment and fit to ensure the child receives the exact prescription. New frames can relax once worn and this may mean the plastics material can slacken off, children may knock their frames out of alignment or even just taking them off with one hand will misalign the frame. On the other hand, 42.1% will *'informally invite only if a problem arises'* which may be interpreted as the optical professional is not delivering the ultimate fit. Parents/carers may perceive a problem to be a broken frame for example and may not have been educated to know what constitutes the best fit of the spectacle frame and how looking over the top of their frame is not acceptable.

As most but not all, high street practices have a registrant on the premises at all times, the questionnaire revealed that 69.9% of respondents make parents/carers aware that their child needs to see a registered practitioner. Only 14.5% of respondents admitted that they do not tell parents/carers that spectacle frame adjustments, repair or collection is a regulated requirement so if a problem arose or an adjustment was required, the service might not be available at all times in their practices.

Summary

This questionnaire gave a useful insight from a good spread of respondents into typical behaviours in selecting frames for, and dispensing paediatric patients in a wide range of practice settings.

To summarise the key findings in terms of clinical recommendations for paediatric dispensing;

- Frames for all children need to be designed with their developing anatomical features in mind.
- More choice in eyesizes across ranges of children's frames.
- Design features to include a degree of adjustability or a range of options, especially sides, lugs and bridges.
- Lens shapes to be more suitable for all children to avoid looking over the frame rim.
- Cosmetic appeal to be considered for all age ranges and balanced with frames that are designed for children.
- Education and clinical experience to build confidence in dispensing younger children.

Chapter 4 Reproducibility of facial measurements.

In this study, all stereophotogrammetry facial measurements were acquired from a three-dimensional image, captured using the 3dmdFace™ system (3dmd, Atlanta, GA, USA) which safely and rapidly acquire a three-dimensional image from which to place landmarks and subsequently measure both linear and angular facial parameters. The process of setting up and calibration, subject instruction, capturing the image, placing the image in a standardised reference plane and achieving facial measurements is detailed in sections 2.6-2.8.

4.1 Accuracy and reliability of stereophotogrammetry

The concept of stereophotogrammetry as a reliable and accurate method for measuring soft tissue parameters of the face has been widely documented. Studies fall into two main categories; those that employ hard facial models or those that use human subjects. The hard facial models maybe in the form of mannequins or printed impressions (Hong et al., 2017, Lincoln et al., 2016) and these are chosen in order to minimise potential error in direct anthropometry where calliper depression of soft tissue known as 'soft tissue pull' can occur. Studies using human subjects note limitations where facial expression (Lubbers et al., 2012) and involuntary facial movements may influence the results.

In addition, eye-related measurements relevant to many anthropometrical studies such as pupil position, endocanthion and exocanthion may be difficult to locate precisely unless the subject has a real and open eye. However, an open eye is also a typically 'wet' and therefore shiny surface (Maal et al., 2011) resulting in image artefacts which is a limitation of 3D stereophotogrammetry systems in general (Tzou et al., 2014).

In 2011, Fourie and colleagues measured cadaver heads pre-landmarked with small glass bead markers and reported a high degree of both accuracy and reliability of stereophotogrammetry, laser surface scans and cone beam computed tomography (CBCT) compared to more traditional anthropometric direct measuring with digital callipers. All systems proved to be reliable and only one of the twenty-one stereophotogrammetry measurements resulted in a mean absolute error in excess of 1.5mm (Fourie et al., 2011). Similarly, Kook et al. (2014) measured mannequin heads comparing direct anthropometry with scans or stereo photogrammetry and reported a high coefficient of reliability (>0.92) and a low technical error of less than 0.9mm. Ayoub et al. (2003) set out to validate a three-dimensional camera system (C3D) compared to a coordinate measuring machine (CMM) by taking an alginate facial cast under general anaesthesia of 21 infants with cleft lip palates, then producing stone casts incorporating facial landmarks. The study findings recognised errors could occur in several areas such as with different observers, during capture and the placement (registration) error. However, cumulatively, these errors remained at less than 1mm.

Using human subjects, Dindaroğlu et al. (2016) measured the accuracy and reliability of direct anthropometry compared to a 2D photogrammetry and a 3D stereophotogrammetry system which in this case was the 3dMDflex™ system (3dmd, Atlanta, USA) which is capable of producing a 360 degrees head and thorax image. Reported findings included 0.21mm as the highest mean difference between direct anthropometry and the 3D system. Interestingly, this study also reported an angular mean error of less than 2 degrees (Dindaroğlu et al., 2016) which is useful as consideration of angular accuracy appears to be lacking in most studies in this field.

4.2 Accuracy and reliability of 3dmdFace™ system

Appraising the 3dmdFace™ system specifically, Ort et al. (2012) found a mean error of 0.86mm with the system, concurring with later studies of this system (Menendez Lopez-Mateos et al., 2019, Hong et al., 2017, Dindaroğlu et al., 2016, Wong et al., 2008) but questioned the reliability of landmark placement and suggested the mean of multiple measurements could reduce this risk and improve accuracy. Metzger et al. (2013) found significant differences in 7 out of 28 linear measurements when measuring live subjects using the 3dmdFace™ system compared to CBCT scans, however it was recognised that the difference in capture speed (1.5ms vs 8.9 seconds) may have caused involuntary movements during processing, also the fact that the subject’s eyes must be closed with CBCT compared to the 3D system.

Looking at landmark placement on the 3dmdFace™ system, Aldridge et al. (2005) reported accuracy of less than 1mm in 14 out of 20 landmarks. Repeatability of images is reported at 95% for 181 out of 190 linear distances which is comparable to other studies (Weinberg, 2019, Kohn et al., 1995). This study reported the glabella as inaccurate on the y-axis and the gonion was inconsistent for all three axes, these exact two points also reported inconsistent by Weinberg (2019). It could be argued that the gonion (the outer point angle of the mandible), requires palpation of the mandible for exact placement and the glabella is reasonably difficult to define exactly as a point. Longer measurements have also been reported as giving the largest variation, as well as across areas of great surface changes, such as exocanthal distance (the outer canthal distance) (Hong et al., 2017). There are fewer variations in measurements reported in the nasal and forehead regions of the face and more variations in the areas of the mouth and eyes (Maal et al., 2011).

A systematic review was conducted in 2013 by Ladeira et al on the use of stereo photogrammetry for evaluating clinical deformities where 3dMD™ featured in almost 60% of those studies reviewed. The review concluded that whilst accuracy and reproducibility is widely reported, there could be difficulties in reviewing studies that align to the same facial parameters where different descriptions or published classification terminology may be used to establish anthropometric reference points.

Placing the 3D image in a reference frame appears to be an acceptable step prior to placing landmarks and achieving the degree of reproducibility and reliability deemed acceptable (Brons et al., 2013, Plooij et al., 2009). Although these initial potential errors in placing the reference frame landmarks should also be acknowledged, a high level of reproducibility, less than 0.5mm, can still be demonstrated (Plooij et al., 2009).

Manual placement of landmarks has shown potential errors for both direct and indirect systems of measuring. For 3D stereophotogrammetry, it could be assumed that pre-marking the face with landmarks is almost impossible with small children and this has reported to be a source of error in certain measurements, such as the soft gonions where the bony underlying structure may need to be palpated (Nord et al., 2015). A study in 2019 compared two datasets of direct versus 3dMDface™ stereophotogrammetry and this reported in half of the linear measurements being larger and half being smaller. The largest discrepancy occurred with the palpebral fissure length, yet intercanthion and exocanthion width were similar across the two sets, suggesting that this measurement is difficult to achieve with direct anthropometry due to having to get into close proximity to the eye (Weinberg, 2019). There were commonalities on the discrepancy in terms of measurements involving the ear, as also reported by Plooij et al. (2009), possibly due to the ear being located on the extremity of the 3D image (Metzger et al., 2013) and the involvement of hair (Launonen et al., 2019).

4.3 Methods

A random selection of 10 boys and 10 girls was made from the collected sample of 811 typically developed White British images. The mean age of the boys was 7.2(1.61) years5.-10. years, and 8.9(3.3) years (range 5.-14) for the girls sample.

The following landmarks were manually placed on each image after it had been into the standard reference plane (section 2.81):

Bearing surface (central), bearing surface (right and left), pupil centres (right and left) top of the lower lid (right and left) and ear points (right and left). After placement of these landmarks, the 'ABDO v13' program was applied which calculated fifteen facial measurements:

Angular measurements:	Frontal angle (right and left)
	Splay angle (right and left)
Linear measurements:	Head width
	Temple width
	Distance between rims at 10mm and 15mm below crest
	Apical radius
	Crest height (right and left)
	Front to bend (right and left)
	Distance between the pad centres
	Pupillary distance

The study was divided into two measures of repeatability; interobserver by comparing all fifteen measurements by two observers (AT1 and RC) and intraobserver between sessions by comparing all fifteen measurements made by the same observer on the group of subjects, separated by a 12-month interval (AT1 and AT2 respectively). The image alignment and placement of facial landmarks was carried out independently by each observer.

4.4 Statistical analysis

The descriptive statistics and differences in parameters were analysed using SPSS (version 26; IBM Ltd, Armonk, NY, USA). In all statistical analyses, the significance level was considered to be $p<0.05$.

The Shapiro-Wilk analysis was conducted for all 15 facial measurements for both observers and sessions to examine the distribution of data. The bias for each facial measurement was determined by mean differences found between the two observers AT and RC, and both the inter and intraobserver differences were evaluated using a paired sample t-test since 12 out of 15 parameters were found to have normal distribution. The intraclass correlation coefficient (ICC) was used to evaluate the agreement between measurements. An ICC of <0.5 was considered as poor agreement, 0.50 to 0.75 as fair, 0.75 to 0.90 as good and 0.90 to 1.0 as excellent (Koo and Li, 2016). Consistency between the two measurements were supported by Bland-Altman plots showing the limits of agreement (LoA), that is, the interval over which 95% of the differences between the two sessions lie (Bland and Altman, 2010). The limits of agreement were calculated using the equation:

LoA = bias ± (1.96 x SD of differences)

In the case of facial measurements where a right and left measurement is presented, the two measurements were analysed separately rather than consideration of the average value. Despite the frame manufacturing process using symmetry in their design, it was felt it may be useful to explore right and left parameters separately as facial asymmetry can lead to spectacle frame fitting issues where the parameter is fixed, i.e. no application of adjustment is possible.

A clinical benchmark for reproducibility were determined as tolerances of 1mm for most linear measurements, with the exceptions of head and temple width and front to bend (5mm) and 5 degrees for all angular measurements. These clinical tolerances are replicated from professional practical examinations for Dispensing Opticians (Association of British Dispensing Opticians, 2021). Dispensing Opticians routinely take these facial measurements in clinical practice with a physical ruler or facial measurement gauge, as described in section 1.42, in order to accurately dispense spectacles and/or produce a bespoke, handmade frame for a particular patient.

4.5 Results

The repeatability results of the facial measurements were expressed as the mean difference, standard deviation and the calculated limits of agreement. The facial measurements independently assessed by the two observers following the same procedures is shown in Figure 4.51a. Intraobserver repeatability for the same observer at a 12-month interval is shown in Figure 4.52a. All of the mean differences, or bias, reported in tables 4.51a and 4.52a were statistically significant different from zero, using paired t-tests, for all angular or linear facial measurements. For the observer RC, 5 of the 15 measurements (pupillary distance, distance between pad centres, temple width, distance between rims at 15mm below crest and front to bend (right)) were not significantly different from zero.

4.5.1 Interobserver Differences

Table 4.51a shows the results of the difference in facial measurements found between two independent observers (AT-RC). Negative values indicate the second observer (RC) reported an overall mean measurement larger than that of the first observer (AT). Angular measurements, splay and frontal angle, showed greater variability than linear measurements. For frontal angle, the difference in measurement was greater than the 5-degree tolerance in 4 out of the 20 subjects whereas the splay angle difference all measurements were within the 5-degree tolerance. Head width and temple width results both also showed a difference of less than the 5mm tolerance.

For the distance between rims measurements at 10 and 15mm below crest, 10 of the 40 measurements were greater than the 1mm tolerance, although this involved only 6 subjects where one or both of these measurements were consistently larger than those found by AT. For apical radius, the tolerance of 1mm was exceeded in 3 out of the 20 subjects. Crest height right and left measurements showed 4 results greater than the 2mm tolerance; again this involved 2 subjects out of the 20 having one or both measurements either larger or smaller than the 2mm tolerance. The front to bend (right and left measurement) showed only 4 out of the 40 measurements being greater than the 3mm tolerance for this facial measurement. For the distance between pad centres, the difference in measurements was less than or equal to the 2mm tolerance for all subjects whereas for pupillary distance only 2 out of 20 measurements had a difference greater than the 1mm tolerance.

Observer 1 (AT1) – Observer 2 (RC)				
Measurement and abbreviation	Mean difference (SD)	Bland-Altman limits of agreement		Tolerances deemed clinically acceptable
		Lower limit	Upper limit	
Angular measurements (degrees)				
Frontal angle right (FAR)	1.31 (2.52)	-3.63	6.26	5 degrees
Frontal angle left (FAL)	1.17 (3.23)	-5.17	7.51	5 degrees
Splay angle right (SAR)	-1.01 (2.36)	-5.62	3.61	5 degrees
Splay angle left (SAL)	-0.86 (2.50)	-5.76	4.05	5 degrees
Linear Measurements (mm)				
Head width (HW)	0.58 (2.19)	-3.71	4.87	5mm
Temple width (TW)	1.06 (2.04)	-2.94	5.07	5mm
Distance between rims @ 10mm (DBR10)	0.36 (0.84)	-1.28	2.00	1mm
Distance between rims @ 15mm (DBR15)	0.64 (1.06)	-1.44	2.72	1mm
Apical radius (AR)	0.16 (0.70)	-1.22	1.54	1mm
Crest height right (CHR)	0.18 (1.18)	-2.14	2.50	2mm
Crest height left (CHL)	-0.06 (1.25)	-2.50	2.39	2mm
Front to bend R (FTBR)	-0.92 (1.93)	-4.69	2.85	3mm
Front to bend L (FTBL)	0.27 (1.93)	-3.52	4.06	3mm
Distance between pad centres (DBPC)	-1.04 (0.84)	-2.69	0.61	2mm
Pupillary distance (PD)	0.43 (0.52)	-0.60	1.45	1mm

Table 4.51a. Table to show results of interobserver mean differences, standard deviation and LoA for fifteen facial measurements taken from a random sample of twenty subjects.

Bland-Altman plots can be used to analyse the agreement between observers. They show the difference in the paired measurements between observers plotted against the mean value with the 1.96xSD value showing limits of agreement parallel to the mean difference (bias) line (Bland and Altman, 2010).

Bland-Altman analysis showed that for the angular measurements, the frontal angle displayed wider limits of agreement than the splay angle, although both angular measurements showed a clinically acceptable level of bias. The head width also yielded a slightly wider limit of agreement compared to the temple width, although a smaller degree of bias between the two observers. The measurements of distance between rims at 10mm and 15mm below crest, apical radius, pupillary distance and crest height (right and left) also displayed relatively narrow limits of agreement and a small degree of bias. The distance between pad centres showed a reasonable negative bias with the majority of differences in the measurement being higher in value for the second observer (RC) resulting in the negative difference illustrated. The front to bend measurement for right and left showed a slightly wider limits of agreement as expected with a higher clinical tolerance in the measurement, although a small degree of bias.

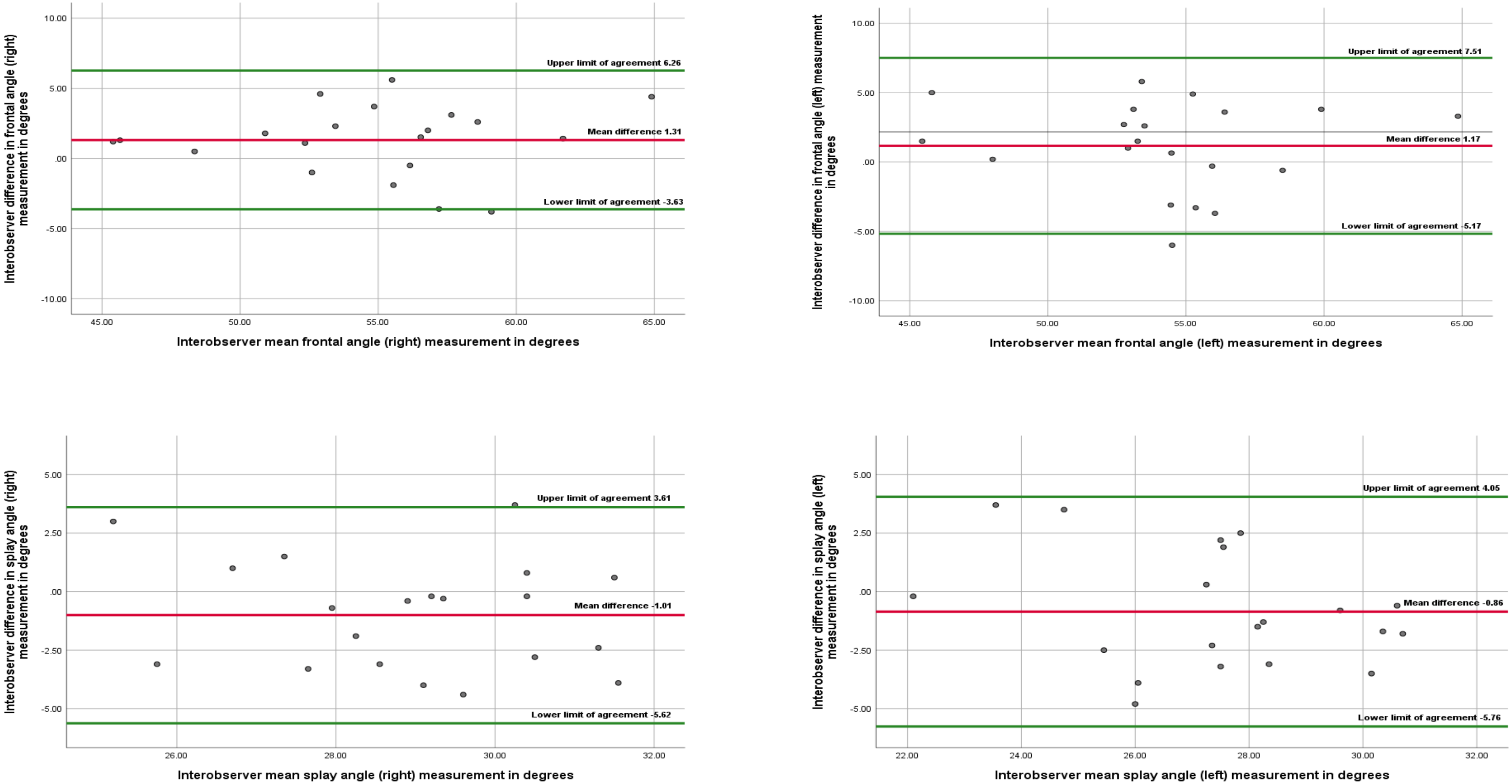
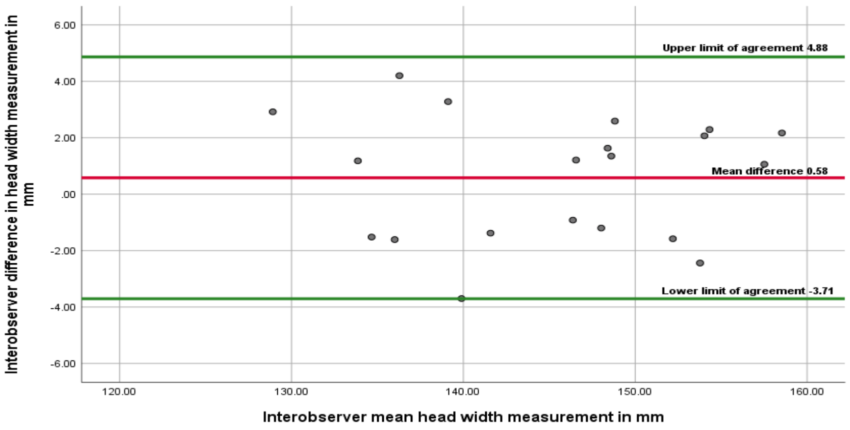
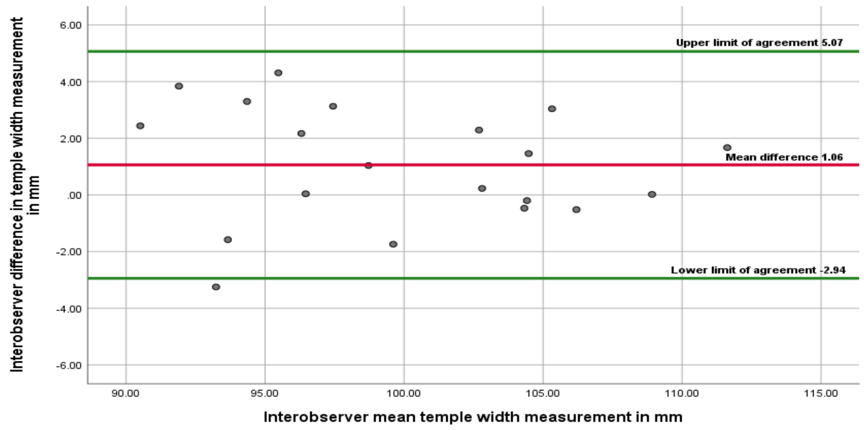
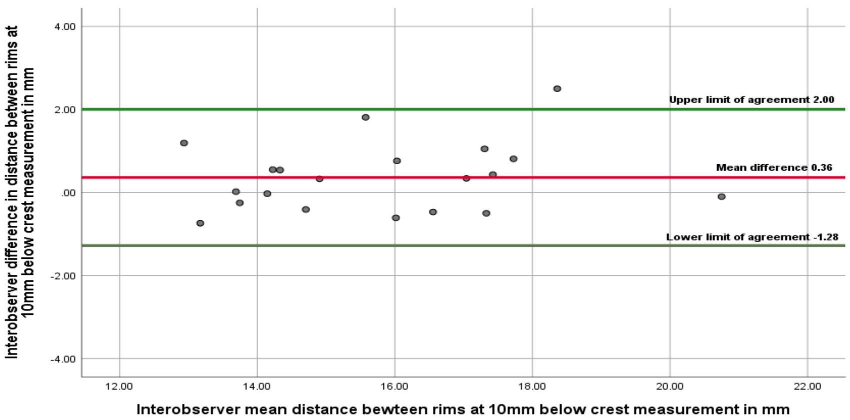
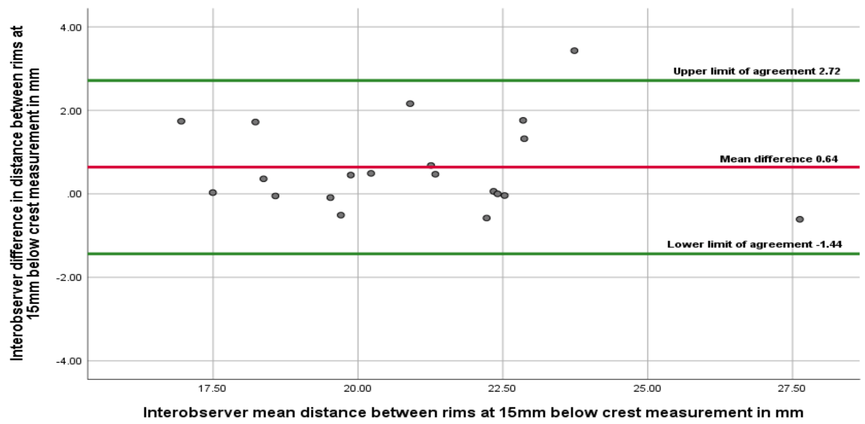


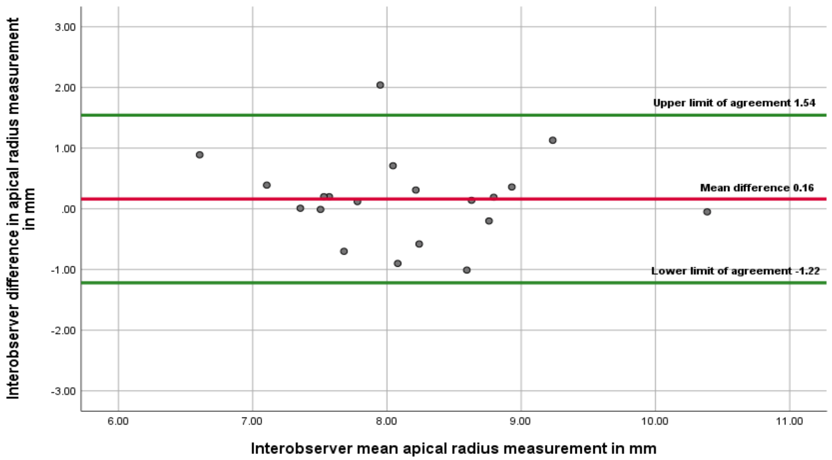
Figure 4.51b. Interobserver Bland and Altman plots for angular measurements: frontal angle right (top left) frontal angle left (top right), splay angle right (bottom left) and splay angle left (bottom right).

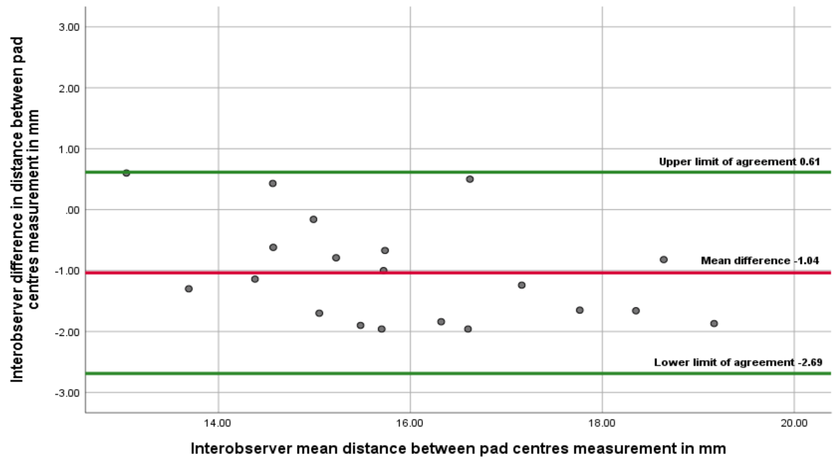

Interobserver difference in head width measurement in mm
Upper limit of agreement 4.88
Mean difference 0.58
Lower limit of agreement -3.71
6.00
4.00
2.00
.00
-2.00
-4.00
-6.00
120.00
130.00
140.00
150.00
160.00
Interobserver mean head width measurement in mm

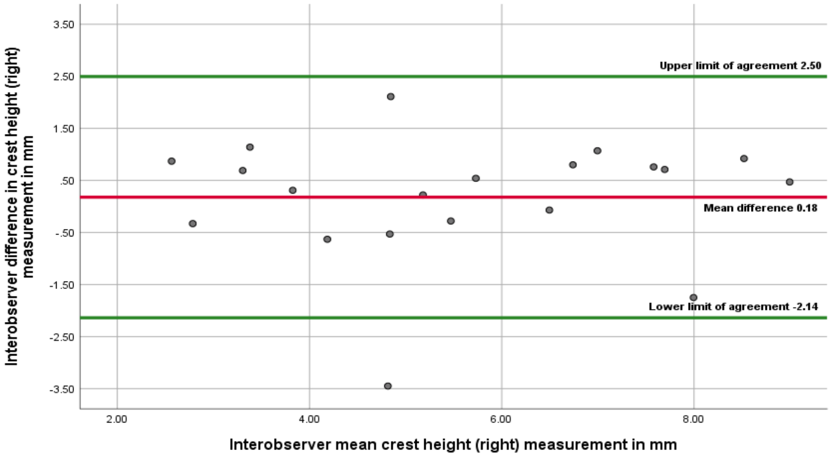

Interobserver difference in temple width measurement in mm
Upper limit of agreement 5.07
Mean difference 1.06
Lower limit of agreement -2.94
6.00
4.00
2.00
.00
-2.00
-4.00
-6.00
90.00
95.00
100.00
105.00
110.00
115.00
Interobserver mean temple width measurement in mm

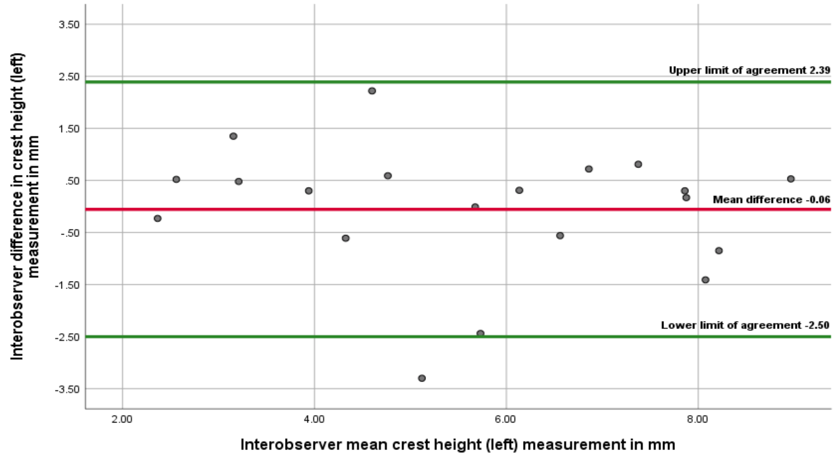

Interobserver difference in distance between rims at 10mm below crest measurement in mm
Upper limit of agreement 2.00
Mean difference 0.36
Lower limit of agreement -1.28
4.00
2.00
.00
-2.00
-4.00
12.00
14.00
16.00
18.00
20.00
22.00
Interobserver mean distance bewteen rims at 10mm below crest measurement in mm

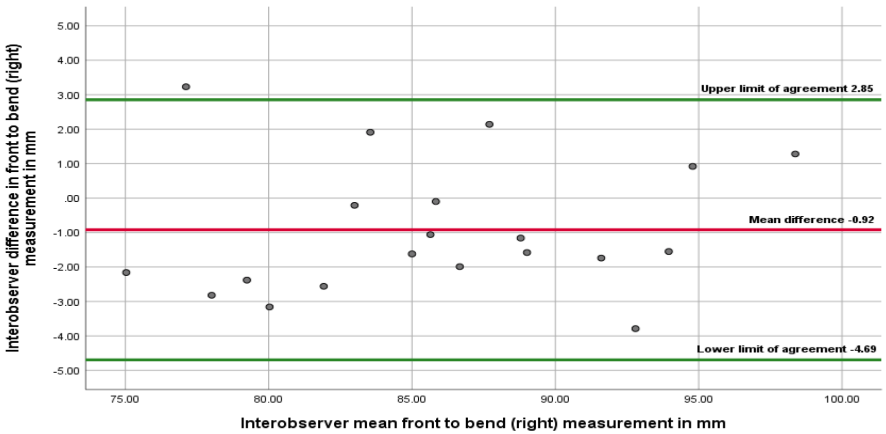

Interobserver difference in distance between rims at 15mm below crest measurement in mm
Upper limit of agreement 2.72
Mean difference 0.64
Lower limit of agreement -1.44
4.00
2.00
.00
-2.00
-4.00
17.50
20.00
22.50
25.00
27.50
Interobserver mean distance between rims at 15mm below crest measurement in mm

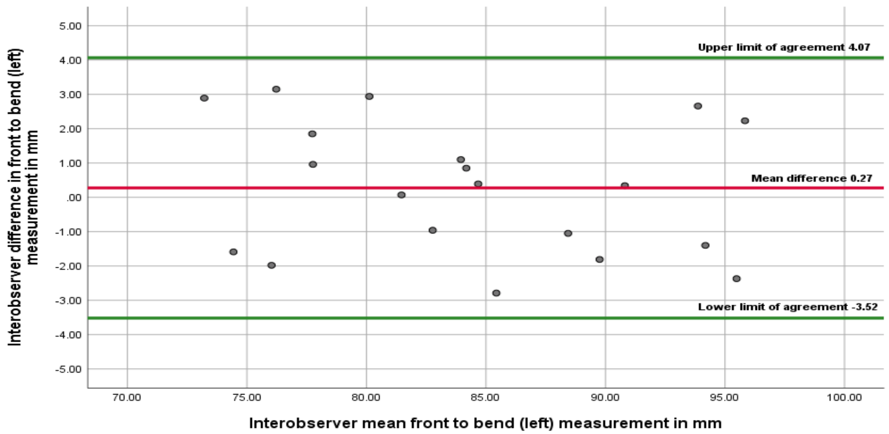

Interobserver difference in apical radius measurement in mm
3.00
2.00
1.00
.00
-1.00
-2.00
-3.00
Upper limit of agreement 1.54
Mean difference 0.16
Lower limit of agreement -1.22
6.00
7.00
8.00
9.00
10.00
11.00
Interobserver mean apical radius measurement in mm


Interobserver difference in distance between pad centres measurement in mm
3.00
2.00
1.00
.00
-1.00
-2.00
-3.00
Upper limit of agreement 0.61
Mean difference -1.04
Lower limit of agreement -2.69
14.00
16.00
18.00
20.00
Interobserver mean distance between pad centres measurement in mm


Interobserver difference in crest height (right) measurement in mm
3.50
2.50
1.50
.50
-.50
-1.50
-2.50
-3.50
Upper limit of agreement 2.50
Mean difference 0.18
Lower limit of agreement -2.14
2.00
4.00
6.00
8.00
Interobserver mean crest height (right) measurement in mm


Interobserver difference in crest height (left) measurement in mm
3.50
2.50
1.50
.50
-.50
-1.50
-2.50
-3.50
Upper limit of agreement 2.39
Mean difference -0.06
Lower limit of agreement -2.50
2.00
4.00
6.00
8.00
Interobserver mean crest height (left) measurement in mm





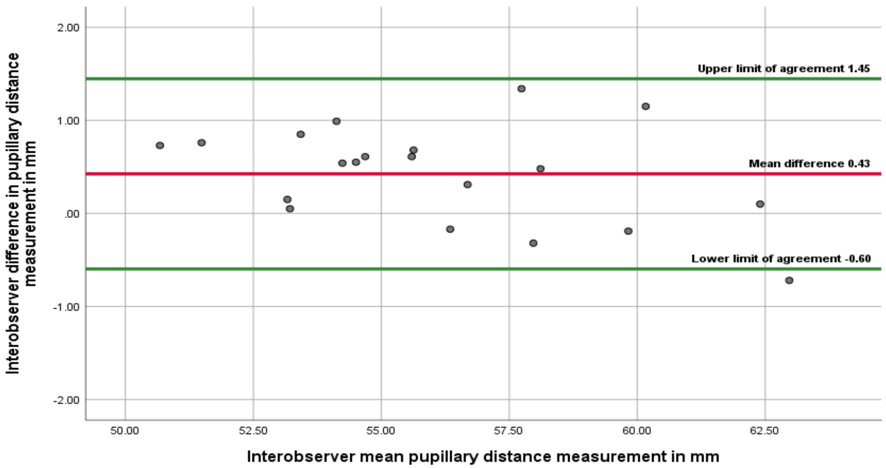


Figure 4.51e. Interobserver Bland and Altman plots for linear measurements: front to bend right (top left) front to bend left (top right) and pupillary distance (bottom left).

4.5.2 Intraobserver Differences

The table below (table 4.52a) shows the results of the difference in facial measurements found between the same observer at a 12-month interval between sessions (AT1-AT2). Negative values indicate the second measurement (AT2) reported an overall mean measurement larger than the first measurement (AT1). As with interobserver comparisons, angular measurements, splay and frontal angle, showed slightly more variability than linear measurements but showed greater consistency; the frontal and splay angles were all within the 5-degree tolerance that is deemed clinically acceptable. All linear measurements, head width, temple width, apical radius, crest height (left and right), front to bend (right and left), distance between pad centres and pupillary distance also fell within their respective tolerances. Distance between rims at 10mm and 15mm below, 5 out of 40 measurements was greater than the 1mm tolerance although this involved 3 of the 20 subjects.

Observer 1 (AT1) – Observer 1 (AT2)				
Measurement and abbreviation	Mean difference (SD)	Bland-Altman limits of agreement (LoA)		Tolerances deemed clinically acceptable
		Lower limit	Upper limit	
Angular measurements (degrees)				
Frontal angle right (FAR)	-0.32 (2.35)	-4.93	4.29	5 degrees
Frontal angle left (FAL)	-0.39 (1.84)	-3.98	3.21	5 degrees
Splay angle right (SAR)	-0.23 (1.49)	-3.15	2.70	5 degrees
Splay angle left (SAL)	0.38 (1.18)	-1.94	2.70	5 degrees
Linear measurements (mm)				
Head width (HW)	0.52 (1.75)	-2.91	3.96	5mm
Temple width (TW)	0.38 (1.65)	-2.93	3.54	5mm
Distance between rims @ 10mm (DBR10)	-0.03 (0.80)	-1.59	1.53	1mm
Distance between rims @ 15mm (DBR15)	0.02 (0.79)	-1.47	1.51	1mm
Apical radius (AR)	-0.02 (0.38)	-0.76	0.73	1mm
Crest height right (CHR)	0.02 (0.56)	-1.07	1.11	2mm
Crest height left (CHL)	0.05 (0.35)	-0.65	0.74	2mm
Front to bend R (FTBR)	0.05 (1.45)	-2.80	2.90	3mm
Front to bend L (FTBL)	0.04 (1.51)	-2.91	2.99	3mm
Distance between pad centres (DBPC)	0.14 (0.61)	-1.06	1.33	2mm
Pupillary distance (PD)	0.19 (0.37)	-0.53	0.91	1mm

Table 4.52a. Table to show results of intraobserver mean differences, standard deviation and LoA for fifteen facial measurements taken on a random sample of twenty subjects measured at a 12-month intersession interval.

Bland-Altman analysis showed that for the linear measurements, the frontal angle yielded wider limits of agreement than the splay angle, although both angular measurements show a clinically acceptable level of bias. The head width and the temple width also displayed a narrow limit of agreement (LoA) and a small degree of bias between the two measurement sessions. Distance between rims at 10mm and 15mm below crest, apical radius, pupillary distance and crest height (right and left) also shows very narrow limits of agreement and a small degree of bias. The front to bend measurement for right and left has a slightly wider limits of agreement as expected with a higher tolerance, although a small degree of bias.

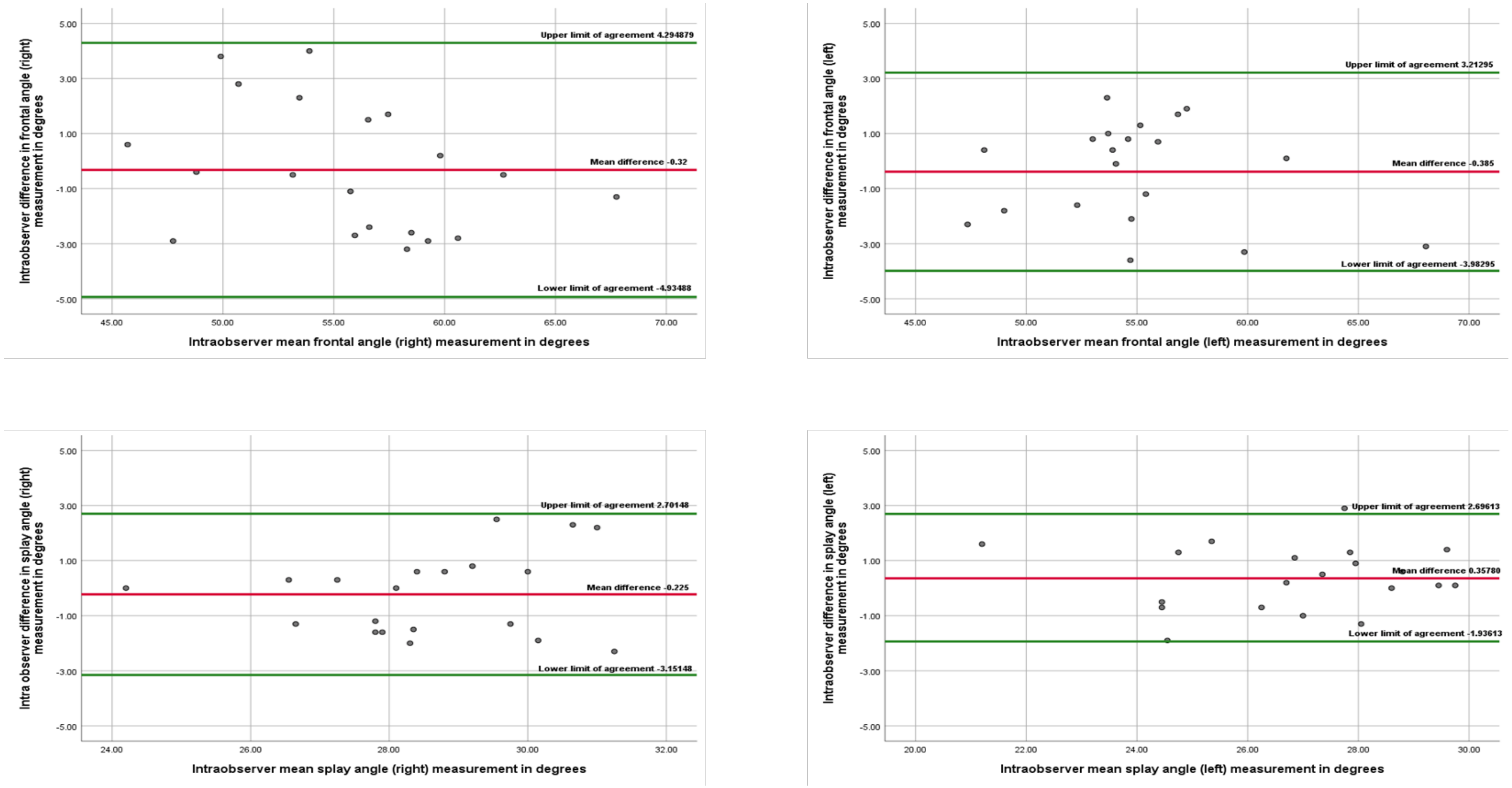
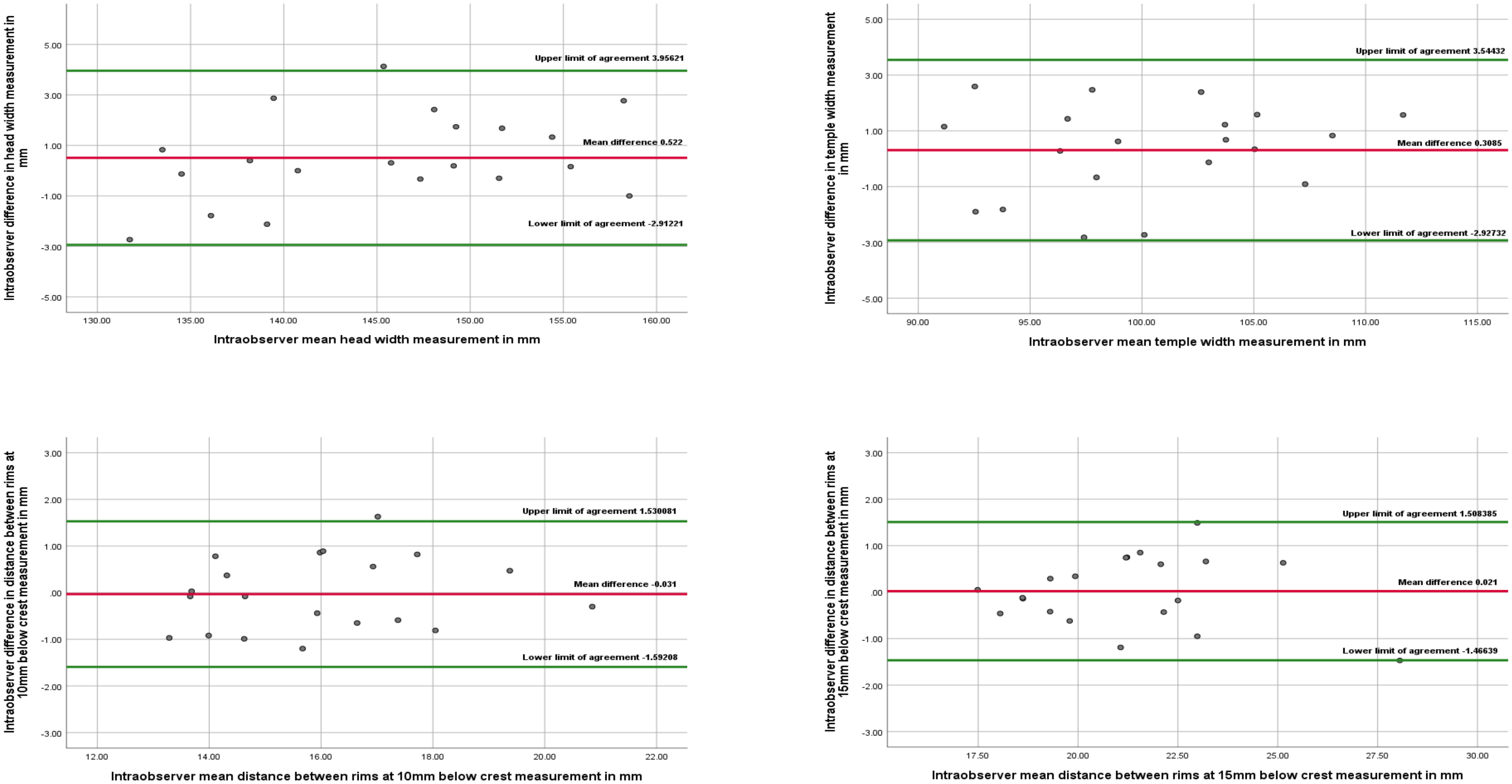


Figure 4.52b. Intraobserver Bland and Altman plots for angular measurements: frontal angle right (top left) frontal angle left (top right), splay angle right (bottom left) and splay angle left (bottom right).



<u>Figure 4.52c.</u> Intraobserver Bland and Altman plots for linear measurements: head width (top left) temple width (top right) DBR at 10mm (bottom left) and DBR @15mm (bottom right).

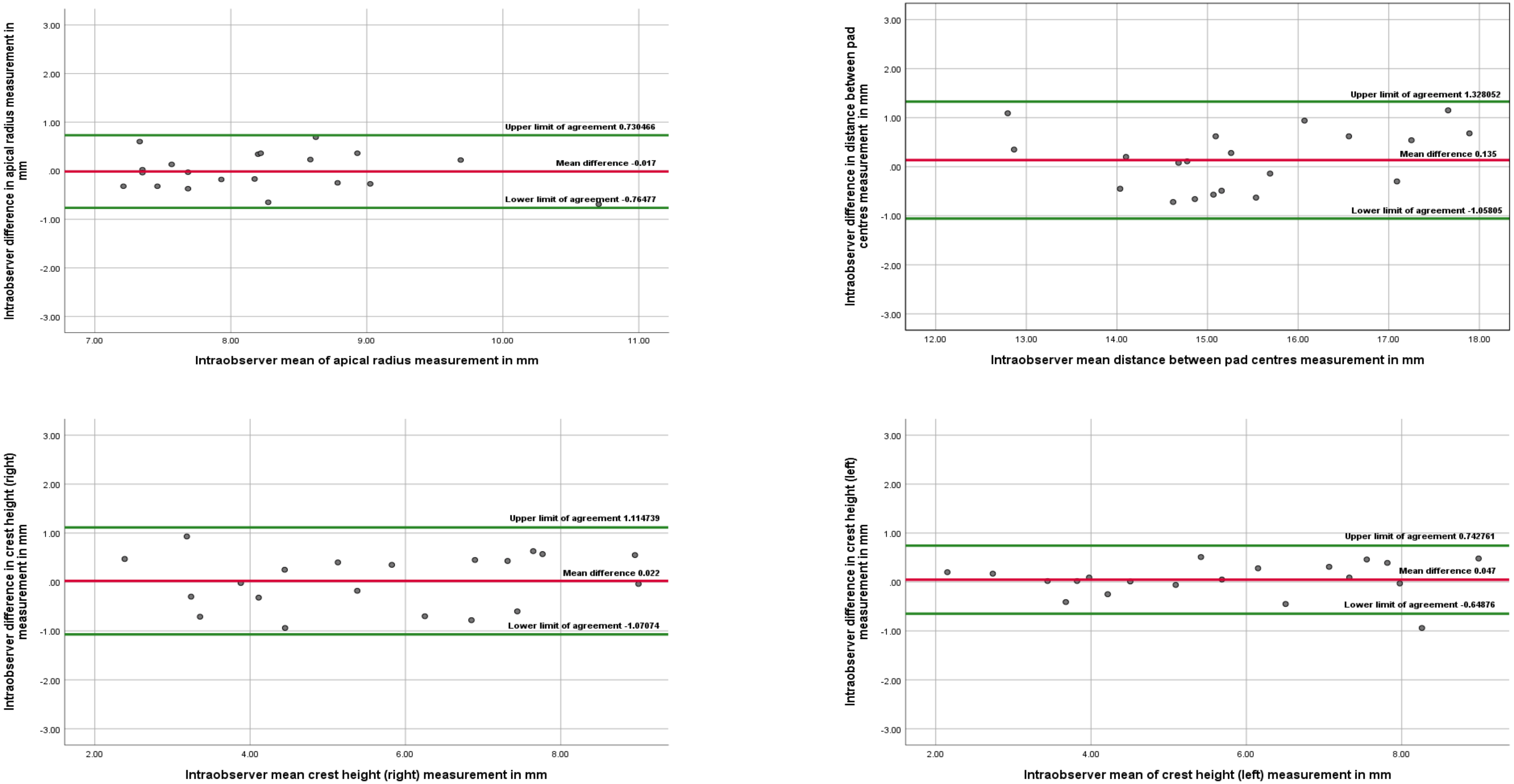
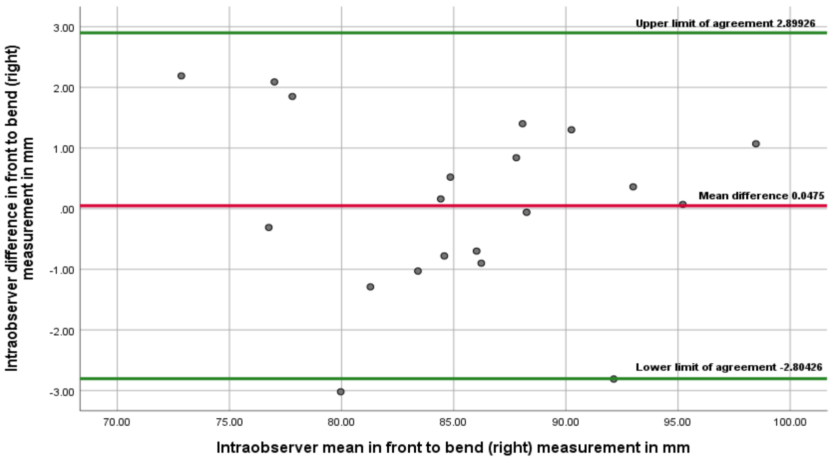
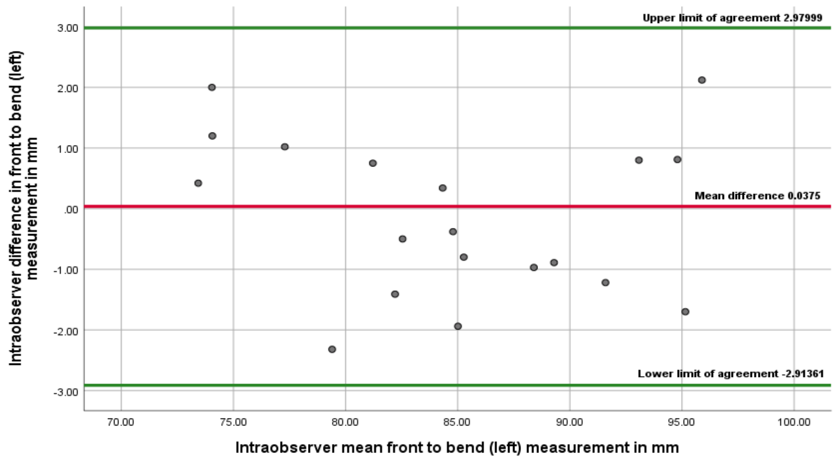


Figure 4.52d. Intraobserver Bland and Altman plots for linear measurements: apical radius (top left) distance between pad centres (top right) crest height right (bottom left) and crest height left (bottom right).





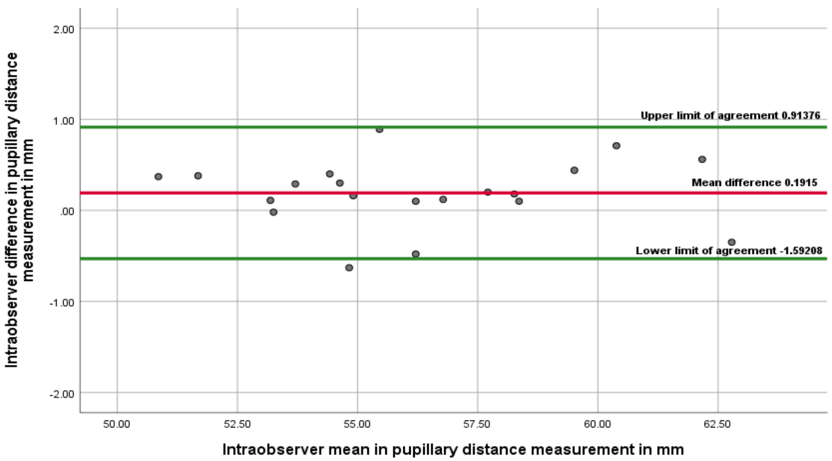


Figure 4.52e. Intraobserver Bland and Altman plots for linear measurements: front to bend right (top left) front to bend left (top right) and pupillary distance (bottom left).

Bland-Altman plots show the correlations between the measurements. They show the 95% limits of agreement (upper and lower green lines) estimated by the red mean line (±1.96*SD) of the differences.

4.5.3 Intraclass correlation coefficients

Intraclass correlation coefficient is commonly employed as a tool to measure intra-observer error estimates. Errors between investigators are calculated with resultant values ranging from 0 to 1; values closer to 1 indicating less measurement error. These are presented in Table 4.5.3.

	Interobserver		Intraobserver	
Measurement and abbreviation	ICC AT-RC	95%CI lower, upper	ICC AT1-AT2	95%CI lower, upper
Angular measurements in degrees				
Frontal angle right (FAR)	0.859	0.582, 0.947	0.954	0.884, 0.982
Frontal angle left (FAL)	0.857	0.643, 0.943	0.961	0.903, 0.984
Splay angle right (SAR)	0.551	-0.046, 0.816	0.813	0.529, 0.926
Splay angle left (SAL)	0.695	0.260, 0.877	0.923	0.807, 0.969
Linear measurements in mm				
Head width (HW)	0.984	0.959, 0.993	0.989	0.971, 0.995
Temple width (TW)	0.965	0.896, 0.987	0.980	0.949, 0.992
Distance between rims @ 10mm (DBR10)	0.951	0.871, 0.981	0.964	0.908, 0.986
Distance between rims @ 15mm (DBR15)	0.943	0.812, 0.979	0.979	0.947, 0.992
Apical radius (AR)	0.827	0.571, 0.931	0.956	0.889, 0.983
Crest height right (CHR)	0.911	0.777, 0.965	0.982	0.954, 0.993
Crest height left (CHL)	0.909	0.770, 0.964	0.992	0.981, 0.997
Front to bend R (FTBR)	0.919	0.769, 0.970	0.988	0.971, 0.995
Front to bend L (FTBL)	0.983	0.957, 0.993	0.990	0.974, 0.996
Distance between pad centres (DBPC)	0.853	0.015, 0.960	0.954	0.886, 0.982
Pupillary distance (PD)	0.990	0.945, 0.9970	0.996	0.988, 0.999

Table 4.53a. ICC results with confidence intervals for both interobserver and intraobserver results.

For the intraobserver values, most of the measurement parameters, the ICC ranges from 0.813-0.996, which shows excellent correlation. Only the splay angle (right) yielded a value of 0.813. For the interobserver values, the ICC ranges from 0.551-0.990. Again, although the splay angle (right and left) showed good correlation, it was not in as close an agreement as the other facial measurements.

For intraobserver results of linear measurements, the highest difference between the means was 0.52mm in the measurement of head width. The lowest linear mean difference was +/-0.02mm for distance between rims@15, apical radius, and crest height right. For interobserver results, the highest difference was 1.06mm in the measurement of temple width and the lowest was -0.06mm for the measurement of crest height left.

For angular measurements, the highest intraobserver difference between means was -0.39 degrees for frontal angle left compared to an interobserver mean difference of 1.86 degrees.

Between the two observers, apical radius and crest heights (right and left) showed the highest degree of reliability (lowest mean difference) at 0.16, 0.18 and -0.06mm respectively. All further linear measurements with the exception of temple width at 1.06mm and DBPC at -1.04 were within 1mm mean difference which is a clinically acceptable tolerance.

In comparison to the interobserver plots (Figure 4.51b-e), the intraobserver results (Figure 4.52b-e) show a smaller bias on all of the four angular and eleven linear measurements with narrower limits of agreement on the Bland-Altman plots. The angular measurement bias for the first observer (AT) fell within the range -0.23 to 0.38 degrees compared to -1.01 to 1.86 degrees for the second observer (RC). For the linear measurements, the first observer reported a mean difference of -0.02 to 0.52mm compared to -1.04 to 1.06mm for the second observer. The intraobserver range was very narrow, within -0.02 to 0.14mm of the mean difference if the three widest parameters were separated from the data. The three wider measurements of the pupillary distance (0.19mm) and the temple and head width measurements (0.38 and 0.52mm respectively) do have slightly wider mean differences, again within a tolerance deemed clinically acceptable. Head width and crest height (left) showed a similar bias (head width (0.52 AT, 0.58 RC), crest height left (0.05 AT, -0.06 RC).

4.6 Discussion

The 3dmdFace™ system has a reported nominal accuracy of ≤0.2mm (Fourie et al., 2011) set by using factory models, but it should be remembered that the complex structure of real faces can mean that the practical accuracy can differ considerably (Zhao et al., 2017). In 2008, Wong et.al. reported a more realistic average absolute value of 0.8mm, ranging from 0.5-1.2mm using the 3dmd system when studying the validity and reliability of facial measurements, concurring with other studies reporting on this system (Menendez Lopez-Mateos et al., 2019, Hong et al., 2017, Dindaroğlu et al., 2016, Ort et al., 2012).

The benchmark used in this thesis for deciding on the clinical validity of the 3dmd system is whether it can be at least as accurate at deriving facial measurements on children compared to using a facial measurement gauge. These results show that the 3dmd imaging system produces highly accurate and reproducible results which are within the accepted clinical tolerances used by Dispensing Opticians. The observer AT was able to make more consistent measurements than RC. AT is clinically much more experienced at taking facial measurements from children than RC and therefore more familiar with identifying the position of facial landmarks. In this study, for linear parameters the highest mean difference for AT is 0.52mm, much lower than 0.8mm previously reported for the 3dmd Face™ system and for angular parameters, <0.40 degrees compared to a reported 2 degree mean error by Dindaroglu in 2016. The mean difference reported by RC was <1.10mm for all linear measurements and <2 degrees for all angular measurements, both of which would still be deemed clinically insignificant when the acceptable tolerances are applied to each measurement. This would indicate that a level of training and clinical experience in identifying facial landmarks on a three-dimensional face is required to take accurate facial measurements. Although RC had the required clinical and anatomical knowledge to carry out measurements, his clinical experience in taking facial measurements was less than for observer AT. Nevertheless, RC was still able to produce highly reliable and accurate results for most facial measurements.

Without pre-marking a child's face, it should be acknowledged that the digital placement of facial landmarks may give rise to a slight increase in the mean error between observers, as this study demonstrates. For this set of facial measurements, palpation of the face was not necessary which has been previously identified as a potential source of error in correctly identifying underlying structure (Nord et al., 2015) however, some knowledge of spectacle frame fitting would be required to accurately place the three bearing surface points straddling the nose.

Reproducibility of angular measurements was shown to be more variable between and within observers than linear measurements, although still within clinically acceptable standards. This may be because the subjective judgement of an anatomical landmark in three-dimensional space is a more complex task than the edge determination required for placement of linear measurements such as pupillary distance. Furthermore, the image used was digitally rendered after image acquisition to show skin tones which may have been misleading when interpreting where a landmark should be placed. The mean differences show a high level of agreement for angular measurements that, by nature, have been previously reported as being more difficult to obtain a high degree of accuracy (Hong et al., 2017). The splay and frontal angles are determined from the bearing surface, which could be expected to be more difficult to place accurately if the observer does not have experience of extensive frame fitting to paediatric patients. This is primarily because the frame will not necessarily sit, or the anatomy of the profile will not have an obvious point where the bridge commences. However, the linear measurements associated with the bearing surface landmark suggest this was not the case. The frontal angle has a wider band of agreement, and this is possibly due to the second landmark of where a pad would sit being placed slightly too far back, making the angle constantly larger; again experience would determine the very small pantoscopic angle the spectacle front would sit at, considering the relatively high cheek position of a child. The splay angle, being in the transverse plane would not be affected by the pad placement if the vertical position was correct and hence the limits were found to be much closer for this measurement.

The longest facial measurements, namely the head width, temple width and front to bend measurements showed slightly larger differences which concur with the findings of Hong et al in 2017 who reported that longer parameters show more variation than compared to shorter parameters. A very high degree of agreement was found on the shorter distance of crest height and the apical radius, potentially due to the automated radius calculation (apical radius) and the physical placement of the more obvious landmark at the top of the lower lid (crest height). Pupillary distance was also shown to be a reliable measurement, despite the fact that it is also a relatively long measurement and traverses a wet surface of the cornea which has also been identified as a potential source for error (Lubbers et al., 2012). It should also be noted that it is far easier to make a subjective judgement on where the centre of the pupil lies in comparison to where the ear point is positioned.

Reliability of landmark placement for both the reference plane and the facial measurements was achieved to a high degree in order to show the levels of reproducibility between observers achieved but it must be acknowledged that these landmarks are not common to other facial anthropometrical studies. In order to directly compare, some degree of experience in fitting spectacles is required in deciding on the exact placement of the three bearing surface landmarks.

Image quality was not an exclusion criterion in this study as it was a study of repeatability of typically acquired clinical images which by their nature would be expected to show a degree of variation in quality. It is important for reliability that the image is clear and free from artefacts in the area to be measured and these can occur at the extremities of the 180 degree view of the image, i.e. the ear points. Artefacts arise from a wet surface, or if hair is present around the ear point, the image may be distorted. This potential error was minimised by instruction to tuck hair behind ears, wiping any wet skin and checking the integrity of the image and repeating acquisition if necessary and the child was agreeable.

The current method of obtaining facial measurements in optical practice involves the facial rule as previously described in section 1.42, albeit not an ideal instrument for a child due to safety reasons with the long metal swinging pointer and the inability of measurement of a negative crest height. Cooperation and the ability of a young child to remain still during manual measuring is a challenge, therefore the fast capture speed of the 3dmd system and subsequent decrease in patient interaction time has been shown to increase the accuracy of measurements (Ort et al., 2012).

The tolerances deemed clinically acceptable of the facial measurements are assessed in professional examinations for Dispensing Opticians whereby this competency will be used to produce hand-made bespoke frames for patients. The facial rule itself, shows only a scale protractor marked at intervals of 10 degrees for angular measurements (tolerance 5 degrees) and 2mm marked linear scale (tolerance range 1mm-5mm) therefore the accuracy of the 3dmd Face™ system widely reported and the reproducibility shown suggests confidence that the parameters suggested in this study to inform frame manufacture are both accurate and representative.

The findings of this study show that the 3dmd system can produce highly accurate and reproducible measurements beyond those that can be made with a manual facial ruler and is therefore capable of showing anatomical differences with respect to facial development in children.

Chapter 5 Statistical analysis of demographic data.

5.1 Sample information

A total of 1349 images were acquired in this study and the demographics of the data acquisition is specified in section 2.5, along with a description of image acquisition in section 2.6. Fifteen of these images were discounted from the following analyses due to the image not being of adequate quality to acquire facial measurements, giving a total of 1334 usable images from which measurements were taken. The benefit of the 3dMDFace™ system is that images can be checked and reacquired relatively quickly if an error or multiple image artefacts occurs, but the children involved in these cases did not wish to have another image taken and their decision was naturally respected. No children between the ages of 0 to 16 years were excluded from participation. Parental or carer declaration of their child's sex and ethnicity was requested using ethnic group descriptors as recommended by the Office for National Statistics (Office for National Statistics, 2015), along with a question on whether the child has Down's syndrome.

The colour bandings refer to how the data has been grouped for analysis where a sufficient sample exists in each category. As the ethnicity groups, shown in green, have multiple categories and smaller numbers of children in each, the presentation of this data will be more descriptive in nature.

Images of typically-developed children	**Male**	**Female**	**Sub-Total**
White British	392	409	801
Chinese	161	148	309
Indian	7	15	22
White and Black Caribbean	6	8	14
White Chinese	4	6	10
White Asian	8	2	10
Black Caribbean	4	4	8
Polish	3	2	5
Bulgarian	4	0	4
Pakistani	3	0	3
Portuguese	3	0	3
Norwegian	3	0	3
Total	**598**	**594**	**1192**

Table 5.1a. Sample of usable images of typically-developed children showing gender and ethnicity information listed in numerical order.

Images of children with Down's syndrome	Male	Female	Sub-Total
White British	58	43	101
Indian	1	5	6
Black British	0	5	5
White and Black African	2	2	4
African	0	3	3
Pakistani	2	1	3
Mixed multiple ethnicities	2	1	3
Portuguese	2	0	2
White Algerian	2	0	2
Asian Caribbean	0	2	2
White and Black Caribbean	2	0	2
White Asian	1	0	1
Philippine	0	1	1
Bulgarian	0	1	1
British German	1	0	1
Italian Bulgarian	0	1	1
Russian	0	1	1
White American	1	0	1
Chinese	0	1	1
Prefer not to say	1	0	1
Total			**142**

Table 5.1b. Sample of usable images of children with Down's syndrome showing gender and ethnicity information listed in numerical order.

5.2 Normality

Each three-dimensional image was measured for 15 facial parameters relating to spectacle frame wear. Measurement methods are described in section 2.82 and are presented in the following results chapters.

There are two angular measurements; splay and frontal angle (right and left), and nine linear measurements: head width, temple width, distance between rims at 10mm and 15mm below crest, apical radius, crest height (right and left), distance between pad centres, front to bend (right and left) and pupillary distance. This produced 15 parameters for each facial image and a further 4 for the mean values of measurements where a right and left measurement was taken.

The first step in analysis was to test the data for normality on all 19 results in order to determine which statistical tests would be most appropriate. These tests were carried out using SPSS (version 26: IBM Ltd, Armonk, NY) and normality was judged across a series of tests which included skew with standard error, kurtosis with standard error, a histogram fitted with a normality line, Shapiro-Wilks test, Kolmogorov–Smirnov test, quantile-quantile (QQ) and a box plot. To consider if the data was normally distributed, all of the above tests were conducted for each parameter to give both visual and theoretical results in order to make a judgement on normality. Based on the results of these individual tests, the normality of the data was decided and summarised in Table 5.2a.

Facial Measurement	Normally Distributed Data
Frontal angle	Yes
Splay angle	Yes
Distance between rims at 10mm below crest	No
Distance between rims at 15mm below crest	No
Apical radius	No
Crest height	Yes
Distance between pad centres	Yes
Head width	Yes
Temple width	Yes
Front to bend	Yes
Pupillary distance	Yes

Table 5.2a. Normality test results for each facial measurement.

The majority of measurements met the criteria for normality in at least 5 out of the 7 tests, except for apical radius and the distance between rims measurements. Most of the measurement data appeared to be normally distributed when viewing a histogram of the data. Skew and kurtosis also indicated a normal distribution, but the Shapiro-Wilks and Kolmogorov-Smirnov tests often showed statistically significant departures from normality. This may be due to the large sample size (n=1334) which caused high statistical and in turn increased sensitivity at detecting very small departures from normality (Frison et al., 2016), thus giving rise to unexpectedly low p-values (Razali et al., 2012).

5.3. Decision Tree Analysis.

Decision Tree Analysis (DTA) by the Chi-squared automated interaction detection (CHAID) is a type of data mining technique that is used to build a model in the form of a tree-like structure having branches to represent the hierarchy of independent variables on a dataset. The dataset is presented with the most influential variable at the top (root node) of the tree and then split into further subsets (sub-nodes) on the basis of significance of the variable; this continues until a terminal (leaf) node is reached when splitting is complete or a restriction on growth is in place. The most influential variables and splitting decisions are made by the algorithms.

Due to the high number of possible interactions between the 15 facial measurement parameters and other factors such as age, Down's syndrome, ethnicity and gender, a decision tree analysis (DTA) method, was selected, primarily to explore the data in depth for the influences of age, ethnicity, gender, and Down's syndrome on each facial measurement in turn. The results show a useful order of importance for each independent variable that shows an influence on the dependent variable. The algorithms determine a very informative split on ethnicity and ages and presents the results in calculated groups of ethnicities or ages dependent on influence and not pre-determined. Initially the parent and child nodes were set to 100 and 50 respectively with a tree depth of 100 to allow the trees to grow without restriction. The tables below (5.3a, 5.3b) presents the data for each measurement (dependent variable) showing the ranked influence (F-value) of the independent variables (age, gender, ethnicity, and Down's syndrome) with the number of resultant nodes and the calculated proportion of variance accounted for by the model.

Dependent Angular Variable in degrees	Independent variables showing statistically significant influence				Number of nodes	Proportion of variance accounted for by model
	Age in years	Gender (M/F)	Ethnicity	Down's syndrome		
Frontal angle (right)	yes F(5,999) = 57, P<0.001	yes F(1,215) = 10, P=0.001 F(1,232) = 9, P=0.003	yes F(11,332) = 823, P<0.001	no	13	0.500
Frontal angle (left)	yes F(5,993) = 60, P<0.001	yes F(1,214) = 17, P<0.001 F(1,232) = 5, P=0.033	yes F(11,332) = 1009, P<0.001	no	13	0.544
Frontal angle (mean)	yes F(5,999) = 63, P<0.001	yes F(1,215) = 14, P<0.001 F(1,232) = 7, P=0.010	yes F(11,332) = 947, P<0.001	no	13	0.536
Splay angle (right)	yes F(2,982) = 37, P<0.001 F(1347) = 8, P=0.036 F(1602) = 7, P=0.043	no	yes F(11,332) = 153, P<0.001	yes F(1,663) = 6, P=0.011	12	0.163
Splay angle (left)	yes F(11,332) = 140, P<0.001	yes F(1,419) = 6, P=0.013	yes F(11,332) = 140, P<0.001	yes F(1,315) = 14, P<0.001	10	0.143
Splay angle (mean)	yes F(3,966) = 27, P<0.001 F(1362) = 8, P=0.049	no	yes F(11,332) = 169, P<0.001	no	9	0.167

Table 5.3a. Decision tree analysis for angular measurements showing right, left and mean results.

Dependent Linear Variable in mm	Independent variables showing statistically significant influence				Number of nodes	Proportion of variance accounted for by model
	Age in years	Gender (M/F)	Ethnicity	Down's syndrome		
Head width	yes F(51,328) = 104, P<0.001	yes F(1,398) = 118, P<0.001 F(1,133) = 21, P<0.001 F(1,265) = 63, P<0.001 F(1,131) = 19, P<0.001 F(1,159) =28, P<0.001 F(1,104) = 4, P=0.044	yes F(1,131) = 69, P<0.001 F(1,265) = 43, P<0.001 F(1,203) = 27, P<0.001	no	25	0.444
Temple width	yes F(4,942) = 31, P<0.001 F(2,307) = 36, P<0.001	yes F(1,198) = 13, P=0.001 F(1,322) = 6, P=0.019	yes F(21,331) = 401, P<0.001	no	16	0.463
Crest height (right)	yes F(5,946) = 62, P<0.001	yes F(1,300) = 50, P<0.001 F(1,328) = 18, P<0.001	yes F(21,331) = 356, P<0.001	no	14	0.497
Crest height (left)	yes F(5,946) = 64, P<0.001	yes F(1,300) = 39, P<0.001 F(1,328) = 15, P<0.001	yes F(21,331) = 360, P<0.001	no	14	0.498
Crest height (mean)	yes F(5,946) = 63, P<0.001	yes F(1,300) = 45, P<0.001 F(1,328) = 17, P<0.001	yes F(21,331) = 382, P<0.001	no	14	0.501
Apical radius	yes F(4,974) = 84, P<0.001 F(3,351) = 18, P<0.001	no	yes F(11,332) = 636, P<0.001	no	12	0.452
Distance between rims at 10mm below crest	yes F(4,981) = 86, P<0.001 F(3,344) = 16, P<0.001	no	yes F(11,332) = 670, P<0.001	no	12	0.472
Distance between rims at 15mm below crest	yes F(4,982) = 44, P<0.001 F(2,344) = 13, P<0.001	yes F(1,428) = 8, P=0.005	yes F(11,332) = 600, P<0.001	no	13	0.394
Front to bend (right)	yes F(81,325) = 127, P<0.001	yes F(1,131) = 22, P<0.001 F(1,131) = 20, P<0.001 F(1,132) = 6, P=0.013	no	no	28	0.488

		F(1,131) = 19, P<0.001 F(1,285) =19, P<0.001 F(1,132) = 17, P<0.001 F(1,132) = 21, P<0.001 F(1,131) = 7, P=0.011 F(1,131) = 6, P=0.015				
Front to bend (left)	yes F(61,327) = 159, P<0.001	yes F(1,131) = 19, P<0.001 F(1,265) = 34, P<0.001 F(1,131) = 30, P<0.001 F(1,399) = 46, P<0.001 F(1,132) =9, P=0.004 F(1,131) = 7, P=0.008 F(1,131) = 6, P=0.015	yes F(1,117) = 18, P=0.001 F(1,198) = 15, P=0.040	no	26	0.486
Front to bend (mean)	yes F(71,326) = 159, P<0.001	yes F(1,131) = 24, P<0.001 F(1,265) = 33, P<0.001 F(1,131) = 30, P<0.001 F(1,265) = 26, P<0.001 F(1,132) =20, P<0.001 F(1,132) = 17, P<0.001 F(1,131) = 8, P=0.005 F(1,131) = 7, P=0.011	yes F(1,117) = 18, P=0.001	no	27	0.521
Distance between pad centres	yes F(1,140) = 23, P<0.001 F(1,596) = 10, P=0.013 F(2,426) = 14, P<0.001 F(1,163) = 12, P=0.005	yes F(11,190) = 4, P=0.047	yes F(1,592) = 19, P=0.002 F(1,240) = 14, P=0.004 F(1,354) = 68, P<0.001	yes F(11,332) = 34, P<0.001	20	0.142
Pupillary distance	yes F(61,327) = 154, P<0.001	yes F(1,131) = 4, P=0.047 F(1,265) = 11, P=0.001 F(1,132) = 13, P<0.001 F(1,265) = 7, P=0.008 F(1,131) =5, P=0.025 F(1,106) =6, P=0.018	yes F(1,131) = 40, P<0.001 F(1,265) = 32, P<0.001	no	24	0.460

Table 5.3b. Decision tree analysis for linear measurements showing right, left and mean results where applicable.

In order to increase the proportion of variance explained by the model and the tree complexity, the DTA was repeated with parent and child nodes limited to 60 and 30 cases respectively. The individual tree results are presented in a summary table below showing the two DTA results and branch positions for each independent variable per facial measurement.

Dependent Variable	Independent variables (Parent 100/Child 50) showing statistically significant influence compared to Parent 60/Child 30 and (tree level position)				Number of nodes and (tree depth) set to a 100 maximum	Proportion of variance accounted for by model
	Age in years	Gender (M/F)	Ethnicity	Down's syndrome		
Frontal angle (right)	yes (2); yes (2)	yes (3); yes (3)	yes (1); yes (1)	no; no	13 (3); 14 (3)	0.500; 0.505
Frontal angle (left)	yes (2); yes (2)	yes (3); yes (3)	yes (1); yes (1)	no; no	13 (3); 13 (3)	0.544; 0.553
Frontal angle (mean)	yes (2); yes (2)	yes (3); yes (3)	yes (1); yes (1)	no; no	13 (3); 15 (3)	0.536; 0.544
Splay angle (right)	yes (2,4); yes (2,4)	no; no	yes (1); yes (1)	yes (3); yes (3)	12 (4); 13 (4)	0.163; 0.169
Splay angle (left)	yes (2); yes (2)	yes (3); yes (3)	yes (1); yes (1)	yes (3); yes (3)	10 (3); 13 (3)	0.143; 0.161
Splay angle (mean)	yes (2); yes (2)	no; no	yes (1); yes (1)	no; yes (3)	9 (2); 12 (3)	0.167; 0.188
Head width	yes (1); yes (1)	yes (2,3); yes (2,3)	yes (2,3); yes (2,3)	no; no	25 (3); 27 (3)	0.444; 0.453
Temple width	yes (2); yes (2,5)	yes (3); yes (3,4)	yes (1); yes (1)	no; yes (3)	16 (3); 24 (5)	0.463; 0.474
Crest height (right)	yes (2); yes (2)	yes (2,3); yes (2,3)	yes (1); yes (1)	no; no	14 (3); 14 (3)	0.497; 0.497
Crest height (left)	yes (2); yes (2)	yes (2,3); yes (2,3)	yes (1); yes (1)	no; no	14 (3); 14 (3)	0.498; 0.498
Crest height (mean)	yes (2); yes (2)	yes (2,3); yes (2,3)	yes (1); yes (1)	no; no	14 (3); 14 (3)	0.501; 0.501
Apical radius	yes (2); yes (2)	no; yes (3)	yes (1); yes (1)	no; yes (3)	12 (2) 19 (3)	0.452; 0.467
Distance between rims at 10mm below crest	yes (2); yes (2)	no; yes (3)	yes (1); yes (1)	no; yes (3)	12 (2); 18 (3)	0.472; 0.485
Distance between rims at 15mm below crest	yes (2); yes (2)	yes (3); yes (3)	yes (1); yes (1)	no; yes (3)	13 (3); 20 (3)	0.394; 0.408
Front to bend (right)	yes (1); yes (1)	yes (2); yes (2)	no; no	no; no	28 (2); 28 (2)	0.488; 0.488
Front to bend (left)	yes (1); yes (1)	yes (2); yes (2)	yes (3); yes (3)	no; no	26 (3); 26 (3)	0.486; 0.486
Front to bend (mean)	yes (1); yes (1)	yes (2); yes (2)	yes (3); yes (3)	no; no	27 (3); 27 (3)	0.521; 0.521
Distance between pad centres	yes (2,3,4); yes (2,3,4)	yes (2); yes (2)	yes (3,4); yes (3,4)	yes (1); yes (1)	20 (4); 19 (4)	0.142; 0.141
Pupillary distance	yes (1); yes (1,4)	yes (2,3); yes (2,3)	yes (2); yes (2)	no; yes (3)	24 (3); 34 (4)	0.460; 0.491

Table 5.3c. Decision tree summary analysis repeated to show the results in red of a more complex tree for all measurements showing branch positions in brackets.

Summary of DTA Outcomes

Overall, ethnicity was the most important influencing factor for the majority of measurements with the exceptions of head width, front to bend and pupillary distance. The DTA calculates by influence how to group the ethnicities together, and the table below shows the groupings determined by the DTA for the majority of results. Any departures from these groupings are described in the individual descriptions in section 5.4.

DTA Group A	DTA Group B	DTA Group C
White British, Pakistani, White Chinese, European	Chinese, White and Black Caribbean, Black Caribbean, White and Asian Caribbean, White and Black African, Black African, Russian, White American, prefer not to say, Mixed multiple ethnicity	Indian, White Asian

Table 5.3d. Decision tree analysis resultant common groupings of different ethnicities.

Age was the next most important factor for the majority of the measurements except for head width, front to bend and pupillary distance followed by gender and Down's syndrome. The DTA determined the appropriate age bandings for each of the resultant trees and this is helpful when determining age bandings for recommending data to children's spectacle frame manufacturers.

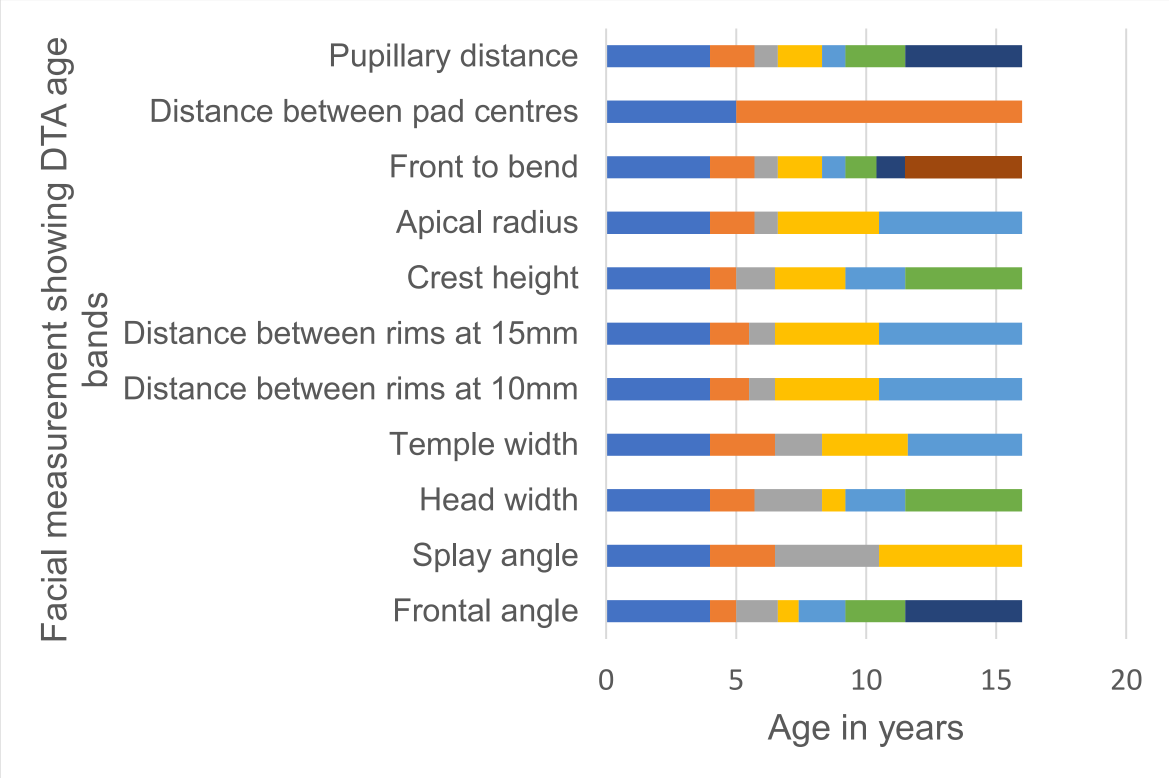


Figure 5.3e. Chart to show age bandings determined by the DTA for each facial measurement.

The majority of measurements show clear age bands fall under 4 years of age and over 12 years with 7/11 showing a band around 6 years of age. On this basis, data was further analysed in Chapter 10 according to the bandings of 0-3.9, 4-5.9, 6-7.9, 8-9.9,10-11.9 and 12-14 years.

Allowing the tree to become more complex, showed more influence of Down's syndrome on facial measurements, namely, splay angle (mean), temple width, apical radius, distance between rims, distance between pad centres and pupillary distance.

The trees for right and left measurements appeared almost identical indicating the mean value may be an acceptable compromise to propose to frame manufacturers, although this proposal is explored further in sections 6.3, 7.3 and 8.3 by comparing the slopes of regression analyses.

5.4. Decision Tree Analysis descriptions by measurement.

5.41 Angular measurements

The trees for frontal angle (FA) (right, left and mean) were identical and therefore it is deemed acceptable to generalise for the mean values. Ethnicity was the main influence on this facial measurement followed by age and finally gender with no influence identified with Down's syndrome. The frontal angle narrowed with age, showing a decrease in value as age increases. The ethnic groups were divided by the DTA as group A (including Indian), group B and a third group containing White and Black Caribbean, Black Caribbean, Pakistani, White Chinese and Russian. Group A showed the smallest frontal angle with a mean value of 55.71 (5.92) degrees, the third group 60.27 (4.28) degrees and group B 67.03 (4.89) degrees. Age was an influence on the data at the next level down and is banded to the following groups by the DTA; less than 4 years, 4-5, 5-6.6, 6.6-7.4, 7.4-9.2, 9.2-11.5, and over 11.5 years. Finally, gender was identified as an influence for two age groups; 9.2-11.5 where males show a larger value than females, and in the 7.4-9.2 age group where females show a larger value than males.

For splay angle (SA), the proportion of the variance explained by the model is weak at only 18% maximum across the three analyses. Ethnicity is consistent as being the most influential variable, group A now also contains Indian and White Asian, group B only contains Chinese, Russian and mixed multiple ethnicity, with the rest moved into a third group (Black Caribbean, White and Black Caribbean, Black African, White and Black African, Philippine and prefer not to say). Group A reported the smallest splay angle at 27.16 (2.36) degrees followed by group B; 29.90 (2.37) degrees and the described third group having the largest mean splay angle; 30.43 (2.48) degrees. Only group A ethnicities grew further by the analysis into an effect on age, bandings being under 4, 4-6.5, 6.5-10.5 and over 10.5.The influence of Down's syndrome (DS) factor as the next branch into only the youngest and oldest age bands; in the under 4 years, the splay is slightly smaller in children with DS 26.19 (2.52) degrees compared to 28.58 (2.65) whereas in the older age band over 10.5, children with DS have a slightly larger splay angle 27.50 (1.65) degrees compared to 26.23 (2.10) degrees. The gender influence identified in the splay angle left DTA but not in the splay angle right or mean DTA's is on the third branch in the 6.5-10.5 group A ethnicities and equates to less than one-degree difference between male and females. The differences between right and left splay angle can be considered as small and can therefore be generalised as a mean value.

5.42 Linear measurements

Head width (HW) produced an extremely complex tree with age being the largest influential factor, split into the most groups; under 4, 4-5.7, 5.7-8.3, 8.3-9.2, 9.2-11.5 and over 11.5. Head width increases considerably with age (under 4 years mean value 134.32 (8.6) mm compared to over 11.5 mean value 152.45 (9.46) mm. Ethnicity then influences the younger years up to age 4 years with Chinese, Indian and European showing a 10mm wider HW than the rest of the ethnic groups combined, reducing to a 5mm difference in the 4-5.5-year group which identifies Chinese and White and Black Caribbean as influencing ethnicities. For the older age groups, gender is the influencing factor with males showing a constant wider head width than females. Further down the tree levels, Chinese is then singled out as a sole ethnic group in the 5.7-8.3 groups showing a larger HW and gender features in the 4-5.5 group, again showing males having a significantly larger head width.

In a similar DTA for temple width (TW), ethnicity was the major influencing factor and Chinese was again singled out as a sole ethnic group along with group A and the rest of group B. Group B shows the smallest mean temple width 98.64 (4.07) mm, followed by group A 101.42 (5.63) mm and the Chinese 111.04 (5.05) mm. Age followed as the next factor on all ethnicities and the groups were split into age bands: under 4, 4-6.5, 6.5-8.3,8.3-11.6 and over 11.6 years. For group A, under 4 years, 4-6.5 and over 6.5 showed an influence for Chinese ethnicity and under 9.5 and over 9.5 for group B ethnicities. DS influences the temple width measurement in group A ethnicities for the younger and older age groups showing a relative 2mm increase in this parameter for children with DS. Gender influences the group A ethnicities in the 6.5-8.3 and 8.3-11.6 age group with males having a larger temple width than females. Temple width widens with age across all groups.

Distance between rims at 10mm below crest (DBR10) also shows ethnicity has the largest influence on this measurement and the DTA split out White British as a group alone, followed by group B and C and a 4th group containing the rest of group A plus Black African and Mixed multiple ethnicities. Group C again showed the smallest measurement 15.33 (2.37) mm, White British 16.252 (2.56) mm Group 4 17.15 (2.66) mm and Group B the largest at 20.85 (3.52) mm. Age was the next factor for White British and again the groups were split at under 4, 5-6.5, 6.5-10.5, and over 10.5 years with this oldest age group then being influenced by DS 17.22 (2.14) mm mean compared to 14.82 (1.79) mm. Ethnic group B age splits were under 4, 4-5, 5-6.5, over 6.5 years with the 5-6.5-year group having a gender influence that showed females having a larger DBR10 than males in this age group.

Distance between rims at 15mm below crest (DBR15) again showed ethnicity has the most influence and the groups were again approximately split by groups A, B and C with the largest mean value in group B of 27.06 (4.74) mm compared to 21.54 (3.18) mm and 20.13 (2.75) mm for groups A and C respectively. For group A ethnicities, the branch of age bands was split into under 4, 4-5.5, 5.5-6.5, 6.5-10.5 and over 10.5. The youngest and oldest age groups are then influenced by DS showing a 2-3mm increase in mean for both age groups compared to those children without DS. Gender shows an influence on the 6.5-10.5 age group with females having a slightly larger DBR15 than males. In group B ethnicities, the ages were split under 4, 4-6.5 and over 6.5 with a gender influence on the under 4 age groups showing females having a smaller DBR15 measurement.

The trees for crest height (CH) (right, left and mean) were identical and therefore it is deemed acceptable to generalise for the mean value. Ethnicity had the most influence on the crest height and the groups fell into approximately groups A, B and a third group containing Black Caribbean, Pakistani, White Chinese and Indian. A large difference in mean values for crest height was reported from group A ethnicities as 5.00 (2.76) mm, group 2; 0.557 (2.07) mm and group 3; 3.138 (2.38) mm. Age then features at the next tree level for group A ethnicities and this is banded into ages under 4, 4-5, 5-6.5, 6.5-9.2, 9.2-11.5, and over 11.5 years. The mean crest height is 1.48 (2.25) mm for under 4 years and this increases with age to 7.15 (3.00) mm at over 11.5 years. Gender features along this level for group B ethnicities, with males showing larger crest heights than females, also the same trend for the age group 6.5-9.2 years of group A ethnicity. No influence detected for Down’s syndrome for this measurement.

Apical radius (AR) was also predominantly influenced by ethnicity, split into three main groups as described in table 5.3d above. The smallest mean AR reported in group C of 8 (0.94) mm followed by group A; 8.4 (1.31) mm and the largest in group B ;10.6 (2.02) mm. Age groups were split for group 1 ethnicities as under 4, 4-5.7, 5.7-6.6, 6.6-10.5 and over 10.5 years, similar groups for group B but stopped at over 6.5 years and no age influence detected for group C ethnicities. DS has an influence on the very young (under 4) and older (over 10.5) age groups. Gender only influenced the 5-6.5 year olds in group B ethnicities with females having a larger apical radius 11.37 (2.29) mm than males 10.40 (1.30) of the same age. AR reduces in size with age across all groups.

Distance between rims at 10mm below crest (DBR10) shows ethnicity has the largest influence on this measurement and the DTA split out White British as a sole ethnic group, followed by group B and C and a fourth group containing the rest of group A plus Black African and mixed multiple ethnicities. Group C again showed the smallest measurement of 15.33 (2.37) mm, White British 16.25 (2.56) mm group 4 17.15 (2.66) mm and group B the largest at 20.85 (3.52) mm. Age was the next influential factor for White British and again the groups were split at under 4, 5-6.5, 6.5-10.5, and over 10.5 years with this older age group then being influenced by DS; 17.22 (2.14) mm mean compared to 14.82 (1.79)mm. Ethnic group B age splits under 4, 4-5, 5-6.5, over 6.5 years with the 5-6.5-year group having a gender influence that showed females having a larger DBR10 than males in this age group. Distance between rims at 10mm below crest narrows with age across all groups.

Distance between rims at 15mm below crest (DBR15) again reported ethnicity showing the most influence and the ethnic groups were again split by groups A, B and C. The largest mean value in group B of 27.06 (4.74) mm compared to 21.54 (3.18) mm and 20.13 (2.75) mm for groups A and C respectively. For group A ethnicities, the following age bands were reported; under 4, 4-5.5, 5.5-6.5, 6.5-10.5 and over 10.5 years. The youngest and oldest age groups are then influenced by DS showing a 2-3mm increase in mean for both age groups compared to those children without DS. Gender shows an influence on the 6.5-10.5 age group with females having a slightly larger DBR15 than males. In group B ethnicities, the ages were split under 4, 4-6.5 and over 6.5 with a gender influence on the under 4 age groups showing females having a smaller DBR than males. Distance between rims at 15mm below crest narrows with age across all groups.

The trees for front to bend (FTB) (right, left and mean) were almost identical and therefore it is deemed acceptable to generalise for the mean value. Age has the most influence on front to bend and this measurement increases with age. A large number of age bandings were reported as under 4 years, 4-5.7, 5.7-6.6, 6.6-8.3, 8.3-9.2, 9.2-10.4, 10.4-11.5, and over 11.5 years. Gender was the next influencing factor and males have longer length to bends than females in all age bandings by approximately 3-5mm. The third branch identified females in the age 4-5.7 as having an ethnical influence with White British and White and Black Caribbean children having a longer length to bend than Chinese, White Chinese and European children.

Distance between pad centres (DBPC) – Down's syndrome (DS) is the most influential variable here showing a smaller mean value 14.34 (2.15) mm compared to 15.20 (1.61) mm for children without DS. Age is the subsequent variable for children with DS splitting the age groups as under and over 5 years. Gender is the second influence for children without DS, however, the mean values between males and females are less than 0.2mm difference. The female line then shows ethnicity, followed by age whereas the males are influenced by age followed by ethnicity. Overall, a small range (<3mm) of mean values for DBPC showing a narrowing with age and a slightly larger value for group B ethnicities. For this measurement the proportion of the variance explained by the model is the weakest at only 14%.

Pupillary distance (PD) continues to grow with age and the multiple age bandings detected by the analysis were quite narrow: under 4, 4-5.7, 5.7-6.6, 6.6-8.3, 8.3-9.2, 9.2-11.5 and over 11.5 years. Each band showed a rate of growth of almost 1mm per year at a constant rate from mean values of 50.61 (3.51) mm at under 4 years old to 59.85 (3.42) mm at over 11.5 years old. The next tree level indicated influences of ethnicity in all age bands except 8.3-9.2 and over 11.5 years which showed a gender influence where males had a wider PD compared to females. Ethnicity groups were mixed, however Chinese featured constantly in groups displaying a wider PD of approximately 2mm. For the youngest age group, under 4 years, DS also had an influence where children with DS had a smaller PD 48.17 (3.17) mm than children without DS 49.96 (2.82) mm.

Facial Measurement	Primary Influence	Secondary Influence	Tertiary Influence
Frontal angle (mean)	Ethnicity	Age	Gender
Splay angle (mean)	Ethnicity	Age	DS
Head width	Age	Gender/Ethnicity	Gender/Ethnicity
Temple width	Ethnicity	Age	Gender/DS
Crest height (mean)	Ethnicity	Age	Age/Gender
Apical radius	Ethnicity	Age	Gender/DS
Distance between rims at 10mm below crest	Ethnicity	Age	Gender/DS
Distance between rims at 15mm below crest	Ethnicity	Age	Gender/DS
Front to bend (mean)	Age	Gender	Ethnicity
Distance between pad centres	DS	Gender/Age	Ethnicity/Age
Pupillary distance	Age	Ethnicity/Gender	Gender/DS

Table 5.4a. Table summary of the three main influences on each facial measurement parameter

Informed by the results of the DTA, it was decided to carry out linear regression analysis of each facial measurement parameter as a function of age for the following ethnicities; typically-developed White British and Chinese, typically-developed White British with Down's Syndrome. Due to the limitations in sample size outside of the White British and Chinese ethnicities, other typically-developed and children with Down's Syndrome ethnic groups were qualitatively evaluated in comparison with the larger ethnic groups.

In order to facilitate provision of measurement parameters to spectacle frame manufacturers, the data was then divided into the following age groups; 0-3.9 (pre-school), 4-7.9 (early years), 8-11.9 (juniors) and 12-15.9 (seniors), age banding supported by the DTA results.

Chapter 6 Facial anthropometry in typically-developed children of White British ethnicity.

6.1 Introduction and methods

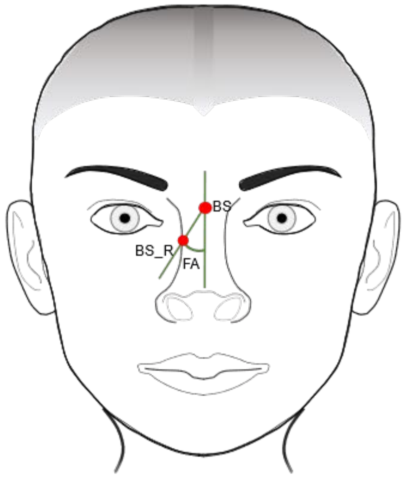
Data was acquired using the method described in section 2.6 with 801 images (392 males, 409 females) acquired in the White British group. These were collected from a variety of settings across the United Kingdom (section 2.5) including nursery, primary and secondary schools, charitable organisations and children's groups.

6.2 Results

For the following figures, curve fitting was carried out for each of the measurement parameters as a function of age and it was determined that linear regression offered the best fit to the data. The linear regression line delineates a model of growth in the age range studied, i.e. birth to sixteen years of age. On this basis, the gradient of the line indicates the rate of change, i.e. growth rate of each of the facial measurements.

White British typically-developed

Frontal Angle (FA)



Landmarks involved:

Bearing surface (BS) and bearing surface right (BS_R) for right frontal angle (as shown in schematic diagram) and bearing surface and bearing surface left (BS_L) for left frontal angle.

Measurement definition:

The angle between the vertical and the line of intersection of the pad plane with the back plane of the front, taken in the lateral plane.

Measurement method:

Angle between the landmarks calculated by 3D stereophotogrammetry.

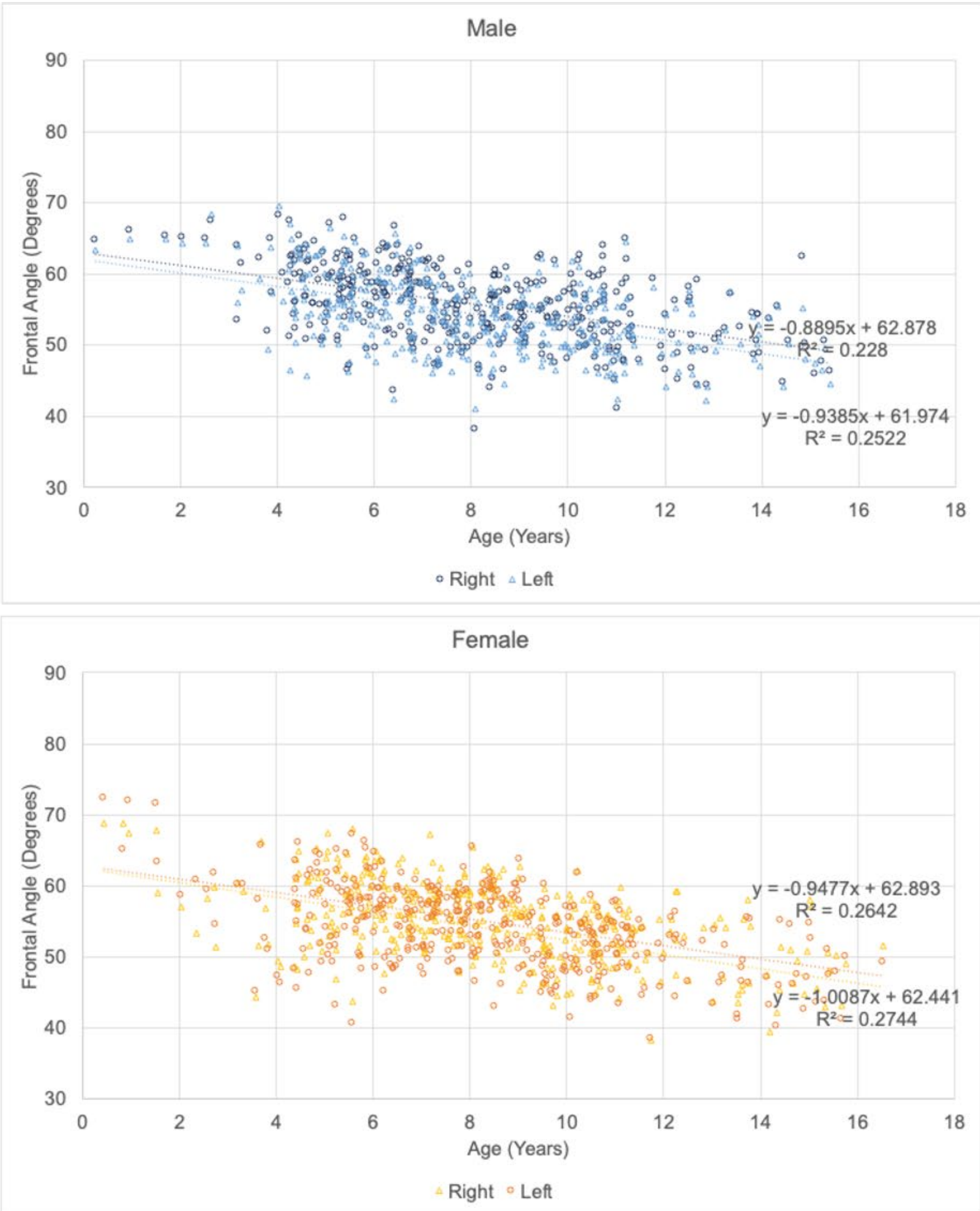


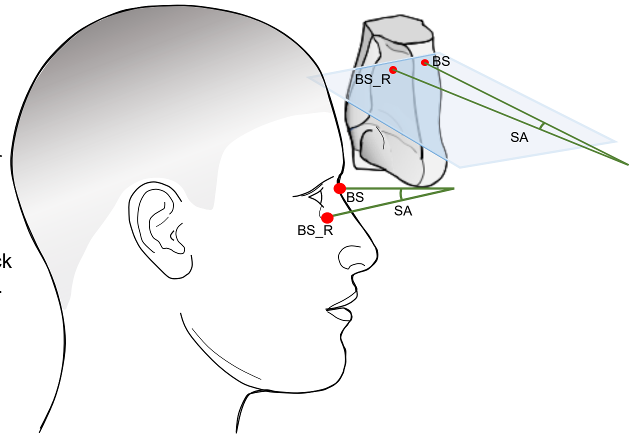
Figure 6.2a. Frontal angle results for White British typically-developed children showing right and left measurements for both male and female subjects.

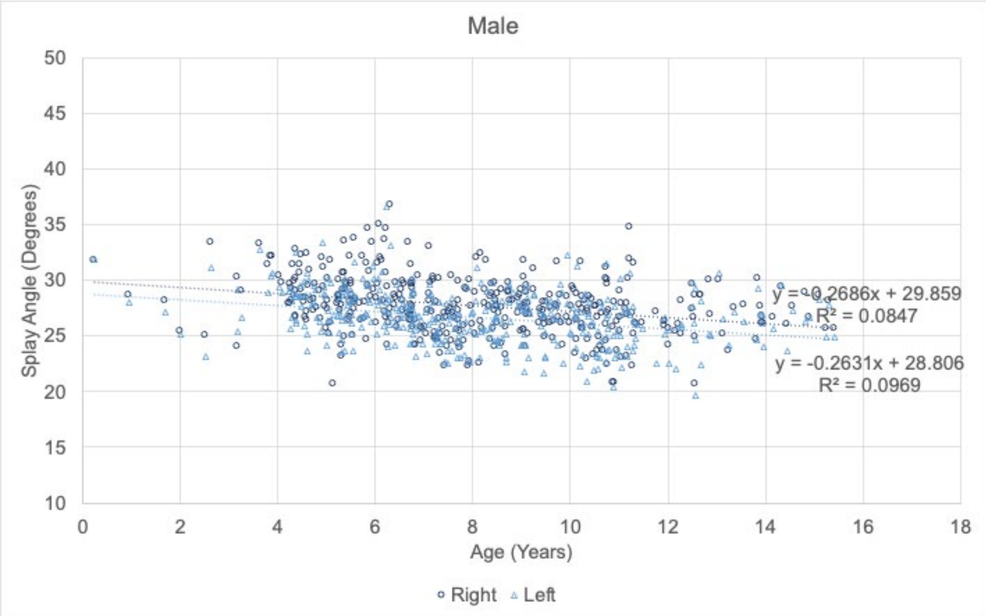
White British typically-developed
Splay Angle (SA)

Landmarks involved:
Bearing surface (BS) and bearing surface right (BS_R) for right splay angle and bearing surface (BS) and bearing surface left (BS-L) for left splay angle.

Measurement definition:
The angle between the pad plane and a normal to the back plane of the spectacle front, taken in the transverse plane.

Measurement method:
Angle between the landmarks calculated by 3D stereophotogrammetry.





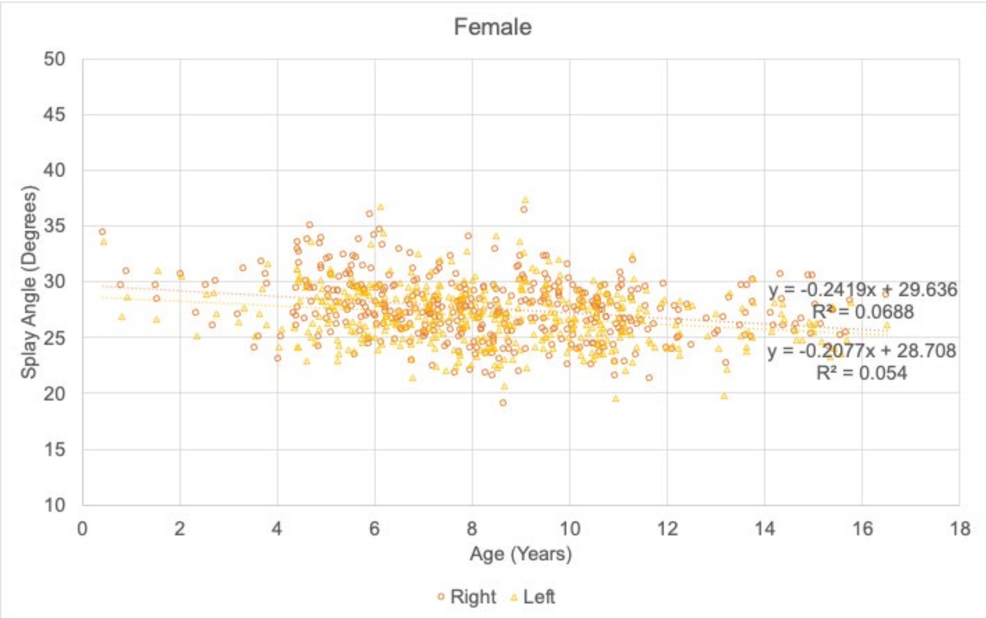
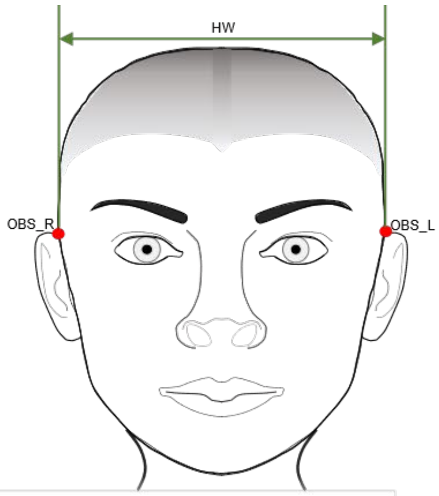
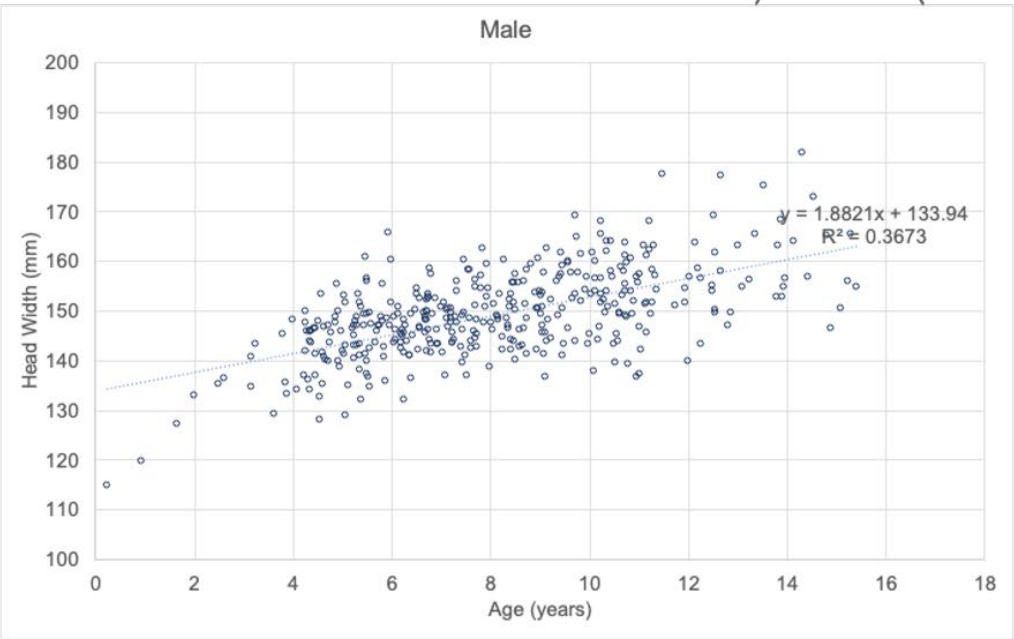


Figure 6.2b. Splay angle results for White British typically-developed children showing right and left measurements for both male and female subjects.

White British typically-developed
Head width (HW)

Landmarks involved:
Otobasion superious right (OBS_R) and left (OBS_L).
Measurement definition:
The distance between the two ear points.
Measurement method:
Linear distance between the landmarks calculated by 3D stereophotogrammetry.





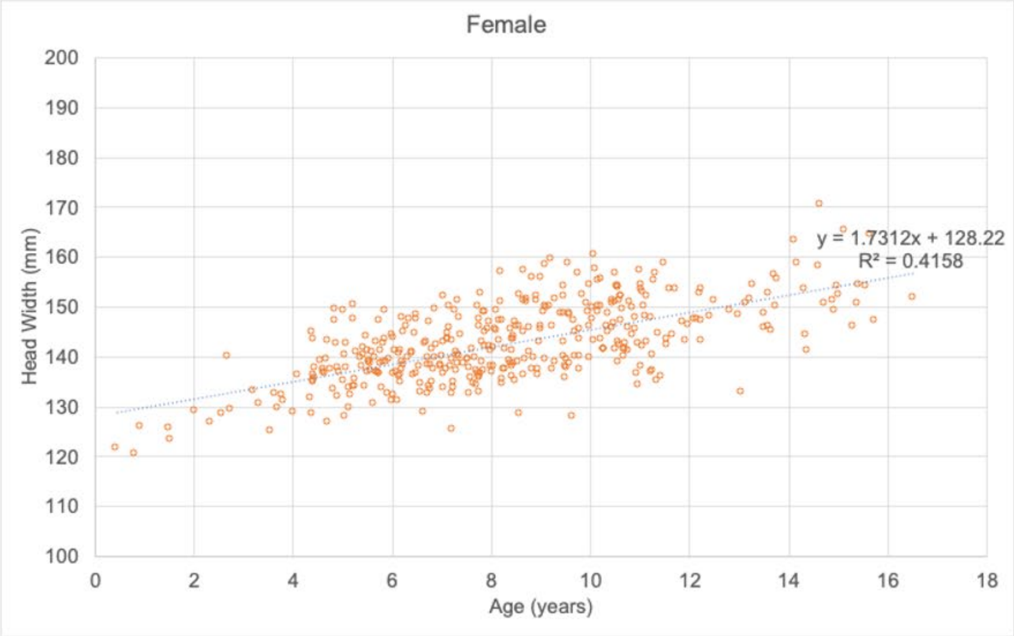


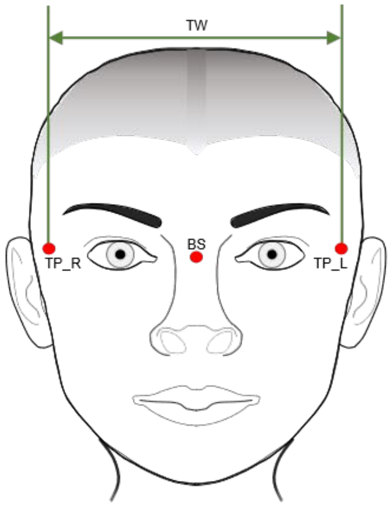
Figure 6.2c. Head width results for White British typically-developed children showing measurements for both male and female subjects.

White British typically-developed
Temple width (TW)

Landmarks involved:
Bearing surface (BS) and temple points right (TP_R) and left (TP_L).

Measurement definition:
The distance between the two temple points at a distance of 25mm behind the back plane of a spectacle front.

Measurement method:
The position of the bearing surface enables the programme to create a virtual frame front in order to generate the temple points at the correct distance behind the front and measure the distance between the landmarks calculated by 3D stereophotogrammetry.



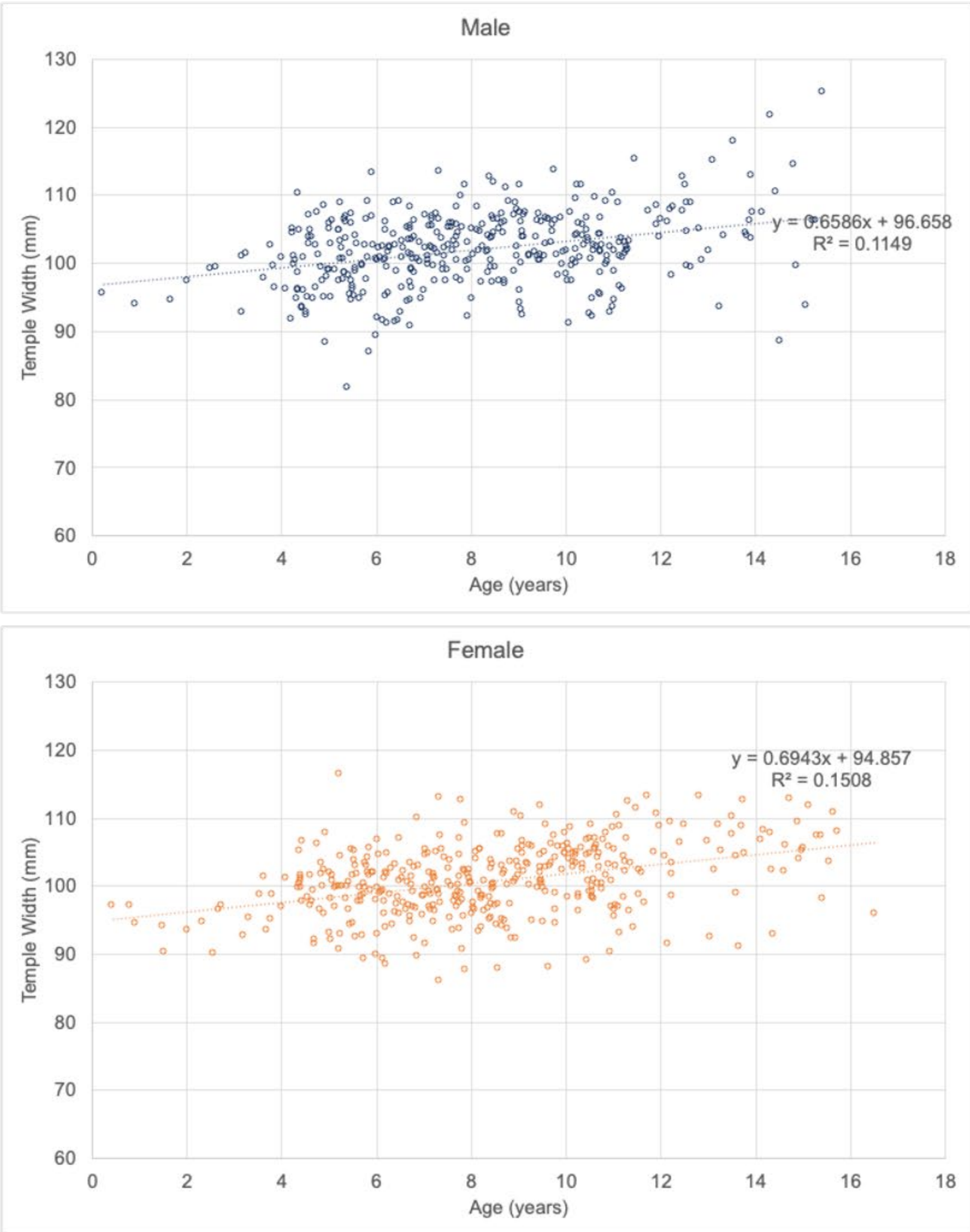


Figure 6.2d. Temple width results for White British typically-developed children showing measurements for both male and female subjects.

White British typically-developed
Distance Between Rims at 10mm
Below Crest (DBR10)

<u>Landmarks involved:</u>
Bearing surface (BS).

<u>Measurement definition:</u>
The width of the nose at a point 10mm below the crest (bearing surface).

<u>Measurement method:</u>
Automated nasal width calculated at a point 10mm below the bearing surface calculated by 3D stereophotogrammetry.

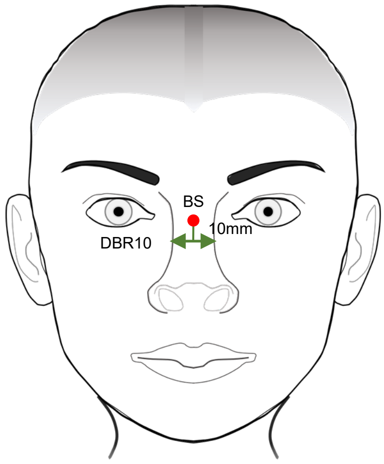


Figure 6.2e. Distance between rims at 10mm below crest results for White British typically-developed children showing measurements for both male and female subjects.

White British typically-developed

Distance Between Rims at 15mm Below Crest (DBR15)

<u>Landmarks involved:</u>

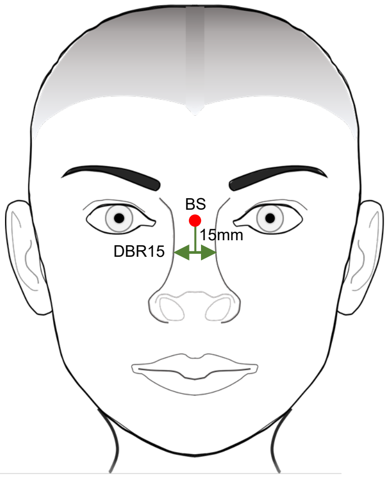
Bearing surface (BS).

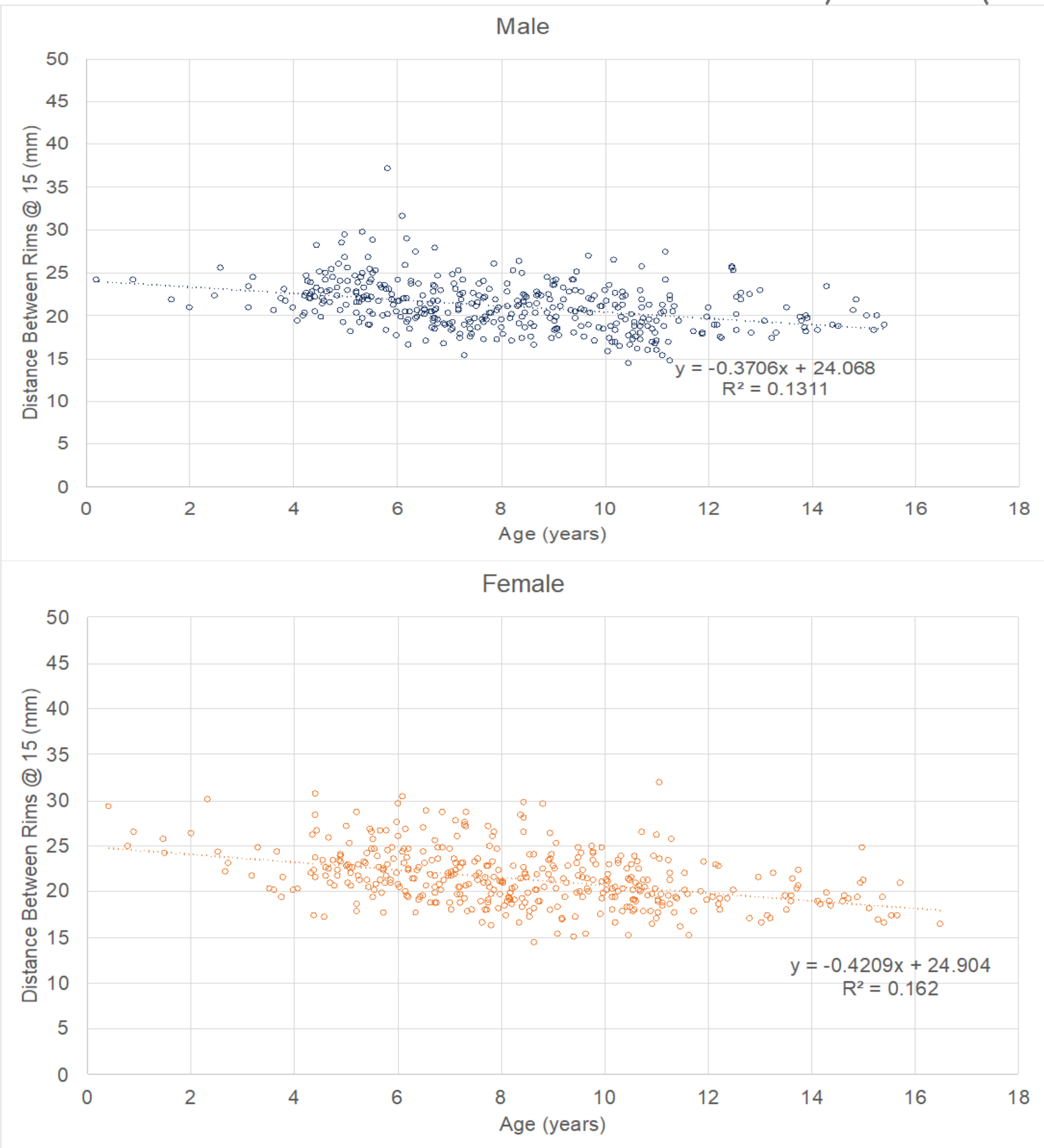
<u>Measurement definition:</u>

The width of the nose at a point 15mm below the crest (bearing surface).

<u>Measurement method:</u>

Automated nasal width calculated at a point 15mm below the bearing surface calculated by 3D stereophotogrammetry.

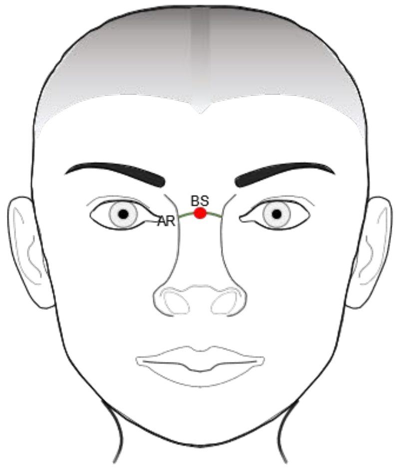


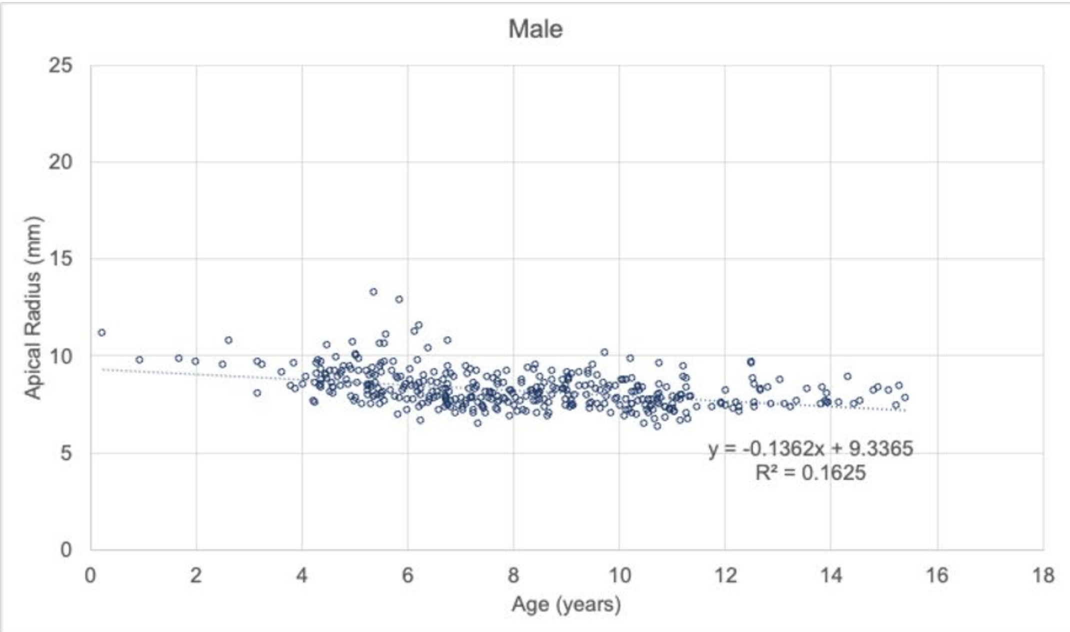


<u>Figure 6.2f</u>. Distance between rims at 15mm below crest results for White British typically-developed children showing measurements for both male and female subjects.

White British typically-developed
Apical Radius (AR)

Landmarks involved:
Bearing surface (BS).
Measurement definition:
The radius of the arc forming the lower edge of the bridge viewed perpendicularly to the back plane of the front.
Measurement method:
Automated radius calculated from the landmark by 3D stereophotogrammetry.





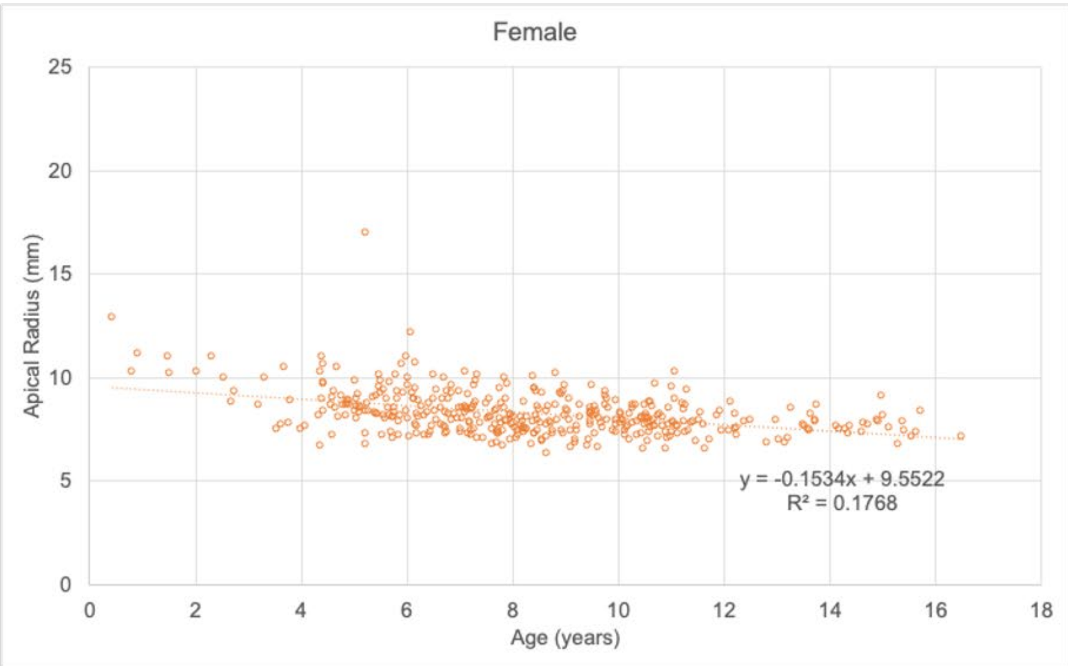


Figure 6.2g. Apical radius results for White British typically-developed children showing measurements for both male and female subjects

White British typically-developed

Crest Height (CH)

Landmarks involved:

Bearing surface (BS) and top of lower lid right (TTL-R) for right crest height and bearing surface (BS) and top of the lower lid (left) for left crest height.

Measurement definition:

The vertical distance from the top of the lower lid to the crest (bearing surface) of the nose.

Measurement method:

Automated vertical height calculated between the landmarks by 3D stereophotogrammetry.

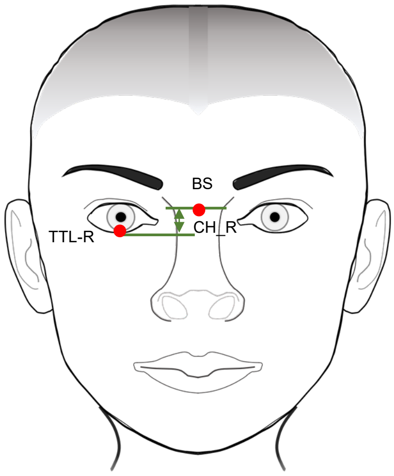


Figure 6.2h. Crest height results for White British typically-developed children showing right and left measurements for both male and female subjects.

White British typically-developed

Front to Bend (FTB)

Landmarks involved:

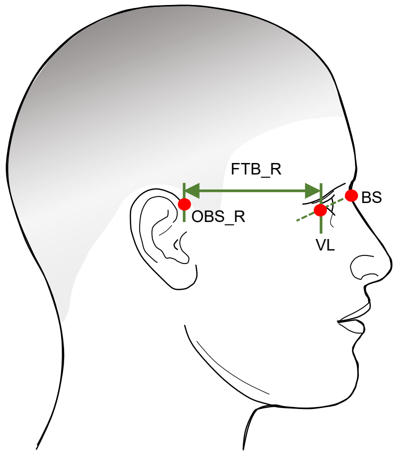
Bearing surface (BS) from which to extend a virtual frame front. Measured to otobasion superious right (OBS_R) for right front to bend and (OBS_L) for left front to bend.

Measurement definition:

The distance between the lug point (point on the back surface of the lug where it begins its backward sweep) and the ear point.

Measurement method:

A virtual front extended from the bearing surface is created by the software, in order to calculate by 3D stereophotogrammetry the length from the virtual lug (VL) to the earpoint.



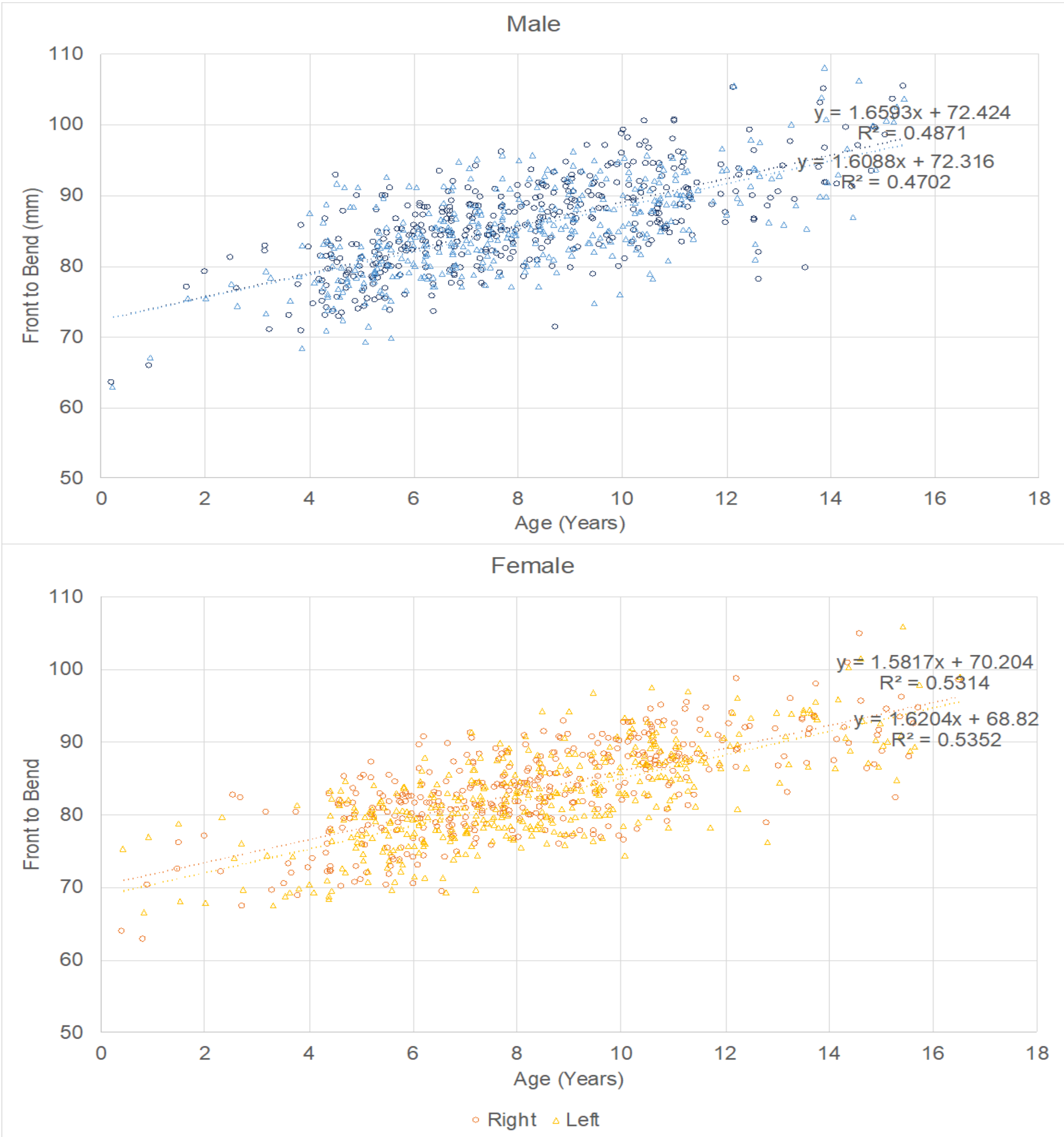
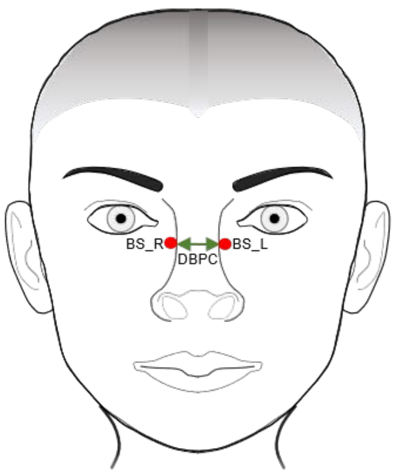


Figure 6.2i. Front to bend results for White British typically-developed children showing right and left measurements for both male and female subjects.

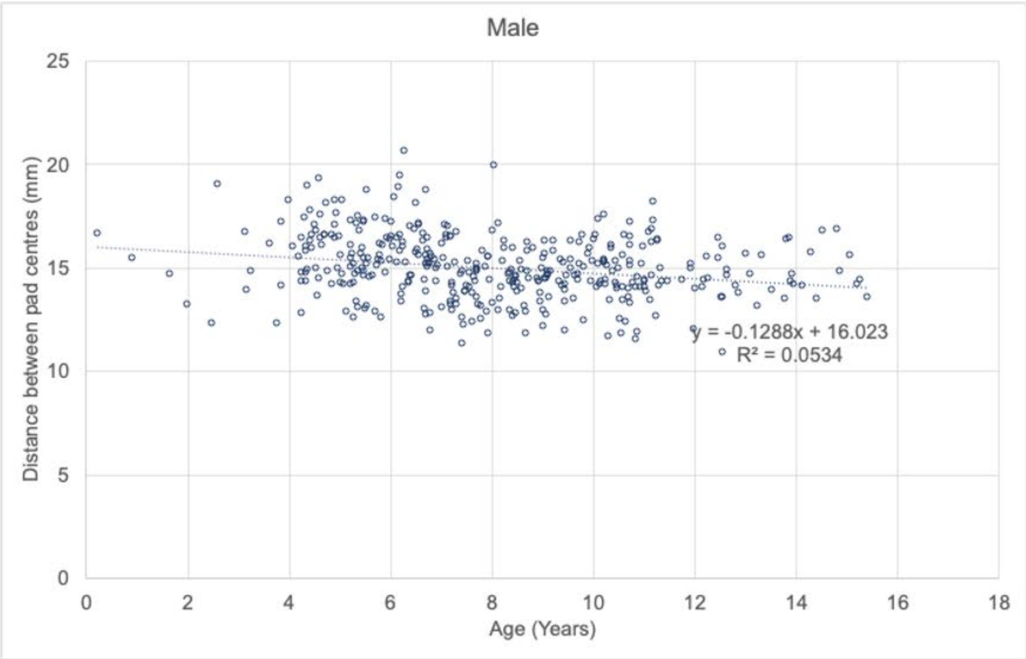
White British typically-developed
Distance Between Pad Centres (DBPC)



Landmarks involved:
Bearing surface right (BS_R) and bearing surface left (BS_L).

Measurement definition:
The width of the nose at the bearing surface points, hence where the pad of a frame would rest.

Measurement method:
Distance between landmarks calculated by 3D stereophotogrammetry.



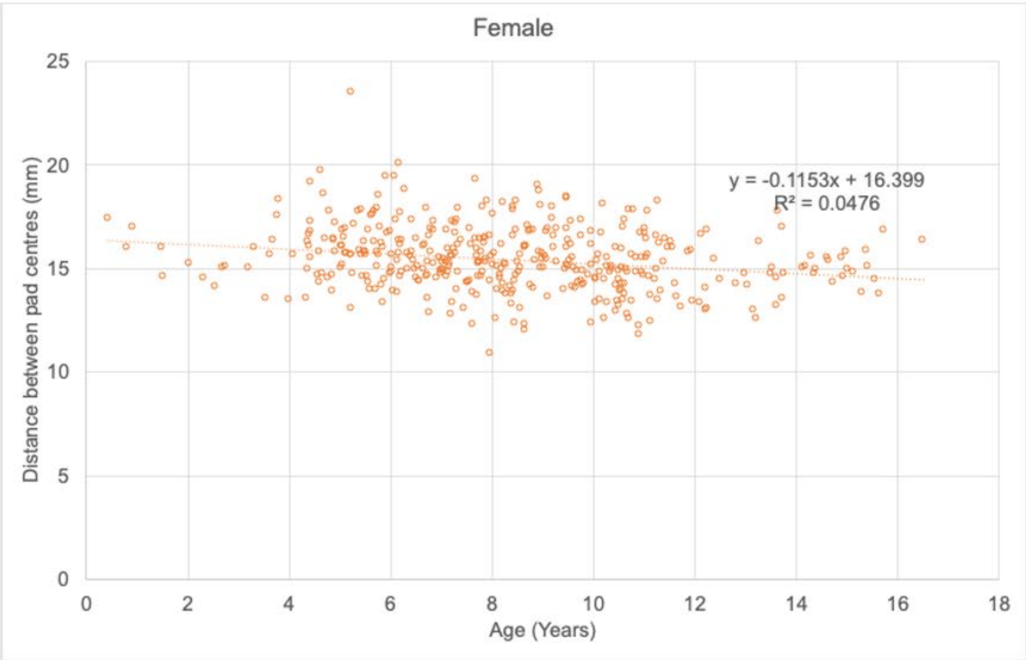


Figure 6.2j. Distance between pad centres results for White British typically-developed children showing measurements for both male and female subjects.

White British typically-developed

Pupillary Distance (PD)

Landmarks involved:

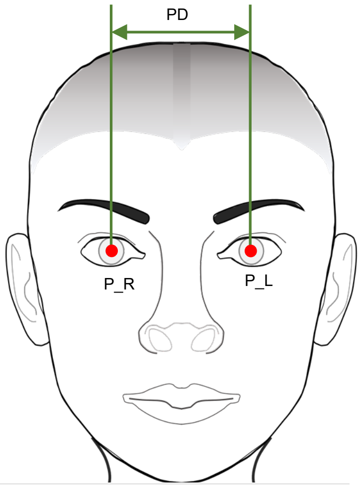
Pupil centre right (P_R) and pupil centre left (P_L).

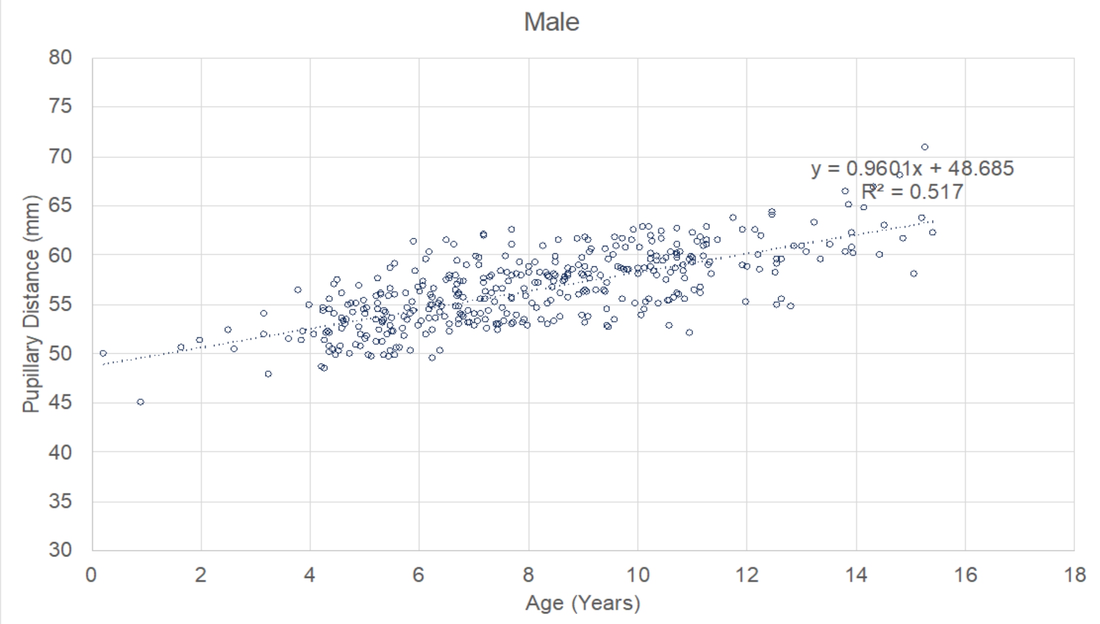
Measurement definition:

The distance between the centres of the pupils when the eyes are in the primary position.

Measurement method:

Distance behind the two landmarks calculated by 3D stereophotogrammetry.





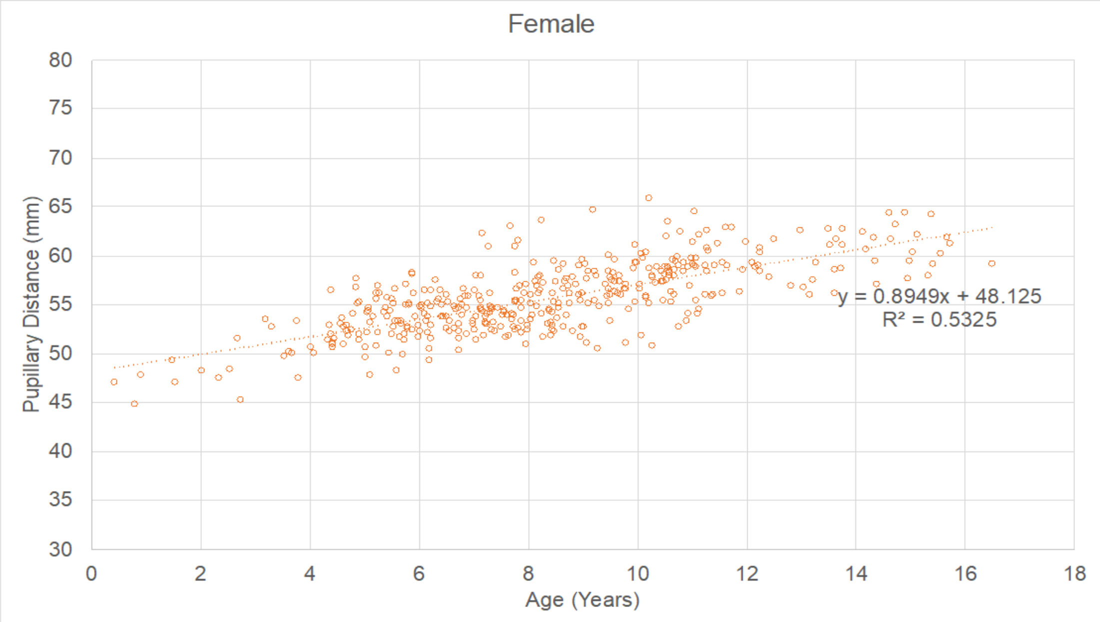


Figure 6.2k. Pupillary distance results for White British typically-developed children showing measurements for both male and female subjects.

6.3 Linear regression analysis

Linear regression analysis using ANOVA and t-testing was carried out to determine the significance of the slope and whether there were differences between gender and right/left measures. Analysis of variance showed that a linear line of best fit described the dependence of each facial measurement parameter on age in both males and females (Table 6.3a). The results showed no statistically significant difference between any right or left facial measurements where relevant, or between male and female measurements.

Measurement	Proportion of variance accounted for by regression (co-efficient of determination, R^2, %	Is linear regression statistically significant (ANOVA)?	Is slope of regression statistically significant (t-test)?	Slope (SE)	Is there a statistically significant difference between the slopes of the male and female slopes	Is there a statistically significant difference between the slopes of the R and L measurements
FAR male FAR female	22.8 26.4	Yes ($F_{1,390}$=115, p<0.001) Yes ($F_{1,407}$=146, p<0.001)	Yes (t=-10.73, p<0.001) Yes (t=-12.09, p<0.001)	4.59 4.64	No (t_{797}=0.51, p=0.611)	
FAL male FAL female	25.2 27.4	Yes ($F_{1,390}$=132, p<0.001) Yes ($F_{1,407}$=154, p<0.001)	Yes (t=-11.47, p<0.001) Yes (t=-12.41, p<0.001)	4.54 4.81	No (t_{797}=0.61, p=0.544)	
FAR male FAL male						No (t_{780}=0.42, p=0.674)
FAR female FAL female						No (t_{814}=0.54, p=0.589)
SAR male SAR female	8.5 6.9	Yes ($F_{1,390}$=36, p<0.001) Yes ($F_{1,407}$=30, p<0.001)	Yes (t=-6.01, p<0.001) Yes (t=-5.48, p<0.001)	2.48 2.61	No (t_{797}=-0.42, p=0.672)	
SAL male SAL female	9.7 5.4	Yes ($F_{1,390}$=42, p<0.001) Yes ($F_{1,407}$=23, p<0.001)	Yes (t=-6.47, p<0.001) Yes (t=-4.82, p<0.001)	2.25 2.55	No (t_{797}=-0.93, p=0.352)	
SAR male SAL male						No (t_{780}=-0.089, p=0.928)
SAR female SAL female						No (t_{814}=-0.56, p=0.579)
HW male HW female	36.7 41.6	Yes ($F_{1,390}$=226, p<0.001) Yes ($F_{1,407}$=290, p<0.001)	Yes (t=15.05, p<0.001) Yes (t=17.02, p<0.001)	6.93 6.02	No (t_{797}=0.94, p=0.347)	
TW male TW female	11.5 15.1	Yes ($F_{1,390}$=51, p<0.001) Yes ($F_{1,407}$=72, p<0.001)	Yes (t=7.11, p<0.001) Yes (t=8.49, p<0.001)	5.13 4.84	No (t_{797}=-0.29, p=0.772)	
DBR10 male DBR10 female	16.2 18.9	Yes ($F_{1,390}$=75, p<0.001) Yes ($F_{1,407}$=95, p<0.001)	Yes (t=-8.67, p<0.001) Yes (t=-9.75, p<0.001)	2.04 2.15	No (t_{797}=0.68, p=0.496)	

DBR15 male DBR15 female	13.1 16.2	Yes ($F_{1,390}$=59, p<0.001) Yes ($F_{1,407}$=79, p<0.001)	Yes (t=-7.67, p<0.001) Yes (t=-8.87, p<0.001)	2.68 2.81	No (t_{797}=0.74, p=0.458)	
AR male AR female	16.3 17.7	Yes ($F_{1,390}$=76, p<0.001) Yes ($F_{1,407}$=87, p<0.001)	Yes (t=-8.70, p<0.001) Yes (t=-9.35, p<0.001)	0.87 0.97	No (t_{797}=0.75, p=0.452)	
CHR male CHR female	34.3 35.1	Yes ($F_{1,390}$=204, p<0.001) Yes ($F_{1,407}$=220, p<0.001)	Yes (t=14.28, p<0.001) Yes (t=14.82, p<0.001)	1.97 1.84	No (t_{797}=1.00, p=0.319)	
CHL male CHL female	34.0 37.2	Yes ($F_{1,390}$=201, p<0.001) Yes ($F_{1,407}$=241, p<0.001)	Yes (t=14.18, p<0.001) Yes (t=15.51, p<0.001)	1.97 1.79	No (t_{797}=0.77, p=0.442)	
CHR male CHL male						No (t_{780}=0.10, p=0.920)
CHR female CHL female						No (t_{814}=-0.15, p=0.884)
FTBR male FTBR female	48.7 53.1	Yes ($F_{1,390}$=370, p<0.001) Yes ($F_{1,407}$=462, p<0.001)	Yes (t=19.25, p<0.001) Yes (t=21.49, p<0.001)	4.78 4.36	No (t_{797}=0.69, p=0.492)	
FTBL male FTBL female	47.0 53.5	Yes ($F_{1,390}$=346, p<0.001) Yes ($F_{1,407}$=469, p<0.001)	Yes (t=18.60, p<0.001) Yes (t=21.65, p<0.001)	4.79 4.43	No (t_{797}=-0.10, p=0.919)	
FTBR male FTBL male						No (t_{780}=0.41, p=0.679)
FTBR female FTBL female						No (t_{814}=-0.37, p=0.712)
DBPC male DBPC female	5.3 4.8	Yes ($F_{1,390}$=22, p<0.001) Yes ($F_{1,407}$=20, p<0.001)	Yes (t=-4.69, p<0.001) Yes (t=-4.51, p<0.001)	1.52 1.51	No (t_{797}=-0.36, p=0.718)	
PD male PD female	51.7 53.2	Yes ($F_{1,390}$=418, p<0.001) Yes ($F_{1,407}$=464, p<0.001)	Yes (t=20.43, p<0.001) Yes (t=21.53, p<0.001)	2.60 2.46	No (t_{797}=1.04, p=0.298)	

Table 6.3a. Linear regression analysis for measurements plotted as a function of age, including comparison of the slopes for gender and right / left measurements where applicable.

As shown by the scatterplots 6.2a-6.2k, some facial measurements decreased and some increased with age. The gradient of the linear regression is a measure of rate of change in growth for a given facial parameter, summarised in Figure 6.3b.

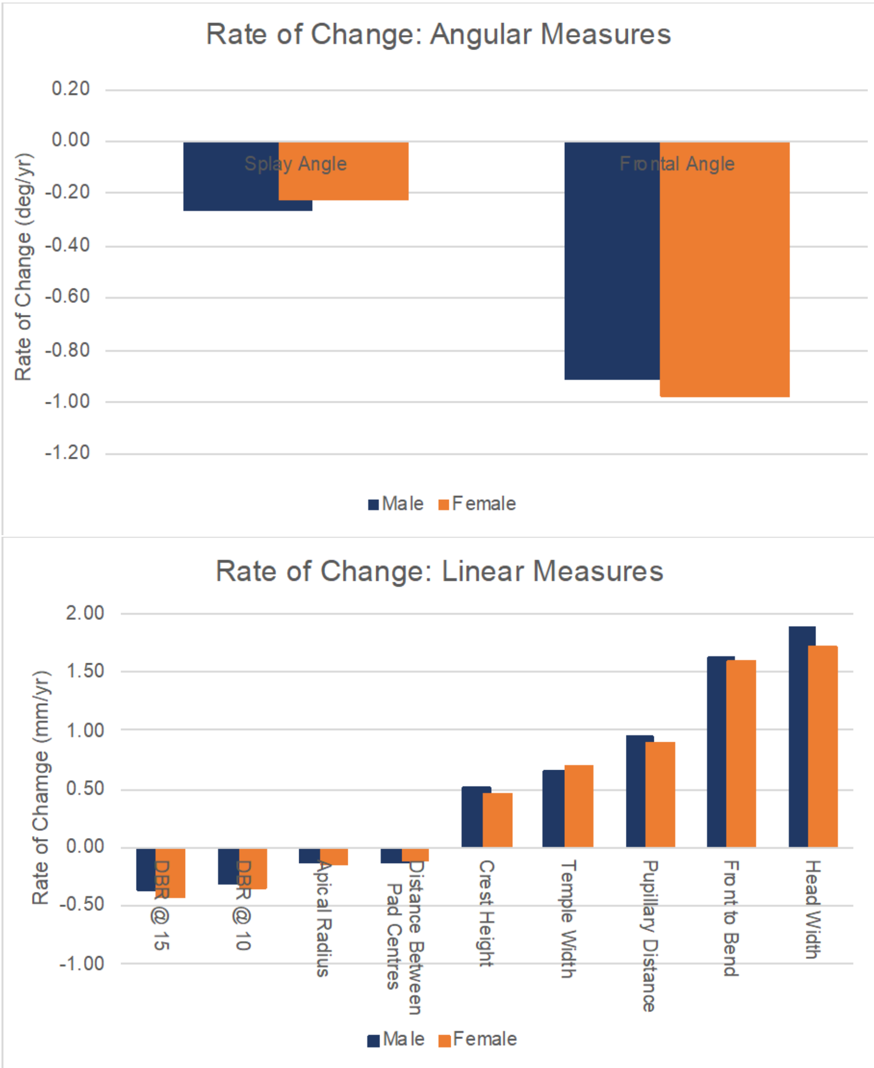


Figure 6.3b. Rate of change and growth direction in typically-developed White British children.

A positive value indicates that the measurement is increasing in magnitude with increase in age. A negative value indicates that the measurement is decreasing in magnitude with increase in age.

It can be observed that the rate of change in growth is not the same for all measurements, indicating that the face and nose are changing shape as a child ages. Measurements concerning the head itself such as head width, temple width, front to bend and pupillary distance changed at a much faster rate than measurements applied to the nose. There were small differences in rate of growth for males and females, but these were not statistically significant (table 6.3a)

6.4. Discussion

The true growth pattern may be expected to follow a polynomial growth pattern with a surge in growth in very early years and a plateau as the face reaches maturity. However, within the ages 0-16 years the linear fit best describes this data. This is most likely to be due to a lack of data subjects in the extremities of age groups, i.e., very young children and mid- to late-teenage years, yet the linear pattern of growth is concordant with a study by Ritschl *et al*. in 2018 who measured new born children each month for a six-month period and reported that nasal height and length, as well as inter-canthal distance showed a linear growth pattern. In addition the World Health Organisation (WHO) growth charts issued by the Royal College of Paediatrics and Child Health (RCPCH) show height, weight and head circumference is also expected to follow a linear pattern of growth from birth until around 13 years for a girl (figure 6.4b) and 14 years for a boy (figure 6.4a) as it is expected the recorded data for each child remains within a particular centile (Royal College of Paediatrics and Child Health, 2013). This difference in growth peak between males and females is well documented, Mellion et al. (2013) describes the growth spurt in girls to be between 9.8 - 11.5 years where their peak is reached, compared to 12 - 14.4 years for boys. In terms of nasal growth, many studies agree that even though males tend to have larger facial parameters (Agbolade et al., 2020, Kesterke et al., 2016), their growth period is longer whereas girls develop earlier (Sforza et al., 2011, Mori et al., 2005, Ferrario et al., 1999) and therefore agree with these findings of generally larger facial parameters for males but a larger rate of change for females in frontal angle, apical radius, distance between rims and temple width.

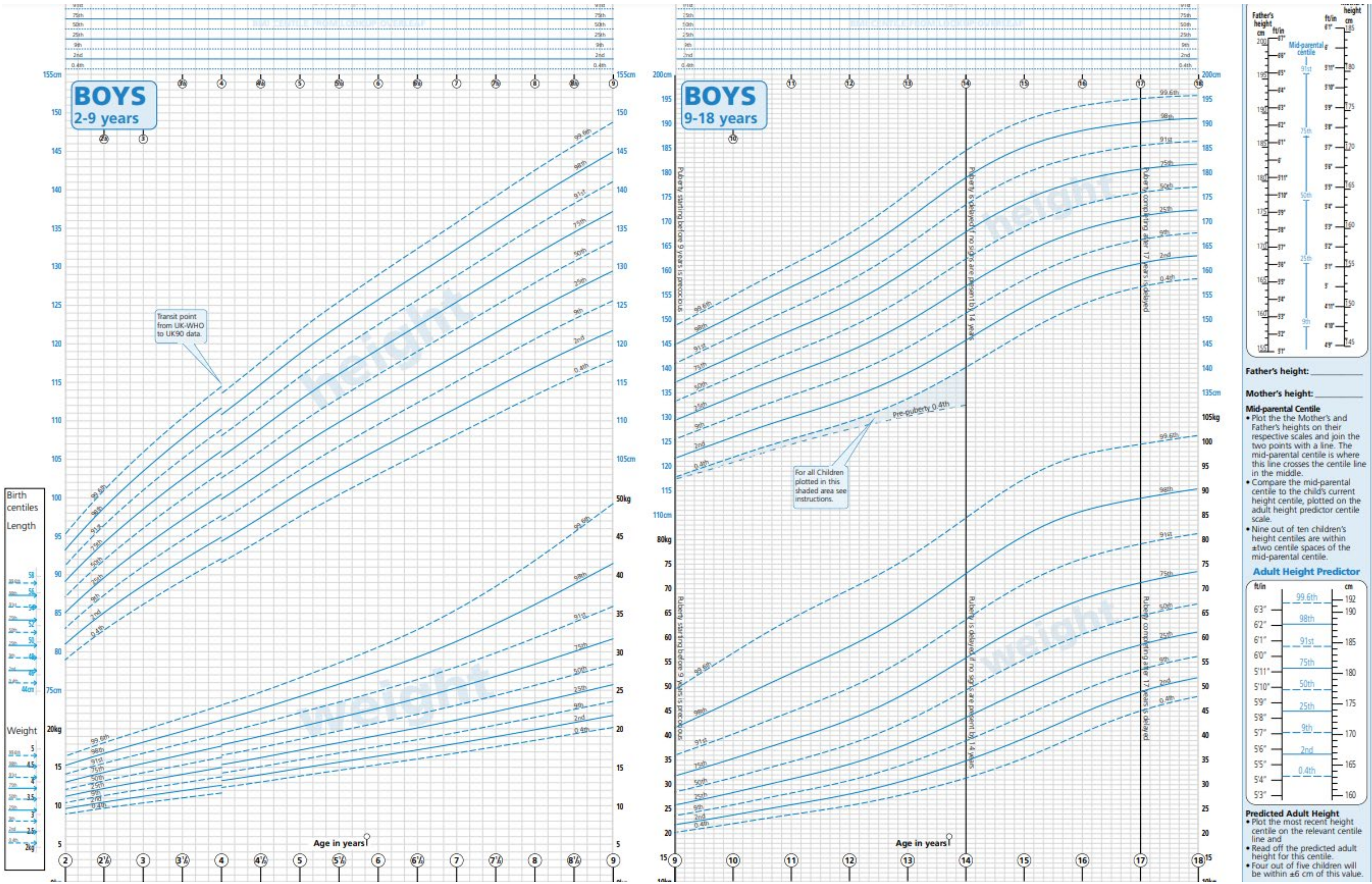


Figure 6.4a. Growth chart for boys showing weight and height expected growth patterns. Reproduced with permission from the Royal College of Paediatrics and Child Health

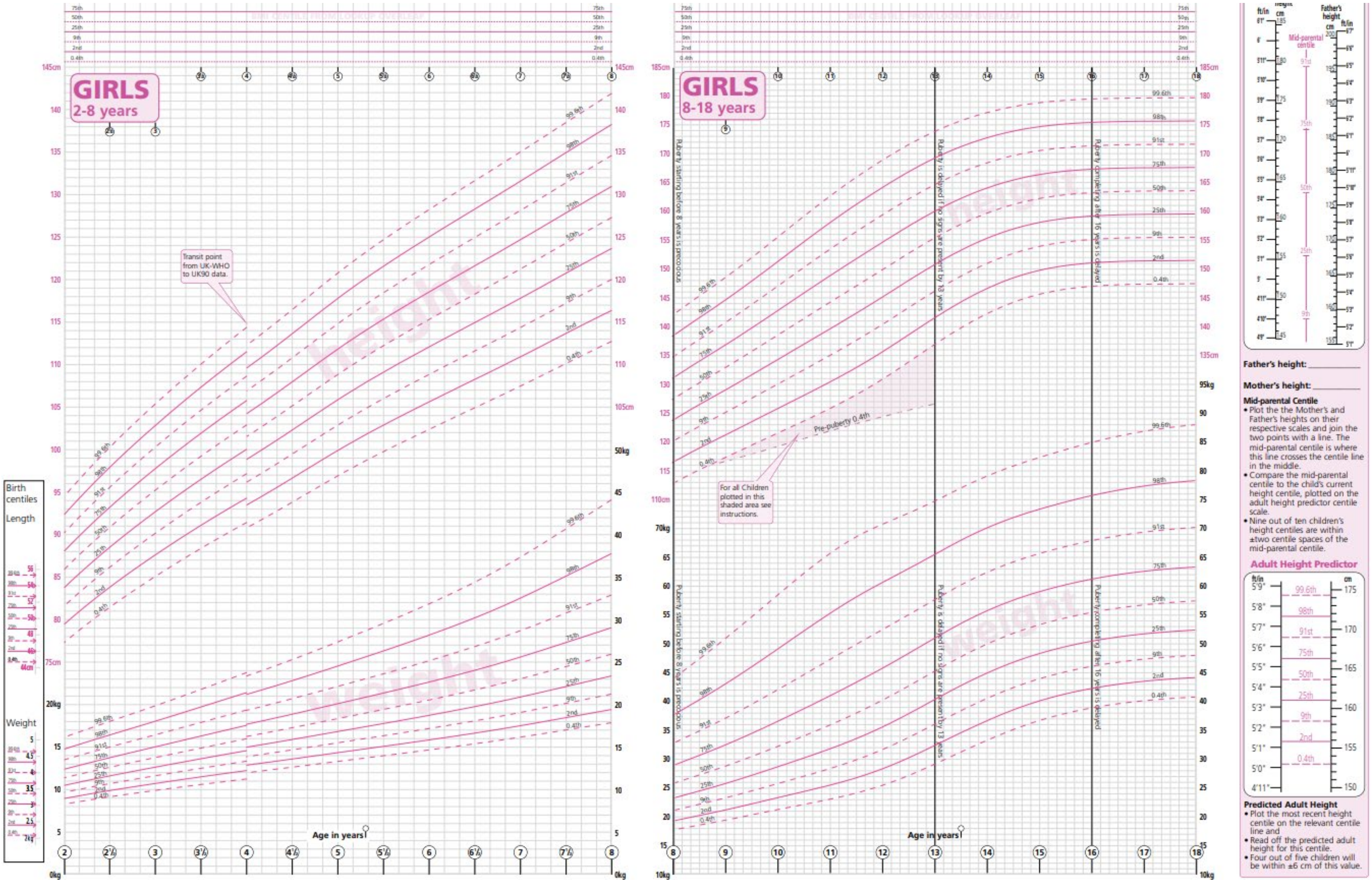


Figure 6.4b. Growth chart for girls showing weight and height expected growth patterns. Reproduced with permission from the Royal College of Paediatrics and Child Health

Table 6.3a shows the gradients of the linear regression for each facial measurement parameter and thereby represents the growth rate for each parameter. This figure highlights how the shape of the nose and face change with increasing age. For the angular facial measurements, it can be seen that the frontal angle changes far more rapidly than the splay angle and decreases at a rate of almost 1 degree a year (figure 6.3b). This indicates that as the crest of the nose emerges, the narrowing of the nasal profile in the frontal plane is much more apparent than in the sagittal plane where the splay angle narrows at a much slower rate. No existing data particular to this parameter has been published for children in the youngest age band, birth to 4 years, where almost all of these data subjects had a frontal angle measuring over 50 degrees. This does however fit with the low, flat, under-developed profile of a young child's nose as described by Schramm (2000) and Obstfeld (1997). It is possible to compare facial data for children aged 5-13 years from the 1989 study by Kaye and Obstfeld that showed a range of values for frontal angle from 30-34 degrees from 154 children measured by a custom-made gauge. No narrowing of the measurement was reported, a small increase of the frontal angle was shown in age groups up until 10.4 years, then a small narrowing after 11.6 years. This finding does not agree with the outcomes of this study. Figure 6.2a shows a constant reduction in this measurement as the nasal crest emerges and also that the values are consistently higher in comparison to Kaye and Obstfelt (1989). The sample size of 154 children was much smaller in comparison to the data presented in this thesis and in addition there is a variation in methodology since the details of the custom-made gauge were not stated. As with the data presented here Kaye and Obstfeld (1989) did not find any statistical differences between genders.

In contrast to the frontal angle, the splay angle yielded a much smaller spread of data (SE=2.48 (male R); SE=2.55 (female L)) with the majority of subjects falling in the range of 22-32 degrees. This measurement parameter narrowed at a slower rate than frontal angle at a rate of just over 0.20 degrees per year. Kaye and Obstfeld (1989) reported a similar range of 26-32 degrees, although they did not report a narrowing of the splay angle across their groups studied of children aged 5-13 years.

In summary, both the frontal and splay angles decrease linearly with age ($p<0.001$) in males and females. Analysis of variance showed that there was no significant difference between the right and left frontal or splay angles (table 6.3a), indicating the rate of change is symmetrical. There was no significant difference in slopes between males and females, indicating that the rate of change is the same in both genders. Frontal angle decreases at a higher rate than the splay angle and more of the variance associated with the frontal angle, 22.8% (males) could be explained by its linear relationship with age compared to the splay angle (8.5% males).

For linear facial measurements, the distance between rims, distance between pad centres and the apical radius are all measured in the same plane as the frontal angle and therefore, with the narrowing of this angle, it naturally follows that these linear measurements will also narrow, i.e. decrease in numerical value, as the crest emerges and develops a narrower form with age. Distance between rims measurements determines width values and these show a small (<0.5mm per year) decrease in value. Equivalent to the '*base 10 and base 15*' measurements of Kaye and Obstfeld (1989), these values show good agreement. DBPC show very little change as a function of growth. This measurement is difficult to place subjectively as it is placed in a position where the pads of the spectacle frame would be expected to sit. This moves in position as the child grows and consequently it is much more difficult to place on the nose of a younger child where the position is ill defined compared to a fully-formed nose. This was evident in the results; the spread of data being much wider in the earlier years, 12-21mm (under 8 years old), than the later years, 13-17mm (for over 12 years). The apical radius shows very little change as the nose emerges with females having a slightly larger measurement in the 6-10-year range. Kaye and Obstfeld (1989) data between 8.8-9.2 mm concurs with the data in this thesis which yielded values of between 7-10mm for an equivalent age band.

The distance between rims (DBR), distance between pad centres (DBPC) and the apical radius (AR) all decrease linearly with age ($p<0.001$) in males and females. There was no significant difference in slopes between males and females (table 6.3b), indicating that the rate of change is equal across the sexes. Distance between rims at 10mm and 15mm below crest decreases at a higher rate than the DBPC and AR and more of the variance was associated with the DBR's; 16.2% (male DBR10) and AR 16.3% (male DBR10). This can be explained by its linear relationship with age compared to the DBPC, (5.3% males).

As the crest of the nose emerges, the position of the crest (crest height) will naturally take on a more superior position in relation to the lower lid and therefore the positive growth is both expected and reported (+0.5mm per year) for this measurement. Kaye and Obstfeld (1989) reported a range of crest height values as 0.2-0.7mm for 5-10 years, jumping to 2.3-3.8mm in the 10-13.7 years. The data in this thesis shows that crest height data are higher in magnitude overall, with a much larger spread of values, for example 2-8mm in males.

The crest height was found to increase linearly with age ($p<0.001$) in males and females and that there was no difference between genders (table 6.3b), indicating that the rate of change is equal across the sexes and 34.3% (male CHR) 35.1% (female CHR) of the variance associated with the crest height could be explained by its linear relationship with age.

In the transverse plane, the width of the head at the ear points grows at a faster rate of over 1.5mm per year compared to the temple width at 0.5mm per year, and the pupillary distance shows growth rate at almost 1mm per year. For head width, the variation in the data for males is quite pronounced, ranging from 115-182mm (SE=6.93). Smaller variation was observed for females, ranging from 120-170 (SE=6.02). On average female head width was 6mm less than that observed in males. This concurs with growth studies across a range of ages where the cranial width is reported to be larger in males than females (Agbolade et al., 2020, Zhuang et al., 2010, Kaye and Obstfeld, 1989). The mean of this data 143mm (7.9SD) female, 149mm (8.7SD) male) concurs with the upper value from Kaye and Obstfeld (1989) who reported a range 125-142mm, although this could be explained by a larger data set in this study for the upper age ranges. Temple width shows a similar pattern but with a much lower observed difference between males 102mm (5.5SD) and females 101mm (5.2SD). For this parameter, there was good agreement with Kaye and Obstfeld (1989) who showed a slightly larger value ranging from 101-113mm, despite this being a manually placed callipered measurement compared to the automated landmark measurement of 25mm behind the frame front measurement used in this thesis.

Pupillary distance shows a larger rate of change than the temple width but less than that of head width which shows the head is not growing at a proportionate rate throughout childhood, i.e. the head is widening but not in proportion with the eyes and at a greater rate across the ear points than the temple points. A noticeably small range of values 45-65mm (females) 45-70mm (males) for pupillary distance was observed which is in agreement to the equivalent age values reported by Kaye and Obstfeld (1989).

Considered together, the head width (HW), temple width (TW) and the pupillary distance (PD) all increase linearly with age ($p<0.001$) in males and females. There was no significant difference in slopes between males and females (table 6.3b), indicating that the rate of change is equal across the sexes. Head width and pupillary distance increases at a higher rate than the temple width and more of the variance associated with the HW, 36.7% (male) and PD 51.7% (male) could be explained by its linear relationship with age compared to the TW, (11.5% males).

Perpendicular to the HW, TW and PD in the frontal plane, the front to bend (FTB) parameter exhibited a similar growth rate to the head width at over 1.5mm a year. Front to bend showed similar scatterplots (figure 6.2i) with no significant difference in slopes between gender or right/left measurements (table 6.3a). The range clustered from 75-95mm up to approximately 12 years of age, then 85-100mm for both boys and girls up to 16 years. In equivalent studies on 154 children (5-13 years) from the Kaye and Obstfeld

(1989) study, a range of 87-100mm was reported, and an older study by Zhuk (1973) measured 400 Russian children aged 6-15 years and reported a range 80-105mm, therefore good agreement between the three studies. 48.7% (male FTBR) of the variance associated with the front to bend could be explained by its linear relationship with age.

Overall, this data has implications for the design of children's spectacle frames which will be explored in greater detail in Chapter 10. There is a sparsity of previous research in this area but in the few studies that have evaluated facial measurements relating to spectacle frame design there is a degree of concordance. This combined with the much larger cohort size in this thesis gives confidence that the results are representative of the population at large.

Chapter 7 Facial anthropometry in typically-developed children of Chinese ethnicity.

7.1 Introduction and methods

Data was acquired using the method described in section 2.6 from 309 individuals (161 males, 148 females). The Chinese ethnicity data was collected principally from a visit to the Wenzhou Medical University in China and supplemented from the United Kingdom data collection sites (section 2.5) including nursery, primary and secondary schools, charitable organisations and children's groups.

7.2 Results

For the following figures, curve fitting was carried out for each of the measurement parameters as a function of age and it was determined that linear regression offered the best fit to the data. The linear regression line delineates a model of growth in the age range studied, i.e. birth to sixteen years of age. On this basis, the gradient of the line indicates the rate of change, i.e. growth rate of each of the facial measurements. The data in this Chapter is presented alongside the typically-developed White British ethnicity data from Chapter 6 in order to aid comparisons between the ethnic groups.

Chinese typically-developed

Frontal Angle (FA)

Landmarks involved:

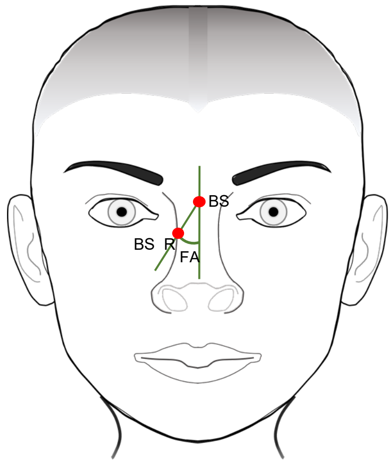
Bearing surface (BS) and bearing surface right (BS_R) for right frontal angle (as shown in schematic diagram) and bearing surface and bearing surface left (BS_L) for left frontal angle.

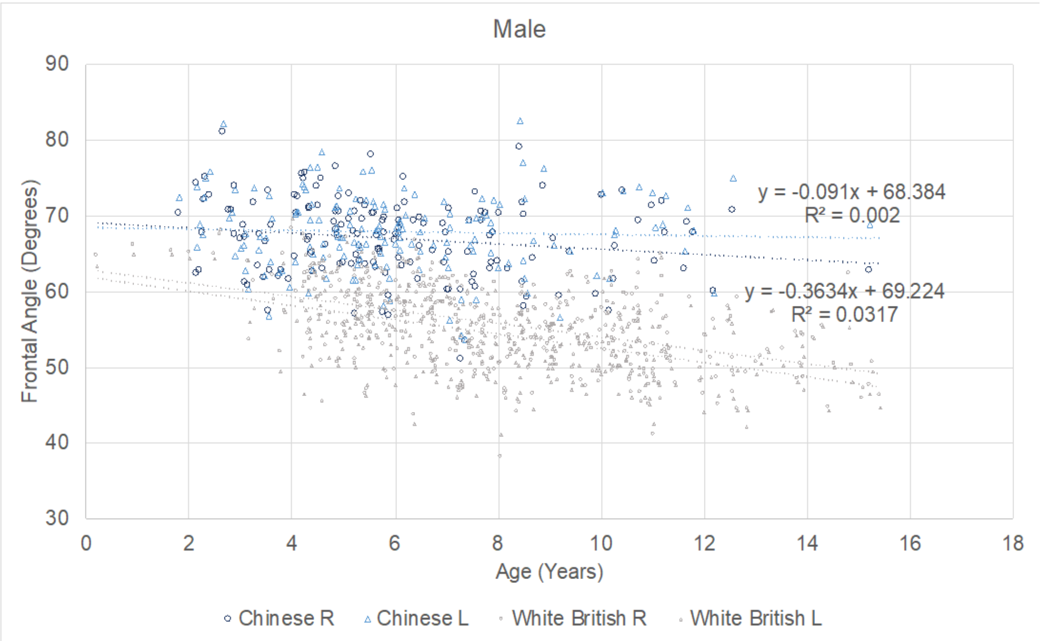
Measurement definition:

The angle between the vertical and the line of intersection of the pad plane with the back plane of the front, taken in the lateral plane.

Measurement method:

Angle between the landmarks calculated by 3D stereophotogrammetry.





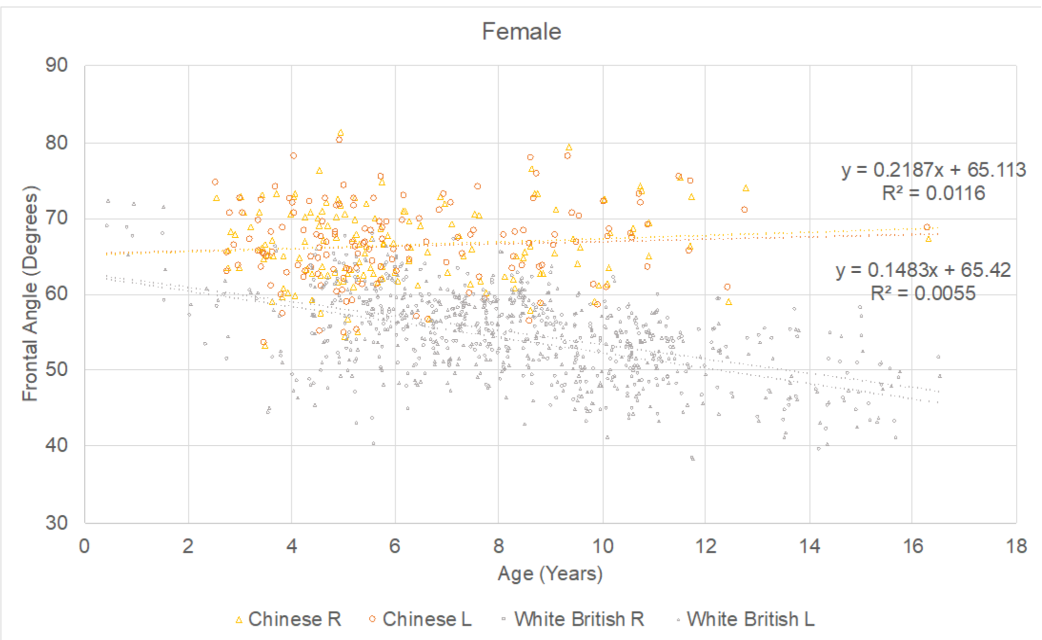


Figure 7.2a. Frontal angle results for Chinese typically-developed children overlaid on White British results, showing right and left measurements for both male and female subjects.

Chinese typically-developed

Splay Angle (SA)

<u>Landmarks involved:</u>

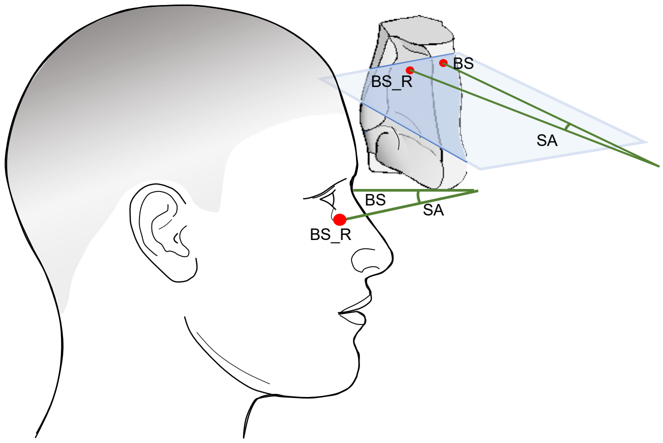
Bearing surface (BS) and bearing surface right (BS_R) for right splay angle and bearing surface (BS) and bearing surface left (BS-L) for left splay angle.

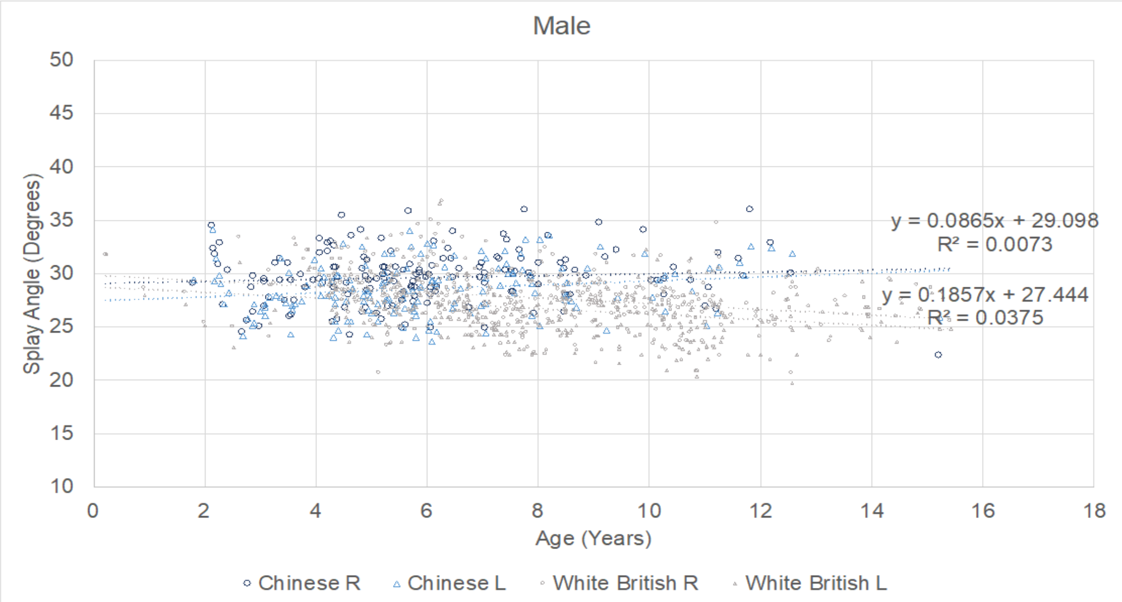
<u>Measurement definition:</u>

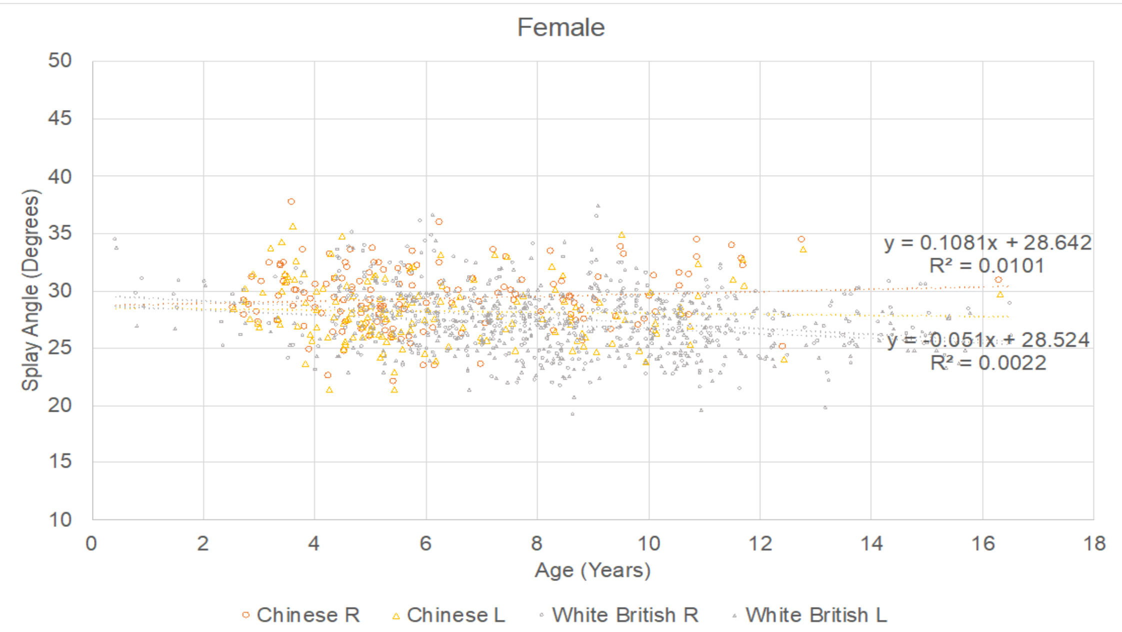
The angle between the pad plane and a normal to the back plane of the spectacle front, taken in the transverse plane.

<u>Measurement method:</u>

Angle between the landmarks calculated by 3D







<u>Figure 7.2b</u>. Splay angle results for Chinese typically-developed children overlaid on White British results, showing right and left measurements for both male and female subjects.

Chinese typically-developed

Head width (HW)

<u>Landmarks involved:</u>

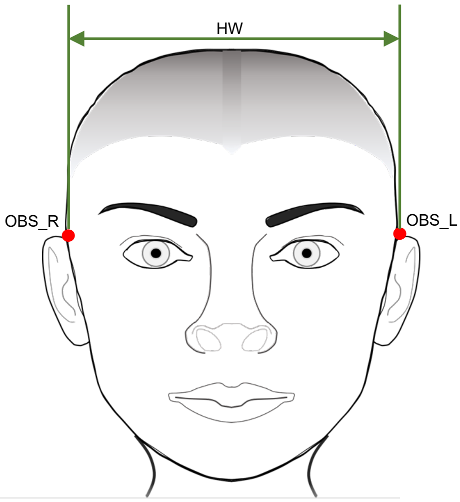
Otobasion superious right (OBS_R) and left (OBS_L).

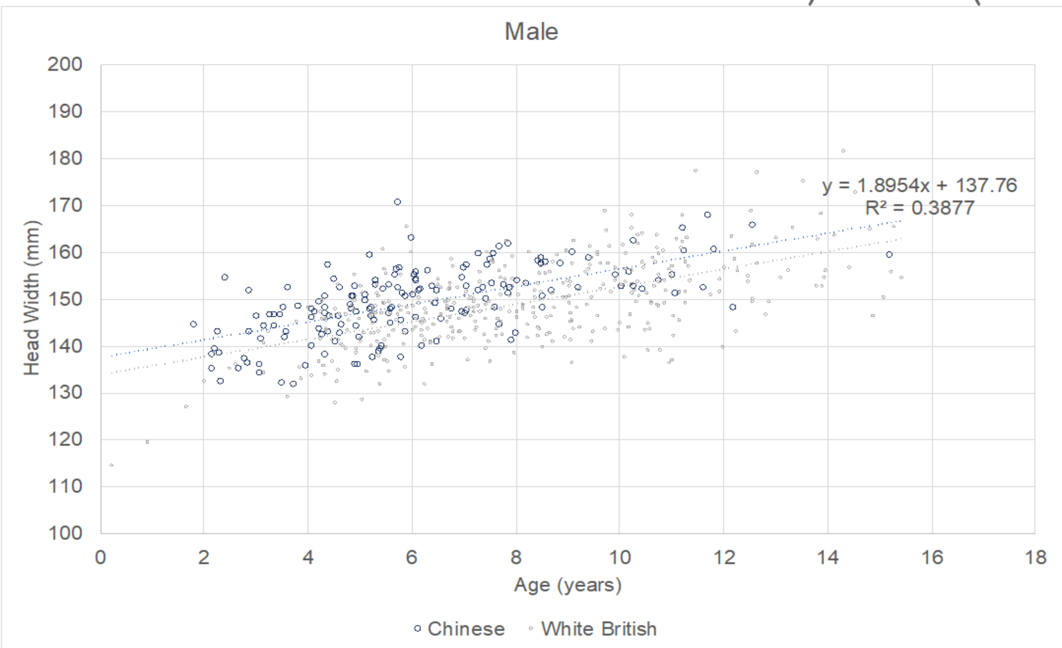
<u>Measurement definition:</u>

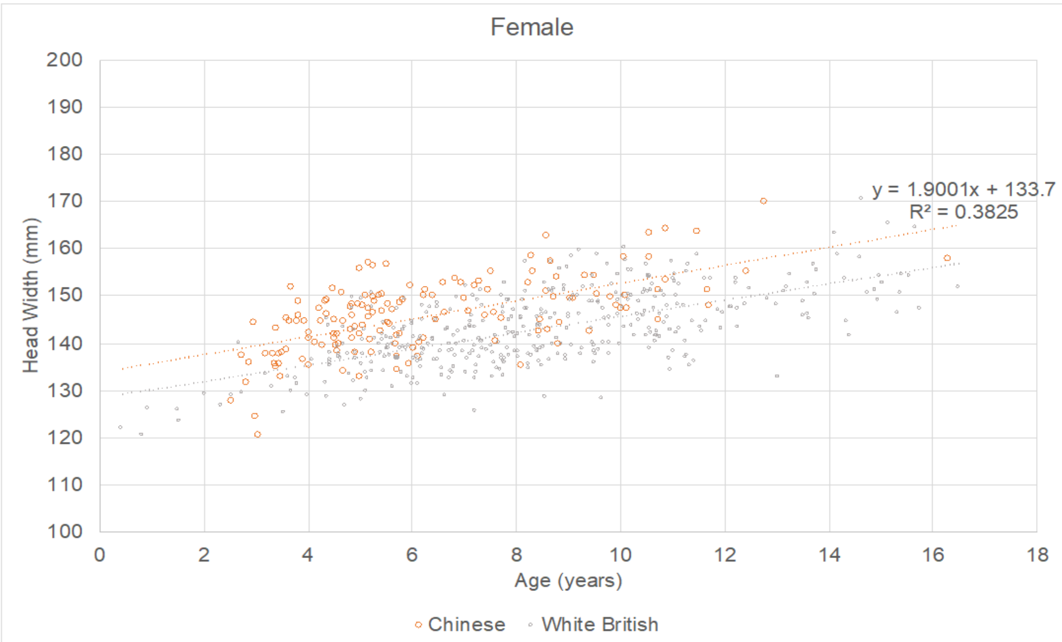
The distance between the two ear points.

<u>Measurement method:</u>

Linear distance between the landmarks calculated by 3D stereophotogrammetry.







<u>Figure 7.2c</u>. Head width results for Chinese typically-developed children overlaid on White British results, showing measurements for both male and female subjects.

Chinese typically-developed
Temple width (TW)

<u>Landmarks involved:</u>

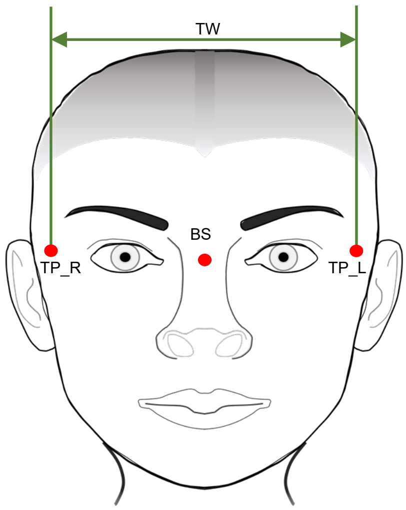
Bearing surface (BS) and temple points right (TP_R) and left (TP_L).

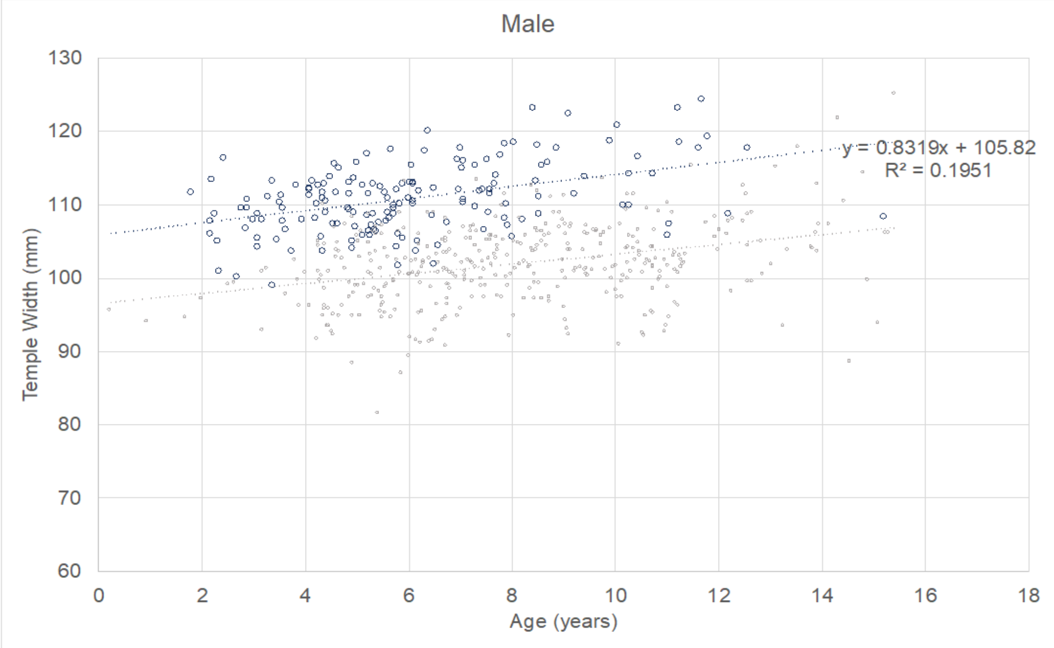
<u>Measurement definition:</u>

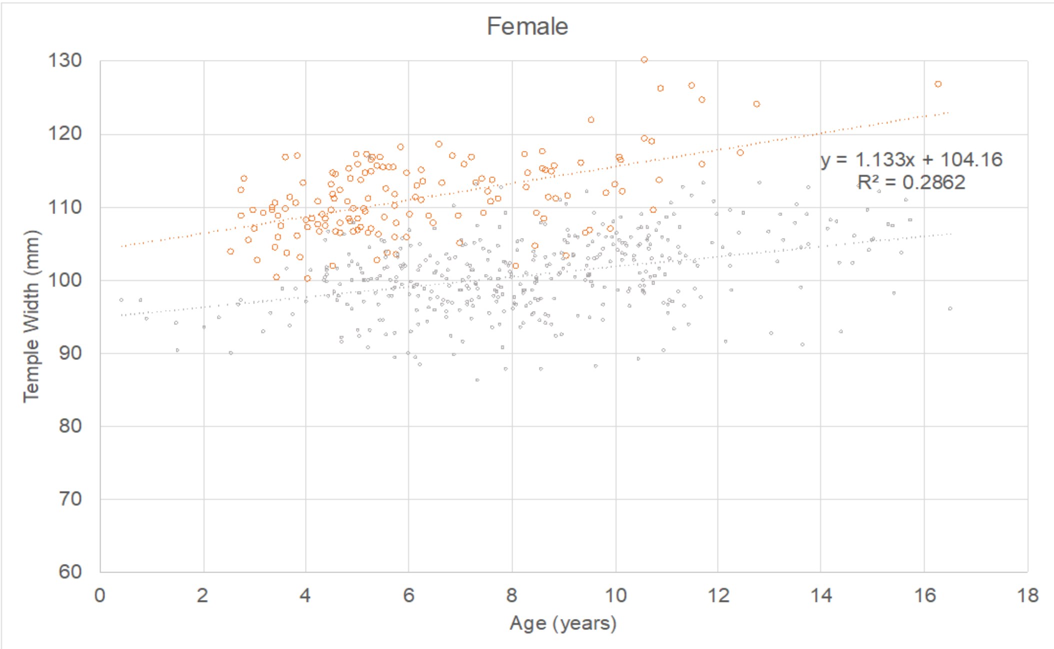
The distance between the two temple points at a distance of 25mm behind the back plane of a spectacle front.

<u>Measurement method:</u>

The position of the bearing surface enables the programme to create a virtual frame front in order to generate the temple points at the correct distance behind the front and measure the distance between the landmarks calculated by 3D stereophotogrammetry.



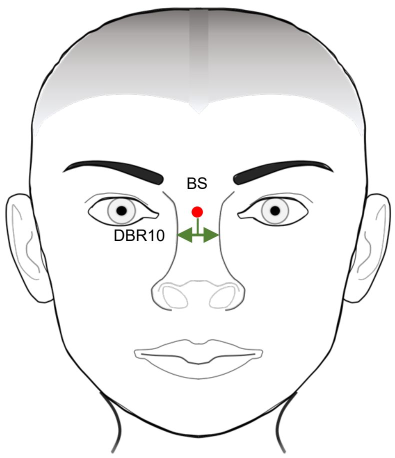




<u>Figure 7.2d</u>. Temple width results for Chinese typically-developed children overlaid on White British results, showing measurements for both male and female subjects.

Chinese typically-developed

Distance Between Rims at 10mm Below Crest (DBR10)



Landmarks involved:

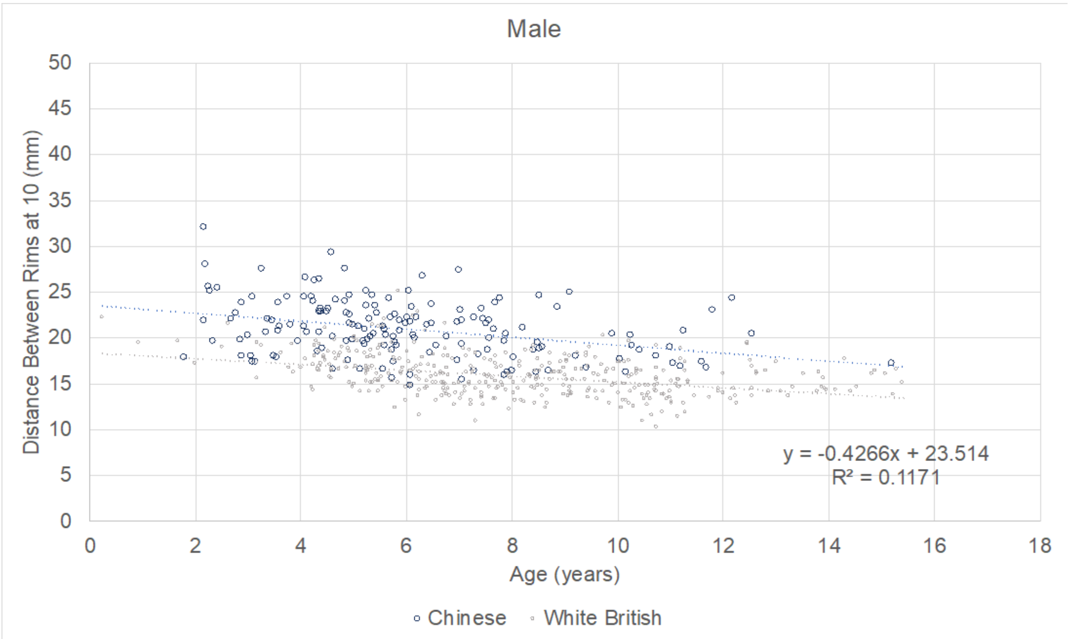
Bearing surface (BS).

Measurement definition:

The width of the nose at a point 10mm below the crest (bearing surface).

Measurement method:

Automated nasal width calculated at a point 10mm below the bearing surface calculated by 3D stereophotogrammetry.



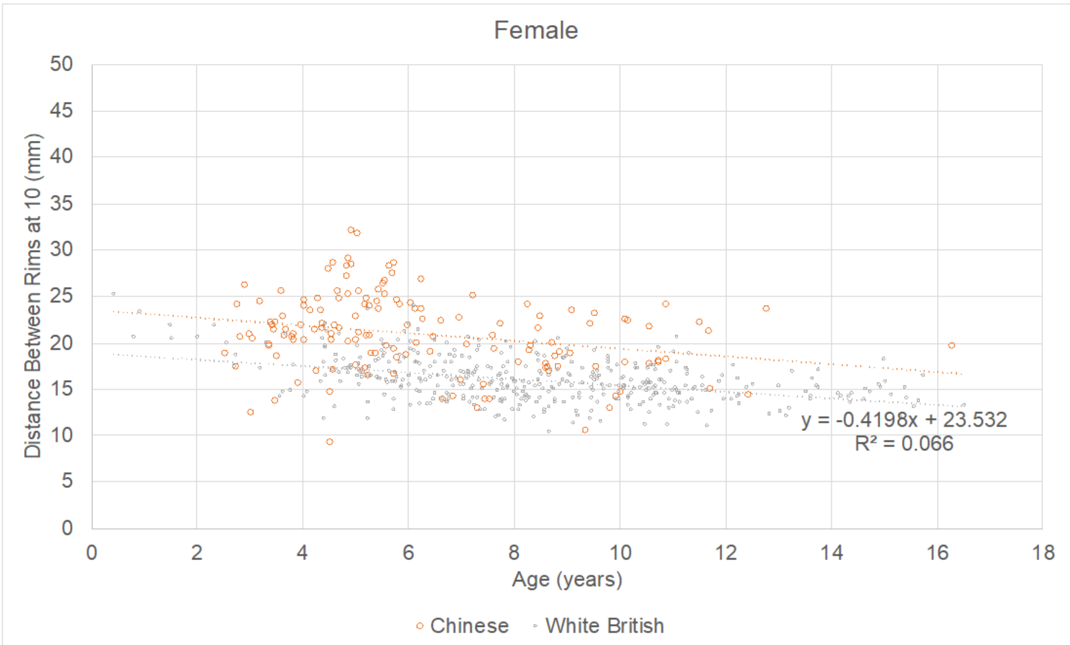


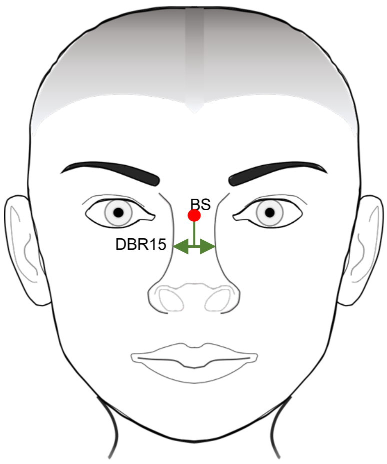
Figure 7.2e. Distance between rims at 10mm below crest results for Chinese typically-developed children overlaid on White British results, showing measurements for both male and female subjects.

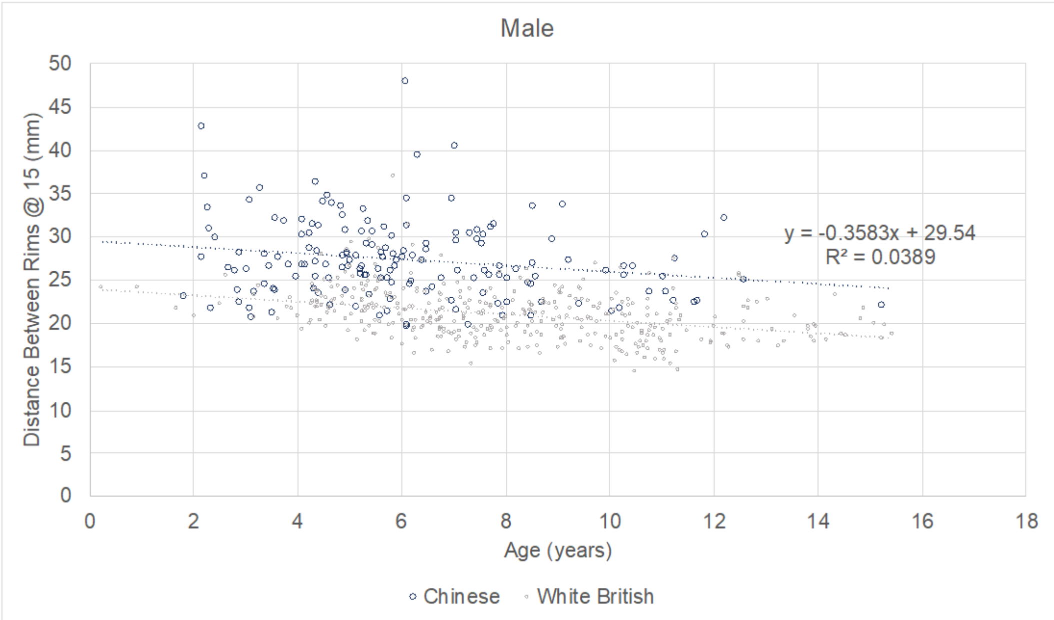
Chinese typically-developed
Distance Between Rims at 15mm Below Crest (DBR15)

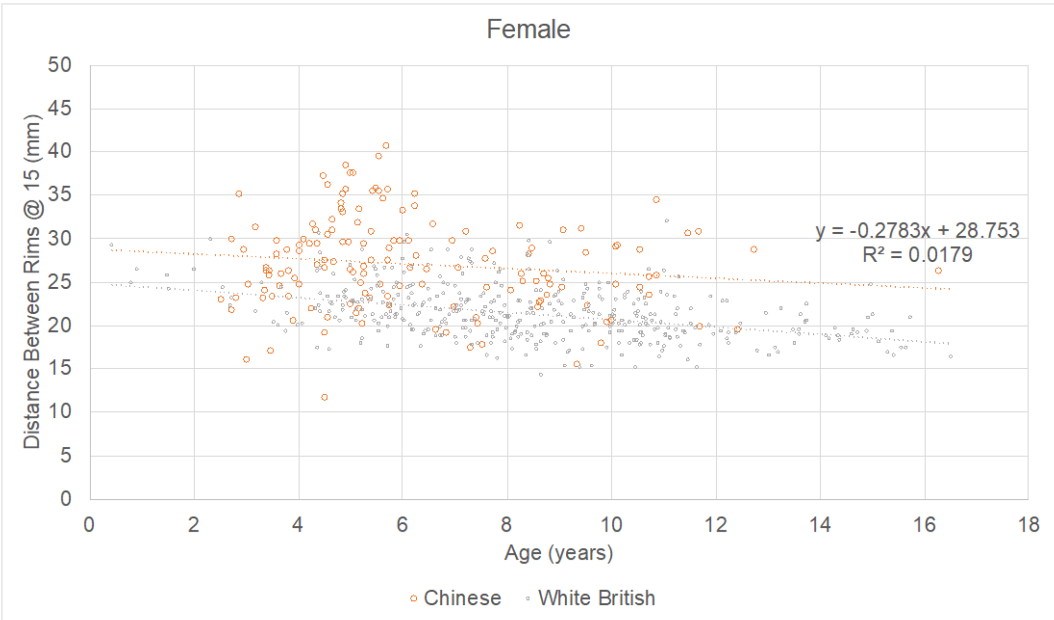
<u>Landmarks involved:</u>
Bearing surface (BS).

<u>Measurement definition:</u>
The width of the nose at a point 15mm below the crest (bearing surface).

<u>Measurement method:</u>
Automated nasal width calculated at a point 15mm below the bearing surface calculated by 3D stereophotogrammetry.







<u>Figure 7.2f</u>. Distance between rims at 15mm below crest results for Chinese typically-developed children overlaid on White British results, showing measurements for both male and female subjects

Chinese typically-developed

Apical Radius (AR)

Landmarks involved:

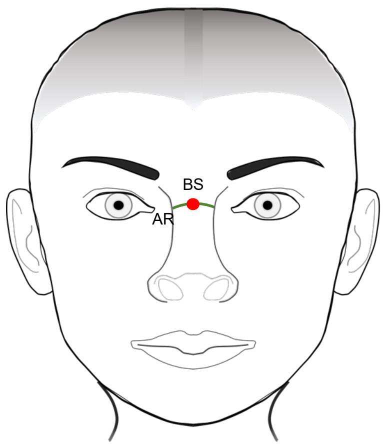
Bearing surface (BS).

Measurement definition:

The radius of the arc forming the lower edge of the bridge viewed perpendicularly to the back plane of the front.

Measurement method:

Automated radius calculated from the landmark by 3D stereophotogrammetry.



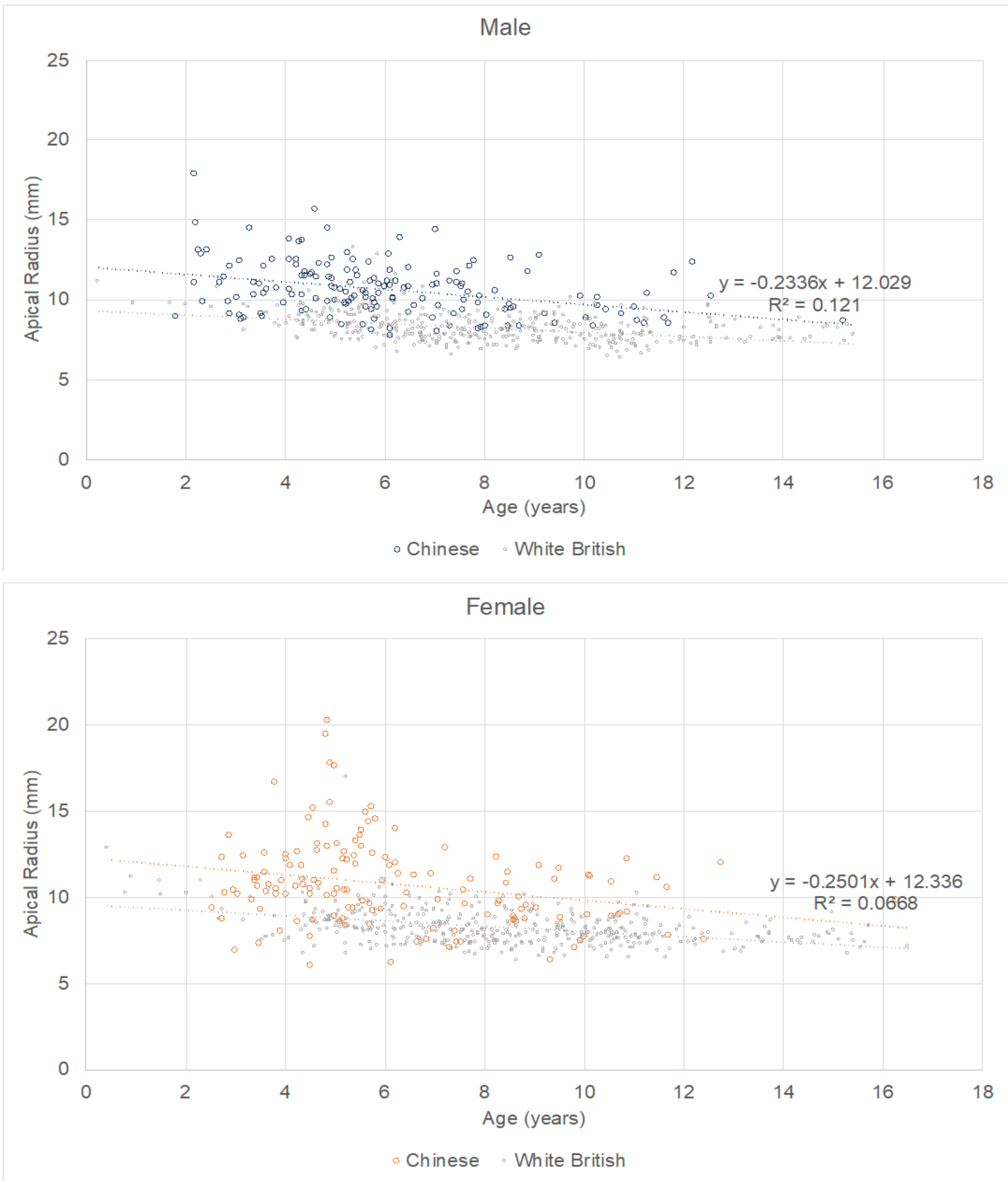


Figure 7.2g. Apical radius results for Chinese typically-developed children overlaid on White British results, showing measurements for both male and female subjects.

Chinese typically-developed

Crest Height (CH)

Landmarks involved:

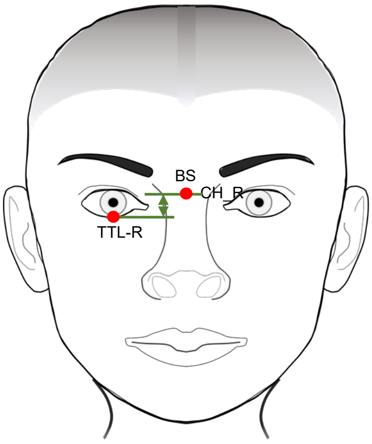
Bearing surface (BS) and top of lower lid right (TTL-R) for right crest height and bearing surface (BS) and top of the lower lid (left) for left crest height.

Measurement definition:

The vertical distance from the top of the lower lid to the crest (bearing surface) of the nose.

Measurement method:

Automated vertical height calculated between the landmarks by 3D stereophotogrammetry.



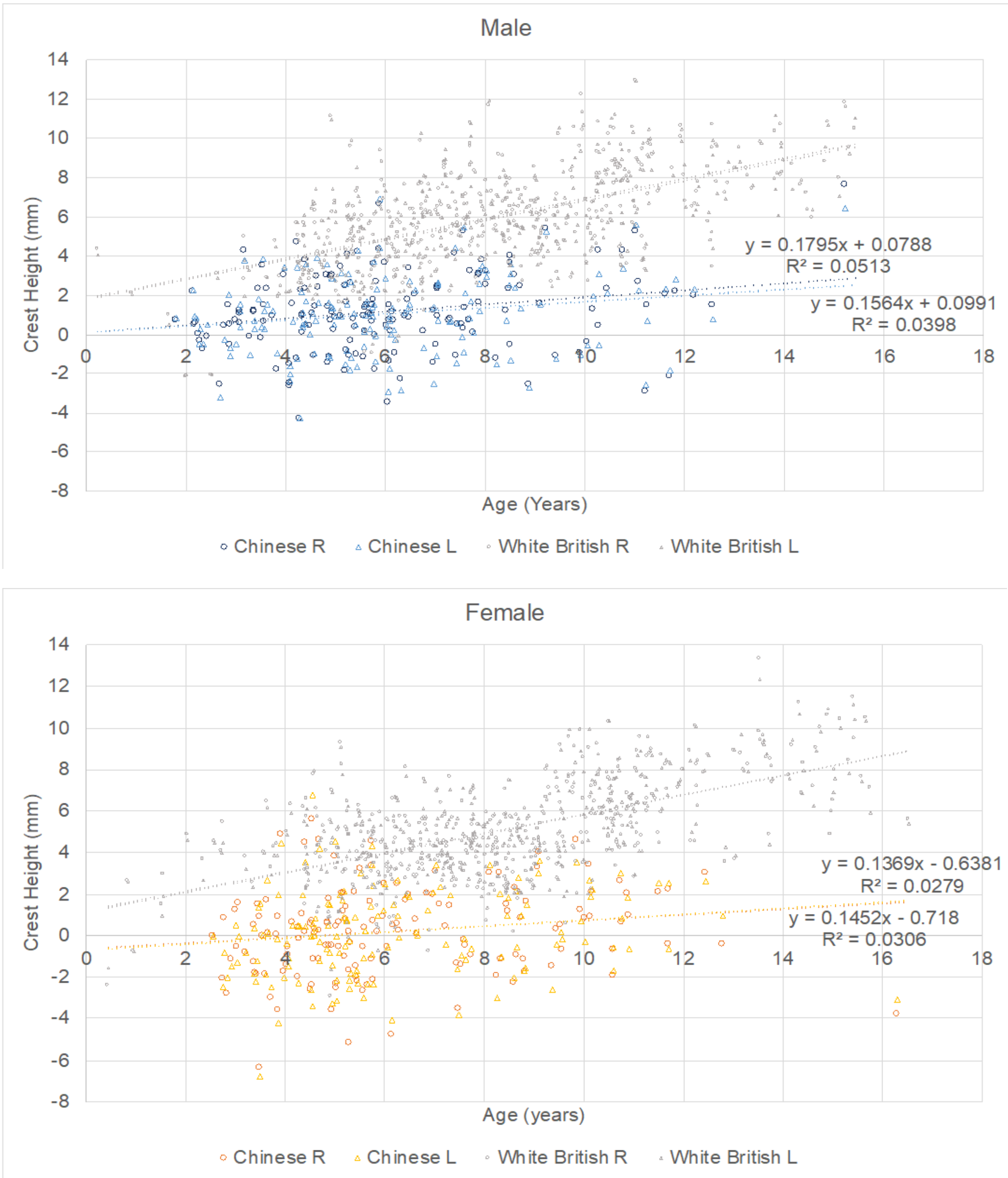


Figure 7.2h. Crest height results for Chinese typically-developed children overlaid on White British results, showing right and left measurements for both male and female subjects.

Chinese typically-developed

Front To Bend (FTB)

Landmarks involved:

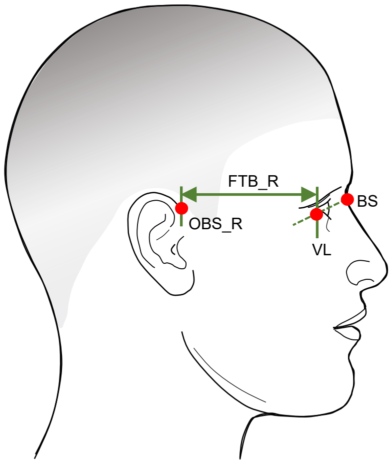
Bearing surface (BS) from which to extend a virtual frame front. Measured to otobasion superious right (OBS_R) for right front to bend and (OBS_L) for left front to bend.

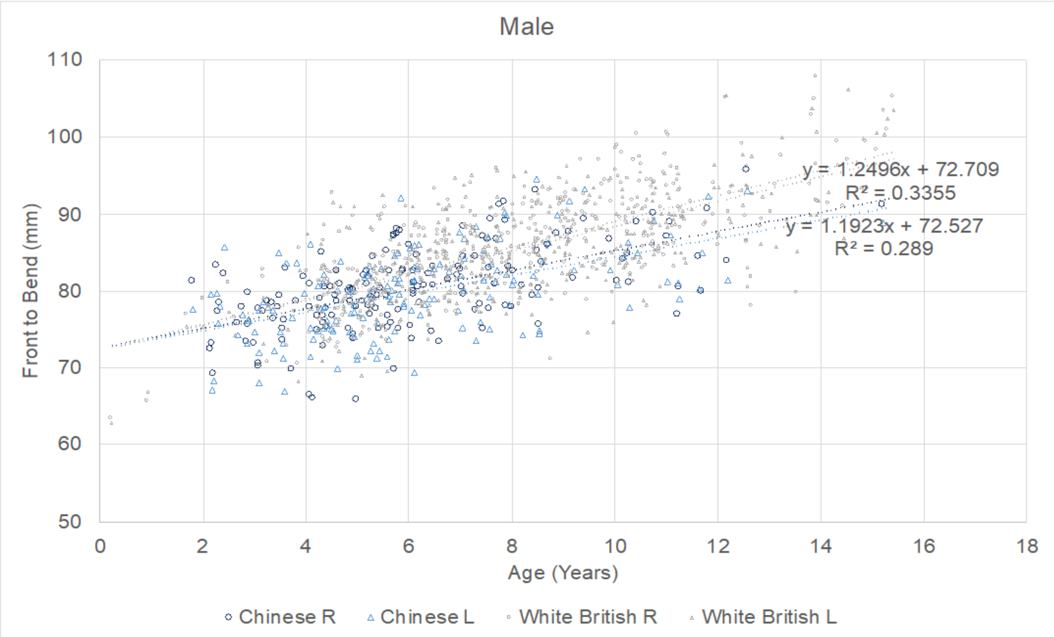
Measurement definition:

The distance between the lug point (point on the back surface of the lug where it begins its backward sweep) and the ear point.

Measurement method:

A virtual front extended from the bearing surface is created by the software, in order to calculate by 3D stereophotogrammetry the length from the virtual lug (VL) to the earpoint.





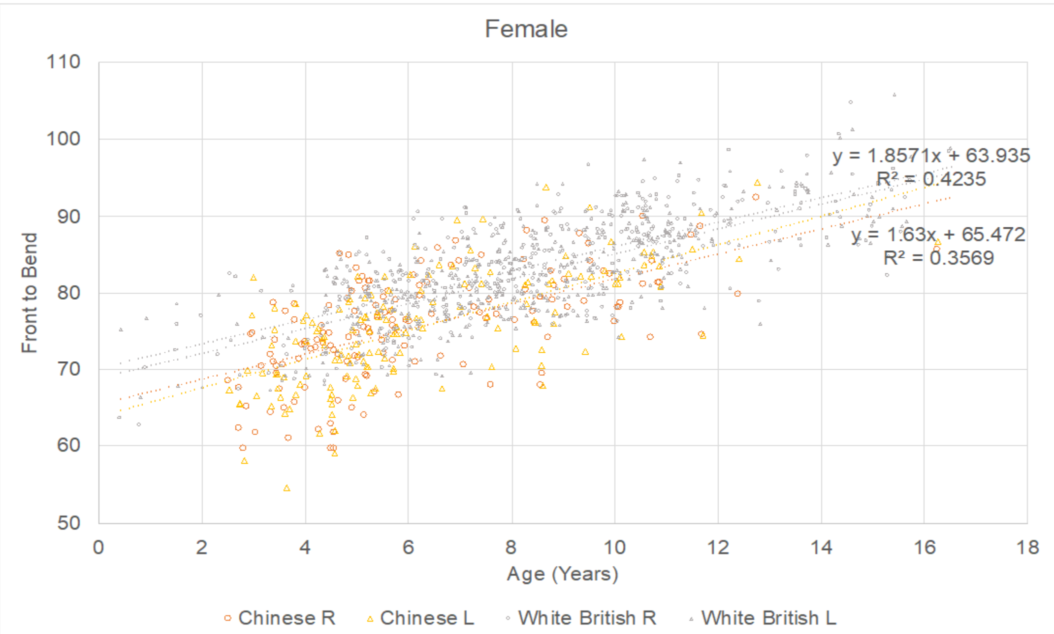


Figure 7.2i. Front to bend results for Chinese typically-developed children overlaid on White British results, showing right and left measurements for both male and female subjects.

Chinese typically-developed

Distance Between Pad Centres (DBPC)

Landmarks involved:

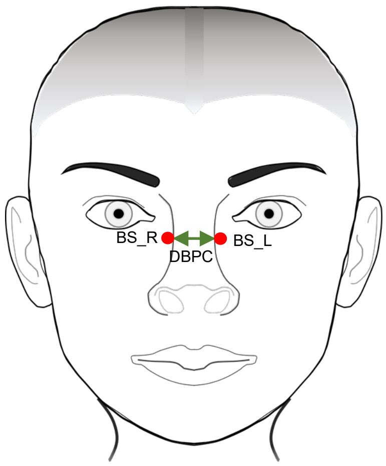
Bearing surface right (BS_R) and bearing surface left (BS_L).

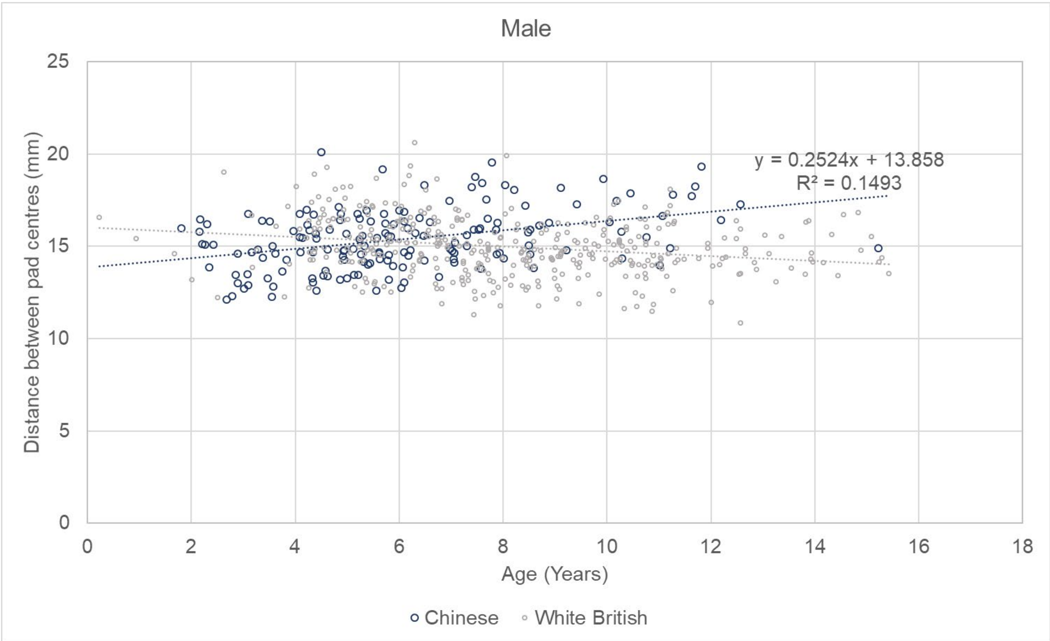
Measurement definition:

The width of the nose at the bearing surface points, hence where the pad of a frame would rest.

Measurement method:

Distance between landmarks calculated by 3D stereophotogrammetry.





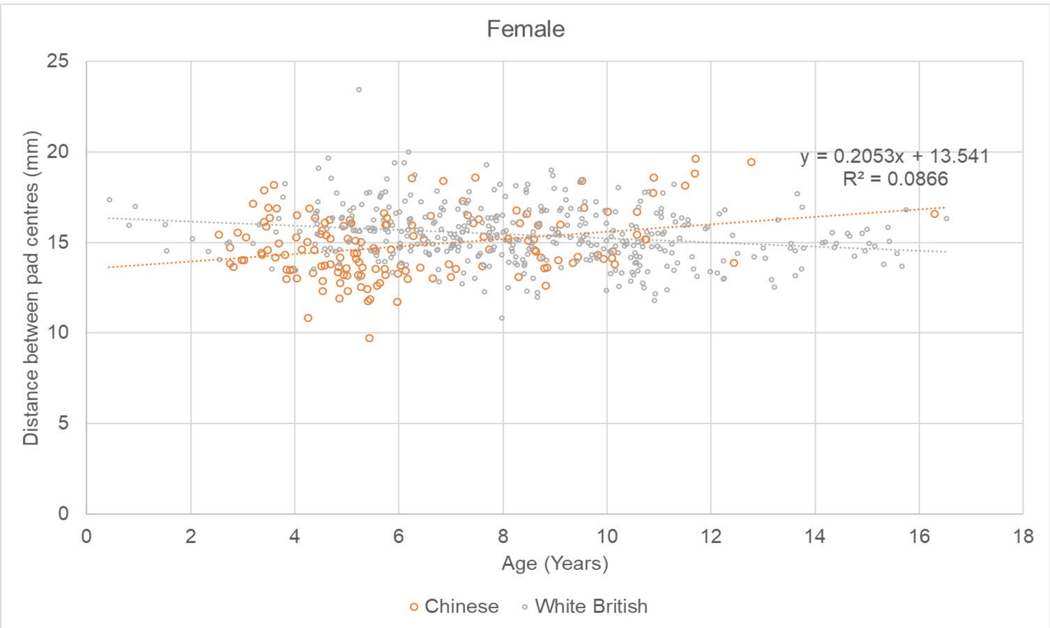


Figure 7.2j. Distance between pad centres results for Chinese typically-developed children overlaid on White British results, showing measurements for both male and female subjects.

Chinese typically-developed

Pupillary Distance (PD)

Landmarks involved:

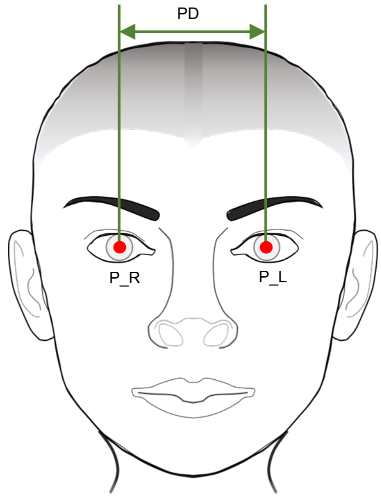
Pupil centre right (P_R) and pupil centre left (P_L).

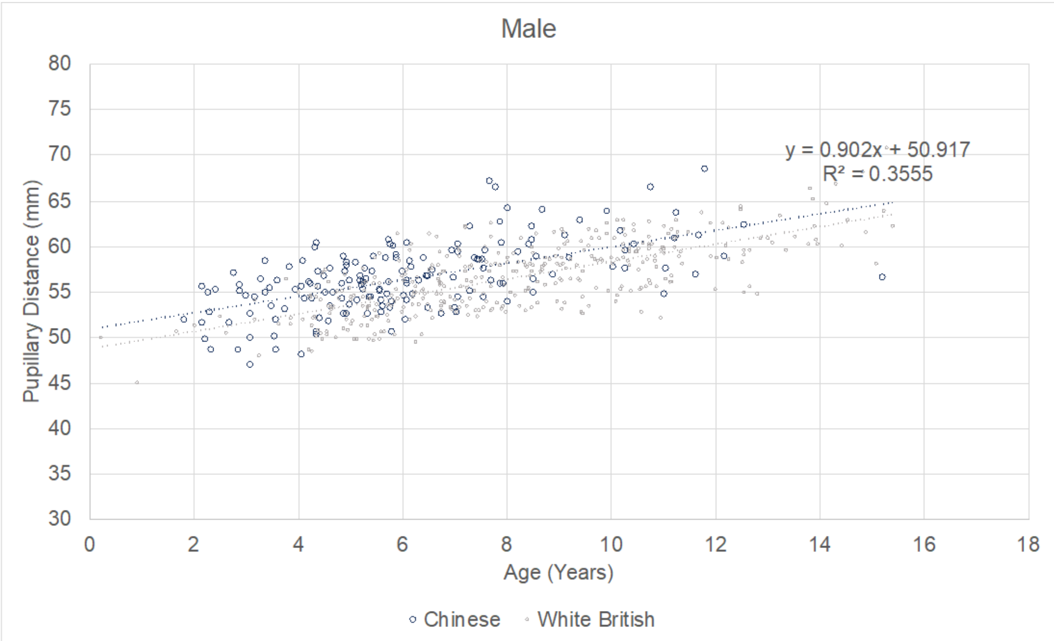
Measurement definition:

The distance between the centres of the pupils when the eyes are in the primary position.

Measurement method:

Distance behind the two landmarks calculated by 3D stereophotogrammetry.





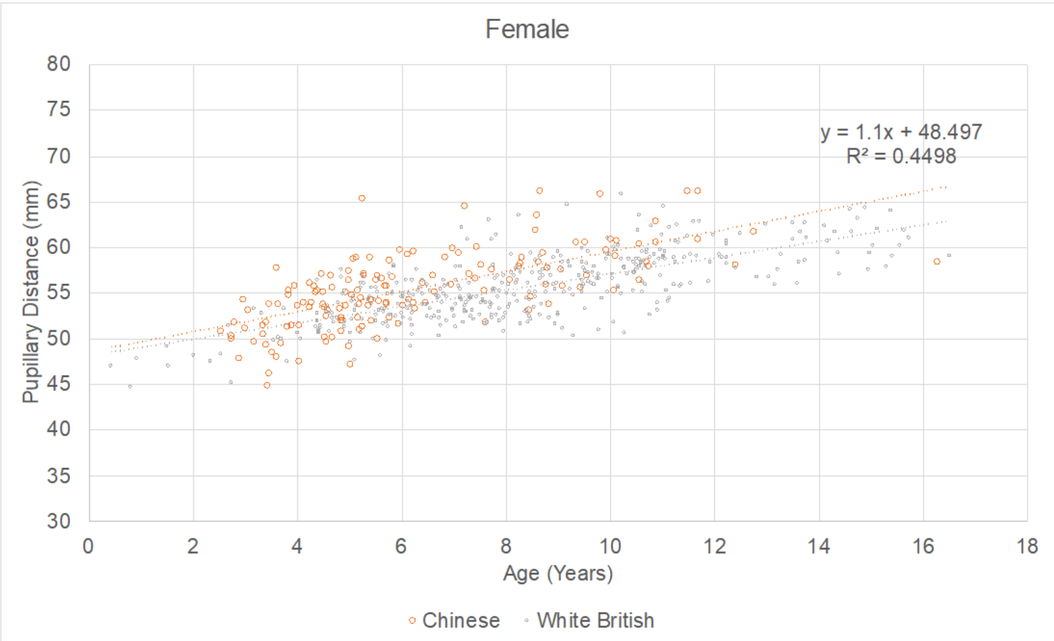


Figure 7.2k. Pupillary distance results for Chinese typically-developed children overlaid on White British results, showing measurements for both male and female subjects.

7.3 Linear regression analysis

Linear regression analysis using ANOVA and t-testing was carried out to determine the significance of the slope and whether there were differences between gender and right/left measures within the Chinese group. Analysis of variance showed that a linear line of best fit described the dependence of each facial measurement parameter on age in both males and females (Table 6.3a). The results showed no statistically significant difference between any right or left facial measurements where relevant, or between male and female measurements.

Measurement	Proportion of variance accounted for by regression (co-efficient of determination, R^2, %	Is linear regression statistically significant (ANOVA)?	Is slope of regression statistically significant (t-test)?	Slope (SE)	Is there a statistically significant difference between the slopes of the male and female slopes	Is there a statistically significant difference between the slopes of the R and L eyes
FAR male FAR female	3.2 0.6	Yes ($F_{1,159}=5$, p=0.024) No ($F_{1,146}=1$, p=0.370)	Yes (t=-2.28, p=0.024) No (t=0.90, p=0.370)	5.04 5.09	**Yes** **($t_{305}=0.51$, p=0.026)**	
FAL male FAL female	0.2 1.2	No ($F_{1,159}=0.3$, p=0.572) No ($F_{1,146}=1.7$, p=0.192)	No (t=-0.57, p=0.572) No (t=1.31, p=0.192)	5.09 5.16	**Yes** **($t_{305}=-2.90$, p=0.004)**	
FAR male FAL male						No ($t_{318}=-1.20$, p=0.230)
FAR female FAL female						No ($t_{292}=-0.30$, p=0.764)
SAR male SAR female	0.7 1.0	No ($F_{1,159}=1$, p=0.281) No ($F_{1,146}=2$, p=0.224)	No (t=1.08, p=0.281) No (t=1.22, p=0.224)	2.53 2.74	**Yes** **($t_{305}=3.03$, p=0.003)**	
SAL male SAL female	3.7 0.2	Yes ($F_{1,159}=6$, p=0.014) No($F_{1,146}=0$, p=0.572)	Yes (t=2.49, p=0.014) No (t=-0.57, p=0.572)	2.36 2.78	**Yes** **($t_{305}=2.44$, p=0.015)**	
SAR male SAL male						No ($t_{318}=-0.91$, p=0.365)
SAR female SAL female						No ($t_{292}=-1.54$, p=0.123)
HW male HW female	38.8 38.2	Yes ($F_{1,159}=101$, p<0.001) Yes ($F_{1,146}=90$, p<0.001)	Yes (t=10.03, p<0.001) Yes (t=9.51, p<0.001)	5.98 6.17	No ($t_{305}=-0.02$, p=0.986)	
TW male TW female	19.5 28.6	Yes ($F_{1,159}=39$, p<0.001) Yes ($F_{1,146}=59$, p<0.001)	Yes (t=6.21, p<0.001) Yes (t=7.65, p<0.001)	4.24 4.58	No ($t_{305}=-1.51$, p=0.132)	
DBR10 male DBR10 female	11.7 6.6	Yes ($F_{1,159}=21$, p<0.001) Yes ($F_{1,146}=10$, p=0.002)	Yes (t=-4.59, p<0.001) Yes (t=-3.21, p=0.002)	2.94 4.04	No ($t_{305}=-0.04$, p=0.966)	
DBR15 male DBR15 female	3.9 1.8	Yes ($F_{1,159}=6$, p=0.012) No ($F_{1,146}=3$, p=0.105)	Yes (t=-2.54, p=0.012) No (t=-1.63, p=0.105)	4.47 5.28	No ($t_{305}=-0.36$, p=0.717)	

AR male AR female	12.1 6.7	Yes ($F_{1,159}$=22, p<0.001) Yes ($F_{1,146}$=10, p=0.002)	Yes (t=-4.68, p<0.001) Yes (t=-3.23, p=0.002)	1.58 2.39	No (t_{305}=0.18, p=0.856)	
CHR male CHR female	5.1 2.8	Yes ($F_{1,159}$=9, p=0.004) Yes ($F_{1,146}$=4, p=0.042)	Yes (t=2.93, p=0.004) Yes (t=2.05, p=0.042)	1.94 2.07	No (t_{305}=0.47, p=0.638)	
CHL male CHL female	4.0 3.1	Yes ($F_{1,159}$=7, p=0.011) Yes ($F_{1,146}$=5, p=0.033)	Yes (t=2.57, p=0.011) Yes (t=2.15, p=0.033)	1.93 2.09	No (t_{305}=0.12, p=0.902)	
CHR male CHL male						No (t_{318}=0.27, p=0.790)
CHR female CHL female						No (t_{292}=-0.09, p=0.930)
FTBR male FTBR female	33.5 35.7	Yes ($F_{1,159}$=80, p<0.001) Yes ($F_{1,146}$=81, p<0.001)	Yes (t=8.96, p<0.001) Yes (t=9.00, p<0.001)	4.41 5.60	**Yes** **(t_{305}=-2.89, p=0.004)**	
FTBL male FTBL female	28.9 42.4	Yes ($F_{1,159}$=65, p<0.001) Yes ($F_{1,146}$=107, p<0.001)	Yes (t=8.04, p<0.001) Yes (t=10.36, p<0.001)	4.69 5.54	**Yes** **(t_{305}=-2.87, p=0.004)**	
FTBR male FTBL male						No (t_{318}=0.28, p=0.779)
FTBR female FTBL female						No (t_{292}=-0.89, p=0.374)
DBPC male DBPC female	14.9 8.7	Yes ($F_{1,159}$=28, p<0.001) Yes ($F_{1,146}$=14, p<0.001)	Yes (t=5.28, p<0.001) Yes (t=3.72, p<0.001)	1.51 1.70	No (t_{305}=0.65, p=0.518)	
PD male PD female	35.5 45.0	Yes ($F_{1,159}$=88, p<0.001) Yes ($F_{1,146}$=119, p<0.001)	Yes (t=9.36, p<0.001) Yes (t=10.93, p<0.001)	3.05 3.11	No (t_{305}=-1.42, p=0.156)	

Table 7.3a. Linear regression analysis for measurements plotted as a function of age, including comparison of the slopes for gender and right / left measurements where applicable.

The results of the analysis show no difference between right and left measurements, however, does show a significant gender difference for the right and left slopes for frontal angle (p=0.026 (FAR), p=0.004 (FAL)), splay angle (p=0.003 (SAR), p=0.015 (SAL)) and the front to bend measurement (p=0.004 (FTBR), p=0.004 (FTBL)) which was not seen in the results for White British children.

	Is there a statistically significant difference between the slopes of the White British and Chinese ethnicities?	
Measurement	Male	Female
Frontal angle (right)	**Yes (t_{549}=2.93, p=0.004)**	**Yes (t_{553}=6.00, p<0.001)**
Frontal angle (left)	**Yes (t_{549}=2.74, p=0.006)**	**Yes (t_{553}=6.61, p<0.001)**
Splay angle (right)	**Yes (t_{549}=3.87, p=0.001)**	No (t_{553}=-0.27, p=0.785)
Splay angle (left)	**Yes (t_{549}=5.28, p<0.001)**	No (t_{553}=1.33, p=0.185)
Head width	No (t_{549}=0.06, p=0.953)	No (t_{553}=0.75, p=0.452)
Temple width	No (t_{549}=1.06, p=0.288)	**Yes (t_{553}=2.59, p=0.010)**
Distance between rims at 10 mm below crest	No (t_{549}=-1.08, p=0.280)	No (t_{553}=-0.49, p=0.627)
Distance between rims at 15mm below crest	No (t_{549}=0.08, p=0.935)	No (t_{553}=0.80, p=0.421)
Apical radius	No (t_{549}=-1.86, p=0.063)	No (t_{553}=-1.22, p=0.222)
Crest height (right)	**Yes (t_{549}=-4.65, p<0.001)**	**Yes (t_{553}=-4.40, p<0.001)**
Crest height (left)	**Yes (t_{549}=-4.92, p<0.001)**	**Yes (t_{553}=-4.35, p<0.001)**
Front to bend (right)	**Yes (t_{549}=-4.11, p<0.001)**	No (t_{553}=0.247, p=0.805)
Front to bend (left)	**Yes (t_{549}=-2.43, p=0.016)**	No (t_{553}=1.22, p=0.224)
Distance between pad centres	**Yes (t_{549}=6.92, p<0.001)**	**Yes (t_{553}=5.27, p<0.001)**
Pupillary distance	No (t_{549}=-0.54, p=0.589)	No (t_{553}=1.88, p=0.06)

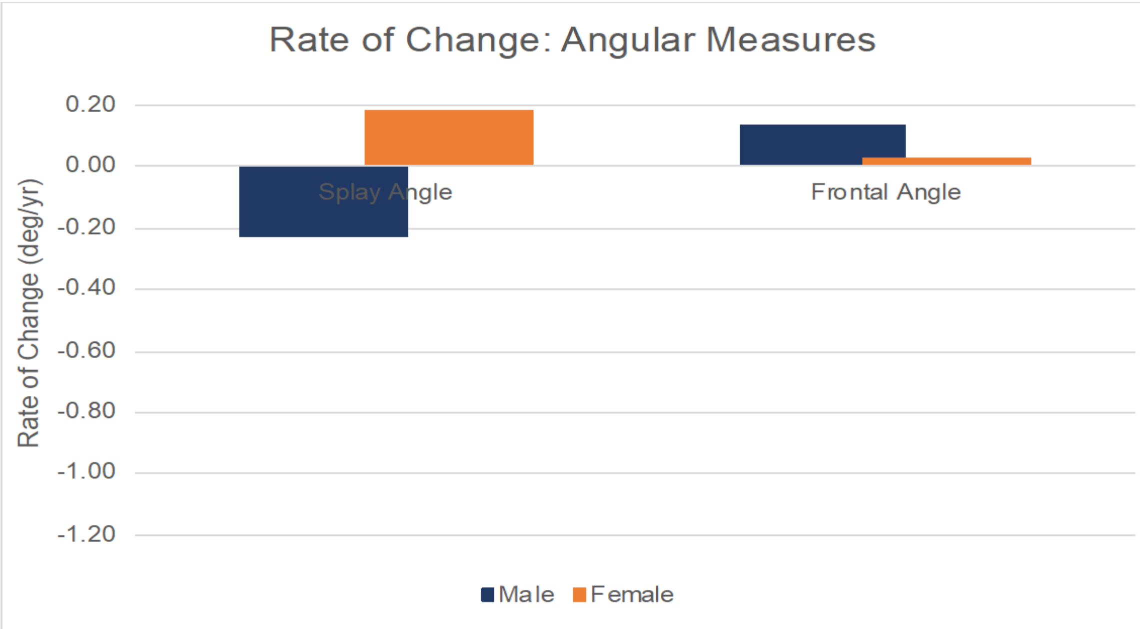
Table 7.3b. Comparison of slopes for Chinese and White British results.

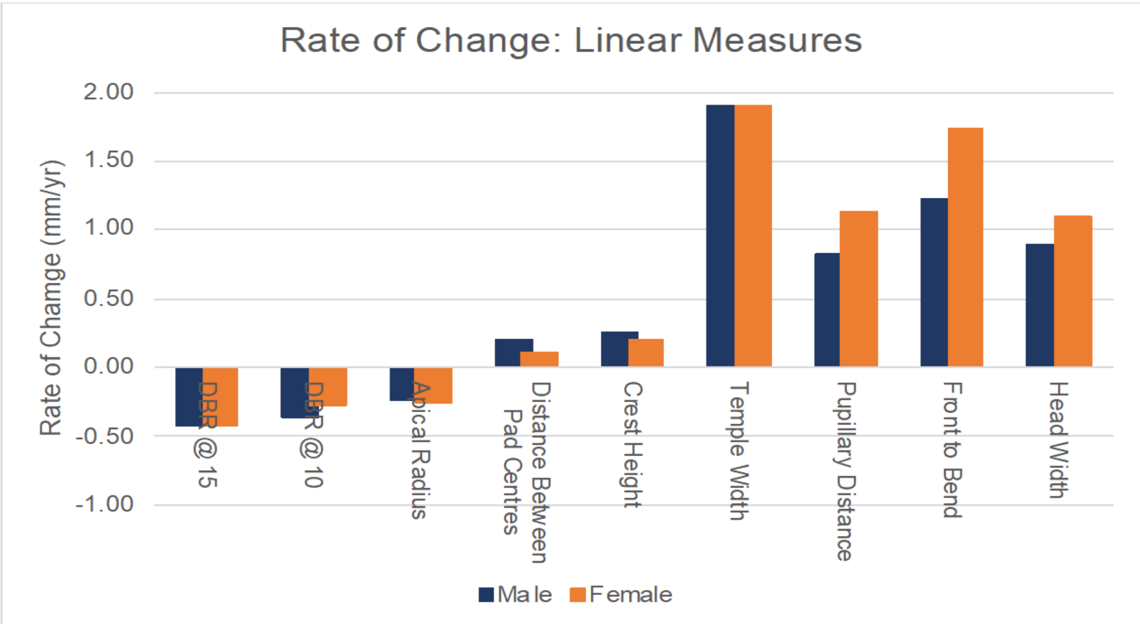
The two slopes of these two independent samples were compared following null and alternative hypothesis using the Slopes Test function (https://www.real-statistics.com/regression/hypothesis-testing-significance-regression-line-slope/comparing-slopes-two-independent-samples/)

For angular measurements, the slopes for frontal angle differ between the measurements of Chinese and White British children for both males and females. Splay angle only showed a significant difference for males ($p=0.001$ (SAR) and $p<0.001$ (SAL)).

For linear measurements, in female measurements only, temple width showed a significant slope difference ($p=0.010$) between Chinese and White British children. In male measurements only, the right ($p<0.001$) and left ($p=0.016$) front to bend measurements also reported a difference. For both male and females, the crest heights (right and left) and distance between pad centres also showed a significant difference ($p<0.001$).

As shown by the scatterplots 7.2a-7.2k, some facial measurements decreased and some increased with age. The gradient of the linear regression is a measure of rate of change in growth for a given facial parameter, summarised in Figure 7.3c.





<u>Figure 7.3c.</u> Rate of change and growth direction in typically-developed Chinese children. A positive value indicates that the measurement is increasing in magnitude with increase in age. A negative value indicates that the measurement is decreasing in magnitude with increase in age.

It can be observed that the rate of change in growth is not the same for all measurements, indicating that the face and nose are changing shape as a child ages. Considering angular measures first, the splay angle changes at a different rate between males and females, decreasing by approximately 0.2 degrees per year in males but *increasing* each year by a similar amount in females. This gender difference was not observed in the White British group who showed a decrease in splay angle of approximately 0.2 degrees per year (figure 6.3b). The frontal angle increases by approximately 0.1 degrees per year in males but hardly changes in females. These changes were significantly different (p=0.004 (FAR male)) from White British children who showed a decrease in frontal angle of approximately 1 degree per year, while there was little change in this measurement in the Chinese group.

For linear measurements, both distance between rims and apical radius show a similar pattern of growth to the White British, with all measurements decreasing by 0.2-0.4mm a year. Distance between pad centres increase slightly with a rate of change of approximately 0.1mm per year in females and 0.2mm per year in males, this is in contrast to the *decrease* reported for the White British results of approximately 0.1mm per year. The crest height for Chinese children increases at approximately 0.2mm which is less than half the rate (approximately 0.5mm) in comparison to White British children. Temple width shows the most significant growth in Chinese children at a rate of almost 2mm per year, with head width achieving approximately half this rate. This pattern of growth is opposite to that seen in White British children where head width achieves the most growth of approximately 1.75mm per year, compared to temple width of only 0.7mm. The front to bend measurement increases annually at a different rate between males at approximately 1.2mm, and females at approximately 1.75mm which is a significant gender difference (p=0.004 (R and L)). This difference was not observed in the White British group who showed an increase of just over 1.5mm per year, similar to that of the Chinese female rate. Pupillary distance shows an annual increase of 0.8mm (male), 1.1mm (female) which is a similar value to the White British results at just under 1mm per year.

7.4. Discussion

The World Health Organisation (WHO) present growth charts for all children as reproduced in section 6.4. The ranges in these charts were informed by a Multicentre Growth Reference Study (MGRS) which measured 8500 children from '*widely different ethnic backgrounds and cultural settings*' between 1997 and 2003 (World Health Organisation). The six countries that participated in contributing to this study were Brazil, Ghana, India, Norway, Oman and the USA. In 2014, Natale and Rajagopalan undertook a systematic review looking at variations in growth from comparable data from 55 countries and ethnic groups, comparing these findings to the WHO growth standards, concluding that, particularly for head circumference, the variations found were extremely large with means constantly 0.5-1 SD above the MGRS mean, therefore potentially raising unnecessary concern and even risk a misdiagnosis of serious conditions such as microcephaly or macrocephaly. With regard to Chinese children, this concern concurs with the findings of Ouyang et al. (2018) who measured 4251 children from birth to 2 years from multiple centres across China and found the head circumference to be constantly greater than the WHO growth standards and therefore advising that Chinese children should have their own growth pattern reference. Facial parameters are different, and growth is reported at differing rates (Wen et al., 2017) for children of Chinese ethnicity compared to children of White British ethnicity, however, growth still shows a linear fit to best describe the data.

The relative lack of change reported for the frontal and splay angles indicates that very little change occurs to the relatively flat, wide appearance of the nose in both the frontal and sagittal planes across this age profile. This is further evidenced on the scatterplot for the frontal angle (figure 7.2a) which shows a larger angle for both males and females when compared to the data for White British children, yet with a relatively similar spread of data (SE=5.04(male R)); SE= (5.16 (female L)). A similar result for splay angle measurements showing larger splay angles, especially in children over 6 years old where a marked separation in values can be seen on the scatterplot (figure 7.2b). This indicates the White British children are experiencing that narrowing of the angles in the younger years as reported and by age 6, the difference in values between children of Chinese ethnicity compared to White British ethnicity is more apparent. In contrast to the frontal angle, the splay angle yielded a much smaller spread of data (SE=2.53 (male R); SE=2.78 (female L)) showing a similar spread to the White British results with the majority of subjects falling in the range of 24-37 degrees. Relatively larger splay and frontal angles appear to continue into adulthood as reported by Tang et al. (1998b) who studied anthropometry for spectacle wear in 500 Chinese adults aged 17-41 years and measured these angles using a custom-designed adjustable frame template with nasal attachments.

For linear facial measurements, the distance between rims (DBR), distance between pad centres (DBPC) and the apical radius (AR) are all measured in the same frontal plane as the frontal angle and therefore, with this angle remaining relatively large with little suggested change as the child grows, it follows that these linear measurements will also remain almost constant, i.e. only showing a very small decrease/increase in numerical value, as the crest fails to emerge at a similar age and all parameters remain larger, i.e. flatter and wider in comparison to White British data. Distance between rims measurements determines width values of the nose and these show a small (<0.5mm per year) decrease in value similar to that of the White British data. Overall, the values are larger than the White British data depicting the wider nasal form. There is no comparable data for this parameter in the literature for Chinese subjects as Tang et al. (1998b) measured this width at 5 different points in relation to the horizontal midline of the frame, rather than the facial measurement in relation to the bearing surface. The distance between pad centres measurement showed very little change as a function of growth and since it is placed in a position where the pads of the spectacle frame would be expected to sit, it is much more difficult to place a landmark where the position is ill-defined compared to a more prominent, developed nasal form. The apical radius also shows very little change as a function of age with a decrease of 0.25mm per year. A much wider spread of data was found for apical radius compared to White British, especially in females (SE=2.39), which may be explained by the difficulty in locating the actual bearing surface on a relatively flat bridge.

The distance between rims (DBR), distance between pad centres (DBPC) and the apical radius (AR) all decrease linearly with age ($p<0.001$) in males and females with the exception of the DBR15 measurement in females ($p=0.572$). There was no significant difference in slopes between males and females (table 7.3a), indicating that the rate of change is equal across the sexes. Distance between rims at 10mm below crest, distance between pad centres and crest height show a larger annual change in male subjects. In comparison of male to female data, more of the variance was associated with DBR10; 11.7% (male) and 6.6% (female), AR; 12.1% (male), 6.7%(female) and DBPC; 14.9% (male), 8.7% (female) could be explained by its linear relationship with age.

As the crest of the nose emerges, it is expected that the position of the crest (crest height) will naturally take on a more superior position in relation to the lower lid and therefore a small but positive growth is reported (+0.25mm per year) which is half the rate of change (+0.50mm per year) for the White British data. For this measurement, Tang et al. (1998b) used a frame front template to assess crest height and reported a negative crest height value for 60% of males and 83% of females which concurs with the findings of this study, the crest height values are significantly lower and frequently negative in value than those reported for White British children. One of the advantages of the 3D measurements used in this study is that negative crest heights can be measured, which is not possible using the Fairbanks facial rule method.

The crest height was found to increase linearly with age ($p<0.001$) in males and females and that there was no difference between the slopes of the genders (table 7.3b), indicating that the rate of change is equal across the sexes. Compared to White British data, a much lower percentage of the variance associated with the crest height, 5.1% (male CHR) 2.8% (female CHR), could be explained by its linear relationship with age.

In the sagittal plane, the pupillary distance (PD) and the width of the head at the ear points (HW) grows at a rate of around 1mm per year compared to the temple width (TW) at almost 2mm per year. This is in contrast to the larger head width growth reported by children of White British ethnicity, however, does concur with the literature that the Chinese head form is more rounded (Ball et al., 2010) and is larger in comparison to *'Caucasian'* ethnicity (Mok et al., 2016, Liu et al., 2013, Quant and Woo, 1993).

The head width rate of change is similar to that of White British but overall larger values, especially in female subjects (figure 7.2c). For head width, the variation in the data for males is less pronounced, ranging from 132-172mm (SE=5.98), with a larger variation observed for females, ranging from 121-170 (SE=6.17). This concurs with facial parameter and growth studies across a range of ages where the head, temple and facial width has been measured in 2-6 year olds (n=448) by tape measure (Mok et al., 2016), 7-11 years (n=232) by sliding callipers (Quant and Woo, 1993) and 12-18 year olds (n=266) by photographic methods (Wen et al., 2017). Wen et al. (2017) looked at facial growth of teenage children and concluded a definite growth in Chinese children beyond the age of 12 years which contrasts that of Italian children (Ferrario et al., 1999) who reported in females particularly, a conclusion of facial growth reached by 12 years old, agreed by Sforza et al. (2009) that females grow more rapidly and develop earlier than males. This concept of a longer growth period is evidenced in the current study where the female annual change rates are significantly more than males for head width, pupillary distance and front to bend. In a large study of over 10,000 5-17 year old Chinese children, Wang et al. (2005) used callipers to measure head width and found that the reported period of growth was between 5-15 years of age with the most significant change of growth occurring at 11 years old, which is later in comparison to the study by Ferrario et al (1999).

In a study aimed to determine values of eye position and head size in 232 Chinese children, Quant and Woo (1993) reported all parameters would need to be larger to fit spectacles to Chinese children, such as 20mm wider in temple and head width measurements in comparison to the study by Kaye and Obstfeld (1989), although the position of the HW measurement in this study was '*behind the ear point'* rather than on top of the ear point, possibly resulting in a slightly larger measurement. However, the conclusion of the Quant and Woo (1993) study noted that for spectacle frame design, these anatomical differences would render frames designed for Caucasian children totally unsuitable for children of Chinese ethnicity.

The scatterplots for temple width (figure 7.2d) show a more marked difference between values for Chinese and White British children in both the male and female data. Mean TW comparison for males 110.89mm (4.7SD) compared to 102mm (5.5SD) and for females 111.25 (5.4SD) compared to 102mm (5.5SD). For this parameter, the values are less than those reported by Quant and Woo (1993) by an average of 10mm, although this being a callipered measurement taken at the bony margin of the orbit compared to the automated landmark measurement of 25mm behind the frame front measurement used in this thesis. There was little difference found between the male and female values across the age groups and temple width shows almost twice the rate of growth annually than head width and pupillary distance, giving the more rounded head profile as described by Ball et al. (2010) and showing growth that is not proportionate.

Pupillary distance shows a similar range of values 45-66mm (females) 47-68mm (males) to the White British children with similar mean values of 56.45mm (3.7SD) White British males compared to 56.42mm (3.8SD) Chinese males. This concurs with the studies by Wang et al. (2005) reporting a range 52.2-60.4mm across 5-17 year old children and Quant and Woo (1993) reporting a similar range of 54-59.5mm from 7-11 years old.

Considered together, the head width (HW), temple width (TW) and the pupillary distance (PD) all increase linearly with age ($p<0.001$) in males and females. There was no significant difference in slopes between males and females (table 7.3a), indicating that the rate of change is equal across the sexes. Temple width increases at a higher rate than head width and pupillary distance and more of the variance associated with the HW, 38.8% (male) and PD 31.5% (male) could be explained by its linear relationship with age compared to the TW, 19.5% (male).

Perpendicular to the HW, TW and PD in the sagittal plane, the front to bend (FTB) parameter exhibited an annual growth at 1.2mm (males) to 1.75mm (females) per year indicating a more rapid expansion of the head in the frontal plane for females. Front to bend showed scatterplots with generally shorter FTB values than White British data (figure 7.2i) with no significant difference in slopes between right and left measurements (table 7.3a). The mean values show the Chinese children have FTB measurements over 7mm shorter; 75.61mm (Chinese female) compared to 82.93mm (White British female). Tang et al. (1998a) found this difference reduced to 4mm on average, nevertheless still present in the data for 500 adults aged 17-41 years of Chinese ethnicity. 33.5% (male FTBR) of the variance associated with the front to bend could be explained by its linear relationship with age.

Summary of parameter differences for a given age in typically-developed Chinese children compared to White British children.

- Larger frontal angle
- Larger splay angle
- Larger DBR
- Larger apical radius
- Lower crest height (often negative)
- Larger temple width
- Shorter front to bend

In general, it appears that facial growth in Chinese children in the age range studied is more associated with cranial changes rather than the emergence of a nasal bearing surface and subsequent narrowing of nasal parameters. Furthermore, these changes appear to take place over a longer growing period.

Overall, this has implications for the design of children's spectacle frames, and the need to provide variations in frame design to suit the facial parameters of Chinese children. Chinese children are not wholly larger or smaller in comparison to White British children and therefore designs should either accommodate these variances or be capable of substantial adjustment. This will be explored in greater detail in Chapter 10. There is a sparsity of previous research in this area but in the few studies that have evaluated facial measurements relating to spectacle frame design or studied growth of Chinese children, there is a degree of concordance.

Chapter 8 Facial anthropometry in children with Down's syndrome of White British ethnicity.

8.1 Introduction and methods

Data was acquired using the method described in section 2.6 with 101 images (58 males, 43 females) acquired in the White British with Down's syndrome group. These were collected from a variety of settings across the United Kingdom (section 2.5) including a specialist clinic at Cardiff University, schools, charitable organisations and children's groups.

8.2 Results

For the following figures, curve fitting was carried out for each of the measurement parameters as a function of age and it was determined that linear regression offered the best fit to the data. The linear regression line delineates a model of growth in the age range studied, i.e. birth to sixteen years of age. On this basis, the gradient of the line indicates the rate of change, i.e. growth rate of each of the facial measurements.

Down's syndrome

Frontal Angle (FA)

Landmarks involved:

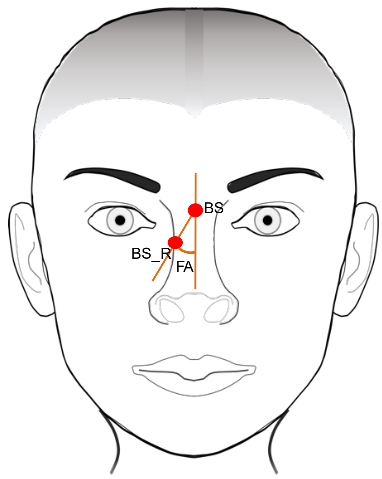
Bearing surface (BS) and bearing surface right (BS_R) for right frontal angle (as shown in schematic diagram) and bearing surface and bearing surface left (BS_L) for left frontal angle.

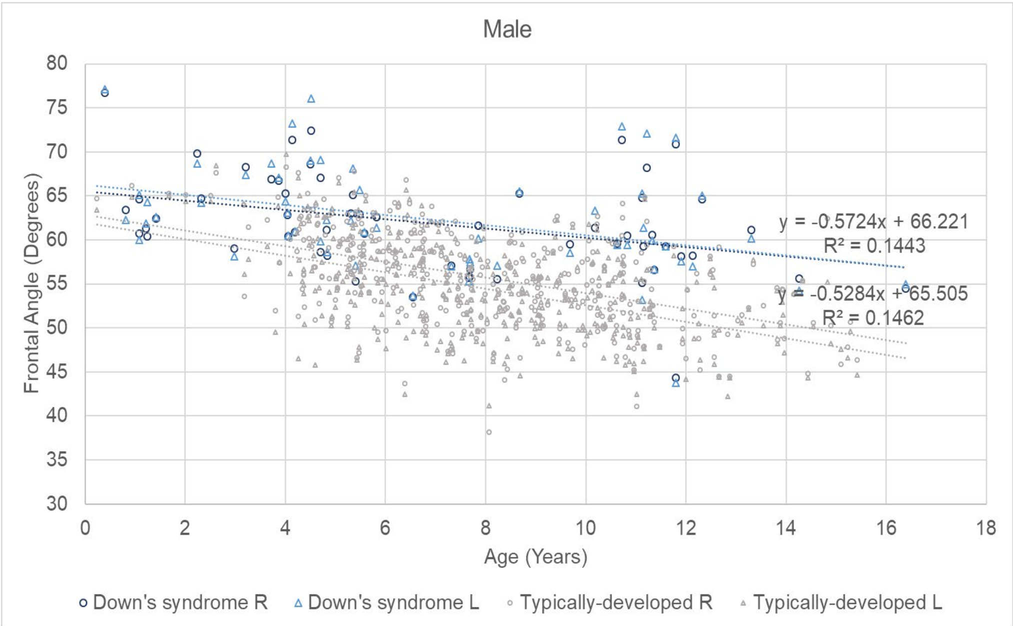
Measurement definition:

The angle between the vertical and the line of intersection of the pad plane with the back plane of the front, taken in the lateral plane.

Measurement method:

Angle between the landmarks calculated by 3D stereophotogrammetry.





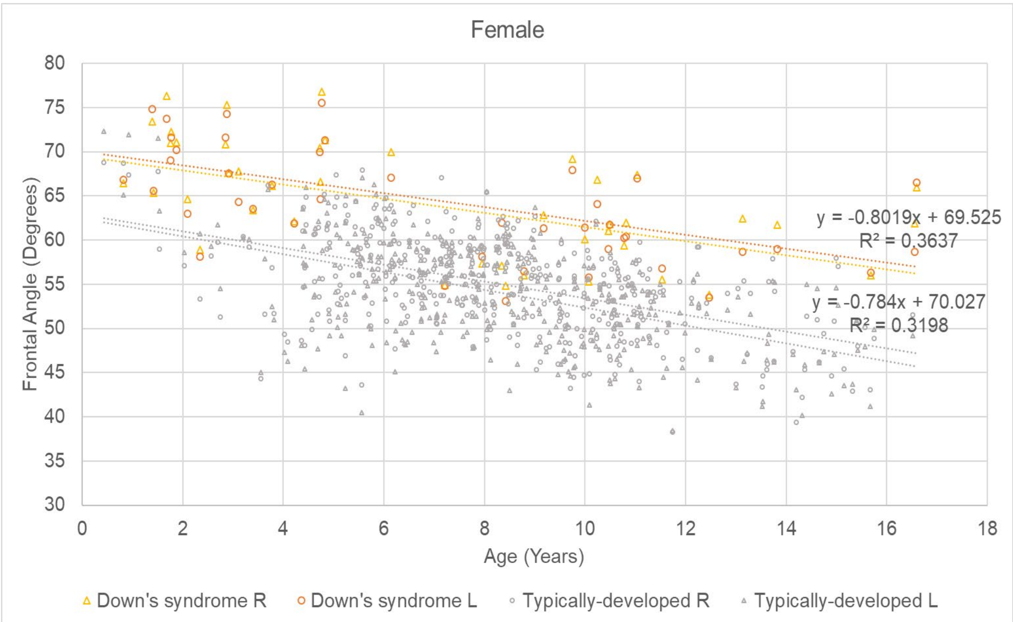


Figure 8.2a. Frontal angle results for White British children with Down's syndrome overlaid on results for typically-developed White British children, showing right and left measurements for both male and female subjects.

Down's syndrome

Splay Angle (SA)

Landmarks involved:

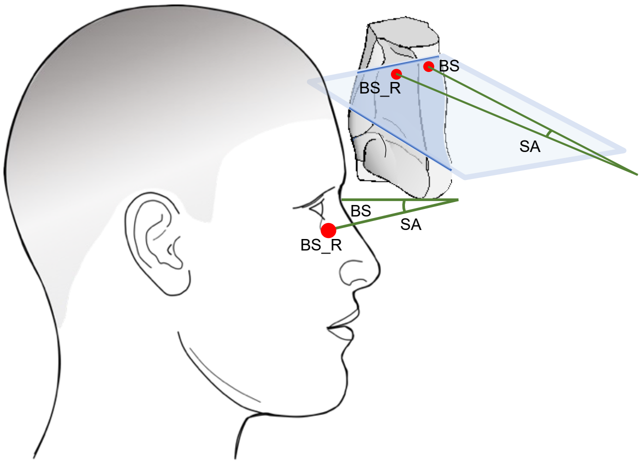
Bearing surface (BS) and bearing surface right (BS_R) for right splay angle and bearing surface (BS) and bearing surface left (BS-L) for left splay angle.

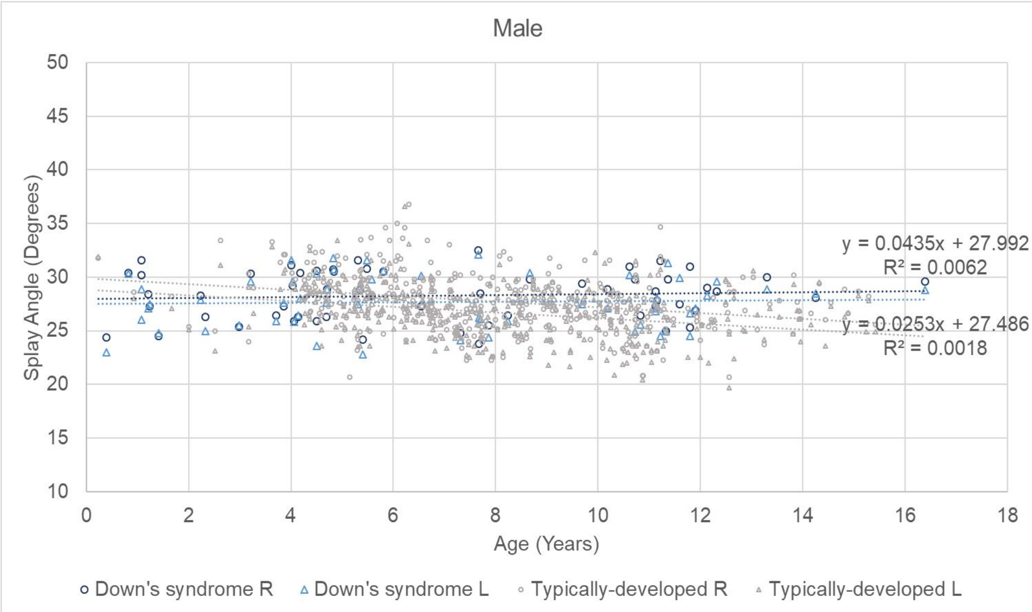
Measurement definition:

The angle between the pad plane and a normal to the back plane of the spectacle front, taken in the transverse plane.

Measurement method:

Angle between the landmarks calculated by 3D stereophotogrammetry.





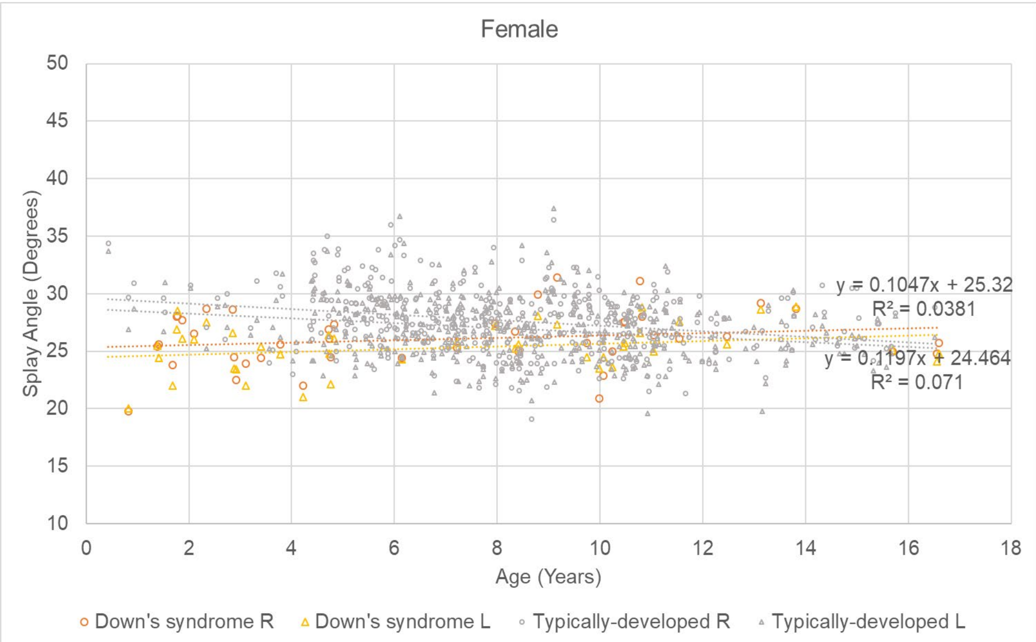
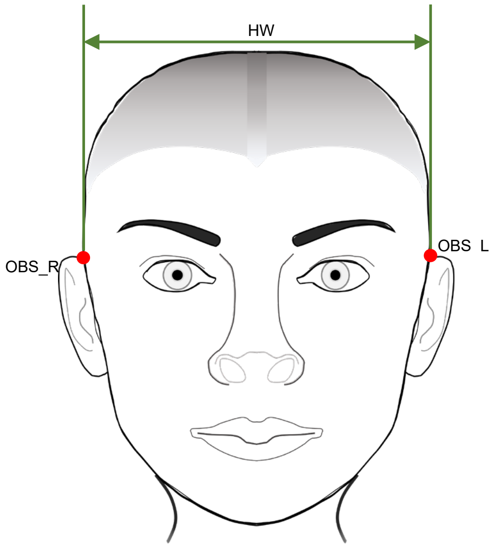


Figure 8.2b. Splay angle results for White British children with Down's syndrome overlaid on results for typically-developed White British children, showing right and left measurements for both male and female subjects.

Down’s syndrome

Head width (HW)



Landmarks involved:

Otobasion superious right (OBS_R) and left (OBS_L).

Measurement definition:

The distance between the two ear points.

Measurement method:

Linear distance between the landmarks calculated by 3D stereophotogrammetry.

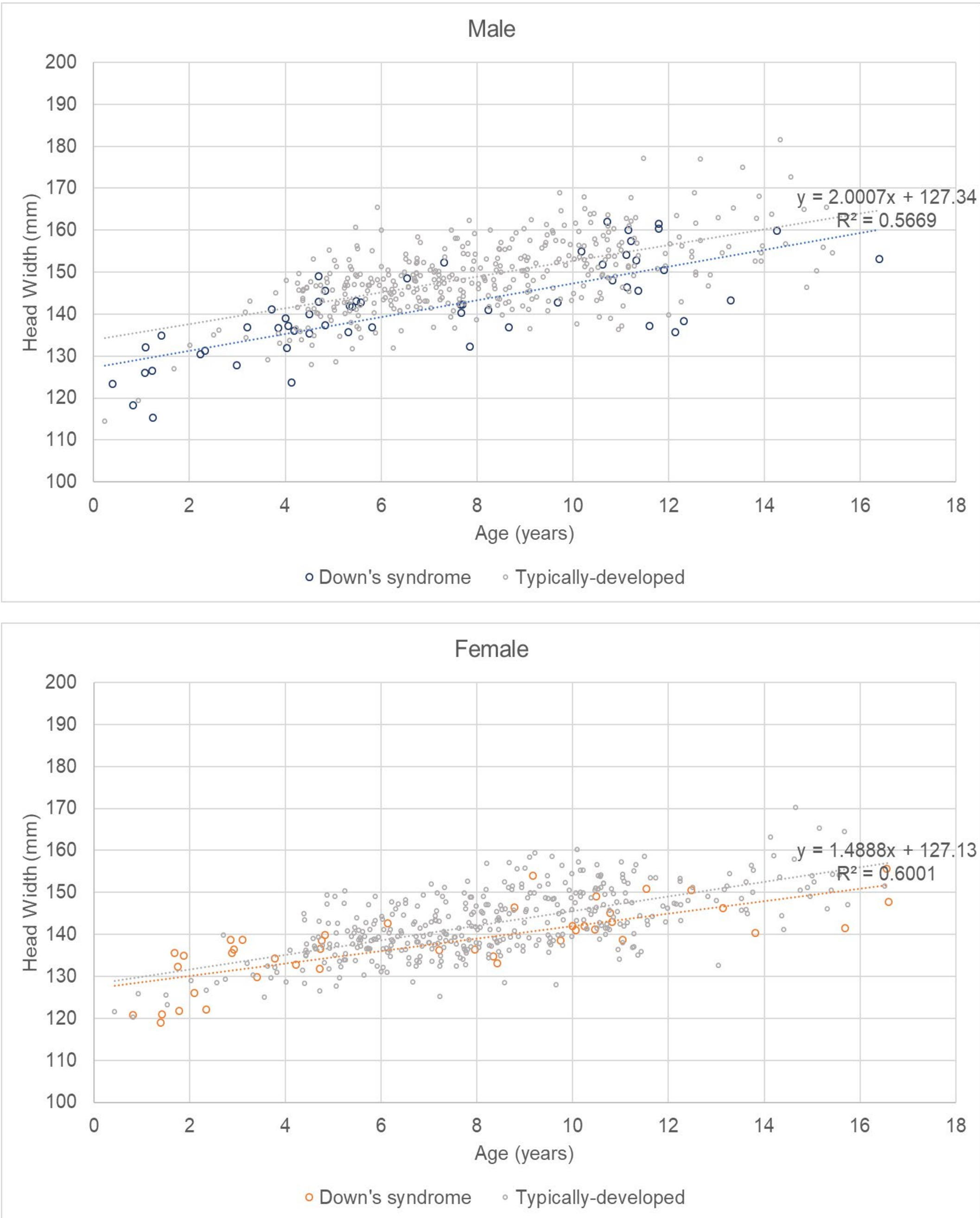
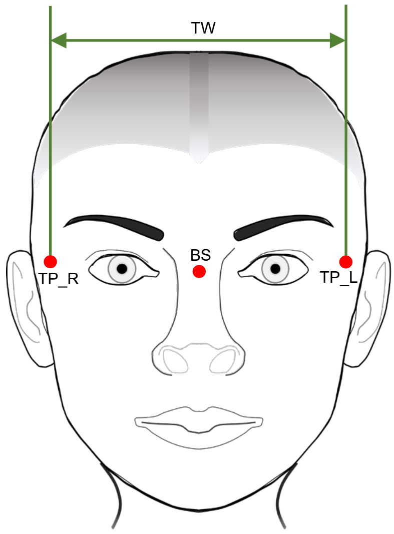


Figure 8.2c. Head width results for White British children with Down’s syndrome overlaid on results for White British typically-developed, showing measurements for both male and female subjects.

Down's syndrome

Temple width (TW)



Landmarks involved:

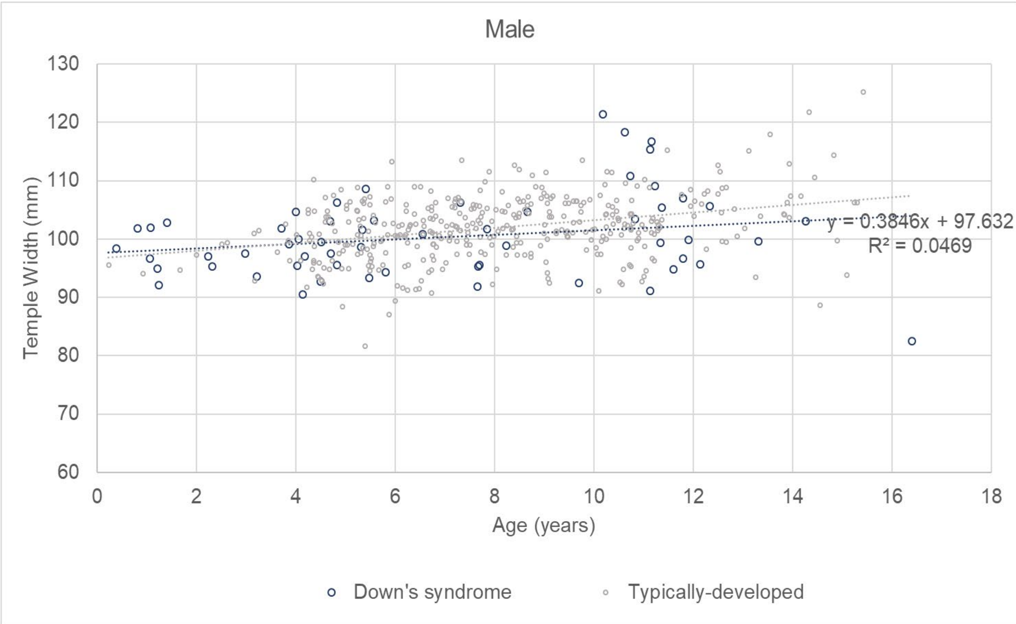
Bearing surface (BS) and temple points right (TP_R) and left (TP_L).

Measurement definition:

The distance between the two temple points at a distance of 25mm behind the back plane of a spectacle front.

Measurement method:

The position of the bearing surface enables the programme to create a virtual frame front in order to generate the temple points at the correct distance behind the front and measure the distance between the landmarks calculated by 3D stereophotogrammetry.



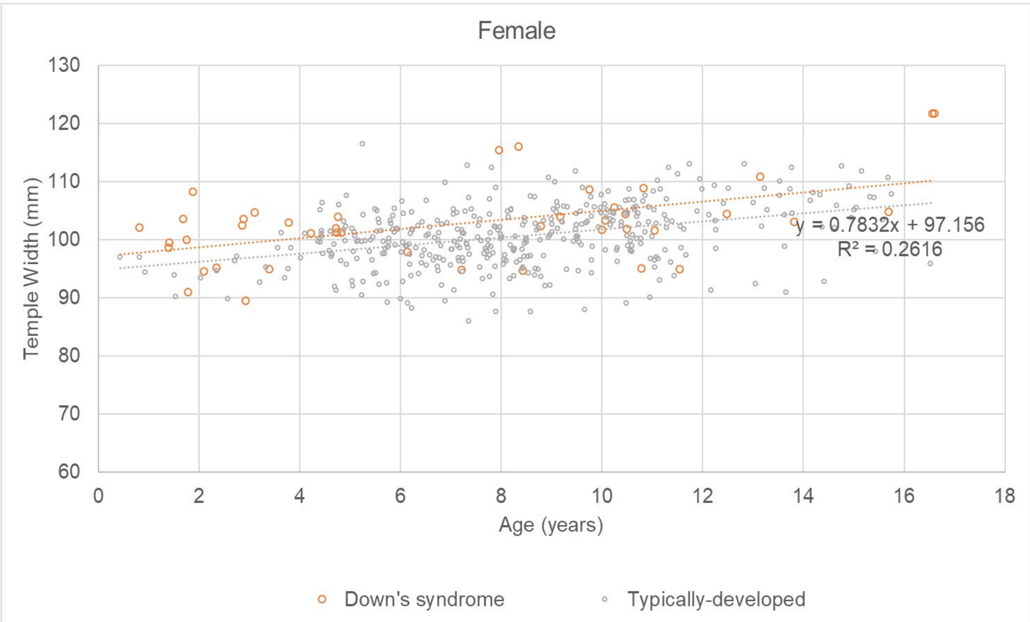


Figure 8.2d. Temple width results for White British children with Down's syndrome children overlaid on results for White British typically-developed children, showing measurements for both male and female subjects.

Down's syndrome

Distance Between Rims at 10mm Below Crest (DBR10)

<u>Landmarks involved:</u>

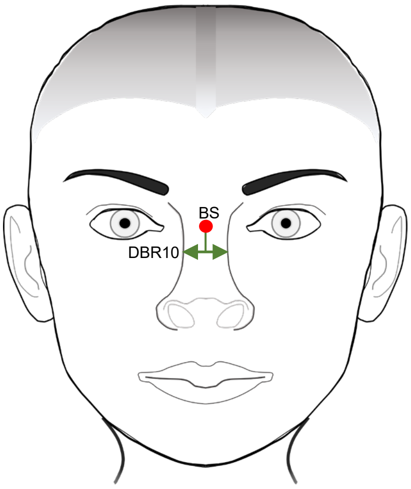
Bearing surface (BS).

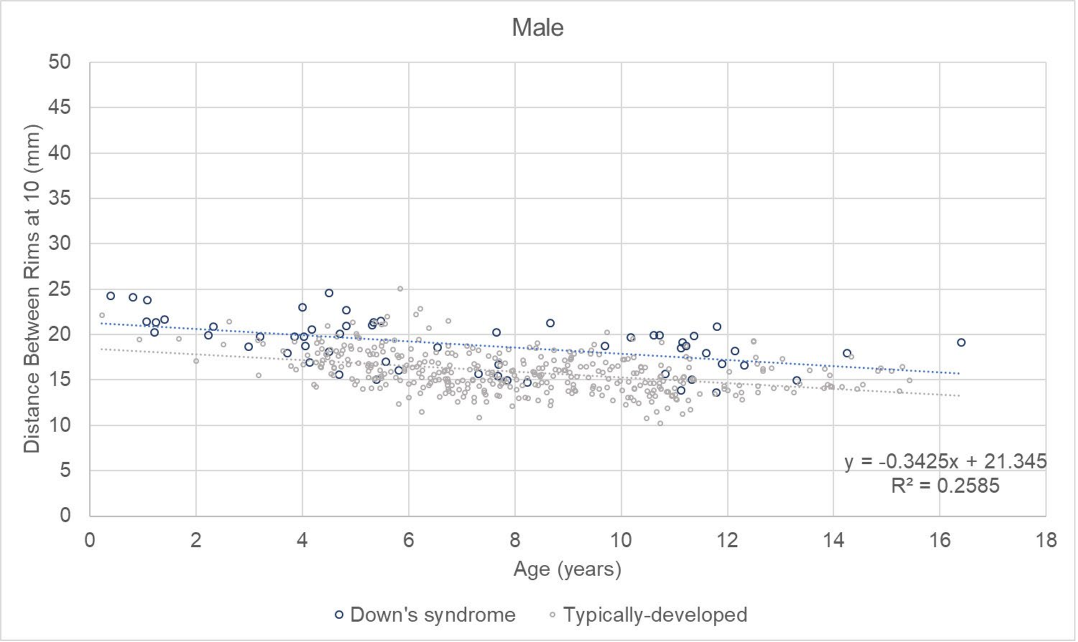
<u>Measurement definition:</u>

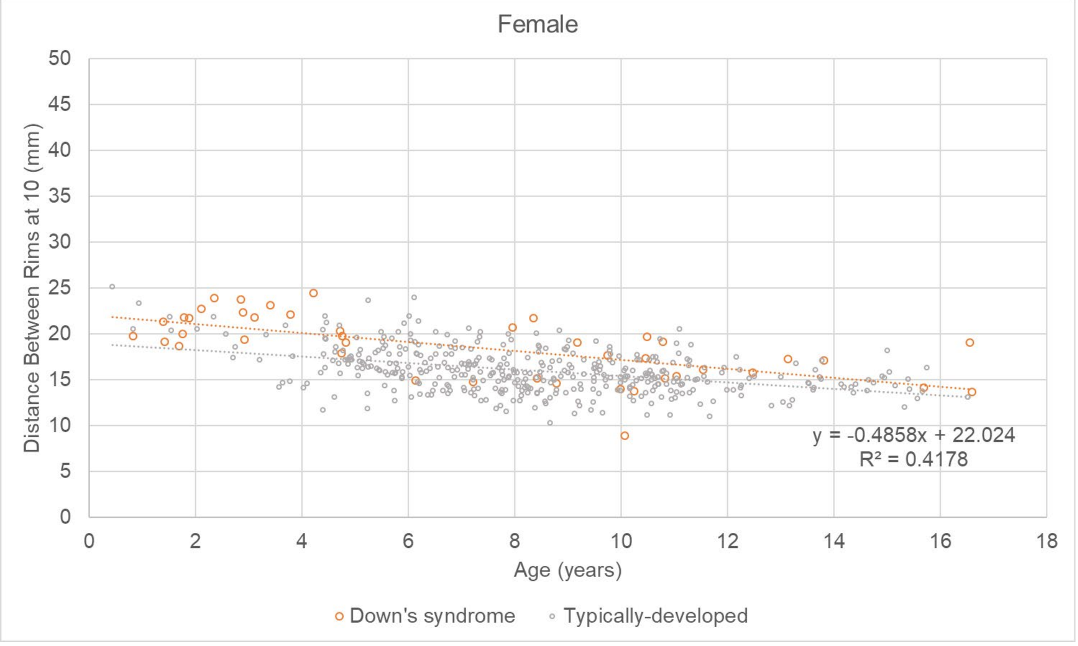
The width of the nose at a point 10mm below the crest (bearing surface).

<u>Measurement method:</u>

Automated nasal width calculated at a point 10mm below the bearing surface calculated by 3D stereophotogrammetry.







<u>Figure 8.2e</u>. Distance between rims at 10mm below crest results for White British children with Down's syndrome children overlaid on results for typically-developed White British children, showing measurements for both male and female subjects.

Down's syndrome

Distance Between Rims at 15mm Below Crest (DBR15)

Landmarks involved:

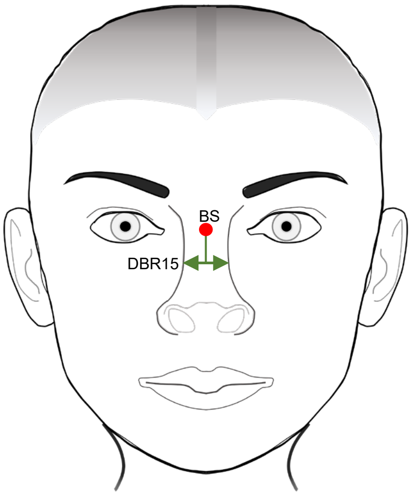
Bearing surface (BS).

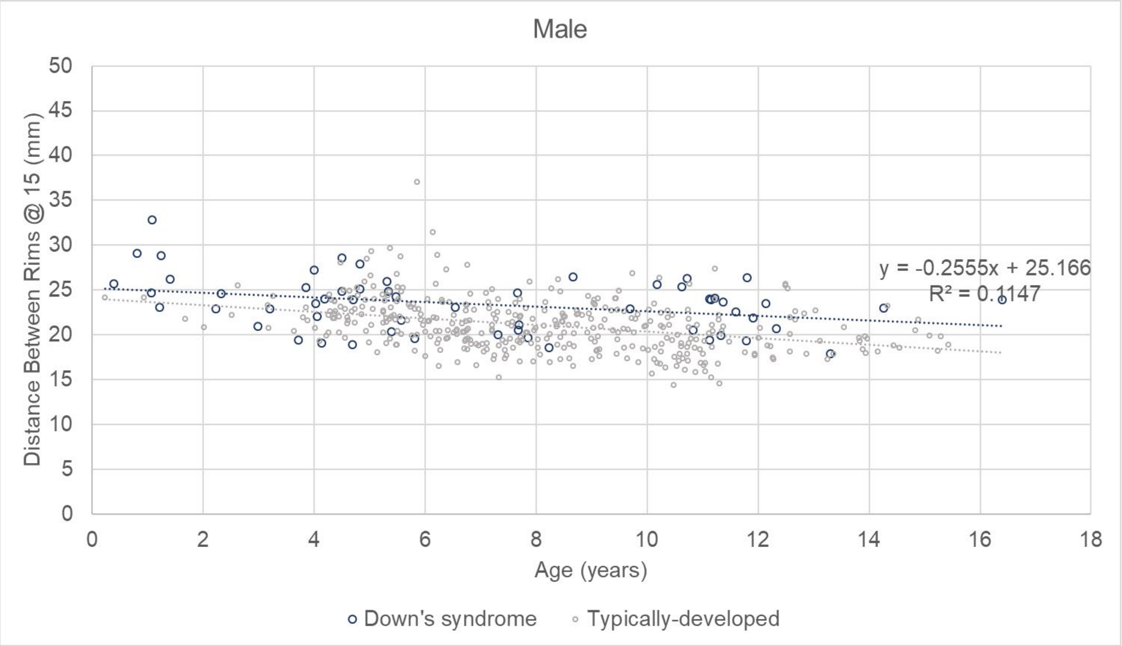
Measurement definition:

The width of the nose at a point 15mm below the crest (bearing surface).

Measurement method:

Automated nasal width calculated at a point 15mm below the bearing surface calculated by 3D stereophotogrammetry.





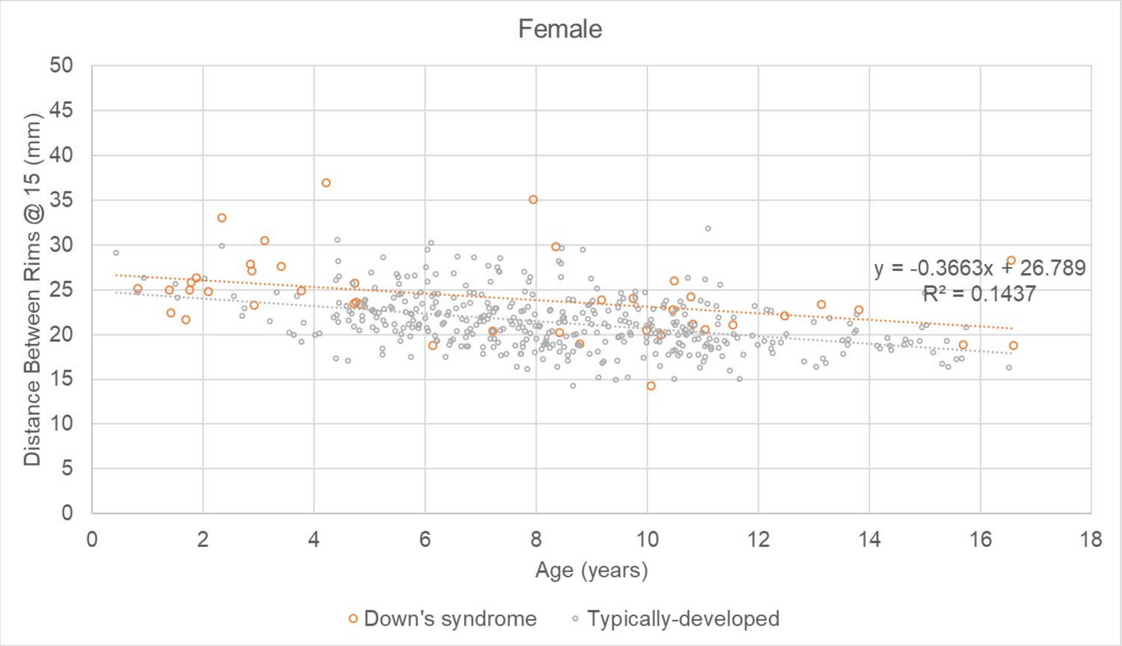


Figure 8.2f. Distance between rims at 15mm below crest results for White British children with Down's syndrome overlaid on results for typically-developed White British children, showing measurements for both male and female subjects

Down's syndrome

Apical Radius (AR)

Landmarks involved:

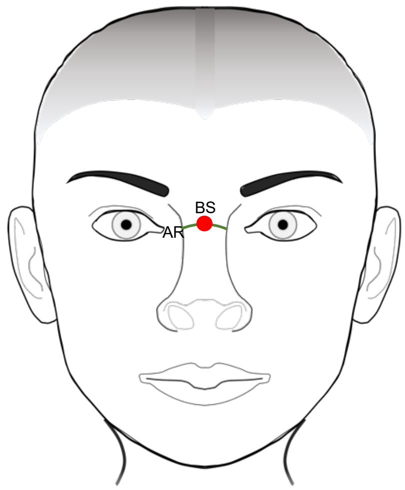
Bearing surface (BS).

Measurement definition:

The radius of the arc forming the lower edge of the bridge viewed perpendicularly to the back plane of the front.

Measurement method:

Automated radius calculated from the landmark by 3D stereophotogrammetry.



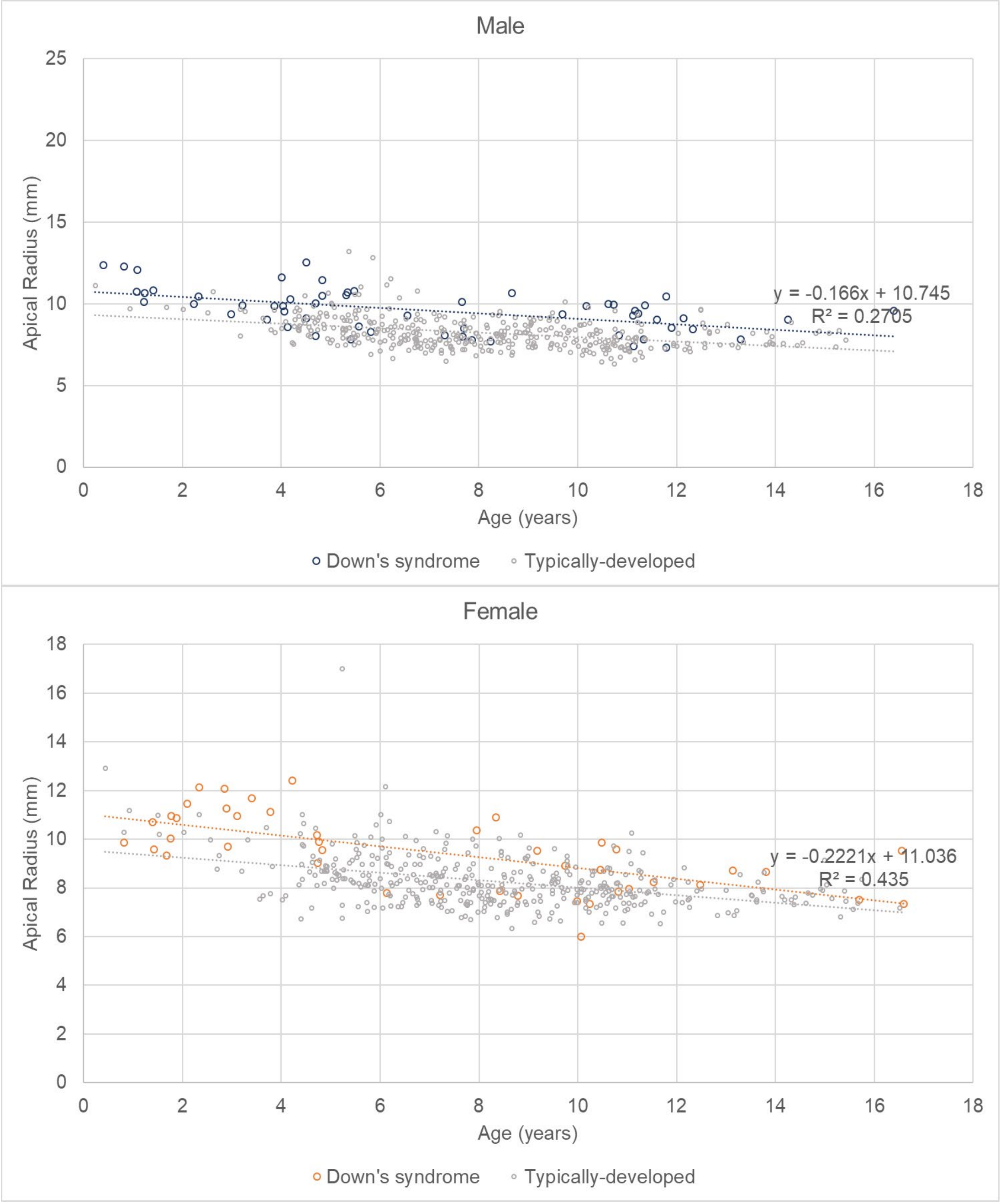


Figure 8.2g. Apical radius results for White British children with Down's syndrome overlaid on results for typically-developed White British children, showing measurements for both male and female subjects.

Down's syndrome

Crest Height (CH)

Landmarks involved:

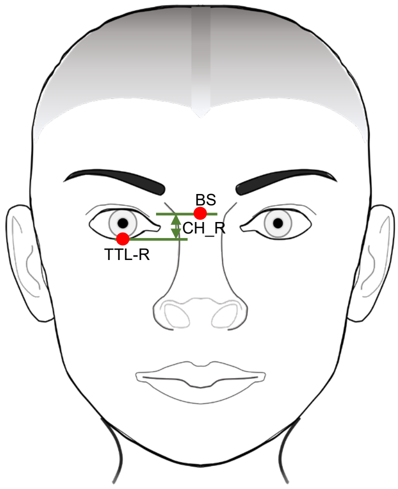
Bearing surface (BS) and top of lower lid right (TTL-R) for right crest height and bearing surface (BS) and top of the lower lid (left) for left crest height.

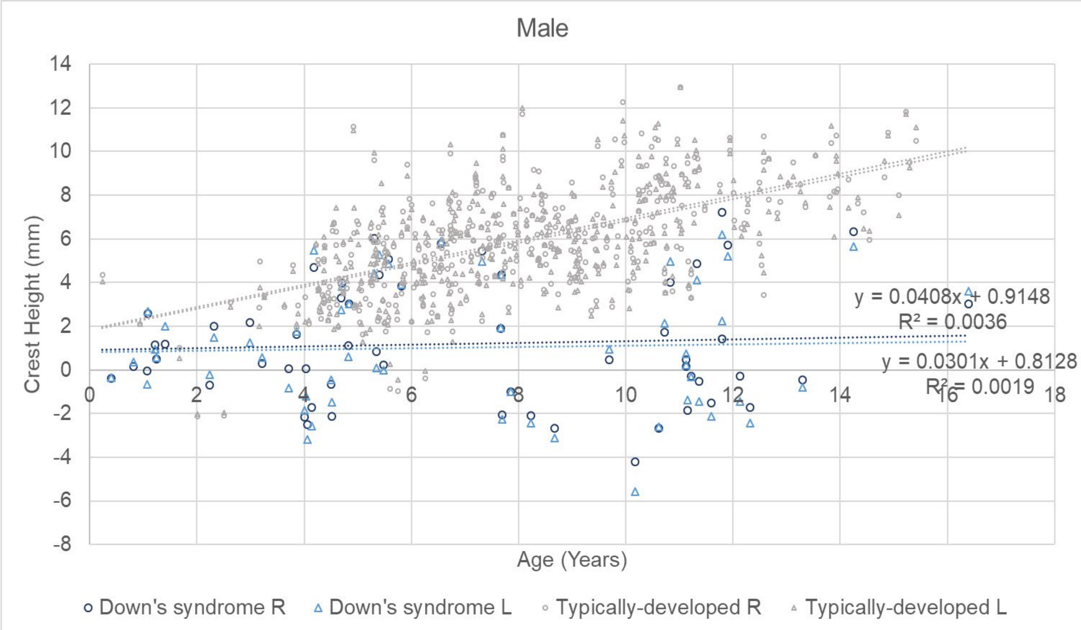
Measurement definition:

The vertical distance from the top of the lower lid to the crest (bearing surface) of the nose.

Measurement method:

Automated vertical height calculated between the landmarks by 3D stereophotogrammetry.





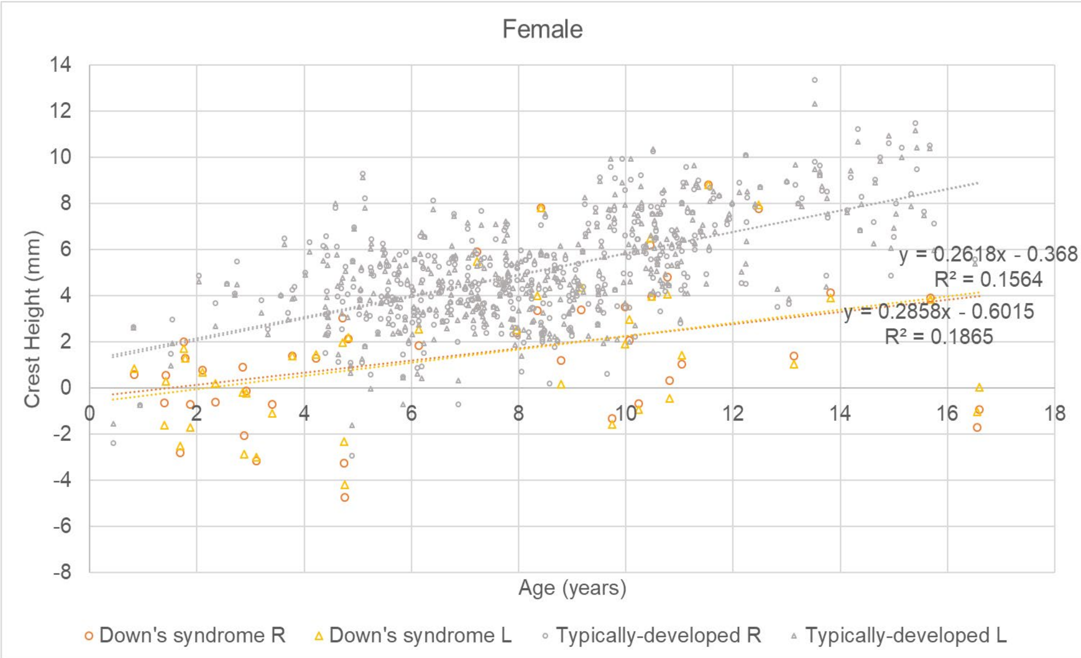


Figure 8.2h. Crest height results for White British children with Down's syndrome overlaid on results for typically-developed White British children, showing right and left measurements for both male and female subjects.

Down's syndrome

Front To Bend (FTB)

Landmarks involved:

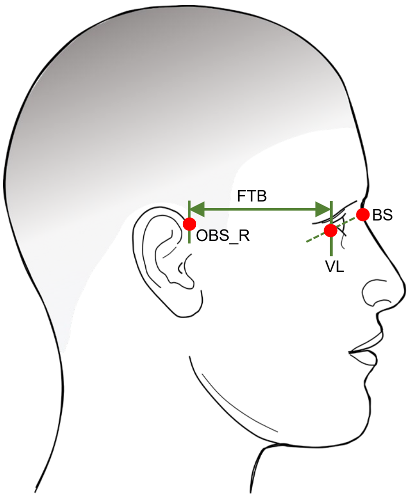
Bearing surface (BS) from which to extend a virtual frame front. Measured to otobasion superious right (OBS_R) for right front to bend and (OBS_L) for left front to bend.

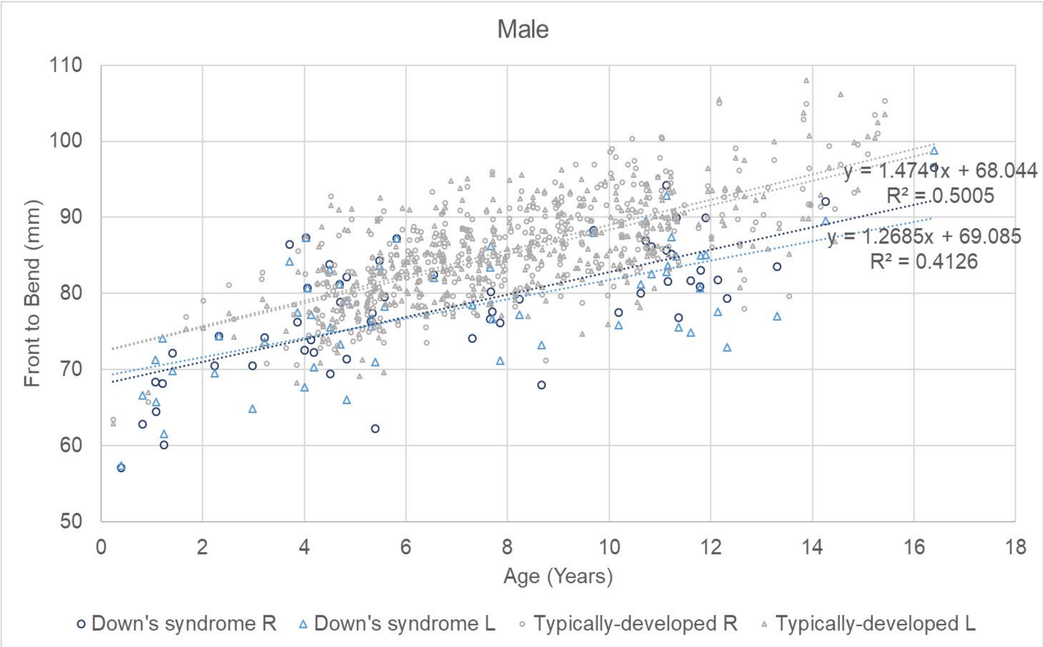
Measurement definition:

The distance between the lug point (point on the back surface of the lug where it begins its backward sweep) and the ear point.

Measurement method:

A virtual front extended from the bearing surface is created by the software, in order to calculate by 3D stereophotogrammetry the length from the virtual lug (VL) to the earpoint.





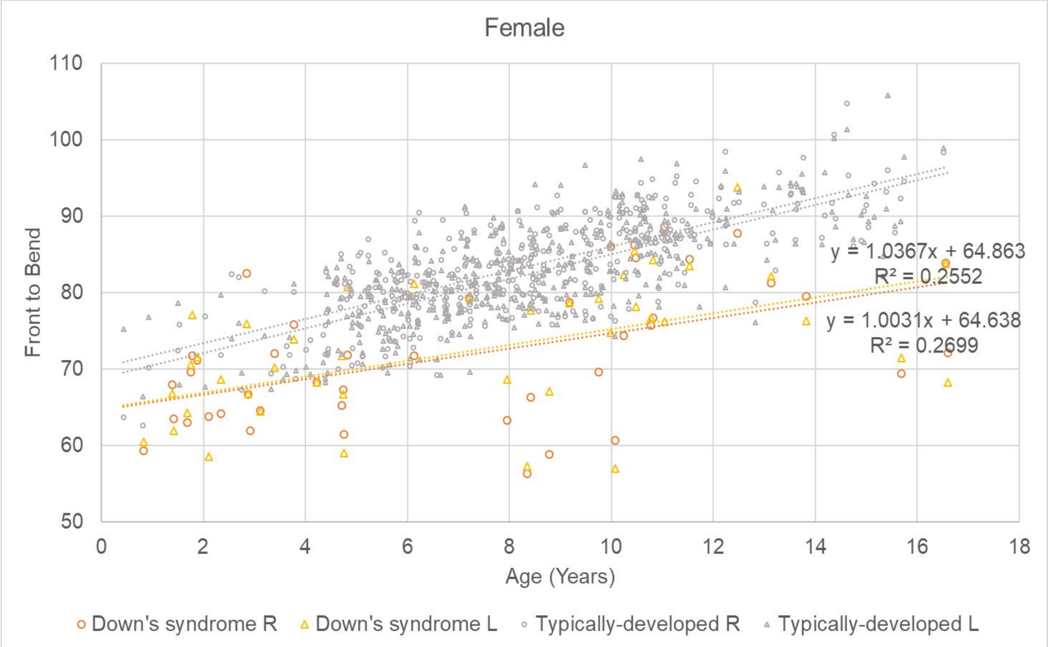


Figure 8.2i. Front to bend results for White British children with Down's syndrome overlaid on results for typically-developed White British children, showing right and left measurements for both male and female subjects.

Down’s syndrome

Distance Between Pad Centres (DBPC)

Landmarks involved:

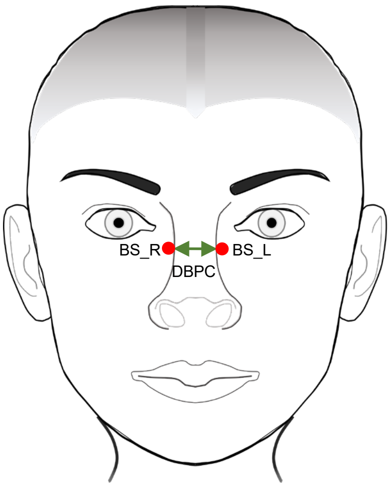
Bearing surface right (BS_R) and bearing surface left (BS_L).

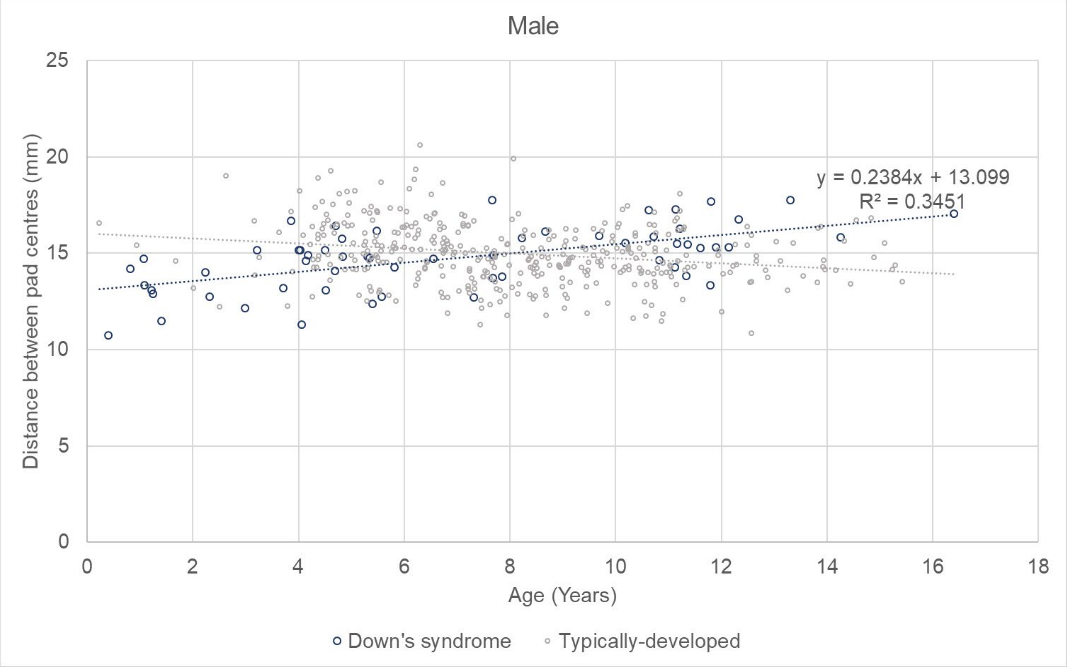
Measurement definition:

The width of the nose at the bearing surface points, hence where the pad of a frame would rest.

Measurement method:

Distance between landmarks calculated by 3D stereophotogrammetry.





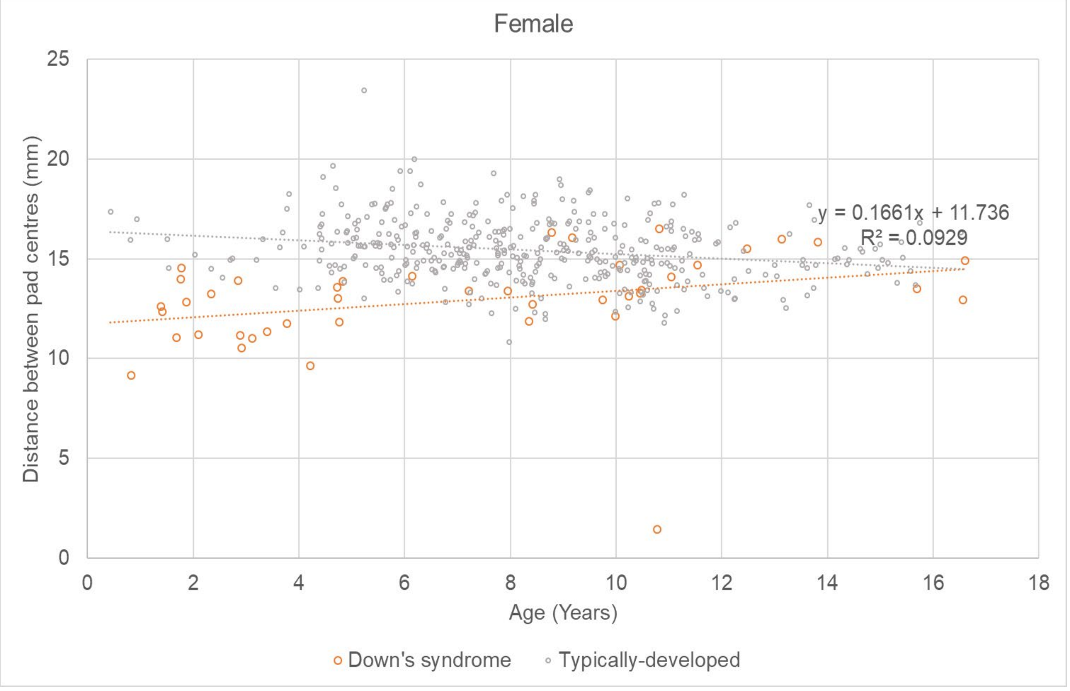


Figure 8.2j. Distance between pad centres results for White British children with Down’s syndrome overlaid on results for typically-developed White British children, showing measurements for both male and female subjects.

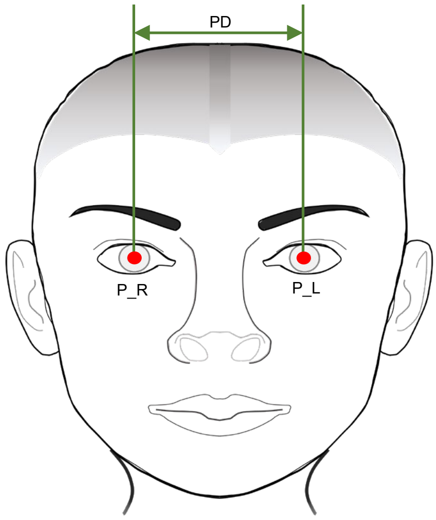
Down's syndrome

Pupillary Distance (PD)

Landmarks involved:
Pupil centre right (P_R) and pupil centre left (P_L).

Measurement definition:
The distance between the centres of the pupils when the eyes are in the primary position.

Measurement method:
Distance behind the two landmarks calculated by 3D stereophotogrammetry.



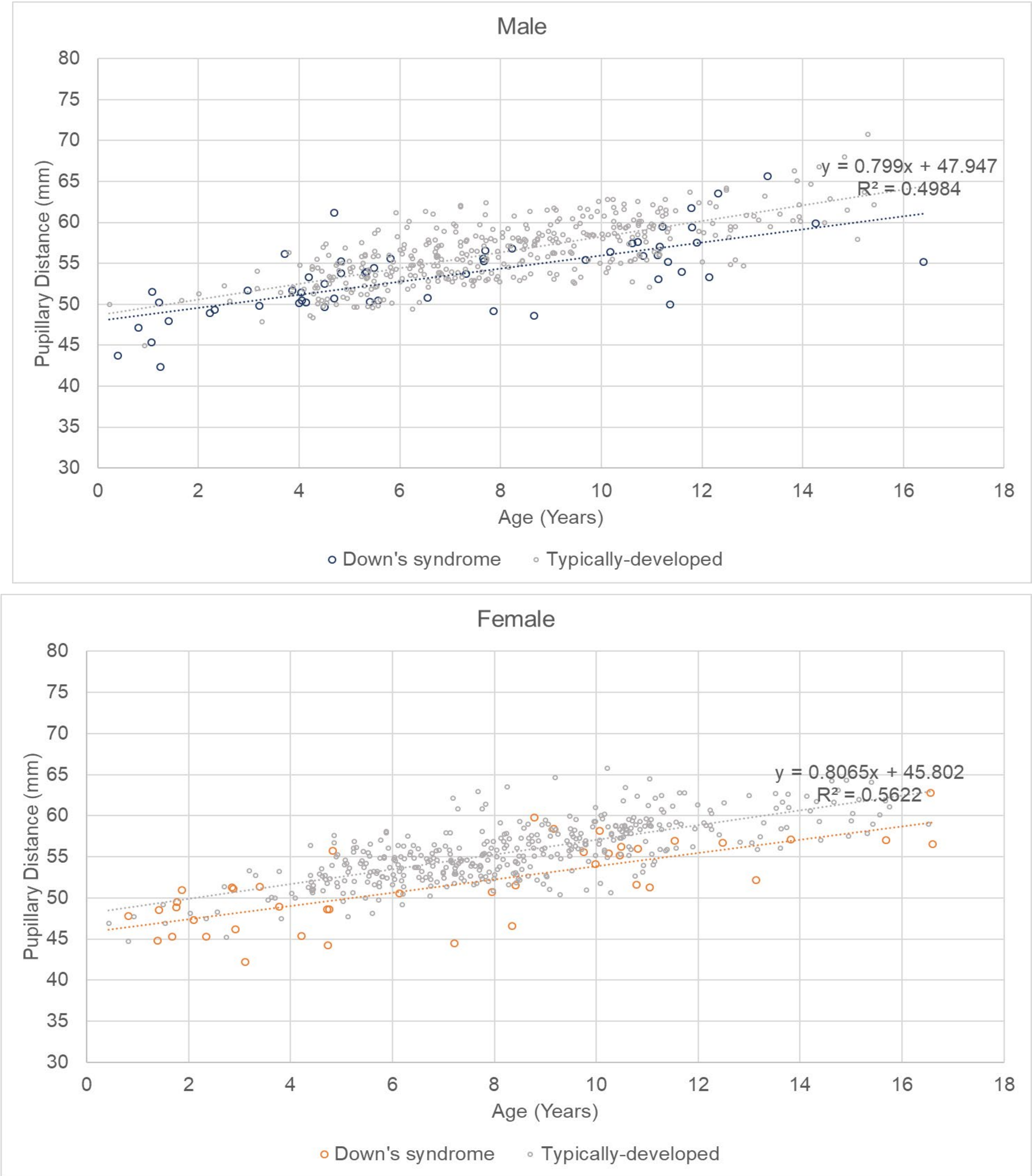


Figure 8.2k. Pupillary distance results for White British children with Down's syndrome overlaid on results for typically-developed White British children, showing measurements for both male and female subjects.

8.3 Linear regression analysis

Linear regression analysis using ANOVA and t-testing was carried out to determine the significance of the slope and whether there were differences between gender and right/left measures. Analysis of variance showed that a linear line of best fit described the dependence of each facial measurement parameter on age in both males and females (Table 8.3a). The results showed no statistically significant difference between any right or left facial measurements where relevant, or between male and female measurements.

Measurement	Proportion of variance accounted for by regression (co-efficient of determination, R^2, %	Is linear regression statistically significant (ANOVA)?	Is slope of regression statistically significant (t-test)?	Slope (SE)	Is there a statistically significant difference between the slopes of the male and female slopes	Is there a statistically significant difference between the slopes of the R and L eyes
FAR male FAR female	14.6 32.0	Yes ($F_{1,056}$=10, p=0.003) Yes ($F_{1,041}$=19, p<0.001)	Yes (t=-3.10, p=0.003) Yes (t=-4.39, p<0.001)	5.21 5.31	No (t_{97}=1.03, p=0.303)	
FAL male FAL female	14.4 36.4	Yes ($F_{1,056}$=10, p=0.003) Yes ($F_{1,041}$=23, p<0.001)	Yes (t=-3.07, p=0.003) Yes (t=-4.84, p<0.001)	5.69 4.71	No (t_{97}=1.18, p=0.241)	
FAR male FAL male						No (t_{112}=0.17, p=0.862)
FAR female FAL female						No (t_{82}=0.32, p=0.749)
SAR male SAR female	0.6 3.8	No ($F_{1,056}$=0.3, p=0.558) No ($F_{1,041}$=2, p=0.210)	No (t=0.59, p=0.558) No (t=1.28, p=0.210)	2.26 2.44	No (t_{97}=-0.55, p=0.581)	
SAL male SAL female	0.2 7.1	No ($F_{1,056}$=0.1, p=0.751) No ($F_{1,041}$=3, p=0.084)	No (t=0.32, p=0.751) No (t=1.77, p=0.084)	2.42 2.01	No (t_{97}=-0.91, p=0.367)	
SAR male SAL male						No (t_{112}=0.17, p=0.867)
SAR female SAL female						No (t_{82}=-0.14, p=0.889)
HW male HW female	56.7 60	Yes ($F_{1,056}$=73, p<0.001) Yes ($F_{1,041}$=62, p<0.001)	Yes (t=8.56, p<0.001) Yes (t=7.84, p<0.001)	7.14 5.65	No (t_{97}=1.70, p=0.092)	
TW male TW female	4.7 26.2	No ($F_{1,056}$=3, p=0.102) Yes ($F_{1,041}$=15, p<0.001)	No (t=1.66, p=0.102) Yes (t=3.81, p<0.001)	7.07 6.11	No (t_{97}=-1.29, p=0.201)	
DBR10 male DBR10 female	25.8 41.8	Yes ($F_{1,056}$=20, p<0.001) Yes ($F_{1,041}$=29, p<0.001)	Yes (t=-4.41, p<0.001) Yes (t=-5.42, p<0.001)	2.37 2.66	No (t_{97}=1.21, p=0.229)	

DBR15 male DBR15 female	11.5 14.4	Yes ($F_{1,056}$=7, p=0.009) Yes ($F_{1,041}$=7, p=0.012)	Yes (t=-2.70, p=0.009) Yes (t=-2.62, p=0.012)	2.90 4.15	No (t_{97}=0.66, p=0.513)	
AR male AR female	27.0 43.5	Yes ($F_{1,056}$=21, p<0.001) Yes ($F_{1,041}$=32, p<0.001)	Yes (t=-4.56, p<0.001) Yes (t=-5.62, p<0.001)	1.11 1.18	No (t_{97}=1.04, p=0.299)	
CHR male CHR female	0.4 15.6	No ($F_{1,056}$=0.2, p=0.654) Yes ($F_{1,041}$=8, p=0.009)	No (t=0.45, p=0.654) Yes (t=2.76, p=0.009)	2.76 2.82	No (t_{97}=-1.697, p=0.095)	
CHL male CHL female	0.2 18.6	No ($F_{1,056}$=7, p=0.748) Yes ($F_{1,041}$=9, p=0.004)	No (t=0.32, p=0.748) Yes (t=3.07, p=0.004)	2.85 2.77	No (t_{97}=-1.94, p=0.055)	
CHR male CHL male						No (t_{112}=0.08, p=0.935)
CHR female CHL female						No (t_{82}=-0.18, p=0.858)
FTBR male FTBR female	50.1 27	Yes ($F_{1,056}$=56, p<0.001) Yes ($F_{1,041}$=15, p<0.001)	Yes (t=7.49, p<0.001) Yes (t=3.89, p<0.001)	6.01 7.66	No (t_{97}=1.45, p=0.149)	
FTBL male FTBL female	41.3 25.5	Yes ($F_{1,056}$=39, p<0.001) Yes ($F_{1,041}$=14, p=0.001)	Yes (t=6.27, p<0.001) Yes (t=3.75, p=0.001)	6.18 8.23	No (t_{97}=0.68, p=0.500)	
FTBR male FTBL male						No (t_{112}=0.73, p=0.468)
FTBR female FTBL female						No (t_{82}=-0.09, p=0.930)
DBPC male DBPC female	34.5 9.3	Yes ($F_{1,056}$=30, p<0.001) Yes ($F_{1,041}$=4, p=0.047)	Yes (t=5.43, p<0.001) Yes (t=2.05, p=0.047)	1.34 2.41	No (t_{97}=0.92, p=0.358)	
PD male PD female	49.8 56.2	Yes ($F_{1,056}$=56, p<0.001) Yes ($F_{1,041}$=53, p<0.001)	Yes (t=7.46, p<0.001) Yes (t=7.26, p<0.001)	3.27 3.31	No (t_{97}=-0.05, p=0.961)	

Table 8.3a. Linear regression analysis for measurements plotted as a function of age, including comparison of the slopes for gender and right / left measurements where applicable.

	Is there a statistically significant difference between the slopes of White British typically-developed children and White British children with Down's syndrome?	
Measurement	Male	Female
Frontal angle (right)	No (t_{446}=1.90, p=0.058)	No (t_{448}=0.84, p=0.402)
Frontal angle (left)	No (t_{446}=1.80, p=0.073)	No (t_{448}=0.83, p=0.406)
Splay angle (right)	**Yes (t_{446}=3.61, p<0.001)**	**Yes (t_{448}=3.72, p<0.001)**
Splay angle (left)	**Yes (t_{446}=3.24, p=0.001)**	**Yes (t_{448}=4.08, p<0.001)**
Head width	No (t_{446}=0.45, p=0.655)	No (t_{448}=-1.13, p=0.261)
Temple width	No (t_{446}=-1.10, p=0.272)	No (t_{448}=0.40, p=0.688)
Distance between rims at 10 mm below crest	No (t_{446}=-0.28, p=0.780)	No (t_{448}=-1.37, p=0.173)
Distance between rims at 15mm below crest	No (t_{446}=1.08, p=0.280)	No (t_{448}=0.37, p=0.711)
Apical radius	No (t_{446}=-0.75, p=0.453)	No (t_{448}=-1.61, p=0.109)
Crest height (right)	**Yes (t_{446}=-4.81, p<0.001)**	**Yes (t_{448}=-2.00, p=0.046)**
Crest height (left)	**Yes (t_{446}=-4.75, p<0.001)**	No (t_{448}=-1.86, p=0.064)
Front to bend (right)	No (t_{446}=-0.86, p=0.390)	**Yes (t_{448}=-2.16, p=0.031)**
Front to bend (left)	No (t_{446}=-1.55, p=0.122)	**Yes (t_{448}=-2.04, p=0.042)**
Distance between pad centres	**Yes (t_{446}=7.09, p<0.001)**	**Yes (t_{448}=3.16, p=0.002)**
Pupillary distance	No (t_{446}=-1.38, p=0.169)	No (t_{448}=-0.75, p=0.457)

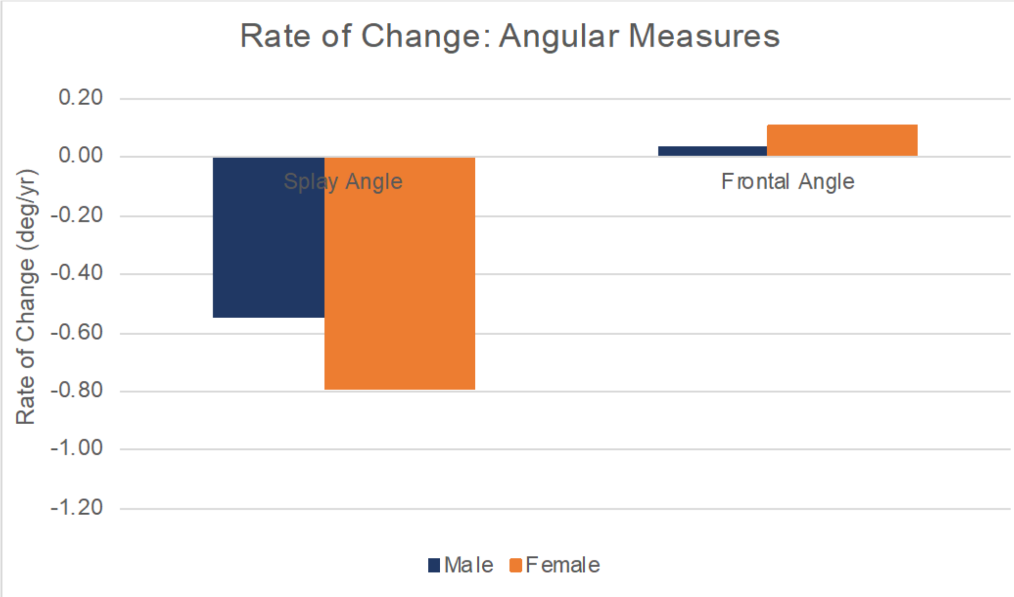
Table 8.3b. Comparison of slopes for White British children with Down's syndrome compared to typically-developed White British children.

The two slopes of these two independent samples were compared following null and alternative hypothesis using the SlopesTest function (https://www.real-statistics.com/regression/hypothesis-testing-significance-regression-line-slope/comparing-slopes-two-independent-samples/)

For angular measurements, the slopes for splay angles differ between the right and left measurements of typically-developed (TD) and children with Down's syndrome (DS) for both males and females. This difference was found to be statistically significant ($p \leq 0.001$).

For linear measurements, in female measurements only, front to bend showed a significant slope difference ($p=0.031$ right, $p=0.042$ left) between TD and DS White British children. For both male and females, the crest heights (right and left males, left females) and distance between pad centres also showed a significant difference ($p<0.001$ (males)).

As shown by the scatterplots 8.2.1-8.2.11, some facial measurements decreased and some increased with age. The gradient of the linear regression is a measure of rate of change in growth for a given facial parameter, summarised in Figure 8.3.



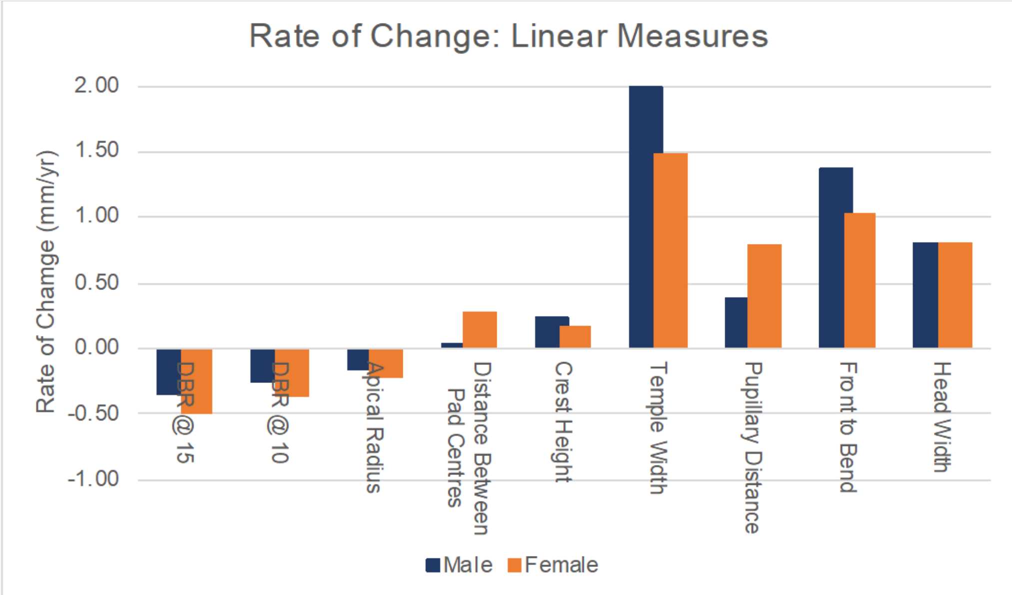


Figure 8.3c. Rate of change and growth direction in children with Down's syndrome of 'White British' ethnicity. A positive value indicates that the measurement is increasing in magnitude with increase in age. A negative value indicates that the measurement is decreasing in magnitude with increase in age.

It can be observed that the rate of change in growth is not the same for all measurements, indicating that the face and nose are changing shape as a child ages. Considering angular measures first, the splay angle changes at a different rate between males and females, decreasing by approximately 0.5 degrees per year in males and 0.8 degrees per year in females. This magnitude of difference was not observed in the TD group who showed that there was a decrease in splay angle of approximately 0.2 degrees per year (figure 6.3b). The frontal angle increases by approximately 0.1 degrees per year in females but hardly changes at all in males. These differences were not significant (p=0.058 (FAR male) compared to TD children despite a decrease shown in frontal angle of approximately 1 degree per year in TD children, there is little change in this measurement in children with DS.

For linear measurements, both distance between rims measurements and apical radius show a similar pattern of growth to the TD children, with all measurements decreasing by 0.2-0.5mm a year. Distance between pad centres increase slightly with a rate of change of less than 0.1mm per year in males and 0.3mm per year in females, this is in contrast to the *decrease* reported for the TD results of approximately 0.1mm per year (figure 6.3b). The crest height for children with DS increases at approximately 0.2mm which is less than half the rate (approximately 0.5mm) in comparison to TD children. Temple width shows the most significant growth in children with DS at a rate of 2mm per year (male) and 1.5mm (female), with head width achieving half this rate at approximately 0.8mm per year. This pattern of growth is opposite to that seen in TD children where head width achieves the most growth of approximately 1.75mm per year, compared to temple width of only 0.7mm (figure 6.3b). The front to bend measurement increases annually at a different rate between males at approximately 1.4mm, and females at approximately 1mm This gender difference was not observed in the TD group who showed an increase of just over 1.5mm per year at similar rates between males and females. Pupillary distance shows an annual increase of approximately 0.4mm (male), 0.75mm (female) which is less than the TD rate of change values at just under 1mm per year.

As expected from the data from Chapters 6 and 7, the rate of change in growth is not the same for all measurements, indicating that the face and nose are changing shape as a child ages. Measurements concerning the head itself such as head width, temple width, front to bend and pupillary distance changed at a much faster rate than measurements applied to the nose; an identical pattern to that found for TD children, albeit differing values between the two groups. There were some differences in rate of growth for males and females, but these were not statistically significant, in agreement with the TD results (table 8.3a).

8.4. Discussion

Children with Down's syndrome (DS) are reported to have a high (77%) prevalence of refractive error (Pueschel, 1987). In addition, 80% of children with DS are reported to have problems of reduced accommodation (Woodhouse et al., 1993b) which often requires a multifocal lens to be dispensed. Therefore, it is imperative that this group of children have spectacle frames available to them that cover the same basic requirements as all other children requiring refractive correction, such as frame stability, (especially important for multifocal lens positioning), safety, durability, comfort and a cosmetically-appealing design.

Children with Down's syndrome (DS) do not grow at the same rate compared to typically-developed (TD) children and therefore the World Health Organisation growth charts are not suitable for tracking growth for these children. Children with DS are at an increased risk of additional medical conditions, such as congenital heart disease and thyroid disfunction, which may impact on body growth (Van Gameren-Oosterom et al., 2012) and therefore charting growth, or indeed a lack of growth, can be a useful indicator to trigger further and earlier investigation. A separate chart for children with DS was devised in 2011 as a joint project with the RCPCH and the UK Down's Syndrome Medical Interest Group (DSMIG). Data for these charts was based on the work of Styles et al. (2002) who retrospectively collected measurements from 1089 records of children with DS aged under 19 years, from 15 areas of the United Kingdom, including one in the Republic of Ireland. These special charts are designed to factor in that most children with DS are born prematurely and general growth often follows a different pattern of more prolonged spurts and plateaus when compared to TD children (Down's Syndrome Medical Interest Group, 2011, Styles et al., 2002). This pattern is described as a slower growth period during the first three years of life, and a further relatively slower period after the age of 12 years in both girls and boys (Van Gameren-Oosterom et al., 2012, Cronk et al., 1988). The period of growth between 3-12 years was also found to be reduced, albeit less severely for girls compared to boys with DS (Cronk et al., 1988).

Generally, craniofacial measurements are relatively smaller in children with DS except for the facial breadth (Korayem and AlKofide, 2014, Alio et al., 2011, Asha et al., 2011, Sforza et al., 2004) with a skull length larger than that of the width giving rise to the brachycephalic description.

Children with DS tend to have a shortened nasal prominence, or even an absent nasal bone giving rise to the 'saddle-shaped' nose (Sperber et al., 2010) in which the maxilla produces a distinct hypoplastic appearance (Alio et al., 2011, Ferrario et al., 2004, Kolar and Salter, 1997). This nasal profile is evident in the results found in this study where very little angular change occurs to the relatively flat, wide appearance of the nose in both the frontal and sagittal planes across this age band. The frontal angle (figure 8.2a) results show a significantly larger angle for both males (mean FAR 61.83 (5.59)) and females (mean FAR 64.43 (6.36)) when compared to the data for TD children (mean FAR 55.69 (5.22)), and females (mean FAR 54.95 (5.40)), yet with a relatively similar spread of data; SE=5.21(male R), SE= 4.71 (female L), and no significant difference between the slopes. Splay angle measurements showed similar results to the TD children but yielded a much smaller spread of data (SE=2.26 (male R); SE=2.01 (female L)) in comparison to the TD children. The majority of means for both TD and DS fell into a range of 25-29 degrees. Both the frontal and splay angles decrease linearly with age ($p>0.05$) in males and females. Analysis of variance showed that there was no significant difference between either the right and left frontal or splay angles (table 8.3a), indicating the rate of change is fairly static. There was a significant difference detected in slopes for crest height right (t_{446}=-4.81, p<0.001 (male), (t_{448}=-2.00, p=0.046 (female)) and crest height left for males (t_{446}=-4.75, p<0.001) indicating that the regression slope is significantly different between TD and children with DS (table 8.3b).

There is a dearth of literature in this area but a significant study of facial parameters for spectacle wear was carried out by Woodhouse et al. (1993a) using a customised manually applied measurement gauge to assess the frontal and splay angles on 20 children with DS aged between 3.6-14.4 years. The gauge was limited to assessing three frontal angles, 25, 30 and 35 degrees. The results concluded that the frontal angle was smaller than the typically-developed mean in 14 out of 20 children, contrasting to this study's findings where the frontal angle mean is greater than 60 degrees and almost 10 degrees larger than found in TD children. The difference between results could be due to both sample size differences and limitations of where the gauge used by Woodhouse et al was placed on the under-developed bridge, as it is difficult to locate a bearing surface and consider the contact line at which the pad would sit on either a pads on arms or fixed pad bridge frame. For splay angle, this study found no significant difference in values between the two groups of children and yet Woodhouse et al. (1993a) found this parameter to be larger overall (approximate mean 35 degrees) in children with DS using a gauge with four cut out angles representing 20,25,35, and 40 degrees.

For linear facial measurements, distance between rims (DBR), distance between pad centres (DBPC) and the apical radius (AR) all decrease linearly with age (p<0.05) in males and females. These facial measurements are all measured in the same frontal plane as the frontal angle and therefore, with this angle remaining relatively large with little suggested change as the child ages, it follows that these linear measurements will also remain almost constant, i.e. only showing a very small decrease/increase in numerical value. Distance between rims measurements determines nasal width values at two points below the crest and these show a small (<0.5mm per year) decrease in value similar to that of the TD data. Overall, the values are larger, as expected, depicting the wider nasal form of a child with DS. In comparison with the study results by Woodhouse et al. (1993a), the values for DBR at 10mm below, (no measurement at 15mm below was taken) there was agreement on the small decrease with age, and the mean values for each age group (approximately 18mm) equate to the mean values 18.96 (2.73) mm for males and 18.56 (3.45) mm for females. In this study, the distance between pad centres increases slightly with age, and at a higher rate for girls, but still at just over 0.25mm per year. This is in contrast to the growth pattern for TD children where the narrowing of the nasal form shows a decrease in value of the DBPC with age. There was a difference detected in slopes for both male and female DBPC ((t_{446}=7.09, $p<0.001$) (DBPC male)) indicating that the regression slope is significantly different between TD and children with DS (table 8.3b). There is no data in the literature to compare this measurement with for children with DS. Distance between pad centres showed very little change as a function of growth and since it is placed in a position where the pads of the spectacle frame would be expected to sit, it is much more difficult to place a landmark where the position is ill-defined compared to a more prominent, developed nasal form. The potential difficulty in location of this landmark can be evidenced in section 4.5 where the mean difference between the two observers (AT-RC) for this measurement was -1.04 (0.84) mm. The apical radius also shows very little change as a function of age with a decrease of less than 0.25mm per year which is in agreement with the Woodhouse et al. (1993a) study. The gauge used for this measurement ranged from 5-10mm and reported that this did not prove to be a limitation, concluding that children with DS have a smaller apical radius in comparison to TD children. These findings are at variance with those of the current study which shows many children having a relatively larger apical radius (figure 8.2g) of over 10mm (mean female 9.45 (1.55) mm) which follows the flat, wide sagittal profile of the nose. The greater sample size of this study in comparison with Woodhouse et al may have elicited this difference. Distance between rims at 10mm and 15mm below crest, distance between pad centres and apical radius show a larger annual change in female subjects. In comparison of male to female data, more of the variance was associated with DBR10; 25.8% (male) and 41.8% (female), DBR15; 11.5% (male) and 14.4% (female), AR; 27% (male), 43.5%(female) and DBPC; 34.5% (male), 9.3% (female) could be explained by its linear relationship with age.

As the crest of the nose emerges, it is expected that the position of the crest (crest height) will naturally take on a more superior position in relation to the lower lid. Consequently this research has found a small but positive growth of >+0.25mm per year which is half the rate of change +0.50mm per year observed in the TD data. For this measurement, Woodhouse et al. (1993a) used a transparent gauge marked with 2mm intervals capable of measuring crest heights between ±4mm to visually assess crest height on the same eye level as the child. The findings reported a significantly lower crest heights with negative values which concurs with the findings of this study. The crest height is lower in children with DS which particularly contrasts with the findings in TD children (figure 8.2h). The rapid emergence of the crest is not apparent in children with DS, especially in males, where the majority of crest height measurements have a negative value across all age groups. This can be explained by the aforementioned midface hypoplasia often found in children with DS (Ferrario et al., 2004) coupled with slow facial growth, (Van Gameren-Oosterom et al., 2012) more apparent in males (Cronk et al., 1988). The crest height was found to increase linearly with age ($p<0.05$) in females but not in males ($p=0.654$ CHR male) and that there was no difference between the slopes of the genders (table 8.3b), indicating that the rate of change is equal across the sexes. Compared to TD data, much lower values 0.4% (male CHR) 15.6% (female CHR) of the variance associated with the crest height could be explained by its linear relationship with age. There was a difference detected in slopes for both male and female crest height right and male crest height left ($t_{446}=-4.81$, $p<0.001$ (CHR male)) indicating that the regression slope is significantly different between TD and children with DS (table 8.3b).

In the transverse plane, the largest rate of growth is shown by the temple width, increasing at 2mm per year for males and 1.5mm per year for females (figure 8.3c), although the spread of data (SE=7.07 (male)) is much wider for this parameter than for TD children. The relatively larger temple width in DS is in agreement with the results found using callipers by Woodhouse et al. (1993a) although the mean measurements found in that study appear to be slightly larger (approx. 110mm) in comparison to the current study at 102.74mm (SD 7.03) (female mean), this is possibly due to manual calliper placement and this was noted as a potential limitation as the children did not enjoy this particular measurement. For head width, annual growth is less than the temple width at a reported rate of 0.75 mm per year, which illustrates that growth is not proportionate across the head in the transverse plane. The head width rate of change is less than half that of TD, with smaller mean values reported for children with DS; male mean 141.26mm (SD 10.75) compared to TD male mean 149.15mm (SD 8.70). From the head width scatterplots (figure 8.2c), female children with DS had respectively larger head widths than males in the early years which then grew at a slower rate than TD children especially in female subjects giving an overall smaller mean value for DS compared to TD children. These findings are concordant with those of Woodhouse et al. (1993a) as it was noted in that study that their youngest age group had a significantly larger head width and a smaller head width in the older group. In comparison of male to female data, more of the variance was associated with females for temple width 4.7% (male) and 26.2% (female), and for head width 56.7% (male) and 60% (female) could be explained by its linear relationship with age.

This research has shown that pupillary distances are generally smaller in children with DS than TD children (figure 8.2k) and this value does increase linearly with age ($p<0.001$). Girls have twice the annual growth at 0.75mm per year compared to boys which may be explained by the fact that the lack of growth during the period of 3-12 years was less severe in girls than boys (Cronk et al., 1988), potentially due to the fact that girls are reported to develop earlier than boys (Sforza et al., 2011, Mori et al., 2005, Ferrario et al., 1999). Relatively smaller pupillary distances were also reported by Woodhouse et al.

(1993a) in the age group of children with DS aged 9-14 years. This could also be due to the faster growth reported in TD children and this parameter then exceeding the values for children with DS. In comparison of male to female data, more of the variance was associated with females for pupillary distance 49.8% (male) and 56.2% (female) could be explained by its linear relationship with age.

Perpendicular to the HW, TW and PD, in the frontal plane, the front to bend (FTB) parameter exhibited an annual growth at 1.4mm (males) and 1mm (females) per year indicating a more rapid expansion of the head in the frontal plane for males. Front to bend showed scatterplots with generally shorter FTB values in DS than in the TD data (figure 8.2i) with no significant difference in slopes between right and left measurements (table 8.3a). The mean values show the children with DS have FTB measurements 7.5mm shorter for males and over 10mm shorter for females in comparison to TD children. These findings concur with Woodhouse et al. (1993a) who reported shorter length to bends across all age groups. Males show a definite faster annual growth in the temple width (sagittal plane) and the front to bend (frontal plane) when compared to females.

To summarise, compared with typically-developed children, children with Down's syndrome show the following differences in facial measurement parameters:

- Larger frontal angle
- Larger DBR
- Larger apical radius
- Lower crest height (which is often negative)
- Larger temple width
- Larger head width in younger years, then smaller in comparison with older children
- Smaller pupillary distance
- Shorter front to bend

This research has shown that facial growth in children with Down's syndrome is more associated with cranial changes than with the emergence of a nasal bearing surface and subsequent narrowing of nasal parameters. It appears that these changes take place over a much longer growing period compared to typically-developed children. These findings have implications for the design of children's spectacle frames as general children's frames are unlikely to provide a good fit. There is a need to provide variations in frame design capable of adjustment in all fitting parameters to suit the facial parameters of children with Down's syndrome, who are not wholly larger or smaller in comparison to typically-developed children This will be explored in greater detail in Chapter 10.

Chapter 9 Facial anthropometry in children of differing ethnicities.

9.1 Introduction and methods

Data was acquired using the method described in section 2.6 with 82 images acquired in the ‘typically-developed ethnic group’ and 41 images acquired in the ‘ethnic group with DS’. Images were collected from a variety of settings across the United Kingdom (section 2.5) including, schools, charitable organisations and children’s groups. Ethnicity was captured on the parental consent form using recommended ethnic group descriptors (Office for National Statistics, 2015).

In order to attempt to describe any remarkable facial characteristics in the variety of ethnicities, it was felt necessary to narrow the number of groups into similar ethnicities. Table 9.1a shows the 6 group names and ethnicities included in each group for the purposes of presenting data for description in this study.

Group name	Black	South Asian	White Chinese	Continental European	Chinese	Mixed multiple ethnicities
Ethnicities	White and Black Caribbean White and Black African Black British Black Caribbean African-Caribbean	Indian White Asian Pakistani	White Chinese	White Polish Bulgarian Polish Portuguese Norwegian	Chinese (DS Only) White Chinese	Mixed multiple ethnicities (DS only)

Table 9.1a. Ethnicities of children grouped into six categories

	Typically-developed	Down's syndrome
Black	22	14
South Asian	35	12
White Chinese	10	2 (Chinese)
Continental Europe	15	7
Mixed multiple ethnicities	0	3
White American	0	1
Russian	0	1
Prefer not to say	0	1
Totals	82	41

Table 9.1b. Numbers of subjects for each ethnic group in typically-developed children and children with Down's syndrome

9.2 Results from typically-developed children from different ethnicities

Because of the low numbers in these ethnic groups statistical analyses would not have enough power to examine differences. Therefore, the data was evaluated qualitatively using either the 'typically-developed White British' or 'White British children with Down's syndrome' datasets for comparison. Male and female values are pooled for this descriptive analysis.

Typically-developed ethnic group

Frontal Angle (FA)

<u>Landmarks involved:</u>

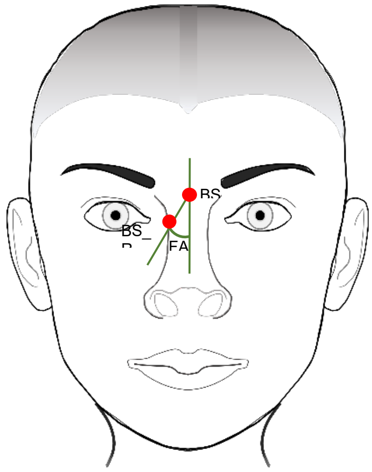
Bearing surface (BS) and bearing surface right (BS_R) for right frontal angle (as shown in schematic diagram) and bearing surface and bearing surface left (BS_L) for left frontal angle.

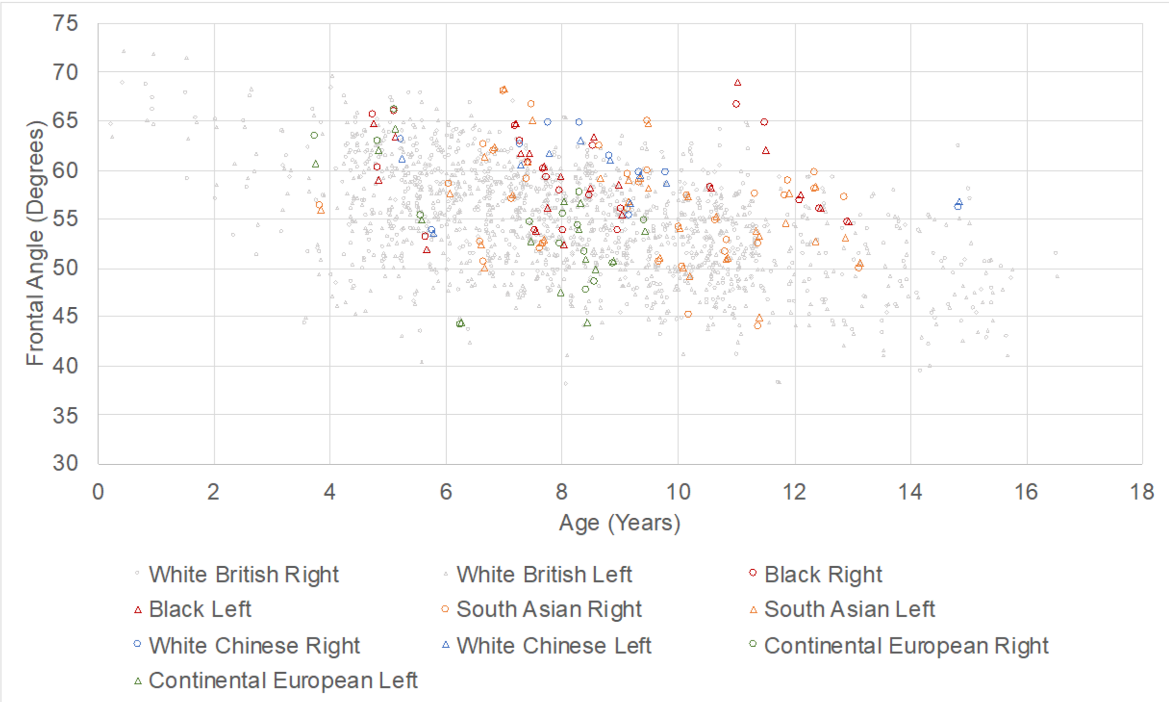
<u>Measurement definition:</u>

The angle between the vertical and the line of intersection of the pad plane with the back plane of the front, taken in the lateral plane.

<u>Measurement method:</u>

Angle between the landmarks calculated by 3D stereophotogrammetry.





<u>Figure 9.2a.</u> Frontal angle results for all ethnic typically-developed children showing right and left measurements overlaid on White British results.

There was a similar spread of values for South Asian and Continental Europe when compared to the White British however, a larger value for the White Chinese and Black groups.

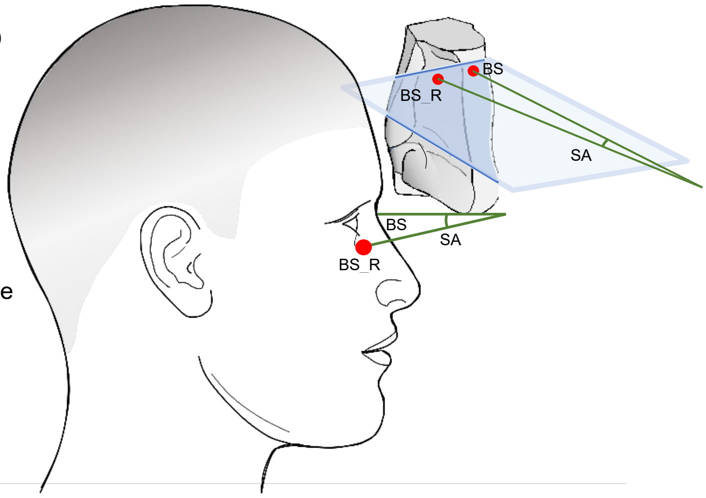
Typically-developed ethnic group

Splay Angle (SA)

<u>Landmarks involved:</u>
Bearing surface (BS) and bearing surface right (BS_R) for right splay angle and bearing surface (BS) and bearing surface left (BS-L) for left splay angle.

<u>Measurement definition:</u>
The angle between the pad plane and a normal to the back plane of the spectacle front, taken in the transverse plane.

<u>Measurement method:</u>
Angle between the landmarks calculated by 3D stereophotogrammetry.



<u>Figure 9.2b.</u> Splay angle results for all ethnic typically-developed children showing right and left measurements overlaid on White British results.

The splay angle was similar to the White British group for all ethnic groups except Black where the angle appeared to be larger. The White Chinese results appear to agree with the earlier results for Chinese children (section 7.3) where both the frontal and splay angle were reported to be larger.

Typically-developed ethnic group

Head width (HW)

Landmarks involved:

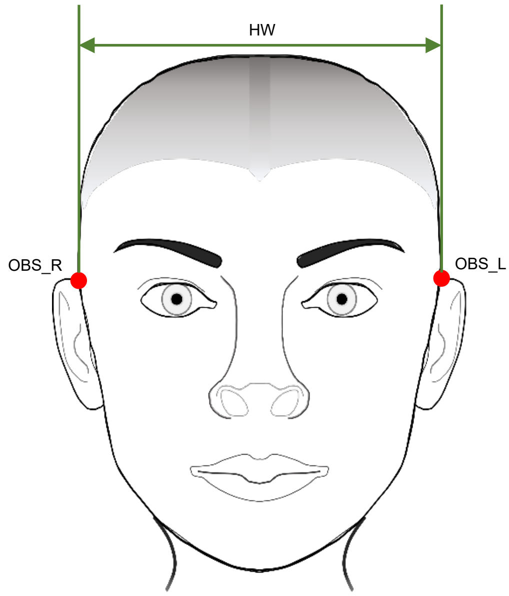
Otobasion superious right (OBS_R) and left (OBS_L).

Measurement definition:

The distance between the two ear points.

Measurement method:

Linear distance between the landmarks calculated by 3D stereophotogrammetry.



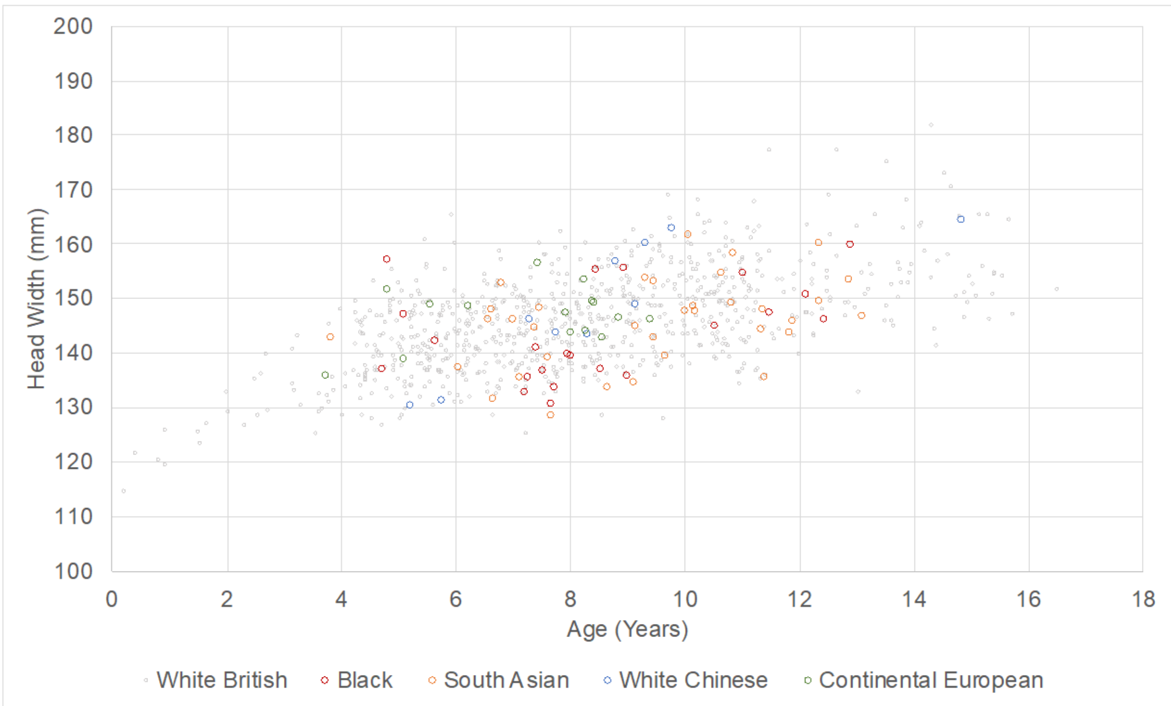


Figure 9.2c. Head width results for all ethnic typically-developed children overlaid on White British results.

All ethnic group measurements fell within the range encountered in typically developed White British children, although data for the Black group fell almost exclusively in the lower range of the data.

Typically-developed ethnic group

Temple width (TW)

<u>Landmarks involved:</u>

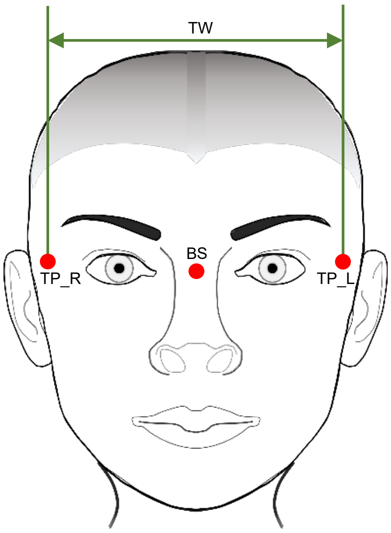
Bearing surface (BS) and temple points right (TP_R) and left (TP_L).

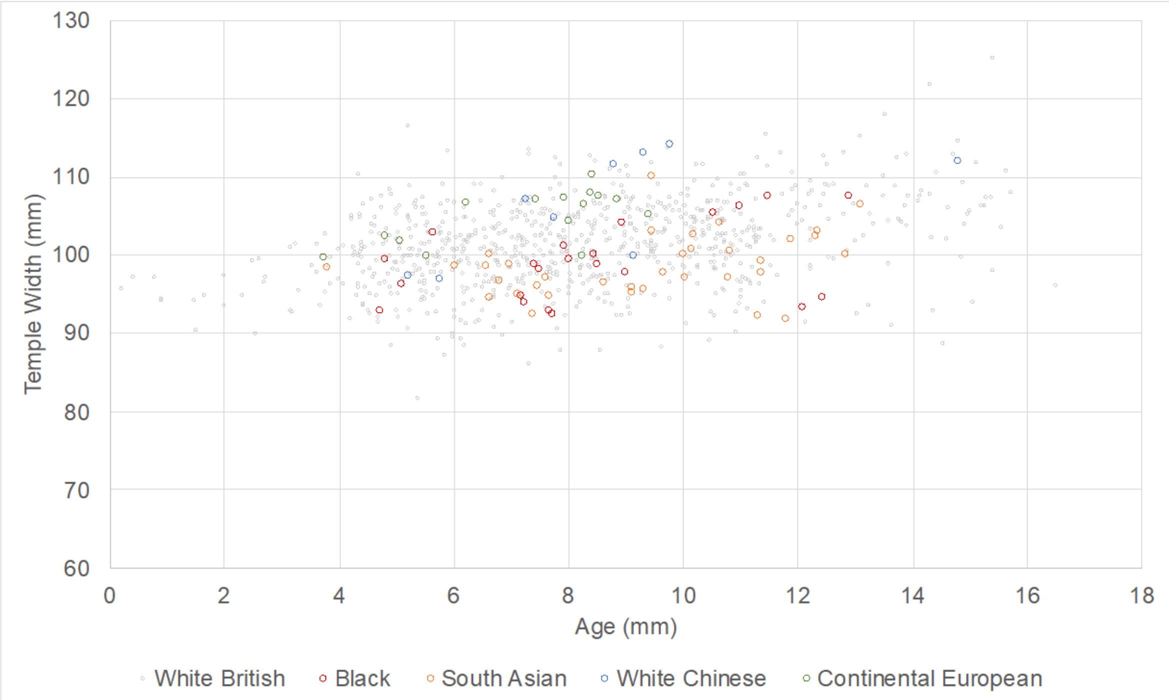
<u>Measurement definition:</u>

The distance between the two temple points at a distance of 25mm behind the back plane of a spectacle front.

<u>Measurement method:</u>

The position of the bearing surface enables the programme to create a virtual frame front in order to generate the temple points at the correct distance behind the front and measure the distance between the landmarks calculated by 3D stereophotogrammetry.





<u>Figure 9.2d.</u> Temple width results for all ethnic typically-developed children overlaid on White British results.

As found in head width, all ethnic group measurements fell within the range encountered in typically developed White British children, although data for the Black and South Asian groups, the measurements fell almost exclusively in the lower range of the data.

Typically-developed ethnic group

Distance Between Rims at 10mm Below Crest (DBR10)

Landmarks involved:

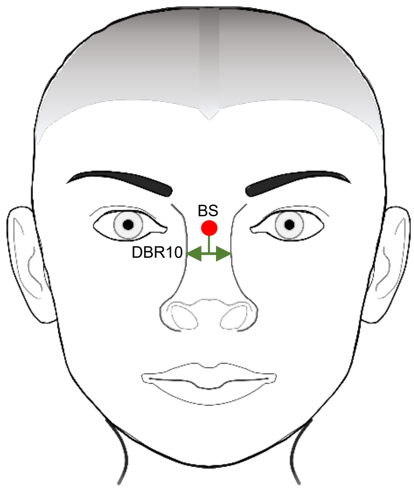
Bearing surface (BS).

Measurement definition:

The width of the nose at a point 10mm below the crest (bearing surface).

Measurement method:

Automated nasal width calculated at a point 10mm below the bearing surface calculated by 3D stereophotogrammetry.



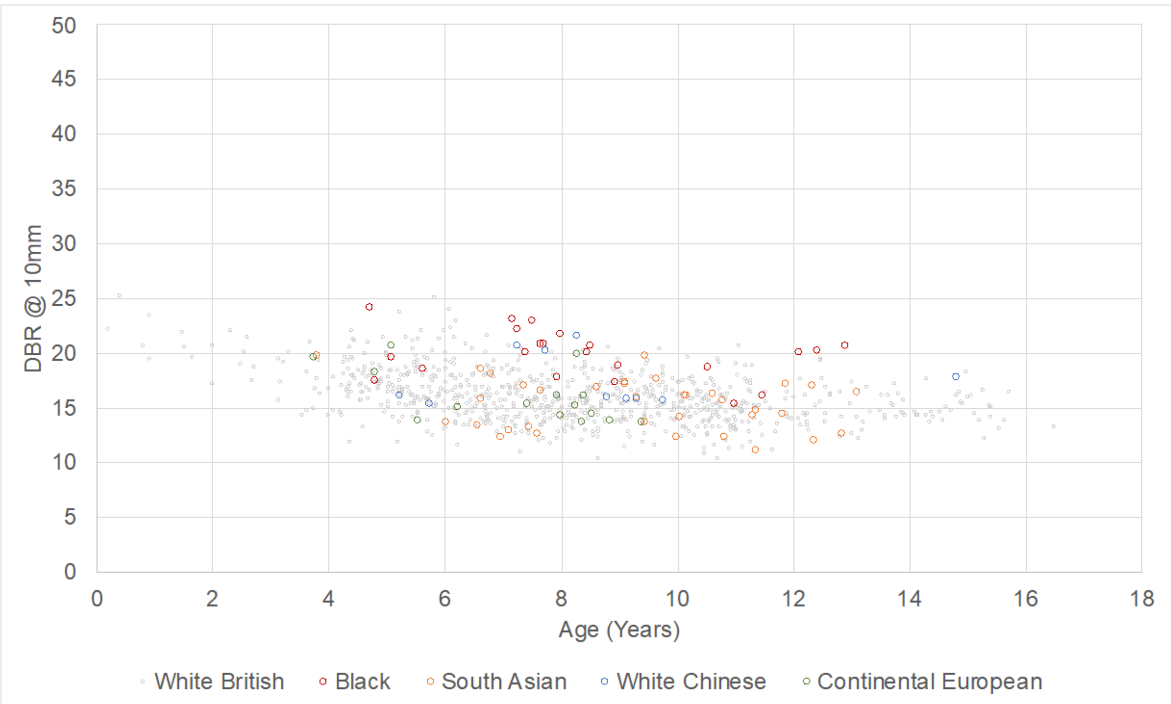


Figure 9.2e. Distance between rims at 10mm below crest results for all ethnic typically-developed children overlaid on White British results.

Typically-developed ethnic group

Distance Between Rims at 15mm Below Crest (DBR15)

Landmarks involved:

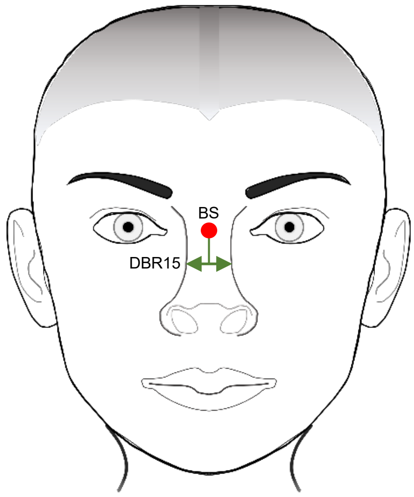
Bearing surface (BS).

Measurement definition:

The width of the nose at a point 15mm below the crest (bearing surface).

Measurement method:

Automated nasal width calculated at a point 15mm below the bearing surface calculated by 3D stereophotogrammetry.



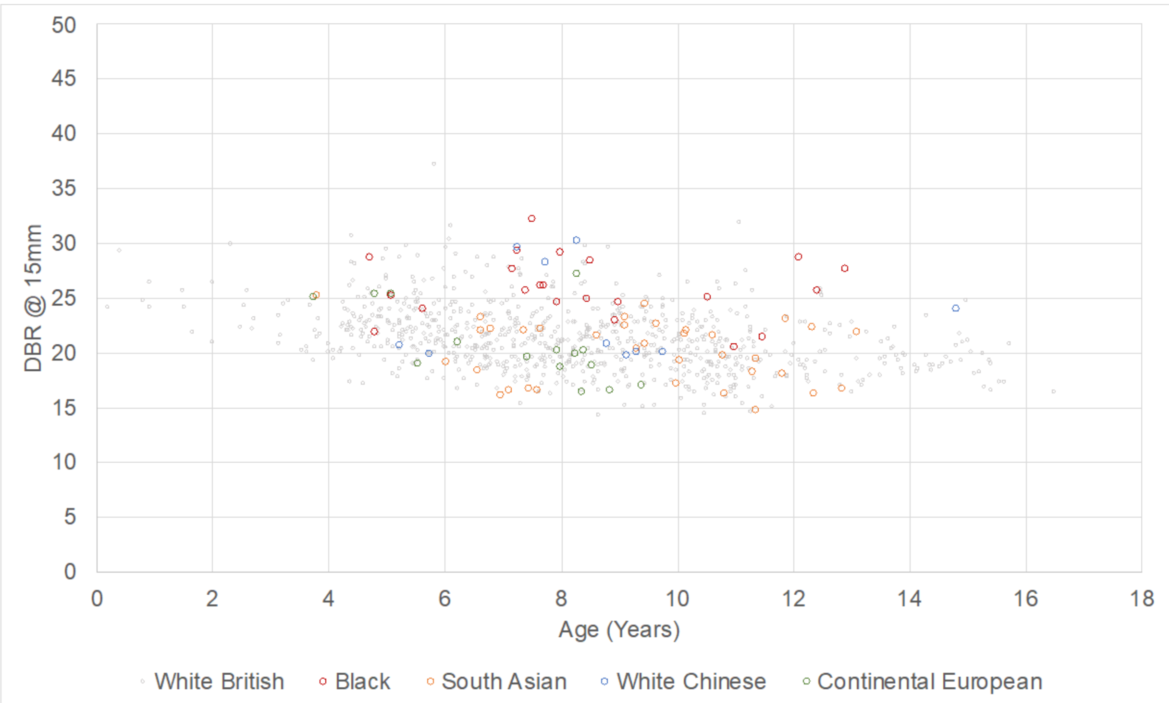


Figure 9.2f. Distance between rims at 15mm below crest results for all ethnic typically-developed children overlaid on White British results.

Distance between rims at both 10mm and 15mm below crest showed agreement in comparison with White British across all ethnic groups except the Black group where the measurements were found to be larger, i.e. a wider nasal width.

Typically-developed ethnic group

Apical Radius (AR)

Landmarks involved:

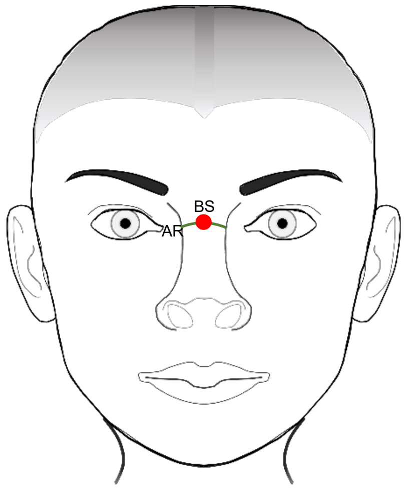
Bearing surface (BS).

Measurement definition:

The radius of the arc forming the lower edge of the bridge viewed perpendicularly to the back plane of the front.

Measurement method:

Automated radius calculated from the landmark by 3D stereophotogrammetry.



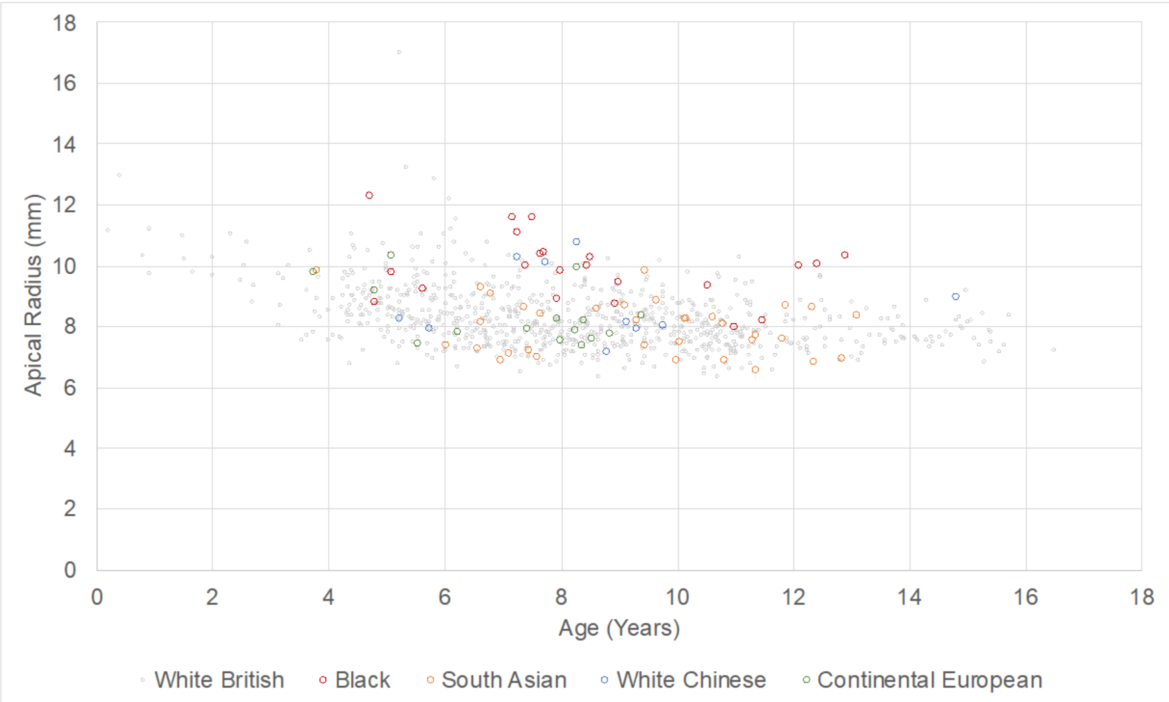


Figure 9.2g. Apical radius results for all ethnic typically-developed children overlaid on White British results.

The apical radius appears to be larger overall in the Black ethnic group with other ethnicities falling within the range of the White British data.

Typically-developed ethnic group

Crest Height (CH)

Landmarks involved:

Bearing surface (BS) and top of lower lid right (TTL-R) for right crest height and bearing surface (BS) and top of the lower lid (left) for left crest height.

Measurement definition:

The vertical distance from the top of the lower lid to the crest (bearing surface) of the nose.

Measurement method:

Automated vertical height calculated between the landmarks by 3D stereophotogrammetry.

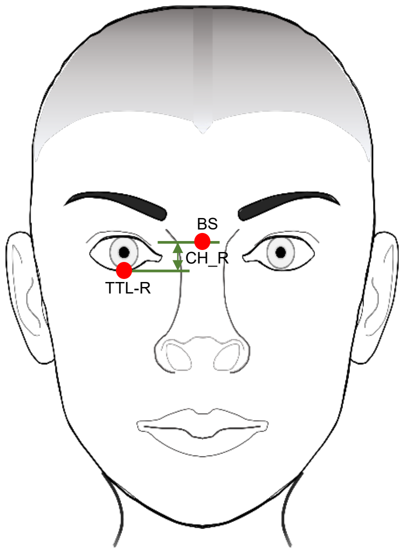


Figure 9.2h. Crest height results for all ethnic typically-developed children showing right and left measurements overlaid on White British results.

A wide variation was observed across all ethnic groups, but the White Chinese group generally showed a lower crest height in agreement with findings in section 7.3.

Typically-developed ethnic group

Front To Bend (FTB)

Landmarks involved:

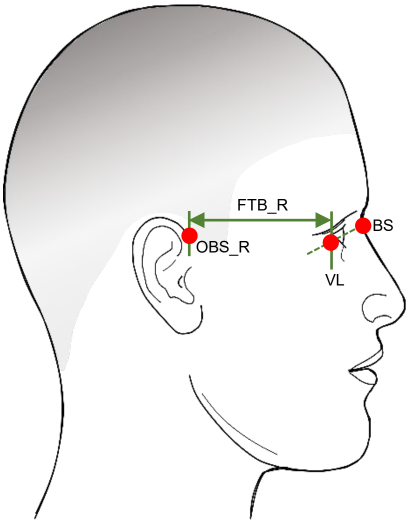
Bearing surface (BS) from which to extend a virtual frame front. Measured to otobasion superious right (OBS_R) for right front to bend and (OBS_L) for left front to bend.

Measurement definition:

The distance between the lug point (point on the back surface of the lug where it begins its backward sweep) and the ear point.

Measurement method:

A virtual front extended from the bearing surface is created by the software, in order to calculate by 3D stereophotogrammetry the length from the virtual lug (VL) to the earpoint.



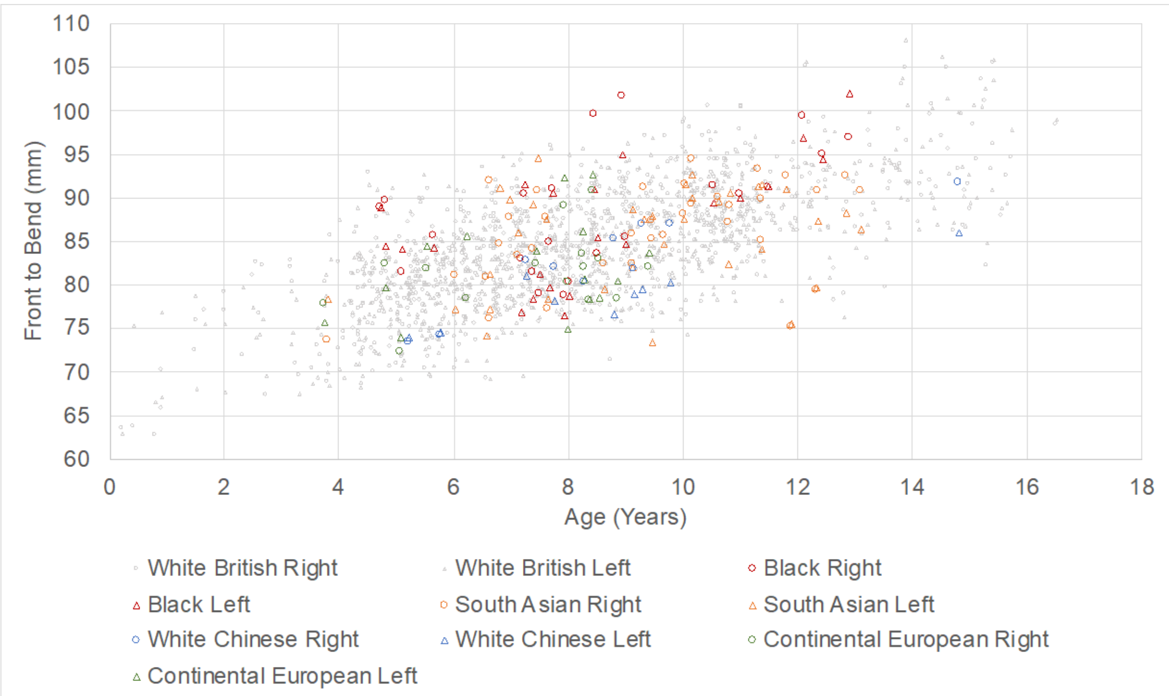


Figure 9.2i. Front to bend results for all ethnic typically-developed children showing right and left measurements overlaid on White British results.

Variation can be seen across all ethnicities. The White Chinese group yielded generally smaller values than other ethnic groups but all fell within the range found in the White British group.

Typically-developed ethnic group

Distance Between Pad Centres (DBPC)

Landmarks involved:

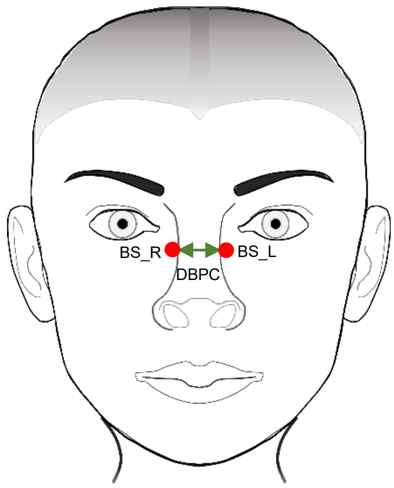
Bearing surface right (BS_R) and bearing surface left (BS_L).

Measurement definition:

The width of the nose at the bearing surface points, hence where the pad of a frame would rest.

Measurement method:

Distance between landmarks calculated by 3D stereophotogrammetry.



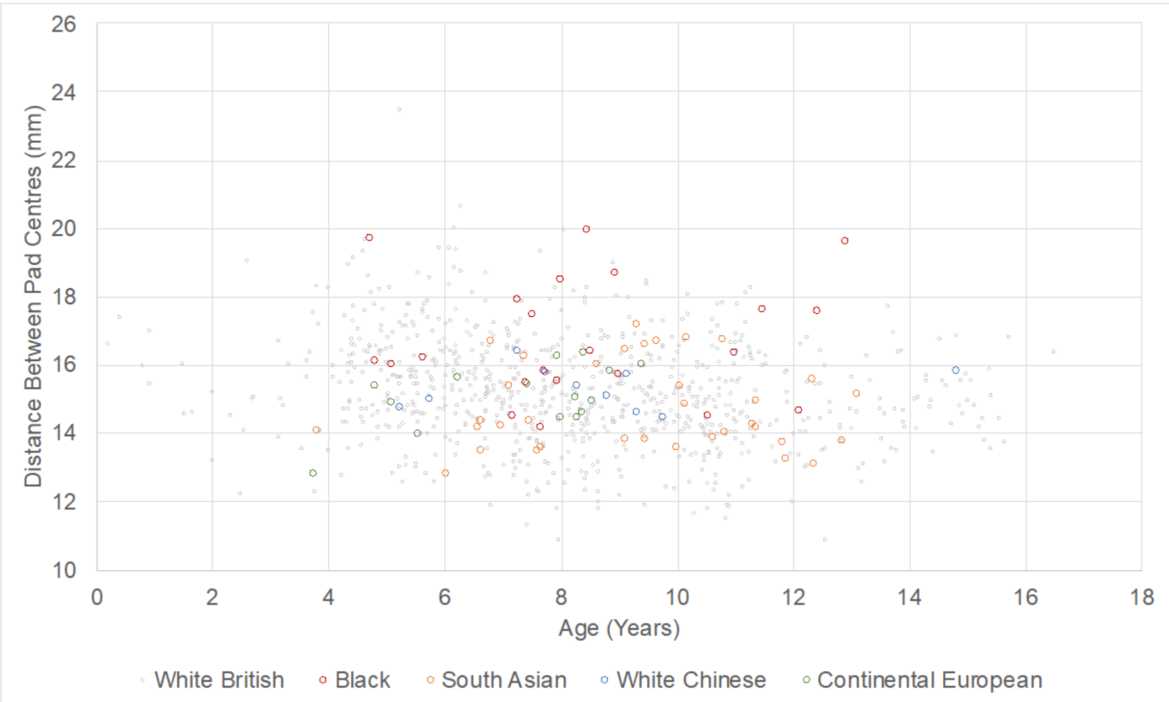


Figure 9.2j. Distance between pad centres results for all ethnic typically-developed children overlaid on White British results.

The Black ethnic group generally showed wider values compared to the White British group and other ethnicities.

Typically-developed ethnic group

Pupillary Distance (PD)

Landmarks involved:

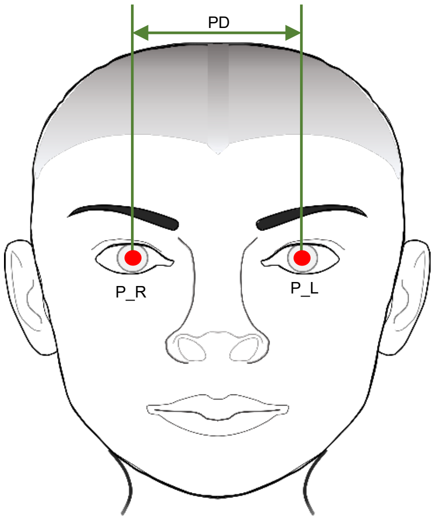
Pupil centre right (P_R) and pupil centre left (P_L).

Measurement definition:

The distance between the centres of the pupils when the eyes are in the primary position.

Measurement method:

Distance behind the two landmarks calculated by 3D stereophotogrammetry.



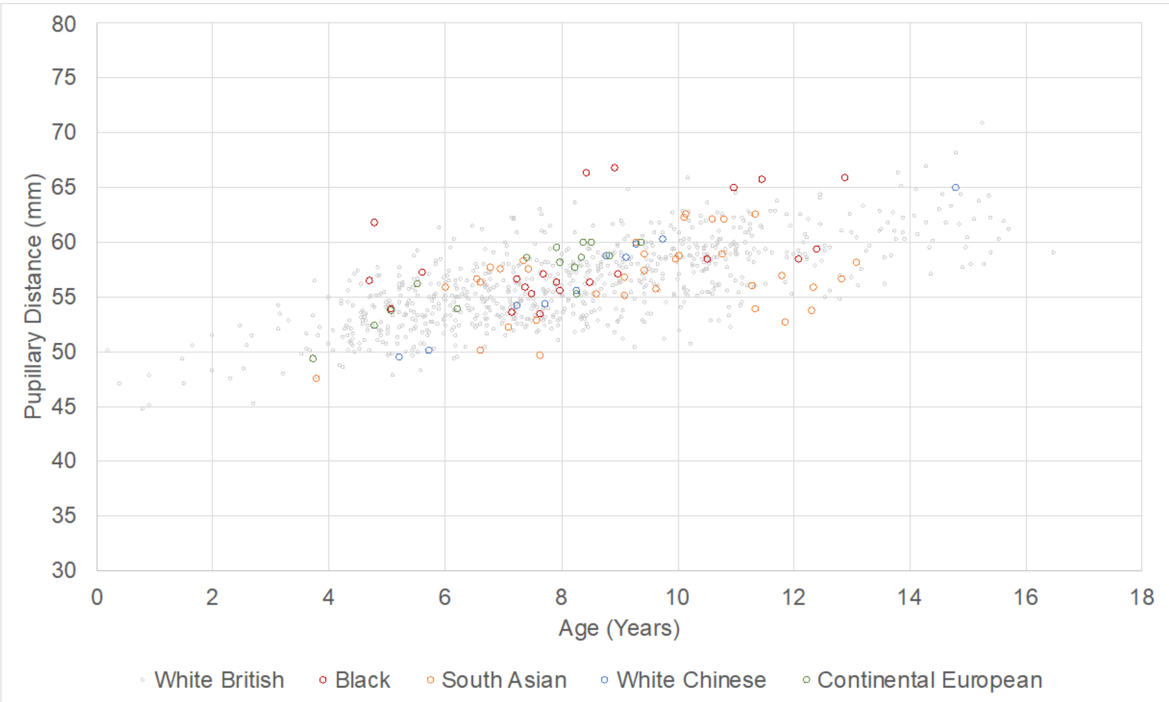


Figure 9.2k. Pupillary distance results for all ethnic typically-developed children showing right and left measurements overlaid on White British results.

The Black ethnic group tended to have wider pupillary distance measurements than other ethnicities of the same age.

9.3 Results for children from different ethnicities with Down's syndrome

Down's syndrome ethnic group

Frontal Angle (FA)

Landmarks involved:

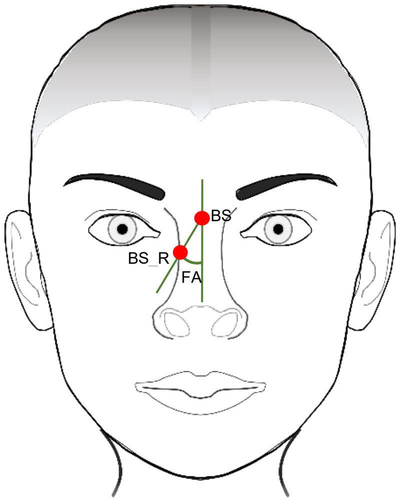
Bearing surface (BS) and bearing surface right (BS_R) for right frontal angle (as shown in schematic diagram) and bearing surface and bearing surface left (BS_L) for left frontal angle.

Measurement definition:

The angle between the vertical and the line of intersection of the pad plane with the back plane of the front, taken in the lateral plane.

Measurement method:

Angle between the landmarks calculated by 3D stereophotogrammetry.



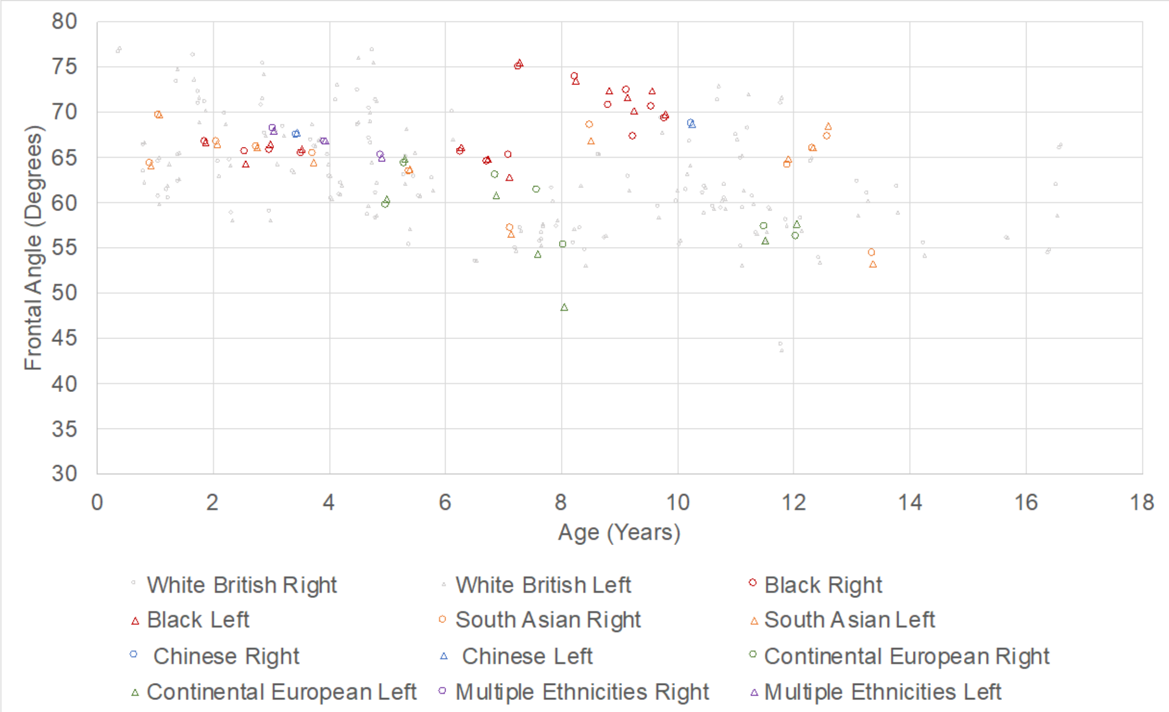


Figure 9.3a. Frontal angle results for ethnic children with Down's syndrome showing right and left measurements overlaid on results for White British children with Down's syndrome.

The data for different ethnicities fell within that found for White British children with Down Syndrome. At ages greater than 8, the Black ethnic group tended to produce the highest values in the distribution.

Down's syndrome ethnic group

Splay Angle (SA)

Landmarks involved:

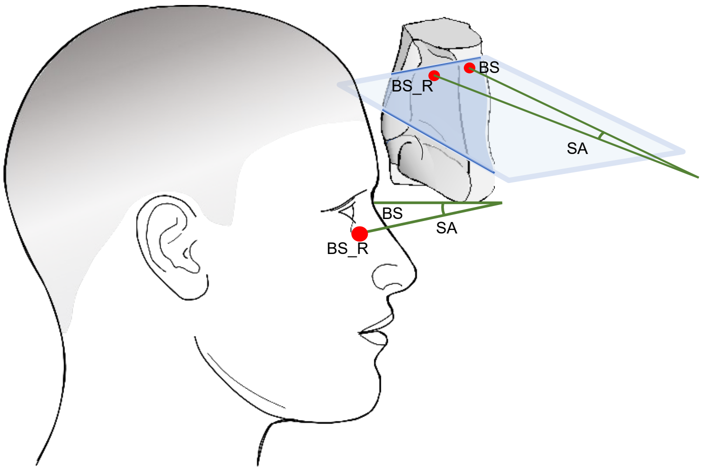
Bearing surface (BS) and bearing surface right (BS_R) for right splay angle and bearing surface (BS) and bearing surface left (BS-L) for left splay angle.

Measurement definition:

The angle between the pad plane and a normal to the back plane of the spectacle front, taken in the transverse plane.

Measurement method:

Angle between the landmarks calculated by 3D stereophotogrammetry.



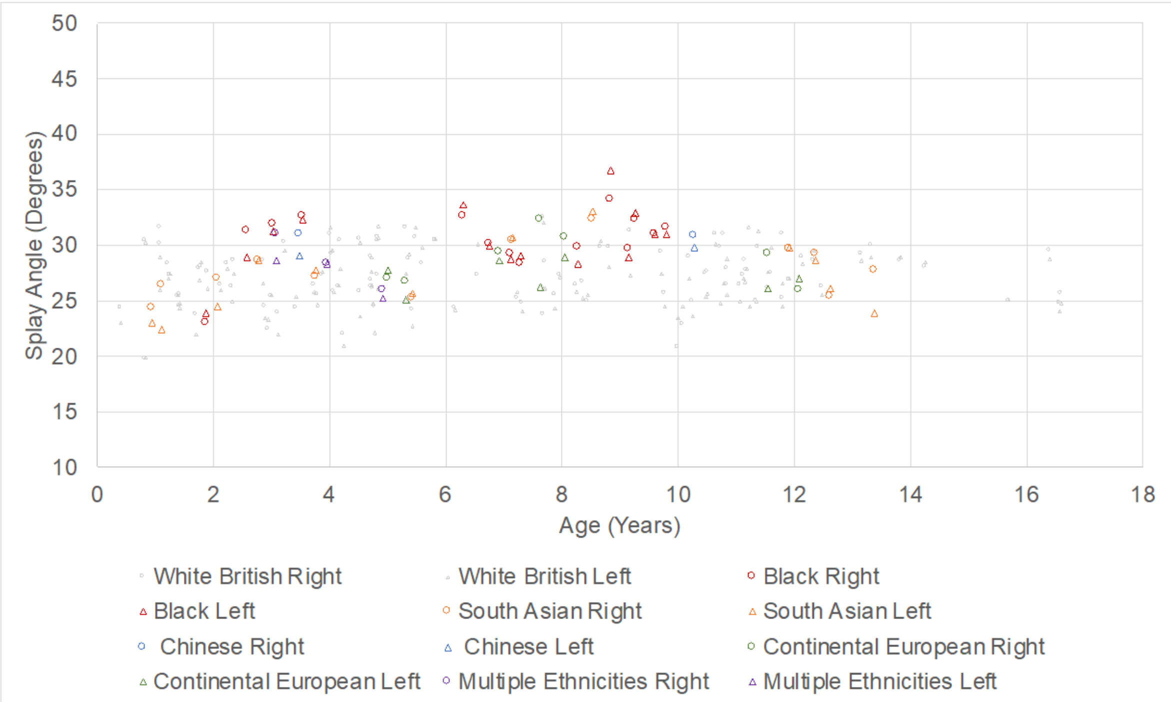


Figure 9.3b. Splay angle results for ethnic children with Down's syndrome showing right and left measurements overlaid on results for White British children with Down's syndrome.

The data for different ethnicities fell within that found for White British children with Down's Syndrome. The Black ethnic group tended to produce the highest values for a given age within the in the distribution.

Down's syndrome ethnic group

Head width (HW)

<u>Landmarks involved:</u>

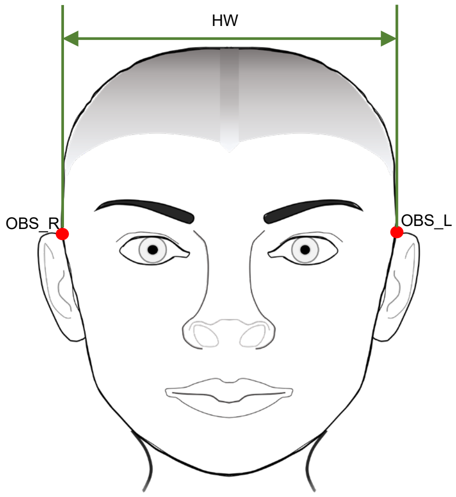
Otobasion superious right (OBS_R) and left (OBS_L).

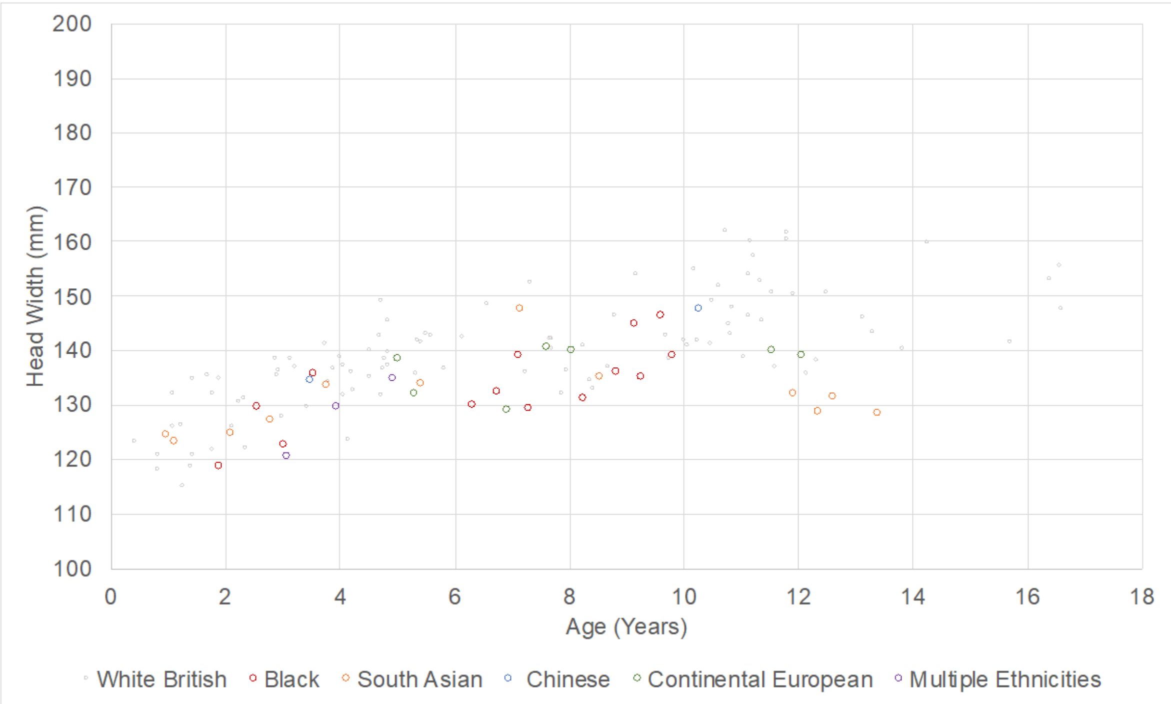
<u>Measurement definition:</u>

The distance between the two ear points.

<u>Measurement method:</u>

Linear distance between the landmarks calculated by 3D stereophotogrammetry.





<u>Figure 9.3c</u>. Head width results for ethnic children with Down's syndrome overlaid on results for White British children with Down's syndrome.

The different ethnicities fit within the data set for White British children with Down's Syndrome but the South Asian group appears at the lower edge of the distribution indicating a relatively smaller head width.

Down’s syndrome ethnic group

Temple width (TW)

Landmarks involved:

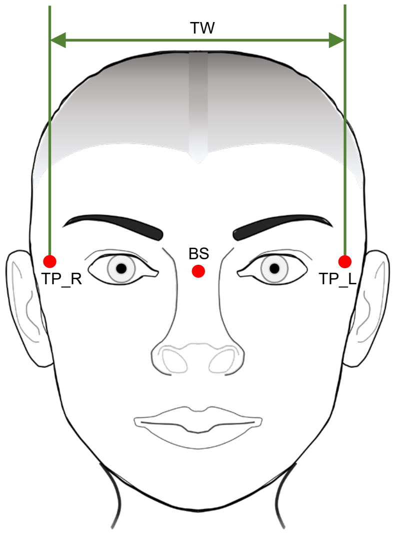
Bearing surface (BS) and temple points right (TP_R) and left (TP_L).

Measurement definition:

The distance between the two temple points at a distance of 25mm behind the back plane of a spectacle front.

Measurement method:

The position of the bearing surface enables the programme to create a virtual frame front in order to generate the temple points at the correct distance behind the front and measure the distance between the landmarks calculated by 3D stereophotogrammetry.



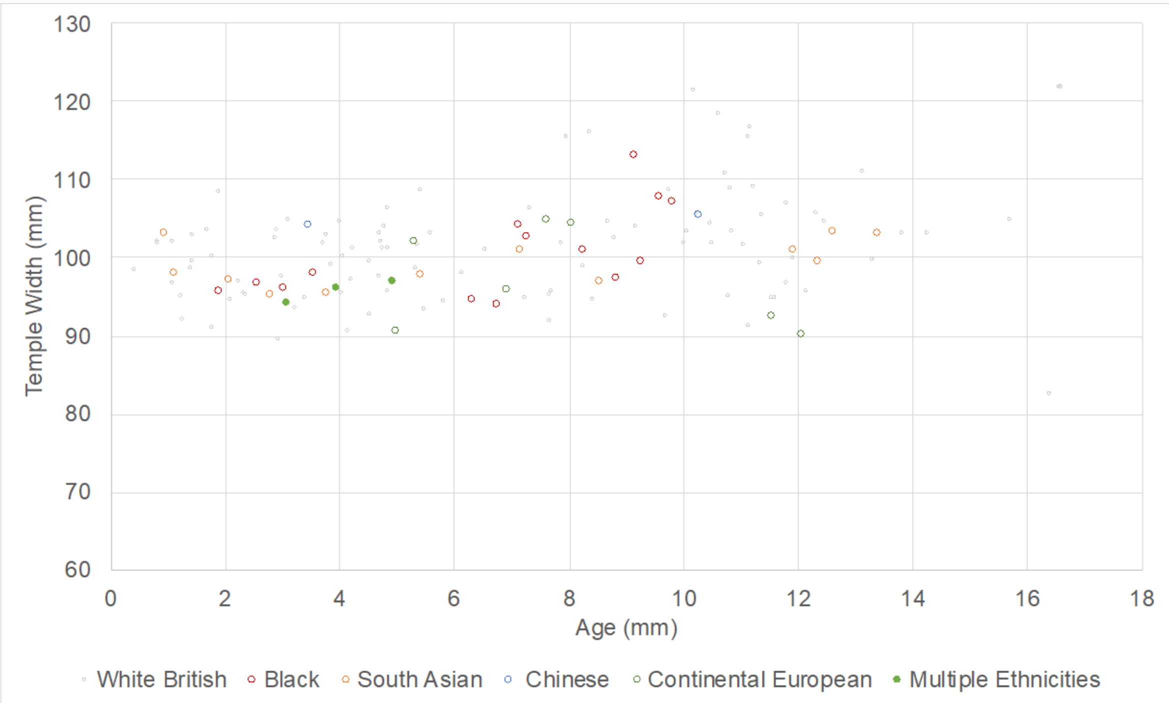


Figure 9.3d. Temple width results for ethnic children with Down’s syndrome overlaid on results for White British children with Down’s syndrome.

The ethnic group data fell within the distribution for White British children with Down’s syndrome.

Down's syndrome ethnic group

Distance Between Rims at 10mm Below Crest (DBR10)

<u>Landmarks involved:</u>

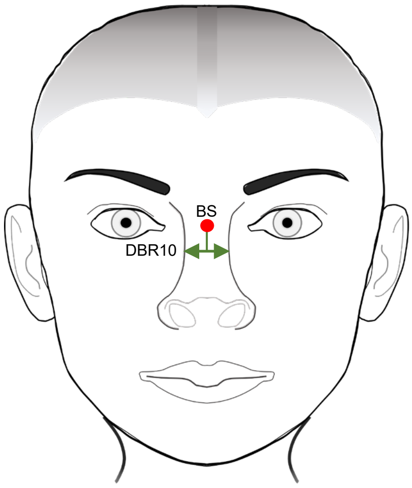
Bearing surface (BS).

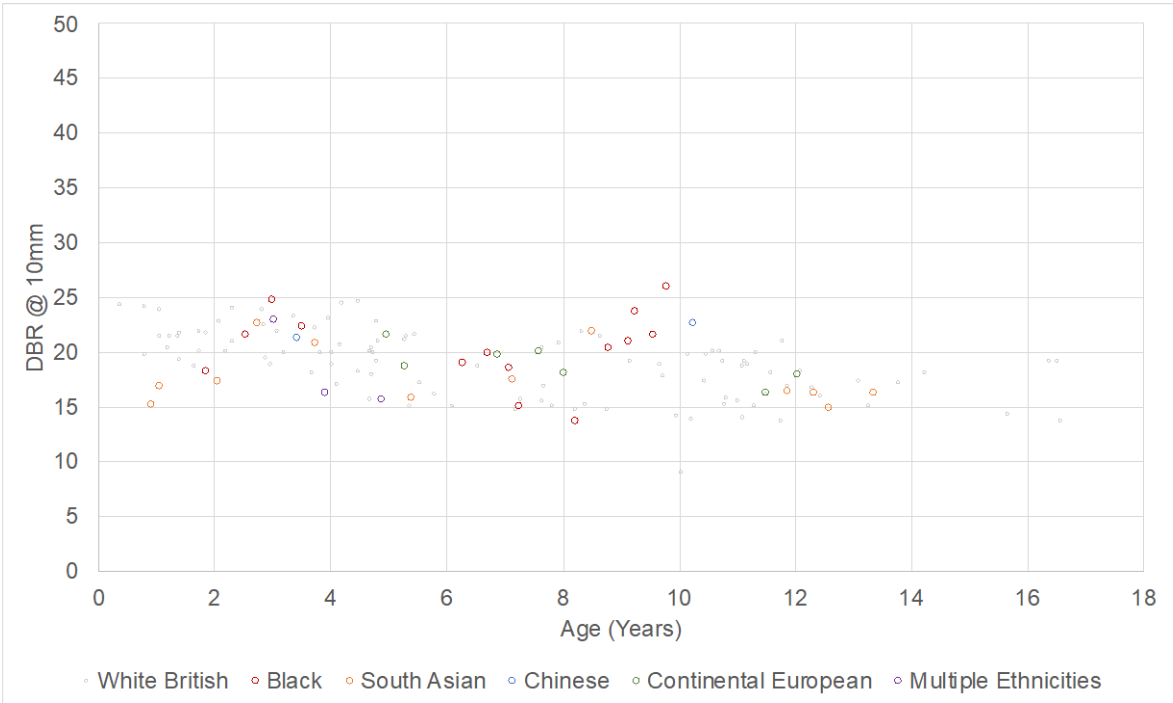
<u>Measurement definition:</u>

The width of the nose at a point 10mm below the crest (bearing surface).

<u>Measurement method:</u>

Automated nasal width calculated at a point 10mm below the bearing surface calculated by 3D stereophotogrammetry.





<u>Figure 9.3e</u>. Distance between rims at 10mm below crest results for ethnic children with Down's syndrome overlaid on results for White British children with Down's syndrome.

Down's syndrome ethnic group

Distance Between Rims at 15mm Below Crest (DBR15)

Landmarks involved:

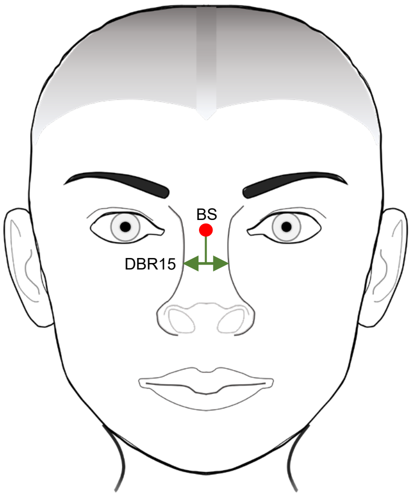
Bearing surface (BS).

Measurement definition:

The width of the nose at a point 15mm below the crest (bearing surface).

Measurement method:

Automated nasal width calculated at a point 15mm below the bearing surface calculated by 3D stereophotogrammetry.



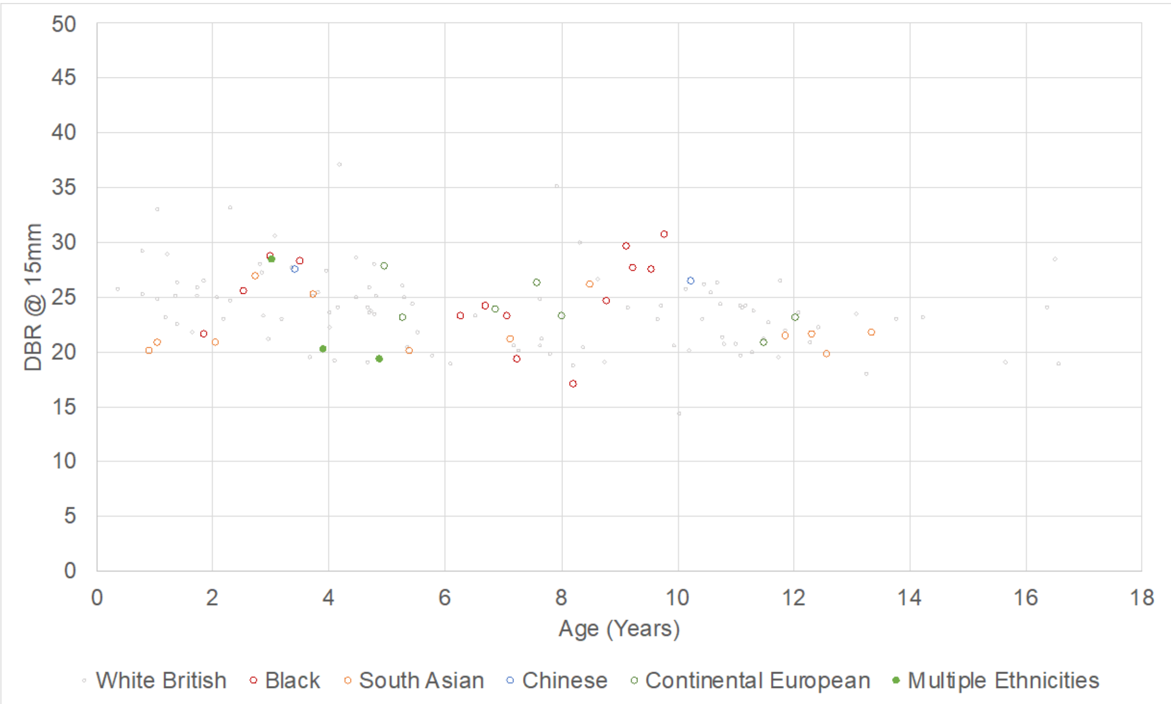


Figure 9.3f. Distance between rims at 15mm below crest results for ethnic children with Down's syndrome overlaid on results for White British children with Down's syndrome.

The ethnic group data fell within the distribution for White British children with Down's syndrome, but the majority of the Black ethnicity measurements at the upper limits of the distribution indicating a wider nasal form.

Down’s syndrome ethnic group

Apical Radius (AR)

Landmarks involved:

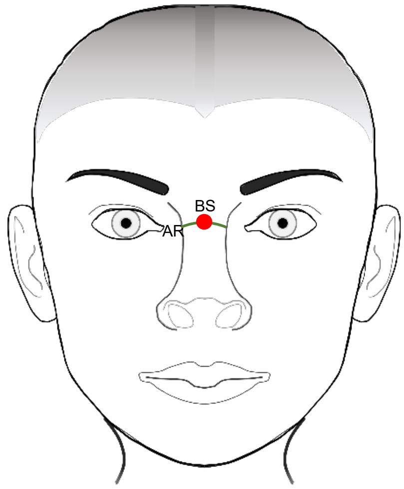
Bearing surface (BS).

Measurement definition:

The radius of the arc forming the lower edge of the bridge viewed perpendicularly to the back plane of the front.

Measurement method:

Automated radius calculated from the landmark by 3D stereophotogrammetry.



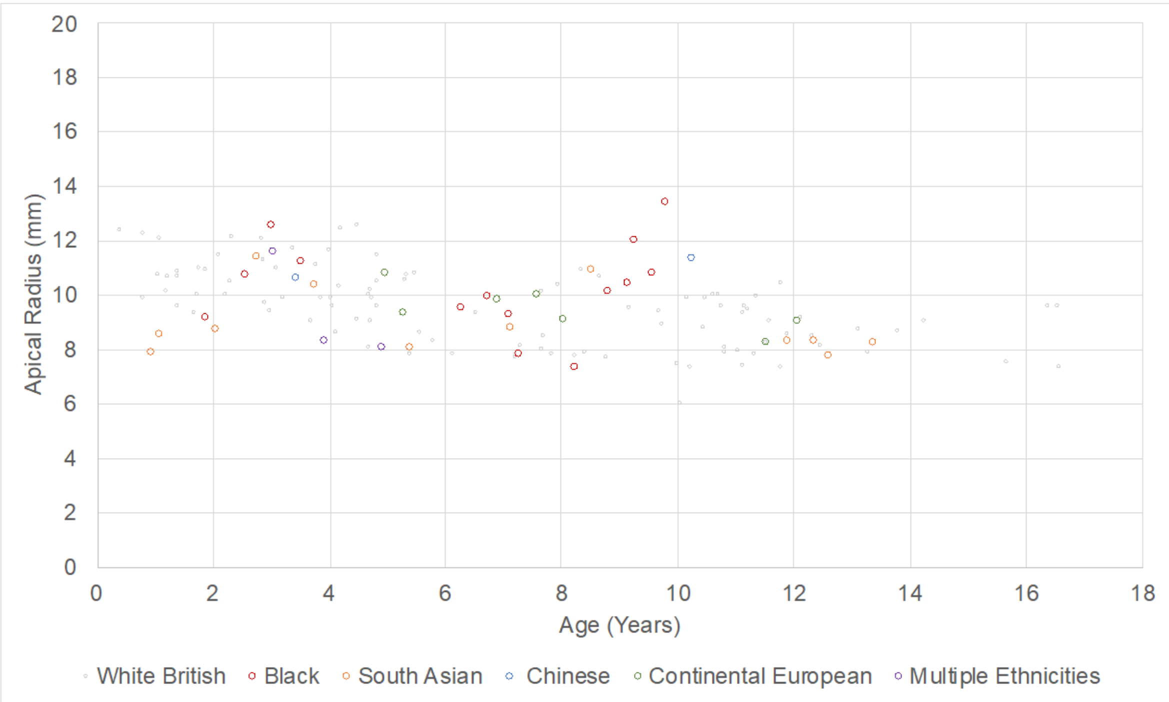


Figure 9.3g. Apical radius results for ethnic children with Down’s syndrome overlaid on results for White British children with Down’s syndrome.

The ethnic group data fell within the distribution for White British children with Down’s syndrome, but the majority of the Black ethnicity measurements at the upper limits of the distribution indicating a wider nasal form.

Down's syndrome ethnic group

Crest Height (CH)

<u>Landmarks involved:</u>

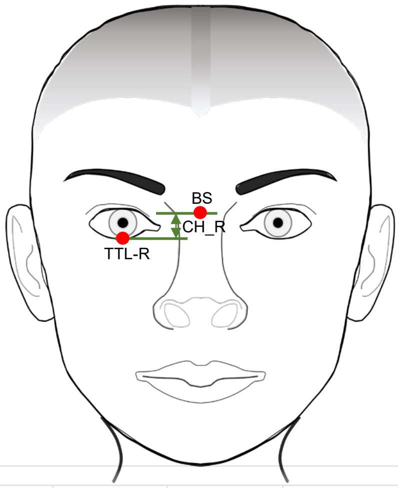
Bearing surface (BS) and top of lower lid right (TTL-R) for right crest height and bearing surface (BS) and top of the lower lid (left) for left crest height.

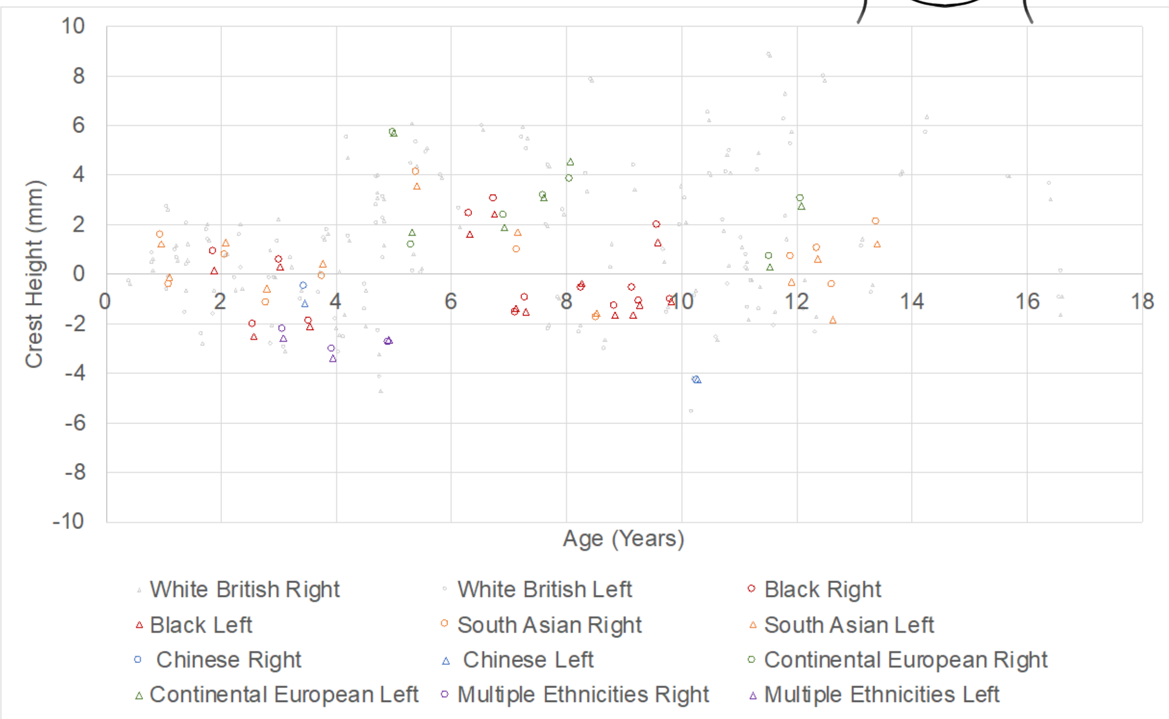
<u>Measurement definition:</u>

The vertical distance from the top of the lower lid to the crest (bearing surface) of the nose.

<u>Measurement method:</u>

Automated vertical height calculated between the landmarks by 3D stereophotogrammetry.





<u>Figure 9.3h</u>. Crest height results for ethnic children with Down's syndrome showing right and left measurements overlaid on results for White British children with Down's syndrome.

The ethnic group data fell within the distribution for White British children with Down's syndrome, but the majority of the Continental European group produced values in the upper regions of the distribution.

Down's syndrome ethnic group

Front To Bend (FTB)

Landmarks involved:

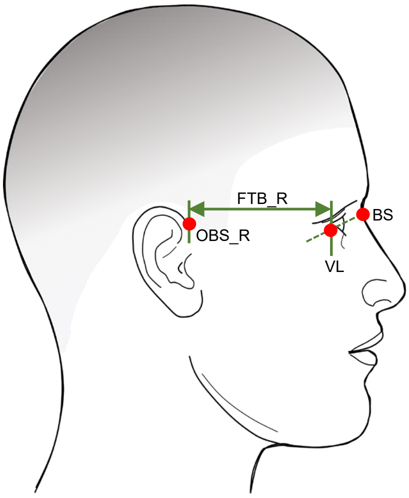
Bearing surface (BS) from which to extend a virtual frame front. Measured to otobasion superious right (OBS_R) for right front to bend and (OBS_L) for left front to bend.

Measurement definition:

The distance between the lug point (point on the back surface of the lug where it begins its backward sweep) and the ear point.

Measurement method:

A virtual front extended from the bearing surface is created by the software, in order to calculate by 3D stereophotogrammetry the length from the virtual lug (VL) to the earpoint.



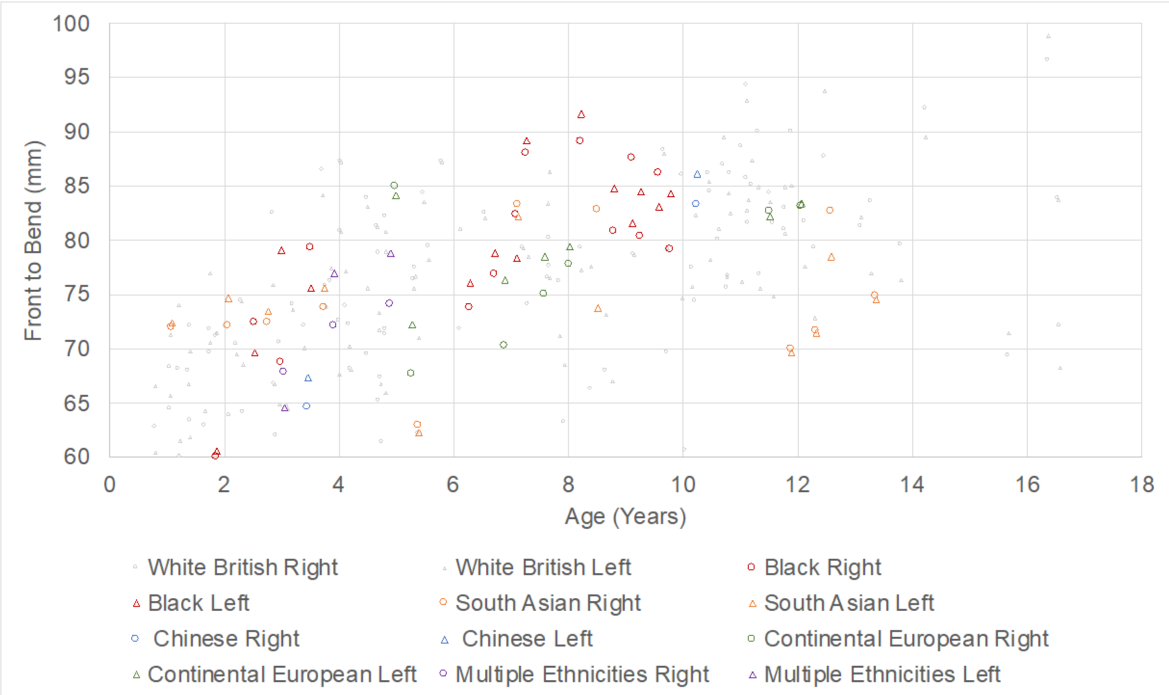


Figure 9.3i. Front to bend results for ethnic children with Down's syndrome showing right and left measurements overlaid on results for White British children with Down's syndrome.

The ethnic group data fell within the distribution for White British children with Down's syndrome.

Down's syndrome ethnic group

Distance Between Pad Centres (DBPC)

Landmarks involved:

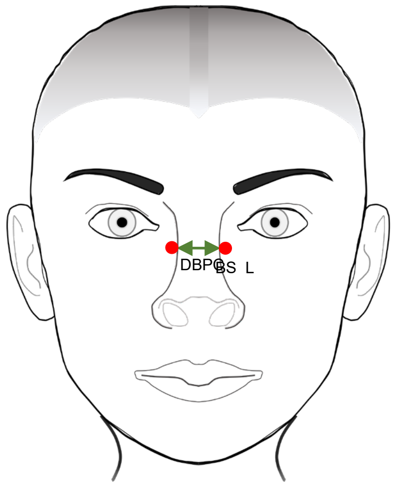
Bearing surface right (BS_R) and bearing surface left (BS_L).

Measurement definition:

The width of the nose at the bearing surface points, hence where the pad of a frame would rest.

Measurement method:

Distance between landmarks calculated by 3D stereophotogrammetry.



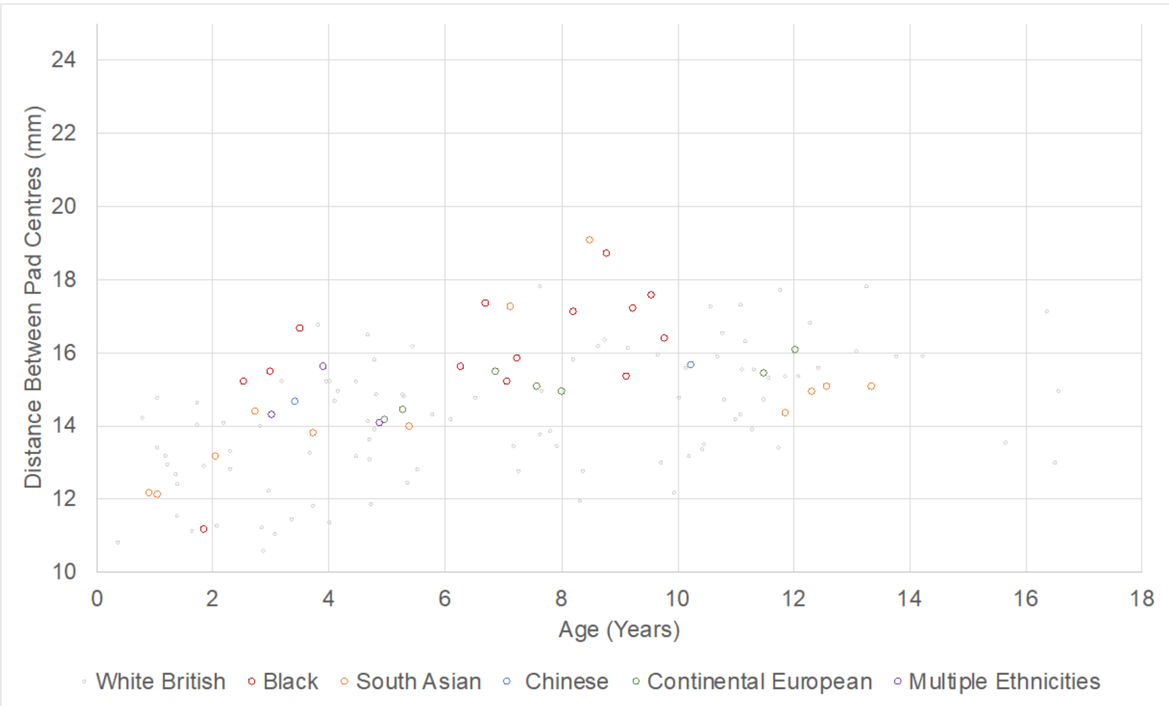


Figure 9.3j. Distance between pad centre results for ethnic children with Down's syndrome overlaid on results for White British children with Down's syndrome.

The ethnic group data fell within the distribution for White British children with Down's syndrome, but the majority of the Black ethnicity measurements at the upper limits of the distribution indicating a wider nasal form.

Down's syndrome ethnic group

Pupillary Distance (PD)

Landmarks involved:

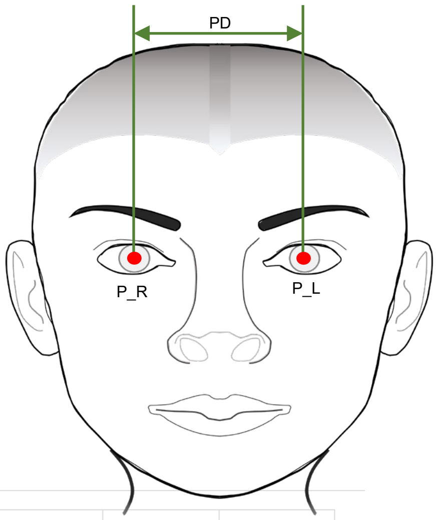
Pupil centre right (P_R) and pupil centre left (P_L).

Measurement definition:

The distance between the centres of the pupils when the eyes are in the primary position.

Measurement method:

Distance behind the two landmarks calculated by 3D stereophotogrammetry.



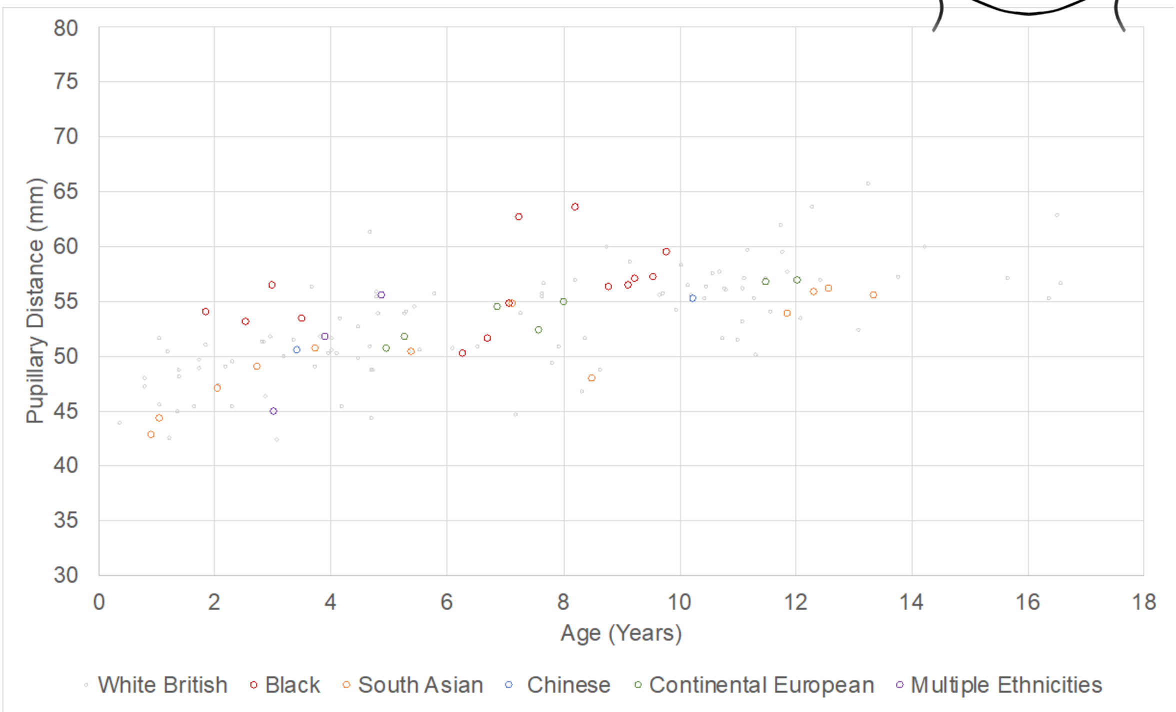


Figure 9.3k. Pupillary distance results for ethnic children with Down's syndrome overlaid on results for White British children with Down's syndrome.

The ethnic group data generally falls within the range of White British children with Down's syndrome although the Black ethnic group tends to yield higher values for a given age in comparison.

9.4 Discussion

9.41 Typically Developed Children

For the angular measurements, the frontal angle scatterplot shows a similar spread of values for South Asian and Continental Europe when compared to the White British however, a larger value for the White Chinese and Black groups. The splay angle was similar to the White British group for all ethnic groups except Black where the angle again appeared to be larger. The White Chinese results agree with the earlier results for Chinese children (section 7.3) where the frontal (and splay) angle were reported to be larger. In an earlier study by Kaye and Obstfeld (1989) on children's facial measurements, the authors noted that 44 children were of African-Caribbean origin and included the differences found between this data and the main study of White British children. For frontal angle, this difference was found to be 7 degrees larger and for splay angle, 9 degrees larger thus agreeing with the findings of this study.

For the linear measurements, head width showed no apparent difference between groups, however temple width showed larger values for White Chinese and Continental European children compared with the White British group. The White Chinese is in agreement with the findings for Chinese children in section 7.3 and the study by Quant and Woo (1993) who measured head and temple width in 232 children from Hong Kong using spreading callipers and found these to be over 20mm larger in ages 7-11 years when comparing to 'Caucasian' children.

Distance between rims at both 10mm and 15mm below yielded good agreement in comparison with White British across all groups except the Black group where the measurements were found to be larger, i.e. a wider nasal width. This agrees with a study by Szychta et al. (2011) who looked at values of nasal shapes in the area of rhinoplasty and concluded that the Black ethnic group has the widest and most prominent nose, with the 'Caucasian' nose being narrower and longer than both Black and Chinese ethnic groups. These findings also concur with Zhuang et al. (2010) who studied facial anthropometric differences between African-American, Hispanic, Caucasian and Asian adults using direct anthropometry, concluding significant higher means in 13 out of 19 facial measurements when comparing African-American with Caucasian results, and interestingly no significant difference found between the Asian group and the Caucasian results which concurs with the comparison in this study between White British and South Asian children. For crest height, a wide variation in data was observed across all groups, showing a similar spread to the White British results with the White Chinese data points generally lower indicating a lower crest height, in agreement with the findings in section 7.3. Apical radius appears to be larger overall in Black ethnic group, in agreement of a 2mm increase when compared with White British children as reported by Kaye and

Obstfeld (1989). Front to bend showed a similar pattern to the White British data with a variation across all ethnicities, White Chinese generally showed smaller values in comparison, concurring with previous findings (section 7.3), although the Black group did not show any remarkable differences in this scatterplot (figure 9.2i), Kaye and Obstfeld (1989) reported a larger value in comparison to White British children of approximately 7mm longer. Distance between pad centres reported a wider value (figure 9.2j) for the Black ethnic group which is a pattern to be expected since the distance between rims measurements are generally wider too in comparison to White British children. Pupillary distance showed the Black group tend to have a wider measurement between pupil centres, in concordance with Kaye and Obstfeld (1989) who, using a 15cm transparent ruler, reported an approximate 3mm increase for this measurement when comparing African-Caribbean children to White British children. A similar increase was found by Murphy and Laskin (1990) who measured 29 adults with a ruler of African-American ethnicity.

9.42 Children with Down's Syndrome

For children with Down's syndrome, the angular measurements showed a similar pattern to typically-developed children with Chinese and Black having larger angles in both the sagittal and transverse planes indicating the importance of ethnical influence on facial parameter.

Head width (figure 9.3c) showed a similar spread of data with South Asian group appearing at the lower edge of the data spread indicating a relatively smaller head width compared to White British children with DS, whereas the temple width and front to bend scatterplots showed an unremarkable result with a similar spread of data across all ethnic groups. Distance between rims at 10mm and 15mm below crest and apical radius reported a similar pattern with the majority of Black children's data again at the upper values indicating a wider nasal form. Crest height showed the Continental European group at the upper values, generally more positive in value than the other ethnic groups. Distance between pad centres and pupillary distance yielded a similar pattern to the typically developed ethnic groups with larger values for the Black ethnic group.

Ethnicity was determined by the subjects themselves and this can lead to potential issues when trying to determine a range of facial parameters as nationality is often the determinator, rather than looking at both migration and ancestry (Doddi and Eccles, 2010). In an attempt to address this, it may have been useful to include ethnicity information on parents and grandparents (Menendez Lopez-Mateos et al., 2019) which this study did not. But, for the purposes of facial parameters in spectacle wear, capturing ethnicity and identifying any trends in parameters to then inform design for the general population appears appropriate due to the sheer variations in individual facial characteristics.

The nasal index as described in section 1.46, gives a reasonable description of differences due to ethnicity but there are always variations (Szychta et al., 2011, Doddi and Eccles, 2010, Leong and Eccles, 2009). Even geographical neighbours show craniofacial variations, such as White British having a more rounded head shape than White Irish adults (Agbolade et al., 2020) and significant variability in facial shape and size between North and East African adults (Bruner and Manzi, 2004).

An appreciation of facial characteristics due to ethnicity is essential when dispensing spectacles and considering design features to allow for such variation in an expanding, diverse population. In the 2011 census, ethnic groups 'other than White British' increased from 13% to 20% with this population more than doubling in size from 3 million in 1991 to 7 million in 2011. The African ethnic group has grown more than any other, followed by Chinese, Bangladeshi and Pakistani (University of Manchester, 2012).

For children with DS, the ethnic results demonstrated the same pattern as for the typically-developed children, therefore children with DS may have facial characteristics due to a differing facial growth pattern, but essentially, they also have characteristics determined by their ethnical heritage and strongly resemble their family members. This is evidenced by a study comparing 118 Italian and Sudanese people with DS (aged 5-52) matched with TD subjects and using computerised digitisers to obtain three-dimensional landmark coordinates, the results of which showed a significant effect of ethnicity (Sforza et al., 2015).

Pure ethnicity is very difficult to determine and subsequently racial groups lack 'scientific definition' (Doddi and Eccles, 2010), however, there are proportional facial differences leading to differing facial parameters as demonstrated in this study and therefore it is important to at least have an appreciation of requirements when designing spectacle frames for all children.

To summarise, children contained within the 'Black' ethnic group show differing facial parameters and will therefore need frames with wider frame fronts to accommodate the larger temple width and pupillary distance, with wider bridges, accommodating the larger frontal angle. Common practice is to use a 'pads on arms' frame for these children but in reality, the pads need to be splayed so wide the rims of the frame, or lens edge thickness usually rest in direct contact with the child's face, causing potential harm and risk of injury.

Chapter 10 Discussion and Conclusions – the inter-relationships between anthropometric measurements and their implications for spectacle frame manufacture.

10.1 Schematic diagrams of facial growth and differences

The preceding chapters have reported on facial parameters for children and investigated any influence by gender, ethnicity, and Down's syndrome.

The following scale schematic diagrams were produced for White British typically-developed, Chinese typically-developed and White British children with Down's syndrome by substituting a value for x (age) into the linear regression equations for each parameter in order to see the pattern of growth and allow comparisons of facial parameters across the age groups observed in this study. The diagrams highlight how individual facial parameters do not change at the same rate as the child grows, nor is it at the same pattern for all children. The emerging crest of the nose impacts on the design requirements for a spectacle frame i.e., the initial relatively low position of a bearing surface with wide angles and a large breadth generally rises and narrows as the child grows, although this pattern cannot be followed for the entire population, where the crest shows little emergence, for example, in the Chinese group of children.

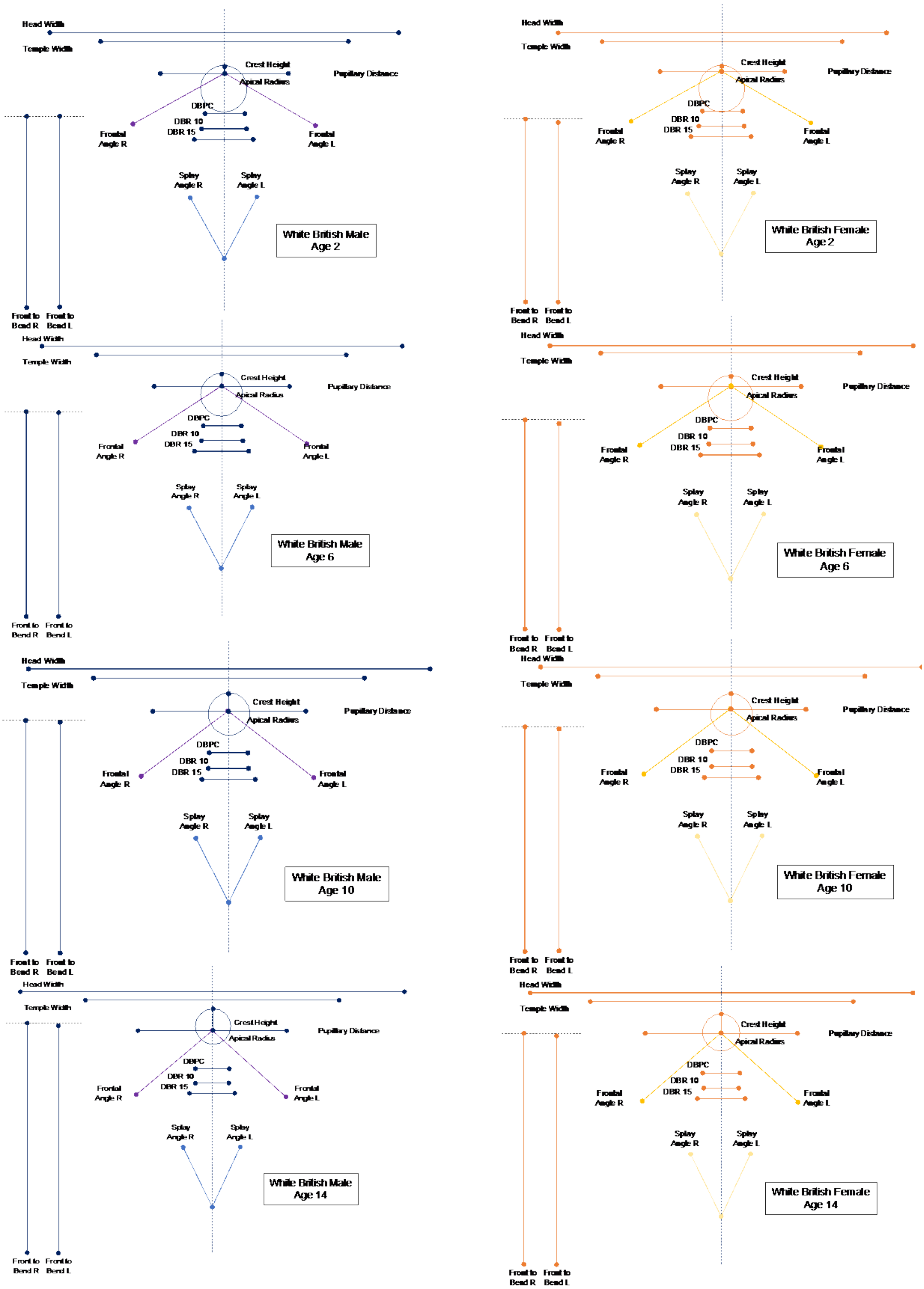


Figure 10.1a. Scale drawings of linear regression equations which represent growth of facial features at the ages of 2, 6, 10 and 14 years as a function of gender (male left, female right) for typically-developed White British children.

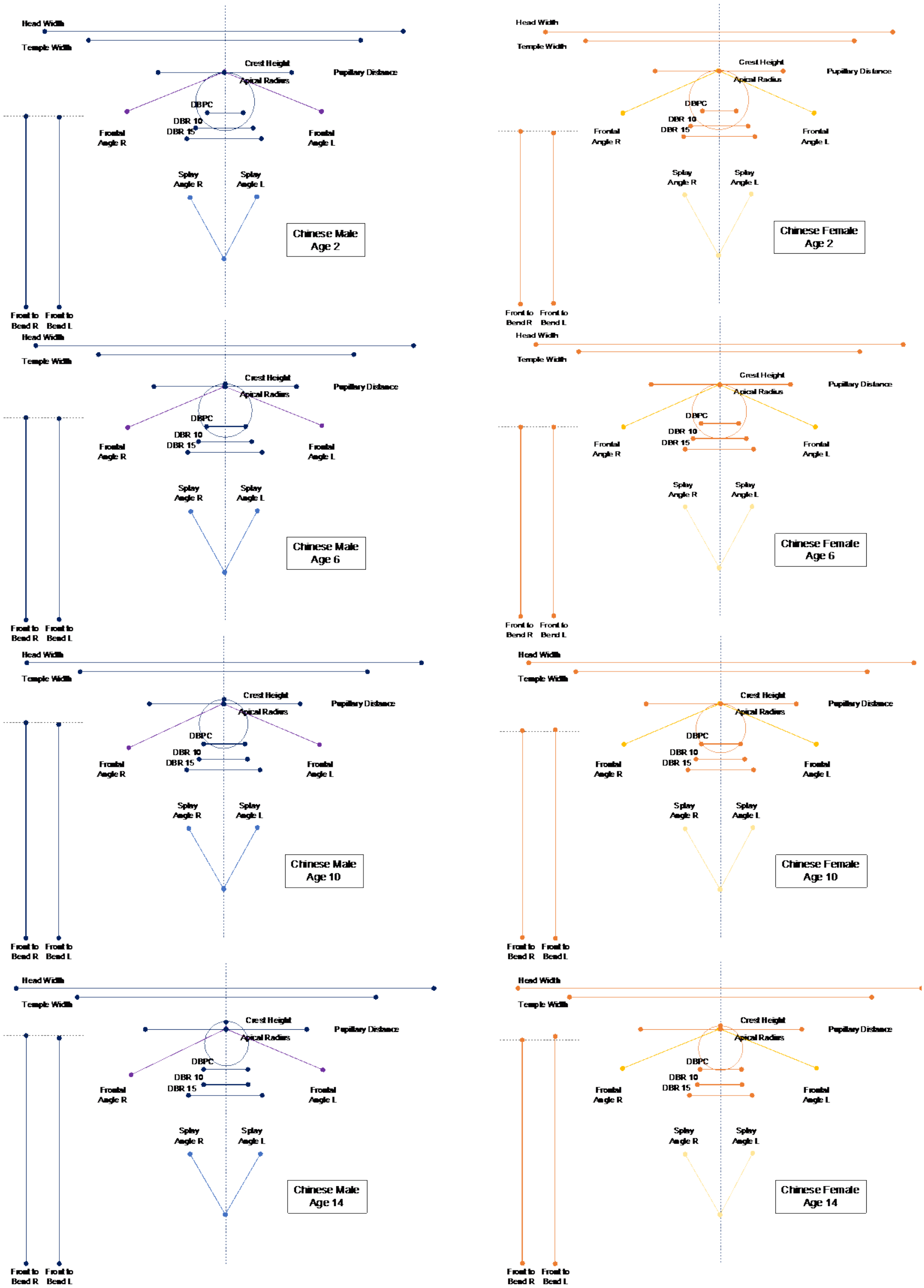
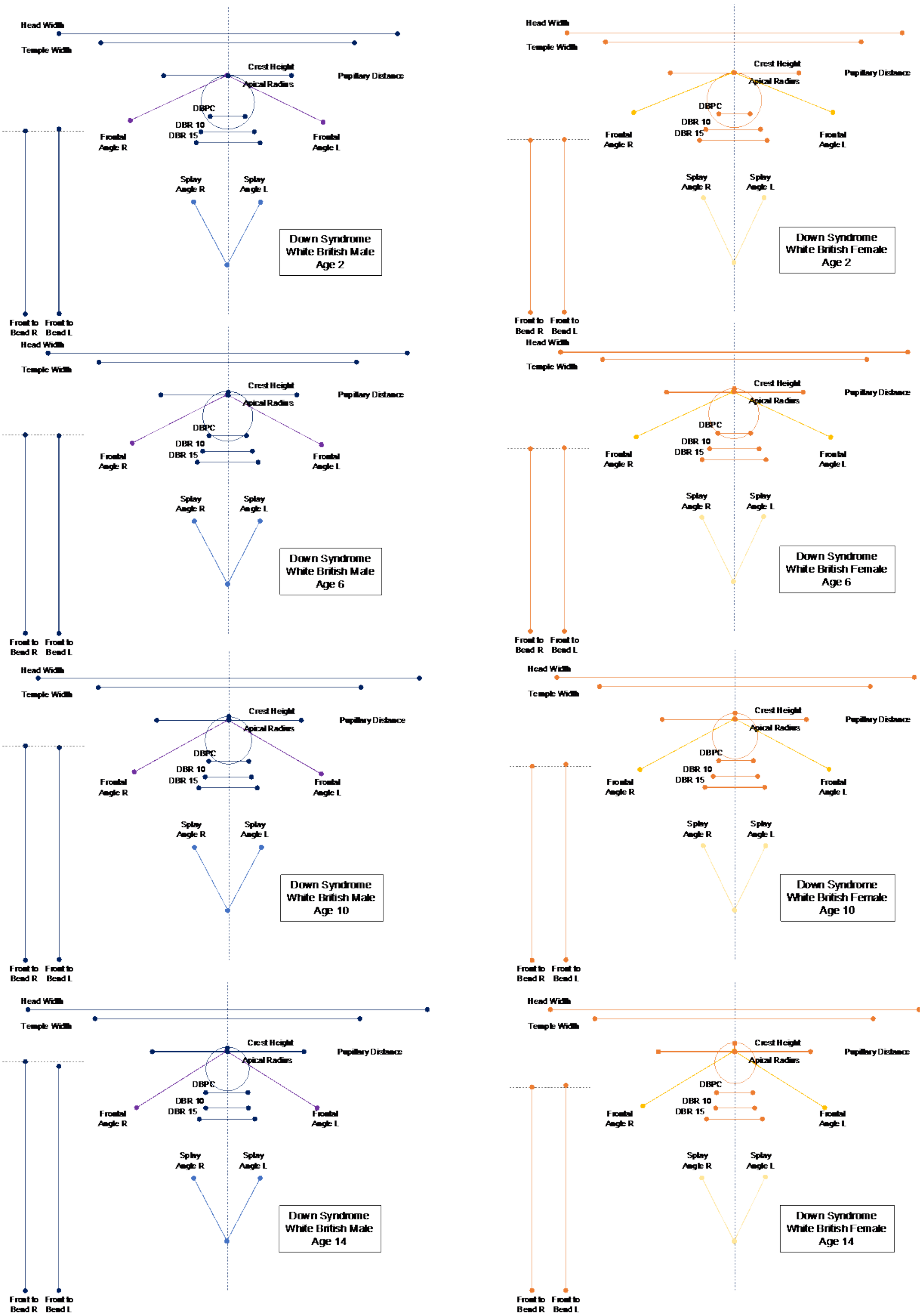


Figure 10.1b. Scale drawings of linear regression equations which represent growth of facial features at the ages of 2, 6, 10 and 14 years as a function of gender (male left, female right) for typically-developed Chinese children.



<u>Figure 10.1c.</u> Scale drawings of linear regression equations which represent growth of facial features at the ages of 2, 6, 10 and 14 years as a function of gender (male left, female right) for White British children with Down's syndrome.

For typically-developed White British children (figure 10.1a), the head width is the fastest growing facial parameter, closely followed by front to bend, then pupillary distance and temple width. This means that for frame manufacture, to scale up all parameters of a children's frame equally in the frontal and sagittal planes would not result in a successful fit as the head is widening faster than the pupillary distance and the temple width so this would result in excessive decentration of the lenses and a frame too wide at the temples. Gender difference should also be observed with females having generally smaller head widths than males. As the bearing surface emerges from the face, the crest height shows a positive growth thus requiring the position of the bridge of the frame to be almost at the horizontal centre line in the younger years, rising above this line continuously to match the more positive crest in older children. The rise in the bearing surface also brings a narrowing of the apical radius, distance between rims and distance between pad centres along with a decrease in frontal and splay angles, although the frontal angle narrows more rapidly than the splay angle. This indicates the degree of adjustability required in bridge designs for children to ensure that the weight of spectacles is distributed evenly across a developing nasal structure.

For Chinese children and children with Down's syndrome, similarities in facial parameters and growth were observed in this study. Indeed, White British children with Down's syndrome have more similarities to typically-developed Chinese children than typically-developed White British children. The differences in facial parameters reported will impact heavily on frame design and even if a range of sizes is produced for White British children, the 'one-design fits all' strategy will not work for these children. The main challenge is the lower crest height apparent across all age groups that does not tend to narrow as observed for White British typically-developed children. This flat low nasal profile means it then follows that the frontal and splay angles are larger and the apical radius, distance between rims are wider too so these features would need to be incorporated into designs for older children too. The larger temple width would need to be considered, although the head width and pupillary distance are not proportionately larger therefore this would need to be addressed in the design of the lug. The shorter length to bend could be accommodated if the design of the sides allowed for considerable, permanent modification rather than adjustment (see section 10.5.4).

10.2 Inter-relationships between facial measurements

As stated, for all children, the rate of growth is not the same for all facial parameters and some measurements increase and some decrease in value. Knowledge of the inter-relationships between parameters would be beneficial to frame manufacturers to further understand the requirements of balancing scale when determining new spectacle frames designed for children and taking into account the impact of altering one parameter, such as distance between rims on the apical radius. In order to examine the relationship each of the facial measurement parameters had with each other, correlation matrices were constructed and tested for statistical significance.

	Strong	Moderate	Weak	No	Weak	Moderate	Strong
STRENGTH OF RELATIONSHIP	r >0.75 <1.00	r >0.50 <0.75	r >0.25 <0.50	r < 0.25 <- 0.25	r >-0.25 <- 0.50	r >-0.50 <- 0.75	r >-0.75 <- 1.00

** correlation significant at the 0.01 level (2-tailed)
*correlation significant at the 0.05 level (2-tailed)

	Frontal Angle R	Frontal Angle L	Splay Angle R	Splay Angle L	Head Width	Temple Width	Distance Between Rims 10	Distance Between Rims 15	Apical Radius	Crest Height R	Crest Height L	Front to Bend R	Front to Bend L	Distance Between Pad Centres	Pupillary Distance
Frontal Angle R															
Frontal Angle L	0.899**														
Splay Angle R	0.314**	0.264**													
Splay Angle L	0.249**	0.316**	0.693**												
Head Width	-0.262**	-0.281**	-0.101**	-0.096**											
Temple Width	-0.233**	-0.248**	-0.09	-0.003	0.526**										
Distance Between Rims 10	0.480**	0.491**	0.617**	0.587**	-0.234**	-0.026									
Distance Between Rims 15	0.414**	0.409**	-0.558**	0.534**	-0.194**	-0.035	0.930**								
Apical Radius	0.477**	0.485**	0.587**	0.553**	-0.233**	-0.012	0.969**	0.898**							
Crest Height R	-0.599**	-0.598**	-0.199**	-0.217**	0.429**	0.324**	-0.350**	-0.335**	-0.361**						
Crest Height L	-0.607**	-0.610**	-0.181**	-0.205**	0.423**	0.315**	-0.349**	-0.330**	-0.359**	0.972**					
Front to Bend R	-0.318**	-0.338**	-0.145**	-0.127**	0.616**	0.216**	-0.299**	-0.297**	-0.296**	0.448**	0.447**				
Front to Bend L	-0.282**	-0.309**	-0.078*	-0.135**	0.623**	0.217**	-0.281**	-0.290**	-0.279**	0.448**	0.455**	0.837**			
Distance Between Pad Centres	0.360**	-0.365**	0.698**	0.692**	-0.110**	-0.126**	0.469**	-0.394**	-0.480**	-0.263**	-0.241**	-0.091**	-0.065		
Pupillary Distance	-0.299**	-0.332**	-0.037	-0.050	0.647**	0.451**	-0.277**	-0.271**	-0.277**	0.494**	0.498**	0.697**	0.682**	0.010	

Figure 10.2a. Correlation matrix with significance values to show relationships between facial parameters for White British children.

	Strong	Moderate	Weak	No	Weak	Moderate	Strong
STRENGTH OF RELATIONSHIP	r >0.75 <1.00	r >0.50 <0.75	r >0.25 <0.50	r < 0.25 <- 0.25	r >-0.25 <- 0.50	r >-0.50 <- 0.75	r >-0.75 <- 1.00

** correlation significant at the 0.01 level (2-tailed)
*correlation significant at the 0.05 level (2-tailed)

	Frontal Angle R	Frontal Angle L	Splay Angle R	Splay Angle L	Head Width	Temple Width	Distance Between Rims 10	Distance Between Rims 15	Apical Radius	Crest Height R	Crest Height L	Front to Bend R	Front to Bend L	Distance Between Pad Centres	Pupillary Distance
Frontal Angle R															
Frontal Angle L	0.875**														
Splay Angle R	0.008	0.008													
Splay Angle L	-0.074	0.009	0.701**												
Head Width	-0.047	0.001	0.152**	0.127*											
Temple Width	0.110	0.120*	0.288**	0.212**	0.583**										
Distance Between Rims 10	0.098	0.127*	0.343**	0.303**	-0.156**	0.018									
Distance Between Rims 15	0.039	0.058	0.335**	0.277**	-0.037	0.106	0.920**								
Apical Radius	0.080	0.092	0.326**	0.279**	-0.157**	0.024	0.947**	0.866**							
Crest Height R	-0.278**	-0.203**	-0.103	-0.076	0.153**	-0.170**	-0.170**	-0.087	-0.179**						
Crest Height L	-0.272**	-0.209**	-0.072	-0.070	0.125*	-0.168**	-0.147**	-0.072	-0.159**	0.959**					
Front to Bend R	-0.005	0.071	0.069	0.137*	0.606**	0.300**	-0.181**	-0.093	-0.195**	0.190**	0.169**				
Front to Bend L	0.047	0.118*	0.148**	0.066	0.587**	0.310**	-0.167**	-0.068	-0.187**	0.161*	0.143*	0.790**			
Distance Between Pad Centres	0.142*	0.180*	0.779**	0.779**	0.327*	0.323**	-0.017	0.018	-0.046	0.002	0.014	0.311**	0.316**		
Pupillary Distance	0.008	0.044	0.247**	0.225**	0.621**	0.511**	-0.234**	-0.149**	-0.239**	0.138*	0.131*	0.593**	0.596**	0.435**	

Figure 10.2b. Correlation matrix with significance values to show relationships between facial parameters for Chinese children.

STRENGTH OF RELATIONSHIP	Strong	Moderate	Weak	No	Weak	Moderate	Strong
	r >0.75 <1.00	r >0.50 <0.75	r >0.25 <0.50	r < 0.25 <- 0.25	r >-0.25 <- 0.50	r >-0.50 <- 0.75	r >-0.75 <- 1.00

** correlation significant at the 0.01 level (2-tailed)
*correlation significant at the 0.05 level (2-tailed)

	Frontal Angle R	Frontal Angle L	Splay Angle R	Splay Angle L	Head Width	Temple Width	Distance Between Rims 10	Distance Between Rims 15	Apical Radius	Crest Height R	Crest Height L	Front to Bend R	Front to Bend L	Distance Between Pad Centres	Pupillary Distance
Frontal Angle R															
Frontal Angle L	0.967**														
Splay Angle R	-0.072	-0.052													
Splay Angle L	-0.258**	-0.235*	0.794**												
Head Width	-0.319**	-0.309**	0.206*	0.103											
Temple Width	0.072	0.077	-0.055	-0.160	0.410**										
Distance Between Rims 10	0.426**	0.451**	0.303**	0.180	-0.376**	-0.069									
Distance Between Rims 15	0.240*	0.257**	0.187	0.033	-0.242*	0.140	0.851**								
Apical Radius	0.417**	0.443**	0.282**	0.166	-0.394**	-0.072	0.994**	0.853**							
Crest Height R	-0.511**	-0.501**	-0.008	0.057	0.241*	-0.199*	-0.288**	-0.209*	-0.289**						
Crest Height L	-0.486**	-0.479**	-0.021	0.017	0.255*	-0.168	-0.281**	-0.176	-0.280**	0.977**					
Front to Bend R	-0.295**	-0.301**	0.300**	0.333**	0.625**	-0.071	-0.286**	-0.294**	-0.315**	0.270**	0.234*				
Front to Bend L	-0.301**	-0.309**	0.344**	0.322**	0.598**	-0.038	-0.297**	-0.260**	-0.330**	0.313**	0.291**	0.868**			
Distance Between Pad Centres	-0.175	-0.167	0.527**	0.586**	0.378**	0.063	-0.181	-0.201*	-0.189	-0.023	-0.017	0.447**	0.465**		
Pupillary Distance	-0.321**	-0.304**	0.290**	0.245*	0.720**	0.255*	-0.449**	-0.395**	-0.456**	0.222*	0.202*	0.579**	0.546**	0.519**	

Figure 10.2c. Correlation matrix with significance values to show relationships between facial parameters for White British children with Down’s syndrome.

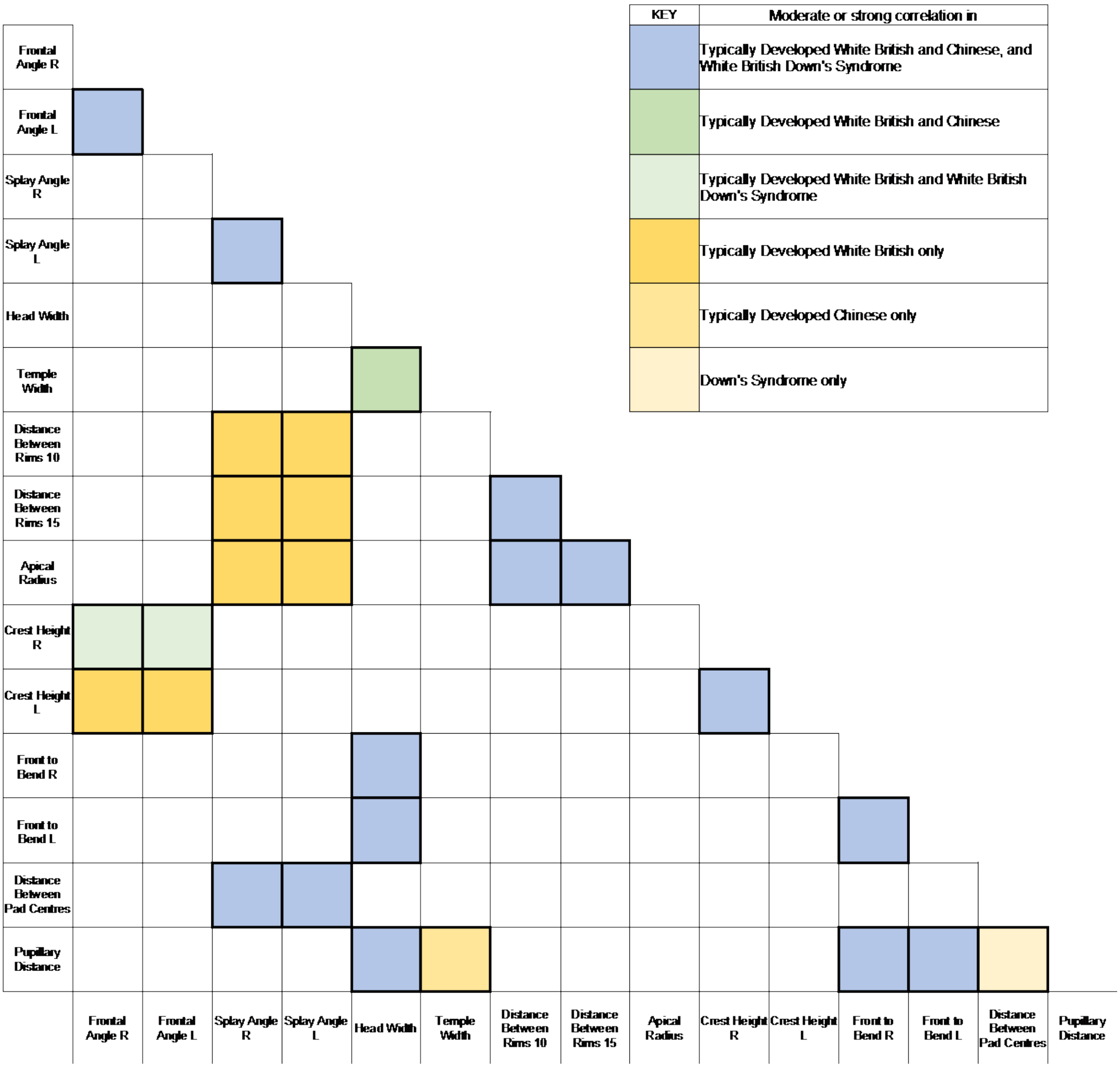


Figure 10.2d. Correlation matrix summary to show the moderate or strong correlations across the White British typically-developed, Chinese typically-developed and White British children with Down's syndrome.

As expected, due to a certain degree of facial symmetry, right and left measurements for frontal angle, splay angle, crest height and front to bend are highly correlated.

Head width and temple width are highly correlated in typically-developed (TD) White British and Chinese children but not in children with Down's syndrome (DS) where the correlation was 0.410. Although significant, the lack of correlation with TD children could be due to the much smaller sample of children with DS or that indeed there is a different growth relationship between these parameters. In the Chinese group temple width was correlated with pupillary distance (r = 0.511). There was a weaker but significant relationship between these parameters in TD White British (r = 0.451) but no meaningful relationship between these parameters in DS (r = 0.255).

Head width and pupillary distance are highly correlated across all groups of children as are front to bend coupled with pupillary distance and front to bend coupled with head width, thus indicating growth relationships across the sagittal and frontal planes. Splay angle and distance between pad centres also showed a correlation across all three groups, the strongest correlation found in the Chinese group (r = 0.779), with a moderate correlation in White British TD and DS groups. As expected, due to the emergence of the nasal bearing surface, albeit at differing rates, the relationship between distance between rims at 10 and 15mm below and apical radius also show a strong correlation across all three groups.

There was a correlation between frontal angle and crest height found in White British children only, TD or with DS. In the Chinese group the correlation was very weak; right comparison r = -0.278 and left comparison r = -0.203. This is likely to be due to different growth characteristics in the Chinese face compared to White British albeit surprising due to the similarities in growth observed between Chinese and children with DS.

Some correlations were only found in TD White British children; distance between rims at 10 and 15mm and apical radius with the splay angle which suggests that the pattern of growth in the white British ethnicity occurs differently compared to Chinese ethnicity and compared to children with DS.

Some correlations were only found to be moderately or strongly correlated in typically developed Chinese children or white British children with Down’s syndrome. In white British children with Down’s syndrome the distance between pad centres was moderately correlated with pupillary distance (r = 0.519). In typically developed White British children there was no correlation (r = 0.010) but although weak the correlation between these measurements in Chinese was 0.435 ($p<0.01$) which may suggest that the nasal characteristics in Down’s syndrome show some similarity with typically developing Chinese children.

Frontal angle and distance between rims measurements showed a weak (r = 0.480 DBR10, FAR) but significant correlation in White British TD and this was also apparent for DBR10 and frontal angle in children with DS (r = 0.426 DBR10 FAR) but no relationship apparent (r = 0.098 DBR10 FAR) for Chinese children. This relationship could be further explained by a mathematical relationship where application of trigonometry could, in theory calculate the frontal angle from two given width measurements (Sasieni, 1975) although that is assuming the side of the nose is straight and the bearing surface of a pad would sit between the two DBR measurements.

10.3 Implications for frame manufacture

It would not be economically viable or prudent for manufacturers to produce frames in a plethora of sizes to accommodate the majority of the population, although more choice and more evidence-based design would be welcomed by dispensing opticians (Chapter 3). There is a balance between size availability and the economics of frame manufacture such that currently, most frames are produced in one or two sizes and the difference between any choice in size is often limited to only a difference in eye size, possibly distance between lenses too, which only impacts on the overall width of the frame.

Due to the lack of facial data in the current literature it is unclear on what data spectacle frame designs are currently produced. In the case of frames for children it appears the majority are scaled-down adult designs (section 1.1) (Sasieni, 1975, Wang et al., 2005) or an estimation of parameter requirement that is tested by prototype on a small, local population (Priest, 2013, Giovanninni, 2014). Measuring frame parameters has been detailed previously (section 1.42a-j) and it is unsurprising that this level of data is not produced at source by the manufacturer. Most frame manufacturers will stamp on the frame the horizontal eye size and the minimum distance between lenses (DBL) which serves of no real value to the patient and their facial measurements, it merely allows the horizontal centre distance of the frame to be determined. The DBL value is often incorrectly perceived as the ‘bridge’ measurement that patients seek out themselves as what they will need for the frame to fit. Side length may also be stamped on the frame, and this is a total side length value, measured from the dowel point to the end of the tip (British Standards Institute, 2020), useful to determine the length of drop once the length to bend has been established, albeit limiting if the side is incapable of adjustment.

It could be argued that more information regarding the parameters should be stamped on the frame itself, such as head width and bridge dimensions, although the latter would vary for differing types of bridges. However. in practice, since these measurements are often adjusted and modified by the Dispensing Optician from a visual appraisal of the fit, factory set information may not be of real value and would serve to cause confusion to the industry. A more tangible benefit to the optical profession would be to manufacture spectacle frames for children using population data and publish this data in online frame catalogues for reference.

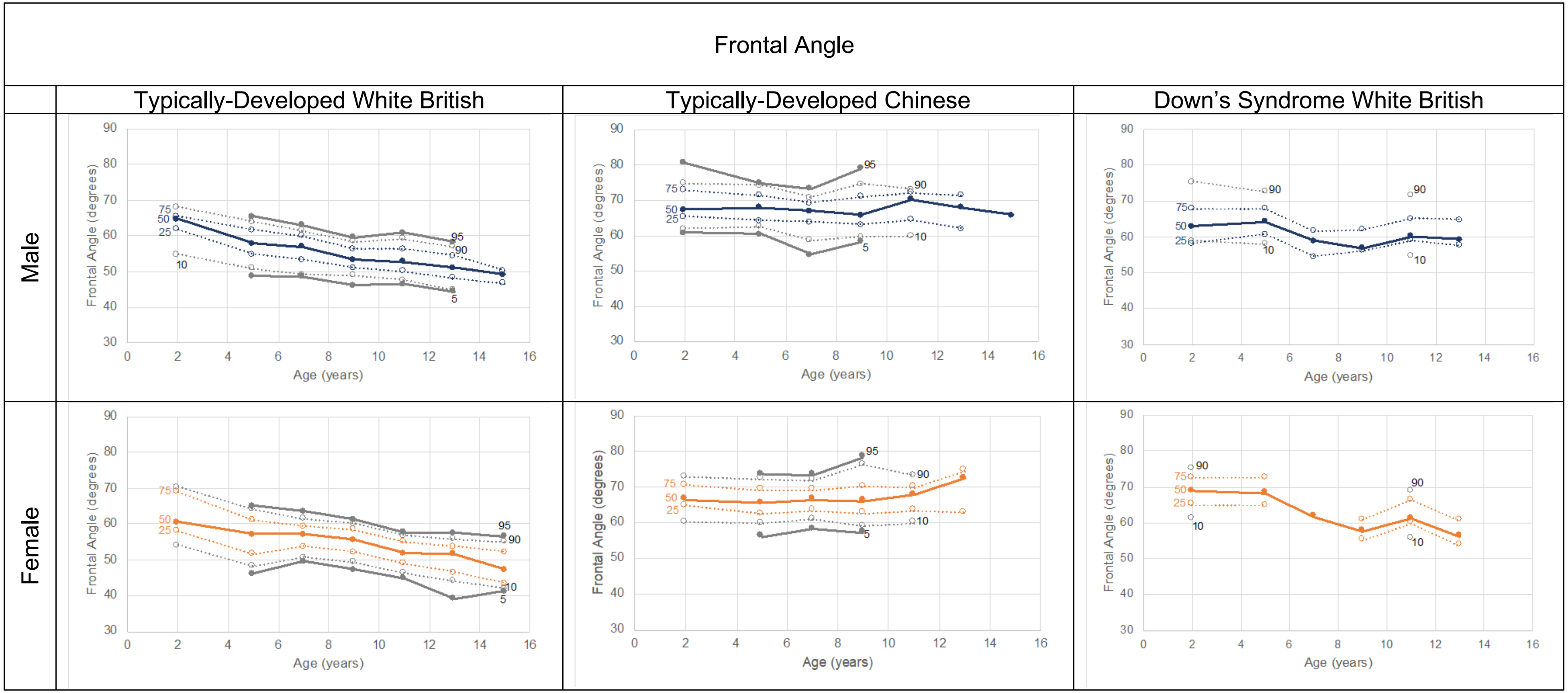
10.4 Facial parameters presented as percentiles

Percentiles are often used when providing human growth information such as height and weight in order that the reader can identify if growth is typical or atypical. Percentile charts can inform frame manufacturers when deciding on an appropriate size range to provide and the numbers of frames that would need to be produced. Figures 10.4a-k show the 5th, 10th,25th, 50th, 75th, 90th and 95th percentiles for each facial measurement parameter as a function of typically developed 'White British' and 'Chinese' ethnicities and 'White British' children with Down's syndrome. Percentiles were calculated in the 0-3.9, 4-5.9, 6-7.9, 8-9.9, 10-11.9, 12-13.9 and 14-16 age bandings using the PERCENTILE.EXC function of Microsoft Excel and plotted graphically at the mid-point of the age banding e.g., a data point at age 5 is derived from data from the ages of 4 to 5.9, etc. This function interpolates when the specified percentile lies between two values in an array. The banded regions on the charts show where the middle 50% of the population lies. Table 10.4a shows the number of subjects in each age-banding from which the percentiles were calculated.

Age Band	Typically-Developed White British		Typically-Developed Chinese		Down's Syndrome White British	
	Male	Female	Male	Female	Male	Female
0-3.9	9	12	22	16	11	15
4-5.9	74	53	52	58	17	6
6-7.9	101	103	45	32	4	3
8-9.9	91	102	25	22	6	6
10-11.9	82	93	15	18	12	9
12-16	40	49	2	2	8	4

Table 10.4a. Numbers of images in each age band used to calculate percentiles.

It can be seen that the number of subjects was lowest in the 0-3.9 and 12-14 age bands. Overall numbers are lowest in the Chinese ethnic group and in particular the Down's Syndrome group. In bands with reduced numbers, it was not possible to calculate the 5th, 10th,90th and 95th percentile. In the Down's syndrome group females, it was only possible to calculate the 50th percentile in the 6 to 7.9 age band. Therefore, although following percentile charts are useful for frame manufacturers, the greatest confidence in the values are where at least the 10th and 90th percentiles have been calculated, which is mostly in the age ranges from 4 to 12 years.



<u>Figure 10.4b.</u> Age percentiles for frontal angle as a function of gender, ethnic group and Down's syndrome.

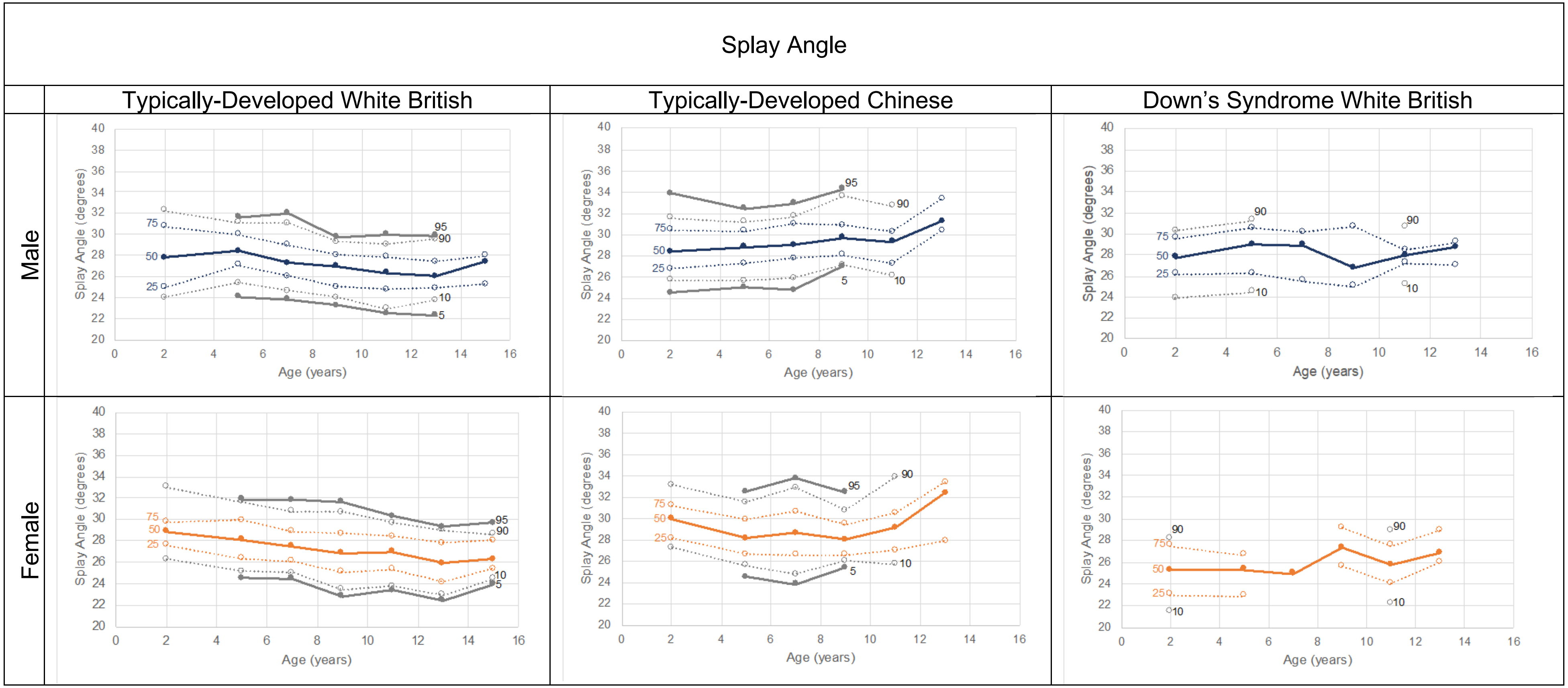


Figure 10.4c. Age percentiles for splay angle as a function of gender, ethnic group and Down's syndrome.

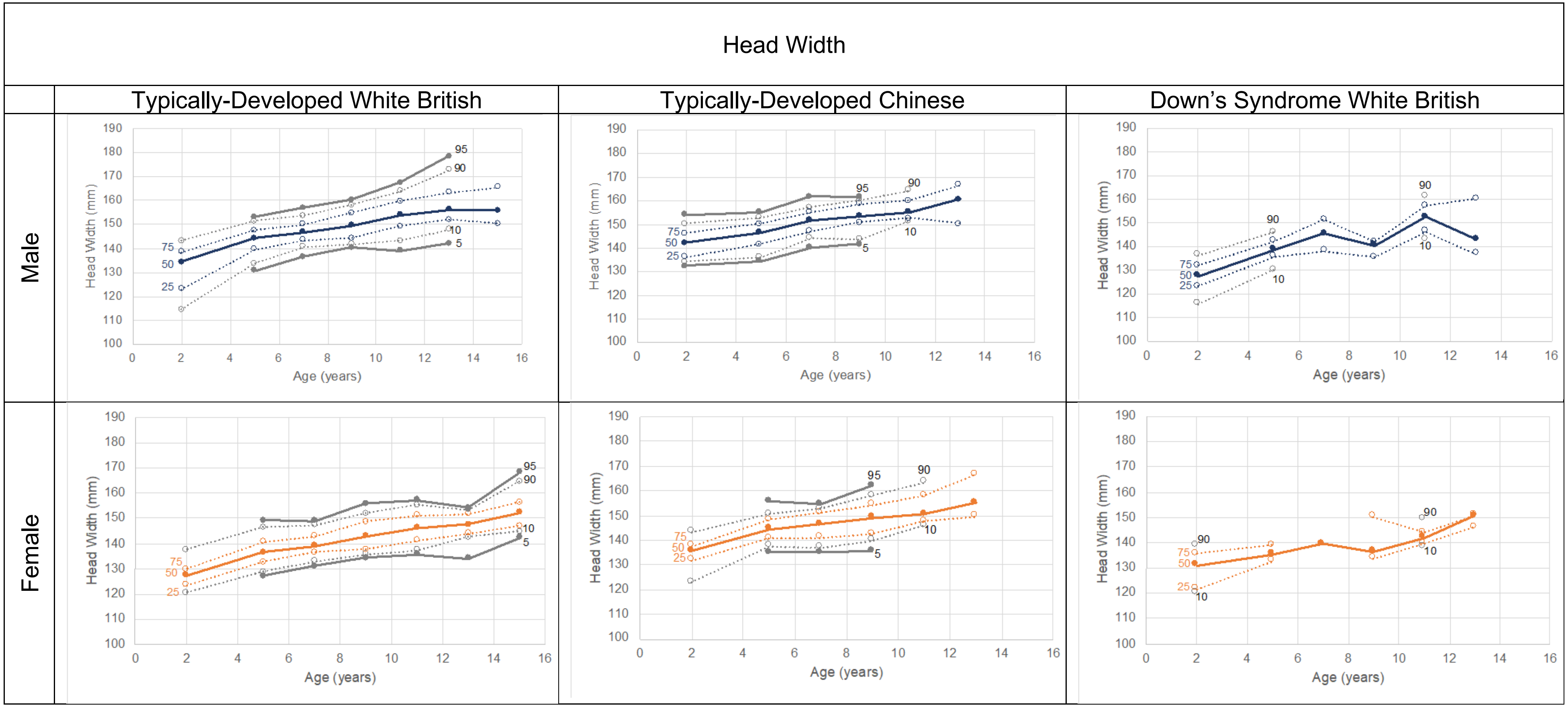


Figure 10.4d. Age percentiles for head width as a function of gender, ethnic group and Down's syndrome.

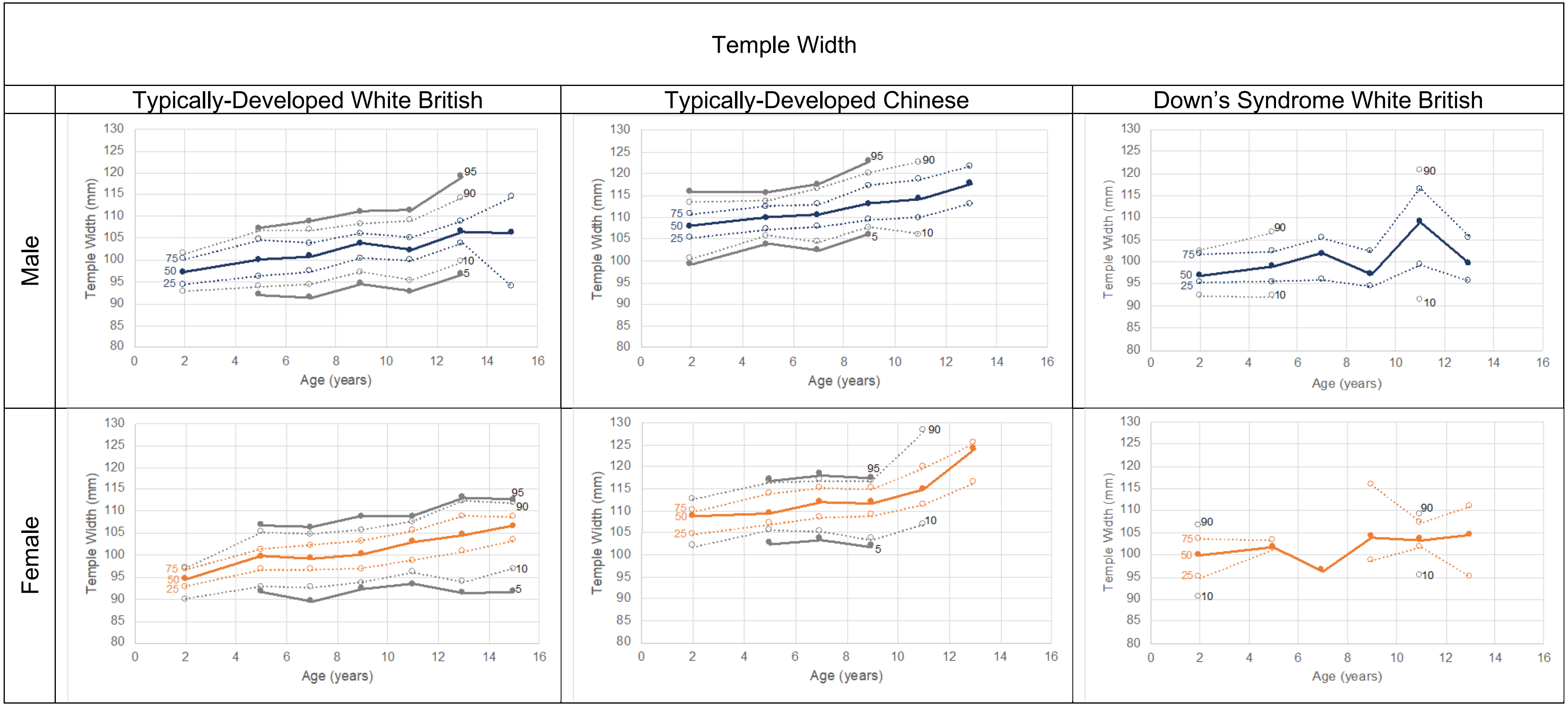


Figure 10.4e. Age percentiles for temple width as a function of gender, ethnic group and Down’s syndrome.

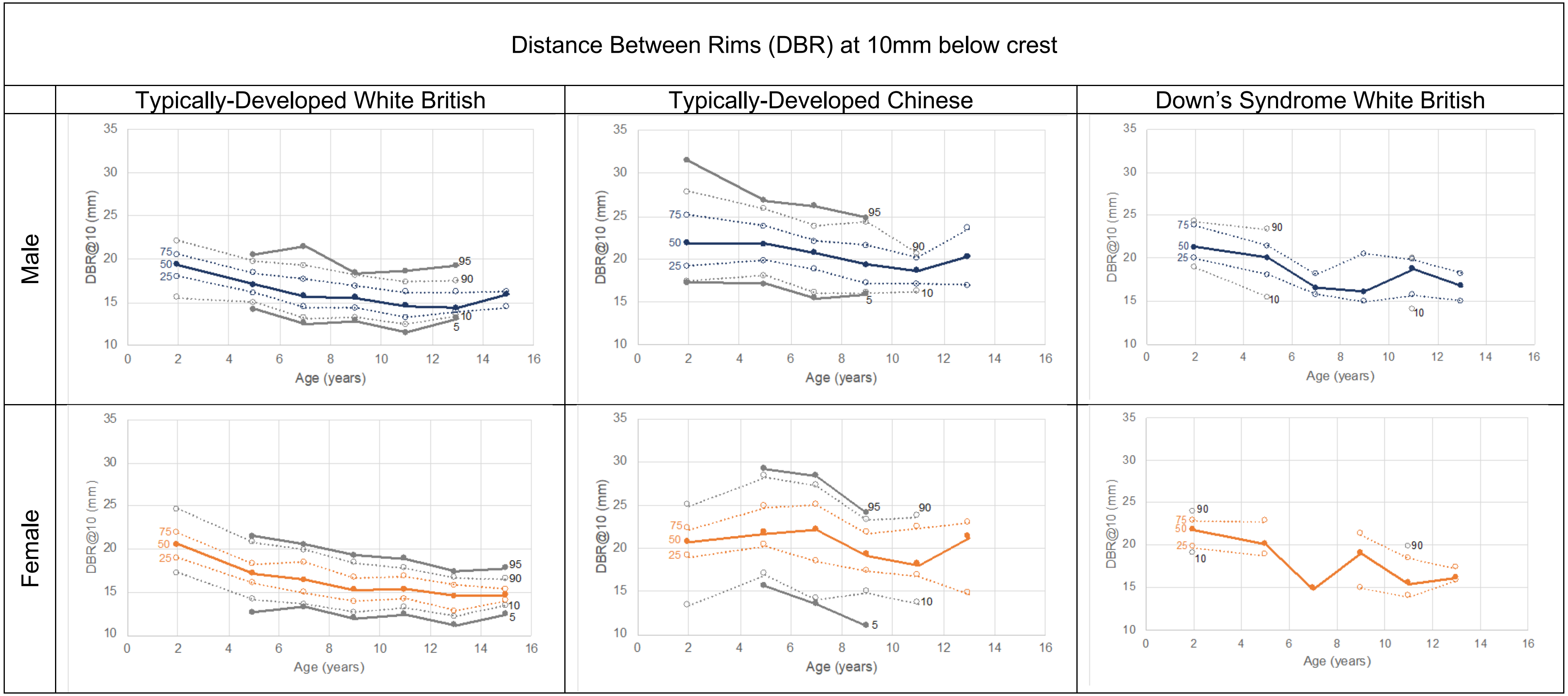


Figure 10.4f. Age percentiles for distance between rims at 10mm below crest as a function of gender, ethnic group and Down's syndrome.

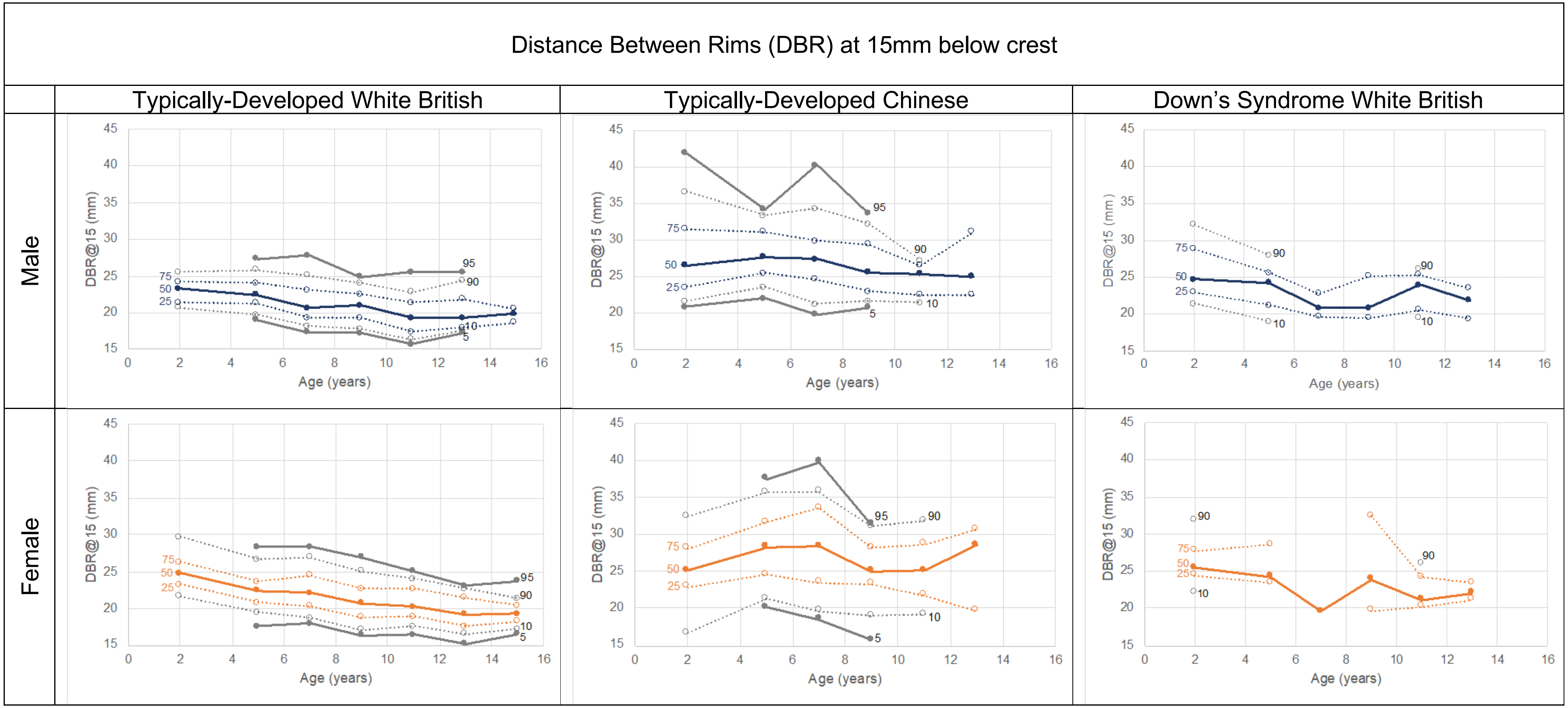


Figure 10.4g. Age percentiles for distance between rims at 15mm below crest as a function of gender, ethnic group and Down's syndrome.

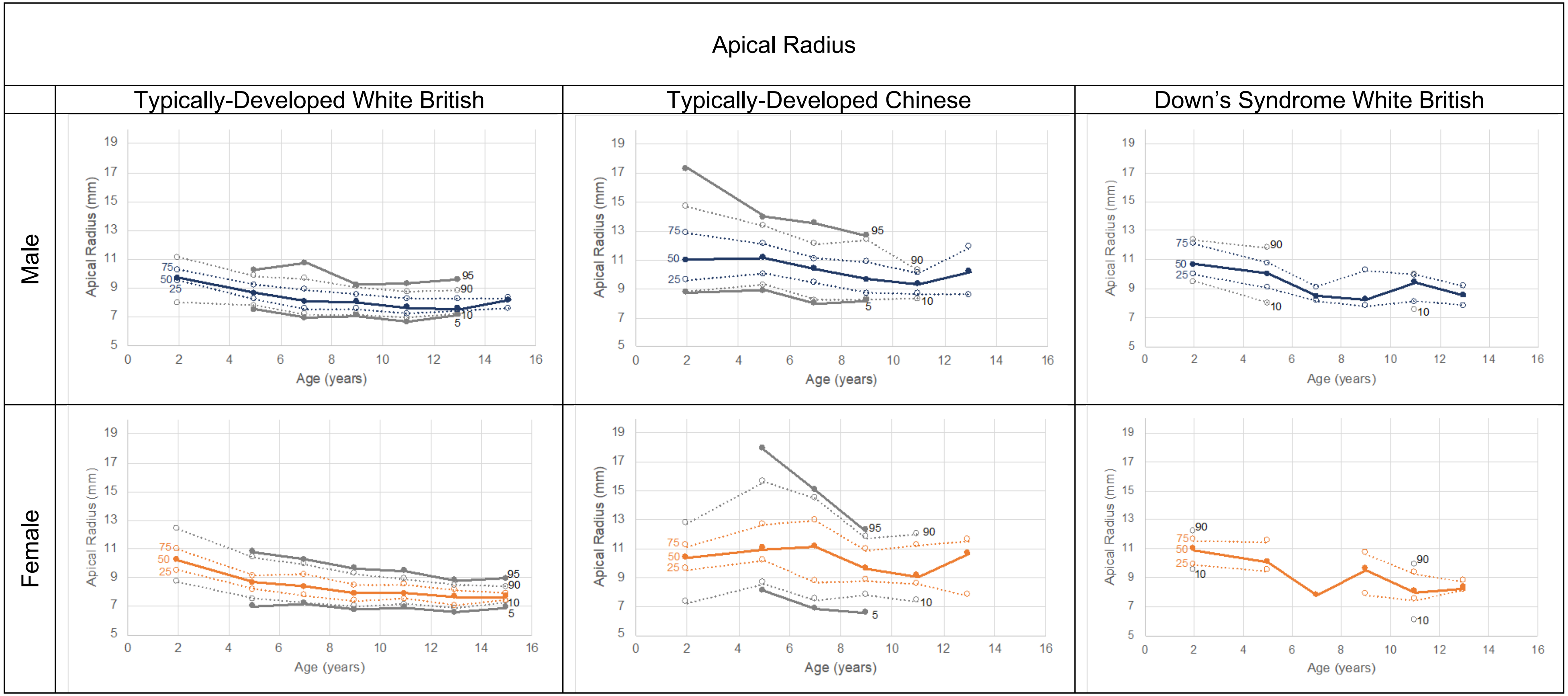


Figure 10.4h. Age percentiles for apical radius as a function of gender, ethnic group and Down's syndrome.

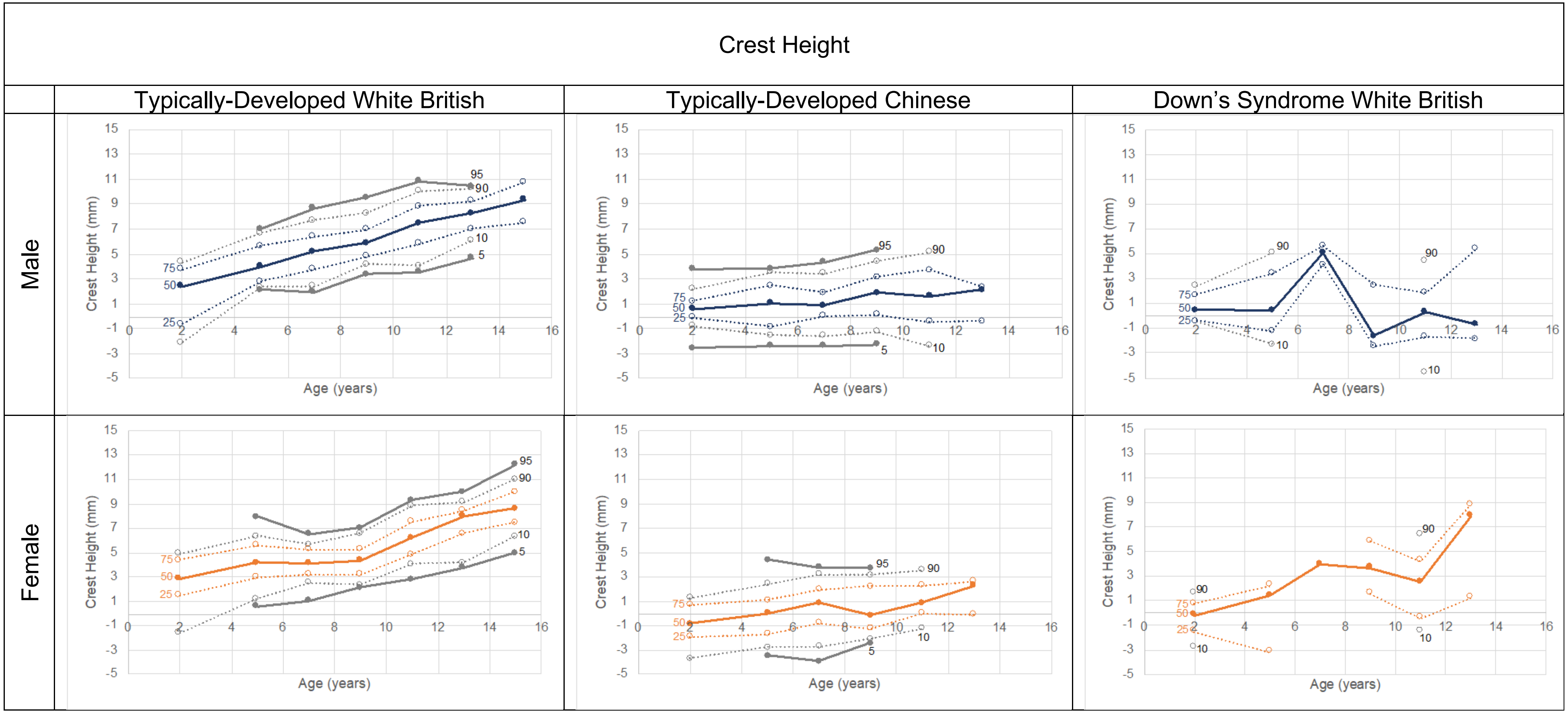


Figure 10.4i. Age percentiles for crest height as a function of gender, ethnic group and Down's syndrome.

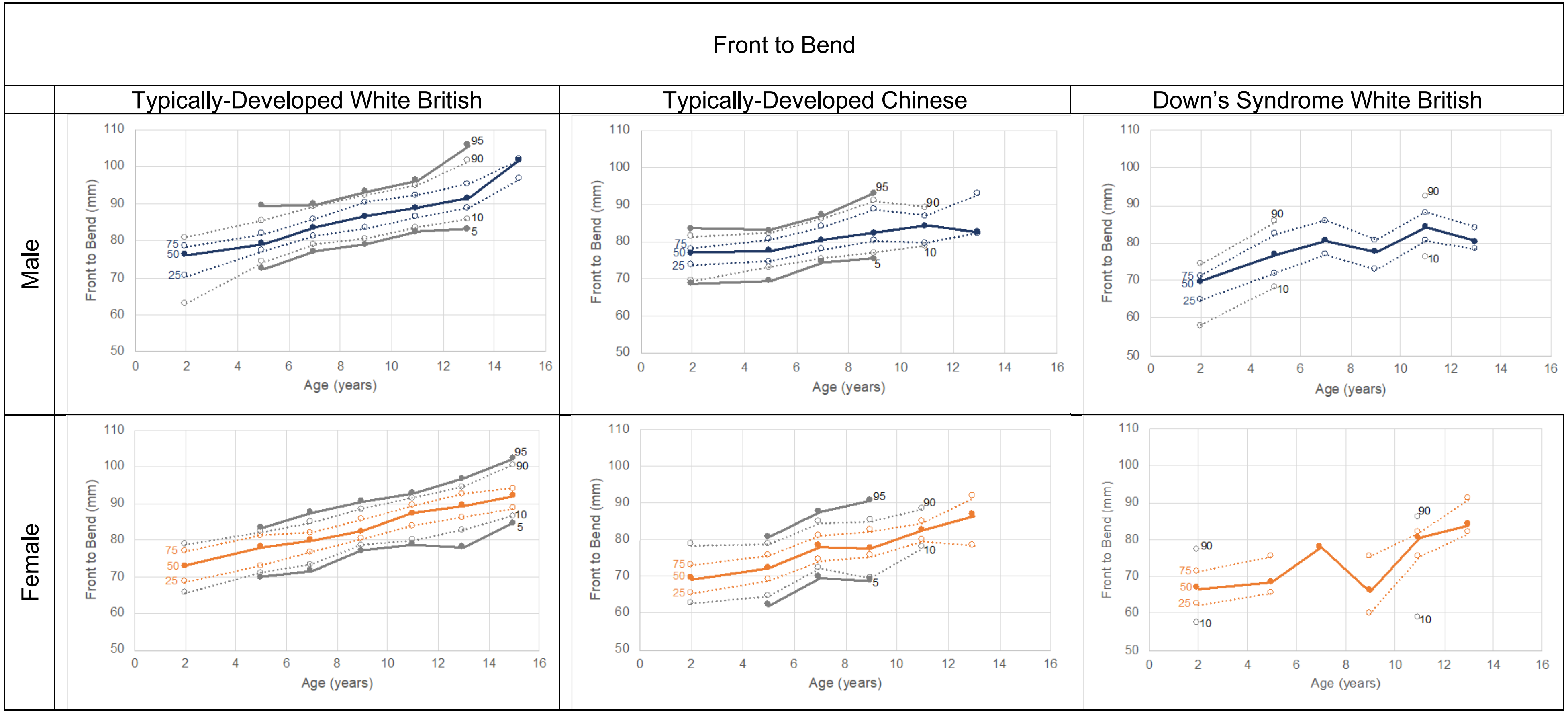


Figure 10.4j. Age percentiles for front to bend as a function of gender, ethnic group and Down's syndrome.

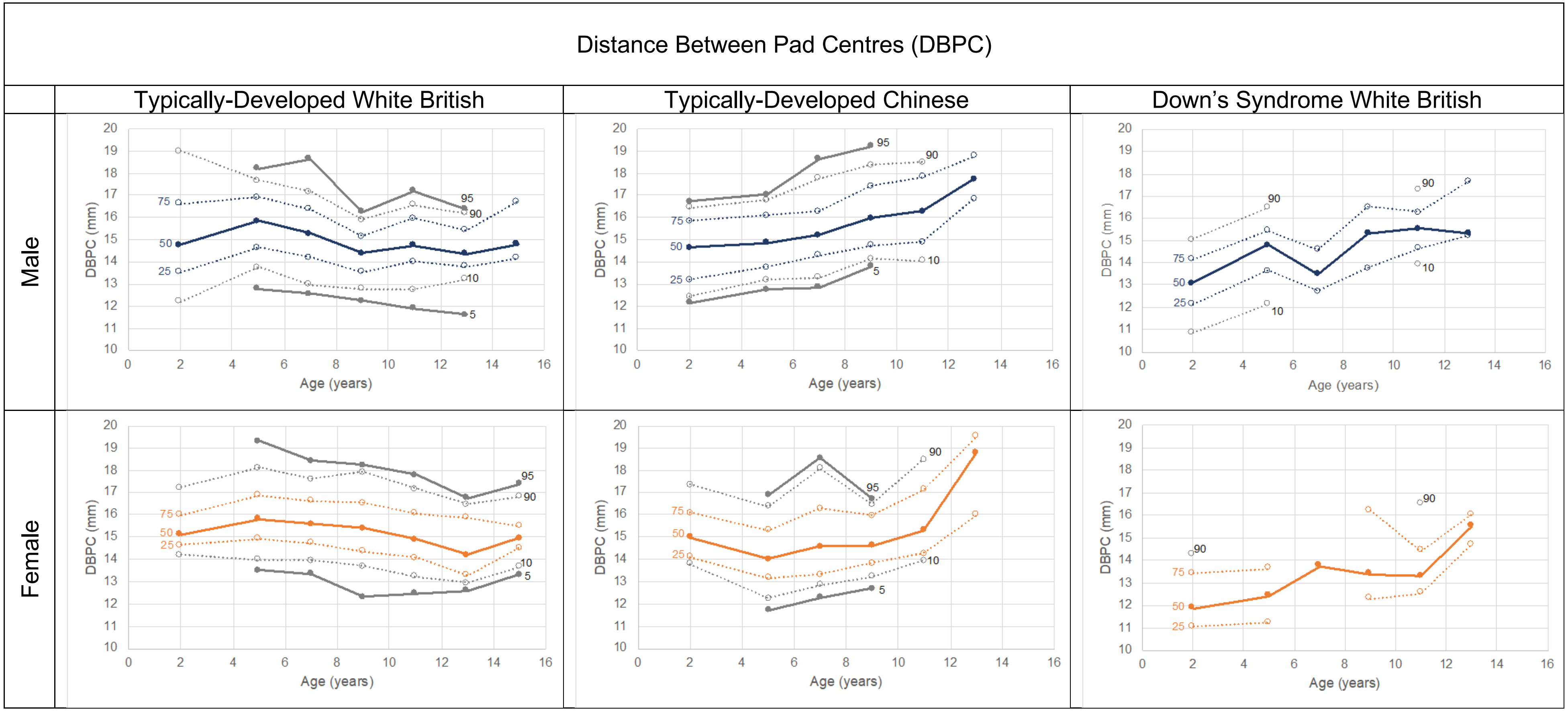


Figure 10.4k. Age percentiles for distance between pad centres as a function of gender, ethnic group and Down's syndrome.

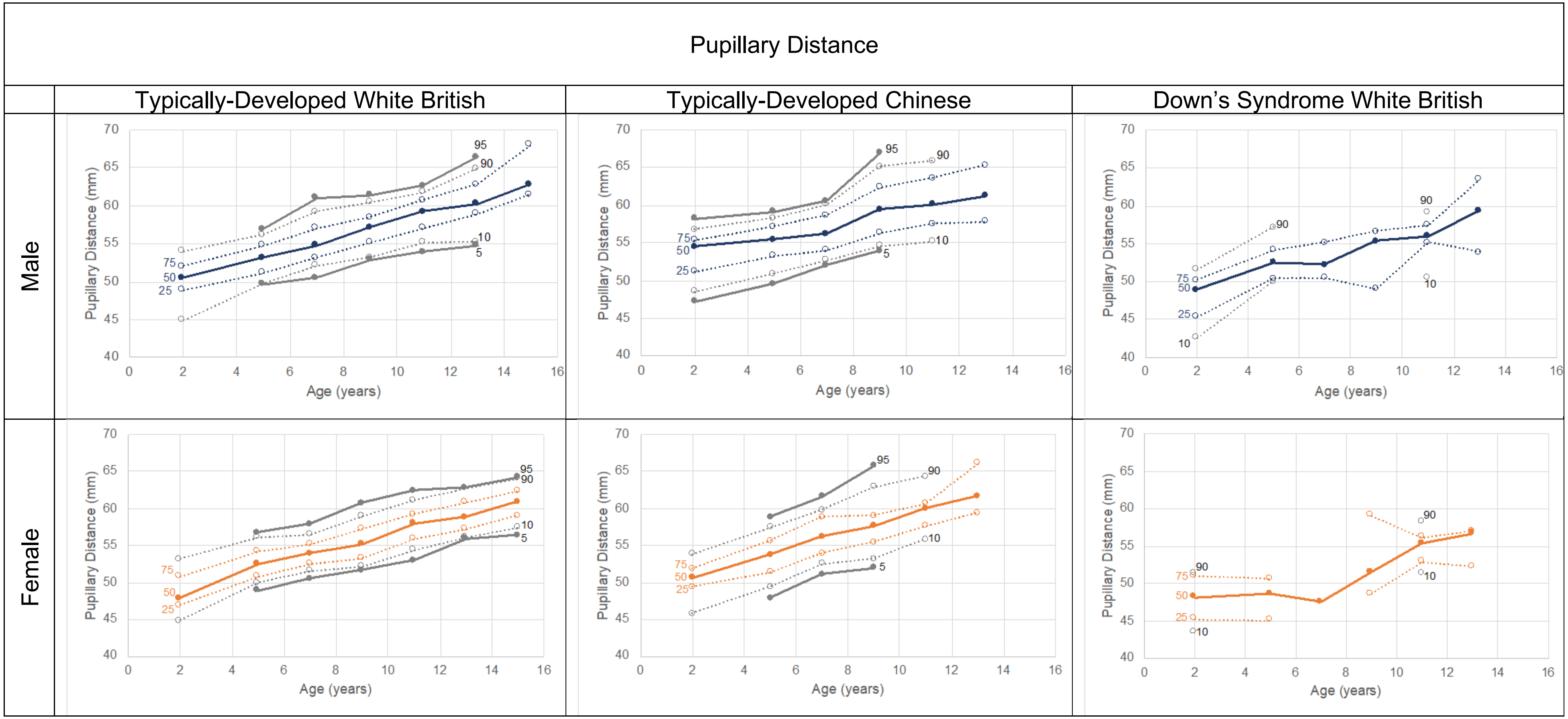


Figure 10.4l. Age percentiles for pupillary distance as a function of gender, ethnic group and Down's syndrome.

10.5. Recommendations for paediatric spectacle frame design

In section 10.4, population data is presented to inform parameters of spectacle frames for typically-developed children of White British ethnicity, Chinese ethnicity and children of White British ethnicity with Down's syndrome.

By utilising the data, frames could then be designed specifically for children and not scaled-down adult designs. A design balance needs to be found between fashion and fit as children tend to want the latest trends and parents/carers often want their child to look like themselves when wearing spectacles. If the child is happy with the look of their spectacles and gains peer approval, that will naturally increase compliance in wear, however in contrast, poorly fitting spectacles are an annoyance and can be uncomfortable and this can also impact on compliance. Certain elements of the frame design would need to look quite different, especially those designed for younger children, utilising different frame element features will assist with the balance between fashion and fit and hence a correct fitting, comfortable, cosmetically appealing frame design can be achieved.

10.51 Lens shape

The shape of the lens aperture in the frame is vitally important, we know that the bridge needs to sit relatively lower than the horizontal centre line in order to raise the entire frame higher in the vertical plane. However, young children will also naturally have an upwards gaze (Obstfeld, 1997) for the majority of their day and therefore to counteract this fact, there is a need to maximise the lens aperture in this vertical direction, especially in the area above the horizontal centre line, as depicted in figure 10.5.1, avoiding flat-topped rectangular lens shapes which limit the upper field of view.

Figure 10.51. Rounded lens shape (left) and rectangular lens shape (right) showing the difference in lens substance above the horizontal centre line.

10.52. Bridge position and design

The percentiles can help determine the proportional differences between age groups when considering spectacle frame design, especially of the bridge as it is evident the crest height needs to be much lower for younger children, with wider angles and distance between rims and pads. These frames would then be useful for older children of differing ethnicities, such as Chinese children, and children with Down's syndrome who have a lower crest overall compared to White British typically-developed children, with negative values reported into the much older age groups. A bridge sat in a negative position, i.e. lower than the midline, as shown in figure 10.52a, may not be as cosmetically appealing to children and parents as it is totally opposite to current fashionable designs.

Figure 10.52a. Low bridge position to accommodate a negative crest height.

Frontal angles vary by approximately 20 degrees across the population in all groups and therefore this would require several designs to accommodate or be capable of major adjustment in the case of pads on arms or use a keyhole bridge design. Splay angles show much less variability (approximately 10 degrees), although adjusting this parameter can again only be performed for a *"pads on arms"* design of bridge. Distance between rims (DBR) and apical radius (AR) are regular bridge frame parameters where adjustability is not possible. Differing options would be required to accommodate the 10mm variation (DBR) and 4mm variation (AR) which was observed in the TD White British and White British with DS subjects of this study. Even more variation would be required in TD Chinese children.

Using different bridge designs or modifications can help achieve the frame to sit higher on the face and solve some of these issues. An example is the keyhole bridge (figure 10.52b), which by design looks more like an adult frame design and may therefore be a more cosmetically appealing option. The bearing surface is not designed to fit into the 'keyhole', the weight is distributed along the long vertical lines of the shape. The 'keyhole' shape allows for the natural fit of variations of the frontal angle, making contact lower down the keyhole shape, thus lifting the front vertically on the face.

Figure 10.52b. Keyhole bridge design.

A regular bridge features no pads at all and would need to fit exactly, contacting all around the bridge, therefore requiring several different size options. If a silicon pad arrangement is added behind the bridge, that gives much more vertical height, adjustability and comfort for the underdeveloped nasal structure, even more useful if the bridge can be repositioned in several pre-drilled options which is a feature of the Tomato™ range of frames (Tomato Glasses, 2021).

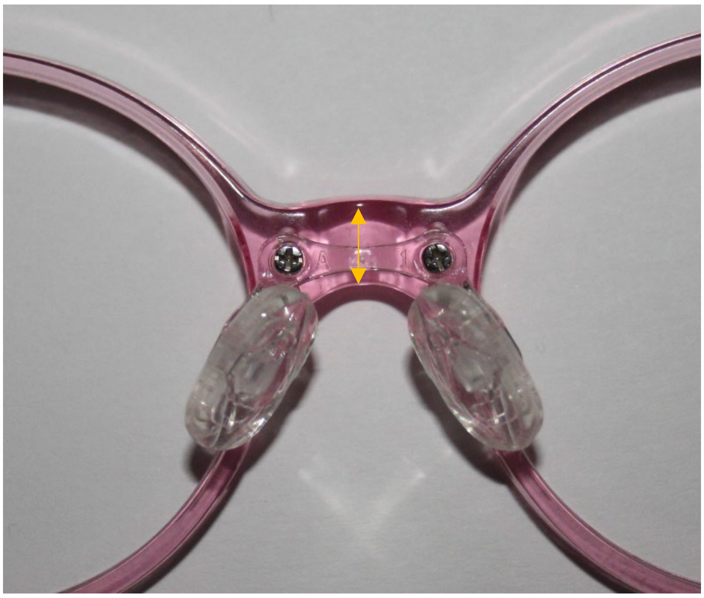


Figure 10.52c. Adjustable pads with the option of three vertical positions, showing the extend of the potential height variation.

The rims are of a reasonable thickness and made of a robust material such as cellulose acetate, then fixed pad bridges can be converted with relative ease into a "*pads on arms*" type of bridge, allowing the Dispensing Optician to place these at an appropriate height and position. Along with adjusting the pad's angles for frontal and splay, the distance between pad centres is also highly adjustable on the pads on arms type bridge, which will accommodate the reported 5-8mm variation across all groups studied. Pads need to spread the weight across the largest pad diameter possible for that particular child's facial anatomy and not be small and round which will concentrate the weight of the spectacles in one small, developing area. The process of conversion is to remove the fixed pads by cutting them flush with the back rim using side cutters, flatten and re-polish the surface of the inner rim, locate the intended position of the pad arm using a hand drill, insert the pad arm into position using a punch tool and attach a suitable pad (Hilco, 2018).

10.53. Head and temple width

The percentiles for head and temple width (figures 10.4d and 10.4e) show that in order to fulfil the needs of all children, a variation of 20-25mm occurs across all child groups with wider values in both parameters for Chinese children. For those children with a wider temple or head width, the initial idea is perhaps to select a wider frame across the horizontal dimension, that may be acceptable if the child also has a relatively wide pupillary distance (PD). But as evidenced in the data for Chinese and children with DS, this relationship does not follow, and since there is an approximate 10mm variation across all age groups for PD, there will be a requirement to adjust or decentre the optical centres of the lens to match the pupillary distance. To have a wider spectacle frame front in an individual with a narrow PD results in excessive decentration which may mean nasal or temporal edge lens thickness will impact on the fit and cosmetic appearance of the finished spectacles, particularly important in high levels of ametropia. The thickness, particularly in myopic and/or high levels of astigmatic correction may also mean there is a limited ability to physically splay adjustable nose pads which is often overlooked at the time of dispensing. An extended metal lug (figure 10.53a) can help with this issue. This feature is found in Erin's World frames, designed for children with DS, (Erin's World Frames, 2021) which also then gives more possibilities in altering the temple and subsequent head width by half-covered nylon pliers. Many metal frames are designed with a thick lug for cosmetic reasons, making let-back adjustment almost impossible. Plastic frames can be filed to increase the angle of let-back if the side joint is on the front and not swept back as in figure 10.53b, in order to create more width across the temple and head. Nevertheless, decreasing this parameter is often more difficult and involves heating and holding the lug in its new position, a task almost impossible with many modern frame materials such as grillamide.

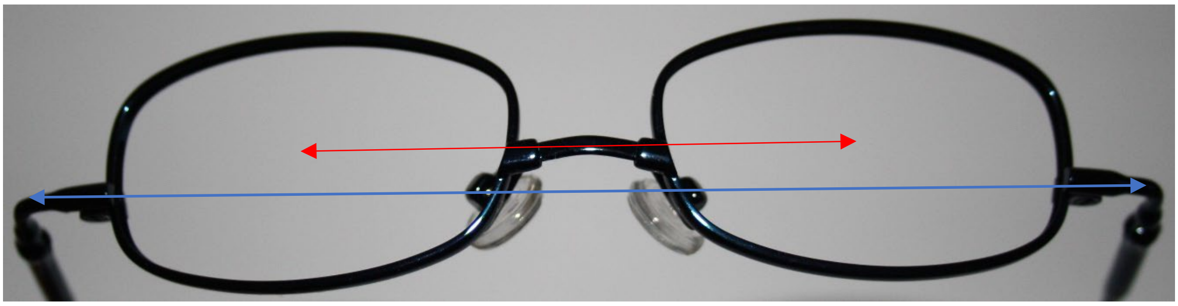


Figure 10.53a. Extended lug showing the extended temple width (shown in blue) in comparison to a relatively narrow horizontal centre distance (shown in red).

Figure 10.53b. Examples of current lug designs; swept-back lug (left) and thick metal lug (right).

10.54 Sides

Sides are currently manufactured in a total length (approximately 125mm) which is too long for the majority of children and approximately 15mm will need to be removed from the average side (Zhuk, 1973), in agreement with the findings of this study where the mean value for typically-developed White British male FTBR is 85.84 (6.66) mm which would result in an unsightly and uncomfortable 40mm long drop, based on a 125mm total side length. The percentile charts in this chapter show that for each age group, an average of 20mm variation occurs for the front to bend measurement (figure 10.4j). Thus, a degree of adjustability is required in the design for this parameter. Plastic sides tend to have no adjustable features which means that the total side length has to remain which in turn becomes an unsightly long drop behind the ear that potentially can sit on the delicate mastoid process of the temporal bone located behind the ear and cause extreme discomfort. Occasionally plastic sides may be cut, but it is not recommended if it exposes the reinforcing wire (often nickel based metal) as this may cause a skin reaction or sore on the child's ear. Metal sides can have their end tip removed and be cut down to size, filed and the end tip replaced if the design lends itself to being altered. A thin, round core wire, such as the Erin's World frames is most useful to this adjustment (figure 10.54a). Fashion designs often feature a flattened, tapered core wire, such as the example in figure 10.54b, and offer a very limited degree of adjustment which is often deemed unsuccessful as the tip cannot slide over the taper and cutting it leaves a lack of protection over the ear point.

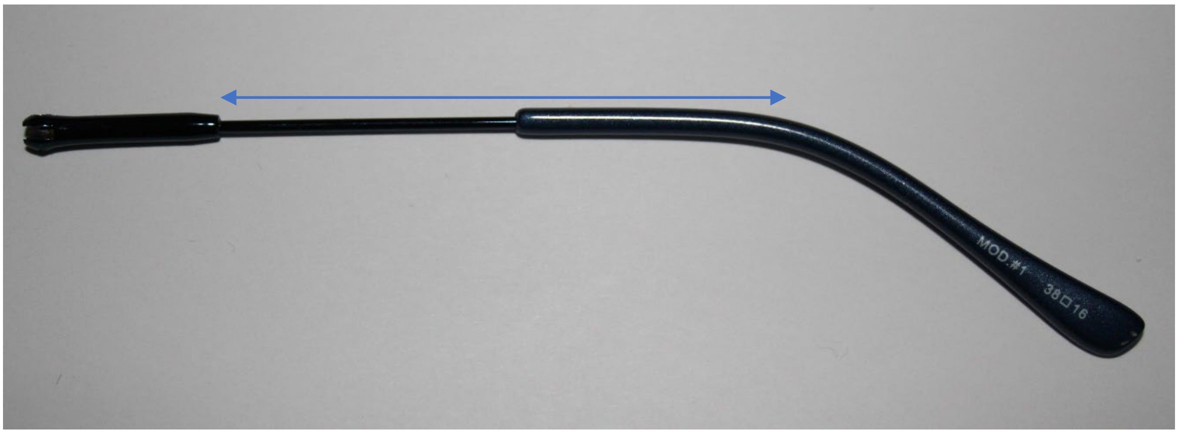


Figure 10.54a. Example of a metal side capable of being cut and re-tipped showing the extent of the adjustability.

Figure 10.54b. Example of a metal side of limited adjustment properties.

Tomato™ have manufactured adjustable plastic sides based on the process for metal side shortening, they have notches cut into the plastic to allow the tips to be removed, cutting of the side for shortening and then the end tip is re-applied to the side and anchored with a screw fixing.

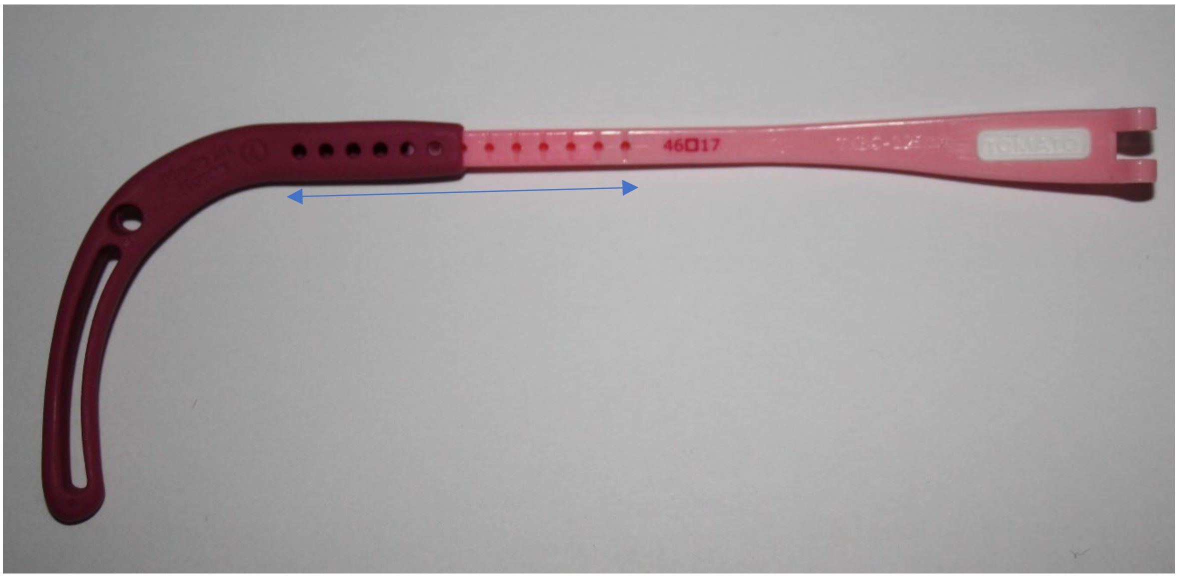


Figure 10.54c. Plastics side showing the potential range of length adjustment.

10.6 Conclusions of this Research

This programme of research was designed after identifying a need to improve the design and fit of spectacle frames for children, a notion investigated and verified with the dispensing profession by means of an online questionnaire. The sparsity in the literature of any anthropometrical facial data relating to spectacle frames indicated that this data needed to be gathered albeit in a manner conducive to working with children. Three-dimensional stereophotogrammetry is a non-invasive, rapid, highly accurate system of gathering anthropometric data and this study validated a new semi-automated programme for this system to take facial measurements relating to spectacle wear.

This study is unique in the fact that it is the first time the growth of facial measurements relevant to spectacle frame design has been quantified in typically-developed children of White British and Chinese ethnicities, along with White British children with Down's syndrome. Recruitment to this study yielded the largest known sample size in each of the groups that is specific to the full suite of facial measurements required for spectacle wear.

For typically-developed White British children, the flat, wide, low bearing surface of the nose follows a definite pattern of emergence from an early age and continues to become more defined with narrowing angles and breadth up to teenage years. Girls tend to have smaller parameters such as head width than boys, and differences in the rate of change was observed between genders due to boys having a relatively longer growth period than girls.

There are different growth patterns and therefore different parameters identified in different ethnicities of children and these are reported in comparison to typically-developed White British children. Chinese children tend not to have the emergence of the crest and therefore the bearing surface remains flat, wide and low. In addition, the head profile differs resulting in a larger temple width in the sagittal plane and a shorter front to bend measurement in the frontal plane. These differences have implications for the design of children's spectacle frames which need to accommodate these facial characteristics.

For White British children with Down's syndrome, the conclusion was similar to the results for Chinese children in the fact that these children are not wholly smaller or larger than typically-developed children and therefore requirements need to be factored into design. Similarities did occur with children of Chinese ethnicity, in such the crest height remains lower by comparison and therefore the nasal profile is low, flat and wide with a shorter length to bend. The head width shows a different growth pattern where it starts off relatively larger then becomes relatively smaller in older children, along with a smaller pupillary distance in comparison to typically developed children.

Whilst the sample of children from other ethnicities was not large enough to formally make comparisons, the data indicated more variations in facial parameters due to ethnicity that would also need to be investigated further and incorporated into future spectacle frame designs.

The right to see clearly, and therefore learn and develop, in a safe and comfortable pair of spectacles should be afforded to all children regardless of age, gender, ethnicity and any genetic or medical condition that may impact on facial features. This data will inform spectacle manufacturers on the requirements of frame parameters and the design features that enables a more encompassing range of paediatric frames to be produced.

10.7 Limitations of this Research

The numbers of subjects were limited in the extremes of the age ranges studied. This impacted on the percentiles and the actual nature of the curve fit, i.e., it would have been informative to expand on the pattern of growth to investigate any early acceleration in growth and the expected plateau in the teenage years. The other ethnic group numbers, except for the Chinese ethnicity were sparse hence limiting the conclusions in this area.

The 3dMD Face™ system used for gathering the anthropometric data has some limitations; the image capture was restricted in this model to a 180-degree image of the face from ear to ear. It therefore limits the 'behind the ear' frame parameters of angle of drop, inward angle of drop and downward angle of drop, however, these would be parameters adjusted each time by the Dispensing Optician rather than being set by manufacturers. Similarly, the bridge projection could not be captured by the system as it requires the subject to blink with the observer analysing the sweep of the lashes with respect to the bearing surface. The system does have some known issues when imaging hair and wet surfaces, such as the cornea and can cause image artefacts which were mitigated by checking the image at the time of acquisition and recaptured if necessary.

10.8 Future work

Future work is planned to target groups of particular ages and ethnicities in order to expand the database and achieve more robust percentile measures. Percentile data will be made available to all manufacturers of paediatric frames and a high level of interest has been expressed, with discussions already underway. It is planned to address the current disconnect between facial measurements and frame parameters which could be aided with the proposal of a new standardised system for frame description that is meaningful to both patients and practitioners alike. The 3dMD Face™ system could also be utilised further to investigate new facial measurements for spectacle design and potentially developing a methodology to determine and quantify what makes a ‘good fit’ of spectacle frames.

In addition, it would be useful to extend the upper age limit of this study to beyond 18 years in order to fully appreciate and inform growth differences between the sexes. Data from the system could be used to simplify the process of producing mannequin paediatric heads for professional training and assessment purposes. Lastly, a longitudinal study is being designed as this would be particularly informative to the differing rates of growth and facial differences identified between the sexes.

REFERENCES

3dmd. (2015). *3dMDFace system* [Online]. Available: https://3dmd.com/products/#https://3dmd.com/products/#!/face [Accessed 27 March 2015].

Agbolade, O., Nazri, A., Yaakob, R., Ghani, A. A. & Cheah, Y. K. (2020). Morphometric approach to 3D soft-tissue craniofacial analysis and classification of ethnicity, sex, and age. *PLoS One,* 15**,** e0228402.

Aldridge, K., Boyadjiev, S. A., Capone, G. T., Deleon, V. B. & Richtsmeier, J. T. (2005). Precision and Error of Three-Dimensional Phenotypic Measures Acquired From 3dMD Photogrammetric Images. *American Journal Of Medical Genetics - A***,** 247.

Alio, J., Lorenzo, J., Iglesias, M. C., Manso, F. J. & Ramirez, E. M. (2011). Longitudinal maxillary growth in Down syndrome patients. *Angle Orthod,* 81**,** 253-9.

Anderson, K. J., Henneberg, M. & Norris, R. M. (2008). Anatomy of the nasal profile. *J Anat,* 213**,** 210-6.

Arshad, T. (2013). Comparison of nasal profiles in various skeletal patterns. *Journal of Ayub Medical College,,* 25**,** 31-35.

Asha, K. R., Lakshmiprabha, S., Nanjaiah, C. M. & Prashanth, S. N. (2011). Craniofacial anthropometric analysis in Down syndrome. *Indian J Pediatr,* 78**,** 1091-5.

Association of British Dispensing Opticians. (2015). *About ABDO* [Online]. Available: http://www.abdo.org.uk/about-abdo/ [Accessed 1 June 2015,].

Association of British Dispensing Opticians. (2021). *PQE Examination Revision Guide* [Online]. Available: https://www.abdo.org.uk/wp-content/uploads/2018/03/ABDO-PQE-Revision-Guide-NOV2016.pdf [Accessed 18 March 2021].

Ayoub, A., Garrahy, A., Hood, C., White, J., Bock, M., Siebert, J. P., Spencer, R. & Ray, A. (2003). Validation of a vision-based, three-dimensional facial imaging system. *Cleft Palate Craniofac J,* 40**,** 523-9.

Ball, R., Shu, C., Xi, P., Rioux, M., Luximon, Y. & Molenbroek, J. (2010). A comparison between Chinese and Caucasian head shapes. *Applied Ergonomics,* 41**,** 832-839.

Bland, J. M. & Altman, D. G. (2010). Statistical methods for assessing agreement between two methods of clinical measurement. *International Journal of Nursing Studies,* 47**,** 931-936.

Brace, I. (2013). *Questionnaire design,* London, England, Kogan Page Ltd.

British Standards Institute (1991). BS 3521-2:1991 Terms relating to ophthalmic lenses and spectacle frames. Glossary of terms relating to ophthalmic lenses. *Section 6: Dimensions and Measurements.* London: British Standards Institute.

British Standards Institute (2004). BS 2738-3:2004+A1:2008 Spectacle lenses. Specification for the presentation of prescriptions and prescription orders for ophthalmic lenses. London: British Standards Institute.

British Standards Institute (2019). BS EN ISO 13666:2019 Ophthalmic Optics. Spectacle Lenses. Vocabulary. *Section 3 Terms and Definitions.* London: British Standards Institute.

British Standards Institute (2020). BS EN ISO 8624:2020 Ophthalmic optics. Spectacle frames. Measuring systems and vocabulary. *3.1: Principal terms of the boxed lens system.* London: British Standards Institute.

Brons, S., Van Beusichem, M. E., Maal, T. J., Plooij, J. M., Bronkhorst, E. M., Berge, S. J. & Kuijpers-Jagtman, A. M. (2013). Development and reproducibility of a 3D stereophotogrammetric reference frame for facial soft tissue growth of babies and young children with and without orofacial clefts. *Int J Oral Maxillofac Surg,* 42**,** 2-8.

Bruner, E. & Manzi, G. (2004). Variability in facial size and shape among North and East African human populations. *Italian Journal of Zoology,* 71**,** 51-56.

Bugaighis, I., Mattick, C. R., Tiddeman, B. & Hobson, R. (2013). Three-dimensional gender differences in facial form of children in the North East of England. *Eur J Orthod,* 35**,** 295-304.

College of Optometrists. (2015). *Membership* [Online]. Available: http://www.college-optometrists.org/en/membership/ [Accessed 4 January 2015].Creative Research Systems. (2012). *Sample size calculator* [Online]. Available: http://www.surveysystem.com/sscalc.htm [Accessed 25 March 2018].

Cronk, C., Crocker, A. C., Pueschel, S. M., Shea, A. M., Zackai, E., Pickens, G. & Reed, R. B. (1988). Growth charts for children with Down syndrome: 1 month to 18 years of age. *Pediatrics,* 81**,** 102-10.

Dindaroğlu, F., Kutlu, P., Duran, G. S., Görgülü, S. & Aslan, E. (2016). Accuracy and reliability of 3D stereophotogrammetry: A comparison to direct anthropometry and 2D photogrammetry. *Angle Orthodontist,* 86**,** 487.

Doddi, N. M. & Eccles, R. (2010). The role of anthropometric measurements in nasal surgery and research: a systematic review. *Clin Otolaryngol,* 35**,** 277-83.

Down's Syndrome Medical Interest Group. (2011). *The 2011 DSMIG/RCPCH Growth Charts for Children with Down's Syndrome - Fact sheet* [Online]. Available: https://www.dsmig.org.uk/wp-content/uploads/2015/10/Chart-Fact-Sheet-A4-4pp.pdf [Accessed 5th June 2021].

Du Raan, E. (2017). Physiological Basis of Growth and Development.[Online]. Available: https://www.researchgate.net/publication/318206960 [Accessed 5 Feb 2019].

Enlow, D. H. (1966). A morphogenetic analysis of facial growth. *Am J Orthod,* 52**,** 283-99.

Erin's World Frames. (2021). *Erin's World Frames* [Online]. Available: https://erinsworldframes.com/ [Accessed 20 June 2021].

Farkas, L. G. & Munro, I. R. (1987). *Anthropometric facial proportions in medicine,* Springfield, IL, Charles C Thomas Publishing Ltd.

Ferrario, V. F., Dellavia, C., Zanotti, G. & Sforza, C. (2004). Soft tissue facial anthropometry in Down syndrome subjects. *J Craniofac Surg,* 15**,** 528-32.

Ferrario, V. F., Sforza, C., Poggio, C. E. & Schmitz, J. H. (1997). Three-dimensional study of growth and development of the nose. *Cleft Palate Craniofac J,* 34**,** 309-17.

Ferrario, V. F., Sforza, C., Serrao, G., Colombo, A. & Ciusa, V. (1999). Soft tissue facial growth and development as assessed by the three-dimensional computerized mesh diagram analysis. *American Journal of Orthodontics and Dentofacial Orthopedics,* 116**,** 215-226.

Fourie, Z., Damstra, J., Gerrits, P. O. & Ren, Y. (2011). Evaluation of anthropometric accuracy and reliability using different three-dimensional scanning systems. *Forensic Sci Int,* 207**,** 127-34.

Frison, S., Checchi, F., Kerac, M. & Nicholas, J. (2016). Is Middle-Upper Arm Circumference "normally" distributed? Secondary data analysis of 852 nutrition surveys. *Emerging Themes in Epidemiology,* 13**,** 1-8.

General Optical Council. (2011). *Core competencies for dispensing opticians* [Online]. Available: https://www.optical.org/en/Education/core-competencies--core-curricula/index.cfm [Accessed 4 February 2014].

General Optical Council. (2018). *Equality and diversity monitoring report* [Online]. Available: https://www.optical.org/en/news_publications/Publications/equality-and-diversity-publications.cfm [Accessed 25 May 2018].

Gilham, B. (2000). *Developing a questionnaire,* London, England, Continuum.

Giovanninni, A. (2014) Email to A Thompson, 23 May.

Gooding, J. (2020). Rather unspectacular: design choices in National Health Service glasses. *Science Museum Group Journal,* 7**,** 1-33.

Hague, P. (1993). *Questionnaire design,* London, England, Kogan Page Ltd.

Hall, D. M. B. & Elliman, D. (2003). *Health for all children,* Oxford, England, Oxford University Press.

Harvey, E. M., Dobson, V., Clifford-Donaldson, C. E. & Miller, J. M. (2007). Optical treatment of amblyopia in astigmatic children: the sensitive period for successful treatment. *Ophthalmology,* 114**,** 2293-301.

Heike, C. L., Upson, K., Stuhaug, E. & Weinberg, S. M. (2010). 3D digital stereophotogrammetry: a practical guide to facial image acquisition. *Head Face Med,* 6**,** 18.

Hilco (2018). *Hilco pad arm conversion.* Available: https://www.youtube.com/watch?v=veG9zPPGJQ4 [Accessed 10 June 2020].

Hong, C., Choi, K., Kachroo, Y., Kwon, T., Nguyen, A., Mccomb, R. & Moon, W. 2017. Evaluation of the 3dMDface system as a tool for soft tissue analysis. *Orthodontics & Craniofacial Research,* 20**,** 119-124.

Hrdlicka, A. (1920). *Anthropometry,* Philadelphia, USA,, The Wistar Institute of Anatomy and Biology.

Kaye, J. & Obstfeld, H. (1989). Anthropometry for childen's spectacle frames. *Ophthalmic Physiol Opt,* 9**,** 293-298.

Kesterke, M. J., Raffensperger, Z. D., Heike, C. L., Cunningham, M. L., Hecht, J. T., Kau, C. H., Nidey, N. L., Moreno, L. M., Wehby, G. L., Marazita, M. L. & Weinberg, S. M. (2016). Using the 3D Facial Norms Database to investigate craniofacial sexual dimorphism in healthy children, adolescents, and adults. *Biol Sex Differ,* 7**,** 23.

Kohn, L. A., Cheverud, J. M., Bhatia, G., Commean, P., Smith, K. & Vannier, M. W. (1995). Anthropometric optical surface imaging system repeatability, precision, and validation. *Ann Plast Surg,* 34**,** 362-71.

Kolar, J. C. & Salter, E. M. (1997). *Craniofacial anthropometry,* Springfield, IL, Charles C Thomas Publisher Ltd.

Koo, T. K. & Li, M. Y.(2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J Chiropr Med,* 15**,** 155-63.

Kook, M.-S., Jung, S., Park, H.-J., Oh, H.-K., Ryu, S.-Y., Cho, J.-H., Lee, J.-S., Yoon, S.-J., Kim, M.-S. & Shin, H.-K. (2014). A comparison study of different facial soft tissue analysis methods. *Journal of Cranio-Maxillo-Facial Surgery,* 42**,** 648-656.

Korayem, M. A. & Alkofide, E. A. (2014). Characteristics of Down syndrome subjects in a Saudi sample. *Angle Orthod,* 84**,** 30-7.

Kouchi, M. & Mochimaru, M. (2004). Analysis of 3D face forms for proper sizing and CAD of spectacle frames. *Ergonomics,* 47**,** 1499-516.

Ladeira, P. R. S. d., Bastos, E. O., Vanini, J. V. & Alonso, N. (2013). Uso da estereofotogrametria nas deformidades craniofaciais: revisão sistemática / Use of stereophotogrammetry for evaluating craniofacial deformities: a systematic review. *Revista Brasileira de Cirurgia Plástica,* 28**,** 147-155.

Launonen, A. M., Vuollo, V., Aarnivala, H., Heikkinen, T., Pirttiniemi, P., Valkama, A. M. & Harila, V. (2019). Craniofacial Asymmetry from One to Three Years of Age: A Prospective Cohort Study with 3D Imaging. *Journal of Clinical Medicine,* 9**,** 70-70.

Leong, S. C. & Eccles, R. (2009). A systematic review of the nasal index and the significance of the shape and size of the nose in rhinology. *Clin. Otolaryngol*, 34, 191-198.

Lincoln, K. P., Sun, A. Y., Prihoda, T. J. & Sutton, A. J. (2016). Comparative Accuracy of Facial Models Fabricated Using Traditional and 3D Imaging Techniques. *J Prosthodont,* 25**,** 207-15.

Liu, X., Wu, J., He, X. & Li, H. (2013). Facial dimensions driven design and optimization techniques for spectacles. *Journal of Theoretical and Applied Information Technology,* 48**,** 918-924.

Long, L., Trivedy, C., Crossman, R.J., Flowers, J., Cooke, M.W. (2014). Imaging paediatric facial injuries in the emergency department. *Emergency Medicine Journal,* 31, 782-783.Lubbers, H. T., Medinger, L., Kruse, A. L., Gratz, K. W., Obwegeser, J. A. & Matthews, F. (2012). The influence of involuntary facial movements on craniofacial anthropometry: a survey using a three-dimensional photographic system. *Br J Oral Maxillofac Surg,* 50**,** 171-5.

Maal, T. J. J., Verhamme, L. M., Van Loon, B., Plooij, J. M., Rangel, F. A., Kho, A., Bronkhorst, E. M. & Bergé, S. J. (2011). Variation of the face in rest using 3D stereophotogrammetry. *International Journal of Oral & Maxillofacial Surgery,* 40**,** 1252-1257.

Mayhew, S.(2020).Email to A Thompson, 25 February.

Mellion, Z. J., Behrents, R. G. & Johnston Jr, L. E. (2013). The pattern of facial skeletal growth and its relationship to various common indexes of maturation. *Am J Orthod Dentofacial Orthop,* 143**,** 845-54.

Menendez Lopez-Mateos, M. L., Carreno-Carreno, J., Palma, J. C., Alarcon, J. A., Menendez Lopez-Mateos, C. & Menendez-Nunez, M. (2019). Three-dimensional photographic analysis of the face in European adults from southern Spain with normal occlusion: reference anthropometric measurements. *BMC Oral Health,* 19**,** 196.

Metzger, T. E., Kula, K. S., Eckert, G. J. & Ghoneima, A. A. (2013). Orthodontic soft-tissue parameters: A comparison of cone-beam computed tomography and the 3dMD imaging system. *American Journal of Orthodontics & Dentofacial Orthopedics,* 144**,** 672-681.

Mok, G. T., Chan, S. S., Chu, Y. W., Chan, S. M., Wong, W. H. & Chung, B. H. (2016). Physical measurements of Chinese children in Hong Kong-A pilot study in preschools and kindergartens. *Am J Med Genet A,* 170**,** 2069-77.

Mori, A., Nakajima, T., Kaneko, T., Sakuma, H. & Aoki, Y. (2005). Analysis of 109 Japanese children's lip and nose shapes using 3-dimensional digitizer. *Br J Plast Surg,* 58**,** 318-29.

Murphy, W. K. & Laskin, D. M. (1990). Intercanthal and interpupillary distance in the black population. *Oral Surg Oral Med Oral Pathol,* 69**,** 676-80.

Myhealthclass.net (2013). *Fetal skull anatomy* [Online].Available: http://myhealthclass.net/fetal-skull-anatomy-whats-the-difference-between-adult-skull-and-pediatrics-skull-anatomy/ [Accessed 4 March 2014].

Natale, V. & Rajagopalan, A. (2014). Worldwide variation in human growth and the World Health Organization growth standards:a systematic review. *BMJ Open,* 4,e003735.

National Health Service. (2019). *Eye tests for children* [Online]. Available: https://www.nhs.uk/conditions/eye-tests-in-children/ [Accessed 3 April 2019].

National Health Service Health Research Authority. (2007). *Consent and participant information sheet preparation guidance* [Online]. Available: http://www.hra-decisiontools.org.uk/consent/style.html [Accessed 13 Feb 2015].

Nord, F., Ferjencik, R., Seifert, B., Lanzer, M., Gander, T., Matthews, F., Rücker, M. & Lübbers, H.-T. The 3dMD photogrammetric photo system in cranio-maxillofacial surgery: Validation of interexaminer variations and perceptions. (2015).*J. Craniomaxillofac. Surg,* 43, 1798-1803.

Obstfeld, H. (1997). *Spectacle frames and their dispensing,* London, England, W.B. Saunders Company Ltd.

Office for National Statistics. (2015). *Primary set of harmonised concepts and questions- ethnic groups* [Online]. Available: http://www.ons.gov.uk/ons/guide-method/harmonisation/primary-set-of-harmonised-concepts-and-questions/index.html [Accessed 6 January 2015].

Ort, R., Metzler, P., Kruse, A. L., Matthews, F., Zemann, W., Gratz, K. W. & Luebbers, H. T. (2012). The Reliability of a Three-Dimensional Photo System-(3dMDface) Based Evaluation of the Face in Cleft Lip Infants. *Plast Surg Int,* 2012**,** 138090.

Ouyang, F., Jiang, F., Tao, F., Xu, S., Xia, Y., Qiu, X. & Zhang, J. (2018). Growth patterns from birth to 24 months in Chinese children: a birth cohorts study across China. *BMC Pediatr,* 18**,** 344.

Pixabay (2015). *Skull*. [Online] Available: https://pixabay.com/photos/skull-and-crossbones-skeleton-skull-638784/ [Accessed 2 October 2015].

Plooij, J. M., Swennen, G. R., Rangel, F. A., Maal, T. J., Schutyser, F. A., Bronkhorst, E. M., Kuijpers-Jagtman, A. M. & Berge, S. J. (2009). Evaluation of reproducibility and reliability of 3D soft tissue analysis using 3D stereophotogrammetry. *Int J Oral Maxillofac Surg,* 38**,** 267-73.

Premkumar, S. (2011). *Textbook of craniofacial growth,* New Delhi, India, Jaypee Brothers Medical Publishers Ltd.

Priest, A. (2013). Email to A Thompson, 5 November.

Proffit, W. R., Fields, H. W. & Sarver, D. M. (2014). *Contemporary Orthodontics* Philadelphia, USA, Elsevier Health Sciences.

Pueschel, S. (1987). Health Concerns in Persons with Down Syndrome. *In:* Pueschel, S., Tingey, C., Rynders, J., Crocker, A. C. & Crutcher, D. (eds.) *New Perspectives on Down Syndrome.* Baltimore, MD, USA: Paul H. Brookes.

Quant, J. R. & Woo, G. C. (1992). Normal values of eye position in the Chinese population of Hong Kong. *Optom Vis Sci,* 69**,** 152-8.

Quant, J. R. & Woo, G. C. (1993). Normal values of eye position and head size in Chinese children from Hong Kong. *Optom Vis Sci,* 70**,** 668-71.

Razali, N. M., Shamsudin, N. R., Azid, N. N. N., Hadi, A. A. & Ismail, A. (2012). A comparison of normality tests using SPSS, SAS and MINITAB: An application to Health Related Quality of Life data. International Conference on Statistics in Science, Business and Engineering (ICSSBE), Langkawi, Malaysia, 1-6th September 2012. Available: https://search.ebscohost.com/login.aspx?direct=true&db=edseee&AN=edseee.6396570&site=eds-live. [Accessed 24 Feb 2021].

Ritschl, L. M., Roth, M., Fichter, A. M., Mittermeier, F., Kuschel, B., Wolff, K. D., Grill, F. D. & Loeffelbein, D. J. (2018). The possibilities of a portable low-budget three-dimensional stereophotogrammetry system in neonates: a prospective growth analysis and analysis of accuracy. *Head Face Med,* 14**,** 1-11.

Robbins, W. J. (1928). *Growth,* New Haven, USA, Yale University Press.

Robison, J. M., Rinchuse, D. J. & Zullo, T. G. (1986). Relationship of skeletal pattern and nasal form. *Am J Orthod,* 89**,** 499-506.

Rossi, M., Ribeiro, E. & Smith, R. (2009). Craniofacial asymmetry in development: an anatomical study. *Angle Orthod* 73**,** 381-385.

Rosyidi, C. N., Riyanti, N. & Iftadi, I. (2016). Head and facial anthropometry for determining the critical glasses frame dimensions. *Journal of Engineering Science and Technology,* 11**,** 1620-1628.

Royal College of Paediatrics and Child Health. (2013). *Growth charts* [Online]. Available: http://www.rcpch.ac.uk/growthcharts [Accessed 8 May 2015].

Sasieni, L. S. (1962). *Principles and practice of optical dispensing and fitting,* Worcester, England, The Trinity Press.

Sasieni, L. S. (1975). *The principles and practice of optical dispensing and fitting,* London, England, Butterworth & Co Ltd.

Schramm, K. D. (2000). *Dispensing pediatric eyewear,* Boston, MA, Butterworth Heinemann.

Sforza, C., Dellavia, C., Zanotti, G., Tartaglia, G. M. & Ferrario, V. F. (2004). Soft tissue facial areas and volumes in subjects with Down syndrome. *Am J Med Genet A,* 130A**,** 234-9.

Sforza, C., Dolci, C., Dellavia, C., Gibelli, D. M., Tartaglia, G. M. & Elamin, F. (2015). Abnormal Variations in the Facial Soft Tissues of Individuals With Down Syndrome: Sudan Versus Italy. *Cleft Palate Craniofac J,* 52**,** 588-96.

Sforza, C., Grandi, G., Catti, F., Tommasi, D. G., Ugolini, A. & Ferrario, V. F. (2009). Age- and sex-related changes in the soft tissues of the orbital region. *Forensic Sci Int,* 185**,** 115 e1-8.

Sforza, C., Grandi, G., De Menezes, M., Tartaglia, G. M. & Ferrario, V. F. (2011). Age- and sex-related changes in the normal human external nose. *Forensic Sci Int,* 204**,** 205 e1-9.

Sperber, G. H., Sperber, S. M. & Guttmann, G. D. (2010). *Craniofacial embryogenetics and development,* Connecticut, NE, People's Medical Publishing House USA.

Stidwill, D. (1990). *Orthoptic assessment and management,* Oxford, England, Blackwell Scientific Publications.

Styles, M. E., Cole, T. J., Dennis, J. & Preece, M. A. (2002). New cross sectional stature, weight, and head circumference references for Down's syndrome in the UK and Republic of Ireland. *Archives of Disease in Childhood,* 87**,** 104.

Swennen, G. R. J., Schutyser, F., Lemaitre, A., Malevez, C. & De Mey, A. (2005). Accuracy and reliability of 3-D CT versus 3-D stereo photogrammetry based facial soft tissue analysis. *International Journal of Oral and Maxillofacial Surgery,* 34**,** 73.

Szychta, P., Rykala, J. & Kruk-Jeromin, J. (2011). Individual and ethnic aspects of preoperative planning for posttraumatic rhinoplasty. *Eur J Plast Surg,* 34**,** 245-249.

Tang, C. Y., Tang, N. & Stewart, M. C. (1998a). Facial measurements for frame design. *Optom Vis Sci,* 75**,** 288-92.

Tang, C. Y., Tang, N. & Stewart, M. C. (1998b). Ophthalmic anthropometry for Hong Kong Chinese adults. *Optometry and Vision Science,* 75**,** 293-301.

Tomato Glasses. (2021). *About Tomato Glasses* [Online]. Available: https://www.tomatoglassesuk.com/about/tomato-glasses/ [Accessed 1 June 2021].

Topinard, P. (1878). *Anthropolgy,* London, England, Chapman and Hall.

Tzou, C.-H. J., Artner, N. M., Pona, I., Hold, A., Placheta, E., Kropatsch, W. G. & Frey, M. (2014). Comparison of three-dimensional surface-imaging systems. *Journal of Plastic, Reconstructive & Aesthetic Surgery,* 67**,** 489-497.

University of Manchester (2012). How has ethnic diversity grown 1991-2001-2011. [Online] Available: http://hummedia.manchester.ac.uk/institutes/code/briefings/dynamicsofdiversity/how-has-ethnic-diversity-grown-1991-2001-2011.pdf [Accessed 3 May 2021].

Van Der Heijden, P., Korsten-Meijer, A. G., Van Der Laan, B. F., Wit, H. P. & Goorhuis-Brouwer, S. M. (2008). Nasal Growth and Maturation Age in Adolescents: A Systematic Review. *Arch. Otolaryngol. Head Neck Surg.,* 134, 1288-1293.

Van Gameren-Oosterom, H. B., Van Dommelen, P., Oudesluys-Murphy, A. M., Buitendijk, S. E., Van Buuren, S. & Van Wouwe, J. P. (2012). Healthy growth in children with Down syndrome. *PLoS One,* 7**,** e31079.

Wang, Y. J., Hong, R. Z., Wei, X. J., Ai, Y. D. & Zhao, Y. (2005). [Analysis of anthropometry on head and eye for stipulating of children's spectacle frames]. *Zhonghua Yan Ke Za Zhi,* 41**,** 20-3.

Weinberg, S. M. (2019) 3D stereophotogrammetry versus traditional craniofacial anthropometry: Comparing measurements from the 3D facial norms database to Farkas's North American norms. *Am J Orthod Dentofacial Orthop.,155, 693-701*

Weinberg, S. M., Raffensperger, Z. D., Kesterke, M. J., Heike, C. L., Cunningham, M. L., Hecht, J. T., Kau, C. H., Ph.D, Murray, J. C., Wehby, G. L., Moreno, L. M. & Marazita, M. L. (2016). The 3D facial norms database: part 1. A web-based craniofacial anthropometric and image repository for the clinical and research community. *Cleft Palate-Craniofac. J.***,** 53,185-197.

Wen, Y. F., Wong, H. M. & Mcgrath, C. P. (2017). A longitudinal study of facial growth of Southern Chinese in Hong Kong: Comprehensive photogrammetric analyses. *PLoS One,* 12**,** e0186598.

Wikimedia Commons contributors (2017). *Anatomy and Physiology Connexions 2302 External Nose.* [Online] Available: http://cnx.org/content/col11496/1.6/ [Accessed 4 Jan 2018].

Wikimedia Commons contributors (2014). *Cephalometric radiograph*. [Online] Avaialble: https://commons.wikimedia.org/w/index.php?title=File:Cephalometric_radiograph.JPG&oldid=487404749 [Accessed 6 Jan 2018].

Wikimedia Commons contributors (2012) *Human skull scheme highlighting the cranial bones in a lateral view.* [Online] Available: https://en.wikipedia.org/wiki/Neurocranium#/media/File:Cranial_bones_en_v2.svg {Accessed 8 October 2021}.

Wikimedia Commons contributors (2015) Facial bones anterior view. [Online] Available: https://upload.wikimedia.org/wikipedia/commons/thumb/2/25/Facial_skeleton_-_en.svg/2000px-Facial_skeleton_-_en.svg.png {Accessed 11 Oct 2021}.

Wong, J. Y., Oh, A. K., Ohta, E., Hunt, A. T. & Rogers, G. F. (2008). Validity and Reliability of Craniofacial Anthropometric Measurement of 3D Digital Photogrammetric Images. *Cleft-Palate Craniofac. J.*, 45, 232-239.

Woodhouse, J. M., Hodge, S. J. & Earlam, R. A. (1993a). Facial characteristics in children with Down's syndrome and spectacle fitting. *Ophthalmic Physiol Opt,* 14**,** 25-31.

Woodhouse, J. M., Meades, J. S., Leat, S. J. & Saunders, K. J. (1993b). Reduced accommodation in children with Down syndrome. *Invest Ophthalmol Vis Sci,* 34**,** 2382-7.

World Health Organisation. *WHO Multicentre Growth Reference Study* [Online]. Available: https://www.who.int/tools/child-growth-standards/who-multicentre-growth-reference-study [Accessed June 27th 2019].

Zankl, A., Eberle, L., Molinari, L. & Schinzel, A. (2002). Growth charts for nose length, nasal protrusion, and philtrum length from birth to 97 years. *Am J Med Genet,* 111**,** 388-91.

Zhao, Y. J., Xiong, Y. X. & Wang, Y. (2017). Three-Dimensional Accuracy of Facial Scan for Facial Deformities in Clinics: A New Evaluation Method for Facial Scanner Accuracy. *PLoS One,* 12**,** e0169402.

Zhuang, Z., Landsittel, D., Benson, S., Roberge, R. & Shaffer, R. (2010). Facial Anthropometric Differences among Gender, Ethnicity, and Age Groups. *Annals of occupational hygiene,* 54**,** 391-402.

Zhuk, G. V. (1973). Investigation of the parameters of spectacle frames for school children. *Biomedical Engineering,* 7**,** 223.

APPENDICES

1. Paediatric questionnaire designed for the optical profession
2. Study patient information sheet (parent)
3. Consent form and ethnic groupings
4. Study patient information sheet (0-5 years)
5. Study patient information sheet (6-10 years)
6. Study patient information sheet (11-16 years)
7. Percentile data

Appendix 1 Paediatric questionnaire designed for the optical profession

#750 v3 amended 7.4.15

Aston University
Birmingham

Paediatric Dispensing

Paediatric Dispensing Questionnaire - Participant Information Sheet

You are being invited to take part in a research project that will be conducted at Aston University. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

What is the purpose of the project?

It is hoped the results will identify and inform any training needs required in the optical sector with regard to dispensing spectacles to children. The intention is to gather useful information on typical behaviour whilst performing this service, and also to identify any issues with both product availability and function.

Why have I been chosen?

You have been chosen to take part in this questionnaire because you are a registered practitioner with the General Optical Council. As dispensing children is a regulated function, only current registrants have been invited to take part.

1 / 19

Do I have to take part?

Participation is entirely voluntary; however, we would appreciate gathering the views of as many practitioners as possible

What will happen to me if I decide to take part?

The questionnaire is delivered online via Bristol Online Surveys and will be open from April 15th 2015 to August 15th 2015. There are 34 questions and these are mostly multiple choice in design. The questionnaire takes approximately fifteen minutes to complete. No questions are compulsory and you can withdraw at any time during the questionnaire.

What are the possible disadvantages and risks of taking part?

Practitioners giving an honest response may cause them to reflect on their own practice and possibly identify areas that may be improved. The reflection will remain personal as no personal details or identification of participants is captured.

What are the possible benefits of taking part?

There are many challenges faced when dispensing spectacles to children and whether these are met in a direct role or a supervisory role, it is hoped that capturing information regarding current practice, confidence levels, service and product availability can inform and direct future training and product specification.

Will my taking part in this project be kept confidential?

The questionnaire is completely anonymous and you will not be asked to supply any personal details at any time.

What will happen to the results of the research project and how will participant anonymity be protected?

The responses may be published in academic and professional journals and conference presentations. Even though personal details are not collected, if a direct quote is used to illustrate a point or stimulate discussion, then we will ensure that people are not identifiable by any means, such as geographical area of practice.

Who has reviewed the project?

This research project has been approved by Aston University's Ethics Committee. If you have any concerns about the way the research has been conducted, then please contact the Secretary of the University Research Ethics Committee j.g.walter@aston.ac.uk or telephone 0121 204 4665

Contact for further information

Any queries to be addressed to

Alicia Thompson thompaj3@aston.ac.uk

Dr Robert Cubbidge r.p.cubbidge@aston.ac.uk

Thank you in advance for your time.

Note that once you have clicked on the CONTINUE button at the bottom of each page you can not return to review or amend that page

Please note that by clicking 'continue' you are agreeing to participate in the study and you understand that the data provided will be used in research as described in the Participant Information on the previous page.

#750 v3 amended 7.4.15

Paediatric Dispensing

Note that once you have clicked on the CONTINUE button your answers are submitted and you can not return to review or amend that page.

General Overview

1 What percentage of your **average working week** do you spend dispensing?

- None
- 1%-25%
- 26%-50%
- 51%-75%
- 76%-100%

2 Do you have **responsibility** in your practice for the following..Select all that apply

- Trainee Dispensing Optician
- Trainee Optometrist
- Overseeing paediatric dispensing
- Overseeing Low Vision/Complex dispensing
- No responsibility

3 Excluding your own patients, how do you rate the **overall fit** of children's spectacle frames?

- Excellent
- Good
- Average
- Poor
- Dreadful

5 / 19

4 How do you rate the choice of frame **sizes available** from manufacturers?

- Excellent
- Good
- Average
- Poor
- Dreadful

Activity and Confidence

Please note if you work as a locum, or between practices, please answer the following questions based on where you spend the majority of your time

5 On average, what would you **estimate the proportion** of your total dispensing is to children under 16 years old?

- Less than 5%
- 5-10%
- 11-20%
- 21-30%
- Over 30%

6 How often do you dispense in practice to each of the following **age groups?**

	Never	Occasionally	Often
Under 12 months	○	○	○
1-3 years	○	○	○
4-6 years	○	○	○
5-7 years	○	○	○
8-10 years	○	○	○
Over 10 years	○	○	○

7 How **confident do you feel** dispensing and fitting spectacles to children of the following age ranges?

	Nervous	Slightly Nervous	Neutral	Confident	Very Confident
Under 12 months	○	○	○	○	○
1-3 years	○	○	○	○	○
4-6 years	○	○	○	○	○
7 years and above	○	○	○	○	○

8 How would you rate the importance of the following factors in terms of **improving confidence** of practitioners?

	Essential	Important	Undecided	Not Important	Not Essential
Exposure to more paediatric patients during training	○	○	○	○	○
Practical hands-on training course	○	○	○	○	○
Wider frame range in terms of sizes to offer all children	○	○	○	○	○
Specialist training in communicating with children and parents	○	○	○	○	○
Skills to adapt and convert frames in order to improve fit	○	○	○	○	○

9 How interested would you be in undertaking the following where 1 is 'not at all interested' and 5 is 'very interested'?

	1	2	3	4	5
Hands-on skills training in aspects of paediatric dispensing	○	○	○	○	○
An additional specialist qualification in paediatric dispensing	○	○	○	○	○

Your Practice

10 Does your practice have a **dedicated area** for children's frames?

○ Yes ○ No

11 Does your practice offer any **activities for a child** to keep them occupied whilst waiting or during the dispense?

○ Yes ○ No

12 Please rate your current **children's frame range** in terms of the following:

	Excellent	Good	Average	Poor	Dreadful
Eye sizes suitable for a range of ages	○	○	○	○	○
Cosmetic appeal	○	○	○	○	○
Ease of adjustment	○	○	○	○	○

13 Do you have any input into **purchasing** the children's frame stock for your practice?

- Yes - go to Question 14
- No - go to Question 15
- Limited input - go to Question 14

14 Who is your **preferred supplier** for children's frames for different age bands? Please give specific reasons for your choice

	Supplier	Reason
Under 12 months		
1-3 years		
4-6 years		
5-7 years		
Over 7 years		

15 Do you agree or disagree that children's frame manufacturer's could **improve their ranges?**

- Agree
- Disagree

- Unsure

15.a If you agree, what would you like to see produced?

16 What range of **horizontal eye sizes** do you currently stock in your practice?

- Under 32mm
- 33-36mm
- 37-40mm
- 41-44mm
- 45-48mm
- Over 49mm

Spectacle Dispensing

17 To **select a frame** for a 5 year old child, would you typically....

- Allow the child/parent to browse alone
- Allow the child/parent to browse with you advising on fit
- Select a range that will fit the child presented in the dispensing area
- Other

17.a If you selected Other, please specify:

18 When discussing lens options, indicate **how often** you consider the following?

	Supplied as standard in our practice	Always if relevant	Mostly	Sometimes	Rarely	Never
Increased impact resistance beyond CR-39	○	○	○	○	○	○
Increased UV protection beyond that provided by the lens material	○	○	○	○	○	○
Improved cosmesis by ordering minimum sized uncut for positive prescriptions	○	○	○	○	○	○
Improved cosmesis by altering the lens form	○	○	○	○	○	○
Improved cosmesis by increasing refractive index to 1.6 or higher	○	○	○	○	○	○
Improved scratch resistance	○	○	○	○	○	○

19 If the prescription is over +/-5.00D, do you **check the fitting vertex distance** matches the testing vertex distance?

○ Yes ○ No ○ Sometimes

20 How do you **measure a child's vertex distance**?

- Callipers
- Ruler
- Other

20.a If you selected Other, please specify:

21 Do you discuss the child's activities with the parent and offer **eye protection** where relevant?

- Always
- Mostly
- Sometimes
- Rarely
- Never

22 In your practice, does the **NHS voucher cover...**

- The whole cost towards the child's spectacles for the entire range of children's frames and lenses
- The whole cost towards the child's spectacles for a limited range of frames and lenses
- Part of the cost towards the child's spectacles
- Other

22.a If you selected Other, please specify:

23 Which statement reflects your **most typical experience** when discussing cost and NHS vouchers Please tick **one** option

- I assume parents do not want to pay anything extra for their child's spectacles
- I always offer the parents additional benefits where relevant to the dispense but they generally do not want to pay any extra cost
- I always offer the parents additional benefits where relevant to the dispense and they generally do pay the extra cost
- I sometimes offer the parents additional benefits where relevant to the dispense only if I think they can afford the extra cost

Spectacle Fitting

24 Do you routinely make a **formal appointment** for the fitting of a child's spectacles?

- Always
- Mostly
- Occasionally
- Rarely
- Never

25 During fitting, **how often** do you need to make the following adjustments/modifications to the frame?

	Every time	Mostly	Occasionally	Rarely	Never
Side re-bend					
Side cut and re-bend					
Add temple grips					
Adjust inward angle of drop					
Alter head width					
Alter splay angle					

13 / 19

Alter pantoscopic tilt	◌	◌	◌	◌	◌
Fit a different type of bridge	◌	◌	◌	◌	◌

26 Do you generally encourage the child to **come back** post-fitting?Please select one option

- ◌ Yes, 'formally book' an appointment to assess fit/check alignment after a few weeks
- ◌ Yes, 'informally invite' when passing to assess fit/check alignment after a few weeks
- ◌ Yes, 'informally invite' only if a problem arises
- ◌ No they will attend if necessary

27 Is a **registered practitioner** on the premises at all times during opening hours?

- ◌ Yes - go to Question 29
- ◌ No - go to Question 28

28 Do you inform parents that their child must be seen by a **registered practitioner** and therefore the service may not be available for part of the day/week?

- ◌ Yes
- ◌ No
- ◌ Sometimes

About you

29 Are you?

- Male
- Female
- Prefer not to say

30 What is your **age** range?

- Under 21
- 21-30
- 31-40
- 41-50
- 51-60
- Over 61
- Prefer not to say

31 **Are you?**

- A registered Dispensing Optician
- A registered Optometrist
- Other

31.a If you selected Other, please specify:

32 How many years have you been registered with the General Optical Council?

- Under 5
- 5-10
- 11-15
- 16-20
- 21-25
- Over 25
- Prefer not to say

33 What is your **primary mode** of practice?

- Independent (1-3 practices)
- Multiple (4 or more practices)
- Hospital Eye Clinic
- Other

33.a If you selected Other, please specify:

34 Which **county** do you currently practice in?

34.a If you selected Other, please specify:

Final Page

Thank you so much for taking the time to complete this survey, it is highly appreciated

---

Key for selection options

34 - Which county do you currently practice in?

Avon
Bedfordshire
Berkshire
Borders
Buckinghamshire
Cambridgeshire
Central
Cheshire
Cleveland
Clwyd
Cornwall
County Antrim
County Armagh
County Down
County Fermanagh
County Londonderry
County Tyrone
Cumbria
Derbyshire
Devon
Dorset
Dumfries and Galloway
Durham
Dyfed
East Sussex
Essex
Fife
Gloucestershire
Grampian

Greater Manchester
Gwent
Gwynedd County
Hampshire
Herefordshire
Hertfordshire
Highlands and Islands
Humberside
Isle of Wight
Kent
Lancashire
Leicestershire
Lincolnshire
Lothian
Merseyside
Mid Glamorgan
Norfolk
North Yorkshire
Northamptonshire
Northumberland
Nottinghamshire
Oxfordshire
Powys
Rutland
Shropshire
Somerset
South Glamorgan
South Yorkshire
Staffordshire
Strathclyde
Suffolk
Surrey
Tayside
Tyne and Wear
Warwickshire
West Glamorgan
West Midlands
West Sussex
West Yorkshire
Wiltshire

Worcestershire
Other

Appendix 2 Study patient information sheet (parent)

#828 v2 190615 – PIS Parents/Carers

Aston University
Birmingham

RESEARCH PARTICIPANT INFORMATION SHEET

For Parents and Carers

Title of the study: Paediatric Facial Analysis for Spectacle Wear

We would like to invite your child to take part in a research project. Before you and your child decide is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish your child to take part. An age-appropriate explanation for your child is accompanied with this information.

What is the purpose of the project?

The purpose is to gather data on how a child's face develops, in particular the nasal area and structures relating to how a spectacle frame would fit. It is hoped that the analysis of this data will inform the optical profession and industry more accurately what sizes of frames need to be manufactured in order to improve the fit of children's eyewear overall. In cases where children already wear spectacles, additional measurements will be taken to assess the wearing position and the exact prescription received by the child.

Why has my child been chosen?

Data is required from as many children as possible from birth to 16 years.
Participation is being sought from local schools and playgroups, centres and associations. The research will take place at these centres.

Does my child have to take part?

A written consent form (attached) is required from every parent or guardian for those children deciding to take part. It is also important that the child is happy to take part on the day and therefore will be asked again prior to participating.

1

It is perfectly acceptable for you and/or your child to withdraw at any time without prejudice.

What will happen to my child if we decide to take part?

A photographic image will be taken on our 3D medical imaging system. This takes 1.5 milliseconds to capture. The child will be shown the image as we check it has captured properly.

It would be beneficial if this process could be repeated at 6 monthly intervals over an 18 month period, although even one image will be useful.

If the child wears spectacles, then there will be additional measurements taken as listed below, these take approximately 5 minutes to capture

- A measurement of the distance between pupil centres with a ruler
- A measurement from the eye to the back of the lens using a ruler
- A mark made with a lens marking pen to show the pupil position on the lens
- The spectacles removed and the curvature, thickness, centration and power of the lenses measured – the spectacles will then be cleaned and returned to the child.

What are the possible disadvantages and risks of taking part?

The three flashes of the imaging system may cause a temporary after-image, this is similar to what is experienced in flash photography and should only last a few minutes.

What are the possible benefits of taking part?

The 3D image captured can be analysed to produce measurements and angles that relate to how a spectacle frame should be designed. It is hoped that this data will be used by frame manufacturers to ensure the fit of children's frames is improved and therefore the full prescription or intervention is delivered at such a critical stage in a child's development.

Will my taking part in this project be kept confidential?

Other children in the class/school may know their friends have participated. A database of participants will be kept for the purposes of creating a unique number and inviting children back after 6 months. This database will be kept securely on a password-protected laptop in a locked safe. No personal details will be published or disclosed to a third party. Only the researcher and supervisor will have access to this database and the images.

What will happen to the results of the research project and how will participant anonymity be protected?

Each image will be stored under a unique identification number and not the child's name. The images will be captured on a computer, and then stored for analysis on a separate password-protected laptop to the database.

Some images may be published if consent is granted, along with the results, in academic and professional journals, academic thesis, conference and educational presentations.

Who has reviewed the project?

This research project has been approved by Aston University's Ethics Committee. If you have any concerns about the way the research has been conducted, then please contact the Secretary of the University Research Ethics Committee j.g.walter@aston.ac.uk or telephone 0121 204 4665

Contact for further information

Any queries to be addressed to

Alicia Thompson thompaj3@aston.ac.uk research student

Dr Robert Cubbidge r.p.cubbidge@aston.ac.uk supervisor

Appendix 3 Consent form and ethnic groupings

#828 v2 190615 – Consent Parents/Carers

Facial Analysis for Spectacle Wear

Parent/Carer Consent Form

Aston University
Birmingham

Please note that **for each child** a separate consent form is required

Block capitals please

Parent/Carer Name	
Your relationship to the child	
Home Address	Postcode
Preferred contact telephone number	
Contact email address	
Child's name	
Child's DOB	
Gender	

Please initial one box per question	**YES**	**NO**
I give my permission for you to ask my child if a facial photograph may be taken		
I give my permission to be contacted in 6 months' time with a view for further images to be taken		
I have read and understood the Participant Information Sheet		
My child has been given an age-appropriate information sheet which I have discussed with my child		
I give permission for the image(s) of my child's face to be published in academic publications and presentations as described in the Participant Information Sheet		
My child currently wears spectacles		
If YES, I am happy for the additional measurements to be taken as described in the information sheet		
I understand that either myself and/or my child can withdraw from the study at any time without prejudice		

Choose **one** option that best describes your child's ethnic group or background	Please Tick
White	
English/Welsh/Scottish/Northern Irish/British	
Irish	
Gypsy or Irish Traveller	
Any other White background, please describe	
Mixed/Multiple ethnic groups	
White and Black Caribbean	
White and Black African	
White and Asian	
Any other Mixed/Multiple ethnic background, please describe	
Asian/Asian British	
Indian	
Pakistani	
Bangladeshi	
Chinese	
Any other Asian background, please describe	
Black/ African/Caribbean/Black British	
African	
Caribbean	
Any other Black/African/Caribbean background, please describe	
Other ethnic group	
Arab	
Any other ethnic group, please describe	

Does your child have Down's syndrome? YES/NO

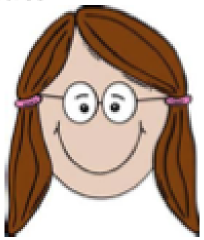
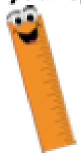
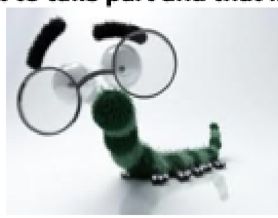
Parent/Carer Signature	Date

Appendix 4 Study patient information sheet (0-5 years)

#828 v1 050515 – PIS0-5

Children aged 0-5years

This information is designed to be shown and read to the child by the parent/guardian

Lots of children wear spectacles 	**We want to make spectacles fit better** 	**This means taking a photograph of your face** 	**It is so fast; it doesn't matter if you blink. There is a big flash!** 
If you wear spectacles, we would like to measure them 	**We use a ruler and a machine that measures your spectacles** 	**We will then clean them and give them back to you** 	**At any time you can say you don't want to take part and that is fine** 

Appendix 5 Study patient information sheet (6-10 years)

#828v1050515 – 6-10PIS

Aston University
Birmingham

RESEARCH PARTICIPANT INFORMATION SHEET

For children aged 6-10 years

Title of the study: Paediatric Facial Analysis for Spectacle Wear

You are being invited to take part in a research project that will be conducted on school premises. Your parent/guardian will need to agree to you taking part but it is important that you know all about the project in order to decide whether to take part. Please read this leaflet carefully and talk about it with your friends, family and teachers if you want to.

What is research? What is the project for?

Research is trying to find out information to answer questions. We want to measure lots of children's faces so that we know more about face sizes and how to make spectacle frames fit better.

Why have I been asked to take part?

We need to measure lots of children of all ages.

Did anyone check the project is OK to do?

Before any research is allowed to happen, it has to be checked by a group of people to make sure it is fair. This project has been checked by the Aston University Research Ethics Committee.

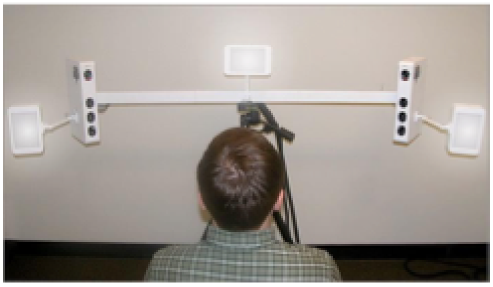
Do I have to take part?

No, it is your choice and you can change your mind at any time.

1

What will happen to me if I take part in the research?

You will be asked to have your photograph taken on this camera



It takes several photos at the same time and these build up a 3D image of your face which we will show you.

After 6 months, you will be invited to come back again for another image to be taken. This process is then repeated until 3 images are taken.

If you wear spectacles, we would like to measure exactly where they sit on your face with a ruler, and mark the point you are looking through with a lens marking pen.

We will then require you to remove your spectacles for a few minutes whilst we measure the power, curves and thickness of your lenses.

Might anything about the research upset me?

The camera has three flashes which all flash at the same time. Some people have an 'after-image' for a few seconds just like when you have a photo taken indoors and you can see the flash image.

Will joining in benefit me?

We cannot promise the study will help you but the information we get might help all young people in the future have spectacles that fit better

Will my taking part in this project be kept private?

Your photograph will be kept with a number and not your name.

Some images may be printed in order to write about the research project results and to teach others. No names will be printed at all.

Contact for further information

Any queries to be addressed to

Alicia Thompson thompaj3@aston.ac.uk research student

Dr Robert Cubbidge r.p.cubbidge@aston.ac.uk supervisor

Appendix 6 Study patient information sheet (11-16 years)

#828v1050515 – 11-16PIS

Aston University
Birmingham

RESEARCH PARTICIPANT INFORMATION SHEET

For ages 11-16 years

Title of the study: Paediatric Facial Analysis for Spectacle Wear

You are being invited to take part in a research project that will be conducted on school premises. Your parent/guardian will need to agree to you taking part but it is important that you know all about the project in order to decide whether to take part. Please read this leaflet carefully and talk about it with your friends, family and teachers if you want to.

What is research? What is the project for?

Research is trying to find out information to answer questions. We want to measure lots of young people's faces in order to learn how the face develops and therefore how we can make spectacle frames fit better.

Why have I been asked to take part?

We need to measure lots of children and young adults from birth to 16 years old.

Did anyone check the project is OK to do?

Before any research is allowed to happen, it has to be checked by a group of people to make sure it is fair. This project has been checked by the Aston University Research Ethics Committee.

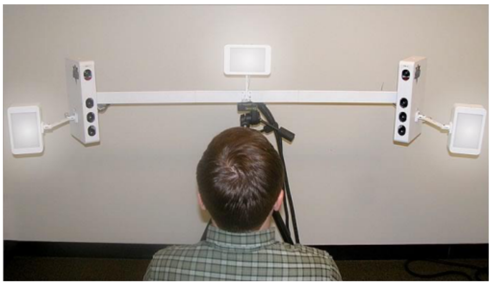
Do I have to take part?

No, it is your choice and you can change your mind at any time.

1

What will happen to me if I take part in the research?

You will be asked to have your photograph taken on this camera, it takes less than two seconds to capture the image.



It takes several photos at the same time from different angles and these build up a 3D image of your face which we will show you. We then can analyse the image and gather data on different angles and measurements.

After 6 months, you will be invited to come back again for another image to be taken. This process is then repeated until 3 images are taken.

If you wear spectacles, we would like to measure exactly where they sit on your face with a ruler, and mark the point you are looking through with a lens marking pen.

We will then require you to remove your spectacles for a few minutes whilst we measure the power, curves and thickness of your lenses.

Might anything about the research upset me?

The camera has three flashes which all flash at the same time. Some people have an 'after-image' for a few seconds just like when you have a photo taken indoors and you can see the flash image.

Will joining in benefit me?

We cannot promise the study will help you but the information we get might help all young people in the future have spectacles that fit better

Will my taking part in this project be kept private?

Your photograph will be kept with a number and not your name.

Some images may be printed in order to write about the research project results and to teach others. No names will be printed at all.

Contact for further information

Any queries to be addressed to

Alicia Thompson thompaj3@aston.ac.uk research student

Dr Robert Cubbidge r.p.cubbidge@aston.ac.uk supervisor

2

Appendix 7 Percentile data

5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles calculated as a function of age bands detailed in Chapter 10

Typically-Developed White British **Male** | Typically-Developed White British **Female**

Frontal Angle (degrees)

Male

	5	10	25	50	75	90	95
0 to 4		54.85	61.85	64.70	65.35	68.00	
4 to 6	48.71	50.89	54.91	57.95	61.74	63.88	65.36
6 to 8	48.65	49.16	53.41	56.98	59.89	61.55	62.95
8 to 10	46.22	49.00	51.13	53.43	56.39	58.46	59.57
10 to 12	46.54	47.72	50.18	52.85	56.33	59.27	60.85
12 to 14	44.44	44.87	48.20	51.05	54.45	56.97	58.23
14 to 16			46.75	49.25	50.40		

Female

	5	10	25	50	75	90	95
0 to 4		54.13	58.08	60.53	68.96	70.28	
4 to 6	46.16	48.32	51.56	57.15	61.18	64.15	65.09
6 to 8	49.65	50.74	53.80	57.15	59.35	61.54	63.48
8 to 10	47.38	49.37	52.23	55.70	58.53	60.23	61.21
10 to 12	44.88	46.45	49.03	51.93	54.99	56.85	57.71
12 to 14	39.12	44.13	46.46	51.58	53.68	55.81	57.45
14 to 16	41.22	41.97	43.60	47.25	52.30	55.10	56.51

Splay Angle (degrees)

Male

	5	10	25	50	75	90	95
0 to 4		24.05	24.98	27.80	30.78	32.25	
4 to 6	24.13	25.47	27.11	28.43	30.01	31.12	31.64
6 to 8	23.86	24.71	26.05	27.35	29.00	31.08	32.05
8 to 10	23.32	24.06	25.08	27.00	28.10	29.30	29.80
10 to 12	22.56	23.02	24.83	26.40	27.88	29.10	30.04
12 to 14	22.37	23.80	24.93	26.10	27.43	29.60	29.92
14 to 16			25.30	27.45	28.00		

Female

	5	10	25	50	75	90	95
0 to 4		26.32	27.66	28.90	29.78	33.02	
4 to 6	24.57	25.19	26.41	28.13	29.95	31.64	31.92
6 to 8	24.52	25.07	26.14	27.53	28.91	30.79	31.83
8 to 10	22.86	23.51	25.15	26.90	28.73	30.69	31.65
10 to 12	23.44	23.82	25.41	27.00	28.45	29.72	30.32
12 to 14	22.52	23.02	24.18	25.93	27.85	29.00	29.36
14 to 16	24.01	24.48	25.45	26.30	28.10	28.67	29.70

Head Width (mm)

Male

	5	10	25	50	75	90	95
0 to 4		114.57	123.24	134.37	138.39	143.13	
4 to 6	130.84	133.81	139.52	144.23	147.59	151.37	153.12
6 to 8	136.59	140.76	143.39	146.91	150.00	153.57	157.08
8 to 10	140.41	141.85	144.43	149.61	154.74	158.08	160.21
10 to 12	139.07	143.32	149.17	153.82	159.71	163.78	167.53
12 to 14	142.05	147.80	152.08	156.20	163.27	172.62	178.44
14 to 16			150.41	155.89	165.39		

Female

	5	10	25	50	75	90	95
0 to 4		120.66	123.77	127.59	130.12	137.84	
4 to 6	127.36	128.92	132.72	136.62	140.74	146.54	149.22
6 to 8	131.24	133.04	136.53	139.00	142.98	147.38	149.08
8 to 10	134.43	135.66	137.85	142.86	148.75	152.00	155.79
10 to 12	135.82	137.46	141.36	146.21	151.18	155.33	157.29
12 to 14	134.10	142.54	144.03	147.69	151.79	153.45	154.31
14 to 16	142.49	144.88	147.07	152.43	156.40	164.64	168.29

Temple Width (mm)

Male

	5	10	25	50	75	90	95
0 to 4		92.86	94.37	97.31	100.16	101.42	
4 to 6	92.11	93.90	96.27	100.06	104.66	106.80	107.29
6 to 8	91.39	94.33	97.47	100.89	103.83	106.82	108.89
8 to 10	94.59	97.28	100.35	103.82	106.09	108.32	111.17
10 to 12	92.79	95.35	99.96	102.36	105.17	109.02	111.36
12 to 14	96.81	99.53	103.93	106.51	108.83	114.22	119.11
14 to 16			93.86	106.20	114.41		

Female

	5	10	25	50	75	90	95
0 to 4		90.00	92.85	94.53	96.85	97.10	
4 to 6	91.74	92.89	96.82	99.77	101.42	105.22	106.88
6 to 8	89.58	92.67	96.80	99.29	102.24	104.83	106.45
8 to 10	92.36	93.84	97.01	100.20	103.21	105.82	108.88
10 to 12	93.54	96.23	98.91	103.08	105.54	107.72	108.89
12 to 14	91.48	93.94	100.93	104.60	108.88	112.31	113.13
14 to 16	91.71	96.98	103.45	106.78	108.78	111.95	112.62

Typically-Developed White British
Male

Typically-Developed White British
Female

DBR@10 (mm)

Male

	5	10	25	50	75	90	95
0 to 4		15.53	18.00	19.36	20.48	22.12	
4 to 6	14.22	14.96	16.08	17.06	18.42	19.73	20.47
6 to 8	12.57	13.20	14.41	15.75	17.67	19.26	21.46
8 to 10	12.90	13.30	14.40	15.57	16.89	18.11	18.40
10 to 12	11.54	12.45	13.30	14.63	16.19	17.34	18.63
12 to 14	13.16	13.52	14.01	14.34	16.19	17.53	19.23
14 to 16			14.47	15.96	16.28		

Female

	5	10	25	50	75	90	95
0 to 4		17.23	18.95	20.48	21.90	24.61	
4 to 6	12.65	14.16	16.03	17.14	18.21	20.78	21.49
6 to 8	13.27	13.62	14.96	16.42	18.44	19.85	20.55
8 to 10	11.90	12.61	13.88	15.20	16.62	18.41	19.25
10 to 12	12.40	13.16	14.24	15.28	16.81	17.77	18.88
12 to 14	11.17	12.17	12.77	14.56	15.83	16.67	17.39
14 to 16	12.40	13.44	13.99	14.61	15.29	16.49	17.74

DBR@15 (mm)

Male

	5	10	25	50	75	90	95
0 to 4		20.76	21.34	23.31	24.25	25.52	
4 to 6	19.02	19.64	21.31	22.46	23.98	25.79	27.35
6 to 8	17.26	18.16	19.33	20.65	23.11	25.10	27.81
8 to 10	17.19	17.79	19.34	20.98	22.55	24.05	24.90
10 to 12	15.67	16.41	17.38	19.30	21.33	22.81	25.52
12 to 14	17.30	17.56	18.01	19.30	21.86	24.41	25.56
14 to 16			18.59	19.85	20.51		

Female

	5	10	25	50	75	90	95
0 to 4		21.70	23.27	24.76	26.32	29.67	
4 to 6	17.61	19.46	20.81	22.39	23.69	26.69	28.35
6 to 8	17.94	18.77	20.36	22.14	24.50	26.99	28.40
8 to 10	16.40	17.12	18.82	20.76	22.68	25.09	26.93
10 to 12	16.42	17.62	18.96	20.24	22.71	24.08	25.08
12 to 14	15.22	16.54	17.62	19.21	21.50	22.74	23.10
14 to 16	16.56	17.18	18.28	19.26	20.47	21.42	23.71

Apical Radius (mm)

Male

	5	10	25	50	75	90	95
0 to 4		8.02	9.50	9.68	10.26	11.11	
4 to 6	7.53	7.80	8.23	8.64	9.24	9.86	10.25
6 to 8	6.98	7.18	7.60	8.10	8.91	9.63	10.76
8 to 10	7.08	7.22	7.60	8.03	8.58	9.10	9.24
10 to 12	6.68	6.94	7.22	7.68	8.28	8.76	9.35
12 to 14	7.18	7.29	7.46	7.58	8.29	8.84	9.63
14 to 16			7.63	8.20	8.31		

Female

	5	10	25	50	75	90	95
0 to 4		8.72	9.49	10.24	10.99	12.39	
4 to 6	7.03	7.51	8.18	8.68	9.14	10.39	10.77
6 to 8	7.21	7.26	7.77	8.37	9.25	9.93	10.28
8 to 10	6.77	6.99	7.40	7.89	8.46	9.30	9.64
10 to 12	6.93	7.17	7.55	7.92	8.51	8.92	9.46
12 to 14	6.57	6.86	7.06	7.66	8.15	8.48	8.79
14 to 16	6.93	7.27	7.45	7.67	7.92	8.40	8.94

Crest Height (mm)

Male

	5	10	25	50	75	90	95
0 to 4		-2.07	-0.62	2.43	3.79	4.39	
4 to 6	2.13	2.37	2.80	4.03	5.65	6.69	7.06
6 to 8	1.97	2.43	3.80	5.23	6.41	7.74	8.67
8 to 10	3.39	4.22	4.83	5.92	6.95	8.31	9.56
10 to 12	3.57	4.10	5.84	7.48	8.89	10.06	10.82
12 to 14	4.69	6.14	7.02	8.28	9.26	10.29	10.48
14 to 16			7.55	9.39	10.82		

Female

	5	10	25	50	75	90	95
0 to 4		-1.58	1.53	2.91	4.40	4.91	
4 to 6	0.58	1.21	3.00	4.17	5.62	6.37	7.95
6 to 8	1.07	2.56	3.25	4.14	5.26	5.67	6.51
8 to 10	2.17	2.36	3.20	4.37	5.30	6.60	7.06
10 to 12	2.81	4.08	4.87	6.23	7.56	8.86	9.31
12 to 14	3.80	4.18	6.60	8.01	8.48	9.16	9.98
14 to 16	4.98	6.34	7.49	8.65	9.98	11.04	12.25

Typically-Developed White British
Male

Typically-Developed White British
Female

Front to Bend (mm)

Male

	5	10	25	50	75	90	95
0 to 4		63.13	70.45	76.16	78.40	80.96	
4 to 6	72.41	74.34	77.25	79.14	81.76	85.50	89.47
6 to 8	77.17	79.10	81.32	83.48	85.90	89.16	89.78
8 to 10	78.95	80.59	83.32	86.60	90.33	92.33	93.24
10 to 12	82.38	83.57	86.41	88.90	92.19	94.88	96.20
12 to 14	83.21	85.79	88.86	91.55	95.25	101.49	105.63
14 to 16			96.59	101.61	101.94		

Female

	5	10	25	50	75	90	95
0 to 4		65.68	68.67	72.89	76.91	78.77	
4 to 6	69.86	71.15	72.99	78.13	81.22	82.30	83.29
6 to 8	71.67	73.31	76.84	80.03	81.98	84.96	87.55
8 to 10	77.10	78.69	80.28	82.51	85.56	88.56	90.58
10 to 12	78.82	80.04	83.95	87.41	89.34	91.45	92.87
12 to 14	78.13	82.88	86.15	89.37	92.61	94.53	96.86
14 to 16	84.69	86.66	88.66	92.13	94.11	100.55	102.23

Distance Between Pad Centres (DBPC) (mm)

Male

	5	10	25	50	75	90	95
0 to 4		12.23	13.54	14.78	16.62	19.01	
4 to 6	12.79	13.75	14.65	15.85	16.93	17.67	18.22
6 to 8	12.58	12.97	14.20	15.29	16.39	17.16	18.65
8 to 10	12.25	12.78	13.54	14.40	15.15	15.90	16.25
10 to 12	11.90	12.75	14.02	14.75	15.96	16.56	17.21
12 to 14	11.63	13.23	13.80	14.36	15.45	16.18	16.38
14 to 16			14.16	14.79	16.74		

Female

	5	10	25	50	75	90	95
0 to 4		14.21	14.66	15.12	16.00	17.25	
4 to 6	13.51	13.98	14.94	15.81	16.88	18.12	19.31
6 to 8	13.37	13.95	14.75	15.59	16.64	17.61	18.42
8 to 10	12.32	13.69	14.38	15.40	16.53	17.93	18.23
10 to 12	12.47	13.22	14.09	14.89	16.05	17.16	17.79
12 to 14	12.60	12.95	13.28	14.21	15.87	16.48	16.77
14 to 16	13.31	13.67	14.53	14.95	15.51	16.83	17.40

Pupillary Distance (mm)

Male

	5	10	25	50	75	90	95
0 to 4		44.94	48.93	50.50	52.07	54.02	
4 to 6	49.65	49.81	51.20	53.17	54.79	56.25	56.92
6 to 8	50.51	52.13	53.19	54.80	57.07	59.27	60.99
8 to 10	52.88	53.20	55.19	57.20	58.46	60.43	61.41
10 to 12	53.91	55.17	57.05	59.25	60.75	61.80	62.59
12 to 14	54.79	55.29	58.96	60.27	62.82	64.89	66.45
14 to 16			61.54	62.86	68.04		

Female

	5	10	25	50	75	90	95
0 to 4		44.83	46.93	47.93	50.82	53.14	
4 to 6	48.90	49.98	50.84	52.50	54.22	56.12	56.78
6 to 8	50.57	51.58	52.53	53.94	55.20	56.46	57.93
8 to 10	51.63	52.17	53.29	55.20	57.26	59.00	60.73
10 to 12	53.00	54.41	55.94	57.97	59.27	61.15	62.41
12 to 14	55.91	56.13	57.29	58.90	60.84	62.71	62.81
14 to 16	56.43	57.43	59.01	60.97	62.35	64.09	64.28

Typically-Developed Chinese Male | Typically-Developed Chinese Female

Frontal Angle (degrees)

Male

	5	10	25	50	75	90	95
0 to 4	60.85	62.03	65.50	67.53	72.95	74.90	80.68
4 to 6	60.49	62.63	64.30	68.13	71.55	74.31	75.02
6 to 8	54.85	58.77	63.93	67.15	69.40	70.98	73.46
8 to 10	58.52	59.71	63.33	65.95	71.13	74.68	79.13
10 to 12		59.90	64.60	70.25	72.25	73.27	
12 to 14			62.10	68.00	71.58		
14 to 16				65.90			

Female

le	5	10	25	50	75	90	95
0 to 4		60.20	64.80	66.48	70.56	72.94	
4 to 6	56.24	59.73	62.56	65.53	69.24	72.31	73.66
6 to 8	58.26	60.90	63.44	66.50	69.28	71.89	73.35
8 to 10	57.34	58.99	62.75	66.15	70.13	76.36	78.47
10 to 12		59.95	63.40	67.95	69.91	73.18	
12 to 14			62.90	72.45	74.55		
14 to 16				67.90			

Splay Angle (degrees)

Male

	5	10	25	50	75	90	95
0 to 4	24.55	25.72	26.80	28.38	30.43	31.54	33.90
4 to 6	25.05	25.64	27.30	28.83	30.30	31.22	32.44
6 to 8	24.78	25.90	27.75	29.00	31.00	31.67	32.91
8 to 10	27.02	27.17	28.08	29.70	30.85	33.62	34.32
10 to 12		26.14	27.25	29.35	30.25	32.66	
12 to 14			30.38	31.25	33.40		
14 to 16				24.10			

Female

	5	10	25	50	75	90	95
0 to 4		27.28	28.16	29.95	31.21	33.12	
4 to 6	24.56	25.58	26.65	28.18	29.90	31.49	32.49
6 to 8	23.85	24.76	26.59	28.65	30.63	32.86	33.72
8 to 10	25.40	26.04	26.61	28.03	29.48	30.79	32.45
10 to 12		25.70	27.01	29.17	30.49	33.85	
12 to 14			27.90	32.40	33.35		
14 to 16				30.25			

Head Width (mm)

Male

	5	10	25	50	75	90	95
0 to 4	132.75	134.48	136.24	142.27	146.46	150.40	154.27
4 to 6	134.65	136.50	141.86	146.80	150.45	153.09	155.24
6 to 8	140.44	144.26	147.37	151.99	155.41	157.34	161.97
8 to 10	141.80	143.91	150.99	153.50	158.68	160.56	161.58
10 to 12		151.52	152.68	155.21	160.27	164.57	
12 to 14			150.38	160.74	166.89		
14 to 16				159.42			

Female

	5	10	25	50	75	90	95
0 to 4		122.91	131.64	135.56	137.40	143.20	
4 to 6	134.98	137.63	140.56	144.52	148.27	150.44	155.67
6 to 8	134.91	136.83	141.03	146.58	151.02	152.71	154.50
8 to 10	135.58	139.71	142.46	149.13	154.25	158.00	162.03
10 to 12		145.87	147.65	150.56	157.97	163.52	
12 to 14			149.49	155.10	166.52		
14 to 16				157.67			

Temple Width (mm)

Male

	5	10	25	50	75	90	95
0 to 4	99.24	100.44	105.23	107.95	110.75	113.39	115.88
4 to 6	103.91	105.71	107.27	109.87	112.53	113.79	115.73
6 to 8	102.44	104.38	107.92	110.64	112.90	116.61	117.63
8 to 10	106.10	107.63	109.54	113.19	117.25	120.12	122.93
10 to 12		106.17	109.96	114.28	118.79	122.70	
12 to 14			113.19	117.72	121.80		
14 to 16				108.31			

Female

	5	10	25	50	75	90	95
0 to 4		101.87	104.47	108.66	109.73	112.54	
4 to 6	102.41	105.55	106.92	109.39	113.73	116.52	116.85
6 to 8	103.44	105.10	108.41	111.87	115.06	116.78	118.13
8 to 10	101.85	103.46	108.77	111.67	114.90	116.70	117.29
10 to 12		106.76	111.18	114.82	119.74	127.98	
12 to 14			116.39	123.93	125.35		
14 to 16				126.51			

Typically-Developed Chinese Male — Typically-Developed Chinese Female

DBR@10 (mm)

Male

	5	10	25	50	75	90	95
0 to 4	17.29	17.47	19.18	21.88	25.11	27.84	31.41
4 to 6	17.11	18.11	19.84	21.75	23.86	25.87	26.82
6 to 8	15.44	16.10	18.79	20.76	22.07	23.86	26.16
8 to 10	15.96	16.14	17.21	19.35	21.63	24.36	24.79
10 to 12		16.30	17.13	18.63	20.18	20.62	
12 to 14			16.97	20.37	23.58		
14 to 16				17.11			

Female

	5	10	25	50	75	90	95
0 to 4		13.28	18.99	20.70	22.18	24.91	
4 to 6	15.58	16.88	20.30	21.71	24.77	28.26	29.10
6 to 8	13.49	14.01	18.42	22.13	24.96	27.25	28.36
8 to 10	10.94	14.80	17.33	19.11	21.69	23.19	24.04
10 to 12		13.55	16.72	17.99	22.32	23.59	
12 to 14			14.71	21.20	22.88		
14 to 16				19.66			

DBR@15 (mm)

Male

	5	10	25	50	75	90	95
0 to 4	20.90	21.67	23.53	26.55	31.53	36.61	41.83
4 to 6	22.05	23.61	25.48	27.69	31.14	33.38	34.22
6 to 8	19.83	21.25	24.61	27.36	29.87	34.35	40.21
8 to 10	20.81	21.68	22.99	25.54	29.41	32.23	33.64
10 to 12		21.44	22.56	25.41	26.51	27.21	
12 to 14			22.52	24.98	31.19		
14 to 16				22.12			

Female

	5	10	25	50	75	90	95
0 to 4		16.68	22.92	25.14	28.06	32.36	
4 to 6	20.09	21.24	24.56	28.27	31.61	35.66	37.48
6 to 8	18.48	19.61	23.47	28.34	33.56	35.71	39.80
8 to 10	15.69	18.95	23.25	24.98	28.15	31.01	31.37
10 to 12		19.13	21.79	25.08	28.68	31.80	
12 to 14			19.63	28.60	30.65		
14 to 16				26.26			

Apical Radius (mm)

Male

	5	10	25	50	75	90	95
0 to 4	8.74	8.82	9.61	10.99	12.88	14.68	17.33
4 to 6	8.89	9.29	10.03	11.17	12.12	13.36	13.96
6 to 8	7.98	8.24	9.42	10.38	11.09	12.11	13.55
8 to 10	8.19	8.26	8.71	9.68	10.85	12.41	12.67
10 to 12		8.32	8.68	9.34	10.09	10.31	
12 to 14			8.61	10.19	11.95		
14 to 16				8.68			

Female

	5	10	25	50	75	90	95
0 to 4		7.21	9.52	10.36	11.14	12.75	
4 to 6	8.04	8.56	10.15	10.98	12.67	15.63	17.85
6 to 8	6.79	7.40	8.64	11.12	12.94	14.48	15.04
8 to 10	6.52	7.77	8.76	9.57	10.88	11.73	12.23
10 to 12		7.31	8.54	9.05	11.22	11.96	
12 to 14			7.71	10.61	11.55		
14 to 16				9.83			

Crest Height (mm)

Male

it	5	10	25	50	75	90	95
0 to 4	-2.55	-0.74	-0.08	0.62	1.21	2.19	3.79
4 to 6	-2.35	-1.51	-0.80	1.07	2.47	3.55	3.83
6 to 8	-2.38	-1.55	0.06	0.90	1.91	3.45	4.36
8 to 10	-2.23	-1.22	0.15	1.91	3.17	4.43	5.35
10 to 12		-2.35	-0.45	1.64	3.73	5.13	
12 to 14			-0.39	2.15	2.36		
14 to 16				7.06			

Female

it	5	10	25	50	75	90	95
0 to 4		-3.65	-1.88	-0.85	0.70	1.32	
4 to 6	-3.45	-2.74	-1.64	0.02	1.11	2.41	4.43
6 to 8	-3.89	-2.68	-0.75	0.89	1.95	3.24	3.77
8 to 10	-2.39	-2.09	-1.23	-0.12	2.28	3.19	3.72
10 to 12		-1.20	0.05	0.88	2.34	3.58	
12 to 14			-0.10	2.34	2.63		
14 to 16				-3.42			

Typically-Developed Chinese Male

Typically-Developed Chinese Female

Front to Bend (mm)

Male

ıd	5	10	25	50	75	90	95
0 to 4	68.88	69.57	73.82	77.02	78.25	81.58	83.60
4 to 6	69.63	73.24	74.77	77.73	80.66	82.43	83.16
6 to 8	74.57	75.54	77.99	80.59	84.28	86.25	87.30
8 to 10	75.50	77.03	80.43	82.39	88.87	91.12	93.12
10 to 12		79.08	79.74	84.36	87.08	89.31	
12 to 14			82.44	82.61	92.95		
14 to 16				90.13			

Female

ıd	5	10	25	50	75	90	95
0 to 4		62.47	65.29	69.18	72.98	78.38	
4 to 6	61.94	64.51	68.92	72.18	75.58	78.71	80.61
6 to 8	69.59	72.10	74.32	78.03	81.02	84.62	87.54
8 to 10	68.79	69.53	75.47	77.58	82.32	84.90	90.58
10 to 12		77.65	79.60	82.40	84.57	88.19	
12 to 14			78.33	86.58	91.44		
14 to 16				86.10			

Distance Between Pad Centres (DBPC) (mm)

Male

	5	10	25	50	75	90	95
0 to 4	12.16	12.43	13.21	14.65	15.84	16.44	16.72
4 to 6	12.75	13.21	13.76	14.86	16.09	16.77	17.04
6 to 8	12.85	13.29	14.31	15.20	16.28	17.77	18.64
8 to 10	13.79	14.14	14.73	15.97	17.43	18.36	19.21
10 to 12		14.04	14.91	16.30	17.82	18.51	
12 to 14			16.87	17.72	18.78		
14 to 16				14.89			

Female

	5	10	25	50	75	90	95
0 to 4		13.78	14.10	15.01	16.10	17.37	
4 to 6	11.71	12.26	13.16	14.01	15.33	16.37	16.87
6 to 8	12.30	12.85	13.33	14.57	16.28	18.09	18.56
8 to 10	12.70	13.24	13.83	14.61	15.97	16.49	16.74
10 to 12		13.96	14.26	15.32	17.13	18.49	
12 to 14			16.01	18.80	19.54		
14 to 16				16.57			

Pupillary Distance (mm)

Male

	5	10	25	50	75	90	95
0 to 4	47.20	48.57	51.18	54.50	55.39	56.75	58.17
4 to 6	49.60	50.87	53.32	55.48	57.13	58.31	59.18
6 to 8	52.09	52.66	54.07	56.22	58.64	60.10	60.60
8 to 10	53.95	54.59	56.26	59.39	62.34	65.07	66.87
10 to 12		55.20	57.55	60.12	63.57	65.86	
12 to 14			57.79	61.20	65.30		
14 to 16				56.58			

Female

	5	10	25	50	75	90	95
0 to 4		45.79	49.41	50.60	51.82	53.89	
4 to 6	47.93	49.40	51.42	53.76	55.61	57.48	58.82
6 to 8	51.10	52.57	53.94	56.19	58.85	59.79	61.56
8 to 10	51.98	53.23	55.42	57.62	59.03	62.95	65.79
10 to 12		55.87	57.67	60.04	60.70	64.37	
12 to 14			59.42	61.67	66.11		
14 to 16				58.37			

Down's Syndrome White British
Male

Down's Syndrome White British
Female

Frontal Angle (degrees)

Male

	5	10	25	50	75	90	95
0 to 4		58.91	58.26	62.85	67.85	75.37	
4 to 6		57.96	60.70	64.30	67.95	72.69	
6 to 8			54.46	58.93	61.70		
8 to 10			56.10	56.95	62.03		
10 to 12		54.65	59.00	60.25	65.05	71.75	
12 to 14			57.60	59.30	64.80		
14 to 16				54.83			

Female

	5	10	25	50	75	90	95
0 to 4		60.98	65.04	68.78	72.45	74.90	
4 to 6			64.70	68.20	72.51		
6 to 8				61.70			
8 to 10			55.10	57.70	60.80		
10 to 12		55.55	59.90	61.20	66.33	68.55	
12 to 14			53.65	56.15	60.55		
14 to 16				58.25			

Splay Angle (degrees)

Male

	5	10	25	50	75	90	95
0 to 4		23.89	26.15	27.75	29.55	30.27	
4 to 6		24.50	26.25	29.00	30.53	31.27	
6 to 8			25.51	28.88	30.18		
8 to 10			24.99	26.73	30.65		
10 to 12		25.20	27.20	27.90	28.45	30.59	
12 to 14			27.00	28.70	29.15		
14 to 16				28.75			

Female

	5	10	25	50	75	90	95
0 to 4		21.40	22.95	25.23	27.49	28.20	
4 to 6			22.85	25.30	26.66		
6 to 8				24.95			
8 to 10			25.63	27.30	29.18		
10 to 12		22.20	24.00	25.70	27.53	28.85	
12 to 14			25.95	26.85	28.90		
14 to 16				26.93			

Head Width (mm)

Male

	5	10	25	50	75	90	95
0 to 4		115.90	123.33	127.80	132.07	136.49	
4 to 6		130.28	135.87	138.96	142.44	146.23	
6 to 8			138.35	145.71	151.44		
8 to 10			135.76	140.58	142.24		
10 to 12		143.35	146.40	152.79	157.48	161.62	
12 to 14			137.16	143.34	160.32		
14 to 16				156.49			

Female

	5	10	25	50	75	90	95
0 to 4		119.88	121.58	131.04	135.81	138.70	
4 to 6			132.59	135.44	138.91		
6 to 8				139.42			
8 to 10			133.88	136.40	150.17		
10 to 12		138.46	139.91	141.97	144.03	149.14	
12 to 14			146.24	150.60	150.80		
14 to 16				140.92			

Temple Width (mm)

Male

	5	10	25	50	75	90	95
0 to 4		92.35	95.38	96.98	101.83	102.63	
4 to 6		92.26	95.48	99.08	102.47	106.69	
6 to 8			95.92	101.99	105.46		
8 to 10			94.44	97.24	102.48		
10 to 12		91.38	99.31	109.07	116.67	120.78	
12 to 14			95.69	99.62	105.67		
14 to 16				92.73			

Female

	5	10	25	50	75	90	95
0 to 4		90.24	94.78	99.77	103.54	106.51	
4 to 6			101.19	101.61	103.18		
6 to 8				96.37			
8 to 10			98.53	103.94	115.73		
10 to 12		95.01	101.69	103.38	107.13	108.91	
12 to 14			94.89	104.48	110.86		
14 to 16				103.91			

DBR@10 (mm)

Down's Syndrome White British — Male

	5	10	25	50	75	90	95
0 to 4		18.92	19.96	21.31	23.82	24.27	
4 to 6		15.47	18.06	20.05	21.43	23.33	
6 to 8			15.75	16.55	18.17		
8 to 10			14.91	16.09	20.52		
10 to 12		14.08	15.68	18.78	19.85	19.96	
12 to 14			14.99	16.79	18.21		
14 to 16				18.54			

Down's Syndrome White British — Female

	5	10	25	50	75	90	95
0 to 4		18.90	19.65	21.75	22.85	23.85	
4 to 6			18.79	20.05	22.71		
6 to 8				14.81			
8 to 10			14.86	19.02	21.22		
10 to 12		8.91	13.85	15.37	18.41	19.71	
12 to 14			15.81	16.09	17.24		
14 to 16				15.63			

DBR@15 (mm)

Male

	5	10	25	50	75	90	95
0 to 4		21.36	22.93	24.71	28.82	32.08	
4 to 6		19.03	21.19	24.21	25.62	28.03	
6 to 8			19.65	20.81	22.73		
8 to 10			19.42	20.80	25.14		
10 to 12		19.54	20.54	23.92	25.34	26.13	
12 to 14			19.33	21.84	23.49		
14 to 16				23.43			

Female

	5	10	25	50	75	90	95
0 to 4		22.03	24.43	25.47	27.67	31.78	
4 to 6			23.41	24.26	28.54		
6 to 8				19.60			
8 to 10			19.61	23.90	32.43		
10 to 12		14.26	20.24	21.16	24.15	26.01	
12 to 14			21.10	22.07	23.37		
14 to 16				20.82			

Apical Radius (mm)

Male

	5	10	25	50	75	90	95
0 to 4		9.48	9.98	10.67	12.07	12.36	
4 to 6		8.00	9.08	10.02	10.74	11.81	
6 to 8			8.14	8.45	9.13		
8 to 10			7.78	8.25	10.26		
10 to 12		7.48	8.08	9.42	9.93	9.98	
12 to 14			7.84	8.52	9.14		
14 to 16				9.31			

Female

	5	10	25	50	75	90	95
0 to 4		9.47	9.83	10.91	11.52	12.11	
4 to 6			9.42	10.03	11.43		
6 to 8				7.76			
8 to 10			7.78	9.52	10.63		
10 to 12		5.99	7.41	7.95	9.25	9.86	
12 to 14			8.12	8.25	8.72		
14 to 16				8.08			

Crest Height (mm)

Male

	5	10	25	50	75	90	95
0 to 4		-0.45	-0.35	0.54	1.72	2.46	
4 to 6		-2.27	-1.19	0.46	3.47	5.10	
6 to 8			4.15	5.09	5.69		
8 to 10			-2.42	-1.59	2.53		
10 to 12		-4.44	-1.63	0.35	1.93	4.49	
12 to 14			-1.83	-0.64	5.46		
14 to 16				4.65			

Female

	5	10	25	50	75	90	95
0 to 4		-2.86	-1.51	-0.19	0.72	1.59	
4 to 6			-3.21	1.39	2.25		
6 to 8				3.95			
8 to 10			1.58	3.69	5.84		
10 to 12		-1.45	-0.43	2.53	4.20	6.34	
12 to 14			1.22	7.87	8.81		
14 to 16				3.95			

Down’s Syndrome White British
Male

Down’s Syndrome White British
Female

Front to Bend (mm)

Male

	5	10	25	50	75	90	95
0 to 4		57.93	64.72	69.82	71.12	74.27	
4 to 6		68.29	71.88	76.88	82.35	85.71	
6 to 8			76.95	80.57	85.95		
8 to 10			72.88	77.69	80.82		
10 to 12		76.28	80.61	84.32	88.14	92.47	
12 to 14			78.28	80.30	84.01		
14 to 16				94.25			

Female

	5	10	25	50	75	90	95
0 to 4		57.11	62.30	66.56	71.18	76.82	
4 to 6			65.32	68.35	75.21		
6 to 8				77.89			
8 to 10			59.84	65.95	75.34		
10 to 12		58.84	75.32	80.39	81.90	85.86	
12 to 14			81.70	83.95	90.78		
14 to 16				74.17			

Distance Between Pad Centres (DBPC) (mm)

Male

	5	10	25	50	75	90	95
0 to 4		10.89	12.16	13.10	14.19	15.07	
4 to 6		12.16	13.65	14.83	15.47	16.48	
6 to 8			12.73	13.52	14.61		
8 to 10			13.77	15.34	16.54		
10 to 12		13.93	14.66	15.55	16.28	17.28	
12 to 14			15.26	15.33	17.68		
14 to 16				16.46			

Female

	5	10	25	50	75	90	95
0 to 4		9.85	11.04	11.87	13.41	14.27	
4 to 6			11.24	12.43	13.64		
6 to 8				13.76			
8 to 10			12.30	13.38	16.20		
10 to 12		1.44	12.53	13.30	14.41	16.50	
12 to 14			14.68	15.52	16.01		
14 to 16				14.68			

Pupillary Distance (mm)

Male

	5	10	25	50	75	90	95
0 to 4		42.61	45.37	48.91	50.24	51.65	
4 to 6		50.07	50.41	52.49	54.19	57.20	
6 to 8			50.52	52.27	55.15		
8 to 10			49.01	55.40	56.62		
10 to 12		50.59	55.18	56.02	57.45	59.13	
12 to 14			53.93	59.43	63.50		
14 to 16				57.53			

Female

	5	10	25	50	75	90	95
0 to 4		43.48	45.29	48.18	50.97	51.31	
4 to 6			45.07	48.61	50.62		
6 to 8				47.53			
8 to 10			48.66	51.55	59.11		
10 to 12		51.30	52.86	55.38	56.13	58.14	
12 to 14			52.21	56.74	56.98		
14 to 16				57.07			